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Radio Frequency Identification from System to Applications

Edited by Mamun Bin Ibne Reaz

RADIO FREQUENCY IDENTIFICATION FROM SYSTEM TO APPLICATIONS

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http://dx.doi.org/10.5772/46210
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First published in Croatia, 2013 by INTECH d.o.o.
eBook (PDF) Published by IN TECH d.o.o.
Place and year of publication of eBook (PDF): Rijeka, 2019.
IntechOpen is the global imprint of IN TECH d.o.o.
Printed in Croatia

Legal deposit, Croatia: National and University Library in Zagreb

Additional hard and PDF copies can be obtained from orders@intechopen.com

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p. cm.

ISBN 978-953-51-1143-6

eBook (PDF) ISBN 978-953-51-6347-3

Meet the editor

Mamun Bin Ibne Reaz was born in Bangladesh, in December 1963. He received his B.Sc. and M.Sc. degree in Applied Physics and Electronics, both from University of Rajhashi, Bangladesh, in 1985 and 1986, respectively. He received his D.Eng. degree in 2007 from Ibaraki University, Japan. He is currently a Professor at the Universiti Kebangsaan Malaysia, Malaysia, involving in teaching, research and industrial consultation. He is a regular associate of the Abdus Salam International Center for Theoretical Physics since 2008. He has vast research experiences in Norway, Ireland and Malaysia. He has published extensively in the area of RFID, IC Design and Biomedical application IC. He is author and co-author of more than 150 research articles in design automation and IC design.

Contents

Preface

From its first use in the World War II to differentiate enemy aircrafts and own aircrafts, Radio Frequency Identification (RFID) has come to an era where it is used as an important identification tool which provides added security and conveniences in our daily lives. Its components and features are still being researched and integrated in existing systems to create a marketable and potential new system. RFID has become and will continue to be very important in the area of automatic identification. Regarded as a potential successor to the bar coding technologies and other automatic identification methods that we are using today, RFID's significant advantage is the contactless, non-line-of-sight nature of the technology. RFID has quietly been gaining momentum in recent years and is now being seen as a radical means of enhancing data handling processes, complimentary in many ways to other data capture technologies.

RFID based application creates tremendous new business opportunities such as the support of independent living of elderly and disabled persons, efficient supply chains, efficient anti-counterfeiting and better environmental monitoring. For better automation, well-organized business processes, and inventory visibility, many organizations have already exploited RFID in their main operations to take advantage of the potential. RFID data management, scalable information systems, business process reengineering, and evaluating investments are emerging as significant technical challenges to applications underpinned by new developments in RFID technology.

In this book, we present contributions from world leading experts on the latest developments and state-of-the-art results in the RFID field to address these challenges. The book offers a comprehensive and systematic description of technologies, architectures, and methodologies of various efficient, secure, scalable, and reliable RFID and RFID based applications.

This book will serve as a valuable reference point for researchers, educators, and engineers who are working in RFID and RFID based applications, as well as graduate students who wish to understand, learn, and discover opportunities in this emerging research and development area. It is our hope that the work presented in this book will open new discussions and generate innovative ideas that will further develop this important area.

We thank the authors for their outstanding and timely contributions. We would also like to thank InTech for the opportunity to publish this book. Our special thanks go to Oliver Kurelic, Natalia Reinic, and Sandra Bakic for their continued support and professionalism during the whole publication process of this book.

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Chapter 1

RFID Applications and Challenges

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53368

1. Introduction

Radio Frequency identification (RFID) is the popular wireless induction system [1-7]. The same as the general bar code identification, each RFID tag in an RFID system is assumed that equips a unique ID (UID) itself. A standard RFID system is consisted of Tag, Reader, and Application. When an independent RFID tag approaches the RFID antenna, the induction between RFID tag and antenna happens. The RFID antenna reads the information and content recorded in the tag. Then the information is translated into the computational data by the RFID reader. Due to the portable RFID tag and untouched data transmission, many local or small area wireless applications for track and trace based on RFID systems were proposed.

RFID today is the popular wireless induction system [2-3,8-11]. Each RFID tag in RFID system is given a unique ID (UID) which records the on demand information. When an independent RFID tag approaches the RFID antenna, the induction between RFID tag and antenna happens. The information and content recorded in the tag is transmitted to the RFID antenna and translated into the computational data. Following up the data translation, the tag recognition can be completed and related applications are provided.

The RFID applications about agriculture that are now in widespread use such as the Animal Identification, the Product Record, and the Manufacturing process management. First, users identify products or materials via the tag and the reader of RFID system, and followed that recorded the data of products or materials on database in foregoing proposals. In a subsequent process, an especial function chose some suitable data from databases for analyzing, integration and description. This process helps users to understand the position and situation about products or materials. Therefore, by using the RFID, the main contributions in agriculture can be described as follows:

1. The data of manufacturing record was transformed from artificial process to electrical process.

2. Increased management (such as Inventory or Supply Chain) and production planning and scheduling efficiency than before.

3. Reduced the cost of operation and increased the economic effect.

4. Supply product safety information to customers to refer.

Many tracking applications based on ubiquitous computing and communication technologies have been presented in recent years such as RFID systems [4,5,7]. Therefore, RFID can be used to trace objects and asset worldwide. In addition, some warehouse systems or supply chain management systems can be combined with RFID to form goods tracking systems. The tracking systems help enterprises to manage their raw materials and products that reduce the cost of operation budget. However, more and more applications of RFID system that were introduced by people, and that the agriculture is the one of them.

Due to the popularity of RFID, many local or small area wireless applications were also proposed. The RFID tags were proposed to be used in hospital or health care [12-15]. Patients should always wear the RFID tag is designed for identification. The patient's current location and condition is monitored every time and everywhere within the hospital. It means that patients are under cared even an emergency state happens. Some entrance guard systems are also based on RFID system. The RFID ticket or RFID card [2, 3, 8, 10] is used to identify that a user is legal or not. According to the short-distance wireless signal, the RFID tag users can be monitored within the specific area. In other words, the RFID systems are generally used to be the hardware identification in many applications. In opposition to using the RFID system as the hardware identification, many software applications adopt software encryption as the identifications to protect the intellectual property of the applications or files. Considering the serious situations of pirate, intellectual property protection is important and becomes a famous issue.

Password protection is the popular encryption method to protect the applications. Each application or file of software is assigned an on demand given serial numbers or calculation function. People who use this application have to input the correct serial number then enable the application. Considering today's applications, personal multimedia services or software applications are popular. Customers use the personal multimedia devices such as MP3, PDA, iPod, Laptop, etc., to download the multimedia or application files from the server or website via Internet. In other words, many files or data are disseminated and exchanged via Internet. In addition, many hackers can crash the software encryption with fewer costs (Only program tools or applications needed). It makes that the piratical files are transmitted widely and the protection of intellectual property exists in name only.

For the purpose that the right of intellectual property and the right of the valid users are further protected and maintained, integration of the software and hardware encryption is needed. Since each RFID tag with a unique ID (UID) which records the on demand information can be used as the individual identification, the small and cheap RFID tag can be

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considered as the hardware/software encryption/decryption key corresponding to the files or applications. In the next section, we give some descriptions for related RFID application and system.

2. Related application and system

Some researchers presented that the embedding RFID can be plugged into a small device such as handheld host [1]. The handheld device users can plug in the SD or CF interface of reader card. Hence, the users can scan and induct the RFID tag everywhere. In other words, to integrate the RFID system hardware into the mobile devices is practicable. Furthermore, the RFID system including RFID induction antenna, RFID parser and reader, RFID tag, etc., today is cheap. In addition, the RFID hardware including antenna and reader is not only cheap but also can be a PnP device. It means that the RFID hardware can be used as a normal user device such as the card-reader.

2.1. RFID encryption and decryption for intellectual property protection

2.1.1. Application

Since the RFID systems are popular and ripe for distinguishing treatment of individual target [16, 17], the unique characteristic or identification of RFID can be the solution of intellectual property protection. Many researches proposed the possible way to protect the intellectual property, products, or applications. In some applications [18], the RFID chips are embedded in the cap of bottle. The medicine can be differentiated between fake and true. In addition, the RFID chip can be placed in the CD or DVD disk. The CD-ROM can accesses and reads the information of the RFID for valid identification check. Only the CD or DVD with the authorized RFID can be played. Although the content is protected, the self-made content that burned in the CD-R/RW or DVD-R/RW may not provide the authorized RFID information. In other words, the private, non-business, or free digital content made by the individual may be limited and cannot be transmitted free. In addition, even the CD or DVD disks are protected, the digital content such as files or data still can be copied from the disk to other devices such as hard disc or MP3 player. Therefore, how to separate the right of the digital content for each user and how to protect the digital content from illegal use become the important issues.

Due to the demand of existed system integration, some applications related to *RFID Encryption and Decryption for Intellectual Property Protection* includes: PnP Middleware, RFID Hardware, End User RFID Device and End User RFID Tag, and Encryption/Decryption Procedure. The system framework is shown as follows.

For a normal user, there are two types of RFID devices for the encryption/decryption on RFID system (E/DonRFID system): End User RFID Device for digital content or multimedia information gaining, and End User RFID Tag for indentifying the legal user.

E/DonRFID not only provides the RFID based protection procedure but also includes the Encryption/Decryption method based on RFID character. The encryption and decryption can be implemented by hardware or software solution. The original digital data is encrypted by 1) hardware, 2) software, or 3) combination of hardware and software. Corresponding to the encryption method, suitable RFID tag of user for decrypting is needed.

Since three possible ways to protect the digital content are proposed, for the end users, there will be at least three possible states and method of *E/DonRFID Encryption/Decryption*, to gain the protected digital data, shown as follows:

1. Encryption and Decryption by Hardware and Software combination,
2. Encryption only by Hardware with Hardware and Software combination Decryption
3. Encryption only by Software with Hardware and Software combination Decryption
4. Encryption only by Hardware with Hardware Decryption
5. Encryption only by Software with Hardware Decryption

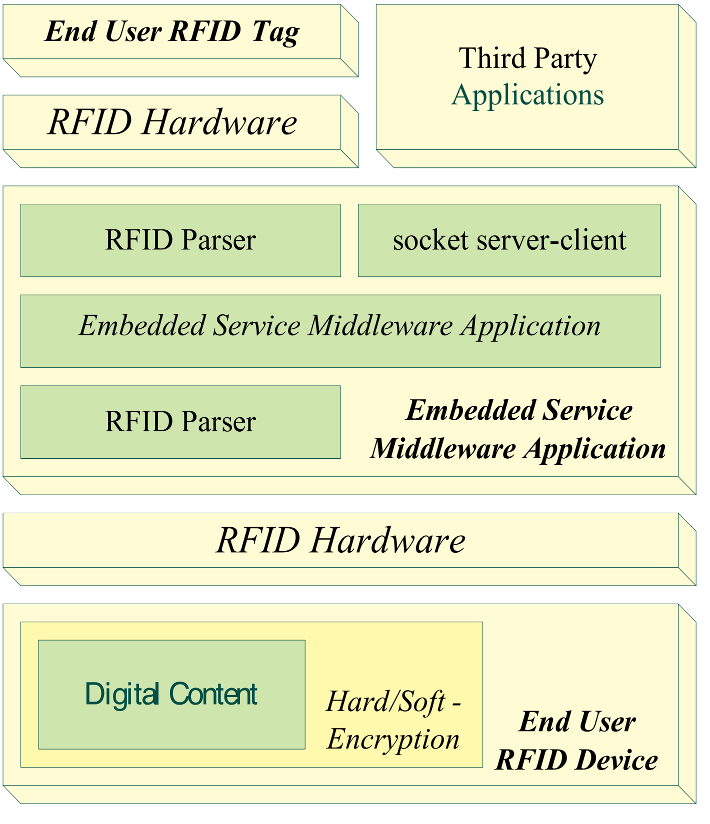

Figure 1. The framework of RFID Encryption and Decryption for Intellectual Property Protection

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2.1.2. Method

First, depending on the digital content storage hardware such as CD-ROM disk, the commercial RFID tag can be embedded into the disk when the disk is made. According to the characteristic of RFID tag, each RFID tag can be set with different individualities. The different encryption code, unique ID, information of the digital content, or authentication serial number can be recorded in the RFID tag. In addition, the RFID tag embedded in the disk is not rewritable. Hence, different disks equip the different IDs of RFID tag. When the RFID reader inducts the tag, the information about this storage can be scanned and presented. In other words, only the digital storage with the valid RFID tag is legal and true.

Second, since the content or data are digital, these software, content or data, can be encrypted as the secret codes or cipher. The key for encryption and decryption can be recorded in the RFID tag. Without the specific key, these secret codes or ciphers cannot be recovered as the original data. In other words, the digital content that recorded in the storage device (such as CD-ROM disk) can be secured. The decryption key can be recorded in the RFID tag embedded in the storage or a palm RFID tag (such as a RFID toy).

For the end users, *End User RFID Device/Tag* is used. The storage, whether hardware (CD-ROM) which includes the encrypted digital content, or software (files or ciphers), is called *End User RFID Device*. If the *End User RFID Device* is hardware, the third party *RFID Hardware* can induct the RFID tag embedded in the hardware. After identifying the *End User RFID Device*, the application or user can execute and read the digital content if only *Hardware - Encryption/Decryption* is used.

According to three possible states, the end user must have the decryption key for executing the digital content. In this paper, the hardware (RFID tag) or software for the decryption key is called *End User RFID Tag*. After identifying the *End User RFID Device*, the end user has to provide the *End User RFID Tag* for the *Embedded Service Middleware Application*. Only the information or password of *End User RFID Tag* is correct and can be used to gain the secured decryption key which recorded in the *End User RFID Device*, the digital content recorded in the *End User RFID Device* can be presented.

Considering that the three possible states are based on the RFID induction, the *RFID Hardware* is divided into two types of equipments: for *End User RFID Device* and for *End User RFID Tag*.

According to the three possible ways to protect the digital content, when the protection is based on the combination of *Hard/Soft- Encryption/Decryption* and Only *Hardware-Encryption* with *Hard/Soft –Decryption*, the *RFID Hardware* for *End User RFID Device* is needed. Due to that the digital content is protected by the RFID tag embedded in the hardware, the information recorded in the tag has to be inducted before using. For example, if a tag is embedded in the CD-ROM disk, the user should have a CD-ROM driver with the *RFID Hardware* when reading the disk. In other words, if the protection is based on the hardware belongs to *End User RFID Device*, the corresponding reader with *RFID Hardware* is necessary. The *RFID Hardware* can be embedded in the CD-ROM driver, reader, or other multimedia devices.

In opposition to *End User RFID Device*, when the decryption is based on the *End User RFID Tag* key, end user has to own the valid RFID tag for decrypting the digital content. For example, the decryption code is recorded in the RFID tag of *End User RFID Device*. However, the decryption code is secured by the password which locks the data slot of RFID tag. Without the correct password, end user cannot gain the decryption code that secured in the RFID tag of *End User RFID Device*. To provide the password, the end users should have the *RFID Hardware* such as the USB-RFID reader, etc.

To manage the RFID information, *Embedded Service Middleware Application* is proposed to parse the information from the *RFID Hardware*. Due to that there are different RFID product, an RFID parser is needed for analyzing and parsing the information from *RFID Hardware*. After gaining the requirements or response, the *Embedded Service Middleware Application* searches the corresponding applications and passes the information. Figure 2 presents the framework of *Embedded Service Middleware Application*.

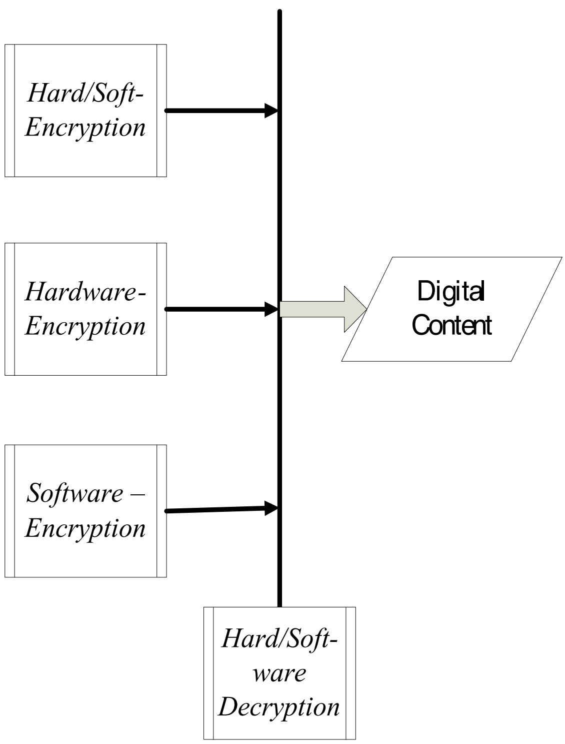

Figure 2. Possible ways to gain the protected digital data

The *Embedded Service Middleware Application* implements the socket server-client structure for communication with other existed or third party applications. The information comes from the *End User RFID Device*, such as specific password-requirement, will be recorded in the database of middleware application. The requirement will be maintained based on the on de-

http://dx.doi.org/10.5772/53368

mand limitation of the period of validity or when the *End User RFID Device* is removed. In addition, when an end user tries to gain the digital data from the *End User RFID Device*, the middleware application request the end user for the password. After receiving the password, the middle application transmits the password and tries to gain the decryption code. If the password is correct, the decryption code will be transmitted to the user application such as multimedia player, etc. Otherwise, the digital content cannot be decrypted and used. Therefore, only the two conditions: 1) the key information of *End User RFID Tag* matches the password requirement of *End User RFID Device*, and 2) the decryption code is correct in decrypting the digital content are satisfied, the user can gain the information from the *End User RFID Device*

2.2. Location aware public/personal information services based on embedded RFID platform

2.2.1. Application

Many researches proposed before presented the importance of providing information and services related the user's location to each person. Some researches assume that there are GPS devices or module included in the users' mobile devices. Then, according to the information of GPS (GIS) [19-22], the location aware or related information or services are provided to the mobile user trough the wireless network. Although the GPS provides the accurate location of users, most users indeed needs the approximate local-area-aware information. The accuracy of location such as longitude and latitude is not the main issue. Furthermore, not everyone can equip the GPS.

Hence, in addition to GPS, according to the orientation made by the station of wireless cellular system [23], the related information according to the user's location can be given to the user via cellular system. Each cellular phone user can be served directly by the telecommunications companies. If a user is served by the specific wireless base station, the information related to the coverage area of this base station are given to the phone user.

Since the RFID system is popular and generally implemented, many researches [24-30] tried to integrate the RFID to and applied RFID technology to context-aware systems. However, in [31], what kind of the context, the corresponding context services, and the context-aware RFID system are important to be provided for user is still an issue of the existing system. In addition, to integrate the existed system such as information service and payment system become the important topic.

Not only supply the public services but also give the personal services, the context aware researches [32-34] were also proposed. Research in [35] was proposed that considering the user's related location. Hospital or health care RFID systems [12-14,34] for monitor the tag users were also proposed. A designed RFID tag is given to each user such as a patient. Each patient should always wear the RFID tag every time and everywhere. Hence, the patients' current information such as location and health conditions are monitored by the hospital. In addition, some entrance guard systems are also based on RFID system. The RFID ticket or RFID card [2, 3, 10, 36] is used to identify that a user is legal or not.

The services and information of user-location-related public places such as the museum [37] are provided. According to the requirement of users, different services are given through wireless network or cellular system to different users even they are in the same places.

Hence, a realistic application such as Location Aware Public/Personal Information Services based on RFID is proposed. By using the location-aware RFID application, the main contributions are :

1. Users of location-aware RFID application can communicate and gain the information corresponding to the users' location through the RFID tag. The handheld devices with RFID reader can also manually obtain the extra or required or local information and services.
2. The efficiency of system management and service utilization can be improved, information can be the digital multimedia and updated immediately,
3. The location-aware RFID application can be embedded in other similar service systems and hardware. The proposed service system can be included in the existed information center or server. The additional cost for integration can be reduced.
4. The service object and function can be various. For example, the location-aware RFID application provides not only the public or general information services to every system user, but also the deferential personal service to individual location-aware RFID application user.
5. The ticket and payment services can be integrated into location-aware RFID application service system. Users needn't to bring too many identification devices or cards. All method of payment and public or personal services are integrated into one RFID tag and location-aware RFID application service system.

2.2.2. Method

The system structure is shown as Figure 2. The *Embedded Service Middleware Platform* is the main system to manage the internal and external system connections. The RFID API and parser are included and provided to communicate with the third party RFID system. The *Embedded Service Middleware Platform* also makes the information connection to other business management system or database via software API. In addition, the related information to the RFID tag inducted is presented by user interface.

For the end users, *End User RFID Handheld Facilities* consists of two appliances: *end user RFID tag* and *end user device with RFID System*. A user can use a given readable and re-writable RFID tag or a handheld device such as PDA which equipped a RFID system to gain the required public/personal services. In Figure 2, the user handheld device also equips the RFID system, RFID API, and parser to scan and induct the commercial RFID tag. The communication and the data transmission between the handheld device and server can be established via 1) Internet, 2) server-client socket, 3) a user RFID tag, or 4) a readable and re-writable RFID tag. A user can view the information or obtain the services via user interface (UI) presented by server or the user handheld device.

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The other business management systems in the framework can be the third party developments and independent of the whole system. When the user approaches the RFID system at the specified area, the induction and communication between end user RFID tag and antenna of *RFID System* is automatically established. A RFID reader will parse the signal into the digital and computing content. Then, the *RFID System* transmits the information obtained from the tag to the *Embedded Service Middleware Platform* via Internet. According to the RFID information, the *Embedded Service Middleware Platform* searches for and provides the specific personal service recorded in local area server according to the on demand conditions of the user. Moreover, the information or services can be updated or provided from the main database via Internet connection. Then, the user can obtain the public/personal information from the user interface.

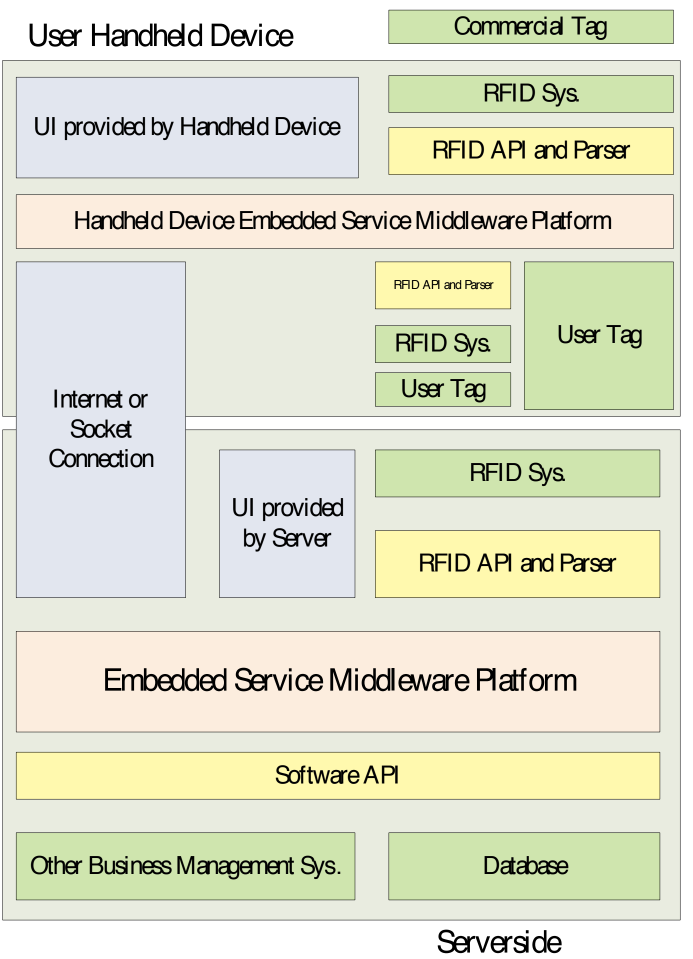

Figure 3. The whole framework of location-aware RFID application service system

In the location-aware RFID application service system, the RFID antennas and reader are deployed 1) at the specific area or location such as the entrance of the rapid transit system or the information service machine, or 2) within the handheld devices such as PDA or mobile phone. When a user is given a readable RFID tag, the related information or the user's on demand service conditions about the user is given by himself and on demand recorded in the database. When the user requires the local area public or personal services, the user should be at the tiny induction area such as a local area information center or a service station. Then, the RFID system placed in the specific area inducts the RFID tag and gain the information such as UID from the RFID tag. The reader of RFID system then sends the information to the local area server via Internet.

After receiving the information and parsing the message from RFID system, the content of RFID tag can be identified. If *end user RFID tag* is used, the *embedded server service middleware* can search and present the local information such as local area shopping information, traffic information, or the customization information, recorded in local database that match the on demand conditions of the RFID tag user. In other words, the RFID user can be directly served with sufficient local area related information. If other further information needed, the *embedded server service middleware* can send the user's request to the remote main server to obtain the requested service or to the other business applications via Internet for extra service obtaining. At last, the user can gain the location-aware information or services via user interface. In opposition to *end user RFID tag*, when a user of *end user device with RFID System* actively scans the RFID tag of the commercial advertisement, the handheld device can send the scanned RFID tag information via wireless network or cellular mobile system to the local area server with *embedded server service middleware* embedded. Then, as the procedure of *end user RFID tag*, the *embedded server service middleware* searches for the requested services and transmits these services to the user's handheld device by wireless network or cellular mobile system.

In addition, the users can use *handheld device middleware application* to select the tag content recorded in handheld device database if needed. Then, the RFID API controls the RFID system embedded in the handheld device to re-write the content (such as UID) of the tag of the handheld device. At last, the RFID content requirement from other business applications or systems can be provided through the RFID tag of the handheld device.

In addition, the database can record the history of the user's requirements. The statistic user requirements can be used to classify that what kind of the service the user requests most. Next time the system can provide the personal services according to the classified results. In other words, the users can be served with the services they most pay attention to.

The real test and verification is implemented as Figure 3. The implementation shows one shoot of the verification. When the user approaches the on demand placed RFID system, the *Embedded Service Middleware Platform* automatically presents the information corresponding the content or user's related information recorded in the RFID tag. For example, if a Taiwanese uses the RFID tag, the presentation of local area server will be based on traditional Chinese. But the local area server will provide English when a native English speaker user his own RFID tag respectively.

Figure 4. The environment of test and verification

2.3. RFID applications on supply chain management

2.3.1. Application

Existing RFID applications on supply chain management (SCM) can record something about materials, goods, and products during production [38, 39]. An integrate system with RFID and SCM also can supplies new value-added services such as products secure protection and to query products record [40]. And integrating promising information technologies such as RFID technology, mobile devices-PDA and web portals can help improve the effectiveness and convenience of information flow in construction supply chain control systems [41]. In addition, RFID can be use in a lifecycle of a product to reduce the time which spend to find a product. Therefore, RFID is a technology to reduce the time to identified objects that can improve automation in the traceability management of Supply Chain.

In Warehouse management, many companies have used RFID technology replaced the Bar Code or QR Code as recognition of the key features. Because of the Bar Code and QR Code are limited in existing format companies decided to select a solution improving automation in warehouse management. Then the RFID technology is an efficient technique to solve that problem. Company integrated RFID technology with warehouse management that is not only an electronic process solution but can provided customers with new services such as location information of products, search stock of products, and provide inventory information [42, 43].

In healthcare, RFID also can use to trace patients, blood sampling, drop management, etc. Kumiko Ohashi, SakikoOta, LucilaOhno-Machado, and HiroshiTanaka [44] developed a smart medical environment with RFID technology. This research used two types of frequency on tracking system for tracking clinical intervention such as drug administrations and blood tests at the patient bedside. Furthermore, Chung-Chih Lin, Ping-Yeh Lin, Po-Kuan Lu, and Guan-Yu Hsieh [45] proposed a healthcare integration system for disease assessment and safety monitoring of dementia patients. The proposed healthcare integration system provides the development of an indoor and outdoor active safety monitoring mechanism.

Hence, due to that the RFID technology could provide some services with auto-identify such as administration of drops and samplings, safe monitoring of patients, process control in medical. These new type services can reduce the search time in administration of drops and samplings and human error in medical process. The major advantage of using RFID technology in medical is reduced the human error.

However, RFID applications on Supply Chain Management and Warehouse Management were provided static information as previously noted which helped to deal with problems after accidents. Information on RFID systems was lacking warning data of preventing accidents [5]. To summarize, both Supply Chain Management and Warehouse Management are increase economic values of product. Those operations of management can be help to support product safety information and attribution of responsibility information for customer and enterprise. When enterprise want reduce possible impaired factors to improve the value of product, the first thing should to do is disease management. In addition, disease management has two important methods which to find out the initial pathogen and reduce the spread of pathogens and the infection rate. The spread of pathogens and the infection rate decide the effect areas and damages. Because of enterprise can economic damage control by detect symptoms of product at early stages that will help to reduce cost of operation by itself.

For example, to improve the efficiency of management in cultivation, an *RFID Based Fuzzy Inference Algorithm for Disease Warning and Tracking via Cloud Platform* is proposed. Users could manage the cultivation history, related bio-information, and possible disease tracking. The proposed system modifies the traditional cultivation management system by several fields: 1) first, to shorten the processing time of object recognition in production operation; 2) second, to establish electronic records of production in production management systems; 3) third, to integrate supply chain managements with a central server and provide real-time environment monitoring and plant disease management services for users; and 4) last, to establish an information platform to share with users.

Due to that the contents storage in the memory of RFID tag can be changed when users need. Furthermore, RFID can apply in recognition and also can work in hostile environment such as wet and dirty [26]. RFID provides large read range (or induction range) than Barcode and QR code. Therefore, the RFID system can help to efficiently identify object which equips RFID tag even in non-uniform position. Besides, RFID tag is rewritable. User can remove or rewrite the content of RFID tag when the induction happened between the RFID tag and the RFID reader. In order to overcome the environment factors of cultivation and the objects size, RFID is the solution that can suitable to solve these problems.

In recent years, transportation becomes faster with long distance and also causes more areas infected by disease more easily. After infectious disease influencing a mounts of areas, disease management is more complex and ineffectual [6]. Therefore, quick disease control and prediction is important since it could help to reduce the cost and complex of disease management. Hence, effective disease data tracking and collection of pathogens is necessary.

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Due to portable RFID tags and non-touched transmission, local area wireless application about disease management for tracking and collection data based on RFID system is proposed. In addition, an information platform which collects data from everywhere and stores the data in its database for the members of supply chain is needed and important. Every platform user can query and access some information from an information sharing platform via network. An information platform can store a lot professional data of a particular field. The platform also can integrate information from each region and has more powerful computing for more information services.

2.3.2. Method

The proposed application system structure is shown as Figure 4. The system infrastructure includes RFID system such as RFID tag, RFID reader, mobile RFID device, etc., and software framework such as database, *Environmental Affection Evaluation Method*, and *Disease Tracking Service* in cloud. The user application layer indicates the mobile RFID device which is used for inducting the RFID tag of local objects such as crops or livestock. The information read from the RFID tag by the RFID reader will be transmitted to the corresponding application and database in cloud. Considering the real implementation, *Environmental Affection Evaluation Method* and *Disease Tracking Service* can be established as the middleware of the whole system or the corresponding applications in cloud. When a user wants to query the information or obtain the disease warning, the proposed *Environmental Affection Evaluation Method* and *Disease Tracking Service* can notify the client user via network from cloud platform.

Generally, an RFID system includes RFID Tags, RFID Readers and Application programs. An RFID tag is a digital storage device that used for identification and information recording. A Reader can access, read, or write data into RFID tags through electromagnetic induction. A user can only use the RFID tag without power consumption. In addition, the mobile device used in RFID system can be a Person Digital Assistant (PDA), a Person Computer (PC) or a laptop (Notebook), which executes the reading and writing actions via RFID systems (include software API and hardware). The middleware mainly manage and deal with the RFID event such as the RFID information sent to or from other systems. After receiving the message from RFID readers, the content of RFID tag can be identified. Then the RFID information will be transmitted and recorded in the database in cloud by *RFID Event Processing*. In addition, the corresponding information sent by *RFID Event Processing* is also presented by the user interface. The *RFID Event Processing* also properly manages and provides the information service for *Environmental Affection Evaluation Method* which analyzes and evaluates the affection degree of the environmental factors.

After inducting the RFID, the information can be transmitted to the corresponding applications and recorded into database in cloud. Each RFID tag will establish an individual object history about the location, resident time, environment state of the RFID tag when it was storaged, etc. To trace and track the potential diseased objects, the *Disease Tracking Service* for client users is needed.

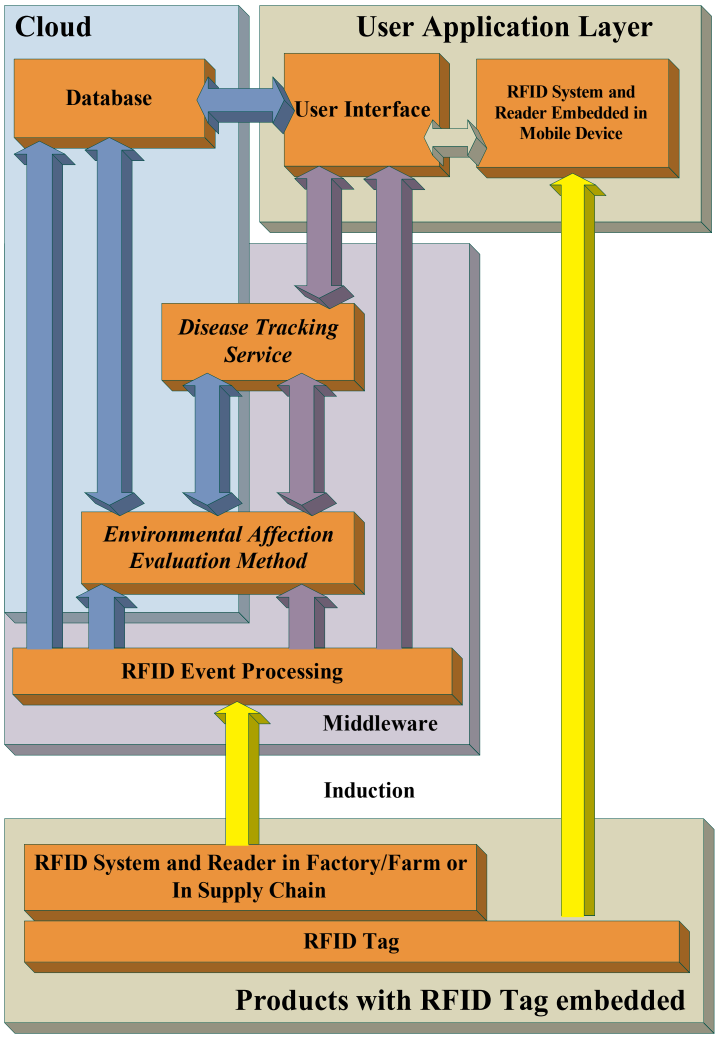

Figure 5. The structure of RFID system with Cloud environment

Via *Disease Tracking Service*, customers or client users can obtain active and passive warning message. First, when a customer or client user uses the mobile RFID system to query the information, the corresponding record in the past will be checked and sent back from the database in cloud platform. Then, the members of the supply chain can monitor and manage the state of objects. Second, if the specific object (crop or livestock) is found to be diseased, this object will be marked as the dangerous object. Then, according to the object history, the route, location, etc., where this dangerous object ever passed will be traced back. According to the structure presented in Figure 2, since the object history is established in cloud, the members of the supply chain can exchange the information via cloud. Therefore, the history of the dangerous object can indicate the information about place, location, resident time, etc.

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Therefore, if the *Disease Tracking Service* finds the dangerous object, the corresponding history, members of supply chain, and the potential diseased that evaluated by *Environmental Affection Evaluation Method* can be notified and traced. In other words, no matter where the objects are, the *Environmental Affection Evaluation Method* can always give the probability value of objects which indicate the potential diseased probability. By using the *Disease Tracking Service*, the location, warehouse, manager, etc., will be notified that how many objects with the different and individual potential diseased probability currently reside at or ever passed the place. Therefore, the object with high potential diseased probability can be discovered in early phase. Figure 5. presents the implementation of the system.

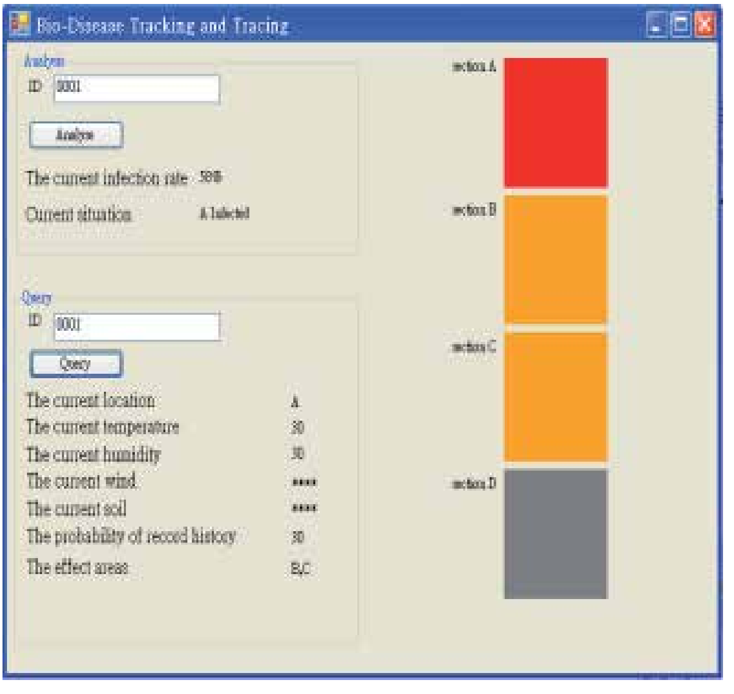

Figure 6. The implementation of tracing and tracking system based on RFID

The tracing and tracking system based on RFID system not only provide original services in supply chain or warehouse which includes the records of products for managing and querying, but also provide new services such as to obtain the potential probability of diseases and send the warning sign for users. Furthermore, the system can derive the possible disease infecting area for users to control and update the latest information of production for users to track and trace. In addition, the verification shows that the proposed system is realistic and can provide the public and personal services automatically. By using this innovation RFID system, users could get most information to prevent disease in agricultures that helps users to reduce the cost of production, control the range of disease occurrence, and providing a warning for disease prediction.

3. Discussion

Radio Frequency identification (RFID) is the popular wireless induction system [7] [2, 3, 8, 30]. Each RFID tag in an RFID system is equips a unique ID (UID) itself. UID can help to shorten the identification time for individual object recognition. In general, there are several methods to achieve aim of Automatic Identification such as Barcode and QR code. However, due to that the Barcode and QR code have the limitation in environmental affection such as wet or water, to maintain the usability and the reliability of the Barcode or QR code is too difficult. Therefore, using RFID can be the solution which provides the distance induction with better characteristics such as anti-water and rewritable memory.

A standard RFID system consists of Tag, Reader, Middleware, and Application. When an independent RFID tag approaches the RFID antenna, the induction between RFID tag and antenna happens [9]. The RFID antenna reads or obtains the information and content recorded in the tag. Then the information is translated into the computational data by the RFID reader. Due to the portable RFID tag and untouched data transmission, many local or small area wireless applications for track and trace based on RFID systems were proposed [2, 7, 8].

RFID reader can access data of RFID tag and transmit the content from RFID tag to middleware which is a necessary component in RFID application system. The middleware is also the interface software that connects new RFID hardware with legacy enterprise IT systems [36]. Middleware is used to route data between the RFID networks and the IT systems within an organization. It merges new RFID systems with legacy IT systems.

RFID Reader is also called Interrogator. The RFID reader can read and write data of RFID tag via radio frequency. RFID readers can classify serial reader and network reader according to connection interface.

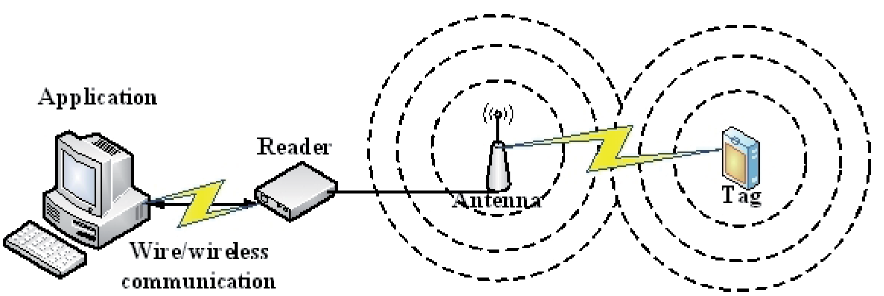

Figure 7. Operation concept of RFID system

In Radio Frequency Identification, there are four standard frequency ranges used: Low Frequency (LF), High Frequency (HF), Ultra-HF (UHF), and Microwave respectively. Frequency decides the reading distance of RFID devices and the interfered with environment. Figure 7 shows the shows the conditions and factors related to the frequency. Higher frequency RFID tag has longer induction distance, higher data rate, and smaller Tag size. On the contrary, lower frequency RFID tag has shorter induction distance, lower data rate, and bigger tag size. In addition, higher frequency RFID tag has bad performance when tag near metal or liquids. In this thesis, the proposed system selects low frequency RFID tag because that the cultivation environment is wet and dirty. Low frequency RFID tag has better performance than high frequency RFID Tag at cultivation environment.

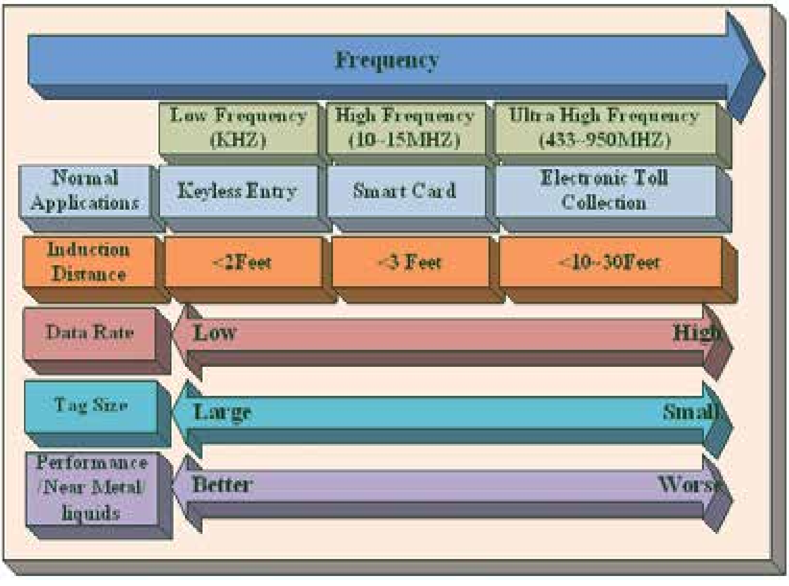

Figure 8. RFID frequency specification chart

There are two main types of RFID tag, active and passive. Active tag is a powered tag which equips battery and actively sends signal itself. In opposition to active tag, passive tag without battery can only send signal when the tag is inducted. Table 1 presents an introduction for RFID Tag.

Freq. Effect	**Low Frequency(LF)**	**High Frequency(HF)**	**Ultra-HF (UHF)**	**Microwave**
Usable Frequency	100~500 KHz	10~15 MHz	433~955 MHz	1GHz~
Common Frequency	125 KHz 135 KHz	13.56 MHz	433 MHz 868~950 MHz	2.45 GHz 5.8 GHz
Power Type	Passive	Active / Passive	Active / Passive	Active / Passive
Reading Distance	Short range	Short range	Longer range	Longer range

Source: EPCglobal.(http://www.gs1tw.org/twct/web/EPC/index.jsp)

Table 1. The relational table of RFID frequency and instruction.

The RFID technology is affected by several factors such as frequency, energy, and environment. When users decide to use RFID in a particular place, users have to select the fittest specification of RFID at first. Because the fittest specification of RFID can make higher performance in the efficient of RFID application system, to select the fittest specification of RFID is important. Furthermore, the cost of RFID is an important factor for users to select.

4. Challenges

4.1. Cost

Today, based on the behavior of customers, the history or record of the production including the delivering is not the most important thing. Most consumers care about the price, expiration date, or packing of the goods. In other words, although the RFID can enhance the management of logistic, to embed the RFID technology into current system also cost a lot. For example, one RFID tag for paste once (non-reusable) may cost $0.8. However, a bottle of water may also cost about $1. Most consumers would not to pay almost twice payment to obtain the information which they do not care about. Comparing with barcode or 417-barcode, the RFID tag costs more than barcode or 417-barcode which can be printed by a printer. In other words, to identify an object via RFID tag costs more than using barcode.

In opposition to once-using RFID tag, to reuse the RFID tag may be a solution. A plastic card where RFID embedded can be used for identification or payment. For example, in Taiwan, most mass transit systems can be paid according to the RFID card that pre-registered and sold to the consumers. Each consumer can use the RFID card to pay the consumption in convenient store, fee of the parking lot, and use the card as a ticket for railway or MRT system. Due to the convenience, most consumers have at least one RFID card for payment. However, the security for financial application is very important. Although there are some security method proposed, no algorithm or system can provide the 100% promise that the security method is always safe.

(a) (b) (c)

Figure 9. The sample of RFID Tag; a.3D Toy, b. plastic card, c. button tag.

In addition to the RFID card, various styles of RFID tag may be required by different consumer. According to the environment, the RFID tag may be designed to anti-water or anti-wet. Some RFID tags need to be applied to the metal environment such as containers. Due to the characteristics of RFID, suitable frequency of RFID corresponding to the environment should be selected carefully. In other words, the cost of different RFID may be also different according to the applications and environment. Furthermore, different shapes of RFID tag also costs. For example, the cost of an RFID tag embedded into a 3D toy is much more expensive than that embedded in a plastic card.

4.2. Hardware and integration

The RFID Antenna is the main component for RFID tag induction. The antenna continuously spreads the electromagnetic wave. The energy is transmitted to the RFID tag. After induction, the RFID Antenna also receives the signal from the RFID tag.

After receiving the signal, the RFID Reader translates the signal into the digital data such as the UID of this RFID tag. Then, the RFID Reader sends the digital data to the corresponding systems or applications. To implement the RFID system, not only the RFID tag but also RFID reader and antenna hardware should be considered. Due to the design and product limitation, the RFID antenna cannot dynamically change. Therefore, similar to the RFID tag, the environment of the RFID system affects the size and cost of the antenna. The size of the antenna increases, the costs also increases. In addition, considering the implementation environment, to place the antenna at the suitable location for signal receiving also affects the performance and costs. Therefore, to integrate the RFID system with the existed system, some additional problems may need to be overcome.

The existed applications or systems should include or integrate the RFID system. In other words, to integrate the RFID system, the original working practices of the existed system may be changed which needs extra costs. For example, to identify goods in warehouse, original applications or systems may only need the manual operation. However, to integrate the RFID system, some infrastructure such as the placement of RFID antenna, wire line for connection between antenna and reader, and the establishment of RFID reader and system server are required. In other words, the extra costs of RFID infrastructure are needed. In addition, some existed systems are based on mechanical operation without too much intelligent analysis. For example, a car parking lot only needs to open the gate when a car approaching or according to the teleswitch. When integrated with the RFID system, the RFID antenna should be placed in front of the gate for induction. All the cars to the parking lot should present the RFID tag given on demand. In addition, the RFID reader should be used to analyze the signal information from the RFID tag. The server which includes the database should be used to judge whether the gate should open or not. Although the RFID system enhances the automation with less manual operation, some extra costs and delay may also happen. Therefore, the benefits of RFID system integration such as automation, information exchanging with third party applications, etc., are very important. Only when the benefits or additional new functions overcome the extra costs of RFID system integration then the integration of system will be used.

4.3. Plug and play middleware

In the RFID systems or applications, there are two partitions: RFID devices (includes RFID tag, antenna, and reader) and other devices or systems. Therefore, the application or middleware for communicating these two parts is needed. When using the RFID device, the third party systems or applications should obtain the information from RFID devices.

Due to that there are many types of RFID hardware, the application program interface (API) for the communication between RFID Hardware and different third party applications is needed. In addition, the end user's devices are also various. Hence, the plug and play middleware for different hardware and applications is important.

To manage the RFID information from different RFID Hardware, and the communication with different applications, the Plug and Play Middleware is proposed. To realize the concept of Plug and Play, the proposed middleware has to manage the information from the all possible third party RFID Hardware, deal with and parse the information, and then provide the required information to the corresponding applications. Therefore, the main purposes of the proposed Plug and Play Middleware are:

1. to parse the information from the RFID Hardware. Due to that there are different RFID product, the RFID parser is needed for analyzing and parsing the information from RFID Hardware. The information about UID, password, etc. will be parsed as the string for the further execution of applications. In this paper, two possible parsers are established. First, the Plug and Play Middleware provides the remote procedure call (RPC) function for the third party RFID Hardware. The UID of the RFID tag inducted by the RFID Hardware will be formulated as the string. In addition, the password or requirements for further information such as decryption code recorded in the End User RFID Device can be provided by the remote procedure call function. Second, for general communication, the Plug and Play Middleware also provides the sever-client socket link between the RFID Hardware and the middleware. In other words, even the RFID Hardware cannot implement the remote procedure call, depends on sever-client socket link, the information can be transmitted between Plug and Play Middleware and RFID Hardware.

2. to provide the application program interface (API). Since the RFID Hardware may not directly communicate with the applications, the Plug and Play Middleware has to implement the corresponding API for other third party applications or software.

Furthermore, the Plug and Play Middleware also should implement two possible APIs: the external procedure call and network communication. If the application is embedded in the Plug and Play Middleware, the external procedure call sends the required information to the specific application. In addition, some communications of the related applications such as database query are also established by the external procedure call. Then, the Plug and Play Middleware deals with the results from the external procedure call. In opposition to external procedure call, for the concept of Plug and Play, normal network communication should also be implemented. Most third party software or applications can communicate with the Plug and Play Middleware via sending the information in string format. For example, if the third party application requires the further checking, the Plug and Play Middleware sends the required information such as UID to the server via Internet. To reduce the cost for communicating with different third party applications, the unify data storage format is necessary. Therefore, the eXtensible Markup Language (XML) can used as a data exchange standard. After obtaining the response from the server, the Plug and Play Middleware can acknowledge the third party application. At last, the corresponding services can be presented.

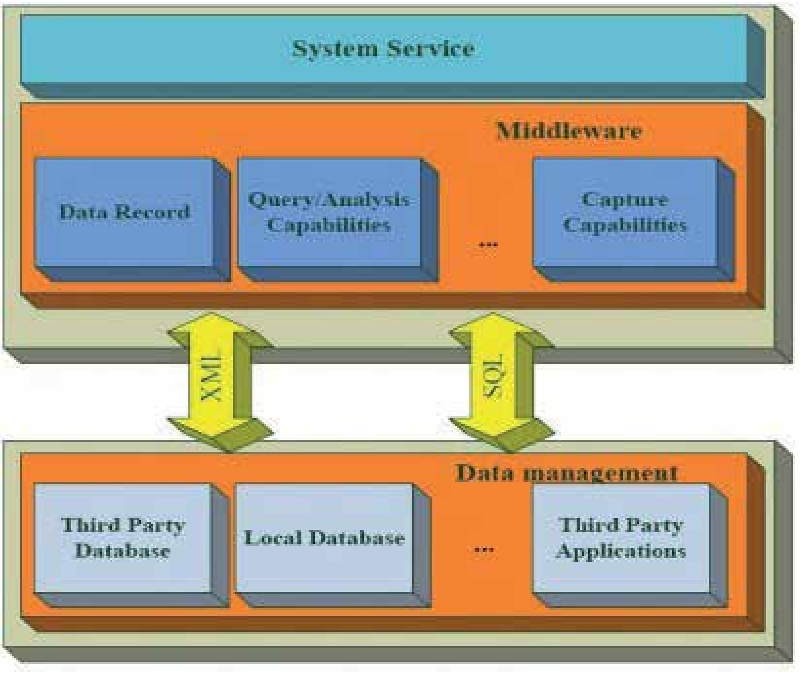

Figure 10. The structure chart of data exchange in Database management

5. Conclusion

In this chapter, we show applications and systems based on RFID technology which integrated into the existed service systems. The RFID technology can enhance the automatic management procedure. Identification and tiny information exchanging can be achieved. Individual or personal services can be provided to different consumers. However, to establish the RFID embedded systems and applications, the cost, convenience, feasibility should be considered. To adopt RFID system, some extra costs such as RFID tag and hardware should be overcome by the enhanced performance of management. In other words, to implement the RFID systems for the consumers, to enhance the convenience for consumers will be an important issue than the cost.

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Chapter 2

Choosing the Right RFID-Based Architectural Pattern

Michel Simatic

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/54069

1. Introduction

RFID provides a way to connect the real world to the virtual world. An RFID tag can link a physical entity like a location, an object, a plant, an animal, or a human being to its avatar which belongs to a global information system. For instance, let's consider the case of an RFID tag attached to a tree. The tree is the physical entity. Its avatar can contain the type of the tree, the size of its trunk, and the list of actions a gardener took on it.

When designing an RFID-based application, a system architect must choose between three locations to store the information: a centralized database, a database locally attached to the device hold by each user of the application, or the tag itself. Each location leads to an RFID-based architectural pattern[1]. But how to choose the right architectural pattern? What are the application attributes which must be taken into account in order to make the right choice?

The state of the art does not bring satisfactory answers. Indeed, when an article describes a RFID-based architectural pattern, it does not mention the application attributes which lead to choose this architectural pattern. On the other hand, some books or articles present the qualities of architectural patterns. But they do not take into account specificities of RFID. For instance, EPCglobal provides a standardized answer [2]: the centralized architectural pattern. A mobile device, NFC-enabled for example, reads an identifier on the RFID tag, then sends a message to a server which associates the identifier to the avatar stored in a central database. Thanks to its simplicity, this architectural pattern is used by several applications. But, it requires a global computer network: Such requirement increases operational costs. Moreover, it does not withstand an important number of simultaneous RFID read operations. Thus this pattern does not fit all RFID-based applications. [3] presents the stakes of introducing RFIDs inside an enterprise. But it does not contain any system architecture

1 . An. architectural. pattern. is. a. description. of. element. and. relation. types. together. with. a. set. of. constraints. on. how. they. may. be. used. [1].

thoughts. In a survey about RFID in pervasive computing, [4] presents several application examples. Depending on the application, avatars are stored either in a central database or in the tags themselves. But the authors do not give any clues on why an application has chosen to store its avatars in a given location. On the other hand, [1] lists the attributes which must be accommodated in a system architecture. Above all, there are the functionalities which are required from the system. Then, orthogonal to these functionality attributes, there are quality attributes. The authors distinguish system quality attributes (availability, modifiability, performance, scalability, security, testability, and usability), business qualities (time to market, cost and benefits, and projected lifetime), and qualities about the architecture itself (e.g. conceptual integrity). But the authors do not focus on RFID specific features.

So we have analyzed several existing industrial or experimental RFID-based applications. Moreover, we have developed RFID-based applications. From this experience, we identify the relevant attributes to compare RFID-based architectural patterns. We present them in section 2. With these identified attributes and their different aspects, we analyze four RFID-based architectural patterns, used by applications to access the avatar of a tagged entity. In the *centralized architectural pattern*, the mobile device reads an identifier on the RFID tag; then it contacts a server which associates this identifier to the avatar stored in a central database or in a database distributed between several companies [2]. With the *semi-distributed architectural pattern*, each mobile device holds a local copy of a central database associating RFID identifiers to avatars [5]. In the *distributed architectural pattern*, each RFID tag holds the avatar [6]. With the *RFID-based Distributed Shared Memory*, RFID tags hold the avatar and a replica of the avatar of other tags [7]. Sections 3 to 6 detail all of these architectural patterns: they present application examples and analyze the architectural pattern with the attributes identified in section 2. Thanks to this analysis, in section 7, we are able to provide guidelines to choose the convenient RFID-based architectural pattern. Finally, section 8 concludes this chapter and proposes perspectives for this work.

2. Architecture attributes and RFID technology

Relying on the experience gained by analyzing existing RFID-based applications and by developing RFID-based applications, we outline three architecture attributes among the attributes presented in [1]: (i) functionality, (ii) scalability, and (iii) cost. For each attribute, we present its different aspects which are influenced by the use of RFID technology.

2.1. Functionality attribute

Functionality is the ability of the system to do the work for which it was intended.

All architectural patterns give the ability to read/write the avatar of a read tag.

A first aspect of the functionality attribute is to check how the application behaves when it queries the avatar of a read tag. Is it guaranteed that the returned avatar has indeed the value which was last written? In other words, is there a staleness issue of avatar of a read tag?

The second aspect concerns the possibility of knowing the value (or having an order of idea of the value) of the avatar of a remote tag. By "remote", we mean that the user is not physically near the tag: The user is not able to put her reader on the tag. All she has is the identifier of the remote tag.

The third aspect is the staleness issue of the avatar of a remote tag. If the user is able to know the avatar of a remote tag, is it guaranteed that the returned avatar has indeed the last values associated to the tag?

2.2. Scalability attribute

The scalability criteria category evaluates how each architectural pattern behaves when there are numerous tags or numerous readers.

Its first aspect is the maximum number of tags which can be handled by the architectural pattern.

The second aspect characterizes the sensitivity of the architectural pattern to the number of simultaneous RFID tag read operations.

2.3. Cost attribute

The cost attribute groups all of the aspects which have an influence on the installation costs or the operational costs of the RFID-based application.

The first cost aspect concerns the requirement for a global network: do RFID readers have to be able to access at any time and any place to a specific computing machine (for instance, a server in the case of the centralized architectural pattern)? To fulfill this requirement, the readers may be equipped with a wired connection. In that case, the mobility of the readers is limited. The readers may also rely on Bluetooth® or Wi-Fi gateways. Both of these gateways may introduce installation costs. Moreover some readers may not be Wi-Fi enabled. For instance, the Nokia 6212 mobile phone is NFC-enabled, but has no Wi-Fi capabilities. Finally the reader may rely on a mobile data connection (e.g. UMTS, HSDPA, etc.). Such solution introduces operational costs because of data plans.

The second cost aspect concerns the RAM requirement on each tag. The more RAM there is on the tag, the more expensive the tag is. Notice that RAM may actually be prohibited on tags for technical reasons and not for cost reasons. For instance, application may require the use of low-frequency tags (e.g. 125 kHz), so that readers can interact with tags even though there is a liquid between tags and readers. In this case, the throughput is too low for a tag to host information other than its identifier.

The third cost aspect concerns the introduction of a new tag in the environment. For each architectural pattern, we determine the sequence of operations which is required in order to introduce a new tag in the environment. Knowing this sequence, we can determine how long this sequence lasts. Because this initialization procedure is executed by a human or a robot operator, its cost is proportional to the time spent.

The final cost aspect is related to the reinitialization of all of the tags. This criterion concerns only applications which, during their lifetime, need sometimes to have each tag given a new initial value. For instance, this is the case of Paris public transportation system. Users are equipped with a transportation pass containing an RFID tag. At the beginning of a month, each user has to reload her pass (to refresh her access rights): in other words, the tag has to be reinitialized. Some RFID-based games also require tag reinitialization. Indeed, in the case of non-permanent games, users play during successive game sessions. Thus at the beginning of each session, all of the tags must be reinitialized.

In this section, we have defined different aspects of three architecture attributes: (i) functionality, (ii) scalability, and (iii) cost. These aspects are influenced by the use of RFID technology. We use them to compare the behavior of four RFID-based architectural patterns. We start by analyzing centralized architectural pattern.

3. Centralized architectural pattern

This architectural pattern is often used by manufacturing applications. It has been standardized by EPCglobal [2]. When a reader is near a tag (for instance, the blue mobile in Figure 1), it reads the tag's identifier or an identifier stored in the tag's data zone (its Electronic Product Code in the case of EPCglobal). This identifier is represented by the hexagon in Figure 1. Then, the reader asks a server (ONS lookup service in the case of EPCglobal) which machine (EPC Manager in the case of EPCglobal) manages the avatar corresponding to the read identifier. When the server responds, the reader contacts this machine with the identifier of the tag. The machine queries its database and returns the avatar (for instance, the contents of the hexagon in the database in Figure 1).

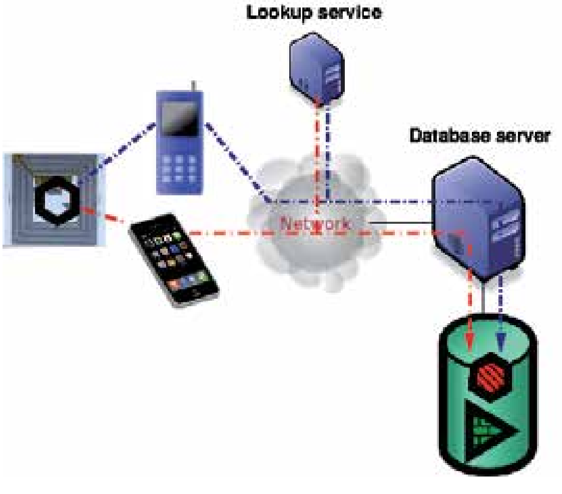

Figure 1. Centralized architectural pattern

Next section gives examples of this architectural pattern.

3.1. Examples

Aspire RFID is an Open Source middleware which is compliant to the specifications of EPCglobal [8]. It proposes several examples of industrial applications for tracking goods.

Next paragraphs present products or prototypes developed according to centralized architectural pattern, but without being compliant to EPCglobal.

PAC-LAN is a game prototype in which players are equipped with NFC mobile phones without any GPS capabilities [9]. Players must interact with NFC tags which have been disseminated throughout a neighborhood. In a central database, the identifier of each tag is associated to geographical coordinates. When a player reads a tag, her mobile phone uses the UMTS network to contact the server with the tag's identifier. The server queries its database, finds the geographical coordinates, and broadcasts them to all of the players. An administrative application is provided to reset a game on the server. Such reset has an impact on all of the players' mobile phones.

[10] proposes an application so that visitors of an art exhibition can discover the paintings in another way. NFC tags are dispatched on the back of exposed paintings. Equipped with an NFC-enabled phone, the visitor puts her phone on spots of the paintings which intrigue her. Phone reads the identifier stored in the tag. Then, it contacts an uGASP server [11-12]. After consulting an internal database, this server indicates to the mobile phone what must be done: display a text, an image, or play an audio comment. Thus the author of the painting is able to communicate with the visitor.

Via Mineralia is a pervasive serious game which goal is to enrich the visit of a Freiberg museum [13]. In this game, the visitor uses a PDA equipped with an RFID reader. RFID tags (holding a unique identifier) are dispatched in the showcases which the museum wants to emphasize. When the PDA scans a tag, it sends an HTTP request (with tag's identifier) to a web server. To do so, the PDA uses a Wi-Fi network which covers the whole museum. The server answers to the PDA with multimedia information. The PDA displays them in a navigator.

Touchatag company (formerly Tikitag) sells NFC readers which can be connected to Windows or Mac-OS personal computers, and NFC tags dedicated to Touchatag [14]. A customer can then connect to http://www.touchatag.com web site, and define the reaction to be associated to the reading of one tag. When the NFC reader reads a tag, it contacts the Touchatag application which runs permanently on customer's personal computer. Then, via the Internet network to which the computer is connected, this application contacts a Touchatag service called *Application Correlation Service* (ACS). Touchatag application gives tag's identifier to ACS. Then, ACS queries Touchatag database to find reaction associated to the reading of this tag. It sends back this information to Touchatag application. The touchatag application reacts in the appropriate way. For instance, let's assume that the customer has specified the following action on Touchatag web site: when tag r with identifier i is put on the reader, customer wants her browser to access to Uniform Resource Locator (URL) of a web site w.

Then, when customer puts tag *r* on the reader, Touchatag application contacts ACS with identifier *i*. ACS replies with URL of *w*. Then, Touchatag application opens a browser with this URL *w*.

Skylanders is a video game developed by *Activision* company [15]. It requires the use of plastic figures. These figures contain an NFC tag. When a player puts her figure on top of a "Portal of Power" (actually, an NFC tag reader), the video game reads the identifier stored in the NFC tag. Then, the game contacts a server to get the information concerning the character which must be displayed: The figure becomes alive on the screen. Notice that, according to [16], information is also stored inside the tag: Thus the game can work without using a global network to contact a server. This means that Skylanders not only uses a centralized architectural pattern, but also a distributed one.

Based on all of these examples, next section analyzes centralized architectural pattern.

3.2. Analysis

Concerning the functional attribute, any transponder which wants to modify the avatar of a tag does so by sending a modification message to the server. Thus the server is always aware of the last update done on any avatar. As a reader always queries the central database to know the avatar of a tag, it is not possible that the read value is stale. Moreover, knowing a tag identifier, a reader is able to query the server to know the avatar associated to this identifier: the reader is able to know the avatar of a remote tag. As a mobile device queries the server to know the avatar of a remote tag, it is sure that the returned value is not stale.

Concerning the scalability attribute, the maximum number of tags which can be handled by this architectural pattern is limited by the number of avatars which can be stored in the central database. Let s be the average size in bytes of an avatar. Let $S_{central}$ be the maximum size in bytes of the database. We neglect the storage of the link between tag identifiers and avatars in the database. Moreover, we neglect the overhead due to the storage of data in the database. Then, the maximum number of tags is bounded by $S_{central}/s$. About sensitivity to the number of simultaneous reads, this architectural pattern is restrained by its centralized nature. The server holding the ONS lookup service may become a bottleneck. Moreover, the different servers of avatars may not return avatar values fast enough. Of course, it is possible to increase the number of servers. But that makes the hardware architecture more complex and more costly (from an installation and a management point of view). Thus this architectural pattern may not be applicable for some applications.

Concerning the cost attribute, the reader must always be in contact with the server holding the ONS lookup service and the servers of avatars: a global network is required. On the other hand, this architectural pattern only needs to read an identifier on the tag. And this identifier can be stored in ROM as it is never modified: no RAM is required on the tags. When a new tag is introduced in the system, three operations are required: (i) the tag is linked to the physical entity; (ii) the avatar of this entity is initialized in the central database; and (iii) a link between the tag identifier and this avatar is created into the central database. When all of the tags have to be reinitialized, a program is run on the server hosting the central database. It sets each avatar to its new value.

This section has analyzed centralized architectural pattern according to the attributes presented in section 2. This architectural pattern fulfills all aspects of functionality attribute. But this is achieved with the operational cost of a global network. Another disadvantage is a high sensitivity to the number of simultaneous read operations.

Next section analyzes semi-distributed architectural pattern which compensates the requirement for a global computer network and reduces sensitivity to the number of simultaneous reads.

4. Semi-distributed architectural pattern

In semi-distributed architectural pattern, mobile RFID-enabled devices (PDAs, mobile phones, etc.) are periodically synchronized with a central database holding all of the avatars (see Figure 2). Then, human operators carry the mobile devices near the entities to which the tags are associated. When a device comes close to an entity, the device reads the identifier of the entity's tag. By querying its local copy of the central database, the device is able to find the avatar of this entity. Any modification of an avatar is done on the local copy. It is propagated to the central database at the next synchronization.

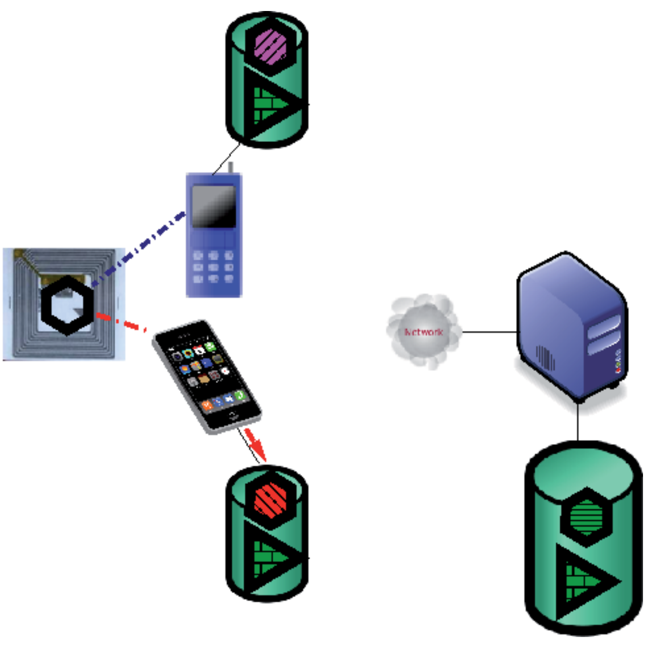

Figure 2. Semi-distributed architectural pattern

Next section presents an example of this architectural pattern.

4.1. Example

The unique example of use of such architectural pattern is Paris trees management application [5]. Each of the ninety-five thousand trees of Paris avenues is equipped with an RFID tag. Each gardener synchronizes her tablet PC with the central database before a new day of work. During her day of work, whenever a gardener does something to a tree, she identifies the tree thanks to its RFID tag: Her tablet PC modifies the avatar in the local database. Then, in the evening, she synchronizes her tablet PC with the central database. Thus she uploads her database updates and downloads updates from other gardeners.

Now, let's analyze the semi-distributed architectural pattern.

4.2. Analysis

Concerning the functional attribute, the avatar of a read tag may be stale. Suppose users U_1 and U_2 synchronize their mobile device with the central database. Then U_1 modifies avatar of tag *r*. Thus she modifies her local copy of the database. When U_2 comes to tag *r*, as her device reads its local copy of the database, the returned value of the avatar is the value before U_1's modification: the read value is stale. Notice we can limit this issue by assigning sets of entities to each mobile device. For instance, in the case of the Paris trees management application, a supervisor can assign a set of trees to be taken care of during the day, to each of the gardeners. If all of these sets are apart, this issue cannot be observed anymore. About remote tags, by querying its local database, the device is able to read the avatar of a remote tag, even though there is no global network. But the read value can be stale. It will be again correct only when all of the mobile devices have synchronized themselves with the central database.

Concerning the scalability attribute, the maximum number of tags which can be handled by this architectural pattern is limited by the number of avatars which can be stored in the central database and in the local copy of this database. Let S_{local} be the maximum size in bytes of the local database. The maximum number of tags is bounded by $min(S_{central}/s, S_{local}/s)$, which is likely to be S_{local}/s as mobile devices do not have as much memory as servers. Notice that this bound can be increased to $S_{central}/s$ by assigning to each mobile only a subset of the central database. For instance, in the case of Paris trees management application, the mobile device of a gardener could receive only the avatars of the trees she will take care of during the day. About sensitivity to the number of simultaneous reads, this architectural pattern is not as sensitive as centralized architectural pattern. It does not need to query a server upon each RFID tag read. Nevertheless all of the readers must periodically synchronize themselves with the central database. As the synchronization time is proportional to the number of readers, it may reach unbearable values. This issue can be tackled by limiting the number of avatars copied on the local devices, thus reducing the volume of data transferred between each device and the central database.

http://dx.doi.org/10.5772/54069

Concerning the cost attribute, the mobile RFID-enabled devices only need an access to the server hosting the central database during synchronization phase. At that moment, devices are probably near the central database: A Wi-Fi network may be used. Otherwise it is the local database which is queried. Thus no global communication network is required around the working area. Moreover, as in centralized architectural pattern, there is no need for RAM on the tags. When a new tag is inserted in the system, the procedure to be applied is the same as in the centralized architectural pattern. When all of the tags have to be reinitialized, a program is run on the server hosting the central database. It sets each avatar to its new value. However, the reinitialization of the tags will be effective only when all mobile devices will get synchronized with the central database.

This section has analyzed semi-distributed architectural pattern according to the attributes presented in section 2. This architectural pattern does not require any global network and has a medium sensitivity to the number of simultaneous tag reads. Nevertheless it faces a functional issue concerning the staleness of avatar read on a local (or remote) tag.

Next section analyzes the distributed architectural pattern which tackles the sensitivity and staleness issues.

5. Distributed architectural pattern

In distributed architectural pattern, the avatar of an RFID tag is stored inside the RAM of the tag (see Figure 3). Whenever a user is in contact with a tag, the reader works with the part of the RAM containing the avatar.

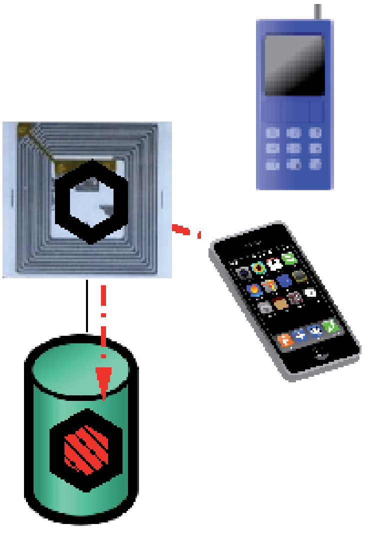

Figure 3. Distributed architectural pattern

Next section gives examples of this architectural pattern.

5.1. Examples

Nokia 6131 NFC phones are sold with three NFC tags. Each one triggers a different function on the telephone: One activates alarm function; another one plays a given music on the phone; the last one displays an NFC tutorial. To do so, the telephone reads the contents of the tag, this contents being coded as a Uniform Resource Identifier (URI) according to the NFC Forum's specifications of *Smarts Posters* [5,17-18]. When the phone is programmed to understand tags' contents formatted according to these specifications, these URIs can be used to tell the telephone to accomplish a given function like send an SMS, call a certain number, open a given web page, etc.

In fact, it is thanks to this Smart Posters specification that any NFC phone can exploit Touchatag tags mentioned in section 3.1. Indeed, these tags contain not only an identifier used by Touchatag application, but also an URI. This URI is the URL of a Touchatag web server with a parameter containing the identifier of the tag. Thus when a user touches a Touchatag tag with her mobile phone, the phone reads the URL and then opens a browser with this URL. Touchatag web server is then contacted, via 3G or Wi-Fi, with the identifier *i*. Then, web server contacts ACS (see section 3.1) with *i*. In the case where *i* is associated with a web site *w*, URL of *w* is sent back to Touchatag web server. This server returns an html page containing a redirection towards *w*. Finally, the browser displays *w*. Notice that, in the case of a Touchatag tag read by a mobile phone, phone uses distributed architectural pattern to determine the Touchatag web server to contact; but, the Touchatag web server uses centralized architectural pattern to translate the tag identifier into an action.

Once again, it is the Smart Posters specification which is used by *Connecthing* company to bring intelligence to mailboxes [19]. When a user scans a mailbox equipped with an NFC tag, her phone reads the URL stored on the tag (which contains an identifier corresponding to the physical location of the mailbox) and opens a browser to access this URL. This web page displays location of nearby mailboxes, the time at which postman takes the mail, etc.

Navigo, the Paris public transportation pass, is an example of an industrial application based on this architectural pattern, which does not use Smart Posters specification [20]. The 4.5 million Navigo pass users do not have an NFC reader. They are only given a pass which contains an NFC tag. With a vending machine, each user initializes her tag with the rights she buys to use the public transportation. Whenever she wants to use a public transportation, she presents her pass in front of an NFC reader. Locally, the reader checks the rights stored in the tag's RAM and opens the gate, if the access is granted.

Ubi-Check is an academic application example of distributed architectural pattern [21]. An RFID tag is attached to each of a traveler's items. At the beginning of their travel, each tag is initialized with a value specific to the traveler. All of these RFID tags are read after special points (e.g. after an airport security control). If an inconsistency is found among the read values, it means that, at some point, the traveler exchanged one of her items with the item of another traveler. An alarm is thus triggered to warn the traveler that one of her items is missing.

[22] proposes an academic system based on digital pheromones to find objects lost in a house. To do so, floor of the house is covered with RFID tags. An RFID reader is coupled with each house object. When user moves an object from point *A* to point *B*, the RFID reader associated with the object behaves like an ant which sets pheromones on the path it takes: The reader writes a digital pheromone (made of object identifier and timestamp of transit) in the RAM of each tag over which it goes. Notice that, like a natural pheromone which evaporates with time, whenever a reader finds no more room in the RAM of a tag (there are too many pheromones stored inside), the reader deletes the oldest pheromone from the tag. In case an object is lost, user takes a dedicated RFID reader and wanders around the house until she finds the digital pheromones of the object. Once she has located it, she follows the pheromone trace until the place where the object was left.

Roboswarn is an (academic) application to position robots (equipped with NFC readers) in a physical space to accomplish a certain task [23]. NFC tags are dispatched in dedicated places of a room (for instance, near a hospital bed which these robots will have to push so that a cleaning robot can accomplish its task). Each tag is initialized with location of other tags in the room and the timestamp of last cleaning. When robots enter the room, they look for an NFC tag. As soon as one robot finds one, it reads the position of other tags and transmits them to other robots. The other robots go to the other tags. If timestamp of last cleaning is too old, robots push the hospital bed and then write new timestamp of cleaning. Otherwise, robots do nothing.

SALTO Systems company is selling locks for electronic doors. The keys are NFC tags. To facilitate the management of all locks and tags, this company has developed SALTO Virtual Network (SVN) [24]. Thanks to this system, Heathrow airport operator is able to manage 1000 standard electronic locks (NFC-controlled) and 37 hot spots. These spots are special locks connected to a global computer network. They can: 1) unlock an entry access on the whole site, 2) initialize an NFC key with the right to open given locks during the day, 3) blacklist some NFC keys, 4) recover data collected by the key during the working day of its user. Indeed, each time a person unlocks an electronic lock with her NFC key, the lock reads data stored on tag to check user permissions and the list of blacklisted tags. But, the electronic lock also writes information like, for instance, the low charge of the battery powering the lock. Thus thanks to SVN, even though standard locks do not have access to a global computer network, they can receive information (e.g. list of blacklisted cards) and send information (e.g. low charge of battery): Standard locks communicate thanks to the network made of the users of the keys/tags.

Based on all of these examples, next section analyzes distributed architectural pattern.

5.2. Analysis

Concerning the functional attribute, as the avatar is written and read only in the RAM of the tag, there is no staleness issue of locally read tags. However, it is impossible to know the avatar of a remote tag.

Concerning the scalability attribute, there is no limit on the number of tags in the application environment. Moreover, such distributed architectural pattern is not sensitive at all to the number of simultaneous read operations (all of the operations are done locally).

Concerning the cost attribute, the reader does not need any global network to access to the avatar of the RFID tag. On the other hand, RAM is required on each tag. Its size must be at least the size of the avatar. This means that the avatar cannot contain too much information (e.g. MIFARE tags can offer up to 4 Kbytes of RAM, with 3440 bytes of net storage capacity). When a new tag is introduced in the system, only two operations are required: (i) the tag is linked to the physical entity; and (ii) the avatar of this entity is initialized in the RAM. About the reinitialization of the tags, it is application-dependant. Some applications require that a dedicated user goes through all of the tags to reinitialize them. In the case of Navigo pass, users are in charge of bringing their pass to a vending machine. This leads to long waiting lines at the beginning of a month, when users must initialize their rights for this month. This is why Navigo operator carries out experiments where users can initialize their tag using a dedicated NFC reader connected to their personal computer. To avoid reinitialization costs, some RFID-based distributed applications put in place special mechanisms. These mechanisms take into account elapsed time in order to automatically reset data. In Roboswarm application (see section 5.1), there is no need to reset the timestamp to trigger a new cleaning of a room. Each robot is aware of a deterioration level. Thus if the timestamp plus this deterioration level is greater than current time, it means that the room needs some cleaning again. With application for pheromone-based object tracking (see section 5.1), although tags have limited RAM capabilities, there is still no need to have a periodic session initialization which would clean up outdated pheromones. Each pheromone is written on a tag with a timestamp. Thus when the device attached to the roaming object meets a tag, it cleans up pheromones which have a too old timestamp, before writing the dedicated pheromone.

This section has analyzed distributed architectural pattern according to the attributes presented in section 2. This architectural pattern does not require any global computer network. And it is not sensitive to the number of simultaneous read operations. Nevertheless it faces a functional issue: it is not possible to get the avatar of a remote tag.

Next section analyzes RFID-based DSM which tackles this issue.

6. RFID-based distributed shared memory architectural pattern

RFID-based distributed shared memory (RFID-based DSM) mixes the qualities of semi-distributed architectural pattern and distributed architectural pattern [7]. The avatar of an RFID tag is stored in the RAM of the tag. In addition, each tag and each mobile device of the application environment holds a local copy of all of the avatars (see Figure 4). Moreover they hold a vector clock (see Figure 5). Each element of this vector clock is a number corresponding to the last version of the avatar which the tag or the device has learnt about (this is why [25] gives the name *version number* to this number). When a mobile device comes to a tag and modifies the avatar of the tag, this mobile increments the element of the vector clock (stored on the tag and inside its own memory) corresponding to the avatar of this tag. Whenever a mobile device meets a tag (respectively another device), the device and the tag (respectively the other device) compare their respective view of the avatars, by comparing their vector clocks values. Doing so, each of them learns from the other one the latest news (which they are aware of) about all of the avatars.

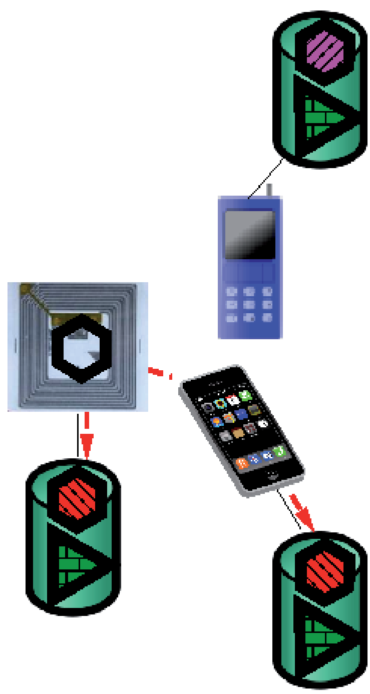

Figure 4. RFID-based distributed shared memory architectural pattern

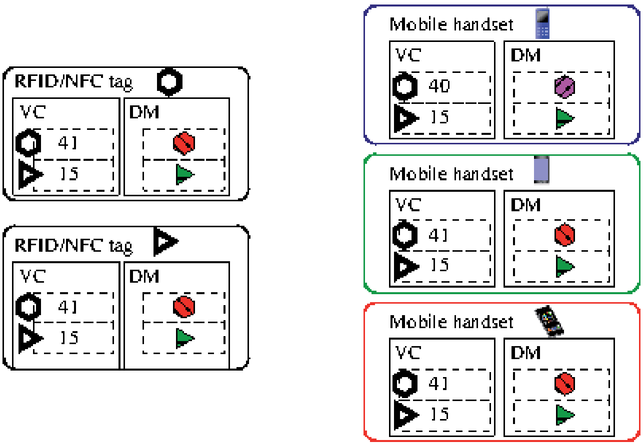

Figure 5. Data of RFID-based distributed shared memory

Next section presents an example of this architectural pattern.

6.1. Example

Plug: Secrets of the museum, an (academic) pervasive game [26] developed in the context of the *PLUG* research project [27], is the unique example of use of RFID-based DSM architectural pattern. In this game, 48 virtual playing cards represent objects of French Museum of Arts and Crafts (*Musée des arts et métiers*). These cards are dealt between 16 NFC tags (1 card per MIFARE tag, each of them being equipped with 1 KB of RAM) and 8 mobile phones (4 cards per Nokia 6131 NFC mobile). The players' goal is to collect cards of the same family on her mobile. To do so, players use their mobile to swap a card with a tag or another mobile.

Next section analyzes RFID-based DSM architectural pattern.

6.2. Analysis

Concerning the functional attribute, whenever a mobile device comes near a tag, there are two possibilities. Either the tag has been already initialized; in that case, as the avatar is stored on the tag, the value read on the tag is the most up-to-date. Or, the tag has not been already initialized; in that case, the first task of the mobile device is to initialize the tag; so that the value read on the tag after this initialization is also the most up-to-date value. Thus there is no staleness issue for avatar of locally read tag. Moreover, a mobile device holds a local copy of all avatars. Thus by querying this local copy, the device is able to answer to queries concerning a remote tag. However this local copy may not be up-to-date: There is a staleness issue for avatar of remotely read tag.

Concerning the scalability attribute, the maximum number of tags is limited by the size of the RAM of the tags. This architectural pattern stores copies of the avatar of all of tags and a vector clock. Let S_{tag} be the lowest size of the RAM of the tags present in the environment. Let L be the length of an element of the vector clock. Then the maximum number of tags is bounded by $S_{tag}/(s + L)$. Let's compare this bound to the bound of semi-distributed architectural pattern. For the latter pattern, the numerator is expressed in terms of Gigabytes. However it is expressed in terms of Kilobytes in the case of a tag's RAM. The maximum number of tags for RFID-based DSM architectural pattern is at least one million times lower than the maximum number for semi-distributed architectural pattern. About sensitivity to the number of simultaneous reads, RFID-based DSM requires that all mobile devices synchronize with a dedicated machine: RFID-based DSM is as sensitive as semi-distributed architectural pattern.

Concerning the cost attribute, in RFID-based DSM architectural pattern, the reader does not need any global network to access to the avatar of the RFID tag. Nevertheless RAM is required on each tag. Its size must be at least the size of the avatar times the number of tags in the environment (so that a tag can hold a local copy of all avatars). This means that the avatar can contain even less information than in the case of distributed architectural pattern.

When a new tag is introduced in the system, four operations are required: (i) the tag is linked to the physical entity; (ii) the avatar of this entity is created and initialized in DB_{init}, the database used to (re)initialize the local copy on each mobile (DB_{init} is stored on a dedicated machine which can be one of the mobiles); (iii) a link between the tag identifier and this avatar is created in DB_{init}; and (iv) all of the elements of the tag's vector clock are initialized to zero.

When tags must be reinitialized, a program P_{init} is executed on the machine hosting DB_{init}. This program computes the initial value VC_{init} of the vector clock for this session, so that each element of VC_{init} is greater, thus more recent, than all the vector clock elements in the mobiles. To do so, P_{init} can use two methods. The first method is twofold: (i) get the vector clocks of all of the mobiles; and (ii) compute the maximum value. This first method does not require additional memory on each tag, but requires additional communication between the mobiles and the dedicated machine. This method works because the vector clock of a tag evolves only when a tag is in contact of a mobile. Thus there is always at least one mobile device which is aware of the values stored in the vector clock of a tag: P_{init} does not need to be aware of the vector clock values stored on the tags. The second method supposes that each vector clock element is made of two fields: a "session identifier" field and a "tick in this session" field. Thus P_{init} has only to increase the session number and set all "tick in this session" fields to zero. This second method requires additional memory on each tag, but no additional communication between the mobiles and the machine running P_{init}. The choice of the method is application dependant. Once one of the two methods has been applied, the dedicated machine synchronizes each mobile device by sending the contents of DB_{init} and VC_{init} to the device. Afterwards, whenever a mobile device is in contact with an uninitialized RFID tag for this session, as the mobile device vector clock is greater than the tag vector clock, the mobile device initializes the tag. In other words, RFID-based DSM architectural pattern takes advantage of the fact that application users will go to tags, to initialize them: This pattern uses the communication network made by application users, instead of using a global computer network.

This section has analyzed RFID-based DSM architectural pattern according to the attributes presented in section 2. This architectural pattern does not require any global computer network. And it does not experience the issue of staleness of an avatar of a read tag. Moreover it is possible to query the avatar of a remote tag. Nevertheless this architectural pattern experiences staleness issues when accessing to avatar of a remote tag. And there is a scalability issue in terms of maximum number of tags which can be handled.

By synthesizing the conclusions observed for the different architectural patterns, the next section provides guidelines for choosing the most adequate pattern for a given application.

7. Guidelines for choosing the right RFID-based architectural pattern

Table 1 synthesizes the analysis of the different aspects of the architecture attributes made on all of the architectural patterns. In this table, values which are in italic correspond to aspects which are a limitation for this architectural pattern.

If the application requires the best level for all aspects of functionality attribute, then the centralized architectural pattern must be chosen. It is the only architectural pattern which experiences no issues within the functionality attribute. But this pattern has an operational cost due to the requirement for a global network. And this pattern is highly sensitive to the number of simultaneous reads.

	Central.	**Semi-distr.**	**Distributed**	**RDSM**
Staleness of locally read tag	No	*Yes*	No	No
Avatar of remote tag	Yes	Yes	*No*	Yes
Staleness of remote read tag	No	*Yes*	n.a.	*Yes*
Maximum number of tags	$S_{central}/s$	S_{local}/s	Infinite	$S_{tag}/(s+L)$
Sensitivity to number of simultaneous reads	*High*	Medium	None	Medium
Network required	*Yes*	No	No	No
RAM required on tag	No	No	*Yes*	*Yes*
Cost of introducing a tag (most costly operation)	Link tag to physical entity	Link tag to physical entity	Link tag to physical entity	Link tag to physical entity
Cost of reinit. Tags (most costly operation)	Reinit. Database	Sync. Database	*Go to all tags*	Sync. database

Table 1. Comparison of the RFID-based architectural patterns (italic values signal a limit for this architectural pattern)

If one of these last two issues is a problem, the system architect must consider the three other architectural patterns. Semi-distributed architectural pattern must be chosen if RFID tags cannot host RAM. This constraint may be due to cost motivations, but also technical constraints (use of low-frequency tags, see section 2).

If there can be RAM on tags, the maximum number of tags must be determined. If it is compatible with RFID-based DSM architectural pattern limitations, then this pattern should be chosen (as it is the least limited pattern for the functionality attribute). Otherwise the system architect should choose distributed architectural pattern (if there must be no staleness issue for read tags) or semi-distributed architectural pattern (if the cost of reinitializing tags is an important factor). Notice that the mixing of distributed architectural pattern and RFID-based DSM may be an interesting alternative. On each tag, we can store its avatar and the vector clock element corresponding to this avatar. Each mobile device holds a copy of all avatars and a full vector clock. By applying RFID-based DSM procedures, we get a solution for the limited maximum number of tags in RFID-based DSM. And in the same time, we solve distributed architectural pattern limitations (as we can query avatar of remote tags and we reduce the high cost of tag reinitialization).

To illustrate the use of these guidelines, let's consider the choice of the architectural pattern for the RFID-based game *Plug: Secrets of the museum* presented in section 6.1.

Each tag costs about 0.10 euro (respectively 1.50 euro) if it has 0 KB (respectively 1 KB with 752 bytes of net storage capacity, S_{tag}=752 bytes) of RAM. The avatar of a tag is the virtual card "contained" in the tag. There is a maximum of 16 cards in the game. Thus the avatar is coded as a byte value (s=1 byte). Concerning the vector clock, the project uses the synchronization method requiring a session identifier. To have an ever-increasing value, "session identifier" field stores the initialization time. This time is the difference, measured in milliseconds, between the session initialization time and midnight, January 1st, 1970 UTC. This storage requires 8 bytes per tag. Moreover, each tag holds the "tick in this session" field of each avatar stored in the tag.

This field is coded as a short (L=2 bytes). It represents a real-time clock, formatted as the number of seconds since the beginning of the game session (A session lasts less than 2 hours: there is no risk of overflow). This clock is the time known by the tag of the last update of the avatar of another tag. It takes about 20 minutes to attach each of the 16 tags to their correct location, so an average of 75 seconds per tag. Linking the tag and the avatar takes about 5 seconds per tag. Initializing the avatar is done in a few milliseconds by an initialization program. For reinitializing tags, synchronizing all of the 8 mobiles with a dedicated machine takes about 1 minute, that is an average of 4 seconds per tag. Notice that synchronization is based on NFC peer-to-peer communication. The project could have saved synchronization time if it has used Bluetooth®, but it would have used more battery.

If the project is going to use centralized or semi-centralized architectural pattern, it will use a dedicated machine for hosting the central database. This machine will be equipped with a 500 gigabytes disk ($S_{central}$=500 GB). In the case of the semi-distributed architectural pattern, the project will use half of the micro-SD memory of each mobile phone to host the local copy of the database (S_{local}=1 GB). If the project is going to use centralized architectural pattern, each mobile will have to be equipped with a SIM card giving access to a UMTS data plan. This will cost 15 euros per mobile per month. If the project is going to use distributed architectural pattern, it will take 13 minutes to go by all of the 16 tags to reinitialize them, so an average of 49 seconds per tag.

We apply these numeric values to table 1. Table 2 synthesizes the results. In this table, values which are in italic correspond to criteria which are a limitation for this architectural pattern.

Centralized architectural pattern requires a global network which costs 120 euros per month. The museum which hosts the game considers it is too expensive. We have to turn to one of the other architectural patterns. As the game must manage 16 tags and as the RFID-based DSM can handle a maximum of 248 tags (as *s*=1 byte), we can choose this architectural pattern. However, if s had been 250 bytes, this pattern could have handled only 4 tags: It would not have fitted. As there must be no issue about avatar of read tags (the game would not be fun), we would have chosen distributed architectural pattern (or combination of distributed and RFID-based DSM patterns, in order to reduce the costs of reinitializing tags).

8. Conclusion and future work

This chapter studies four RFID-based architectural patterns: centralized, semi-distributed, distributed and RFID-based DSM. It compares them according to nine aspects of three architecture attributes: functionality, scalability and cost. Despite their specific limitations, each architectural pattern fits the requirements of existing applications.

	Central.	**Semi-distr.**	**Distributed**	**RDSM**
Maximum number of tags if s=1 byte (s=250 bytes)	500 x 109 (2 x 109)	109 (4 x 106)	Infinite (Infinite)	248 (2)
Cost of computer network (per month)	*120 euros*	0 euro	0 euro	0 euro
Cost of tag (per tag)	0.10 euro	0.10 euro	*1.50 euro*	*1.50 euro*
Cost of introducing a tag (in seconds per tag)	80 s/tag	80 s/tag	80 s/tag	80 s/tag
Cost of reinitializing tags (in seconds per tag)	0 s/tag	4 s/tag	*49 s/tag*	4 s/tag

Table 2. Comparison of the RFID-based architectural patterns in the case of the game *Plug: Secrets of the Museum* (italic values signal a limit for this architectural pattern)

The chapter proposes guidelines for choosing the RFID-based architectural pattern which will best fit a given application requirements. These guidelines are tested in the context of an RFID-based pervasive game.

Future work concerns the analysis of these architectural patterns with respect to security architecture attribute. Security is a measure of the system's ability to resist unauthorized usage while still providing its services to legitimate users [1]. This future work will determine the influence which the level of resistance to security attacks and the cost of implementing such resistance have on the guidelines provided in this paper. Another attribute we would like to study is the fault-tolerance of the different elements of the system.

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Chapter 3

An RFID Anti-Collision Algorithm Assisted by Multi-Packet Reception and Retransmission Diversity

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/54069

1. Introduction

1.1. RFID technology and previous works

RFID (Radio Frequency Identification) is a technology that uses radio frequency signals for purposes of identification and tracking of objects, humans or animals. In passive RFID systems, where tags reuse the energy radiated by the reader, coordination capabilities can be considerably limited [29]. This issue leads to conflicts or collisions between the transmissions of the different elements of an RFID network, i.e., readers an tags. An efficient medium access control layer (MAC) is thus crucial to the correct operation of RFID [3].

Two types of RFID MAC collision can be identified: tag and reader collision. A tag collision arises when several tags simultaneously respond to a given reader request, thus causing the loss of all the transmitted information. To address this issue, tag anti-collision schemes such as ALOHA and binary tree algorithms are commonly employed [3, 31]. Improvements on these solutions have been further proposed by using tag estimation methodologies [14], and modified frame structures [3, 30], among many other approaches in the literature. Two types of reader collision can also be identified: multiple-reader-to-tag collision and reader-to-reader collision [2]. To address these two issues, reader anti-collision algorithms based on scheduling or coverage control have been proposed. Typical scheduling schemes are frequency division multiple access (FDMA) [7] or listen-before-talk (LBT) [8]. Advanced schemes such as Colorwave in [28] and Pulse in [2] implement inter-reader control mechanisms to assist in the collision resolution process. Other approaches such as HiQ in [11] use an analysis of collision patterns over consecutive time-slots to improve scheduling policies. Regarding coverage-based algorithms, two types of scheme can be commonly found: those that reduce the overlapping coverage area between readers (e.g., [12]), and those that monitor interference to adapt power levels accordingly (e.g., [4]).

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1.2. Open issues and chapter objectives

Despite recent advances in RFID MAC layer design, several issues remain open today. Current RFID algorithms are designed under simplistic assumptions such as the collision-model. In such a collision-model, collisions are regarded as the loss of all the transmitted information. On the contrary, collision-free transmissions are always assumed to be correctly received. These assumptions are, however, highly inaccurate, particularly for wireless settings with rapidly changing channel conditions and assisted by modern signal processing tools. In wireless networks, packet transmissions can be lost due to random fading phenomena and not only due to collisions. On the other hand, a collision with multiple concurrent transmissions can be resolved by means of multiple antenna receivers. Therefore, a new approach for a more accurate design and modeling of random access protocols in modern wireless networks is required. In the literature of conventional random access protocols, considerable advances in these aspects have been recently made using the concept of cross-layer design [18–26]. The objective of this chapter is to use two of these recent cross-layer solutions and modeling approaches to improve the performance of RFID. In particular, we focus on those solutions that make use of signal processing tools that exploit diversity in the space (multi-packet reception) and time domains (retransmission diversity).

1.3. MAC-PHY cross-layer design: Multi-packet reception and retransmission diversity

Multi-packet reception is a concept that has revolutionized the design paradigm of random access protocols. Conventionally, collisions were always considered as the loss of all the transmitted information. However, modern multiuser detection and source separation tools allow for the simultaneous decoding of concurrent transmissions. Design of random access protocols with multi-packet reception has been addressed in [9] using a symmetrical and infinite user population model, and in [16] using an asymmetrical and finite user population model. A novel multi-packet reception scheme that exploits the time domain in order to achieve diversity has been proposed in [26], and it has been called network diversity multiple access (NDMA). In NDMA, a virtual MIMO (multiple-input multiple-output) system is induced by requesting as many retransmissions as needed to recover the contending packets using source separation. A hybrid algorithm with multi-packet reception and retransmission diversity has been proposed in [21].

1.4. Chapter contributions

This chapter aims to use the concepts of multi-packet reception and retransmission diversity in the MAC layer design of passive RFID systems. To investigate these two cross-layer random access algorithms in the context of RFID, a novel framework which includes PHY (physical) and MAC (medium access control) layer parameters of RFID is here employed. The framework consists of the co-modeling of both the down-link (reader-to-tag) and up-link (tag-to-reader) signal-to-interference-plus-noise ratio (SINR) experienced in a multi-tag and multi-reader environment. This framework was first proposed in our previous work in [22], and it has been modified here to be used in the context of multi-packet reception and retransmission diversity. Based on this updated framework, stochastic models for tag activation/detection processes (considering multi-packet reception and retransmission diversity) are then proposed. The proposed approach also allows for a novel joint design of reader and tag anti-collision schemes. Conventionally, these two algorithms were designed independently from each other. However, readers and tags operate in the same frequency band. Therefore, contention between their transmissions can potentially arise. Furthermore, reader anti-collision policies directly influence tag activation, and thus also the way in which tags collide when responding to readers' requests. Therefore, a complete model of RFID MAC layer should consider both processes together rather than independently. The proposed framework fills this gap by simultaneously modeling tag activation and the corresponding tag responses to readers, while also considering multi-packet reception and retransmission diversity at the reader side.

To complement the framework for MAC/PHY cross-layer design, a Markov model is also presented, which allows for capacity and stability evaluation of asymmetrical RFID systems. The approach consists of defining the states (i.e., the set of active tags/readers) that describe the network at any given time, and then map them into a one-dimensional Markov model that can be solved by standard techniques such as eigenvalue analysis. The results show that the proposed algorithms as well as the joint cross-layer approach and the Markov model provide considerable benefits in terms of capacity and stability over conventional solutions.

1.5. Organization

The organization of this chapter is as follows. Section 2 describes the framework for cross-layer design, and gives details of the operation of the protocol with multi-packet reception and retransmission diversity. Section 3 describes the proposed metrics and the Markov model. Section 4 addresses the optimization of the system and displays the results using different scenarios. Finally, Section 5 presents the conclusions of the chapter.

2. System model and cross-layer framework

Consider the slotted RFID network depicted in Fig. 1 with a set $\mathcal{R}$ of K readers $\mathcal{R} = \{1, \dots K\}$ and a set $\mathcal{T}$ of J tags $\mathcal{T} = \{1, \dots, J\}$. Each reader is provided with M antennas that will be used to recover, using source separation, the simultaneous transmissions of several tags. Two main processes can be distinguished in the RFID network in Fig. 1: Tag activation by the transmission of readers, also called the down-link transmission; and the backscattering response towards readers by previously activated tags, also called up-link transmission. In the down-link, the transmit power of reader k will be denoted by $P_{r,k}$ while its probability of transmission will be denoted by $p_{r,k}$. All the antennas will be assumed to transmit the same signal in the down-link. The subset of active readers at any given time will be denoted by $\mathcal{R}_t$. Tags are activated when the signal-to-interference-plus-noise ratio (SINR) given a reader transmission is above an activation threshold. The set of activated tags will be denoted by $\mathcal{T}_P$. In the up-link, the active tags proceed to transmit a backscatter signal using a randomized transmission scheme. The subset of tags that transmit a signal once they have been activated will be given by $\mathcal{T}_t$, where each tag j will transmit with a power level denoted by $P_{t,j}$. Details of the down- and up-link models are given in the following subsections.

2.1. Tag activation process: Down-link model

Consider that the instantaneous channel between reader k and tag j is given by the column vector $\mathbf{h}_{k,j}$ with dimensions $M \times 1$, the channel experienced between reader k and reader m is given by the matrix $\mathbf{G}_{k,m}$ with dimensions $M \times M$, and the channel experienced between tag i and tag j is given by the scalar value $u_{i,j}$. The SINR experienced by tag j due to a transmission of reader k is denoted by $\gamma_{k,j}$, and it can be mathematically expressed as follows:

$$\gamma_{k,j} = \frac{P_{r,k}\mathbf{h}_{k,j}^{H}\mathbf{h}_{k,j}}{I_{r_{k,j}} + I_{t_j} + \sigma_{v,j}^{2}}, \qquad k \in \mathcal{R}_t, \tag{1}$$

where $I_{r_{k,j}} = \sum_{m\in\mathcal{R}_t, m\neq k} P_{r,m}\mathbf{h}_{m,j}^{H}\mathbf{h}_{m,j}$ is the interference created by other active readers, $I_{t_j} = \sum_{i\in\mathcal{T}_t, i\neq j} P_{t,i}(|u_{j,i}|^2)$ is the interference created by other tags, $(\cdot)^H$ is the hermitian transpose operator, and $\sigma_{v,j}^2$ is the noise. If the SINR experienced by tag j is above the tag sensitivity threshold $\tilde{\gamma}_j$, then the tag becomes activated. The probability of tag j, which was previously inactivated, to become activated will be given by

$$\Pr\{j \in \mathcal{T}_P\} = \Pr\{\max_{k} \gamma_{k,j} > \tilde{\gamma}_j\}. \tag{2}$$

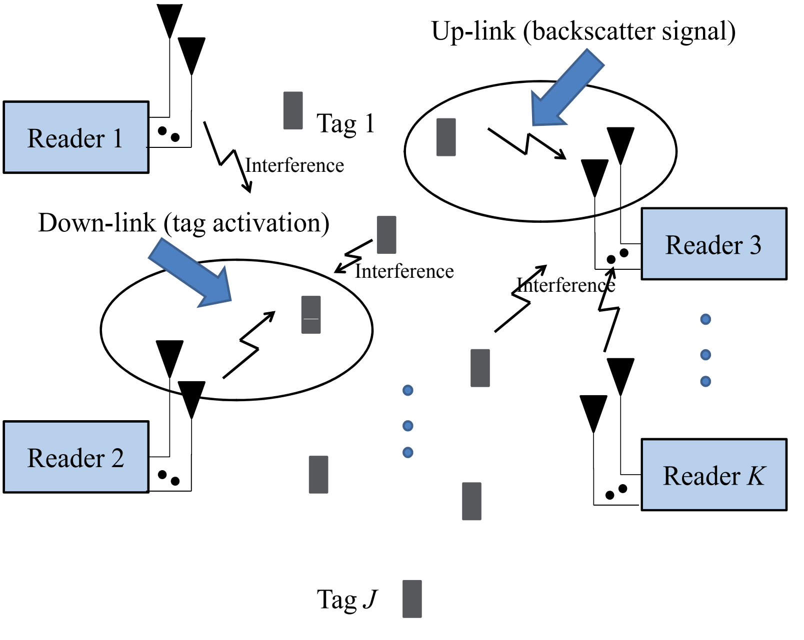

Figure 1. Multi-tag and Multi-reader deployment scenario.

2.2. Backscattering process: Up-link model

Once a tag j has been activated by the transmission of a given reader, it then starts a random transmission process to prevent collisions with other active tags using a Bernoulli process with parameter $p_{t,j}$, which is also the transmission probability. The backscattering factor β_j is the fraction of the received power reused by the tag to reply to the reader. Therefore, the transmit power of tag j can be calculated as $P_{t,j} = \beta_j P_{r,k} |h_{k_{opt},j}|^2$, where $k_{opt} = \arg\max_k \gamma_{k,j}$ denotes the reader that has previously activated the tag. At the reader side, source separation tools for multi-packet reception and retransmission diversity will be used. The proposed protocol consists of ensuring that the number of diversity sources is equal or larger than the number of contending tags so that the source separation technique is successful. For example, if 4 tags collide at a particular time-slot (see Fig. 2) and the reader is provided with only 2 antennas, then the system will request a retransmission from the contending tags in the following time slot. The reader will store all the signals collected during these 2 time-slots and will create a virtual MIMO system from which the signals of the contending tags can be estimated using multiuser detection. The array of stacked signals received at reader k across all r sources of diversity[1] is given by:

$$\mathbf{Y}_{r,k} = \mathbf{HS} + \mathbf{I}_{r,k} + \mathbf{E}_{r,k} + \mathbf{V}_{r,k} \tag{3}$$

where $\mathbf{H}$ is the stacked version of all the channels of the contending tags, $\mathbf{S}$ is the stacked version of all the signals of the contending tags, $\mathbf{I}_{r,k}$ is the collected interference created by other active readers, $\mathbf{E}_{r,k}$ is the collected leaked signal power from the transmission chain, and $\mathbf{V}_{r,k}$ is the noise term. At the reader side, a multiuser receiver such as zero forcing (ZF) or minimum mean square error (MMSE) can be implemented. For example, the zero forcing receiver can be described as follows:

$$\widehat{\mathbf{S}} = \widehat{\mathbf{H}}^{-1}\mathbf{Y}_{r,k}, \tag{4}$$

where $\widehat{\mathbf{S}}$ is the array of estimated signals of the contending tags, and $\widehat{\mathbf{H}}$ is the estimated channel of the contending tags. Since the resolution of a collision may take place over a random number of time slots due to the retransmission diversity scheme, then we will denote this collision resolution period as an *epoch-slot* with a length denoted by the random variable l_{ep}.

For simplicity, it will be assumed that the performance of the multiuser receiver is described by the ability to correctly detect the presence of all the contending tags. This assumption has been used in the analysis of conventional NDMA protocols in [26]. In this assumption any detection error yields the loss of all the contending packets. Thus, it is possible to propose the detection SINR of tag j at reader k, denoted by $\widehat{\gamma}_{j,k}$, as follows:

$$\widehat{\gamma}_{j,k} = \frac{P_{t,j}\mathbf{h}_{k,j}^H \mathbf{h}_{k,j}}{\widehat{I}_{r,k} + P_{r,k}\eta_k + \widehat{\sigma}_{v,k}^2}, \qquad j \in \mathcal{T}_t \tag{5}$$

[1] the number of diversity sources is the total number of combinations of antenna elements and retransmissions

where $\widehat{I}_{r,k} = \sum_{m \neq k} \mathrm{tr}(\mathbf{G}_{k,m}^H \mathbf{G}_{k,m})$ is the interference created by other active readers, $\mathrm{tr}(\cdot)$ is the trace operator, η_k is the power ratio leaked from the down-link chain, and $\widehat{\sigma}_{v,k}^2$ is the noise. Note that tag-to-tag interference is not considered as an independent orthogonal training signal for each tag is used in each transmission for purposes of tag detection and channel estimation, which is also used in the original NDMA protocol in [26]. Thus, tag j can be detected by reader k if the received SINR is above a threshold denoted by $\check{\gamma}_k$. The set of detected tags by reader k will be denoted by $\mathcal{T}_{D,k}$, thus the probability of tag j being in $\mathcal{T}_{D,k}$ will be given by

$$\Pr\{j \in \mathcal{T}_{D,k}\} = \Pr\{\widehat{\gamma}_{j,k} > \check{\gamma}_k\}. \tag{6}$$

The set of correctly detected tags across all the readers will be simply given by $\mathcal{T}_D$, where $\mathcal{T}_D = \cup_k \mathcal{T}_{D,k}$. Since this detection process is prone to errors, we will use in this paper the same assumption used in the original paper for NDMA in [26] where tags are only correctly received at the reader side if all the contending tags are correctly detected and none of the remaining silent tags is incorrectly detected as active (i.e., false alarm). This means that correct tag reception for tag j only occurs when:

$$\Pr\{j \in \mathcal{T}_R\} = \Pr\{\mathcal{T}_D = \mathcal{T}_t\}, \quad \text{where} \quad j \in \mathcal{T}_t, \tag{7}$$

where $\mathcal{T}_R$ is the set of tags correctly received at the reader side. A tag that has transmitted to the reader side can be correctly detected with probability P_D, which can be defined as:

$$P_D = \Pr\{j \in \mathcal{T}_D | j \in \mathcal{T}_t\} = \sum_k \Pr\{\widehat{\gamma}_{j,k} > \check{\gamma}_k | j \in \mathcal{T}_t\}, \tag{8}$$

and which can be read as the probability that tag j is correctly detected as active given it has transmitted a signal. Similarly, the probability of false alarm is given by:

$$P_F = \Pr\{j \in \mathcal{T}_D | j \notin \mathcal{T}_t\} = \sum_k \Pr\{\widehat{\gamma}_{j,k} > \check{\gamma}_k | j \notin \mathcal{T}_t\}, \tag{9}$$

which can be read as the probability that tag j is incorrectly detected as active when it has transmitted no signal at all.

3. Performance metrics and Markov model

The main performance metric to be used in this chapter is the average tag throughput, which can be defined as the long term ratio of correct tag readings to the total number of time-slots used in the measurement. Before providing an expression for this metric, it is first necessary to define the network state information, as well as the tag activation and tag reception probability models, and the definition of the Markov model for the dynamic analysis of an RFID network.

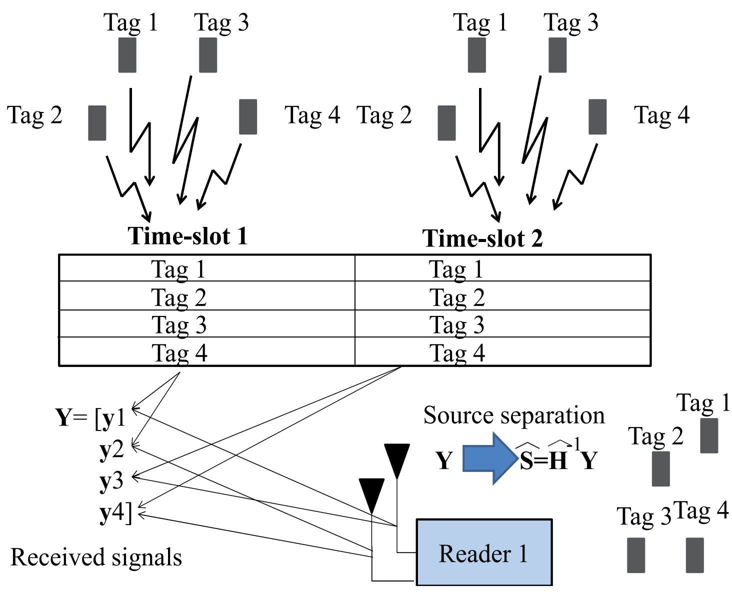

Figure 2. Example of the operation of the proposed protocol with multi-packet reception and retransmission diversity.

3.1. Network state information and tag activation model

The network state information can be defined as all the parameters that completely describe the network at any given time. In our case, the network state information $\mathcal{N}(n)$ at epoch-slot n is defined as the collection of the sets of active readers $\mathcal{R}_t(n)$ and contending tags $\mathcal{T}_t(n)$:

$$\mathcal{N}(n) = \{\mathcal{R}_t(n), \mathcal{T}_t(n)\}. \tag{10}$$

Once the network state information has been defined, we can define the probability of tag j being activated in slot n conditional on a given realization of the network state information $\mathcal{N}(n)$ and given that the tag was previously inactivated as follows:

$$Q_{j|\mathcal{N}(n)} = \Pr\{j \in \mathcal{T}_P(n+1)|\mathcal{N}(n), j \notin \mathcal{T}_P(n)\} = \Pr\{\max_k \gamma_{k,j}(n) > \tilde{\gamma}_j\}. \tag{11}$$

For convenience in the analysis, let us rewrite this tag activation probability in terms of the set of active tags $\mathcal{T}_P(n)$ by averaging over all values of $\mathcal{N}(n)$ where $\mathcal{T}_t(n) \in \mathcal{T}_P(n)$:

$$Q_{j|\mathcal{T}_P(n)} = \sum_{\mathcal{N}(n);\mathcal{T}_t(n)\in\mathcal{T}_P(n)} \Pr\{\mathcal{N}(n)\} Q_{j|\mathcal{N}(n)} \tag{12}$$

where $\Pr\{\mathcal{N}(n)\}$ is the probability of occurrence of the network state information $\mathcal{N}(n)$. This term can be calculated by considering all the combinations of active tags and readers as follows:

$$\Pr\{\mathcal{N}(n)\} = \prod_{k\in\mathcal{R}_t} p_{r,k} \prod_{m\notin\mathcal{R}_t} \overline{p}_{r,m} \prod_{j\in\mathcal{T}_t} p_{t,j} \prod_{i\notin\mathcal{T}_t} \overline{p}_{t,i} \tag{13}$$

where $\overline{(\cdot)} = 1 - (\cdot)$. This concludes the definition of the tag activation probability and the network state information.

3.2. Markov model

In order to define the Markov model for dynamic analysis of the system, let us now calculate the probability of having a set of active tags $\mathcal{T}_P(n+1)$ in epoch-slot $n+1$ conditional on having the set of active tags $\mathcal{T}_P(n)$ during the previous epoch-slot. This transition probability must consider all the combinations of tags that either enter (i.e., they are activated in epoch slot n) or leave the set of active tags (i.e., they transmit in epoch slot n). This can be expressed as follows:

$$\Pr\{\mathcal{T}_P(n+1)|\mathcal{T}_P(n)\} = \prod_{j\in\mathcal{T}_P(n), j\notin\mathcal{T}_P(n+1)} p_{t,j} \prod_{i\notin\mathcal{T}_P(n), i\in\mathcal{T}_P(n+1)} Q_{i|\mathcal{T}_P(n)} \prod_{l\notin\mathcal{T}_P(n), l\notin\mathcal{T}(n+1)} \overline{Q}_{l|\mathcal{T}_P(n)}$$

$$\times \prod_{w\in\mathcal{T}_P(n), w\in\mathcal{T}_P(n+1)} \overline{p}_{t,w}. \tag{14}$$

Let us now arrange the probability of occurrence of all the possible sets of activated tags $\Pr\{\mathcal{T}_P\}$ into a one-dimensional vector given by $\mathbf{s} = [s_0, \ldots s_{JI}]^T$, where $(\cdot)^T$ is the transpose operator (see Fig. 3). This means that we are mapping the asymmetrical states into a linear state vector where each element represents the probability of occurrence of one different state $\Pr\{\mathcal{T}_P\}$. In the example given in Fig. 3 we have only two possible tags, where the first system state is given by both tags being active, the second state with only tag 1 as active, the third state with only tag 2 as active, and the fourth state with both tags inactive. Once these states are mapped into the state vector $\mathbf{s}$, the transition probabilities between such states $(\Pr\{\mathcal{T}_P(n+1)|\mathcal{T}_P(n))$ can also be mapped into a matrix $\mathbf{M}$, which defines the Markov model for state transition probabilities (see Fig. 3). The i, j entry of the matrix $\mathbf{M}$ denotes the transition probability between state i and state j. The vector of state probabilities can thus be obtained by solving the following characteristic equation:

$$\mathbf{s} = \mathbf{M}\mathbf{s}, \tag{15}$$

by using standard eigenvalue analysis or iterative schemes. Each one of the calculated terms of the vector $\mathbf{s}$ can be mapped back to the original probability space $\Pr\{\mathcal{T}_P\}$, which can then be used to calculate relevant performance metrics.

3.3. Tag detection model

Before calculating the tag throughput, first we must define the correct reception probability of tag j at the reader side conditional on the network state information $\mathcal{N}(n)$ as follows:

$$q_{j|\mathcal{N}(n)} = \Pr\{j \in \mathcal{T}_R(n+1)\} = \Pr\{\mathcal{T}_D = \mathcal{T}_t\}, \quad \text{where} \quad j \in \mathcal{T}_t \tag{16}$$

It is also convenient to re-write this reception probability in terms of the set of active tags $\mathcal{T}_P(n)$ by averaging over all values of $\mathcal{N}(n)$ where $\mathcal{T}_t(n) \in \mathcal{T}_P(n)$:

$$q_{j|\mathcal{T}_P(n)} = \sum_{\mathcal{N}(n);\mathcal{T}_t(n)\in\mathcal{T}_P(n)} \Pr\{\mathcal{N}(n)\} q_{j|\mathcal{N}(n)} \tag{17}$$

3.4. Tag throughput and stability

The tag throughput per resolution period can be finally calculated by adding all the contributions over the calculated probability space $\Pr\{\mathcal{T}_P\}$ using the Markov model presented in previous subsections. This can be mathematically expressed as:

$$S_j = \sum_{\mathcal{T}_P, j\in\mathcal{T}_P} \Pr\{\mathcal{T}_P\} q_{j|\mathcal{T}_P}. \tag{18}$$

Now, the throughput per time-slot can be calculated as the ratio of the throughput per resolution period to the average number of time-slots per resolution period:

$$T_j = \frac{S_j}{\sum_{\mathcal{T}_D} \Pr\{\mathcal{T}_D\} \left\lceil \frac{|\mathcal{T}_D|}{M} \right\rceil + \Pr\{\mathcal{T}_D = \emptyset\}}, \tag{19}$$

where $|\cdot|$ is the set cardinality operator and $\lceil\cdot\rceil$ is the ceil integer operator. As a measure of stability we will use the average number of activated tags, which can be calculated as follows:

$$E[|\mathcal{T}_P|] = \sum_{\mathcal{T}_P} \Pr\{\mathcal{T}_P\}|\mathcal{T}_P|. \tag{20}$$

A high number of activated tags means that stability is compromised, while a relatively low number indicates that the algorithm is more stable.

4. Optimization and results

The parameters to be optimized are the vector of reader transmission probabilities $\mathbf{p}_r = [p_{r,1}, \ldots p_{r,K}]^T$, the vector of reader transmit powers $\mathbf{P}_r = [P_{r,1}, \ldots P_{r,K}]$ and the vector of transmission probabilities of the active tags $\mathbf{p}_t = [p_{t,1}, \ldots p_{t,J}]$. The objective of the optimization is the total throughput, so the optimization problem with transmit power constraint can thus be written as follows:

$$\{\mathbf{P}_r, \mathbf{p}_t, \mathbf{p}_r\}_{opt} = \arg \max_{\{\mathbf{P}_r, \mathbf{p}_t, \mathbf{p}_r\}} \sum T_j \quad \text{s.t.} \quad \mathbf{P}_r < \mathbf{P}_{r,0} \tag{21}$$

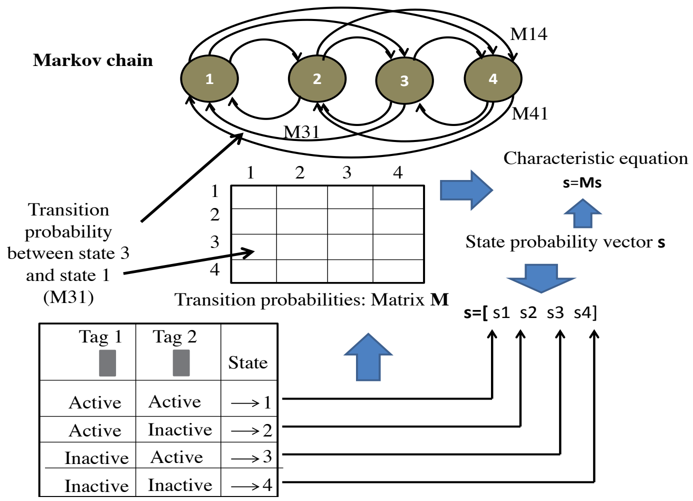

Figure 3. Example of the Markov model for a two-tag system.

Since the explicit optimization of the expressions is difficult to achieve, particularly when considering the Markov model proposed in the previous section, in this section we will simplify the optimization problem by applying the previous concepts to an ALOHA protocol implemented at the reader side. This means that tags can be only activated when the readers' transmissions are collision-free. Power levels will be fixed, and the maximum throughput performance will be investigated by simply plotting the surface versus the reader and tag transmission probabilities. At the tag side we will consider the following three options: a conventional ALOHA protocol without MPR, ALOHA with multi-packet reception (simply tagged ALOHA MPR), and the proposed scheme with retransmission diversity and multi-packet reception (tagged NDMA MPR).

Two scenarios are considered: one in which tags and readers operate in the same channel, thereby interfering with each other, and the second scenario where readers and tags operate in a synchronized manner in different channels, which eliminates the probability of collision between them. For convenience, let us consider in first instance that all tags and readers experience channel and queuing states that are statistically identical (symmetrical system). A tag activation probability of $q = 0.7$ and a tag detection probability at the reader side of $Q = 0.95$ have been used in the theoretical calculations. A probability of false alarm for the NDMA protocol has been set to $P_F = 0.01$. The results have been calculated with $J = 15$ tags and $K = 5$ readers.

Fig. 4 shows the results of average throughput $T = \sum_j T_j$ versus various values of reader and tag transmission probability p_t and p_r for a conventional ALOHA protocol without multi-packet reception ($M = 1$) and without retransmission diversity considering full interference between readers an tags. Fig. 5 shows the results of average throughput T versus various values of reader and tag transmission probability p_t and p_r for a conventional ALOHA protocol without multi-packet reception ($M = 1$) and without retransmission diversity considering no interference between readers an tags. Note how the throughput shape is considerably affected by the interference assumption between readers and tags. Fig. 6 shows the results of average number of tags versus various values of reader and tag transmission probability p_t and p_r. Fig. 7 shows the results of average throughput T

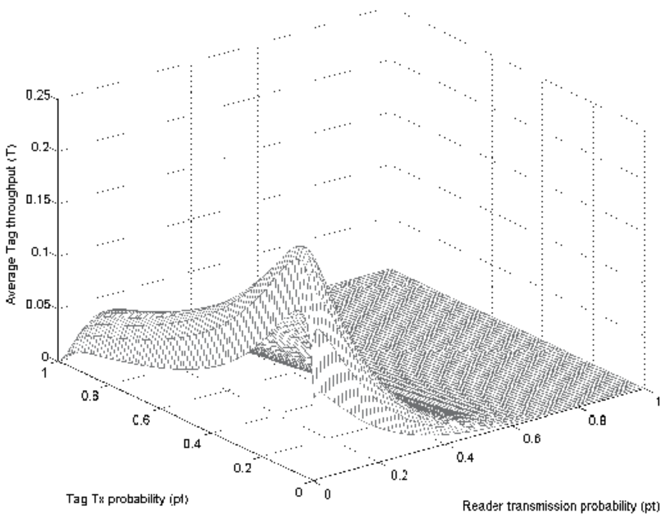

Figure 4. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical ALOHA protocol for reader and tag anti-collision assuming interference between readers and tags.

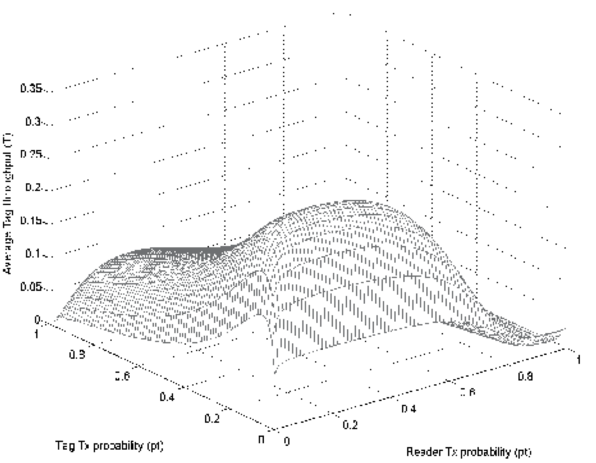

Figure 5. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical ALOHA protocol for reader and tag anti-collision assuming no interference between readers and tags.

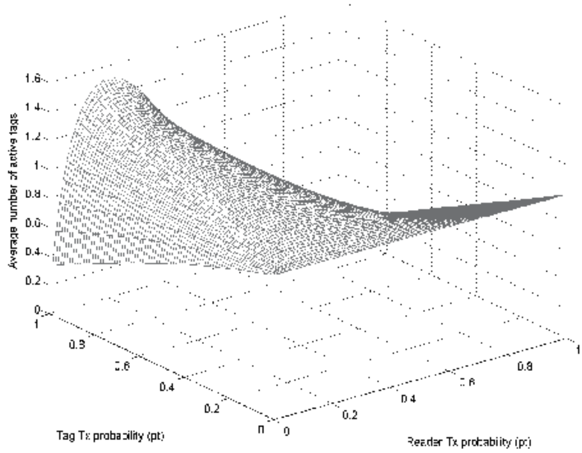

Figure 6. Average number of active tags vs. reader and tag transmissions probabilities (p_r and p_t).

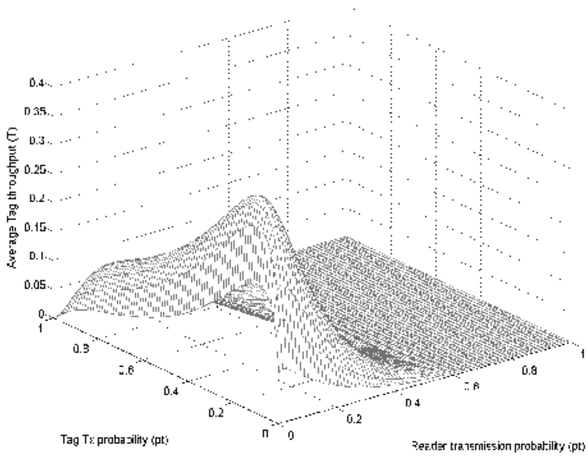

Figure 7. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical ALOHA MPR protocol for reader and tag anti-collision assuming interference between readers and tags.

versus various values of reader and tag transmission probability p_t and p_r for a conventional ALOHA protocol with multi-packet reception ($M = 2$) and without retransmission diversity considering no interference between readers an tags. Note that the maximum throughput has been considerably improved over the conventional ALOHA protocol without MPR capabilities in Fig. 4. Similarly, Fig. 8 shows the results of average throughput T versus various values of reader and tag transmission probability p_t and p_r for a conventional ALOHA protocol with multi-packet reception ($M = 2$) and without retransmission diversity by considering no interference between readers an tags. The improvement over the algorithm without MPR in fig. 5 is considerable from almost 0.2 tags/timeslot in the case of ALOHA, to almost 0.4 tags/time-slot in the case of ALOHA MPR, and up to 0.7 tags/time-slot in the case of NDMA MPR. Fig. 9 shows the results of average throughput T versus various values

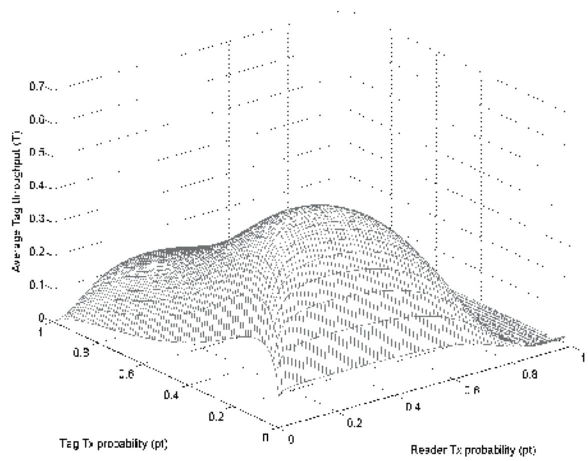

Figure 8. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical ALOHA MPR protocol for reader and tag anti-collision assuming no interference between readers and tags.

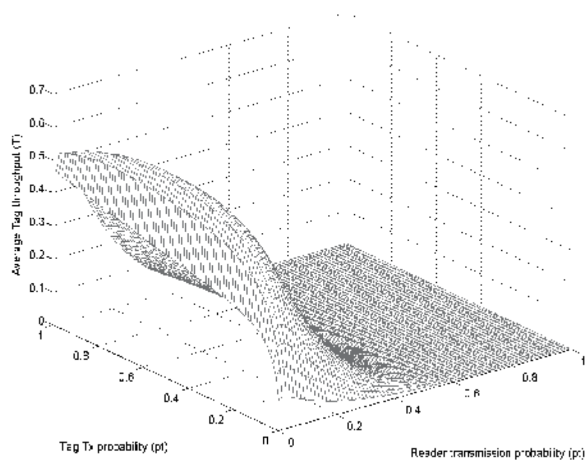

Figure 9. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical NDMA MPR protocol for reader and tag anti-collision assuming interference between readers and tags.

of reader and tag transmission probability p_t and p_r for an NDMA MPR protocol considering interference between readers an tags, while Fig. 10 shows the results without considering interference between readers an tags. The results in Fig.9 and 10 show that the proposed NDMA MPR solution considerably outperforms its ALOHA counterparts in both scenarios: with or without interference between readers and tags.

Let us now address an asymmetrical scenario. For this purpose consider that the tag/reader space is divided into two different sets of readers and three different sets of tags. Readers and tags are working in different channels. The first and second sets of tags can only be reached by the first and second sets of readers, respectively. The third set of tags can be reached by both sets of readers. All tags have the same transmission probability p_t as well as

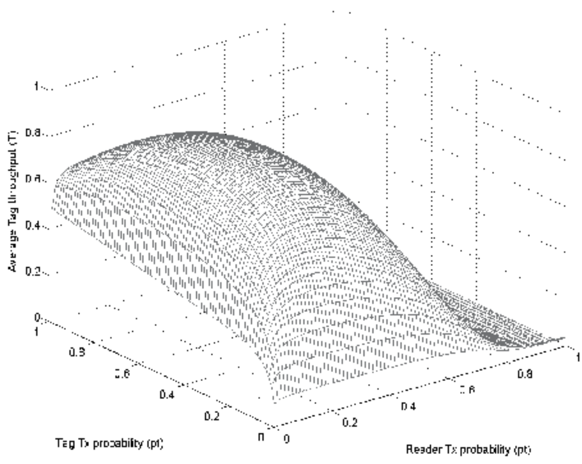

Figure 10. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of a symmetrical NDMA MPR protocol for reader and tag anti-collision assuming no interference between readers and tags.

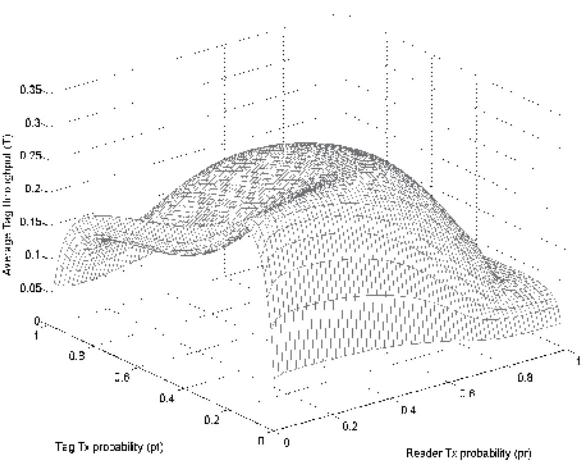

Figure 11. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of an asymmetrical ALOHA protocol for reader and tag anti-collision without interference between readers and tags.

all readers transmit with the same parameter p_r. A tag activation probability of $q = 0.7$ and a tag detection probability at the reader side of $Q = 0.95$ have been used in the theoretical calculations. A probability of false alarm for the NDMA protocol has been set to $P_F = 0.01$. The results of Fig. 11 and Fig. 12 have been obtained using three groups of tags with $J_1 = 3$,$J_2 = 5$ and $J_3 = 7$ tags, and two groups of readers with $K_1 = 5$ and $K_2 = 10$ readers. While Fig. 11 shows the results of an ALOHA protocol without MPR capabilities ($M = 1$), Fig. 12 shows the results of the proposed NDMA protocol with $M = 1$. In both cases, the readers and tags are assumed to transmit in different channels, thereby avoiding interference between their transmissions. It can be observed the significant gain provided by the NDMA protocol for all values of p_t and p_r.

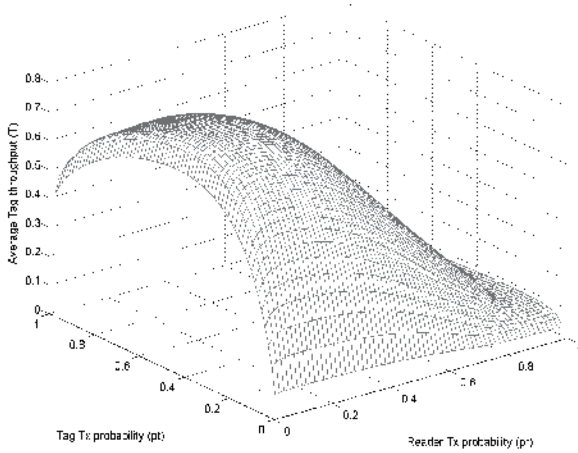

Figure 12. Throughput (T) vs. reader and tag transmissions probabilities (p_r and p_t) of an asymmetrical NDMA protocol for reader and tag anti-collision without interference between readers and tags.

5. Conclusions

This chapter presented a novel algorithm for passive RFID anti-collision based on the concepts of multi-packet reception and retransmission diversity. In addition, the design of the algorithm has been based on a new design paradigm called cross-layer design, where physical and medium access control layers are jointly designed, and where reader and tag anti-collision components are also jointly considered. The proposed Markov model is a new approach for the modeling of RFID networks, as it captures both the activation process given by the operation of readers sending requests to tags, and the tag detection process that results from tags randomly transmitting their information back to the readers that previously activated them. The results for tag throughput showed considerable improvement over conventional ALOHA solutions that have been implemented in current deployments and commercial platforms for RFID. This opens an interesting area for the design of advanced random access protocols for future RFID systems and for the internet of things.

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Chapter 4

Implementation of a Countermeasure to Relay Attacks for Contactless HF Systems

Pierre-Henri Thevenon and Olivier Savry

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53393

1. Introduction

Nowadays, HF contactless technologies following the ISO 14443 standard are extensively used worldwide. Critical applications like access control or payment require high security guarantees. However, contactless channels are less secure and offer more opportunities for any kind of intrusion than other ways of communication; e.g. eavesdropping and contactless card activation using false reader [1, 2, 3, 11]. Among the attacks on the physical layer, relay attack is the most dangerous because of its simplicity, its impact and its insensitivity to cryptographic protections. It consists in setting up an unauthorized communication between two devices out of their operating range [4, 6]. On Figure 1, two attackers are able to create a link between the reader and the contactless card without the agreement of the owner. A relay is composed of two elements: a first one close to the reader and called proxy, a second one close to the card and called mole. These two elements communicate together by a wired or a wireless link

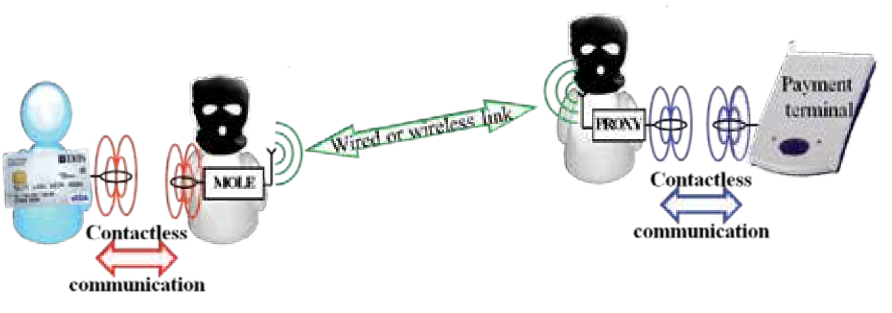

Figure 1. Relay scenario in a queue

A relay attack is thoroughly transparent for current contactless systems and cryptographic protocols. A possible countermeasure is the distance bounding protocol which can add an upper bound for the distance between the two communicating devices.

In this chapter, we will first assess the potential of relay attacks by implementing them and by keeping in mind the concern of introducing a delay as low as possible. Indeed, this time remains the only detectable feature of such an attack and the existing countermeasures rely on its accurate assessment.

The delay constraint guides us towards the development of three kinds of relay: a wired passive relay, a relay based on a wireless super-heterodyne system and a wireless relay with a complete demodulation of the signal. Our experimental results show that those cheap devices introduce really low delay from 300 ns to 2 μs jeopardizing the use of current distance bounding protocols. A more adapted solution will then be implemented and addressed in the second part of the document. It modifies the stage of the distance bounding protocol which uses the physical layer to carry out a delay assessment with a correlation in the reader between the received signal and the expected one. Finally, a security analysis will be performed and improvements will be discussed.

2. Relay attacks

2.1. Related work

The relay attack is based on the Grand Master Chess problem described by Conway in 1976. The latter shows how a person, who does not know the rules of this game, could win against one of two grand masters by challenging them in a same play. The relay attack is just an extension of this problem applied to the security field. By relaying information between a reader and a card outside the reader field, an attacker can circumvent the authentication protocol. This attack needs two devices: a mole and a proxy. The mole pretends to be the true reader and exchange data with the proxy which pretends to be the true card.

The larger the distance between the different elements is, the more efficient is the relay. Typical maximum distances between the reader and the proxy or between the mole and the card are roughly 50 cm. The distance between the mole and the proxy is not limited; it just depends on the chosen technology [5].

By using a relay, an attacker can transmit requests and answers between an honest reader and an honest card separated by 50 metres [6]. Many communication channels can be used to link the mole and the proxy like GSM, WIFI or Ethernet [8]. The delay, introduced by such a relay is more than 15 μs. At the physical layer, this attack is the most dangerous for many reasons:

- The card is activated and transmits information when it is powered, without the agreement of the victim. Anyone can be a victim because the attacker has just to be close enough to control your card like in a crowd.

- The attack occurs on the physical layer i.e. the relay transmits coded bits without knowledge about the frame significance. The ISO9798 standard presents an authentication protocol to prove that the contactless devices involved in the communication share the same secret key. For eavesdropping or skimming attacks, the use of this kind of protocol limits the risks. For the relays attacks, knowing the key is not necessary. Actually, a relay does not neither modify the information of the frame nor has to know its meaning. It just transmits the data. The encrypted data are transmitted as plain text.
- Contactless standards such as standard ISO14443 impose timing constraints in order to synchronize data sent by many cards at the same time, especially during the anti-collision protocol. However, these constraints are not enforced by the majority of cards [9]. These requirements would complicate the relay attack if they were really applied. Another weakness of the standard is the time delay between the reader request and the card answer. These time delay is not only such long but also expandable by the card and consequently by an attacker.

2.2. Presentation of relay attacks

The delay in current relays is mainly due to the use of components such as microcontrollers or RFID chips. This kind of components is used for the reconstruction of the decoded signals. So, the original signal becomes compatible with other protocols, like Wifi or GSM, used in the wireless communication between the mole and the proxy. All these signal processes lead to the addition of delays in the relay. They can be considerably lowered by the only use of analog components. Attack scenarios with wired relays must then be considered because they can induce very low delays. Moreover, this kind of relays is simple to realize, with few cheap components. Even if they seem to be unlikely, they can be effective in a queue for example or if they are hidden in the environment.

2.2.1. Passive wired relay

Fig. 2 depicts a simple design of a relay which introduces a very low delay close to a period of the carrier 13.56 MHz. This relay does not require an amplifier or other active components. The coaxial cable between the two antennas can be longer than 20m. Such a system is very low cost; the attacker needs a piece of PCB, few components for the matching and a coaxial wire. Overall cost is a few dollars at most. We claim that wired relays are the simplest and fastest relays by design and as a consequence, they should challenge the approaches of countermeasures which only parry the largest delays.

2.2.2. Relay based on a wireless super heterodyne system

This relay, shown on fig. 3, is quite similar to the relay attack developed by Hancke because it is not restricted by a wired link. Contrary to Hancke's relay, our wireless relay does not use digital components like microcontrollers or RFID chips to process the signal. The delay induced by this relay should be shorter. To do so, the reader signal of frequency fc is mixed with another signal of frequency F, generated by a local oscillator. It results a signal of frequency fc+F, easier

Figure 2. Potential use of a wired relay

to amplify and to send further. A PLL is used as a local oscillator to have the same frequency in the modulation and demodulation circuit.

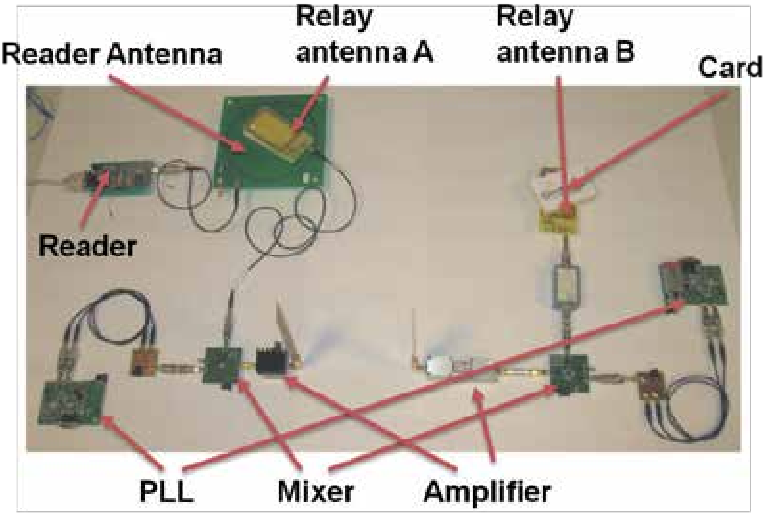

Figure 3. Forward wireless relay

2.2.3. Relay with demodulation of the signal

We have developed a more advanced relay (Fig. 4) close to those realized by Hancke or Kasper.. To realize a relay which demodulates the signal is more complex for an attacker, because it must have a perfect knowledge of the contactless standards. Our system is compliant with the

ISO14443-A standard to be compared with literature relays. However, it can be adapted to a different contactless standard such as ISO15693 or ISO14443-B.

The proxy is mainly based on thus developed by Carluccio et al. [7]. This electronic card can be divided into two subsystems: one for demodulation and decoding of the reader signal and one for the load modulation of the card.

The Mole is based on a reader developed in our laboratory. This device has a RF front-end RF which allows amplitude modulation and demodulation. The heart of the mole is a FPGA which separates the phase of emission and reception phase. The proxy signal is processed by the FPGA of the mole; it is coded in modified Miller and modulated in OOK. The HF signal is then amplified and injected in the antenna. The victim's card understands the request of our Mole as a frame from a standard reader and answers by modulating its load. This signal is firstly processed by an analog system and then sampled, demodulated and decoded by the FPGA.

The proxy and the mole communicate together through a wireless system. We have used chips used in the video/audio wireless transmission systems since they allow a sufficient bit rate of 212kbits/s.

The datasheet of video transmission systems provides a theoretical distance operation of 100 metres. In practice, problems of propagation in a building must be taken into account but this distance is sufficient to realize the attack in a shop. Based on experiments realized with the relay, we have obtained a maximum distance of 10 cm between the card and the mole but also between the proxy and the reader.

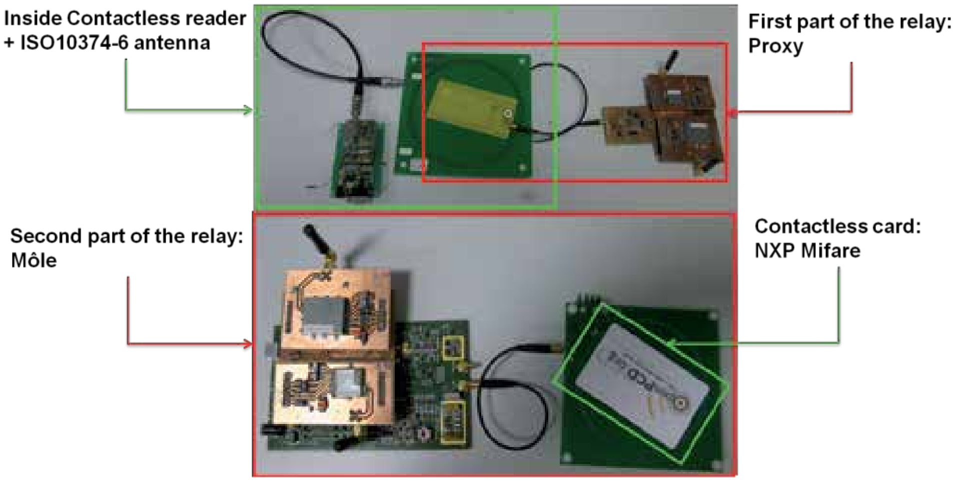

Figure 4. Relay with demodulation of the signal

2.3. Experiments on introduced delay

This experiment is performed to measure the introduced delays of the different relays. To do so, a reader sends a fixed sequence through a relay. With an oscilloscope, this sequence is recorded directly on two calibration coils located close to the two relay antennas. This sequence is a signal modulated in amplitude with a subcarrier at 848 kHz. The cross-correlation of the two recorded signals allows the computation of the temporal shift between them. In this experiment, we assume that the delay is the same for the forward and the backward channel so the results are the double of the value which is computed.

Fig. 5 gives an overview of the computed delays. Each type of relay is characterized by a temporal distribution. The delay introduced by the relay can be used to detect the presence of a relay. Wireless relays and wired relays have roughly the same delays because the mix of the signals is very fast in the case of the wireless relay. The relay with demodulation introduces a delay 7 times inferior to Hancke's relay.

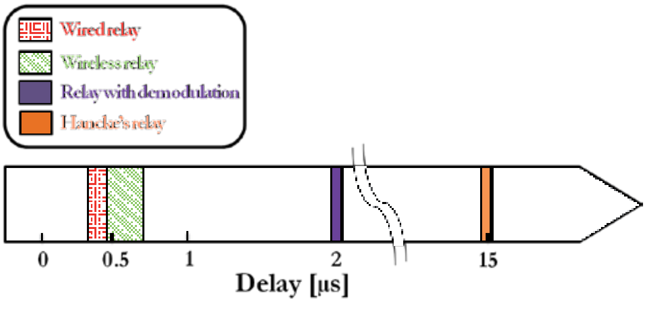

Figure 5. Measured delays

3. Countermeasures

In this part, we first describe the main existing relay detection systems and have a critical look to these solutions. Then, a new protocol based on the correlation, is described and implemented on a real contactless system.

3.1. Existent countermeasures and weaknesses

As mentioned before, design of a suitable countermeasure against relay attacks is a veritable challenge. This is partially because cryptography has no effect on it. Currently, there are few methods to detect relay attacks: distance bounding protocols, countermeasures based on timing measurements or physical structures implying the denial of service of the card.

3.1.1. Distance bounding protocols

In 2003, Hancke et al. have presented the first distance bounding protocol designed for contactless systems [11]; it is based on Brands and Chaums description [10]. Since then, many others distance bounding protocols have been published to improve the security of the scheme.

However, if they have been designed to use the physical layer of the system, they never have been implemented and tested in the HF band.

Distance bounding protocols are used to detect additional delays introduced by a relay during a transaction between two devices. This kind of protocol is often divided into three stages. In such a protocol, the card, named prover, must convince the reader, named verifier, that they are close to each other. During the first stage, the verifier and the prover exchange encrypted sequences, used during the second stage. While, the second stage consists of a timed exchange between the prover and the verifier, in order to verify the card's location. This analysis is made by measuring the time between the request of the verifier and the response of the prover. The last stage is an authentication and verification. The verifier computes and checks the measured times to define the location of the prover and analyses the prover answers to verify its honesty.

The reliability of such protocols depends mainly on the physical layer; the communication channel during the exchange stage affects the accuracy of the propagation time measurements. However, Hancke et al. and recently Rasmussen et al. are the only authors who gave a number of indications related to the protocol implementation at the physical layer level [13]. Other authors claim the merits of their distance bounding protocols such as cost, complexity, reliability but none of them has treated the problem of the protocol implementation for a contactless system.

Such discussions and analysis may be proposed before further works on these protocols.

Distance measurements based on the use of electromagnetic and acoustic waves are used in many applications such as radars. The distance resolution is inversely proportional to the bandwidth; this relation shows one of the weaknesses of distance bounding protocols implemented on a contactless or UWB communication channel:

These two communication channels use electromagnetic waves which have celerity close to the speed of light. In a contactless system, the distance between the verifier and the prover is smaller than 10 cm. Propagation time is then smaller than 300 ps. The first assumption of distance bounding protocol is that the processing time of the signal is assumed to be much smaller than the propagation time of the signal transmitted between the two parts, so smaller than 300 ps.

- HF communication channel: For a contactless system with a bandwidth of 848 kHz, the spatial resolution is around 350 m. Such resolution is too weak to measure a distance between two communicating entities. Moreover, establishing time in HF antennas, processing time for modulation and demodulation take too much time to measure small delays

- UWB communication channel: The bandwidth of a UWB system is equal to 20-25% of its central frequency. The spatial resolution is then close to 1.6 m for a 1GHz UWB system. Such resolution is suitable to detect any kind of relays. However, UWB implementation on an HF contactless system is complex. Hardware constraints are required such as the modification of all RF front-end: add of electrical antennas and specific modulation and demodulation systems.

To summarize, distance bounding protocols are really difficult to implement since the use of the UWB adds cost and complexity. By using HF communication channel, the propagation time remains difficult to isolate because it can be small compared to the processing time. To consider the constraints imposed by the physical layer of HF contactless systems is a priority for developers of algorithms against relay attacks

3.1.2. Solutions based on time measurements

Reid et al. have proposed a solution allowing the measurement of the time duration between the end of the request and the start of the reply [9]. For that, the authors have identified two reference points which represent the state change of the system. In theory, this system can measure average delays of 300 ns; this resolution is 50 times smaller than the delay introduced by Hancke's relay. This counter-measure can be accurate enough to avoid relay attack. However, some problems remain:

- The card does not always reply at the same time;
- No protocol authentication are implemented;
- The signal processing can increase the duration of the delay;
- The attacker can act on the relay to disturb the counter measure.

Munilla et al. have proposed a protocol based on the ISO14443-A standard [10]. In this solution, the reader measures the delay between its request and the card answer. It computes the number of carrier periods between the end of its synchronization bit and the time when the carrier becomes stable after the card response. The authors concluded that their protocol can be used to detect simple relay attacks which induced delays lower than 1 μs. However, this resolution is inefficient against distance fraud attack. Moreover, this countermeasure imposes the modification of standards and of the physical layer. In this solution, the carrier is switched off regularly so the card cannot be powered during this time.

3.1.3. Solution based on the denial of service

The literature provides some examples of solutions that enable the card's holder to disable their card temporarily [1, 18]. The easier solution is a wallet made of metallic sheets, which acts as a faraday cell. Reference [17] presents physical structures which enable the card's holder to turn off their card by separating the chip and the antenna.

3.2. Our solution

This part describes a new protocol compliant with contactless standards which authenticates the two communicating parties. A first implementation of this countermeasure on a real contactless system demonstrates its reliability.

3.2.1. The proposed scheme

The main objective of this countermeasure is to detect relay attacks by measuring the delay introduced by them by using the correlation method.

The first assumption of our protocol is not based on the propagation time but on the complete delay between a triggering pulse of the reader and the answer of the card received by the reader. This delay is different when a relay is inserted between the reader and the card. For an easier understanding of the solution, we suppose that the forward and backward times induced by the relay are the same to make the explanations easier. In this solution, a recorded sequence is correlated with the same sequence sent by the card. The solution is based on an authentication of the card and the measurement of delay induced by a potential relay, as shown in the fig. 6 and the fig. 7. Our protocol is similar to the distance bounding one; it could be divided into three stages: initialization, time measurement and verification.

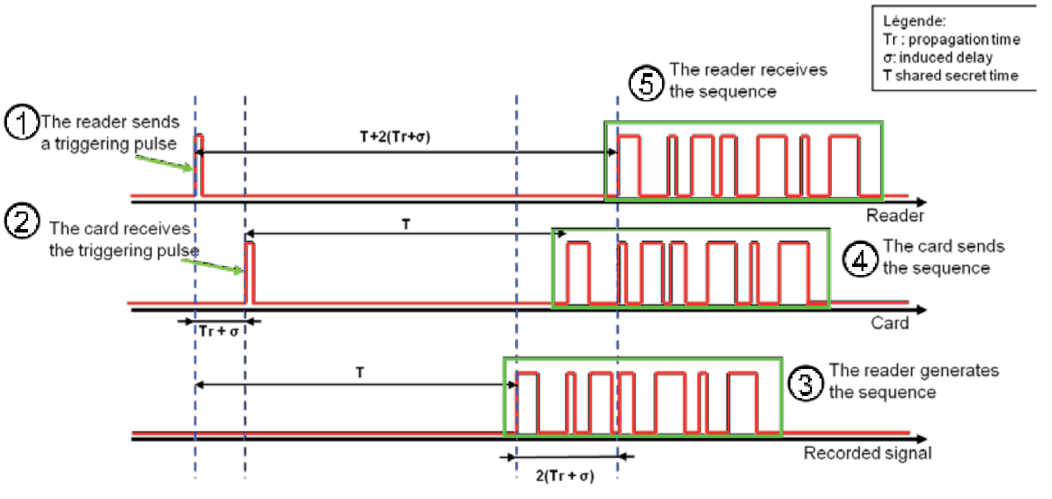

Figure 6. Time measurement stage in the proposed protocol

The first part of our protocol starts by the sending of a nonce from the reader to the card. The reader and the card use any validated symmetric lightweight cryptographic algorithm E, a shared key k and an exchanged random number to calculate T, the waiting time before the sending of the card answer and S, the sequence send by the card and synthesized in the reader. Hence, the computation of T and S by the reader and the card allows the authentication of the card. The first objective of our solution is to detect the relay so there is no mutual authentication in this protocol. However, few modifications of our protocol are possible to have this option.

After the exchange of the random sequence, the second stage starts (fig. 6). A random number of clock cycles after the end of the request frame, the reader modulates briefly its field to create a synchronization pulse. This pulse is received by the card with a delay function of the propagation time Tr and the delay induced by the uplink relay σ. It acts as a start point of the protocol for the reader and the card. Once the triggering pulse is received, the card has to send

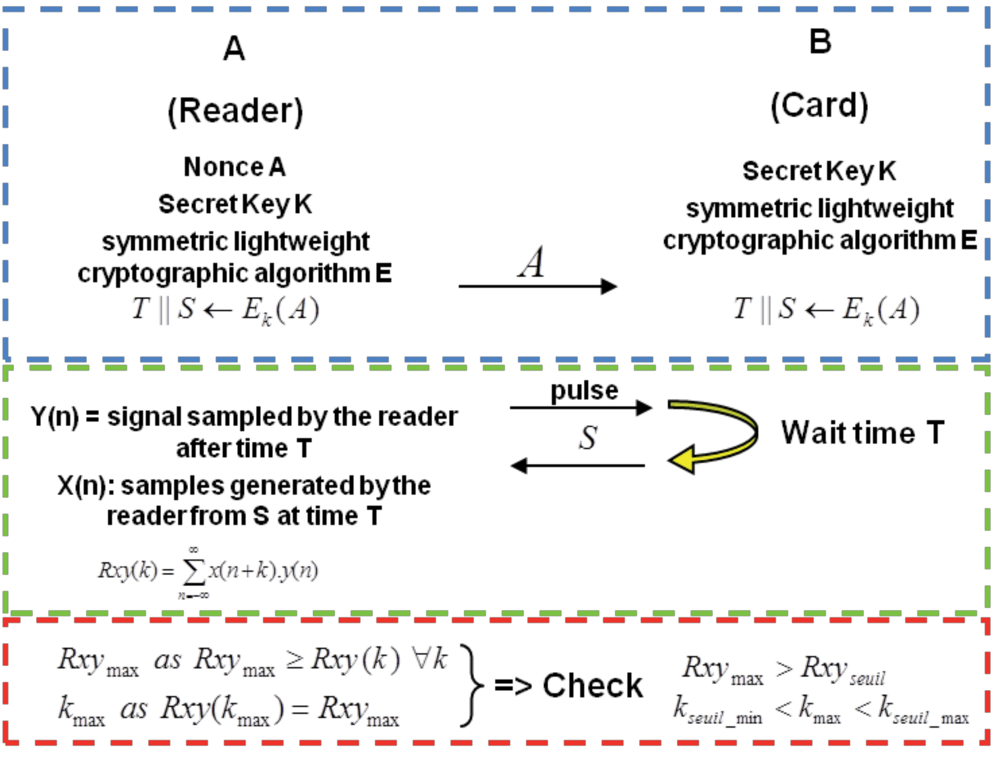

Figure 7. The proposed protocol consists of three stages. The first stage calculates two pseudorandom numbers, using a symmetric cryptographic algorithm and a secret key k and an exchanged nonce. The second stage is time critical as the card has to answer one of the generated pseudorandom sequences, a time T after a synchronization pulse. The third is the verification of the relay presence

the sequence S after a time duration T measured from the synchronization start by using its load modulation. The time duration between the reader request and the card answer is usually sufficient to send this sequence. The reader received the sequence S with a delay from its sent synchronization. This delay depends strongly on the delays introduced by the uplink and downlink relay. A time T after its synchronization pulse, the reader synthesizes the sequence S as it was sent by the card but without any delay. The received sequence S from the card is sampled by the reader after a time T from the triggering pulse to synchronize the samples Y(n) from the card answer and the sample X(n) from the synthesized sequence of the reader.

During the verification stage, the reader correlates the two recorded sequences X(n) and Y(n) to determine the delay between the two sequences. The index corresponding to the maximum value of the correlation is the number of samples of the delay. This number and the maximum correlation value are used to determinate the presence of a relay in the reader field.

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3.2.2. Experiments and results

This part presents the first results of correlation based on our solution implementation. The solution is implemented on an "open" reader and contactless card that we developed, illustrated in fig. 8.

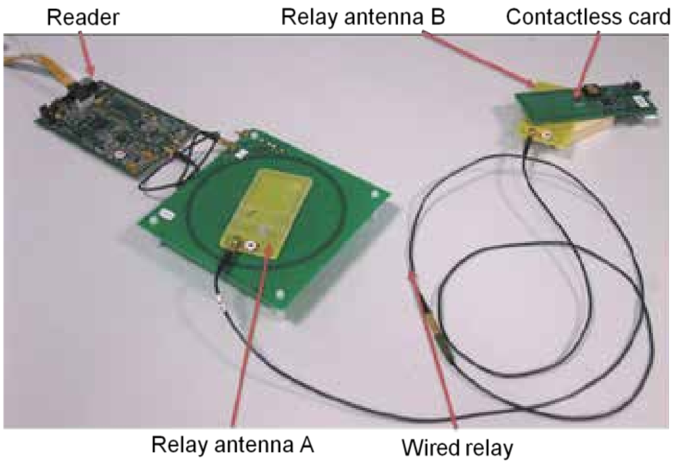

Figure 8. Experimental setup with an open reader and an open card in the presence of a wired relay.

The objective of our experiment is to demonstrate that the computed delay depends on the relay. We perform our four scenarios: one without relay, the others with the three relays studied previously.

Based on 2000 delay values taken in presence or not of a relay and for different distance between antennas, we compute the distribution of these four cases.

This first implementation of a cryptographic protocol based on the physical layer gives interesting results. The chart on fig. 9 shows three different histograms: one for each implemented relay (the wired relay and the fastest wireless relay) and one in the case without relay. These first results prove the efficiency of our solution since it is able to detect a relay with the help of the maximum delays occurred in a classical contactless system. Only relay designed by us are tested but we assume that delay induced by these relay are close to the theoretical minimal delay induced by the most critical relay. Then, we can claim that our solution can detect the most existed relay attacks.

3.3. Discussion

The objective of this discussion is the analysis of the security and the privacy of this solution.

Card cloning and replay attacks with a false card could not be authenticated by the reader and the threat will be detected. In fact, the card must compute two random binary sequences during the first stage of our protocol. The result of this computation is checked during the second

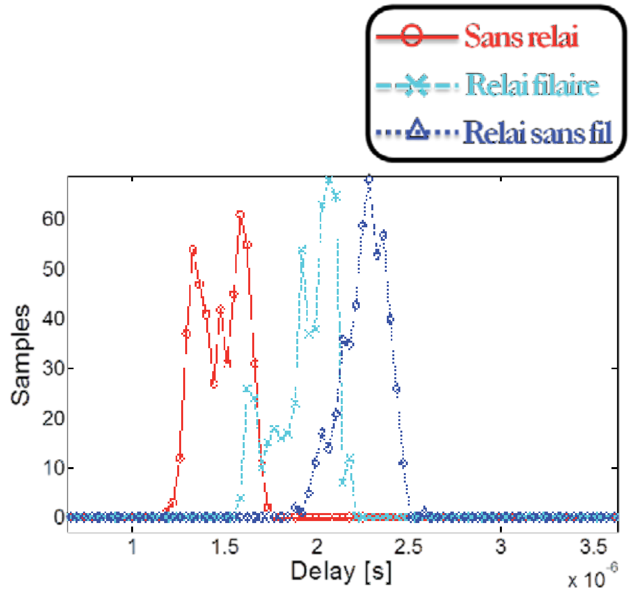

Figure 9. Delay distribution with our solution for each case (with one of the two most critical relays or without relays) for different distance between antennas.

stage. A false card could not send the correct sequence at the correct time to the reader because they depend on the knowledge of the secret key k.

In the case of distance bounding protocols, the security is analyzed by exposing the protocol to three different attacks. Our solution can be exposed to the same attacks to detect possible weaknesses.

3.3.1. *Distance fraud*

The scenario of this first attack requires a true reader, named verifier, and a false contactless card, named prover. The prover must convince the verifier they are close to each other when it is outside the communicating range. Firstly, this attack is only theoretical in the domain of contactless systems since no author implements this attack. Thus, the prover authenticates the card during the challenge; a corrupted card will be detected (see above). The detection of distance fraud attacks depends on the delays introduced by a modified card.

3.3.2. *Mafia fraud*

In the mafia fraud attack, the attacker does not perform any cryptographic operations based on the security protocol, and only forwards the challenges and the responses between the honest prover and the honest verifier: it is the standard relay attack.To convince the verifier and the prover they are close to each other, the relay can speed up the clock of the carrier to improve the response time of the prover answer [14]. The received signal will be compressed and the correlation value will be weaker so this attack will be detected. In the same way, the

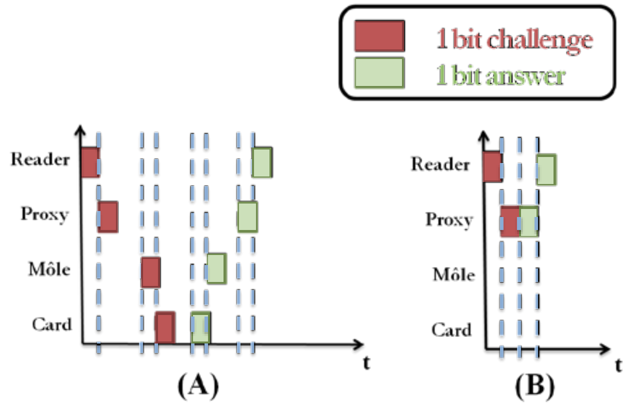

Figure 10. Noisy environment (A) classical case (B) Case with the anticipation of the answer

relay can not anticipate the synchronization pulse of the card because the pulse position in the time is random. Our protocol is resistant to the mafia fraud.

3.3.3. Terrorist fraud

This attack is similar to the previous one, the only difference is that the contactless card and the relay cooperate to mislead the reader. This attack is possible if the protocol does not guarantee a link between the authentication part and the timed challenge part. In our case, the answer of the card and the time between the pulse and this answer are deduced by the cryptographic key during the authentication part. Our solution is resistant to terrorist fraud.

3.4. Physical attacks

The main objective of this article is to prove the reliability of a solution based on the HF physical layer. We assume that the authentication protocol can be improved based on the literature. However, our solution must be resistant to such physical attacks.

3.4.1. Noisy environment

Distance bounding protocols are usually based on the use of an Ultra Wideband modulation. This modulation is sensitive to noise because its spectral power density is weak. In the case of a noisy channel, the attacker can anticipate the bits sent by the card to reduce the value of the delay measured by the reader. The answer of the card is just one bit; the attacker has a fifty-fifty chance to discover the real value. Then the reader can believe these errors are due to the noisy environment since they are introduced by the attacker. Then the reader concludes that the card is closer than it is and it does not detect the relay (fig. 10).

In our solution, the use of the HF physical layer which is less sensitive to noise and a length of many bits for the sequence S circumvent the anticipation of the sequence by the relay.

3.4.2. Timing attacks

The clock of the card is linked to the carrier frequency of the device which is powered it. This attack, described by Hancke [14], allows an attacker to speed up the clock and then the processes computed by the card to reduce the secret time T of our protocol. Then, the relay transmits the card answer earlier and the relay is not detected (fig. 11). In [16], the authors show that few solutions allow the limitation of the clock increase such as low-pass filters or internal clock. With this kind of solutions implemented on the card, an attacker can absorb 2-3 ns by clock cycle (73.74 ns). To realize such attacks, the attacker has to use a complex relay which demodulates the signal. This kind of systems introduces delays of few µs. Then this attack is not possible if the secret time T between the reader request and the card answer is lower than a determined threshold. This threshold must be inferior to the necessary time to compensate the delay introduced by the processing times of the relay.

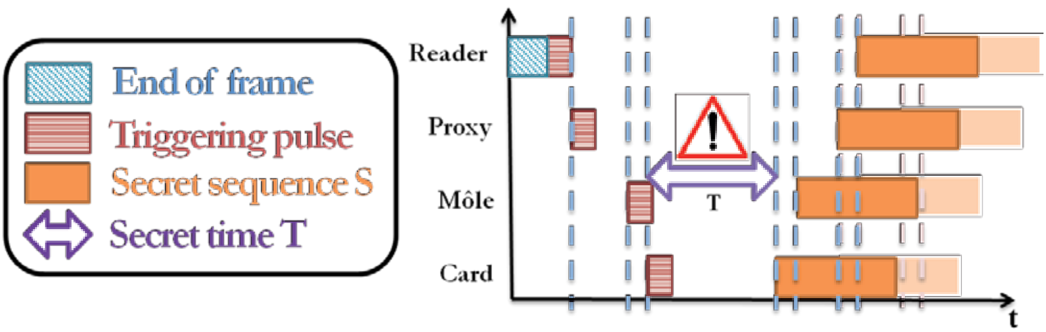

Figure 11. Timing attacks

3.4.3. Anticipation of the synchronisation pulse

The anticipation of the pulse by the relay is a weakness of this kind of protocols because our pulse does not contain a challenge. The relay does not have to wait the pulse and can anticipate and send it earlier. This solution cancels the delay introduced by the forward processing times of the relay (fig. 12). A first solution is to send the pulse just after the end of frame of the reader. Then, the attacker can just cancel the delay introduced by the forward relay. Secondly, our system can use multi level modulation to encrypt the pulse. This modulation can be in amplitude or phase. The value of the secret time T and the secret sequence S can be linked to the value of the modulation level.

Then, this solution limits the anticipation of the pulse since the answer of the card is function of the modulation of the reader.

3.5. Countermeasure improvement

The accuracy and the reliability of our solution can be enhanced:

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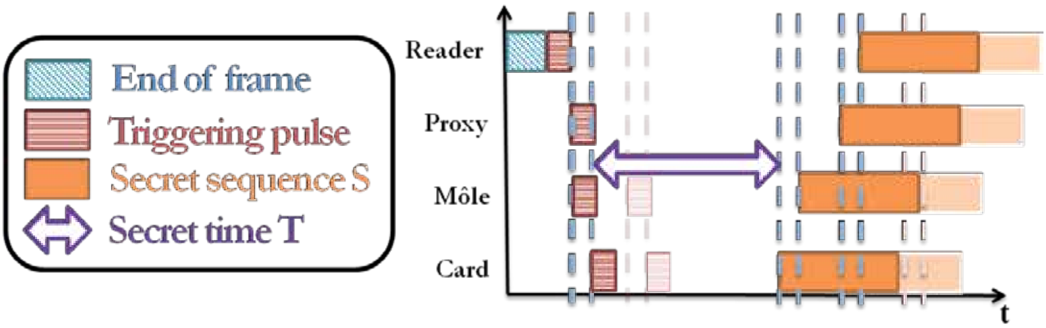

Figure 12. Anticipation of the synchronisation pulse

3.5.1. Pulse detection

An important improvement concerns the detection of our reference point; the accuracy is mainly due to the triggering pulse identification. It is currently realized using a binary signal, this signal results of the demodulation of the RFID signal. We do not control this demodulation but we suppose that it adds a shifting delay to our total delay. We have to develop a system which can detect a pulse with a fixed delay to reduce delay accuracy significantly. The improvement of the accuracy and the rapidity of the pulse detection can be made by using phase modulation only for the pulse. This solution has been implemented on the previously used contactless reader and a new contactless card able to decode a signal modulated in phase. Our approach, c.f. B.1?, was tested with the new parameters for the pulse emission and reception. The results are described on fig. 13. The delay distribution for the case without relay and the case wired relay show an important improvement. Indeed, the two histograms are significantly different; the introduced delay becomes more important with the presence of the wired relay. This experiment shows that all relay attacks can be detected efficiently using the phase modulation for the synchronization pulse. However, this improvement implies the modification of the existing Radio-Frequency front-end equipment.

3.5.2. M-sequences

M-sequences present many properties which can improve the accuracy and the sequence generation of our solution. An M-sequence is a pseudo random sequence generated in most cases by linear feedback shift register and is used in many cryptographic applications. Two properties of M-sequences are of interest: randomness and correlation properties. The sequence is composed of pulses with variable width multiple of the minimal period. The autocorrelation of this kind of signals is an approximation of a Kronecker delta function. Such functions present an important peak when there is no delay between the signals is null which is easy to detect in the case of an implementation.

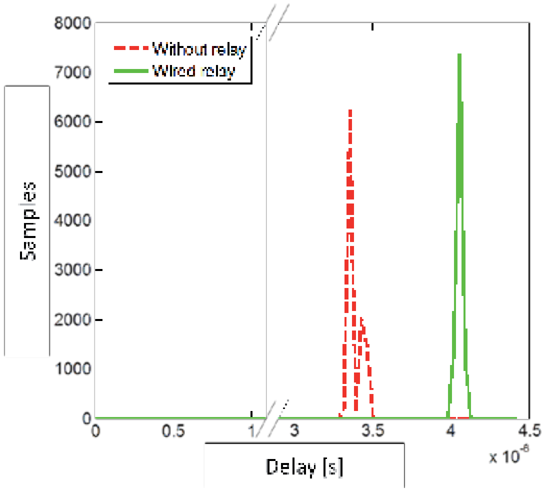

Figure 13. Delay distribution with our solution for the case without relay and in the case with a wired relay for different distance between antennas.

3.5.3. Correlation on PM (Phase Modulation) signals

In the case of NFC use in smartphones for critical application, we can suppose that the target (corresponding to the contactless card) uses active mode to answer to the initiator (the reader in our solution).

Then, the target can modulate its signal by varying the instantaneous phase of the carrier signal. The phase modulation can be more complex for implementation but more accurate in terms of correlation. In fact, the signal received and recorded by the initiator must be in phase with the generated one. There are fewer problems with establishing times in antennas because there is no subcarrier, c.f. II.C.2. The obtained accuracy depends on the phase modulation but we can think that we can detect delays close to half of a carrier. Such improvements imply modifications of standards.

4. Conclusion

The relay attack is an attack on physical layer which should be seriously considered because it can be easily implemented and used in a lot of applications. Moreover, the increasingly use of NFC technology, especially in phone applications, opens new opportunities for intruders. Nowadays, contactless readers are unable to detect a relay. This attack does not modify the signal, nor disturb the transaction and induce delays close to a few periods of the signal carrier. Additionally, cryptography, which is the best solution for most threats, cannot detect this attack.

The first objective of our work was to realize relay attacks with the shortest delays. Within this chapter, we have presented three different solutions to overcome this problem. Experiment results show that the designed wired relay is the most critical relay in terms of the introduced time delay. Our work shows that with two simple antennas and a wire, an attacker can relay data between a reader and a card with delays close to 300 ns, i.e. 50 times shorter than Hancke's relay attack. Today, no countermeasure is able to detect this kind of relays.

The second objective was to develop a new solution to detect such delays with maximum certainty. This countermeasure uses correlation between two sequences to compute the delay introduced by the relay. This will be used to determine the presence of a relay in the reader's field. For the first time, a solution was implemented on a contactless system and the results are interesting. A contactless system does not require additional hardware resources to use our protocol which allows accuracy close to 300 ns. This solution respects the contactless standards and does not disturb the communication between the reader and the card since the protocol can run during the response time of the card. Apart from the most critical relay, namely wired relay, which is not detected in few rare cases, all kind of relays are detected with our counter-measure. However, we developed another solution that detects all kind of relays attacks by improving the accuracy of our contactless system. However, the latter requires a modification of the RF front end.

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Chapter 5

Localizing with Passive UHF RFID Tags Using Wideband Signals

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53769

1. Introduction

Localization of positions and detection of objects is a key aspect in today's applications and, although the topic exists a while ago, it is still under ongoing research. The introduction of global navigation satellite systems (GNSS), particularly GPS [1], and its improvements with accuracies down to a few meters, was a huge step towards ubiquitous localization [2, 3]. This is almost valid for outdoor environments, whereas indoor localization is still a challenging issue [4, 5]. The reason for that is the demanding, dynamic indoor environment, causing severe multipath fading, leading to hard predictable propagation models - thus influencing time, power and phase measurements. However, in the past, much effort has been put into designing high accurate indoor localization systems, including technologies like ultrasonic sound, infrared light, Wi-Fi, Bluetooth, ZigBee, cellular mobile communication (GSM, UMTS), ultra-wideband and RFID just to mention a few of them. Despite all the effort, there is no outstanding technology comprising all indoor localization contingencies as every technology in use has its advantages and disadvantages regarding accuracy, availability, complexity and costs.

Due to constantly falling prices of UHF RFID tags [6] additional applications arose beside the traditional concept of radio frequency identification (RFID). Major applications include supply chain technologies [7] and logistics [8], from container level tagging even down to item level tagging [9]. Regarding the Internet of Things [10], UHF RFID has some advantages over other RFID technologies, i.e., LF and HF: UHF RFID tags are small, do not require a battery, allow high data rates and high reading ranges, whereas LF and HF cannot serve with these issues at the same time [10]. Together with the mentioned low costs, the UHF RFID technology may be available in lots of objects (walls, carpets, doors, etc.) in the future. Therefore, indoor positioning using UHF RFID technology could be one solution towards ubiquitous localization, as efforts are made to shrink the size of RFID reader ICs and to integrate them into mobile phones.

The chapter is organized as follows. Section 2 gives a brief overview of today's wireless positioning technologies with a focus on RFID. Section 3 introduces the proposed positioning system and shows the theoretical approach along with an example. Section 4 focuses on challenges and limitations of the system and Section 5 presents results from measurements carried out underlining the principle of operation. Section 6 provides a discussion based on the results. Finally, Section 7 gives a short summary and concludes with a perspective for future work.

2. Basics and state of the art

This section provides an overview of state-of-the-art wireless positioning technologies. The section is divided into two subsections, with the first subsection describing measurement principles for positioning, whereas the second subsection has a focus on current positioning technologies based on RFID, particularly UHF RFID within the 900 MHz frequency band.

2.1. Positioning measurement principles

The first paragraph provides definitions for the terms precision, rightness and accuracy, whereas the following paragraphs describe the main positioning processes comprising lateration, angulation and fingerprinting. The last paragraph depicts the measurement techniques used for the positioning process, for instance, time of arrival, angle of arrival and received signal strength.

2.1.1. Precision, rightness and accuracy

Often, the terms "precision" and "accuracy" are used to define the same issue, namely how well a localization system or method works, e.g., the measurement error expressed in meters. However, precision and accuracy are not similar to each other. Therefore, this paragraph points out the differences and relations of the terms precision, rightness and accuracy.

Precision shows how well independent measurement values are located to each other. That means, if many measurement values are in dense proximity to each other, the measurement has a high precision; on the other hand, it does not mean that the measurement is accurate in any case. A standard term that is used to measure the precision is the standard deviation σ_x with

$$\sigma_x = \sqrt{E\left\{\left(\hat{x} - E\{\hat{x}\}\right)^2\right\}} \text{ and } \hat{\sigma}_x = \sqrt{\frac{1}{N-1}\sum_{k=1}^{N}\left(\hat{x}_k - \bar{\hat{x}}\right)^2}, \text{ with} \tag{1}$$

$$\bar{\hat{x}} = \frac{1}{N}\sum_{k=1}^{N}\hat{x}_k \tag{2}$$

$\hat{\sigma}_x$ describes the estimated standard deviation of the measurement, N describes the number of measurements, $\hat{x}_k$ the measurement value at the kth measurement, $\bar{\hat{x}}$ the estimated mean

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value of the measurement values. $\hat{x}$ describes the random variable of the measurement process, whereas $E\{\cdot\}$ is the corresponding expectation value. In the following, the standard deviation σ_x is used as a measure for the precision of a positioning technique.

Rightness or trueness describes how well the measured values respectively the expectation of the estimated values $\hat{x}$ fit to the expectation of the true values x, i.e., a so called bias with

$$Bias = E\{\hat{x} - x\} = E\{\hat{x}\} - x \quad \text{and} \quad \widehat{Bias} = \bar{\hat{x}} - \bar{x} \tag{3}$$

$\widehat{\text{Bias}}$ is the estimated rightness of the measurement and $\bar{x}$ is the mean value of the true values. The rightness is a measure for the average discrepancy between a measured and a reference value and may be described as bias or offset.

Accuracy takes both, the precision and the rightness, into account. In fact, only high accuracy may be achieved if precision and rightness is high, too. A well known definition of the accuracy is the root mean square error RMSE, which is defined as

$$\text{RMSE} = \sqrt{\text{MSE}} = \sqrt{\text{E}\{(\hat{x} - x)^2\}} \text{ and } \widehat{\text{RMSE}} = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(\hat{x}_k - x_k)^2} \tag{4}$$

$\widehat{\text{RMSE}}$ describes the estimated RMSE of the measurement and x_k the true value at the the kth measurement.

According to [11] the first expression in Equation (4) can be transformed into

$$\text{RMSE} = \sqrt{\sigma_x^2 + \text{Bias}^2} \tag{5}$$

Equation (5) shows that a distorted measurement with a high precision may be more accurate than an undistorted measurement with a low precision respectively standard deviation.

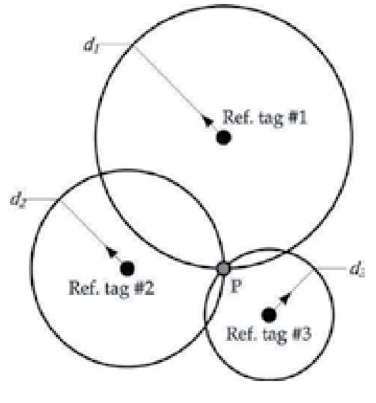

Figure 1. Example of trilateration with RFID reference tags

2.1.2. Lateration

Lateration is used to determine the position using distances to known reference points. For instance, an RFID reader may localize itself by evaluating distances to certain reference points, e.g., RFID tags, using the principle of trilateration, as shown in Figure 1. In this figure, two-dimensional (2D) positioning of **P**, an RFID reader, can be realized using three reference points, here reference tags. Assuming the reader is able to exactly determine its distance $d_i \ \forall\, i \in \{1,2,\, 3\}$ to each of the tags, a circle is drawn around each tag with radius equal to the measured distance d_i. The intercept point of the three circles with radii $d_1 \ldots d_3$ indicates the position of the reader **P**. If the positions of the reference tags are known, the reader may determine its position by solving the set of equations

$$\sqrt{(x_{\mathrm{P}} - x_i)^2 + (y_{\mathrm{P}} - y_i)^2} = d_i\,, \quad i \in \{1,2,\, 3\}. \tag{6}$$

$(x_{\mathrm{P}}; y_{\mathrm{P}})$ is the position of the reader, which shall be estimated and $(x_{\mathrm{i}}; y_{\mathrm{i}}) \ \forall\, i \in \{1,2,\, 3\}$ is the position of each of the reference points respectively tags. Solving the set of equations in (6) for three reference points yields [12, 13]:

$$\begin{pmatrix} x_{\mathrm{P}} \\ y_{\mathrm{P}} \end{pmatrix} = \begin{pmatrix} a_{1,2} & b_{1,2} \\ a_{1,3} & b_{1,3} \end{pmatrix}^{-1} \begin{pmatrix} g_{1,2} \\ g_{1,3} \end{pmatrix}, \tag{7}$$

with

$$a_{1,i} = 2(x_i - x_1), \quad i \in \{2,3\} \tag{8}$$

$$b_{1,i} = 2(y_i - y_1), \quad i \in \{2,3\} \tag{9}$$

and

$$g_{1,i} = d_1^2 - d_i^2 - (x_1^2 + y_1^2) - (x_i^2 + y_i^2), \quad i \in \{2,3\}. \tag{10}$$

In the case of three-dimensional (3D) positioning, a minimum of four reference points is necessary to unambiguously determine the exact position. However, due to the imperfectness of the distance measurement (noise, fading channel, etc.), there is usually no exact interception point, but rather an intersection area. Therefore, different error-minimizing algorithms can be used to make a best estimate for the position determination [14]. The accuracy of the measurements can be further increased by making use of more than the necessary minimum of reference points [15].

In RFID, generally, there exists clock synchronization between transmitter and receiver, as both components are located within the RFID reader. If, however, there is no clock synchronization between transmitter and receiver, the clock offset τ_{offset} will lead to a constant distance error d_{offset} within each range measurement. This additional parameter can be solved by adding one more equation (equal to one additional tag) to the minimum number of equations when there is no synchronization error:

$$\sqrt{(x_{\text{P}} - x_i)^2 + (y_{\text{P}} - y_i)^2} + d_{\text{offset}} = d_i \quad \forall\, i \in \{1,2,\ 3,4\} \tag{11}$$

As mentioned before, there should be no time offset in RFID systems. Nevertheless, constant phase shifts due to the non-constant reflection coefficient of RFID tags [16] can lead to an additional offset distance d_{offset}, having the same effect as a time-based clock offset. The set of equations in (11) describe hyperbolas rather than circles around the reference points. Figure 2 shows the effect of an offset distance d_{offset} and two out of four hyperbolic curves, which would intercept in position P.

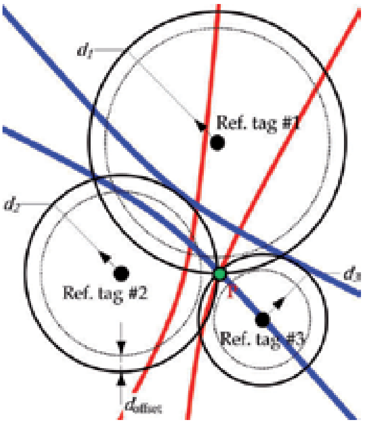

Figure 2. Example of hyperbolic lateration using RFID tags as reference points

2.1.3. Angulation

The principle of angulation rests upon the relations between angles and distances within a triangle; therefore, it is mostly common under the term triangulation. If two angles and one side of a triangle are known the remaining distances respectively the position to be determined can be calculated using the *law of sines* and the *angle sum of a triangle*. Figure 3 shows the principle used: Two antennas (Ant. #1 and Ant. #2) of an RFID reader are deployed to calculate the position of the RFID tag. This can be realized using, for instance, phase-based or direction-defined measurements. From independent angle measurements one obtains the angles α and β; the distance d_0 is known in advance. Subsequently, the remaining angle γ is calculated (angle sum in triangle) and from that the missing two distances d_1 and d_2 from the antennas to the RFID tag (law of sines). Angulation may be used in 2D or 3D localization problems.

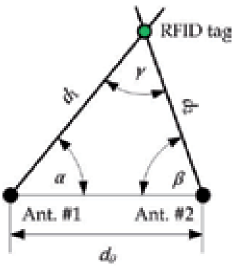

Figure 3. Triangulation example using two antennas to determine the position of an RFID tag

2.1.4. Scene-based localization / fingerprinting

Scene-based localization is divided in two sequential processes, a calibration process and an operational process. The calibration process records any environmental values (optical, electrical, physical, etc.), also known as fingerprints, at several positions within a scene and stores the data in a database [17, 18]. The following operational process is thus able to determine the position by measuring the current environmental values and comparing them with the values in the database. Special algorithms estimate the position by finding the position with the minimal error [19]. Figure 4 shows a room map with different WLAN base stations showing the electrical field strength at different locations [20] used along with WLAN positioning.

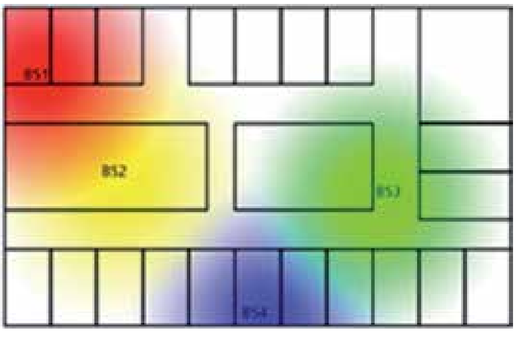

Figure 4. Electrical field strength distribution within a building to be used for WLAN positioning [20]

2.1.5. Positioning measurement techniques

After highlighting the measurement principles, this paragraph gives a brief overview over the common technologies used. Distance measurements may be based on measuring the time of flight, the signal strength and the phase between transmitted and received signal.

Time measurements include Time of Arrival (ToA) and Time Difference of Arrival (TDoA) measurements.

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ToA measurements directly determine the distance by using the time of flight t_{ToA} of the signal. Multiplied with the corresponding propagation speed c, the speed of light in case of electromagnetic waves, this results directly in the distance d_{ToA} between transmitter and receiver as described in Equation (12). ToA measurements can be used directly along with trilateration methods.

$$d_{\mathrm{ToA}} = t_{\mathrm{ToA}} \cdot c \tag{12}$$

TDoA measurements determine the time difference of a signal received at known reference points rather than measuring directly the time between transmitter and receiver. This means, that the time stamp of the signal transmitted via the object to be localized is unknown, but the time differences at the synchronized receivers are determined. In contrast to ToA, TDoA does not require any synchronization between transmitter and receiver. The reference stations must be synchronized, indeed. One positioning method using TDoA measurements is hyperbolic lateration (see Paragraph 2.1.2).

RSS (Received Signal Strength) measurements are based on the received signal strength at the receiver. Hence, there are two possible candidates to process RSS-based data. The first one is based on the propagation conditions, usually including a modified and enhanced form of Friis transmission equation

$$P_r = P_t + G_t + G_r + 20\log\left(\frac{\lambda}{4\pi d}\right)[\mathrm{dB}], \tag{13}$$

e.g., the log-distance path loss model

$$\mathrm{PL}(d) = \mathrm{PL}(d_0) + 10\alpha\log\left(\frac{d}{d_0}\right) + X\ [\mathrm{dB}]. \tag{14}$$

Equation (13) describes the free space attenuation formula depending on the distance d and wavelength λ with receiving power P_r, transmitting power P_t, receiving and transmitting antenna gains G_t and G_r together with the free space attenuation $\left(\frac{\lambda}{4\pi d}\right)^2$ in dB. Equation (14) on the other hand describes the path loss $\mathrm{PL}(d)$ depending on the distance d related to a reference path loss $\mathrm{PL}(d_0)$at distance d_0. The path loss may be described as the difference of transmitted and received power in dB. α represents the path loss exponent that depends on the propagation environment, whereas X is a zero-mean Gaussian distributed random variable describing the fading effects at different locations and instants of time. If, in case of the usage of Equation (14), $\mathrm{PL}(d_0)$, α and the variance of X is known, one can calculate directly the probability for a certain distance d between transmitter and receiver. One disadvantage is that α and X are very dependent on the environment and can change significantly. The RSS measurements can be used along with lateration methods.

The second RSS-based approach is to measure in advance RSS values at certain positions within the localization area (fingerprints). The measured values are pre-processed and stored into a database. During the proper localization process, the current measurement values are compared to the values in the database and a best-fit position, based on the current values, is estimated. The advantage of using RSS values for this approach is that almost all devices come along with some kind of RSS-based output, including RFID readers. This method is used in scene-based positioning techniques.

Phase measurements can be used to provide information about speed, distance and angle. A good overview over these techniques is given in [21]. The radial velocity v of a tag is measured by evaluating the phase shift $\partial\varphi$ during different moments in time ∂t as given in Equation (15).

$$v = -\frac{c}{2\omega_0}\frac{\partial\varphi}{\partial t} \tag{15}$$

with c being the propagation speed and ω_0 the fixed circular frequency. The distance d between a tag and a reader can be calculated according to Equation (16) by measuring the phase shift at different frequencies.

$$d = -\frac{c}{4\pi}\frac{\partial\varphi}{\partial f} \tag{16}$$

Finally, phase measurements may be used to measure the angle θ between reader and tag (Angle of Arrival, AoA) using multiple receiving antennas. For two receiving antennas, Equation (17) describes the relation between the incoming angle θ, the phase difference $\varphi_2 - \varphi_1$ at a certain carrier frequency, and the spacing a between the receiving antennas.

$$\theta \approx \sin^{-1}\left[-\frac{c}{\omega}\ \frac{\varphi_2 - \varphi_1}{a}\right] \tag{17}$$

Phase measurement are used along with lateration and angulation principles to calculate the distance between transmitter and receiver respectively reader and tag.

2.2. Survey on UHF RFID-based localization systems

The following paragraphs provide a brief survey on state-of-the-art RFID localization systems within the UHF and microwave frequency band. The survey includes systems using RSS values, ToA and TDoA measurements, phase-based measurements as well as fingerprinting methods. Further surveys are provided in [22, 23, 24].

2.2.1. RSS-based direct range estimation

The SpotON system [25] is based on active RFID tags (working at 916.5 MHz) and provides a 3D ad hoc localization. RFID readers measure the signal strength of active RFID tags and a central server performs the calculation of the position within the environment. The relation between the RSS value and the position is based on the indoor channel model from Seidel and Rappaport [26]. The accuracy of the SpotON system is given with a cube of 3 m edge length, but this is dependent on the number of reference tags used. A disadvantage of the system is the long position calculation time from 10 to 20 s; an advantage is the easy to extend infrastructure and low system costs.

2.2.2. *ToA-based range estimation*

A 2.4 GHz RFID system based on SAW transponders is described in [27]. The SAW tags use a bandwidth of 40 MHz and reduce the echoes from the environment as the reflected tag signal is delayed due to the lower surface speed on the SAW material. The signal time on the SAW transponder is $T_{\mathrm{SAW}}=2.2\ \mu\mathrm{s}$; so the reflections and echoes from the reader are almost faded out before the SAW-reflected signal responses back to the reader. A three-antenna system is used to perform a 2D positioning. However, the localization accuracy is strongly temperature-dependent and adds up to around 20 cm in a room with the dimension 2 m × 2 m.

2.2.3. *TDoA-based range estimation*

A localization system in the 5.8 GHz frequency band is described in [28]. The system is build upon active transponders and multiple base stations. One reference transponder is used as wireless synchronization source for the base stations. The system operates on the FMCW (frequency modulated continuous wave) principle (see [29]) and evaluates the time difference of a measurement transponder signal to determine the position of the measurement transponder. The position accuracy is given with 10 cm on an area of 500 m × 500 m.

2.2.4. *Phase-based range estimation*

The principle of FMCW is used to measure the distance to a certain object. The idea behind FMCW is to sweep a frequency band with the sweep rate α and record the phase and frequency differences. Furthermore, the transmitted signal from the reader is modulated by the transponder with a modulation frequency f_{mod}. The usage of a modulation frequency shifts the measurement signal into a higher frequency band (by f_{mod}), in order to suppress certain disturbances and noise within the baseband. The distance d is calculated through the frequency difference Δf and the phase difference $\Delta\varphi$ [30], with the latter providing a high range resolution within half a wavelength of the signal. Therefore, Δf provides a coarse distance estimation and $\Delta\varphi$ a more accurate one. $\Delta\varphi$ alone cannot be used as direct distance estimation due to ambiguities of the phase information. According to [30] the distance to a transponder can be calculated with

$$d_{\mathrm{coarse}}=\frac{\pi\cdot c\cdot\Delta f}{2\cdot\alpha}\ \text{and}\ d_{\mathrm{precise}}=\frac{c\cdot\Delta\varphi}{4\cdot\omega_0}. \tag{18}$$

[31] describes an FMCW-based RFID system using a transponder with an UHF front-end working at 868 MHz. The transponder IC provides a modulation frequency of

f_{mod}=300 kHz and is driven by a 2.45 GHz FMCW signal with a bandwidth of 75 MHz. The system is tested on a cable-based setup and delivers an RMSE of 1 cm with cable lengths between 1 m and 9.5 m.

The system in [32] uses the phase difference observed at different frequencies to estimate the range between transponder and reader. The range estimation is performed according to Equation (16), whereas the maximum range d_{max} due to phase ambiguities is given with

$$d_{\mathrm{max}} = \frac{c}{2B}. \tag{19}$$

However, the choice of the bandwidth B strongly influences the system's capabilities. A high B generates a high accuracy but a low maximum range; a low B leads to a higher range but at the expenses of a lower accuracy. Simulations at an SNR of 10 dB results in errors of 2.5 m for a frequency separation of B = 1 MHz, and errors of 0.1 m for a B of 26 MHz. One has to keep in mind that the separation of 26 MHz is only valid within the US frequency band for RFID that ranges from around 902 MHz to 928 MHz. The European band is smaller (865.6 MHz to 867.6 MHz) leading to a lower accuracy.

2.2.5. Scene-based range estimation

LANDMARC [33] is an extension and improvement of the SpotON system [25, 34]. The system consists of fixed RFID readers, active reference tags (landmarks) and tags to be localized. The system uses RSS values connected with the kNN (k-nearest neighbor) algorithm [35] to estimate the position. The average error of the system is given with 1 m [33].

[36] examines the localization error of the LANDMARC system using passive, instead of active RFID tags. As a result, the orientation of the tags has a major influence on the total performance of the system. Using the kNN algorithm, in 47.5 % of the cases, the error was less than 0.5 m and in 27.5 % of the cases, the error was less than 0.3 m. However, in comparison to the original LANDMARC system, the overall range is smaller due to the usage of passive RFID technology.

A system based on a particle filter is proposed in [37]. It uses two RFID readers mounted on a small mobile vehicle to localize itself using RSS values. The calibration phase is performed in a room of size 5 m × 10 m. Depending on the speed of the vehicle and the material on which the tags are located (plastics, concrete, metal) the average error is between 1.35 cm and 2.48 cm. This system is based on the mobile robot system in [38] that incorporates a SLAM algorithm [39] based on Monte Carlo methods [40].

[41] describes a positioning system using fingerprints (RSS values and read rate) to localize tagged objects. First, a rough positioning is done using antenna cells, with each antenna illuminating a different room zone. This rough classification is realized using either Bayesian filter, kernel density estimation (KDE) based measurement models, support vector machines (SVM) or LogitBoost [42]. RSS-based values and read rate is used along with the algorithms to roughly estimate the position of the tagged object. One result was that the estimations based on RSS values perform better than the estimations based on the read rate. An even more

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accurate positioning is realized when RSS values are used along with read rates of the transponders. Within the calibration phase, one tries to generate a high amount of reference points (fingerprints). Two algorithms are used and compared to perform within the positioning phase, a cascaded algorithm and a kNN algorithm. The cascaded algorithm runs the rough localization followed by the kNN algorithm for the high accuracy. The second algorithm resigns to use the rough position estimation. Similarly, the RSS-based fingerprints perform better than the read rates. Dependent on the environment, positioning errors between 37.9 cm and 42.1 cm may be achieved.

3. Wideband UHF RFID positioning system

This section introduces a brief motivation for the realized RFID positioning system before describing the basic structure of the system.

As derived from Section 2, current passive RFID localization systems suffer either from a high effort in the calibration phase (fingerprinting) or from bandwidth limitations which hold down the system's overall accuracy. Higher accuracies may be achieved using phase-based approaches at the expense of more complex hardware structures and necessary volume (see, for instance, phased array antennas [43]), only usable for fixed reader hardware. Therefore, an ideal passive mobile RFID positioning system should have:

- no change in hardware,
- high bandwidth,
- direct position estimation.

The here proposed system offers high bandwidth, but with very low power, and is based on a ToA method performing direct position estimation. As a consequence, additional hardware effort is necessary to provide the generation and evaluation of the high bandwidth signals.

In the following, a brief overview of the system, particularly its principle working structure, is provided.

Assuming a scenario as given in Figure 5. The scenario consists of n tags, whereby the distance to the ith tag has to be evaluated. The RFID reader is indicated at the bottom (only the coupler with antenna in monostatic mode) with input signal x_{reader} (into the antenna) and output signal y_{reader} (from the antenna). s_1 to s_n describe the backscatter modulation factors of the transponders, i.e., the factor with which the incoming signal from the reader is reflected with (principle of backscatter). If this factor is one, the complete signal is backscattered to the reader. Indeed, data from tag to reader is transmitted by varying this factor in time with the data to be sent [10, 44]. h_1 to h_n describe the bidirectional channel impulse responses between reader and tags. For reasons of simplification the following equations and terms are written without using the time t, although the expressions depend on it.

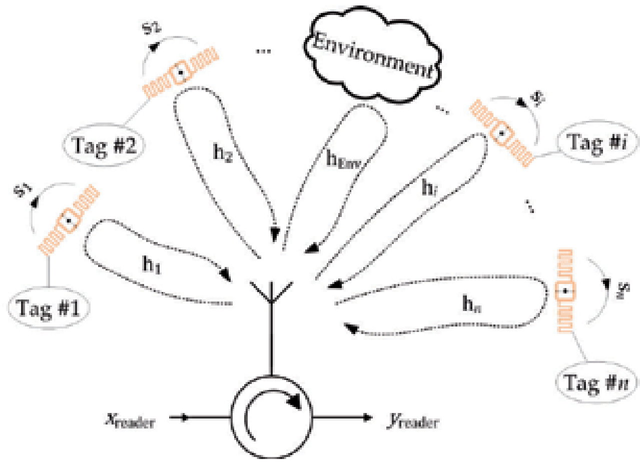

Figure 5. Scenario with passive RFID tags and reader in monostatic antenna setup

According to Figure 5 we can state (in time domain) by using the convolution $*$:

$$y_{\text{reader}} = [(h_1 * s_1) + (h_2 * s_2) + \ldots + (h_i * s_i) + \ldots + (h_n * s_n) + h_{\text{Env}}] * x_{\text{reader}} \tag{20}$$

For simplicity, let us assume that each backscatter modulation factor s_i has two modulation states according to

$$s_i = \begin{cases} s_{i,1} & \text{for modulation state 1} \\ s_{i,2} & \text{for modulation state 2} \end{cases} \tag{21}$$

In a first attempt, all tags are set into modulation state 1. The resulting signal $y_{\text{reader},1}$ is

$$y_{\text{reader},1} = [(h_1 * s_{1,1}) + (h_2 * s_{2,1}) + \ldots + (h_i * s_{i,1}) + \ldots + (h_n * s_{n,1}) + h_{\text{Env}}] * x_{\text{reader}} \tag{22}$$

In a second attempt, only tag *#i* is set into modulation state 2, all other tags stay in modulation state 1. This can be described as one small sequence of data transmission from the *i*th tag to the reader (uplink). The resulting signal $y_{\text{reader},2}$ is

$$y_{\text{reader},2} = [(h_1 * s_{1,1}) + (h_2 * s_{2,1}) + \ldots + (h_i * s_{i,2}) + \ldots + (h_n * s_{n,1}) + h_{\text{Env}}] * x_{\text{reader}} \tag{23}$$

The difference Δy_{reader} between both resulting signals $y_{\text{reader},1}$ and $y_{\text{reader},2}$ is

$$\Delta y_{\text{reader}} = y_{\text{reader},2} - y_{\text{reader},1} = [(h_i * s_{i,2}) - (h_i * s_{i,1})] * x_{\text{reader}} = [s_{i,2} - s_{i,1}] * h_i * x_{\text{reader}}, \tag{24}$$

thus, taking the difference results into observation of the *i*th tag with the *i*th channel. By assuming that the tag's data contain the position of the tag (i.e., a reference tag), the reader has to evaluate the *i*th channel, regarding the range, to estimate the distance between reader and *i*th tag. In a 2D scenario, three tags must be read to get the position data, and three channels to the tags must be evaluated in order to localize the reader itself. The principle is described in more detail in Section 4.

The experimental hardware architecture of the reader is shown in Figure 6.

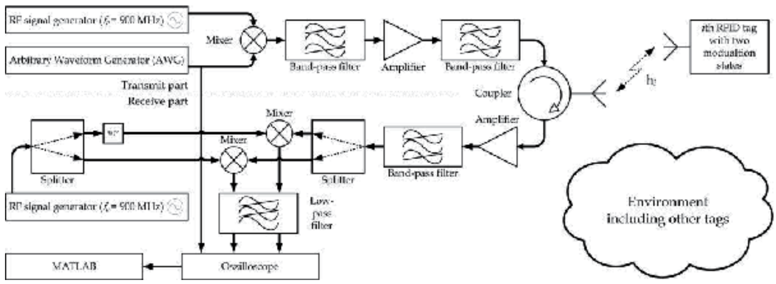

Figure 6. Experimental hardware architecture of the realized RFID localization system based on passive UHF RFID tags

The frequency-coupled RF signal generators generate carrier signals at the center frequency of f_c=900 MHz. The arbitrary waveform generator (AWG) creates the localization signal x_{reader} (in baseband). After upconversion of the localization signal, it is filtered, amplified and emitted into the environment through the antenna. The backscattered signal from the tag, the environment, and all other tags which may be in read range is also amplified, filtered and down-converted into complex baseband. The baseband signals are low-pass filtered and sampled with an oscilloscope, as is the original transmitted localization signal. Further processing is realized in MATLAB. Exemplary signals are shown in Section 6.

3.1. Derivation of the localization principle

Based on the result of the last equation (24) in Section 3, it is necessary to evaluate the channel response h_i regarding the distance between tag and reader. As stated at the beginning of Section 3 the localization should be performed using direct distance estimation, thus, the signal's time of flight t has to be evaluated in order to determine the distance d with the help of the propagation speed c, i.e.,

$$d = \frac{1}{2} c \cdot t, \tag{25}$$

with c usually being the propagation speed of electromagnetic waves complying to the speed of light. The factor one-half is introduced to compensate for the double distance the signal has to travel, i.e., from the reader to the tag and back.

In order to have a high positioning accuracy the signal must be broad regarding bandwidth, but the free spectrum for RFID, especially in Europe, is too small for that application. Therefore, higher out-of-band frequencies must be used. However, due to legal regulations, high bandwidth signals must be very low power, if applied. Ultra-wideband (UWB) signals [45] are such kind of signals and regulated by the Federal Communications Commission (FCC) and its counterparts in other regions, in order not to disturb any other in-band applications. UWB signals are defined as signals with bandwidths greater than 500 MHz or 20 % of the arithmetic mean of lower and upper cutoff frequency. The bandwidth used for the proposed system is 100 MHz due to the capability of UHF RFID tags working worldwide from around 840 MHz up to 960 MHz. Based on these conditions, although the proposed system only occupies 11 % of the arithmetic mean of the cutoff frequencies, the idea is to use low-power spreading signals for the ranging process. These signals are used to calculate the channel to a specific tag and back, thus extracting the time of flight information. As the low-power signals are hard to evaluate directly, the SNR is increased by performing coherent integration [46].

3.2. Mathematical model

Drawing up on Section 3, Equation (24), one can see that it is possible to derive the channel's impulse response upon evaluating the difference between both modulation states of the RFID transponder. Necessary for calculating the distance between tag and reader is the signal propagation time t of the up- and downlink channel. Multiplying half of t with the propagation speed results into the distance d between tag and reader (Equation (25)). As the bandwidth is limited to 100 MHz (Subsection 4.1), the pulse width is 10 ns minimum. Accordingly, a pulse width of 10 ns corresponds to a distance of around 3 m, supposing the speed of light in air is approximately 30 cm per nanosecond. Furthermore, the distance to be covered by this passive localization system is limited to the distance passive RFID tags are able to handle, which is, currently, limited to around 8 m [47]. In addition, the transmitted signal consists of more than one single pulse. These conditions lead to the fact, that the transmit signal and the receiving signal cannot be separated in time, as in ordinary RADAR applications. Another alternative is the principle of correlation, that can be used to determine the time shifted replica of the transmit pulse signal within the receiving signal [48]. The discrete correlation $R_{xy}[\tau]$ between two signals $x[t]$ and $y[t]$ is given with

$$R_{xy}[\tau]=\sum_{k=-\infty}^{+\infty} x[k]\cdot y[\tau+k]= x[t]\cdot y[t]. \tag{26}$$

The correlation term shows the time-shifted replicas of the signal $x[t]$ within the signal $y[t]$. A local maximum within the correlation term means a high correlation between $x[t]$ and $[t]$, i.e., a high linear match. The point in time of the maximum shows the time shift between $x[t]$ and $y[t]$, that is used to calculate the time between transmitted signal $x[t]$ and received signal $y[t]$.

3.3. Example

Let us derive the principle at a simplified example. Assuming the channel of the *i*th transponder is noise-free and multipath-free given with just

$$h_i[t] = a \cdot \delta[t - T_{\text{delay}}] \cdot e^{j\varphi_0}, \tag{27}$$

with a representing the reciprocal of the attenuation, $\delta[t - T_{\text{delay}}]$ the time delay T_{delay} of the channel with the Dirac delta function $\delta[t]$, and an initial phase shift of φ_0. Furthermore, the transponder modulation states $\text{s}_{\text{i},1}$ and $\text{s}_{\text{i},2}$ are given with 0 (full tag absorption) and 1 (full tag reflection). Equation (24) may now be written as

$$\begin{aligned}\Delta y_{\text{reader}}[t] &= [\text{s}_{\text{i},2} - \text{s}_{\text{i},1}] * \text{h}_{\text{i}}[t] * x_{\text{reader}}[\text{t}] = [1 - 0] * a \cdot \delta[t - T_{\text{delay}}] \cdot e^{\varphi_0} * x_{\text{reader}}[\text{t}] = \\ &= a \cdot \delta[t - T_{\text{delay}}] \cdot e^{j\varphi_0} * x_{\text{reader}}[t]\end{aligned}. \tag{28}$$

Performing the correlation to Equation (28) leads to

$$x_{\text{reader}}[t] \cdot \Delta y_{\text{reader}}[t] = x_{\text{reader}}[\text{t}] \cdot \left(a \cdot \delta[t - T_{\text{delay}}] \cdot e^{j\varphi_0} * x_{\text{reader}}[\text{t}]\right) \tag{29}$$

The convolution of $x_{\text{reader}}[\text{t}]$ with the time-shifted Dirac impulse $\delta[t - T_{\text{delay}}]$ delivers a time-shifted signal:

$$x_{\text{reader}}[\text{t} - T_{\text{delay}}] = \delta[t - T_{\text{delay}}] * x_{\text{reader}}[\text{t}] \tag{30}$$

The correlation of $x_{\text{reader}}[\text{t} - T_{\text{delay}}]$ with the original reader signal $x_{\text{reader}}[\text{t}]$ results in a time-shifted cross-correlation signal $R_{x_{\text{reader}}}[\tau - T_{\text{delay}}]$:

$$x_{\text{reader}}[t] \cdot \Delta y_{\text{reader}}[t] = a \cdot e^{j\varphi_0} \cdot R_{x_{\text{reader}}}[\tau - T_{\text{delay}}] \tag{31}$$

Performing the square of the absolute value to Equation (31), finally, leads to

$$|x_{\text{reader}}[t] \cdot \Delta y_{\text{reader}}[t]|^2 = |a|^2 \cdot |e^{j\varphi_0}|^2 \cdot |R_{x_{\text{reader}}}[\tau - T_{\text{delay}}]|^2 = |a|^2 \cdot |R_{x_{\text{reader}}}[\tau - T_{\text{delay}}]|^2 \tag{32}$$

The wanted time delay T_{delay} is evaluated by searching for the the maximum within the term $|x_{\text{reader}}[t] \cdot \Delta y_{\text{reader}}[t]|^2$:

$$T_{\text{delay}} = \underset{\tau}{\text{argmax}} \left\{|a|^2 \cdot |R_{x_{\text{reader}}}[t - T_{\text{delay}}]|^2\right\} \tag{33}$$

By receiving T_{delay} the distance d between reader and tag can be calculated by evaluating Equation (25) with

$$d = \frac{1}{2} \cdot c \cdot T_{\text{delay}}. \tag{34}$$

Multipath fading and receiver noise corrupt and distort the distance estimation. Gaussian noise on the low-power signals can be suppressed through coherent integration at the receiver. However, the increase in SNR due to integration is at the cost of receiving time [46]. The effect of multipath fading is more severe as it distorts the measurements in a way that is non-predictable without any a priori knowledge of the channel, which is given for a localization system working without channel prediction. The deployment of high-gain (low beam width) antennas with an electronic beam former can reduce the amount of multipath fading to an acceptable level.

4. Challenges and limitations

This section reveals the limitations and challenges of the proposed UHF RFID positioning system. Theoretical calculations show an accuracy limit at around 1 cm with the given hardware and signal limitations.

4.1. Limitations

The limitation of the system regarding the accuracy can be estimated using the Cramér-Rao Lower Bound (CRLB) [49], which defines a lower bound for an unbiased estimator $\hat{\theta}$. This means that the unbiased estimator of θ is always worse or equal to the CRLB. For an unbiased estimator $\hat{\theta}$ the standard deviation $\sigma_{\hat{\theta}}(\theta)$ is defined as [50]:

$$\sigma_{\hat{\theta}}(\theta) \geq \sqrt{\mathrm{CRLB}_{\hat{\theta}}(\theta)} \tag{35}$$

Estimating the time-of-flight corresponds to the following CRBL definition of the standard deviation σ_x of the localization, i.e., the precision [50, 51]:

$$\sigma_x \geq \frac{c}{2\pi \cdot B_{RMS} \cdot \sqrt{2 \cdot \mathrm{SNR}}} \tag{36}$$

$c$describes the propagation speed, SNR is the signal-to-noise ratio and B_{RMS} is the effective bandwidth of the signal used and is defined as

$$B_{RMS} = \int_B f^2 |S(f)|^2 \mathrm{d}f \Big/ \int_B |S(f)|^2 \mathrm{d}f \tag{37}$$

with the Fourier transform of the signal $S(f)$ over the signal bandwidth B.

As the CRLB states in Equation (36), possible increases in precision are possible by either increasing the effective bandwidth of the signals or increasing the signal-to-noise ratio. If the given bandwidth is fixed, only an increase in SNR results in a higher measurement precision. As stated earlier, the SNR is increased by performing coherent integration. For instance, integration over $n = 10{,}000$ signals, results in an SNR increase of factor 10,000, but only in a precision increase of $\sqrt{10{,}000} = 100$. Theoretically, it is possible to increase the SNR as high as wanted, but receiver restrictions and timeouts limit the SNR to a certain level. These restrictions, mainly due to phase and quantization noise, define the limitations or the lower bounds of the localization system to a certain precision.

The applied hardware setup delivers the following SNR values for the quantization and phase noise. Thus, the receiver has an quantization error leading to an SNR of

$$\mathrm{SNR}_{\mathrm{quantization}} \approx 50 \ \mathrm{dB} = 10^5, \tag{38}$$

and phase noise leads to an SNR of

$$\mathrm{SNR}_{\mathrm{phase}} \approx 34 \ \mathrm{dB} = 2{,}512. \tag{39}$$

The total SNR is defined as

$$\frac{1}{\mathrm{SNR}} = \frac{1}{\mathrm{SNR}_{\mathrm{quantization}}} + \frac{1}{\mathrm{SNR}_{\mathrm{phase}}} + \frac{1}{\mathrm{SNR}_{\mathrm{signal}}}. \tag{40}$$

$\mathrm{SNR}_{\mathrm{signal}}$ is the power of the signal to the Gaussian noise power at the receiver. Figure 7 shows the maximum precision σ_x over certain $\mathrm{SNR}_{\mathrm{signal}}$ values and coherent integrations with a factor of n. The effective bandwidth of the signal is given with $B_{RMS} = 36.66$ MHz. The SNR values and the effective bandwidth are derived from the receiver properties and the shape of the transmit pulse. Also, the factor one-half is considered due to half of the distance from tag to reader that reduces the precision σ_x in Equation (36) by a factor of 0.5.

As from Figure 7, it is shown that the lower bound for the standard deviation is around 1 cm. By increasing the number of coherent integrations n, the bound can be shifted to the left, which means, that the lower limit of the precision is reached for a lower $\mathrm{SNR}_{\mathrm{signal}}$ value. For the proposed system, one measurement takes 1 μs, which increases to 1 s, if the coherent integration factor is $n = 1{,}000{,}000$.

4.2. Challenges

Challenges this localization system is facing are mainly:

- Multipath fading
- Non-constant tag reflection factors which vary by frequency and power

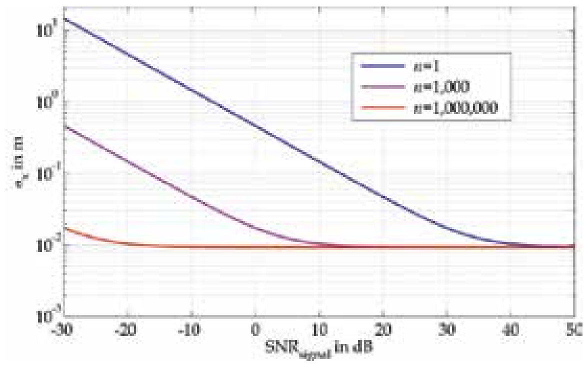

Figure 7. Cramér-Rao Lower Bound of the localization system

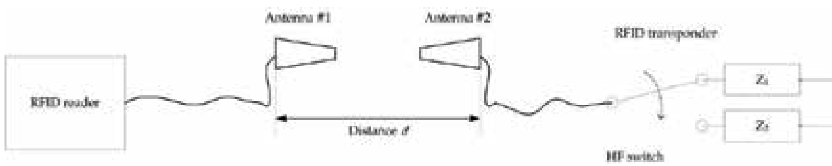

Figure 8. Measurement setup of RFID localization system

Multipath fading due to reflections, scattering and diffraction can be suppressed by using high-gain antennas with a high-focussed beam. Hence, electronic beam steering is necessary to cover the area to detect RFID tags. Using an omni-directional antenna avoids electronic beam steering at the cost of more multipath fading. Another alternative, to minimize multipath fading is the use of a much higher bandwidth. In future, UWB technology combined with RFID could have a major effect on improvements in positioning accuracy [52, 53].

The non-constant tag reflection factors that vary over frequency and power are able to strongly deteriorate the position estimation [16], if disregarded. One solution for this problem is revealed in [54].

5. Measurement results

This section shows the obtained measurement results. The first measurements are taken in an anechoic chamber, the second measurements are taken in an office environment. Both measurements are one-dimensional measurements.

5.1. Measurement setup

The measurement setup is given as in Figure 8. It consists of the reader unit as described in Section 3, an reader antenna (Antenna #1) and an RFID tag with tag antenna (Antenna #2) followed by a HF switch for emulating the tag modulation states with impedances Z_1 and Z_2. For the sake of simplicity Z_1 and Z_2 are chosen as *Short* and *Open*, i.e., $Z_1 = 0\ \Omega$ and $Z_2 = \infty\ \Omega$.

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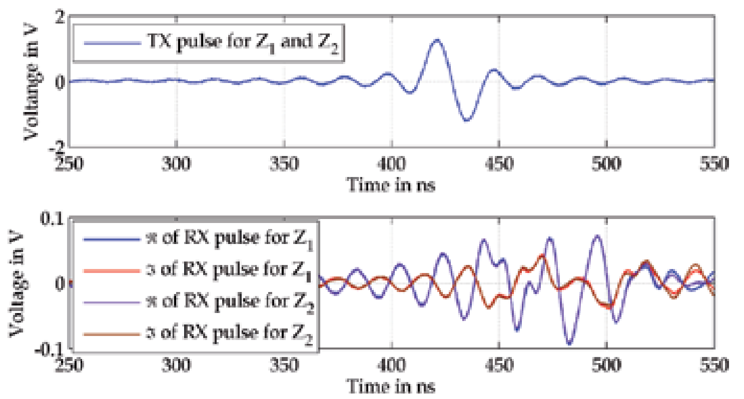

Figure 9. Exemplary transmit (TX) and receive (RX) pulses of the reader for Z_1 and Z_2, divided in real (ℜ) and imaginary (ℑ) signal components for an antenna to antenna distance of $d = 100$ cm

The measurement procedure is as follows. The HF switch toggles to impedance Z_1. Subsequently, the reader transmits and receives its signals as shown in Figure 9. Then, the switch toggles to Z_2 and, again, the reader transmits and receives its signals. Dependent on the number of coherent integrations, this procedure is repeated up to n. Finally, the sampled signals are evaluated in MATLAB. Figure 9 displays the transmit and receive signals for a given setup (anechoic chamber at a distance of 100 cm). The upper half of the figure shows the transmit signal – based on the Barker code [+1,-1] – used for both modulation states, Z_1 and Z_2. The lower half of the figure indicates the received signals for Z_1 and Z_2, respectively. As the received signals are complex-valued, real and imaginary parts are depicted for each RX signal. As seen in Figure 9, the received signals match each other for a certain period of time, until the difference in reflection (of Z_1 and Z_2) emerges (beginning at around 500 ns). These signals are used to determine the time shift between TX and RX signal and thus the distance between reader and tag. Evaluations of the correlations can be found in [48, 55].

The following two subsections show the measurement results, i.e., the result of the correlation difference, for two environments. First, a measurement in an anechoic chamber (Figure 10, left), second, a measurement in an office environment (Figure 10, right).

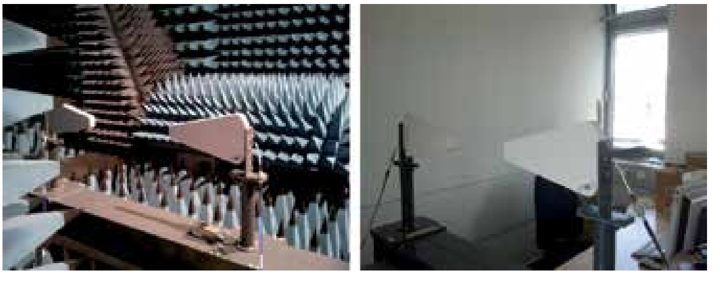

Figure 10. Measurement environments; left: anechoic chamber, right: office

5.2. Anechoic chamber measurements

The results of the measurement carried out in an anechoic chamber are depicted in Figure 11. The x-axis describes the real distances between the antennas, the y-axis describes the estimated distances. For normalization (cables, amplifiers, etc.) issues, the system is range-normalized to a distance of d =90 cm (measurement with lowest variance). The coherent integration factor was chosen to be n=100, i.e., each location was measured once with 100 transmit signals coherently integrated. The total RMSE error is 1.74 cm, which is the accuracy for a measurement distance from 80 cm to 280 cm. The fitting line in Figure 11 describes the regression line of the estimated distances. Hence, we can state that the system performs in the expected error ranges under very low multipath conditions.

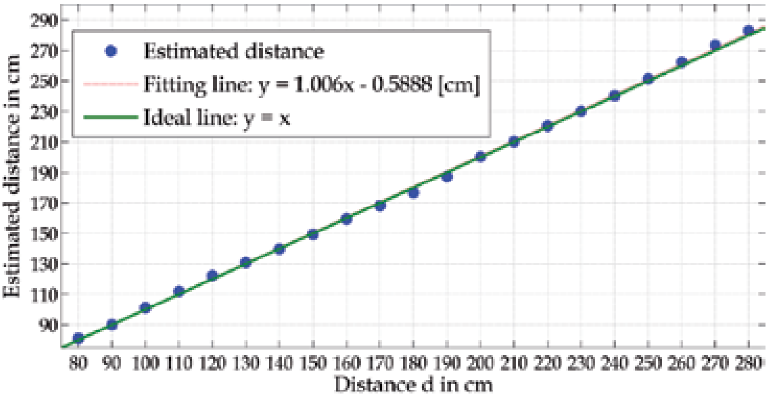

Figure 11. Results of the measurement carried out in anechoic chamber

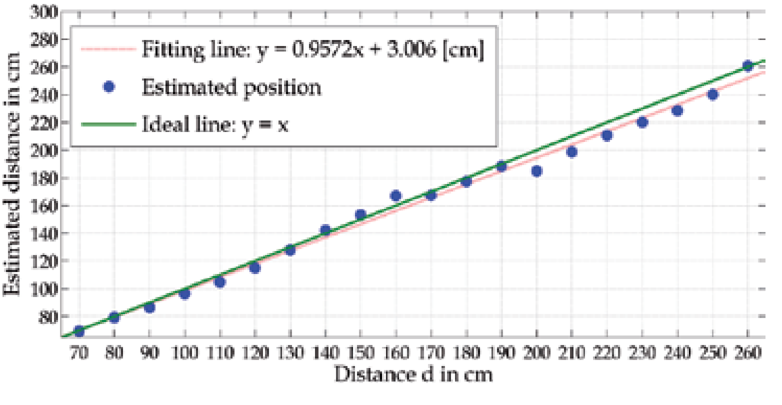

Figure 12. Results of the measurement carried out in an office environment

5.3. Office measurements

The results of the measurement carried out in the office environment are shown in Figure 12. Again, the x-axis describes the real distances between the antennas, the y-axis describes the estimated distances. The system is normalized to the distance of $d = 90$ cm, performed in the anechoic chamber. The coherent integration factor was chosen to be $n = 100$. The total RMSE error is 6.82 cm, which is the accuracy for a measurement distance from 70 cm to 260 cm. The fitting line describes the regression line of the estimated distances. The estimated values describe a nearly linear relation from 70 cm to 190 cm. The following estimated values are around 10 cm below the ideal line, the estimated value at the distance of 260 cm is back on track regarding the ideal line.

6. Result and discussion

The above measurements show that it is basically possible to gain range information down to accuracies of a few centimeters from the different modulation states of UHF RFID tags using wideband signals. However, there exist some simplifications, including the high-gain antennas and the tag modulation impedances given with open and short circuit (see also Subsection 5.2).

The idea behind the introduced localization system is based on the fact that current RFID-based localization systems either need a high effort in pre-calibration phases, suffer from bandwidth limitations, particularly in small frequency bands, e.g., as in Europe or need more complex hardware structures (phased array antennas) that only may be used in stationary, immobile applications. Therefore, a passive RFID-based positioning system should have ideally (Section 3) no change in hardware, high bandwidth, no pre-calibration phases and should be used in mobile applications. The suggested system includes these issues in the following way. There is no pre-calibration phase necessary as the system uses direct range estimation. This, however, is only possible due to the high bandwidth used along with low-power signals to stay within the required power spectrum densities. Changes in hardware would incorporate high bandwidth filter structures, a fast signal generator for the transmit pulses and a high accurate A/D converter for the incoming signals. Finally, it can be stated that such a localization system for mobile indoor positioning is possible, if the required hardware prerequisites are created.

7. Summary and conclusion

This chapter dealt with the concepts of localization comprising primarily UHF and microwave RFID systems. After describing the fundamental principles behind localization, a survey was given for state-of-the-art RFID localization systems. Subsequently, a novel RFID localization system using wideband signals was introduced. A theoretical derivation of the range determination was given in Section 4, whereas Section 5 revealed the limits and challenges of the proposed localization system, e.g., through evaluation of the Cramér-Rao lower bound.

Finally, measurement results carried out in different environments (anechoic chamber, office) showed that the proposed system works within the former deduced limitations. The measurements showed a one-dimensional accuracy (RMSE) of 1.7 cm in the anechoic chamber, and an accuracy (RMSE) of 6.8 cm within the office environment. Tag reflection normalization and the usage of omni-directional antennas along with real-time localization are subjects to future work.

Acknowledgements

The authors would like to thank their colleagues from the Chair of Information Technology as well as from the Fraunhofer Institute for Integrated Circuits. Special thanks to our colleagues Frederik Beer, Gerd Kilian and Hendrik Lieske from the telemetry group for their valuable feedback.

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Chapter 6

Integrating RFID with IP Host Identities

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53525

1. Introduction

The "Internet of Things" semantically means ''a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" [1]. The vision describes a world that enables physical objects to act as nodes in a networked physical world [2]. The terms ''Internet of Things" can be attributed to The Auto-ID Labs, a world-wide network of academic research laboratories in the field of networked RFID and emerging sensing technologies [2]. Together with EPCglobal®, these institutions have been architecting the Internet of Thing since their establishment. Their focus has primarily been on the development of the Electronic Product Code™ (EPC) to support the wide-spread use of RFID in modern, global trading networks, and to create an industry-driven set of global standards for the EPCglobal Network.

EPCglobal Network was created for "traditional" low-cost tags [3]. The main functionality of the EPCglobal Network is to provide data assigned to a specific tag, so that each RFID read event can be stored in a database and applications can be built on this data. Since tags were not originally considered to carry or compute additional data, the EPCglobal Network does not traditionally provide a mechanism to address remote tags from networked applications.

The data flow in these networks works from tags via readers to a couple of networked servers. Passive, low-cost RFID tags are widely available and the EPCglobal Network was defined to support open-loop supply chain applications. Basically, this is accomplished by allowing servers to communicate over the Internet. Although RFID technology is quite accepted in closed-loop applications, the evolution towards open-loop systems using the EPCglobal Network with distributed databases did not take place as predicted due to problems in the access control layer of such systems.

RFID-sensor networks are an emerging part of the Internet of Things [5]. These devices combine sensing capabilities with an RFID interface that allow the retrieval of sensed data. In fact, they can cooperate with RFID systems to better track the status of things e.g., their location, temperature, movements, etc. A sensor-enabled RFID tag (also known as sensor-tags) is an RFID tag which contains one or more sensors to monitor some physical parameter (e.g., temperature) but also contains the same identification function as a "normal" RFID tag does. This kind of sensor tag may fall into class 2, class 3 or class 4 in EPCglobal's tag classification [3]. A fully passive, class 2 sensor-tag can measure physical parameters, i.e., use sensors, only when powered by a reader. In contrast, class 3 tags are battery assisted. They can work independently of the reader and can be suitable for RFID-sensor networks.

In this chapter, we will discuss different ways to achieve the Internet of Things vision by internetworking passive RFID tags over IPv6. The chapter is organized as follows: Section 2 presents related works and discusses the novelty of the work presented here. Section 3 introduces the key technologies for the convergence of RFID and Internet namespaces and to provide an address mapping needed to internetwork passive RFID tags. In Section 4, some common examples of RFID usage are given and discussed in the context of globally networked tags. Subsequently, Section 5 introduces a testbed built to study the interconnection of passive RFID tags over IPv6. The different strategies that can be used for integrating RFID with IPv6 are discussed in Section 6 and this discussion is followed by mobility considerations in Section 7. Finally, Section 8 concludes the discussion and outlines anticipated future work in this area.

2. Related works

Most objects in our surrounding are not equipped with microprocessors and hence cannot attach to a computer network. However, these objects can be equipped with passive, low-cost RFID tags either as tags integrated or adhesively stuck to the object and hereby provide a mean of communications. Dominikus et al. [14] has suggested a way to integrate passive RFID systems into the Internet of Things, by using readers that function as IPv6 routers. In their work, an IPv6 addressing scheme that map tag IDs to network addresses was defined. Furthermore, the mobility problem, which arises when tags physically moves around, was investigated and the use of Mobile IPv6 (MIPv6) to cope with tag mobility was suggested. In contrast to the work presented by Dominikus et al. [14], this chapter opens the discussion on the proper formatting of the IPv6 addressing by introducing cryptographic hashing techniques as well as the possibility of separating identity and location information when forming an IPv6 address. The use of hashing techniques to construct an IPv6 address from an EPC, as opposed by using a compressed EPC format [14], eases practical implementations and allows the use of the same mapping scheme for all EPC types.

An alternative approach is to provide the tags themselves with the IPv6 protocol stack, making them able to use IPv6 communication over the Internet whenever close to a reader. This requires several changes to the design of existing tags. In this case, the tags do all the work themselves and need a separate power source. A solution where the tags are modified to hold the IPv6 stack on them is discussed by Rahman et al. [4]. The tags EPC, which is its identity, would then be made into a part of the tags IPv6 address due to the design of the tags proposed. This makes these tags too expensive for integration into the Internet of Things since the price of the tags could easily exceed the value of the “things” themselves.

Barish et al. [13], describes a somewhat similar setup than the one proposed here. In their approach, a global address manager is used to keep track of tags. The basic idea is that an application sends the EPC to a global server along with the IP address that the tag has been associated with. When a corresponding node wants to communicate with the tagged object, it contacts the last known address. If the tag is in the field of the reader the connection is established and communication can begin. If the tag is not present at the location the request is redirected to the global address server that returns the tag’s present address or just redirects the request to the correct address. In contrast to the proposed solution by Barish et al. [13], the approach described here does not include extra nodes in the network to construct network addresses but adds functionality to the RFID readers residing at the network edge.

Xu et al. [25] proposed a general address mapping scheme based on a proprietary protocol named General Identity Protocol (GIP). The scheme takes all existing RFID systems into account, and allows heterogeneous RFID systems to interwork over the Internet. This is accomplished by mapping RFID tag identifiers to IPv6 addresses, constructing a GIP message with details of the RFID systems in use, and finally encapsulating the message in IPv6 and routing the packet over the Internet. This chapter describes a solution that minimizes the need for control protocols.

3. Enabling technologies

There are a couple of ways to interconnect objects by using RFID with IPv6 [6]. One solution would be to give the tags the ability to communicate via the Internet. The communication can be both reader-initiated and tag-initiated. The latter requires specific tags that require electrical and processing power to be available in the tag such as e.g., EPC class 3 tags. Most of the computational work takes place in the tags, i.e., the tag is reachable and visible as an IPv6 connected host as long as it is within the electric field of a reader.

Passive RFID tags, such as EPC class 2 tags, do not have the possibility to power a network protocol stack and therefore a network address cannot be directly assigned to the tag’s microchip. However, the passive tag can be represented by virtual interfaces residing in the reader interrogating the tag.

3.1. Radio Frequency Identification (RFID)

RFID systems are composed of one or more readers and several electronic tags. Tags are characterized by a unique identifier that takes the form as a binary number. They are applied to objects and even persons or animals as implants. From a physical point of view, an

RFID tag is a small microchip attached to an antenna that is used for both receiving the reader signal and transmitting the tag ID. The dimensions of each tag can be very small with tag dimensions down to 0.05 mm x 0.05 mm with a thickness of 0.005 mm [7]. There are more than 60 tag manufacturers world-wide [8].

RFID tags will act as electronic identification for physical objects to which they are linked. In the Internet of Things, all objects, virtual as well as physical, are interconnected and reachable via for example IPv6 in combination with RFID technology [6]. Essentially, the tag connects to physical objects that we want to authenticate and track when they come in contact with readers. A reader can read or modify tag's information. The back-end database keeps information related to different tags/readers.

For reader-initiated communication the reader triggers the tag's transmission by generating an appropriate signal, which represents a query for the possible presence of tags in the surrounding area and for the reception of their identification codes (IDs).

Active tags come with a power source that can drive a microprocessor (or microcontroller). Furthermore, it allows a stronger electromagnetic field to be generated in response to an incoming RFID air protocol message and larger read distances can be achieved. More advanced active tags or sensor-tags may run additional software and can be equipped with communication software such as an IP protocol stack [9].

In contrast, passive tags rely on the incoming electromagnetic field from the reader to power the circuit and to deliver power to drive the response to an interrogating request. These devices do not run communication software and cannot be actively involved in a protocol message exchange. To communicate with these devices there is a need for software agents to act on their behalf.

RFID tags can only be "online" when they are in the electric field of a reader field. For high velocity applications, where tags only remain certain seconds in a reader field, the proposed approach of networking these tags is not applicable.

3.2. RFID namespaces

Essentially, RFID comes with two namespace to be used with RFID applications: the EPC addresses and the Object Name Service (ONS). A namespace can represent objects as well as concepts and may be generalized as a container for a set of identifiers (names). The EPC is an identifier based on the standards established by EPCglobal® [10]. It is designed to allow the automatic identification of objects anywhere. EPC defines three layers of identity: the *pure* identity, the encoding layer identity and the physical realization of an encoding. The EPC tag data standard [10] identify how existing coding systems such as the GS1 family codes for serialized human readable representations e.g. GTIN, GCN, SSCC, GRAI, GIAI, GSRM, GDTI and a small number of other identities should be embedded within the EPC.

A canonical representation of an EPC is the *pure identity* Uniform Resource Indicator (URI) representation, which is intended for communicating and storing EPC in information systems, databases and applications. The purpose is to insulate EPCs from knowledge about the physical nature of the tag, so that although 64-bit tags may differ from 96-bit tags in the choice of binary header values and in the number of bits allocated to each element or field within the EPC, the pure identity URI format does not require the information system to know about these details. Hence, the pure identity URI can be regarded as a pure identifier [10]. Tags are identified by URIs such as e.g., urn:epc:id:sgtin:0523141.000024.120 that comprise both tag number and associated coding scheme.

Encoding is the process of translating the pure identity EPC into a specific instantiation incorporated into tags for a specific purpose. During the encoding process the URI information is translated into a binary encoding that is stored in the tag. Subsequently, translating between the different levels of representation can be accomplished in a consistent way.

Figure 1 shows the structure of the data layout of an EPC code for the Global Trade Item Number (GTIN) and Serialized Global Trade Item Number 96-bit (SGTIN-96) tag.

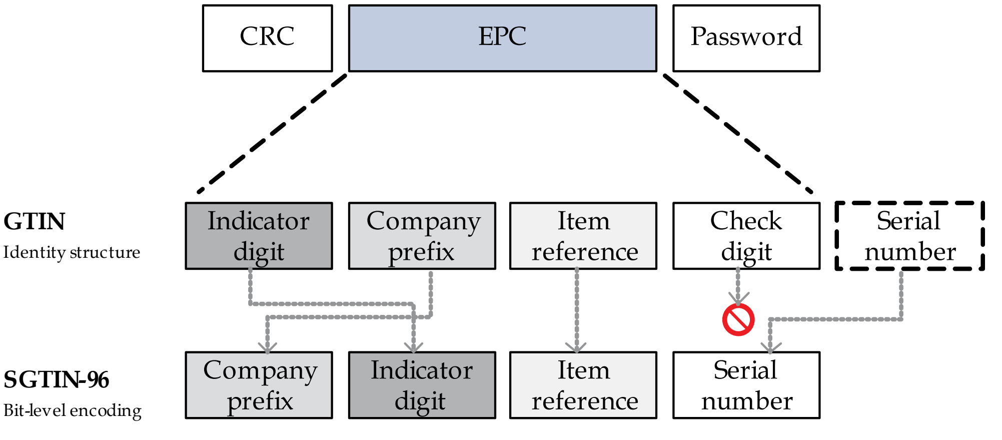

Figure 1. Tag data layout example.

EPC generation 1 standards, i.e., class 0 and class 1 tags, use a Cyclic Redundancy Check (CRC) to verify data integrity and a password as a "kill code" to disable the tags. The password must never be transmitted under any circumstances [3]. The *Item reference* identifies a class of objects to be tagged and it allows the grouping of items. The *Serial number* identifies an instance of a particular item. Company prefixes (also known as General Manager Numbers) point to the organization responsible for the subsequent partition. Finally, *Indicator digits* are used to specify length, type, structure, version, and generation of the EPC. This latter part is further used to guarantee uniqueness in the EPC namespace. For the GTIN encoding a *Check digit* is used.

Since the EPC is the only required data stored on a tag, it must be used as a "pointer" to find additional data about an object to which it attaches. This additional data should be stored on a server connected to the enterprise network or to the Internet. The server is identified via a look-up system which is called ONS.

ONS acts as a directory service for organizations wishing to look up product numbers (also known as EPC numbers) on the Internet. The ONS is operated as part of the EPCglobal Network. It is based on the well-known DNS service and it realizes the link between EPC numbers and EPC Information Services (EPCIS) as illustrated in Figure 2. When an RFID reader reads a tag, the EPC is passed to a middleware which then looks the EPC up either on the local machine, or enquires ONS through the Internet.

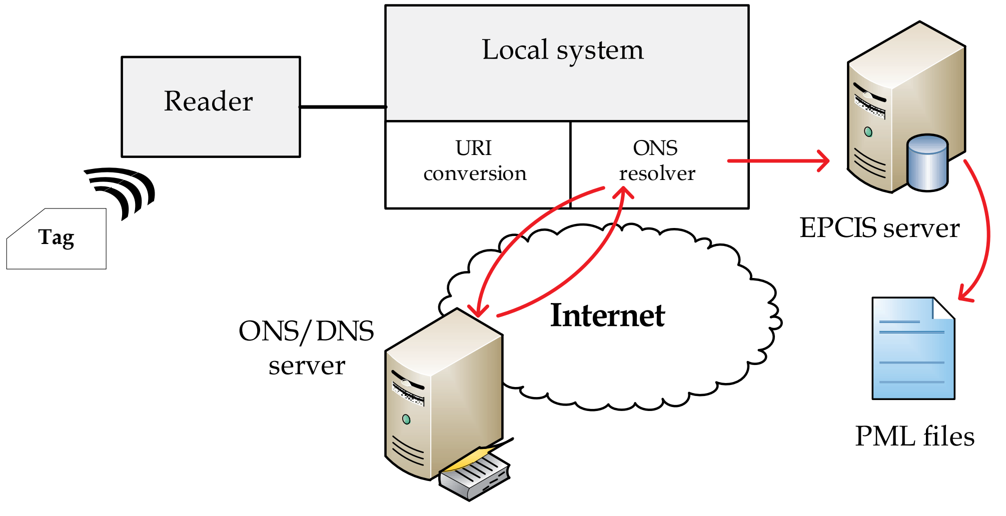

Figure 2. The Object Name System (ONS). Adapted from [11].

The ONS resolution process takes the EPC code and returns network location(s) where information resides, i.e., the EPCIS server, which typically holds web pages with information about tags. The Physical Markup Language (PML), based on XML technology, is intended to be the standard in which information about tags should be written.

In contrast, the DNS of the Internet will handle many more requests in the future. Therefore, enterprises will likely maintain ONS servers locally, which will store information for quick retrieval. Hence, a manufacturer may store ONS data from its current suppliers on its own network, rather than pulling the information off a Web site every time a shipment arrives at the assembly plant.

3.3. Internet namespaces

There are two principal namespaces in use in the Internet: IP addresses and domain names. Domain names provide hierarchically assigned names for some computing platforms and some services. Each level in the hierarchy is delegated from the level above. Email, Hypertext Transfer Protocol (HTTP), and Session Initiation Protocol (SIP) addresses all reference domain names to mention its most wide-spread use.

On the network layer, IP addresses are used. IPv6 was introduced in the 90'ies due to the foreseen lack of globally unique IPv4 addresses, resulting in a protocol specification released in 1998 [17]. The IPv6 address is a 128-bit address that takes the form of a 64-bit network prefix appended by a 64-bit host suffix/interface identifier. The network prefix is used for routing purpose and determines the location of the host in the Internet. The host itself is identified by an interface ID. Figure 3 shows the IPv6 address format and gives an example on how a 96-bit EPC can be mapped to a network address.

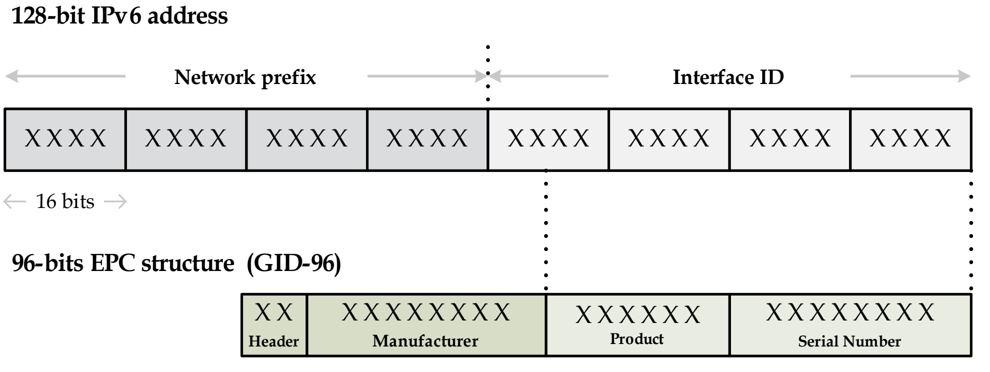

Figure 3. IPv6 address format compared to a 96-bit General Identifier (GID-96) EPC format. An 'X' indicates a grouping of 4 bits.

It can be observed form the figure that not all 96 bits of the EPC can be fitted within the host suffix/interface identifier of an IPv6 address. Because of this deficiency, the implementers of an RFID-to-IPv6 mapping scheme is faced with a number of design options. These options basically govern the strategy for the mapping and are the subject of our discussion in Section 6.

3.4. Cryptographically generated addresses

Cryptographically Generated Addresses (CGAs) are IPv6 addresses for which the host suffix/interface identifier is generated by computing a cryptographic one-way hash function from a binary input such as e.g., a public key [27]. CGAs are intended to be globally unique in a statistical sense but these may not necessarily be routable addresses at the IP layer [12].

The Overlay Routable Cryptographic Hash Identifiers (ORCHID) is a new, experimental class of identifiers based on CGAs. ORCHIDs have an IPv6-like address format and can be used with existing applications built on IPv6 [12]. These identifiers are intended to be used as pure endpoint identifiers for applications and Application Programming Interfaces (APIs) and not as identifiers for network location. This is in contrast to the IPv6 address that uses the 64-bit network prefix as locator [17].

While ORCHIDs use public cryptographic keys as input bit strings, it is possible to use the binary EPC encoding instead. The algorithm to generate an ORCHID in an RFID context is outlined below [12]. The algorithm takes a bitstring and some *context identifier* as inputs and produces an ORCHID output that is formatted as an IPv6 address.

$$Input := anybitstring \tag{1}$$

$$HashInput := ContextID \mid Input \tag{2}$$

$$Hash := Hash\_function(HashInput) \tag{3}$$

$$ORCHID := Prefix \mid Encode_n(Hash) \tag{4}$$

Concatenation of bitstrings is denoted '|'. The *Input* is a bitstring that is unique within a given context. The *Context ID* is a randomly generated value defining the expected usage context for the particular ORCHID and the hash function to be used for generation of ORCHID in this context. The purpose of a context ID is to be able to differentiate between various experiments that share the ORCHID namespace. The *Hash_function* is a one-way hash function to be used to generate ORCHIDs such as SHA1 [23] or MD5 [24]. SHA1 and MD5 produce a 160-bit and a 128-bit output, respectively. $Encode_n$ is a function to extract an n-bit-long bitstring from its argument. Finally, *Prefix* is an IPv6 network prefix.

To construct a CGA an input bitstring and context identifier are concatenated to form an input datum, which is then fed to the cryptographic hash function. The result of the hash function is processed by an encoding function, resulting in an n-bit-long output. This value is prepended with the network prefix resulting in a 128-bit-long bitstring identifier that can be used for programming with the IPv6 API.

To create a CGA namespace for RFID tags the EPC of a tag and the network prefix assigned to the reader that interrogates the tag are used as input. Furthermore, an Encode_{64} function is used to extract 64 bits from the hash. A key advantage of using hash values over the actual raw host identity resulting from the EPC is its fixed length. This makes protocol implementations easier and it alleviates the management of packet sizes. However, a claimed drawback is that CGAs work one-way, meaning that it is not possible directly to create the original identity from the hash.

A CGA can be globally unique or globally unique in a statistical sense. That is, the probability of the same CGA being used to refer to different entities in the Internet must be sufficiently low so that it can be ignored for all practical purposes. Even though CGA collisions are expected to be extremely rare, collisions may still happen since it is possible that two different input bitstrings within the same context may map to the same CGA. A second type of collision can happen if two input bitstrings, used in different contexts, map to the same CGA. In this case, the main confusion is about which context to use. In order to preserve a low enough probability of collisions, it is required that applications ensure that distinct input bitstrings are either unique or statistically unique within a given context. By adhering to the EPCglobal standards, this requirement is fulfilled.

3.5. Host identities and host identity protocol

A host identity is an abstract concept assigned to a computing identity platform. In this section, we will generalize this concept to cover thin compact platforms that can be equipped with RFID tags. The discussion starts by introducing the host identities and the host identity protocol [15][16].

The Host Identity Protocol (HIP) supports an architecture that decouples the transport layer (TCP, UDP, etc.) from the internetworking layer (IPv4 and IPv6) by using public/private key pairs, instead of IP addresses, as host identities [15][16]. The public keys are typically, but not necessarily, self-generated. HIP introduces a new Host Identity (HI) namespace, based on these public keys, from which end-point identifiers are taken. Host identifiers are used to bind to higher layer protocols instead of binding to IP addresses. A key benefit of this approach is that it is compatible with existing APIs such as the socket API. HIP uses existing IP addressing and forwarding for locators and packet delivery, respectively.

Figure 4 illustrates the difference between binding of the logical entities service and end-points to an IP address (left side of figure). The service typically binds to the IP stack via the socket API. By using the host identity abstraction of the HIP architecture, the service and the end-point bind to the host identity whereas the location is still anchored with the IP address.

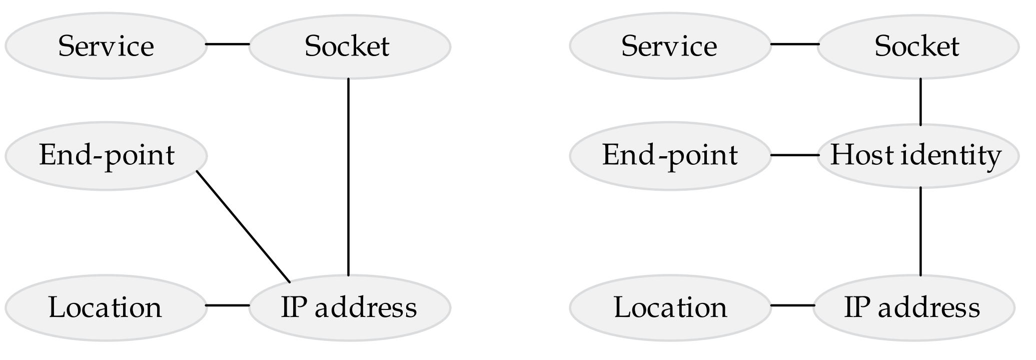

Figure 4. Illustration of the difference between the bindings of the logical entities. Adapted from [15].

There are two main representations of the host identity, the full Host Identifier (HI) and the Host Identity Tag (HIT). The HI is a public key and directly represents the identity. The HIT is the operational representation of a host. It has a 128-bit long representation and is used in the HIP payloads to index the corresponding state of the end hosts. By introducing an identity concept at the network layer, where every host is represented by an asymmetric key pair consisting of a public and private key, it turns IP addresses into pure locators.

The proposed HI namespace fills an important gap between the IP and DNS namespaces. A public key is used as the HIP Host Identity (HI), while the private key serves as proof of ownership of the public key. To seamlessly integrate HIP with protocols above the network layer, a 128-bit cryptographic hash of the HI, i.e., the HIT, was introduced to fit the IPv6 address space. The HIT is a statistically unique flat identifier. When HIP is used, the transport layer binds to HITs. In this process it becomes unaware of the IP addresses that are used for routing.

To be able to setup communication between peers that use HI, a light-weighted protocol exchange called the HIP Base Exchange has been specified. In Figure 5, the HIP Base Exchange is adapted to an RFID setup. The setup is somewhat similar to the one presented by Urien et al. [11].

Since the deployed tags are passive, there is a need for a proxy to act on behalf of the tags in the protocol exchange. The role of this proxy will be explained further in Section 5.

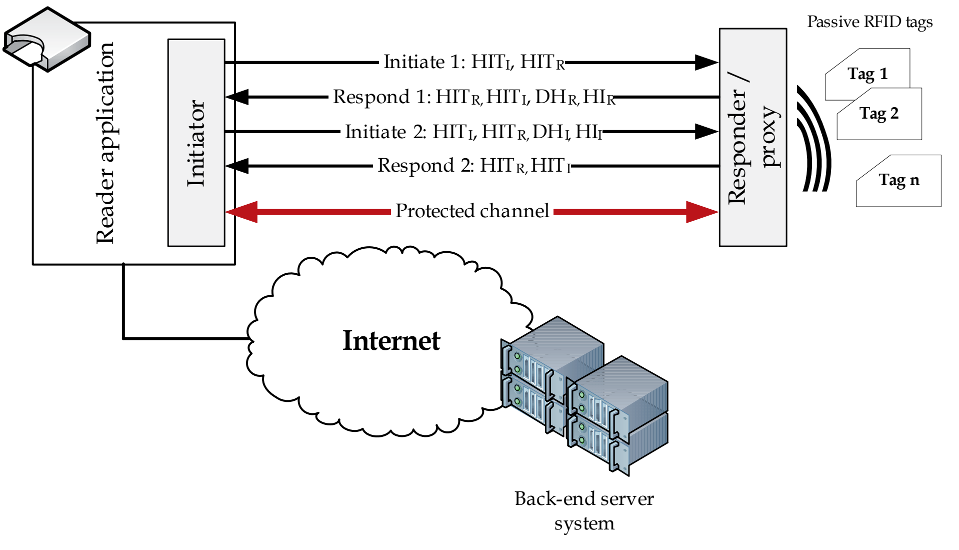

Figure 5. HIP Base Exchange adapted to a RFID communication scenario. Adapted from [15].

The HIP Base Exchange is a four-way handshake between two hosts wanting to initiate communication (see Figure 4). The *Initiate 1* packet is the first packet sent in the handshake. It is an unencrypted and unsigned packet, meaning that the Initiator would like to talk HIP with the Responder. The HIP packet contains the HIT of the Initiator (HIT_I) and the Responder (HIT_R). The responder's IP address can be derived from the DNS. *Respond 1* is sent as a reply to the *Initiate 1* packet. Besides the HIT_I-HIT_R identity pair, it contains a cryptographic puzzle challenge, and Diffie-Hellman parameters (DH_R) for the Diffie-Hellman key agreement. The Diffie–Hellman key exchange method allows two parties that have no prior knowledge of each other to jointly establish a shared secret key over an insecure communication channel. Subsequently, the secret key can be used for encryption and integrity protection of the communication channel. The purpose of the HIP puzzle mechanism is to protect the Responder from denial-of-service attacks. The *Initiate 2* packet returns the corresponding Diffie-Hellman parameter (DH_I) to the Responder. It carries an encoded solution to the puzzle.

Upon reception of the *Initiate 2* packet, the responder can now generate the keying material, and it is capable of using it in encryption and integrity protection algorithms. The Response 2 packet completes the HIP Base Exchange. After the Base Exchange, there is no longer difference between the Initiator and Responder and data can securely be exchanged between the communicating peers.

4. Use cases and application examples

RFID applications are numerous and far reaching [8]. The most interesting and widely used applications include those for security and access control, supply chain management, and the tracking of important objects and personnel. This section outlines a number of commonly encountered use cases for RFID technology, and discusses these in the context of networked RFID tags.

4.1. Access control

Access control systems are an important part of the security of government buildings, companies, schools, residences and private areas and RFID technology has been widely adopted in access control systems. These systems often use RFID identification cards based on the IEC/ISO 14443 [18], IEC/ISO 15693 [19], or IEC/ISO 18000 standards [20]. The identification cards work much like a traditional key for unlocking doors or otherwise granting access. However, RFID technology does not provide authentication to the holder of the RFID card (or tag). Any unauthorized people holding an authorized RFID card could get access to secured area. Therefore, RFID technology should be combined with other means of identification such as e.g., face recognition to strengthen the security of the access control system.

By associating a passive RFID tag such as a key card with a globally unique IPv6 address we will be able to use access control and security policy mechanisms with Internet technologies to provide the desired access control applications. In this scenario a door locking mechanism would be connected over the Internet resulting in a more open system architecture.

4.2. Supply chain management

Most supply chain applications involve the concept of inventory tracking. An example of a proposed use of RFID is to ensure safety in the supply chain [21].

To illustrate the potential of using network RFID tags with supply chain applications an example taken from the Tag Data Standard v1.6 issue 2 [10]. The example text is quoted below:

"… a shipment arriving on a pallet may consist of a number of cases tagged with SGTIN identifiers and a returnable pallet identified by a GRAI identifier but also carrying an SSCC identifier to identify the shipment as a whole. If a portal reader at a dock door simply returns a number of binary EPCs, it is helpful to have translation software which can automatically detect which binary values correspond to which coding scheme, rather than requiring that the coding scheme and inbound representation are specified in addition to the input value."

Each of the cases tagged will be given a unique IPv6 address when they enter the electric field of a reader. This process involves the extracting of the essential bitstring of the SGTIN identifier for each case. Likewise, the returnable pallet and the shipment as a whole will be given IPv6 addresses that can be built based on the GRAI and the SSCC, respectively. By using the assigned IPv6 unicast addresses it is possible to establish communication to individual cases as well as the pallet. However, it may be of less interest to address individual cases at this point in the supply chain but rather to address the ensemble of cases. By introducing multicasting at the network layer it can be possible to communicate with groups of cases on the pallet.

4.3. Object/asset tracking

Because moving objects can easily carry RFID tags, a common use is to track the movement of people and the information associated with them. By associating a particular tag's EPC with a global network address the task of tracking the object/asset become equivalent to locating a mobile host in the network. In general, this is a key challenge in mobility research and several solutions have been proposed [22][26], and this will be the subject of our discussion in Section 7. Another interesting use case can be applied to sensor-tags. When these sensor-tags connect to a network sensor data can be retrieved from the tag.

5. Networked RFID testbed

To study the internetworking of objects with passive RFID tags, a simple testbed has been built. The approach makes use of an RFID reader and an application that works as a proxy for the tags we wish to communicate with. The proxy is capable of making a virtual representation of the passive RFID tag on the Internet by creating a Virtual Network Interface (VNI) with an IPv6 address that can be attributed to each tag that comes within the electric field of a reader. Hence, the tags do not terminate IPv6 traffic directly but merely communicate with an entity which represents the tag (physical object) that we wish to communicate with.

The approach taken is software-oriented. The application runs as standalone but it can be embedded on the reader or it can be run on a computer local to the reader. The application receives the EPC of a tag attached to a physical object via the reader. The application then creates an IPv6 address from one of the mentioned methods. Hereafter, it is possible to route IP traffic to the particular Internet end-point. This will in effect make the application act as a proxy that for example can keep the most recently read tags "online". The solution gives a one-to-one mapping of physical objects to the virtual representations that are needed to communicate over the Internet.

Figure 6 illustrates the system implemented. In practice, the application host has a predetermined number of Virtual Network Interfaces (VNIs) installed. These interfaces work as the online virtual representation of the tag swiped at the reader. In other words, this is the interface the outside world can contact. In the testbed, the network interfaces are virtualized in a way similar to a loopback interface [17]. As the system works as a testbed the database is merely there as a logging service. In the future, it is planned to use the database as foundation for a local ONS. The corresponding node is there to illustrate possible communication over the Internet.

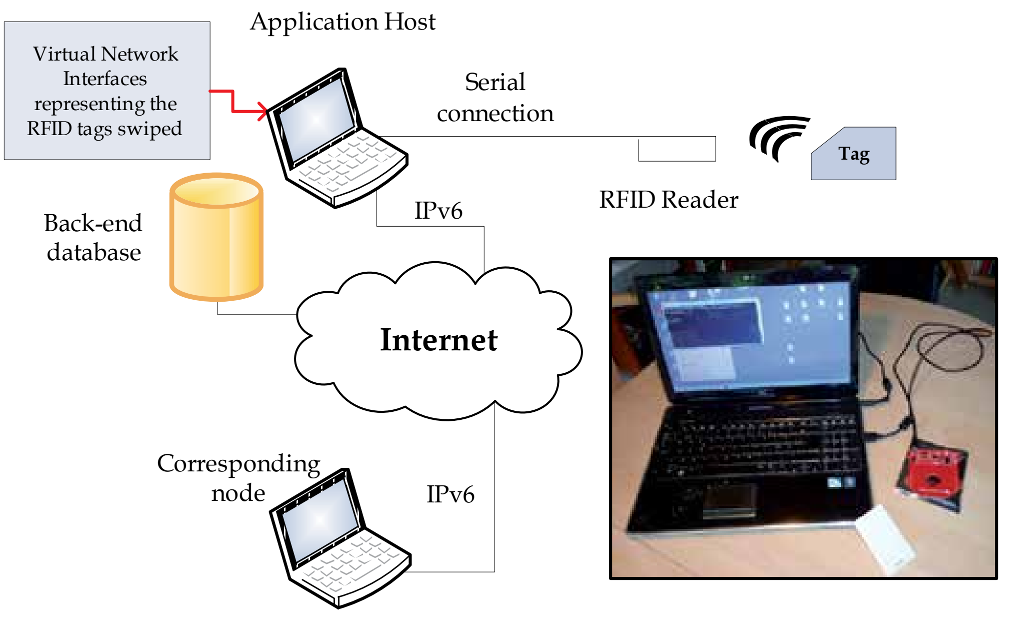

Figure 6. Simple setup to give RFID tags virtual identification on the Internet. A RedBee RFID Reader v1.1 is used. The application is built on the Microsoft®.NET connection software.

Figure 7 shows a state machine diagram for a single VNI resulting from a tag swiped in an access control application.

When the tag is swiped at the reader, the application host creates an IPv6 address by combining the network prefix configured at the reader with the tags identity as illustrated by the Example in Table 1. In the initial state, the software is waiting for a TagSwipe event to occur. Subsequently, the interface is put online with the address constructed, and it is kept alive as long the *expiration time* is greater than 0 (zero) seconds.

Tags are only reachable while they are within reader range. This makes it hard to communicate with the real tag, simply because it is only reachable for a short duration of time. When the tag's attachment to the network is virtualized it is possible to set up an expiration value. This value effectively serves as the time the tags virtual representation on the network can be reached.

The tag identity together with the constructed IPv6 address and a timestamp is stored on the database. Table 1 shows an example of the steps taken to construct an IPv6 address from an EM4100 tag ID.

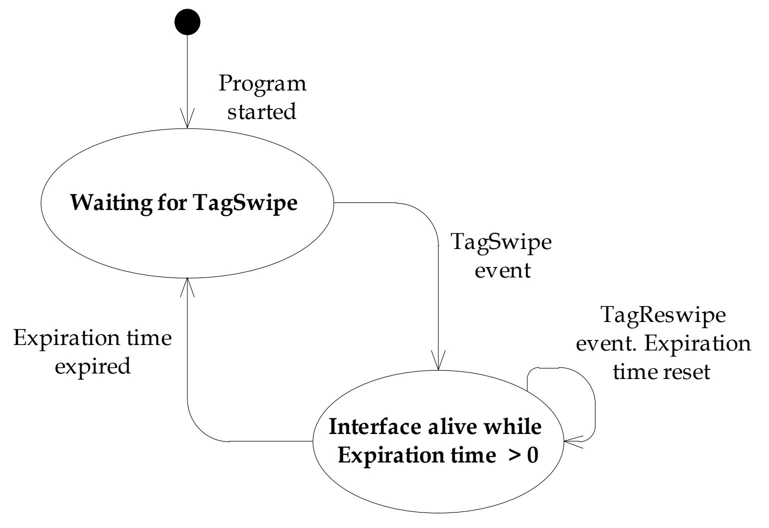

Figure 7. State machine for the virtual interface resulting from a TagSwipe event at the reader.

Tag identity (Example with EM4100 tag)	5 decimal numbers (40 bits)	127 0 58 207 19
Binary ID representation with left-zero-padding	64 bits	0000 0000 0000 0000 0000 0000 0111 1111 0000 0000 0011 1010 1100 1111 0001 0011
Converted to hexadecimal	4 groups of 4 hex. digits	0000 007f 003a cf13
Network prefix of RFID reader (example)	4 groups of 4 hex. digits	2001:16d8:dd92:aaaa::/64
Unicast IPv6 address associated with the tag	8 groups of 4 hex. digits	2001:16d8:dd92:aaaa::007f:003a:cf13/128

Table 1. Example of IPv6 network address construction from on EM4100 tag ID.

The application has no visual interface and all configurations must be done in software. For example, it is possible to use more than one virtual interface to represent the tags online. These interfaces need to be preinstalled, as already mentioned, and some parameters in the application need to be configured. Hereafter, it is possible to make use of at least 5 virtual interfaces.

Although focus is on the assignment of IPv6 unicast addresses, tags can also be assigned to become member of multicast groups thereby facilitating one-to-many communication. As an example an application may want to address all tags at a particular reader. Likewise, readers can become members of multicast groups hereby enabling communication to all readers

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in the multicast group e.g., a particular logical area. Details on how to operate an RFID in IPv6 multicast networks are beyond the scope of this chapter.

6. Strategies for interworking IPv6 with RFID tags

In this Section we will discuss different methods of mapping between an RFID namespace and an Internet namespace.

6.1. Address mappings

The most simple approach to find IPv6 addresses for tags is the mapping of the tag ID to an IPv6 address, i.e., the bits from the ID are used to form the IP address [14]. As different passive RFID standards exist there is no common ID structure for tags. Even within standards, there are different types of IDs with different structures. This means, that a general concept to map tag IDs to IPv6 addresses will not work.

Table 2 shows a list of some commonly encountered passive tags and their ID formats.

IC type	Frequency band	Memory	Standards compliance
EM4100 series	LF (125 KHz)	64 bits	EM4100. Proprietary standard issued by EM Microelectronics [28].
EM4450/4550	LF (125 KHz)	1024 bits	EM4450/4550. Proprietary standard issued by EM Microelectronics [29].
NXP Hitag family (Hitag 1, Hitag 2, Hitag S, Hitag µ)	LF (125 KHz)	256 bit to 2048 bit	IEC/ISO 18000-2 (Hitag µ) [20].
NXP Mifare family (Ultralight/ MF1S20/MF1S50/MF1S70/ DESFire EV1)	HF (13,56 MHz)	64 bytes to 4096 bytes 2K/4K/8K	ISO 14443A [18].
LEGIC Advant family (ATC128, ATC256, ATC1024, ATC2048, ATC4096)	HF (13,56 MHz)	128 bytes to 4096 bytes	IEC/ISO 15693 [19] (ATC128, ATC256, ATC1024), IEC/ISO 14443 A [18] (ATC 2048, ATC 4096).
NXP UCode HSL	UHF (868 MHz or 915 MHz)	2048 bit	ISO18000-4 and 18000-6B [20].
NXP UCode EPC Gen2	UHF (868 MHz or 915 MHz)	512 bit	EPCglobal class 1 gen2 and ISO 18000-6C [20].

Table 2. Common passive RFID tag and their characteristics.

An EPC with the length of 64 bits maps well in the IPv6 address format and can result in globally unique addresses. With longer EPCs it is impossible to map the EPC directly into the IPv6 address space and here specialized functions are needed. One solution would be to simply hash the longer EPC's into a length of 64 bits and then use the direct mapping method again. The hashing technique used to derive identifiers was described in Section 3.4, when the CGA namespace was introduced. Another method would be to identify if there are some bits in the longer EPC's that can be removed without affecting the uniqueness property of the tags.

A key benefit of the proposed solution is that there is no need to change the design of existing RFID technology with its EPC namespace conventions. The application can be installed on a computer connected to the reader, and then all objects with RFID tags that pass this reader will put the objects online and thereby giving them the ability to communicate over the Internet as long as the tag is within range of a reader.

	Strategy/method	Comments
Tag with ID of 64 bits or less	1. Use zero padding left-to-right to create a 64-bit input datum from the tag ID. Map this input to the host suffix/interface ID of the IPv6 address.	The tag ID can be read directly from the IPv6 address as the last 64 bit, i.e., the tag identification works two-ways. There is a risk of address collision with other networked systems that use IPv6 in the same logical subnet e.g., hosts using autoconfiguration. Uniqueness of the RFID naming space in use is conserved.
Tag with ID of more than 64 bits	2. Use CGA namespace adapted to RFID as described in Section 3.4.	Statistical uniqueness is achieved. The tag ID is hashed and cannot be directly read out of the IPv6 address. The reverse process of finding the tag ID from the IPv6 address requires a separate system to perform the mapping since the hashing works only one-way. Extra computational power is required because the method is based on cryptography.
	3. Use the tag ID as input bitstring to create a HIT. The ID should be treated as a public key in accordance with the HIP specification (see Section 3.5). End result is a 128-bit address compliant with the IPv6 addressing format.	Non-compliance with IPv6 address format. Addresses are non-routable because of the separation between locator and the end-point identifier. The solution requires changes in the reader's TCP/IP protocol stack. The solution will function with IPv6 API deployed in applications on the Internet.

Table 3. Overview of strategies for mapping Tag ID codes to IPv6 network addresses.

Table 3 outlines the different strategies for mapping of tag IDs to IPv6 addresses. Essentially, these divide into methods that work with tags of 64-bit identification or less and tags that use more that 64-bit for identification.

7. Mobility considerations

One of the largest challenges for a dynamic, networked system lies within the mobility support of the network. In the case described here, we consider a system of fixed readers that are connected in a common network infrastructure. Mobility arises when tags are moved between readers. Readers will be wired or wireless and they will have different communication ranges according to their MAC technology. Moreover, they will forward the read tag IDs to the server through the common network infrastructure.

When a tag moves from one reader to another, the network prefix will change but the host suffix/interface ID will still match the tag's EPC. The tag will in effect change its network address every time it passes a new reader. Hence, the challenge is to effectively keep track of tags when the address changes this rapidly.

There are basically two distinct ways to solve the mobility problem. One is a centralized approach, such as mobile IPv6 [30], where a central server, i.e., the home agent, is used to keep track of the mobile hosts that move around in the world. The mobile IPv6 architecture relies on the concept of a home agent and a care-of address. The method is based on some software on the network layer that can send messages to the home agent making sure that the home agent is holding an updated address list at all times. Initially, traffic destined to the mobile host is routed to the home network and subsequently tunneled to the foreign network that the host is visiting. Fortunately, IPv6 supports mechanisms to circumvent the triangular routing problem that arises in this setup [30].

Dominikus et al. [14], proposed to use mobile IPv6 to handle the mobility of IPv6-enabled tags. In their approach, the care-of address refers to the subnet of the RFID reader, where the tag is currently present. Whilst the care-of address is a globally unique address assigned to the host, i.e., the tag visiting a foreign network, the home agent address is specific to the enterprise using the issued tags.

Alternatively, mobility support can be obtained in a more distributed way by separating location and identity information. This can be achieved by using the HIP approach [22]. In this approach, there is a need to compute the routable IPv6 address from the given non-routable HIT the host has been given.

HIP allows consenting hosts to securely establish and maintain shared IP-layer state, allowing separation of the identifier and locator roles of IP addresses, thereby enabling continuity of communications across IP address changes. A consequence of such a decoupling is that new solutions to network-layer mobility and host multi-homing are possible [22].

8. Conclusions

Metcalfe's law states that the value of a telecommunications network is proportional to the square of the number of connected users of the system. When the law is applied to a network of objects on the scale predicted by the vision of the Internet of Things it is clear that a single, open architecture for networking physical objects is much more valuable than small scale and fragmented alternatives.

RFID plays an increasingly important in our daily life from management of goods, e-tickets, healthcare, transports, even the identity cards are embedded with RFID tags. In this chapter, we have sketched methods on how to use RFID technology to connect “things” over the Internet by using IPv6. This includes a discussion on the different strategies for mapping of tag IDs to globally unique IPv6 addresses.

For tags with large identification numbers (more than 64 bits) it is proposed to use cryptographic techniques to extract the 64 bits and use these to create a host suffix that is statistically unique.

A testbed used to experiment with the internetworking of low-cost, passive RFID tags to the Internet has been presented. Since these tags do not have electrical and processing power to run an IP protocol stack a virtual network interface (VNI) concept has been introduced. Proxies can be deployed on the edge of the Internet to act on behalf of these passive tags in a protocol message exchange.

To solve the mobility problem, two approaches have been discussed: one being the mobile IPv6 approach and the other being the HIP approach. Both have strengths and both have weaknesses. Mobile IPv6 will need some software to make the connection between the tags and the home agent. The HIP approach needs some computation to take place in order to be able to construct routable IPv6 addresses. Both approaches imply changes to be made to the Internet, as we know it today, before it is possible to effectively achieve the desired results.

Most RFID applications today include mobility as an essential part of their value creation. Therefore, future research in this area must focus on mobility aspects of the Internet of Things.

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Chapter 7

Design of a Zeroth Order Resonator UHF RFID Passive Tag Antenna with Capacitive Loaded Coplanar Waveguide Structures

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Benjamin D. Braaten

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53284

1. Introduction

The use and development of Radio Frequency Identification (RFID) systems has undergone substantial growth in the past decade in many new areas. Some of these areas include wireless sensor systems, metamaterials and compact antennas [1-8]. However, much of this new growth has required more performance from traditional passive RFID systems. In particular, the need for more compact antennas with performances comparable to much larger resonant antennas is one such condition. To fulfill the requirements of compact antennas, researchers have developed various novel RFID antenna designs [2-4], including metamaterial-based RFID antenna designs [1,5-8] to improve the performance of RFID systems. Using composite right/left-handed (CRLH) transmission line (TL) based metamaterials to show the unique property of zeroth-order resonance (ZOR) [9,10] is one such method to reduce the overall size of an antenna. More specifically, a ZOR-TL can be used to make an electrically small antenna to appear electrically large; which leads to improved matching and radiation properties. This is done by producing a zero phase constant at a non-zero frequency (i.e. the wavelength of the travelling wave becomes infinite) on the TL. This is a unique property which makes the resonance condition independent from the physical dimensions of the antenna or TL [11-13] so it can be used to design miniature antennas for passive UHF RFID applications. The resonance of such antennas at any operating frequency only depend on its CRLH characteristics to acquire ZOR at that frequency and less to do with the physical dimensions of corresponding antenna.

This chapter will focus on the design of ZOR antennas for passive UHF RFID tags. First, a brief introduction and working principles of RFID systems is presented using Friis's transmission equation. Then, the characteristics of CRLH transmission lines will be discussed and its Bloch impedance will be derived to introduce the ZOR concept. Then coplanar-waveguides (CPW) and its characteristics are presented. Then the design of a capacitive loaded CPW based ZOR antenna for passive UHF RFID tag is discussed. Finally, future work and conclusion about this chapter is presented.

2. Introduction to RFID systems

RFID technology has drawn great attention in the past decade. Recently it has been used in inventory control, managing large volumes of books in libraries and tracking of products in the retail supply chain [14,15]. Its usage is growing and replacing the bar code technology used for the purpose of object identification and recognition. A bar code requires a clear line of sight and a small distance between the object and the laser bar code scanner (which is a limitation) whereas RFID works at microwave frequencies so it can identify the object from a distance, it does not require line of sight for its operation and unlike bar codes it can also store some additional information which makes it very attractive as compared to bar codes [1].

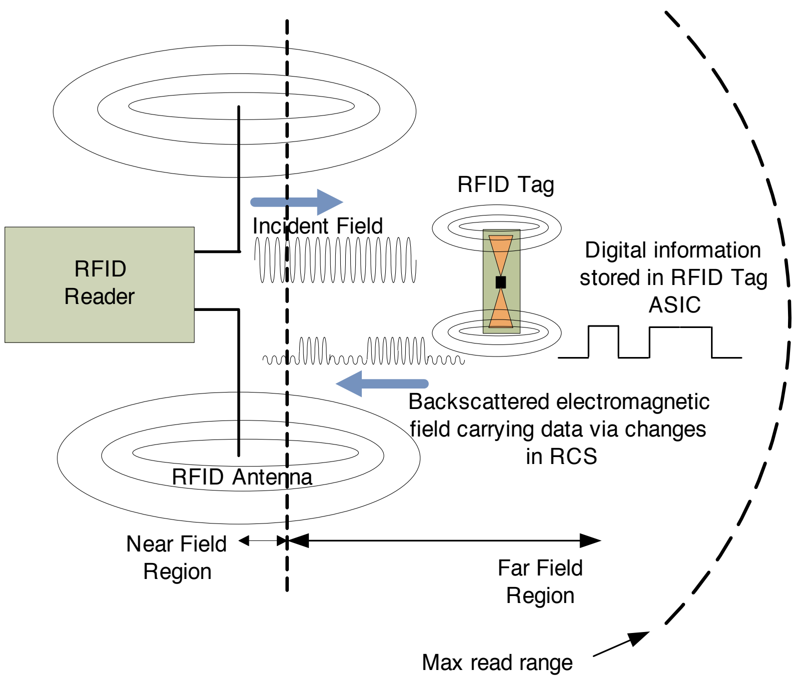

Figure 1. Overview of RFID System

A RFID system consists of a RFID reader and a RFID tag. An overview of a typical RFID system is shown in Fig. 1. RFID systems comprise of RFID tags or transponders which are fairly simple, small and inexpensive devices at one end and a reader which is relatively complex and a bigger device on the other end. Application Specific Integrated Circuits (ASICs) are attached to the tag antenna and are used for sensor applications, to harvest energy, communicate and store information for later recovery. The reader emits an electromagnetic field which contains power and timing information for use by the passive RFID. If a RFID tag comes within the range (also known as the interrogation zone [1]) it receives the information which is fed to the ASIC and in response the ASIC switches its impedance states between a lower and higher value in a predetermined fashion as shown in Fig. 2. By changing the impedance states the ASIC changes the radar cross-section (RCS) of the tag antenna thus changing the backscattered power. This backscattered power is collected at the reader and is used for tag identification and information. The maximum distance for which a reader can successfully identify a tag is known as max read range.

RFID tags are usually classified into three categories: active tags, semi-passive tags and passive tags [1]. An active tag has a dedicated power supply for operation on the tag. A semi-passive tag has an integrated power supply attached to it and it only starts working when electromagnetic power transmitted by the reader is incident on the tag. This feature enhances the maximum read range of the tag [1] because less power is required from the incoming incident field from the reader. A passive tag has no power source attached to it and it harvests power for its operation from the incident electromagnetic field transmitted by the reader.

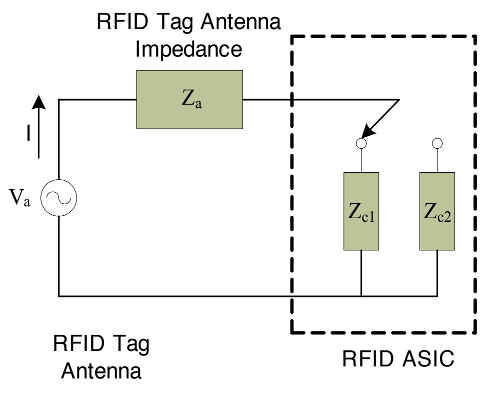

Figure 2. Thevenin equivalent circuit of RFID tag

A common method to describe the RFID wireless communication system is the following Friis transmission equation [16]:

$$P_r = P_t \frac{G_r G_t \lambda^2}{(4\pi R)^2} q \qquad (1)$$

where P_r is the power received by RFID tag, P_t is power transmitted by RFID reader, G_r is the gain of tag antenna, G_t is the gain of reader, λ is free space wavelength of the operating frequency of reader, R is distance between reader and tag and q is impedance mismatch factor ($0 \le q \le 1$) between impedance of the antenna on the tag and the input impedance of the ASIC on the tag. Equation (1) assumes a perfect polarization match between the antenna on the reader and the antenna on the RFID tag. Reorganizing (1) and solving for R, the following equation for determining the read rang of a tag can be derived [17,18] as:

$$R = \frac{\lambda}{4\pi}\sqrt{\frac{qG_tG_rP_t}{P_r}} \tag{2}$$

If the minimum power required for tag operation is P_{th} then Equation (2) can be written as

$$R_{max} = \frac{\lambda}{4\pi}\sqrt{\frac{qG_tG_rP_t}{P_{th}}} \tag{3}$$

Equation (3) is useful for designers to determine the maximum operating range of the tag. Typically the approach by a designer is to maximize the R_{max}. One way of achieving this is to minimize the mismatch between tag antenna and ASIC impedances or design a receive antenna on the RFID tag with a maximized gain G_r.

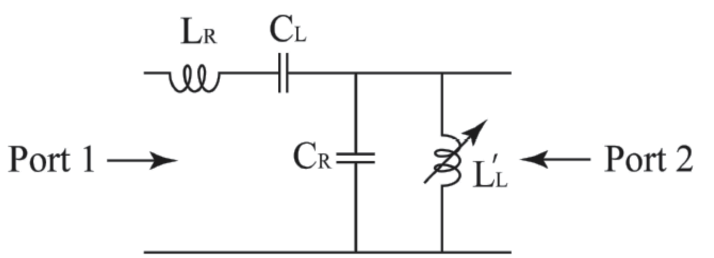

Figure 3. Reconfigurable CRLH-TL

3. Introduction to left-handed propagation

To help illustrate the use of ZOR properties to improve the gain and matching of a compact antenna on a passive UHF RFID tag, several properties of left-handed (LH) propagation will be introduced and summarized here. It is well known that the equivalent circuit of a traditional printed microstrip TL consists of a series inductance and a shunt capacitance. The series inductance is caused by the current travelling down the printed TL and the shunt capacitance represents the capacitance between the printed signal conductors on one side of the board and the reference or ground plane. In fact, this inductance and capacitance exists on every printed TL (traditional or CRLH) because in the propagating band current is travelling down the TL and there is always capacitance between the conductors supporting this current and a reference conductor. When introducing the CRLH-TL, this series inductance and shunt capacitance is referred to as the parasitic values and are denoted in Fig. 3 as L_R and C_R. The subscript R stands for right-handed (RH) propagation.

Next, to support LH-propagation, a series capacitance and a shunt inductance is introduced. These values are shown in Fig. 3 and are denoted C_L and L_L, respectively. The subscript L stands for left-handed propagation. More particularly, the series capacitance is in series with the inductance and the shunt inductance is in parallel with the shunt capacitance. Therefore, to achieve LH-propagation, C_L and L_L should dominate over the values of L_R and $C_{R.}$ Closer observation of the equivalent circuit in Fig. 3 shows that the LH-values will only dominate over a certain band which is called the LH-propagating band. When the RH-values of L_R and C_R are dominant, this is called the RH-propagating band. When both the RH- and LH-values are equal; this is called the transition frequency between the RH- and LH-propagating bands or simply the transition frequency. In practice, the series capacitance is usually introduced by defining interdigital capacitors down the length of the TL [10]. The shunt inductance has been introduced in many different ways such as split ring resonators and shunt stubs [10].

A CRLH-TL has several unique properties as a result of the introduction of C_L and L_L. The property used in this work is the sign change associated with the phase constant. The phase constant on a CRLH-TL is opposite to the phase constant on conventional RH-TL. This phase advance feature can be very useful for antenna designers and will be used in the next few sections to introduce the idea of ZOR antennas.

4. Coplanar-waveguide structures

The term “Coplanar” means sharing the same plane and this is the type of transmission line where the reference conductors are in the same plane as of signal carrying conductor. The signal carrying conductor is placed in the middle with a reference plane conductor on either side as shown in Fig. 4. The advantage of having both conductors in the same plane lies in the fact that it is easier to mount lumped components between the two planes and it is easier to realize shunt and series configurations. The CPW was first proposed by Wen [19] and since then have been used extensively in wireless communications [20,21].

The disadvantage of CPW is that it can be difficult to maintain the same potential between the reference and signal conductors throughout the signal trace. Nevertheless many advances have been made by using CPW such as novel filters [22] and right/left handed propagation on CPW lines [23].

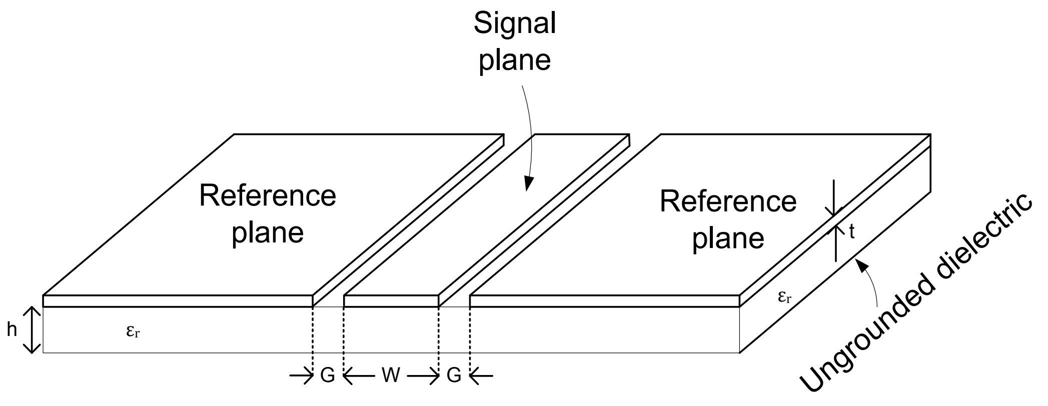

Figure 4. CPW transmission line on ungrounded dielectric

Several properties of the CPW-TL in Fig. 4 are derived next. These expression will be used later to describe the ZOR-RFID antenna. The attenuation and phase constants can be derived by performing a quasi-static analysis of a CPW [24]. The phase velocity and characteristic impedance equations can be written as [24]:

$$v_{cp} = \left(\frac{2}{\varepsilon_r + 1}\right)^{1/2} c \tag{4}$$

and

$$Z_{0cp} = \frac{30\pi}{\sqrt{\varepsilon_{re}^{t}}} \frac{K(k_e')}{K(k_e)} \tag{5}$$

where

$$k_e = \frac{W_e}{(W_e + 2G_e)} \cong k + \frac{(1 - k^2)\Delta}{2G} \tag{6}$$

$$k = \frac{W}{W + 2G} \tag{7}$$

$$\Delta = (1.25t / \pi)[1 + \ln(4\pi W / t)] \tag{8}$$

$$k' = (1 - k^2)^{1/2} \tag{9}$$

$$\varepsilon_{re}^{t} = \varepsilon_{re} - \frac{0.7(\varepsilon_{re} - 1)t / G}{\left[\frac{K(k)}{K(k')}\right] + \frac{0.7t}{G}} \tag{10}$$

and

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2}\left[tanh\{1.785\log(h / G) + 1.75\} + \frac{kG}{h}\{0.04 - 0.7k + 0.01(1 - 0.1\varepsilon_r)(0.25 + k)\}\right] \tag{11}$$

Here W is the width of the center conductor, G is the spacing between the center conductor and the reference conductor, ε_r is the relative permittivity of the dielectric, c is the speed of light and t is the thickness of the conductor. K(k) is the complete elliptic integral of the first kind and the ratio K(k)/K(k') has been reported in [24,25] as:

$$\frac{K(k')}{K(k)} = \frac{1}{\pi} ln\left[2\frac{1 + \sqrt{k}}{1 - \sqrt{k}}\right] for\ 0.707 \le k \le 1 \tag{12}$$

and

$$\frac{K(k')}{K(k)} = \frac{\pi}{ln\left[2\frac{1 + \sqrt{k'}}{1 - \sqrt{k'}}\right]}\ for\ 0 \le k \le 0.707 \tag{13}$$

Using equations (4)-(13) the attenuation constant due to ohmic losses can be calculated as [24]:

$$\alpha_c^{cw} = 4.88*10^{-4} R_s \varepsilon_{re} Z_{0cp} \frac{P'}{\pi G}\left(1 + \frac{W}{G}\right)\left\{\frac{\frac{1.25}{\pi} ln\frac{4\pi W}{t} + 1 + \frac{1.25t}{\pi W}}{\left[2 + \frac{W}{G} - \frac{1.25t}{\pi G}\left(1 + ln\frac{4\pi W}{t}\right)\right]^2}\right\} dB \Big/ unit\ length \tag{14}$$

where

$$P' = \left(\frac{K}{K'}\right)^2 P \tag{15}$$

$$P = \begin{cases} \dfrac{k}{\left(1 - \sqrt{1 - k^2}\right)\left(1 - k^2\right)^{3/4}}\ for\ 0.0 \le k \le 0.707 \\ \dfrac{1}{(1 - k)\sqrt{k}}\left(\dfrac{K}{K'}\right)^2\ for\ 0.707 \le k \le 1.0 \end{cases} \tag{16}$$

and

$$R_s = \sqrt{\rho \pi f \mu} \tag{17}$$

The attenuation constant due to dielectric losses is [24]:

$$\alpha_d = 27.3 \frac{\varepsilon_r}{\sqrt{\varepsilon_{re}}} \frac{\varepsilon_{re} - 1}{\varepsilon_r + 1} \frac{\tan\delta}{\lambda_0} \ dB \Big/ \ unit\ length \tag{18}$$

Here tan(δ) is the loss tangent of the dielectric and the total attenuation can be written as:

$$\alpha_{cwp} = \alpha_c + \alpha_d \tag{19}$$

Thus, the phase constant can be calculated as [20]:

$$\beta_{cpw} = \frac{2\pi f}{v_{cp}} \tag{20}$$

Next, these expressions will be used to introduce the interdigital capacitor loaded CPW which will then be used to design a ZOR-RFID antenna.

5. Interdigital capacitor loaded CPW

An Interdigital capacitor loaded transmission line provides a series resonance. The Zeroth Order Resonance (ZOR) of an interdigital capacitor loaded CPW has been investigated and reported in [26]. The equivalent transmission line model of an interdigital capacitor loaded transmission line is shown in Fig. 5 and consists of two symmetric transmission lines interconnected with a series capacitance. The host transmission line has been shown equally divided into two parts. Since the size of the unit cell is much smaller than the guided wavelength, the transmission line can be modeled with an equivalent circuit with a series inductance and shunt capacitance (as discussed in Section 3).

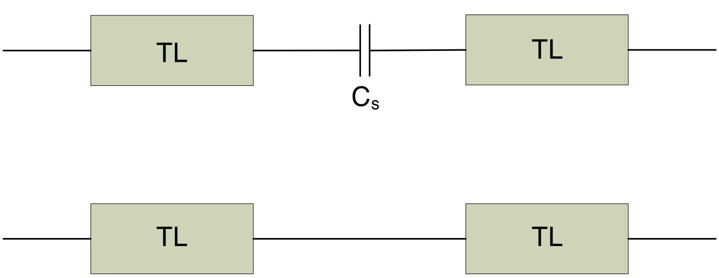

Figure 5. Equivalent circuit model of interdigital capacitor loaded

The geometry (layout) of the interdigital capacitor based unit cell is shown in Fig. 6. The capacitance between the interdigital capacitor and bilateral ground plane is fairly small as compared to the series capacitance of the interdigital capacitor so it can be neglected. This unit cell can be repeated periodically to design the ZOR antenna.

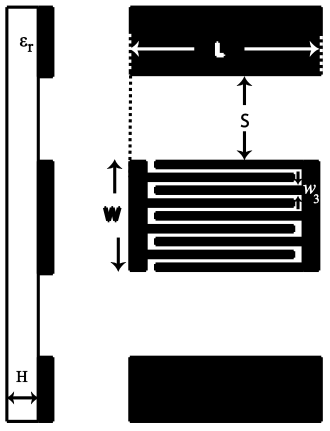

Figure 6. Interdigital capacitor loaded CPW unit cell

Since the unit cell will be repeated periodically and will be symmetric about the port of the antenna, it will resemble the TL in Fig. 5. Therefore, the propagation constant γ (where $\gamma = \alpha + j\beta$) and characteristic impedance (also known as block impedance) Z_B can be expressed in terms of an ABCD matrix as [20]:

$$\cosh \gamma L = A \tag{21}$$

and

$$Z_B = \frac{B Z_0}{\sqrt{A^2 - 1}} \tag{22}$$

Here L is the length of the unit cell and Z_0 is the characteristic impedance of the CPW. The propagation constant of the TL is $\gamma_{CPW} = \alpha_{CPW} + \beta_{CPW}$ where α_{CPW} and β_{CPW} can be calculated from (19) and (20), respectively.

Next, the ABCD matrix of the circuit shown in Fig. 5 can be determined as [20]:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} = \begin{bmatrix} \cosh \frac{\gamma_{CPW} L}{2} & Z_0 \sinh \frac{\gamma_{CPW} L}{2} \\ Y_0 \sinh \frac{\gamma_{CPW} L}{2} & \cosh \frac{\gamma_{CPW} L}{2} \end{bmatrix} \tag{23}$$

and

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{inter\text{-}digital\ capacitor} = \begin{bmatrix} 1 & \frac{1}{j\omega C} \\ 0 & 1 \end{bmatrix} \tag{24}$$

Here L/2 represents half of the CPW length. The ABCD matrix of the whole unit cell can be calculated from (23) and (24) as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} * \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{inter\text{-}digital\ capacitor} * \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} \tag{25}$$

From (25), parameter A can be calculated and (21) can be written as:

$$\cosh \alpha L \ \cos \beta L \ + j\sinh \alpha L \ \sin \beta L \ = M + jN + \frac{1}{j2Z_0\omega C}(O + jP) \tag{26}$$

where

$$M = \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \tag{27}$$

$$N = \sinh \alpha_{CPW} L \ \sin \beta_{CPW} L \tag{28}$$

$$O = \sinh \alpha_{CPW} L \ \cos \beta_{CPW} L \tag{29}$$

and

$$P = \cosh \alpha_{CPW} L \ \sin \beta_{CPW} L \tag{30}$$

In (26) α represents the attenuation constant and β represents the phase constant of the Bloch wave propagating on the unit cell whereas α_{CPW} and β_{CPW} are attenuation and phase constants, respectively, of the host CPW. From (26) the real and imaginary parts can be separated which gives:

$$\cosh \alpha L \ \cos \beta L \ = \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \ + \frac{\cosh \alpha_{CPW} L \ \sin \beta_{CPW} L}{2Z_0\omega C} \tag{31}$$

and

$$\sinh \alpha L \ \sin \beta L \ = \sinh \alpha_{CPW} L \ \sin \beta_{CPW} L \ - \frac{\sinh \alpha_{CPW} L \ \cos \beta_{CPW} L}{2Z_0\omega C} \tag{32}$$

The unknowns in (31) and (32) are α and β of the Bloch wave. Solving for α and β gives:

$$\alpha = \frac{1}{L} cosh^{-1}\left(\frac{\sqrt{Q^2 + (R+1)^2} + \sqrt{Q^2 + (R-1)^2}}{2} \right) \tag{33}$$

and

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$$\beta = \frac{1}{L} cos^{-1}\left(\frac{\sqrt{Q^2 + (R+1)^2} - \sqrt{Q^2 + (R-1)^2}}{2} \right) \tag{34}$$

where Q and R are the right hand sides of (31) and (32), respectively. The key idea when designing a ZOR antenna is to determine the frequency at which equation (34) is equal to zero. Since the propagation constant is inversely proportional to the wavelength, when equation (34) is zero, the wavelength at that frequency is equal to infinity. At this frequency, the antenna looks infinitely long electrically. In the next section, the expressions derived here for the interdigital capacitor loaded CPW will be used to design a ZOR-RFID antenna.

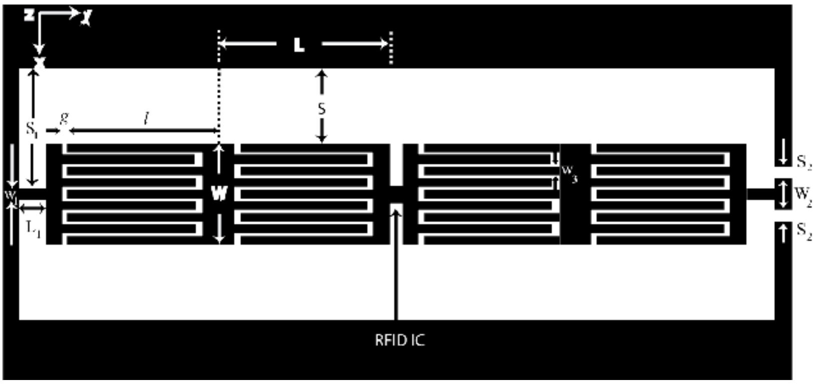

Figure 7. Layout of proposed ZOR RFID antenna with capacitor loaded CPW [30]

5.1. Zeroth order resonance

The layout of the proposed ZOR RFID antenna is shown in Fig. 7 [30]. The port of the antenna is located in the middle of the antenna with series capacitance down each arm. The operating principle of this antenna is based on the capacitive input impedance of the passive RFID ASIC. At resonance, the interdigital capacitors are supporting a wave propagating along the antenna. Since the input impedance of the ASIC is also capacitive the ASIC also supports wave propagation along the antenna in a manner similar to the interdigital capacitors [30]. During this process, the ASIC harvests the required power to perform the desired tasks and communicate while simultaneously supporting the wave propagating on the antenna.

The first step in the design process is to determine what capacitance is required to equate β to zero at the desired operating frequency such that the antenna looks infinitely long. For discussion, the non-zero frequency at which β becomes zero is known as the zeroth order resonance (ZOR) frequency [26], [30]. For simplicity a lossless ($\alpha = 0$) CPW line is assumed and then from (31) the required capacitance can be calculated to achieve ZOR at a particular design frequency as:

$$C = \frac{\cosh \alpha_{CPW} L \ \sin \beta_{CPW} L}{2\omega_r Z_0 (1 - \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \ )} \tag{35}$$

Since we are interested in designing a ZOR antenna for the passive UHF RFID band, 915 MHz is taken as the operating frequency and from (35) the required capacitance can be calculated as C = 2.64 pF.

The unit cell shown in Fig. 7 was simulated in ADS 2009 with design parameters L = 17.56 mm, W = 8.82 mm, w_3 = 0.36 mm, S = 7.96 mm and H = 1.524 mm. A Rogers TMM4 (ε_r = 4.5 and tan δ = 0.002) was used as a substrate. For the lossless case the attenuation constant of the CPW and loss tangent of the substrate was assumed to be zero and a perfect conductor was considered. The capacitance of the unit cell was extracted [10] to be $C_{extracted}$ = 2.4 pF which is close to the required capacitance for ZOR at 915 MHz. The dispersion characteristics are plotted in Fig. 8. It can be noted that the attenuation constant decreases monotonically and becomes zero after 944 MHz. Similarly the propagation constant remains zero and after 944 MHz it increases monotonically. Thus 944 MHz can be taken as ZOR frequency for the given unit cell which comes within 3.2% of the required resonance frequency of 915 MHz. More discussion on this is reported in [30].

For the lossy case the attenuation constant of the CPW was calculated using (19) and the loss tangent was taken as tan δ = 0.002. The conductivity was defined as σ = 5.8 x 10^7 S/m with a conductor thickness of 35 μm. The dispersion characteristics for the lossy case were also presented in Fig. 8. A similar response for both the lossy and lossless case is shown except for the fact that the phase constant is non-zero below the ZOR point and similarly the attenuation constant is non-zero after the ZOR point. Here the ZOR point is taken as the point at which α = β and it coincides with the lossless ZOR point [26],[30].

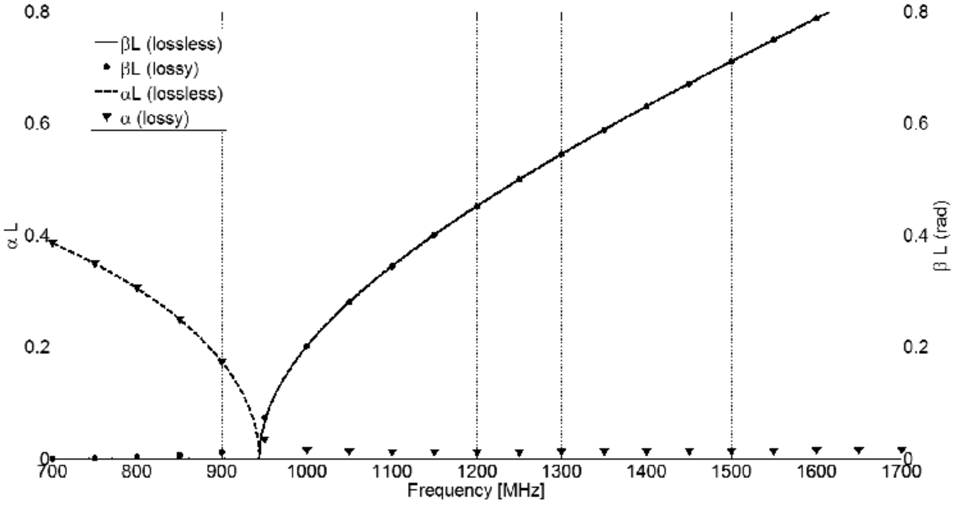

Figure 8. Dispersion diagram of lossless and lossy interdigital capacitor loaded CPW

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5.2. Zeroth order resonator RFID antenna measurements

Again, the proposed ZOR RFID antenna with the capacitor loaded CPW is shown in Fig. 7. The antenna is composed of four series connected unit cells, where each unit cell has a layout similar to the image in Fig. 6. The proposed antenna has a 50 ohm CPW at one end and a high characteristic impedance short circuit line on the other end similar to [26] and [30]. The Higgs-2 by Alien Techonologies [29] RFID ASIC was used and attached at the port of the antenna (at the center). The Higgs-2 has an input impedance of Z_{in} = 13.73 + j142.8 Ω at 915 MHz. The antenna was designed on a Rogers TMM4 substrate with $\varepsilon_r = 4.5$, tan δ = 0.002 and a substrate thickness of H = 1.524 mm. The design parameters of the proposed ZOR RFID antennas are given in Table 1 and [30].

A wider central strip was used to obtain the required series capacitance as shown in Fig. 7 and the gap between the central conductor and reference conductors on either side was made as large as possible so that the parasitic shunt capacitance could be made as small as possible. This ensured a dominant series capacitance created by the interdigital capacitance and the input impedance of the passive UHF RFID ASIC connected to the antenna port. Furthermore, this will simplify the ABCD matrix representation of each unit cell.

The ZOR RFID antenna shown in Fig. 7 was simulated in Ansoft HFSS v.13. The simulated input resistance, reactance and reflection coefficient are shown in Fig. 9, Fig. 10 and Fig. 11, respectively. The fabricated prototoype ZOR RFID antenna is shown in Fig. 12 [30].

C	2.4 pF	w_3	0.66 mm
W	8.82 mm	S_1	12.17 mm
L	17.56 mm	S_2	0.35 mm
S	7.96 mm	L_1	5 mm
w_1	0.4 mm	l	16.2 mm
W_2	3 mm	g	0.36 mm

Table 1. Design parameters of proposed ZOR RFID antenna

Next, to measure the read range of the prototype tag, an Alien Technologies ALR-9900 RFID reader was used [29] (with maximum output power of 1W). It was connected to a circularly polarized antenna with a gain of 6dBi and the RFID Tag was placed in an anechoic chamber. A read range of 3.4 m was determined with the RFID reader; however the *max read range* was not determined because the overall dimensions of the anechoic chamber were too small. An alternate method has been provided in [30] and [31] to predict the maximum achievable read range based on system power levels and measurements. This method uses the Friis transmission equation and the fact that a certain minimum power is required to activate the tag. Using this information the output power of the RFID reader was reduced until the reader could no longer detected the tag at 3.4 m. The required attenuation was 7 dB. Then the following equations were used to predict the maximum read range:

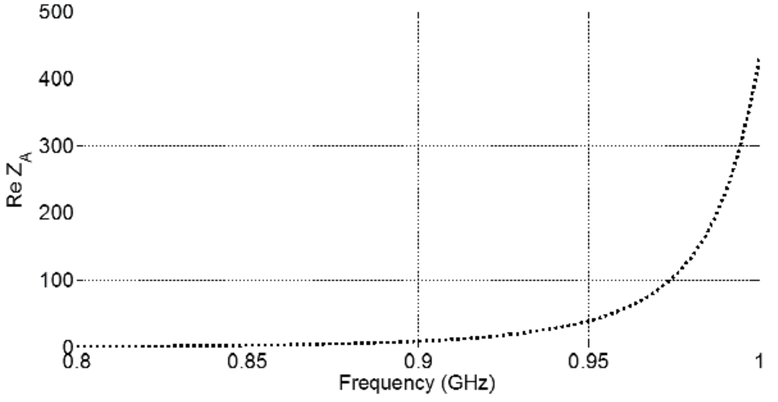

Figure 9. Proposed ZOR RFID antenna input resistance

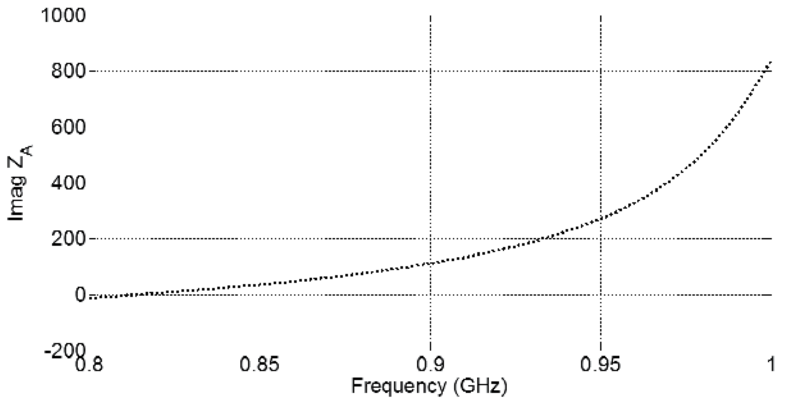

Figure 10. Proposed ZOR RFID antenna input reactance

$$P_{r_{min}} = \frac{P_{t_{max}} G_t G_r \lambda^2}{(4\pi R_{max})^2} \tag{36}$$

and

$$P_{r_{min}} = \frac{P_{t_{max}}}{\alpha} \frac{G_t G_r \lambda^2}{(4\pi R_{measured})^2} \tag{37}$$

Since (36) and (37) both use minimum received power, they can be equated to produce

$$R_{max} = 10^{\alpha_{dB}/20} R_{measured} \tag{38}$$

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Putting α = 7 dB and $R_{measured}$ = 3.4 m in (38) gives a predicted max read range of 7.6 m which meets or exceeds the performance of similar and large passive UHF RFID tags available on the market today.

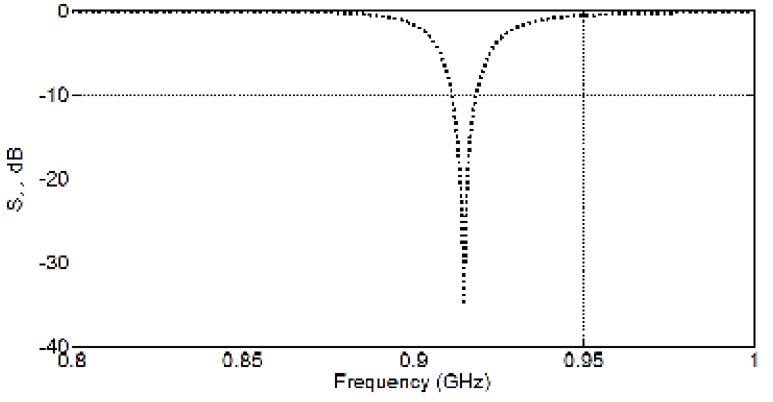

Figure 11. Input reflection coefficient of proposed ZOR RFID antenna

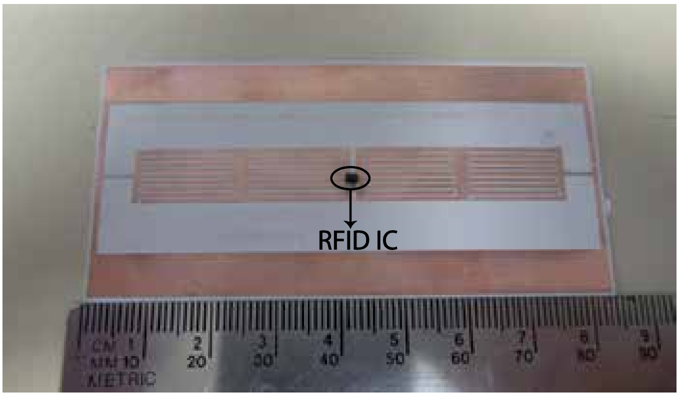

Figure 12. Fabricated ZOR RFID antenna [30]

6. Conclusion

The expanding use of passive UHF RFID systems has increased the performance demands on readers, tags, software and manufacturing costs. Because of these new constraints, the desire for more compact and better performing tags is beginning to grow. In this chapter, a summary of passive UHF RFID systems has been presented with several of the key antenna design requirements mentioned. Following this introduction, background on left-handed propagation, co-planar waveguides and interdigital capacitor loaded co-planar waveguides have been introduced and summarized. From these sections, the ZOR-RFID antenna for passive UHF RFID tags is presented. The operating principle behind the ZOR-RFID antenna is the use of interdigital capacitors along the length of the antenna to support wave propagation. Furthermore, the capacitive input impedance of the passive RFID ASIC attached to the port of the antenna supports propagation in a manner similar to the interdigital capacitors. This allows the ASIC to still harvest power and communicate while supporting wave propagation. Measurements show that a predicted 7.6 m read range is possible with this new antenna design. This read range is comparable to existing commercially available passive UHF RFID tags with similar overall sizes.

7. Future work

There are several different avenues of future work possible. The first topic of interest is to reduce the overall size of the ZOR RFID prototype antenna. This could be done by using resonator elements instead of the interdigital capacitors. Further development on printing the ZOR-RFID antenna on flexible substrates would be of great interest. Maybe the investigation of paper, LCP and Kapton substrates could be performed. Extending this work to develop a multi-band antenna would also be possible. This would allow this antenna design to be used in multiple countries.

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Chapter 8

Advancements and Prospects of Forward Directional Antennas for Compact Handheld RFID Readers

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Rabah W. Aldhaheri

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53283

1. Introduction

In the current age of rapid technological progress and development, radio frequency identification (RFID) technology has found many applications in various areas such as supply chain, warehouse, and retail store management. Alike mobile communications, the high data performance and compact profile are becoming obvious expectations of the users of handheld RFID devices. In this regard, directional antennas have a bright prospect for a more user friendly experience even in the rugged environments.

This chapter presents a comprehensive review of RFID technology concerning the prospects of directional especially forward directional antennas and propagation for multi-band operation. The technical considerations of directional antenna parameters are also discussed in details in order to provide a complete realization of the parameters in pragmatic approach to the directional antenna designing process, which primarily includes scattering parameters and radiation characteristics. The antenna literature is also critically overviewed to identify the possible solutions of the directional antennas to utilize in single and multi-band handheld RFID reader operation. However, it has been seen that these techniques can be combined to enhance the directional antennas with wider bandwidths and higher gain. Last but not least, the possibilities of forward-directional antennas which spectacularly use the surface wave for the radiation will be explored, and the difference with the conventional directional antennas with them will be discussed.

2. Prospects of forward directional antennas for handheld RFID readers

Radio frequency identification (RFID) technology having a huge potential with higher production efficiency, real-time inventory updates, greater product security and restricting counterfeit products, is becoming rapidly engaged in production, transportation, and retailing of products. On the investment front, more than 40% of shippers have increased their investment in RFID technology for supply chain applications (Research and Markets 2012). RFID technology is rapidly evolving due to (Cole P. H. 2003):

- increased awareness of the technology;
- development of improved techniques for multiple tag reading;
- realization in the business community of the benefits of widespread adoption in the supply chain;
- adoption by designers of sensible concepts in the arrangement of data between labels and databases;
- development of efficient data-handling methodologies in the relevant supporting communication networks;
- appreciation of the need for cost reduction, and
- development of new manufacturing techniques that will achieve manufacture of billions of labels at acceptable costs.

The global RFID market is projected to reach US$18.7 billion by the year 2017 where growth will be primarily driven by fast paced deployments of RFID projects in developing Asian countries, especially in China. Developments in the field of smart labels are projected to hold the key to future revenue growth (Research and Markets 2012). However, RFID is now at a stage where there are potentially large benefits from wider application but still some barriers remain.

It is widely known that handheld RFID readers need more compactness in design than fixed or mounted readers. Thus it is more challenging to make the designs more compact to meet the expectations of the users. Similar to mobile communications, the multi-standard capability, high data performance and compact profile are becoming obvious expectations of the users of RFID devices. Among the frequency bands that have been assigned to RFID applications, higher-frequencies have the advantage of high data transfer rate with far field detection capability (Islam et al. 2010).

Directional antennas usually radiates in a directive manner. They force the electromagnetic energy into a specific and desired direction. This type of antenna decreases the interferences of other tags in the undesired direction, while also increasing the reading range as well, since the gain of the directional antennas are higher than the omni-directional antennas.

In order to reduce the overall size of the handheld RFID readers, the need to reduce the size of the antenna is highly essential. But reducing the size of antenna limits its performances.

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Also when the operating frequency of RFID systems rises to the microwave region (2.45/5.8 GHz bands), the reader antenna design becomes more delicate and critical. This is especially true when a directional antenna is needed for handheld applications. However, it is a popular practice for handheld RFID readers to assemble a vertically radiating directional antenna in right angle with the reader; thus the radiation literally becomes front-directional to the reader (Fig. 1). This arrangement significantly increases the actual RFID reader profile. Hence it is greatly advantageous for a compact RFID reader to produce antennas with front-directional radiation patterns.

(a) (b)

Figure 1. Handheld RFID reader with an external antenna module (a) (Ukkonen et al. 2007), (b) (MC3190-Z Handheld RFID Reader 2012).

3. Evolution of forward directional antennas & limitations: A literature scenario

In this section we will focus on the development of multi-band antenna designing process. In last few years, there are a lot of antennas multi-band antennas has been designed, but most of them are omni-directional in radiation manner. But still some novel structures can be found in recent researches, that provide multi-band operation with directional radiation characteristics (Li et al. 2012, Mobashsher et al. 2010, Sabran et al. 2011). However, all of these antennas use a big metallic ground plane in order to reflect the radiation from the patch. Hence the actual applied antenna profile is bigger than the patch alone. So these antennas are not suitable for portable RFID applications. Another technique is widely applied in antenna domain in order to achieve directional radiation patters- the utilization of surface waves (also called trapper waves) (Zucker 1993).

In literature, surface-wave or end-fire antennas are mostly used to produce front-directional radiation patterns. Folded dipole (Fan et al. 2009) and folded (Yang et al. 2010) antennas are reported to have this type of radiation. Although these antennas produce good directional patterns, they are inappropriate for compact multi-band applications as they are printed in both sides of the substrate and resonate only in one operating frequency. The reported conformal (Dong & Huang 2011) and plate (Yao et al. 2011) end-fire antenna with good radiation patterns have a bulky profile and are unsuitable for a portable use. It is worth to mention that for handheld compact applications, uni-planar antennas are more beneficial than double-sided microstrip in terms of compactness and the integration capability with solid-state active and passive components. The uni-planar compact yagi antenna, reported in (Nikitin & Rao 2010), is difficult to be incorporated with the circuitry due to its construction.

Several quasi-Yagi (Kan et al. 2007) and bow-tie (Eldek et al. 2005) antenna provides wide bandwidth, but they do not give flexibility to choose specific frequencies of operation, thus in turn increases interference with neighboring operating bands. The frequency reconfigurable planar quasi-Yagi antennas (Qin et al. 2010) are also unsuitable for its complex feeding structure. A printed dipole (He et al. 2008) with etched rectangle apertures on surface has reported to have dual-band characteristics; but it suffers mostly in the consistency of the radiation patterns. Again, these are mostly double sided planar antennas. A multi-band Quasi-Yagi-type antenna is reported in (Ding et al. 2011). However, the feeding transition takes a wide area which in turn increases the antenna size significantly. It is obvious that the front directionality of the antennas will provide the handheld RFID readers a compacter solution and there is a huge research interest in this area in recent years to achieve optimum solution for the practical application.

4. Possibilities of forward-directional antennas for compact handheld RFID readers: An example from single & multi-band perspectives

Forward directional antennas can provide the RFID readers the desired compactness both in single and multi-band applications. In this section an example of forward directional antenna is discussed which is enhanced from single band to multi-band operation. The frequency of operation is chosen from the microwave ISM bands (2.45/5.8GHz), while the same methodology and design procedures are applicable for any combination of narrow RFID bands as the design has much flexibility. The details of the design process and the optimization are also discussed for the better understanding of the readers.

The flow chart in Fig. 2 describes the design and fabrication process of a desired single antenna. Firstly the requirements of the RFID antenna are collected according to the specifications of the RFID reader module. An extensive literature is reviewed for the design purpose. In this case some models are chosen which provides proper forward directionality. These are discussed in previous section. However, every design has some advantages and also some disadvantages. Proper understanding of the antenna operation is effective for proper chose of the antenna model. Meanwhile the familiarization with the simulation software IE3D EM simulator has been performed and an appropriate model is chosen for the design by using mathematical models. The design is simulated and its performance is examined and optimized until satisfactory result is obtained. When the optimized antenna is achieved, it is time to enhance the performances by using some techniques. This section is discussed more in the next sections. The last but not the least step is the fabrication process where the prototype is going to be built and finally the measurement of the antenna parameters for validation and comparison with the simulated results. At the end of this process the desired antenna with the given specification is attained. However, if any step fails to achieve its objectives, it is repeated again until the aims are met.

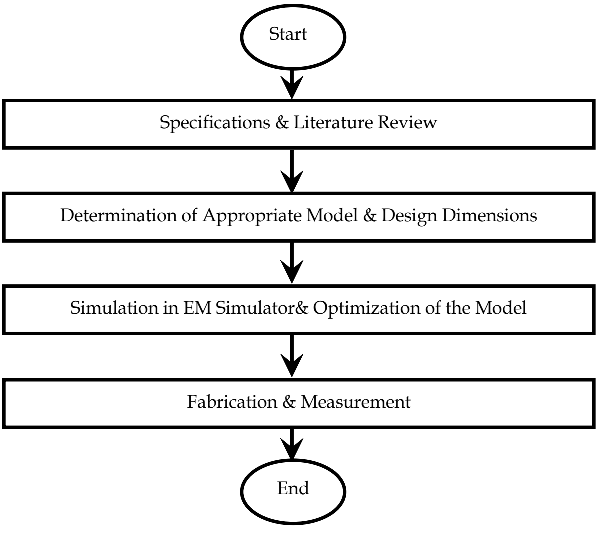

Figure 2. Flow chart design and fabrication process of a desired single band RFID antenna

The dual-band operation of the any antenna is an additional advantage. The design procedure of the dual band antenna is slightly different from the previously discussed the single band antenna. The design process is illustrated in the Fig. 3.

In order to meet the requirements of dual-band RFID reader antenna specifications, first the lowest cutoff frequency of the operation should be met. It is because of the fact that at the lowest frequency means the biggest wavelength in comparison to other higher frequencies and hence the respective current path should be the longest. Thus, the basic dimension of the antenna is defined by the lowest operating frequency. Electromagnetic simulation is an advanced technology to yield high accuracy analysis and design of complicated microwave and RF printed circuit, antennas and other electronic components. In antenna designing process, after the determination of the antenna dimensions with suitable model, the next step is to simulate the design in suitable electromagnetic software. The modeling and formulation are mainly derived through the use of Green's functions.

In simulation there may be some disagreements with calculated designed dimensions. In that case, the antenna should be optimized varying the parameters. When the lowest frequency is attained, then as the next step, further simulation and optimization is needed to meet the next operational frequency band with the same antenna. The possible solution is to achieve multi-resonance by employing notches, slots or additional current paths. Similarly, when optimizing, it should be taken care that the lowest frequency should not shift from the desired frequency. At the end of this design process, the antenna goes for prototyping and performance evaluation process.

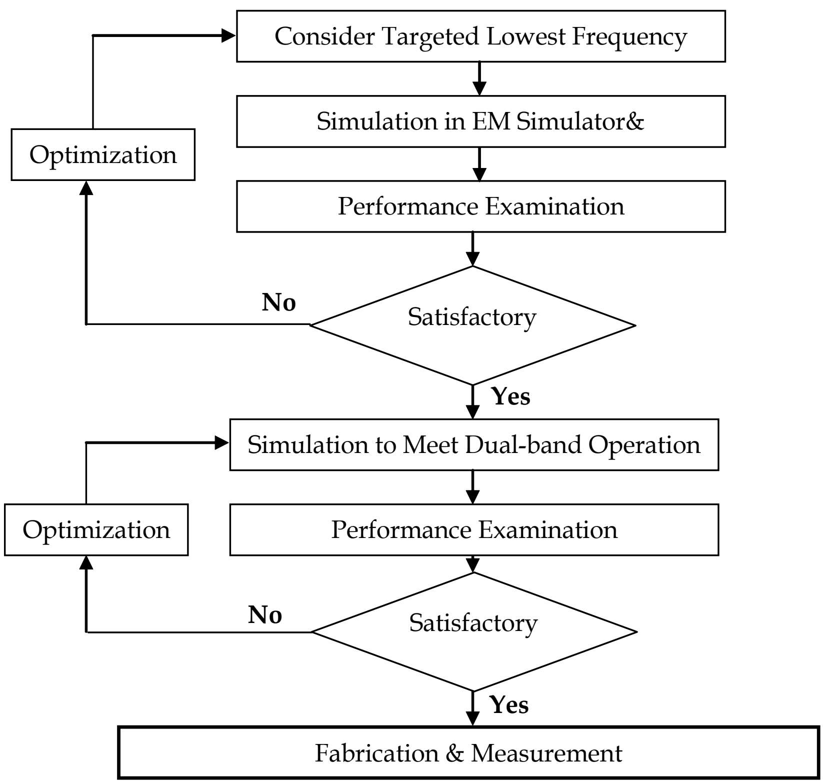

Figure 3. Flow chart simulation process of the multi-band RFID antenna

4.1. Antenna geometry

The schematic diagram of the proposed antenna is exhibited in Fig. 4. The antenna is fabricated on a low-loss substrate of medium permittivity (Rogers TMM4 ε_r = 4.5, $tan\delta$ = 0.002) with height 1.52 mm. Metallization of 1 oz copper cladding is used in only one side, which makes the antenna uni-planar and suitable to incorporate into the circuitry of the RFID reader. Also, the fabrication process of the antenna is relatively easy and cost effective. The antenna consists of a microstrip feeding line, two unsymmetrical ground planes and a folded strip with a small top branch. The width of the CPW feed line is fixed at F_w = 3mm. In order to achieve 50Ω characteristic impedance, the feeding line section (X-axis) is separated by a gap of g = 0.3mm from both right and left sides of ground plane. At the end, the antenna is

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fed by a 50Ω SMA coaxial connector from the side. Three triangular periodic open-end stub (POES) cells are infixed on the upper edge of each side of ground plane. The POESs are symmetrical with respect to the center line of the feeding strip in longitudinal direction (Y-axis). The POESs are optimized to improve the impedance matching of the antenna with no other effect on other characteristics of the antenna.

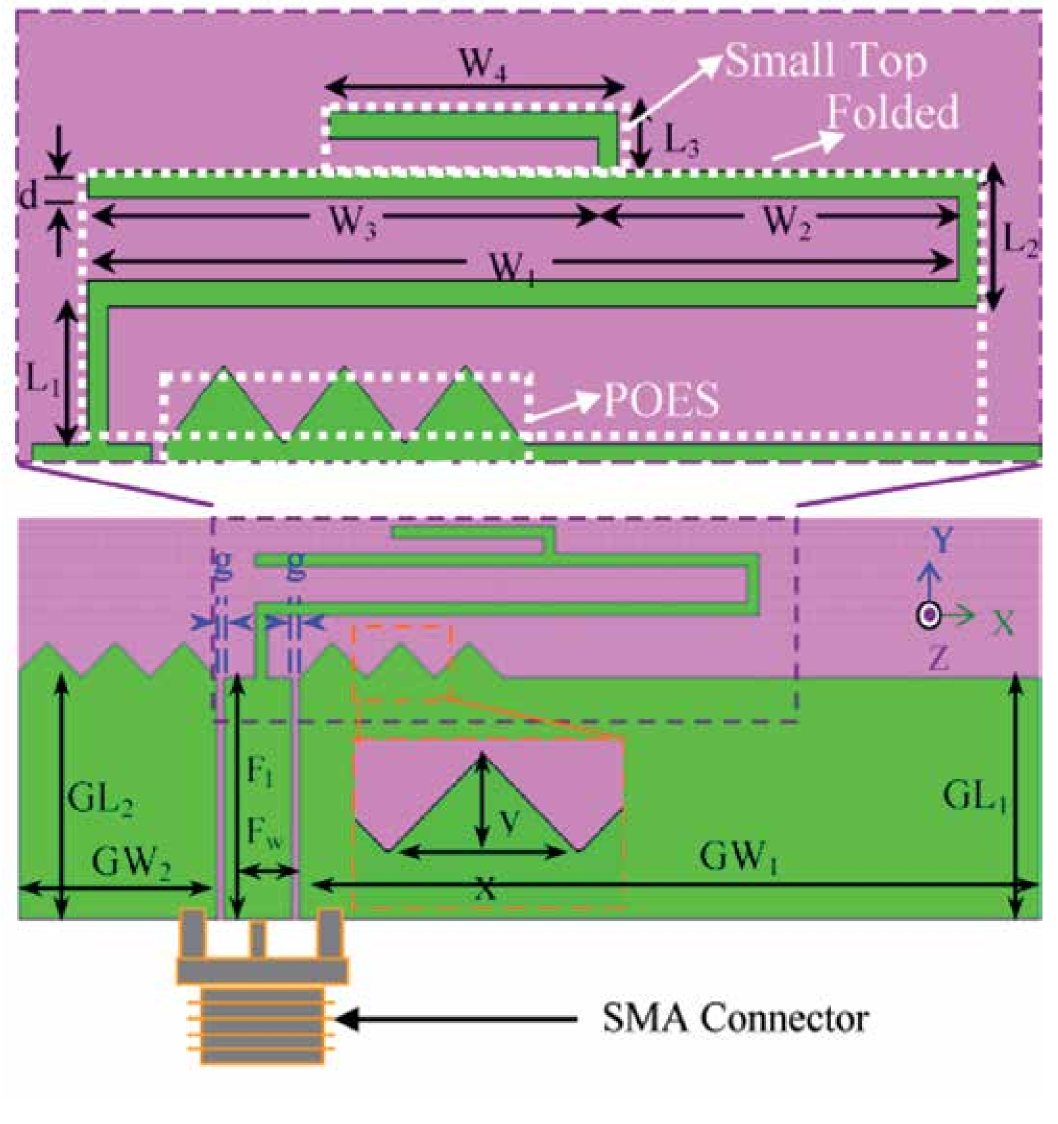

Figure 4. Geometric structure of the proposed antenna

4.2. Design procedure

Fig. 5 shows the design procedure of the proposed antenna. In design process, the lower band was first designed, since the antenna profile is usually circumscribed by the wavelength of lower frequencies. Inspired from (Yang et al. 2010) Design A was optimized to operate in the lower band with a small and uni-planer orientation. The 3D full-wave commercial package, Ansoft HFSSv10 was utilized in assisting the optimization of the antenna.

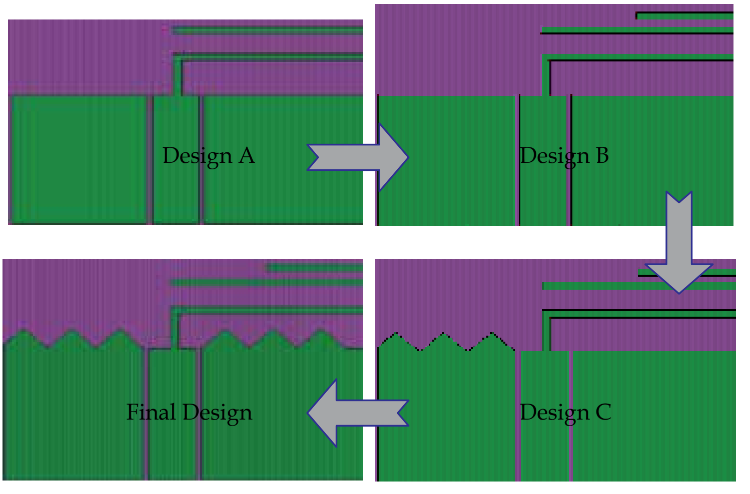

Figure 5. Adopted design steps of the proposed antenna

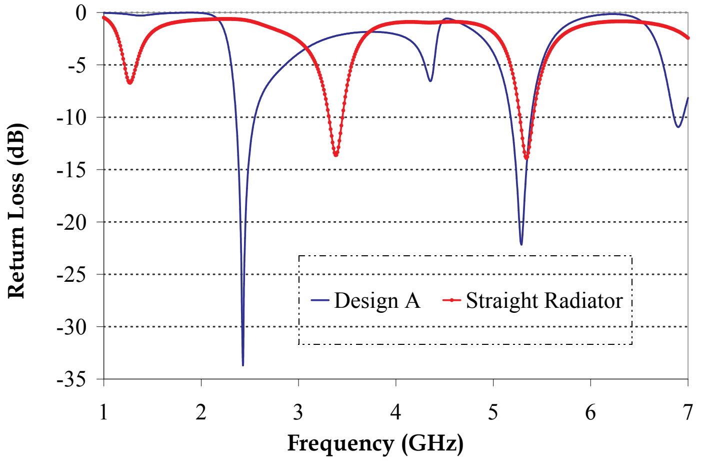

Figure 6. Comparison between straight and folded design (Design A)

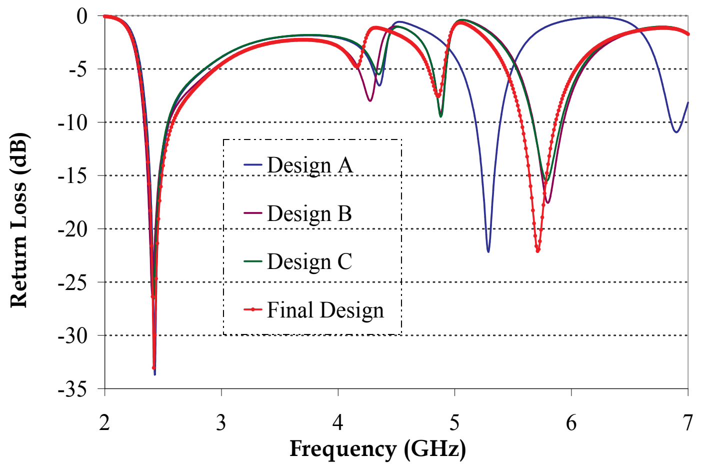

Figure 7. Improvement in impedance matching

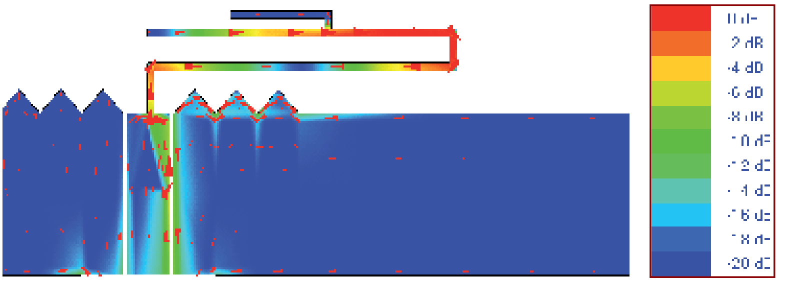

Figure 8. Surface current distributions of the antenna at 2.45 GHz

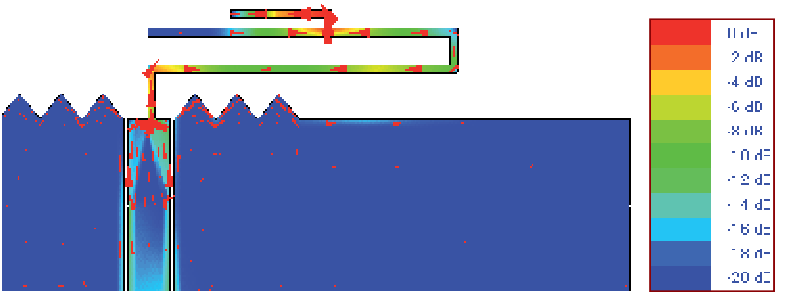

Figure 9. Surface current distributions of the antenna at 5.8 GHz

As shown in Fig. 6, it was observed that folded configuration is better suited for a good impedance matching and directional characteristics; while the radiating strip is placed straight, it acts as a long monopole antenna, resonating (f_{r1}) in some lower value. When folded, the coupling effects among the horizontal parts and ground plane appear and the radiating strip acts like a quasi-folded dipole antenna.

Design B was then introduced to provide desired dual band characteristics. The basic folded strip was designed to support the lower frequency band of ISM 2.45GHz and the forth resonance (f_{r4}) was dragged down to the desired 5.8GHz by introducing the small top branch. Thus small top branch confirms the proper selection of upper band to ISM 5.8GHz. However, it is the main folded strip which supports the small top branch for its radiation and impedance matching. Next, three optimized POES cells were inserted on the top edge of the left co-planar ground plane in Design C, which provides better impedance matching. Lastly, the final optimal design (Final Design) of the proposed antenna was derived by introducing another three POES cells in the upper left edge of the right ground plane. This orientation of POES cells improves both the impedance matching and bandwidths of both the desired bands (f_{r1}, f_{r4}). It is noted that the second resonance (f_{r2}) is generated mostly from the lower arm of basic folded strip; and the third resonance (f_{r3}) is influenced by the upper arm. Hence introduction of the small top branch vitally changed f_{r3}, while the resonance did not change with the application of POES. On the other hand the matching of f_{r2} varies by the affixation of POES cells. Fig. 7 describes the improvement in impedance matching through the design procedure.

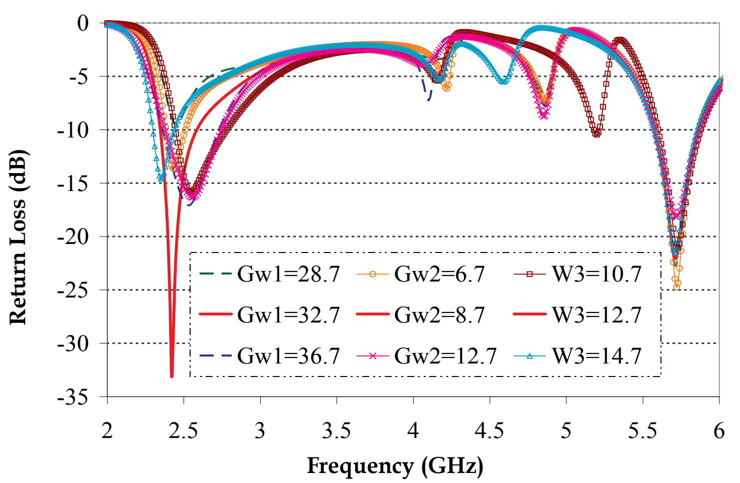

Figure 10. Comparison of Return Loss of the proposed antenna as a function of G_{w1}, G_{w2} & W_3 which dominate only lower operating band

In order to gain further understanding of the way resonances are excited, we also examine surface current distributions of the proposed antenna extracted from the full-wave, method-of-moment based electromagnetic simulator Zeland IE3D. From Fig. 8 & 9, it is evident that at both resonating frequencies, the current density is indeed higher on the folded strip of the antenna, thus the dimensions of the folded strip are assumed to govern both bands. The top small branch is active only in the upper frequencies, and has so effect for the 2.45 GHz resonance. So the optimal value of top small branch is vital for 5.8 GHz operation. Nevertheless, it is noted that the ground plane do not resonate in any of the desired resonances, but it provides better impedance matching for the desired bands. It is seen that the triangular POES cells increase the current path in the ground plane without influencing the currents on the radiating strip; hence only effects the scattering parameters, not radiation characteristics.

4.3. Optimization, parametric analysis & guidelines

A parametric analysis of the proposed antenna was carried out in order to illustrate the optimization process of the proposed antenna. The results are exhibited in Figs. 11 to 14. All the parameters have been studied to find the impact of the impedance matching, especially on the resonance frequencies and bandwidth.

It is observed that both the bands varied in terms of resonance, whenever the dimensions of the lower portion of folded strip, like L_1, L_2, W_1 and W_2 are changed. The length, x of the triangular POES cell do not have much effect on the antenna performances, but the height, y is very crucial for the bandwidth of the lower band and adjusting the upper band. Also, the number of POES cells are important for adjusting the impedance matching of both bands.

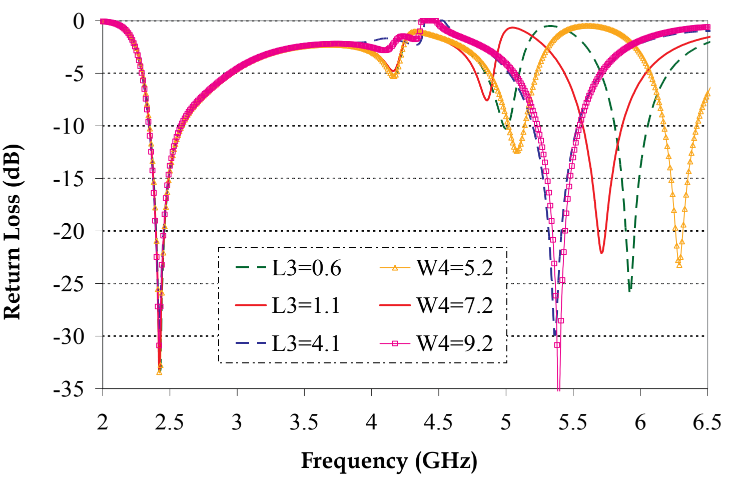

Figure 11. Performance comparison of Return Loss of the proposed antenna for the variation of L_3 & W_4 which dominate only higher operating band

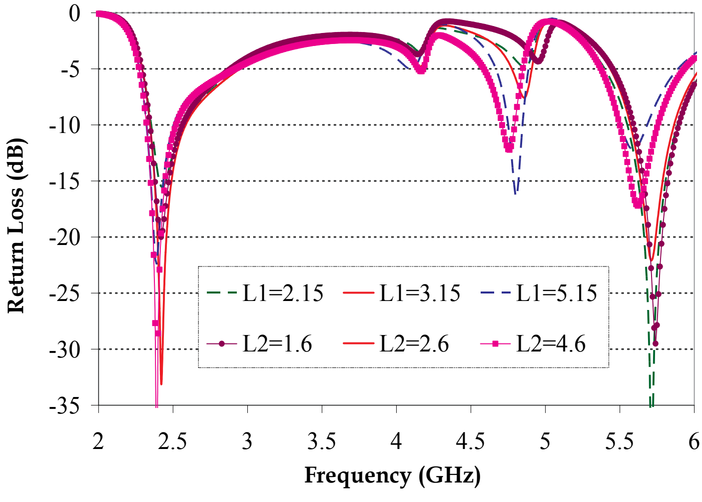

Figure 12. Return Loss comparison of the proposed antenna as a function of L_1 & L_2 which dominate both the higher and lower operating bands

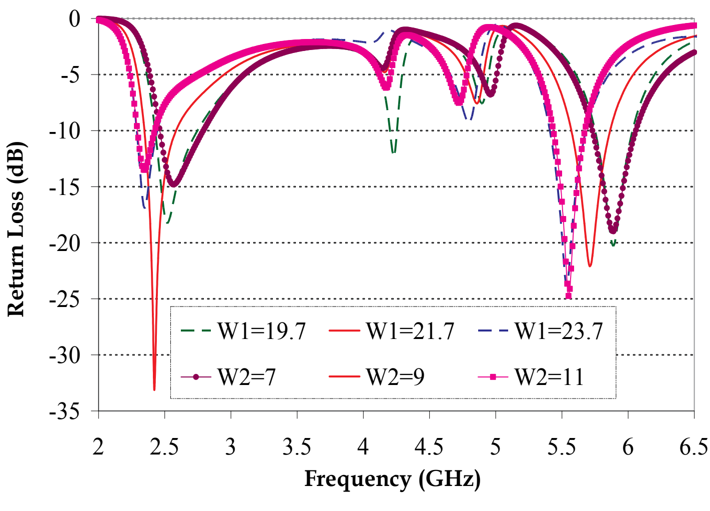

Figure 13. Comparison of Return Loss Vs Frequency of the proposed antenna when the values of W_1 & W_2 are varied that dominate both the operating bands

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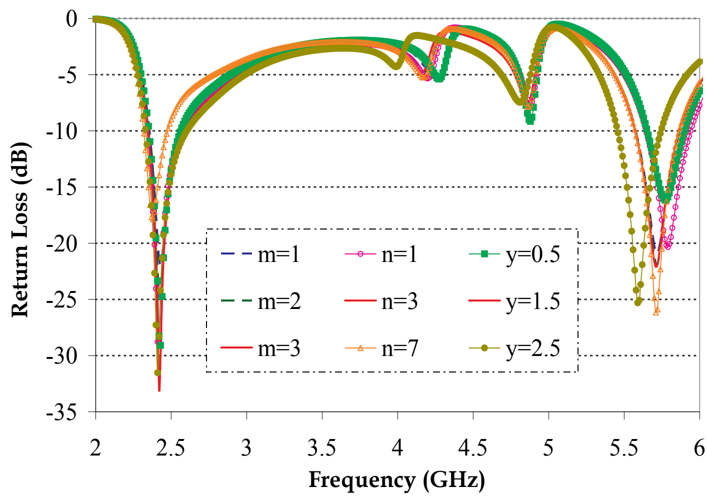

Figure 14. Dependencies of lower & higher operating bands for various heights (y) of the POES as well as for various left POES numbers (m) & right POES numbers (n)

The bandwidth and resonating frequency of the lower frequency band can be further improved by increasing the structure of the ground plane. However, in that case the return loss degrades and the antenna becomes bigger in size. As a design guideline, it is suggested that the dimension of W_3 is very useful for tuning up the lower resonance without changing the overall antenna profile. It is also feasible to generate another resonance near 2.45GHz by adding another radiating upper element with the existing one. But the high electromagnetic coupling makes it difficult to match the reflection coefficient; even in some cases the antenna might loose its front-directive radiation characteristics when achieving multi resonance near lower operating band.

After dealing with the lower band, the upper band can be tuned by proper selection of L_3 and W_4. Nevertheless, if the investigated front-directional antenna was required to operate in a number of discrete bands for higher frequencies, a set of top branches equal to the number of the resonating bands could be used. In that case, the coupling effect should be carefully eliminated by adjusting the width, W_4 and distance, L_3 for each top branch.

These are illustrated in Table 1 for better realization of the antenna geometry. The calculated parametric values of the radiating strip are based on the guided quarter wavelength of the substrate of the predicted dominating portion at the resonances; the rest are assumed in an arbitrary manner. Afterwards all the parameters are optimized through empirical observations.

Parameters	Calculated Value	Optimized Value	Variation	Lower Band			Upper Band		
				f_{r1}	$\|RL\|$	BW	f_{r4}	$\|RL\|$	BW
GW_2	-	8.7	>	↑	↓	↑	-	↑	-
			<	-	↓	↓	-	↓	-
GW_1	-	32.7	>	↑	↓	↑	-	-	-
			<	-	↓	↓	-	-	-
GL_1=GL_2	-	10	>	↓	↓	↓	-	↓	-
			<	↑	↓	↓	~	-	~
L_1	-	3.15	>	↓	↓	-	↓	↓	↓
			<	-	↓	-	-	↑	↑
L_2	-	2.6	>	↓	↑	-	↓	↓	-
			<	-	↓	-	↑	↑	-
L_3	-	1.7	>	-	-	-	↓	↑	-
			<	-	-	-	↑	↑	-
W_1	19.7	21.7	>	↓	↓	↓	↓	↑	-
			<	↑	↓	↑	↑	↓	-
W_2	12.9	9	>	↓	↓	↓	↓	↑	-
			<	↑	↓	↑	↑	↓	-
W_3	12.9	12.7	>	↓	↓	↓	-	-	-
			<	↑	↓	↑	-	-	-
W_4	6.8	7.2	>	-	-	-	↓	↑	-
			<	-	-	-	↑	~	-
x	-	3	>	-	-	↓	-	-	-
			<	-	-	-	-	-	-
y	-	1.5	>	-	-	↑	↓	↑	-
			<	-	-	↓	↑	↓	↓
m	-	3	>	-	↑	↑	-	↑	↑
			<	-	↓	↓	-	↓	↓
n	-	3	>	↓	↓	↓	~	~	-
			<	-	↓	↓	↑	↓	↓

* '-' represents the frequency phenomenon is independent for the increment of the parameter. '~' represents the non-monotonic fluctuation of the criteria upon increasing the geometry. '↑' and '↓' represent the enhanced and deteriorated phenomenon of the antenna upon changing parameter-values.

Table 1. Sensitivity of the antenna resonance frequencies (f_{r1}, f_{r4}), return loss (|*RL*|) and bandwidth (*BW*) when varying geometric parameters

4.4. Prototyping & measurements

The antennas were fabricated with the optimized parameters for experimental verification. A photograph of the prototypes is presented in Fig. 15. An Agilent N5230A PNA-L network analyzer was used to measure the electrical performance of the prototype. The simulated and measured return loss of the prototype is presented in Fig. 16. A good agreement between the simulated and measured results is observed. The small difference between the measured and simulated results is due to the effect of SMA connector soldering and fabrication tolerance. The measured return loss curve shows that the proposed antenna is excited at 2.45 GHz band with a –10 dB return-loss bandwidth of 320 MHz (2.35–2.67 GHz) and at 5.8 GHz band with an impedance bandwidth of 310MHz (5.6–5.91 GHz). The maximum return loss of -28.4dB and -34.2dB is obtained at the resonant frequencies of 2.46 GHz and 5.76 GHz respectively. Most of the desired frequencies are below -15dB level. The narrowband characteristics are useful to minimize the potential interferences between the RFID system and other systems using neighboring frequency bands such as UWB, WiMAX etc.

Figure 15. Photograph of the fabricated prototypes

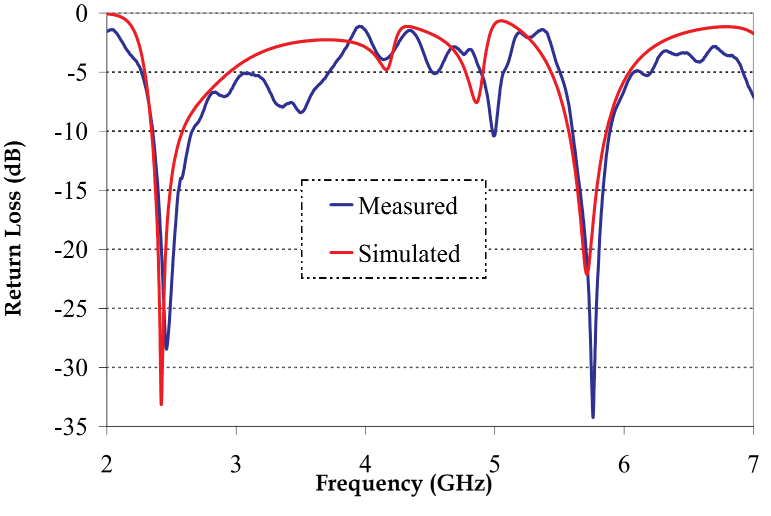

Figure 16. Return loss comparison of the proposed prototype

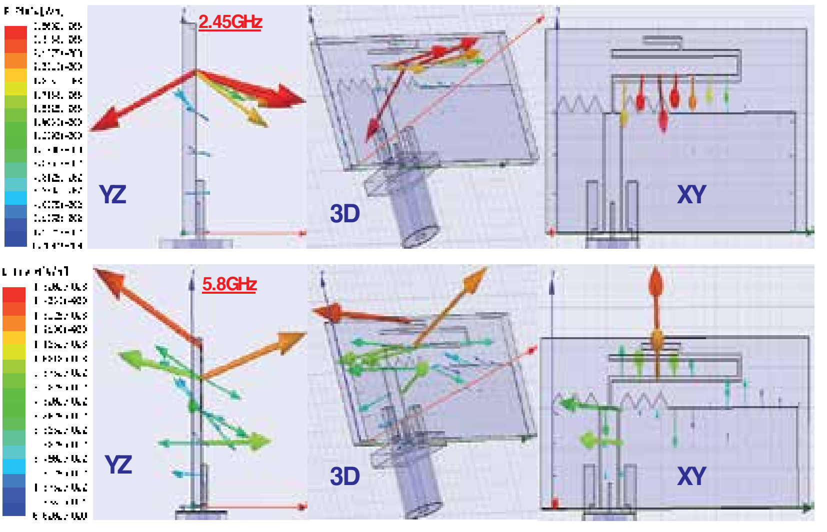

Figure 17. Electric field vector distribution of the proposed antenna

The electrical field vector distribution of the proposed antenna at frequencies 2.45 and 5.8 GHz is illustrated in Fig. 17. This distribution is extracted from HFSS software. It is noticed that the vital electric fields are generated from the folded resonating portion. The middle horizontal portion of the strip generates the radiation and the upper horizontal directs the energy propagation towards the end fire direction. The ground plane acts more likely as a reflector or suppressor. It mainly suppresses the back radiation and improves the impedance matching of the radiation element. The electric fields generated from the top edge of the ground plane are observed to extend in the forward direction. Thus it forces the electromagnetic energy and produces the front-directional radiation patterns. The measured radiation patterns of the fabricated prototype antenna at 2.45 and 5.8 GHz are illustrated in Fig 18. It is seen that the antenna provides front-directional radiation pattern for both bands. More importantly the cross-polarization levels are low (at least -10 dB) in both E- and H-planes. Also the front to back ratio in the scale of -10 dB is observed in the lower resonance; and at upper band it increases around the scale of -20 dB. The peak gain of the prototype is found to be 3 and 3.2 dBi at 2.45 and 5.8 GHz respectively.

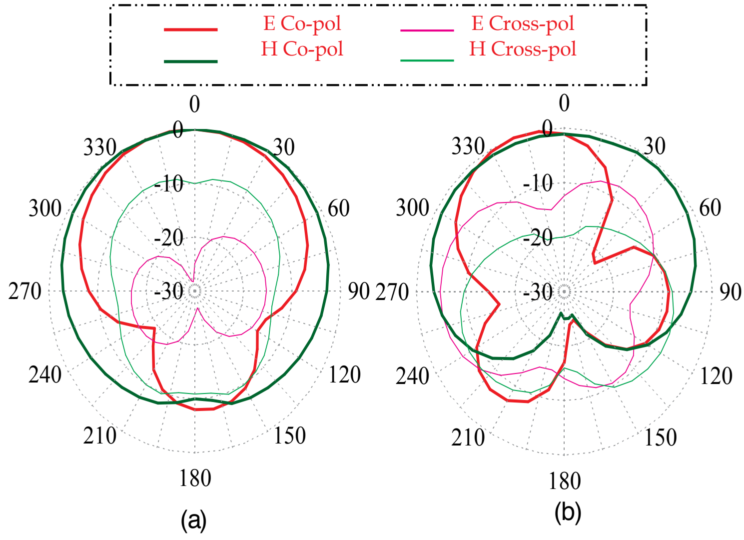

Figure 18. Measured normalized radiation patterns of the fabricated prototype at (a) 2.45 and (b) 5.8 GHz

4.5. Guidelines of future works

The design procedure of the presented dual-band antenna is applicable for multi-band extension. Following this design and optimization steps a more efficient antenna covering triple band including UHF and ISM microwaves is quite feasible. However, the antenna profile will increase when the operating frequency decreases, but yet the front directionality of the antenna is very effective for the compact handheld RFID reader design.

5. Conclusion

This chapter reveals the advantages and limitations of forward directional antennas to the readers for compact handheld RFID operation for multi-band operation. A comprehensive review and limitations of RFID technology concerning the prospects of directional antennas and propagation for both single and multi-band operation are presented in this chapter. The technical considerations of directional antenna parameters are also discussed in details in order to provide a complete realization of the parameters in pragmatic approach to the directional antenna designing process, which primarily includes scattering parameters and radiation characteristics. The antenna literature is also critically overviewed to identify the possible solutions of the directional antennas to utilize in single and multi-band handheld RFID reader operation.

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Chapter 9

RFID Textile Antenna and Its Development

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Marek Neruda

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53521

1. Introduction

Textile fabric material has become one of the most important things in life. In early times people used to wear the animal skin to cover their body. The advance form of this is all the clothes we wear today. They protect our body from changing environment conditions and keep us warm. As the technology is increasing day by day, it is influencing every sector. With the increase in wireless technology the electromagnetic radiation also increases. This increased radiation may affect human body severely. Thus with invent of problem, cure was also proposed to make a conductive textile material that could be equally wearable but at the same time work as a filter and does not allow the harmful frequency signal to penetrate into the human body. This completely changed the purpose of fabric material which was previously assumed to be used only for keeping human body warm as now it can be used for protection against the harmful electromagnetic radiation.

Going one step further ahead, we have tried to explore more advantage of textile fabric. With this new invention of conductive textile, we have designed an antenna for RFID (Radio Frequency Identification) applications made out of conductive textile material.

2. RFID basics

The RFID uses wireless technology to identify the objects. It consists of RFID tag and a reader. The bi directional communication between the tag and the reader is accomplished by the Radio Frequency (RF) part of the electromagnetic spectrum, to carry information between an RFID tag and reader. There are two types of RFID tag. Passive RFID tags are the ones that does not require any external power supply and works by receiving the signal from reader and retransmit the signal back to reader. Active RFID tag consists of external source in them. These are more complex than passive RFID tags and also give long range communication between tag and reader, when compared with passive tag.

The basic block diagram describes the bi directional communication between the tag and the reader, see Figure 1. The tag antenna in the block diagram receives the RF signal from the reader. This signal is received by the tag antenna, rectified and supplied to the chip to power it up. After the chip is powered up, it now acts as a source and retransmits the signal back to the reader. The reader after receiving the signal sends further to the computer to process the data. The method used to send the signal back to the reader from the tag is called back scattering.

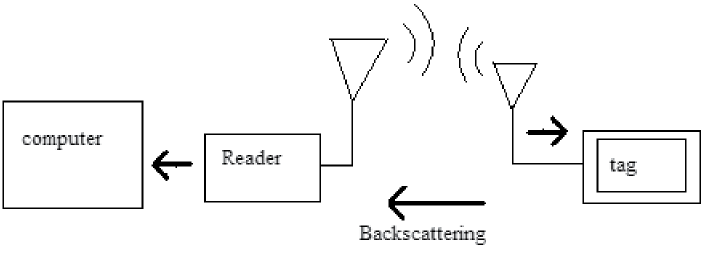

Figure 1. Block diagram of RFID system

2.1. RFID transponder

RFID Transponder is basically a radio transmitter and receiver. It mainly consists of two parts, antenna and the integrated circuit (IC). The main function of an antenna is to capture the radiated electromagnetic field by the reader at a definite frequency. The received electromagnetic energy is converted to electrical power and supplied to integrated circuit. The IC chip in the transponder has the capability to store the information to be transmitted to the reader, execute the series of command and also sometimes stores new information sent by the reader [1]. The IC chip mainly consists of a rectifier which rectifies the alternating voltage (AC) received by antenna to the continuous voltage (DC) and supplies to the rest of the circuit in the IC chip.

The IC used for the research is EM4222. This is a read only UHF identification device. The EM4222 is used as a passive chip for UHF transponder. It does not have any internal power supply source. The RF beam is transmitted by the reader. The antenna in the transponder receives the signal, rectifies it and supply the rectified voltage to the chip. The basic block diagram is shown in Figure 2.

From the block diagram, it can be seen that the radio beam is received at the terminal *A* in the chip. This signal is rectified to a DC voltage. The shunt regulator is used to limit the input voltage to the logic circuit. It also protects the Schottky diode which is used as a rectifier.

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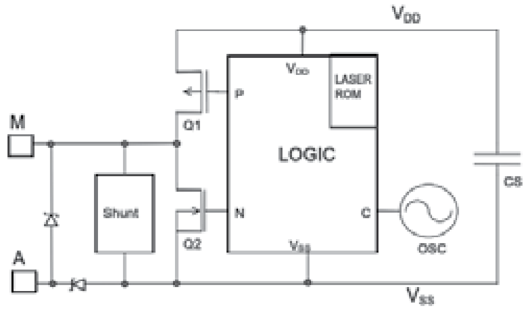


Figure 2. Block diagram UHF transponder EM4222 [2]

The on chip oscillator in the transponder is used to provide the clock pulse to the logic and also defines the data rate. On chip oscillator present in the transponder oscillates at a frequency of 512 kHz.

If the supply voltage is less than the threshold voltage, the oscillator and the logic cannot function properly and thus the transponder cannot be activate. At this condition, the logic is in reset position. This ensures that the transistor Q2 is off during power up and do not let any false operation to act.

Among the two transistors, Q1 is turned on during power up. Q2 is the modulation transistor which when turned on, loads the antenna with the information from the tag. Q2 is active when the data is to be transmitted from transponder to reader.

In order to have a maximum power transferred from antenna to the chip, the antenna should be designed such that the impedance of the antenna is conjugated matched with that of chip for the given frequency. Generally the chip has capacitive impedance so to have a perfect match the antenna impedance should be inductive in nature.

Parameter	Symbol	Test conditions	Min	Type	Max	Units
Oscillator frequency	Fosc	-40°C to +85°C		512		KHz
Wake up voltage	Vwu	VM-VA rising		1.4		V
Static Current Consumption	I STAT	VM=1v	400	1	600	µA
Input Series Impedance	Zin	869 MHz ; -10dBm	1.0	128-j577	1.8	Ω
Input Series Impedance	Zin	915 MHz ; -10dBm		132-j553	5	Ω
Input Series Impedance	Zin	2.45 GHz ; -10dBm		80-j232		Ω

Table 1. Electrical characteristics of IC EM4222, VM-VA=2V, TA=25°C, unless otherwise specified [2]

2.2. RFID matching

The tag antenna receives RF energy from the reader. The tag antenna works for a definite resonant frequency. So when the reader transmit RF signal with the desired frequency, the tag receives the signal and supplies to the chip which is attached to it in the transponder. The chip after getting sufficient voltage is able to wake up and hence retransmit the signal at the same frequency to the reader. Thus the purpose of matching an antenna with its load is to insure that maximum power transferred from antenna to chip. To do this, it is needed to have a perfect match between the antenna and the chip. Perfect antenna matching can be achieved by changing the dimension of an antenna, by adding a reactive component or implementing both of them. A mathematical expression can be overviewed as depicted in Figure 3.

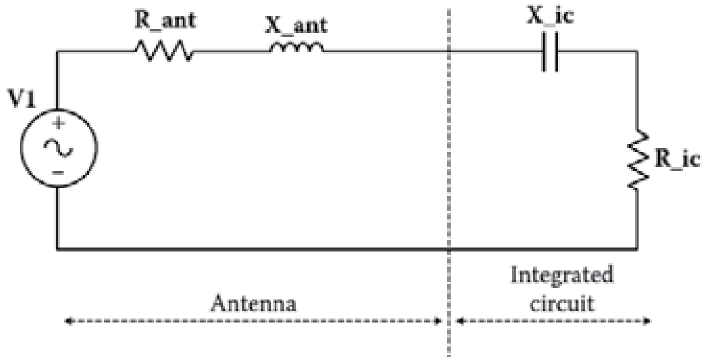


Figure 3. Series model for transponder chip and antenna [3]

The power delivered form antenna to the load or chip is given as [3]:

$$P_{l}=\frac{R_{ic}}{2\left[(R_{ant}+R_{ic})^{2}+\left(X_{ant}+X_{ic}\right)^{2}\right]}V^{2}{}_{ant} \tag{1}$$

In the above equation it can be seen that the maximum power can be delivered from the antenna to the IC only if $R_{ic}= R_{ant}$ and $X_{ic}= - X_{ant}$. Thus it can be observed that the maximum power can be delivered from antenna to load only if they are conjugate matched. This gives one of the favorable conditions for antenna designer as generally the antenna impedance is inductive in nature and the impedance of the chip is capacitive.

In this research the antenna is designed to work at 869 MHz. At this frequency the input series impedance of the chip is 128-j577 Ω. Thus the requirement is to have antenna impedance of 128+j577 Ω such that it is complex conjugate matched with the load and maximum power is transferred.

Conjugate Match Factor (CMF) is the factor which tells how good matching is done between the chip impedance and the antenna impedance. It can be described as the ratio between antenna input power with given chip impedance Z_s and antenna impedance Z_a assuming Z_a is complex conjugate of Z_s.

The value of CMF changes between 0 and 1 in linear. To receive maximum power from the reader and retransmit the maximum power to the reader, the antenna impedance should be complex conjugate match and equaled with that of chip.

3. H-slot microstrip patch antenna for UHF RFID

In this section the passive UHF RFID tag design is discussed. This RFID tag is textile made and involving the human body as the object to be tagged.

The designed antenna layout is an H-shape slot place onto a patch, Figure 4.

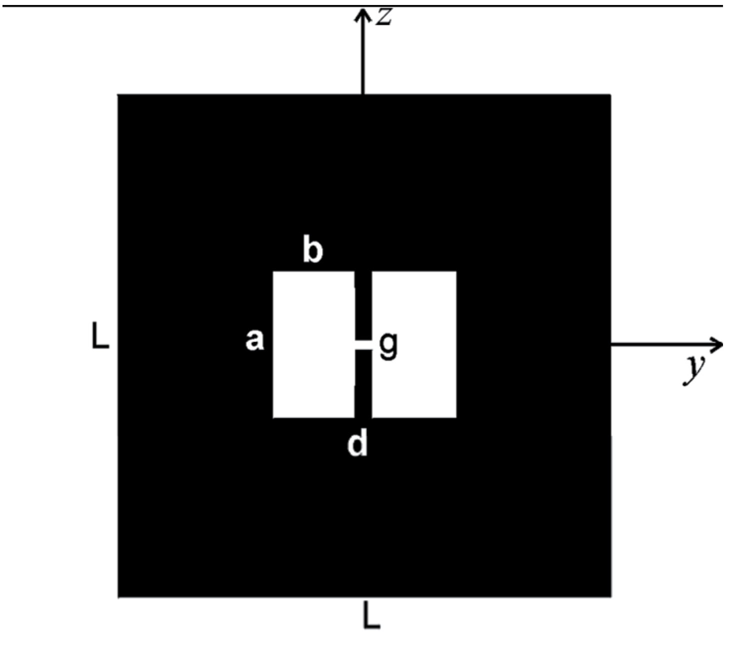


Figure 4. Geometry of nested - slot. The microchip is placed in the central gap of the slot [4]

The patch with H-slot is placed on a substrate and grounded by a conductive material to decouple from the human body. H-slot is a tuning slot for the required conjugate impedance matching between the microchip and the antenna tag. The maximum size of the antenna is 150 mm x 180 mm and the gain is rather poor around -7 dB due to the bidirectional radiation of the slot. But the maximum gain can be increased by increasing width of the tag antenna. And also the impedance matching is done by tuning the internal slot size.

Dielectric material of this patch antenna has a thickness of h and it has a longer face of it in the lower part which is placed on the human body through the conductive ground plane. It is an advantage to have longer ground plane because it will avoid the effect of human body radiation.

The radiation is produced by the patch open edge and by the slot. To achieve better radiation performance, width of the antenna can be increased depending of available place for tag. The dimension of the central gap is kept fix by the microchip packing but for tuning the other dimensions of the slot are optimized. The perfect conjugate matching should be done between antenna and microchip to obtain the maximum reading distance.

4. Observations

4.1. Impact on antenna performance with radiating element having different surface resistivity.

While working with textile antenna, it is found that the antenna is not working properly as it should work. This is because the antenna which is generally made of very high conductive material has very good radiation efficiency and gain. However the antenna made of conductive textile material has very high surface resistivity and hence lower conductivity. Because of this property of textile material it is difficult to choose the appropriate conductive textile material for desired gain. Also the height of dielectric constant plays a major role in determining the radiation efficiency.

Because of the problem of higher surface resistivity associated with the conductive textile material, a relation between surface resistivity, gain and radiation efficiency is analyzed. For this purpose the microstrip patch antenna is simulated in simulation software IE3D. First the measurement is performed by simulating two different microstrip patch antenna. Both of these antennas are simulated to work at a frequency of 2.45 GHz but with the radiating element having different surface resistivity.

The surface resistivity for two different radiating elements was chosen to be 0.02 Ω/sq and 1.19 Ω/sq. Fleece fabric is used as dielectric material which has a dielectric constant of 1.25. The antennas are simulated for reflection loss less than -40 dB and the result is noted.

It is observed from the simulation result that, though all the other antenna parameter are same, the difference in surface resistivity of the two radiating element affect a lot in their radiation efficiency and gain.

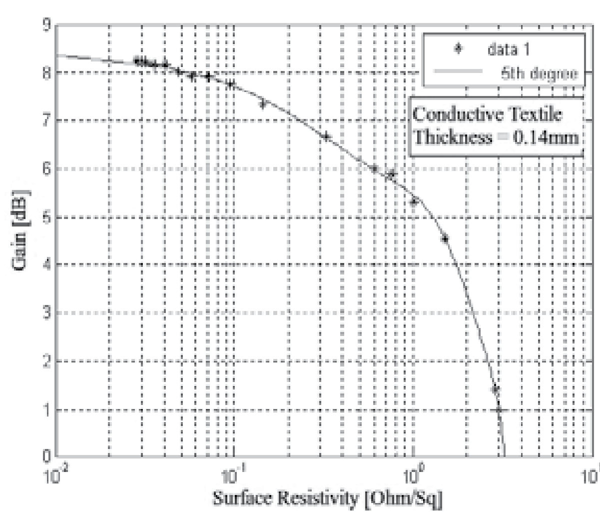


Figure 5. Gain Vs Surface Resistivity Plot

To know the relation between these parameters, a measurement is done for 20 different microstrip antennas keeping other parameters same and only changing the surface resistivity. The result is then plotted in matlab. These measurement results obtained when analyzing different antennas provide valuable information when a conductive textile material is to be used to design an antenna.

Figure 5 depicts that for very low surface resistivity, the gain is maximum. When the radiating element (antenna) surface resistivity is increased, the gain of the antenna starts to decrease.

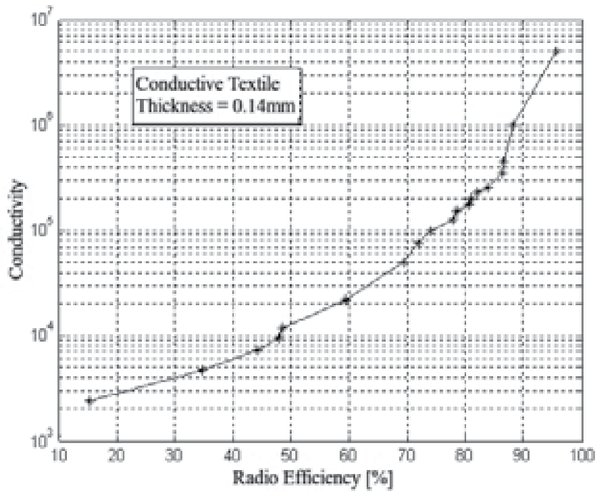


Figure 6. Radiation Efficiency vs. Conductivity Plot

Figure 6 illustrates the relation between the conductivity and the radiation efficiency for above mentioned conductive textile material when used as an antenna. Radiation efficiency is a ratio of power radiated by antenna and power input to antenna. If most of the power input to the antenna is radiated, then the antenna is said to have high radiation efficiency. It can be seen from Figure 7 that conductivity is related to radiation efficiency in logarithmic manner. When the conductivity of radiating element is lower, the radiation efficiency is also very small, and increases as the conductivity increases. However radiation efficiency does not increase in linear way, and to achieve the radiation efficiency in higher percentage, the conductivity of the radiating material should be very high.

The entire simulated antenna has reflection (S_{11}) less than -35 dB. However the entire antenna does not have same S_{11}. This affects the smoothness of the curve obtained in Figure 5 and 6.

4.2. The impact on antenna performance when the thickness of dielectric material is changed to different values.

When the dielectric material thickness is changed, this affects the radiation efficiency. To analyze this effect, three microstrip patch antenna is designed.

Frequency	2.45	GHz
Surface resistivity of radiating element	0.02	Ω/sq
Thickness of radiating element	0.14	mm
Dielectric material	Fleece fabric	-
Dielectric constant	1.25	-
Height of Dielectric material	1, 2, 3	mm

Table 2. Technical specification for the antenna

Three rectangular patch antennas are designed for different height of dielectric material. On doing simulation, various parameters like reflection, gain, radiation efficiency and antenna efficiency for different patch antenna were observed. The obtained results are shown in Figure 7 and 8.

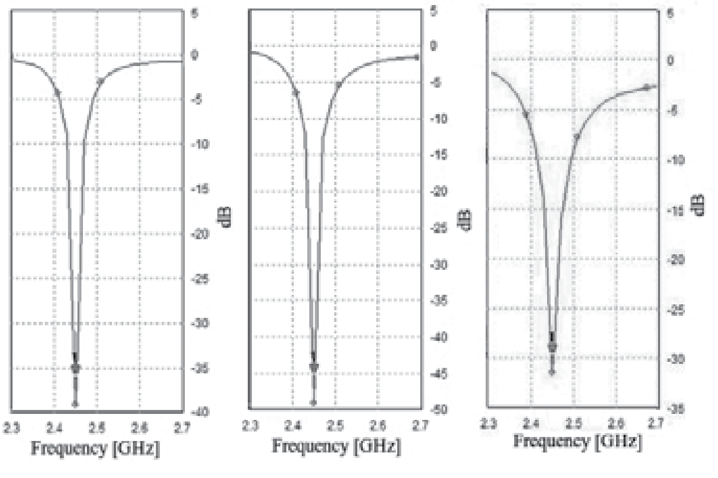


Figure 7. S_{11} for antenna with dielectric thickness 1 mm, 2 mm and 3 mm correspondingly

From above S_{11} plot it can be seen that the reflection is less than -30 dB for all three antennas with dielectric thickness 1 mm, 2 mm and 3 mm.

For the same specification of antennas, the radiation efficiency is measured with different height of dielectric material.

The above plot gives the measure of radiation efficiency of the antenna with three different thicknesses. It can be seen that for an antenna working at 2.45 GHz and dielectric thickness of 1 mm, the radiation efficiency is 61.2 %, for dielectric thickness of 2 mm, the radiation efficiency is 83.4 % and for dielectric thickness of 3 mm, the radiation efficiency is 90.2 %.

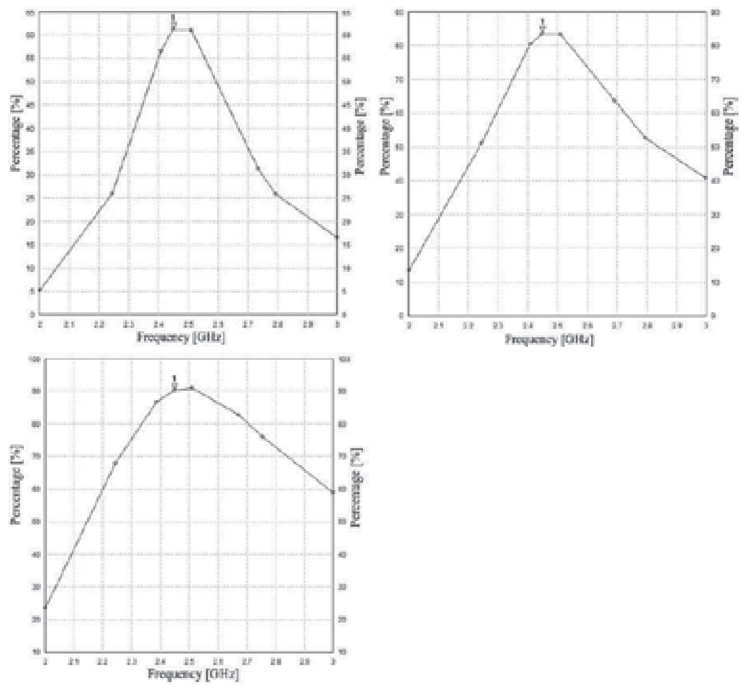


Figure 8. Radiation Efficiency for antennas having thickness 1 mm, 2 mm, 3 mm respectively

5. Conductive textile materials

The fabric that can conduct electricity is called conductive fabric. The conductivity of the fabric depends on how it is manufactured. Conductive fabric can be made in various ways. They can either be produced by metal inter woven fabric during manufacturing or by metal coated fabric [5] also called electro thread. These conductive textiles have wider application in various fields as they are used for shielding human body and some special equipment from external electromagnetic radiation, and also as pressure sensor or flexible heaters, which are made out of easily wearable conductive textile [6].

For a good design of a textile antenna, the conductive fabric should satisfy some of the conditions as given below.

- The electrical resistance of the conductive textile fabric should be small in order to reduce the ohmic losses in the fabric.
- The surface resistivity should be homogeneous over the entire conductive textile fabric i.e. the variation of resistance should be minimum.
- The fabric should be flexible enough to be able to use as a wearable antenna.

The antenna performs better if the conductive textile fulfills the above given characteristics.

Non woven fabric

By the name it can be concluded that non woven fabric is prepared by neither knitting process, nor are woven fabric. Thus the non woven fabric does not go through the initial stage of yarn spinning and also a definite web pattern as that of a woven fabric is not obtained. Non woven fabric manufacturing process is similar to that of paper manufacturing process.

The material used is Cu-Ni with the thickness measured in the lab is 0.14 mm.

Description	copper + nickel plated non-woven polyamide fabric
Roll widths	102 cm ± 2 cm
Surface resistivity	Max average 0,02 Ohm/square
Shielding effectiveness	70-90 dB from 50 MHz to 1 GHz
Purpose	conductive fabric for general use
Temperature range	-30 to 90 (degree centigrade)

Table 3. Technical specification of Cu-Ni textile material [7]

These kind of fabric are generally manufactured in three ways namely, drylaid syste, wetlaid system and polymer based system. After the fabric is manufactured, it is then strengthened. There are various ways for strengthening fiber web as by using chemical means by spraying, coating. This can also be achieved by thermal means by blowing air or by ultrasonic impact which partially fuses (connects) the fiber thread. Thus finally the metal layer is coated.

Woven Fabric

Woven fabric is a construction design for lab use at CTU in Prague. The woven fabric consists of silver nano particles attached to the thread of fiber when being constructed and then woven to form a conductive textile, Figure 9.

Name	Betex
Materials Used	Shiledex (60%), Polyster (40 %)
Number of fiber threads per centimeter	20
Surface Resistivity	1.19Ω /sq.

Table 4. Technical specification of Betex textile material

5.1. Electrical resistance and resistivity of textile materials

Electrical conductivity of textile materials is calculated from electrical resistivity as:

$$\sigma = 1/\varrho \qquad (2)$$

whereσ is electrical conductivity [S/m], ϱ is electrical resistivity [Ω m].

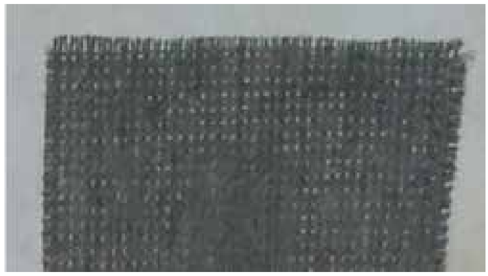


Figure 9. Photo of woven Betex textile material

Electrical resistivity can be obtained via resistance mesurement [8-10]. We differentiate surface and bulk electrical resistance. Surface resistance is defined as the ratio of a DC voltage U to the current I_S which flows beteen two specific electrodes. The electrodes are placed on the same side of measured material and it is assumed all currents flows only between electrodes and do not penetrate into the bulk of material [8].

Bulk resistance or electrical resistance takes into account all currents flowing in the material, not only on the surface. It can be measured by RLCG bridge or DC power source (showing voltage and current values).

5.2. Resistance modelling

The textile material can be modelled as finite grid of resistors. However, it assumes only woven fabric [11]. The example is depicted in Figure 10.

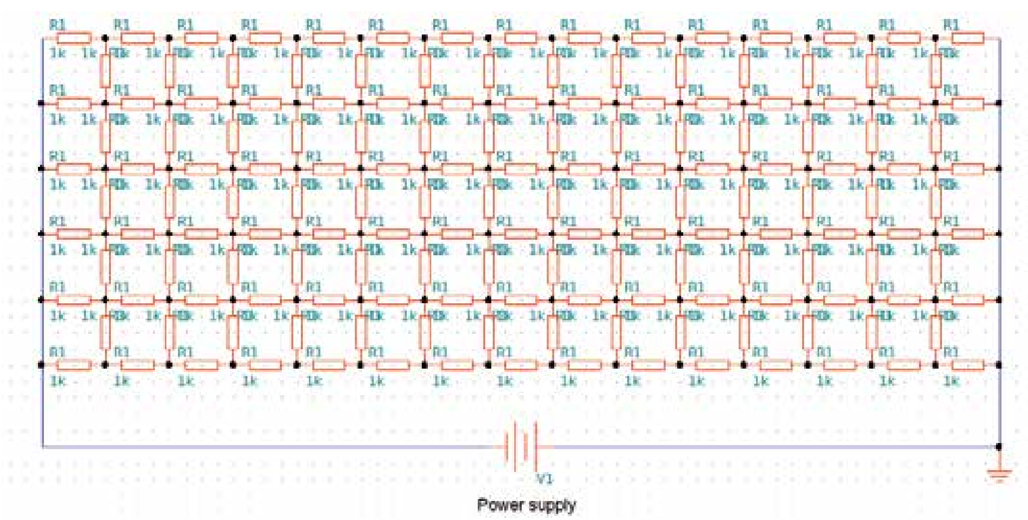


Figure 10. Equivalent circuit diagram of Betex textile material

Measurement of resistance (bulk or surface) is based on placing two square electrodes on two ends of the woven textile material. The structure can be interpreted as series-parallel connection of resistors. The battery represents electrodes and resistors the textile fibres.

The equivalent circuit diagram can be simplified with respect to basic physical laws. Equipotential points in this diagram are in all individual „vertical" resistor connections. The resistors placed between the points with same potential can be eliminated because they are equalled to zero. The voltage probes are placed in the equipotential points in Figure 11. The results are depicted in Figure 12. All probes reach the same value and therefore the resistors can be eliminated.

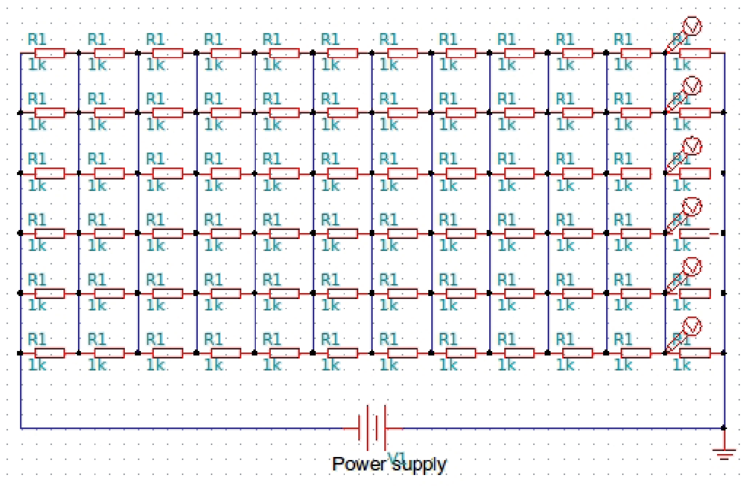


Figure 11. Simplified equivalent circuit model

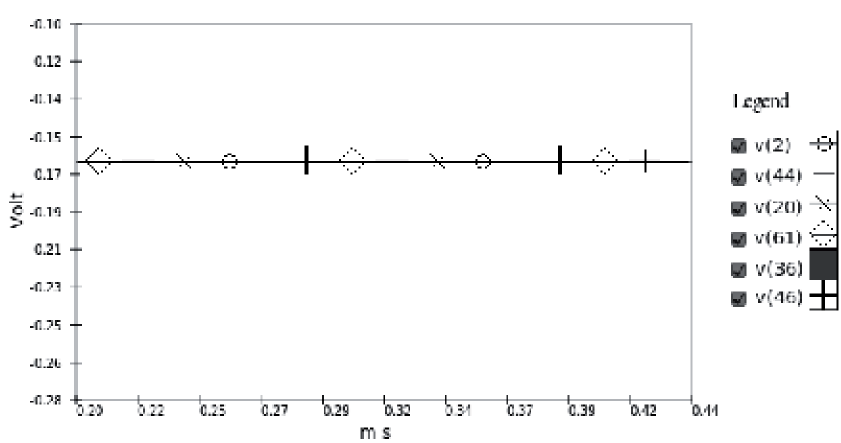


Figure 12. Result values of placed voltage probes.

The resultant resistance of this model can be calculated as series-parallel connection of resistors as:

$$R = \sum_{1}^{12} \frac{R1}{6} = \frac{12\,R1}{6} = 2R1 \tag{3}$$

Formula (3) can be generalized as:

$$R = \sum_{n=1}^{r} \frac{R1}{s}, \;\; \mathrm{n,\ r,\ s} \in \mathrm{N} \tag{4}$$

where n, r represents number of squares in „horizontal" direction and s in „vertical" direction.

Considering Betex sample and setup measurement, the Betex sample reach dimensions 10 x 3 cm, 25 threads/cm in warp and 20 threads/cm in weft. Parameters n and s are then equalled to:

$$r = 10 \cdot 25 - 1 = 249 \tag{5}$$

$$s = 3 \cdot 20 - 1 = 59 \tag{6}$$

Resultant resistance is equalled to:

$$R = \sum_{n=1}^{r} \frac{R1}{s} = \sum_{n=1}^{249} \frac{R1}{59} = \frac{249R1}{59} = 4.22R1 \tag{7}$$

The parameter $R1$ represents a resistance element of used fiber which forms the whole fabric. It can be calculated from the dimensions of textile structure with the aid of fiber diameter measurement. $R1$ is set to 0.97Ω and $R=4.09\Omega$. It meands the structure is very conductive.

Figure 13. Measurement setup

5.3. Resistance measurement

The Betex sample is measured by RLCG bridge with respect to its calculated resistance. DC power source can cause sample damage at low voltage values (10 V corresponds to approx. 10 A). The measurement setup is depicted in Figure 13.

The measurement of Betex sample shows the resultant resistance is approx. 4Ω which confirms the modelling results.

6. Simulations

In this chapter different two antenna types are designed for the conductive textile material.The two designed antennas are H-slot antennas for RFID having an IC chip EM4222 at 869 MHz with the impedance 128-j577, microstrip patch antenna for RFID having T-match. Manual calculations and simulation results for all the antennas are presented below.

6.1. Simulation of H-slot patch RFID tag antenna

The wearable tags are designed on IE3D, fabricated and tested in real conditions. The overall size of the H-slot antennas is 180 mm x 200 mm. This big dimension of the antennas can be smaller by using a substrate which has a high dielectric constant, because the antenna size depends on the dielectric constant ε_r of the substrate and also the design frequency. In this design a fleece fabric is used as a substrate which has a dielectric constant of 1.25. This fabric is chosen because of its better radiation performance. When a substrate has low dielectric constant and small thickness then the designed antenna has good radiation performance. But if a small tag is requested then a substrate with high dielectric constant can be used.

Three different substrate materials are used for comparison. The first substrate is Polyethylene ($\varepsilon_r = 2.25$, thickness h =1.7 mm). This design gives smaller dimensions (145 mm x 160 mm) then fleece fabric.

Later on this substrate replaces with the fleece fabric to increase the radiation performance because of fleece's low dielectric constant.

Third design is made by a substrate material which has a very high dielectric constant ε_r, to reduce the antenna size. The material is silicone slab. Silicone slab is chosen because it is elastic, hydrophobic material and this property gives an advantage of avoiding the water absorption into the substrate, this is important property of silicone slab because when water absorbed into the substrate, the dielectric constant of the substrate changes. This also gives homogeneous connection between the substrate and radiating patch. The antenna design with silicone slab is giving as a size of 57 mm x 78 mm, much smaller than other designs. But a decreasing in the radiation performance is achieved. Thus there is a trade of between antenna performance and size of the antenna.

In this work, two different conductive textiles are used to design and fabricate two different tags, TAG1 and TAG2.

Parameter	Cu-Ni	BETEX
Frequency	869 MHz	869 MHz
Surface resistivity	0.02 Ω/sq.	1.19 Ω/sq.
Thickness	0.14 mm	0.35 mm
Conductivity	357143 S/m	2381 S/m

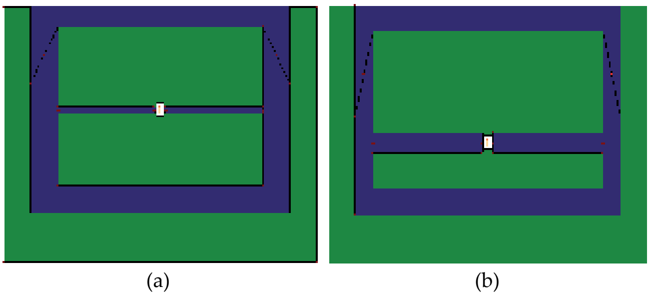
Table 5. Specifications for the conductive textile radiating element

Parameter	TAG1	TAG2
Conductive Material	Cu-Ni, conductivy of 357143 S/m	BETEX, conductivity of 2381 S/m
Substrate Material	Fleece Fabric	Fleece Fabric
Thickness of the Substrate	4 mm	4 mm

Table 6. Specification for simulating antenna (TAG1 and TAG2)

6.1.1. Antenna layouts and designs

Cu-Ni conductive textile has high conductivity and the designing with this conductivity gives better radiation performance then Betex textile which has low conductivity. The simulation of two antennas with two different materials having same dielectric substrate and the same dielectric constant is shown in Figure 14.



(a) (b)

Figure 14. Simulated H-slot antenna for radiating element having surface resistivity = 0.02(a), and surface resistivity =1.19(b)

As expected, the tag with high conductive material is giving better radiation performance. When a comparison made between this two tag's simulations, a high reading distance and high radiation efficiency are achieved from TAG1 which is designed with high conductive textile. This can be shown by the plot obtained from the simulation, Figure 15.

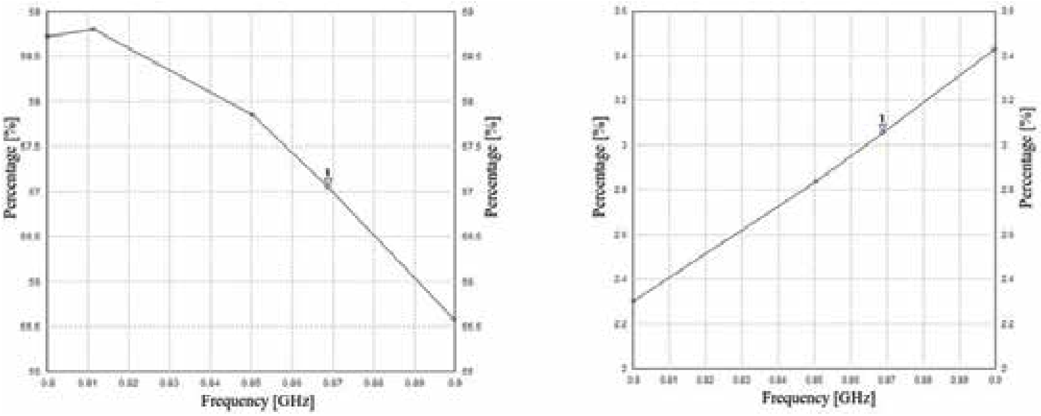


Figure 15. Radiation efficiency Vs Frequency plot for TAG 1 and TAG 2 respectively

It can be seen that radiation efficiency obtained for TAG1 is 57.1% and that for TAG 2 is 3.05%. As it is concluded before that the radiation efficiency is directly proportional to the surface resistivity of the radiating patch. Therefore, higher radiation efficiency is obtained for the TAG having lower surface resistivity. If the antenna were designed from copper material the simulated efficiency would be very high because copper has high conductivity then these conductive textiles. This is shown in later case. Therefore, this value of 57% radiation efficiency is quite good result for this conductive textile.

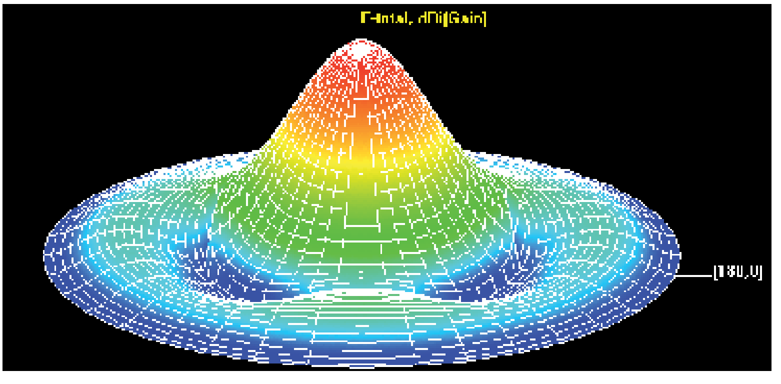


Figure 16. pattern of TAG1

The value of CMF is used to find how good the matching is in between the antenna impedance and chip impedance. The plot obtained for TAG 1 and TAG 2 is depicted in Figure 18.

From the above figure it can be observed that the CMF for TAG1 is 0.975 and that for TAG2 is 0.874. It can be considered that both of the tag antennas has good matching with the chip, however TAG 1 shows better match among the two.

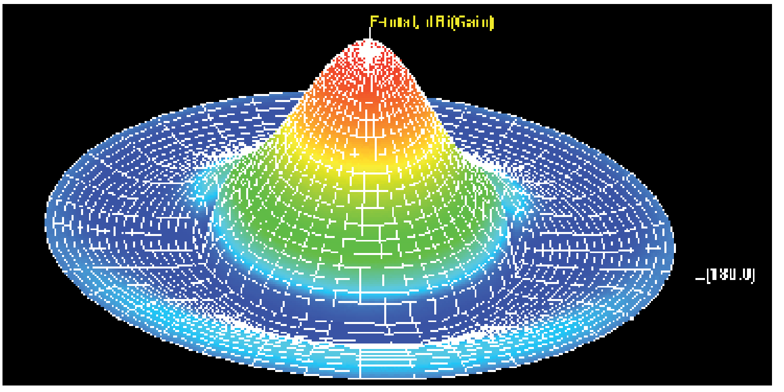


Figure 17. pattern of TAG2

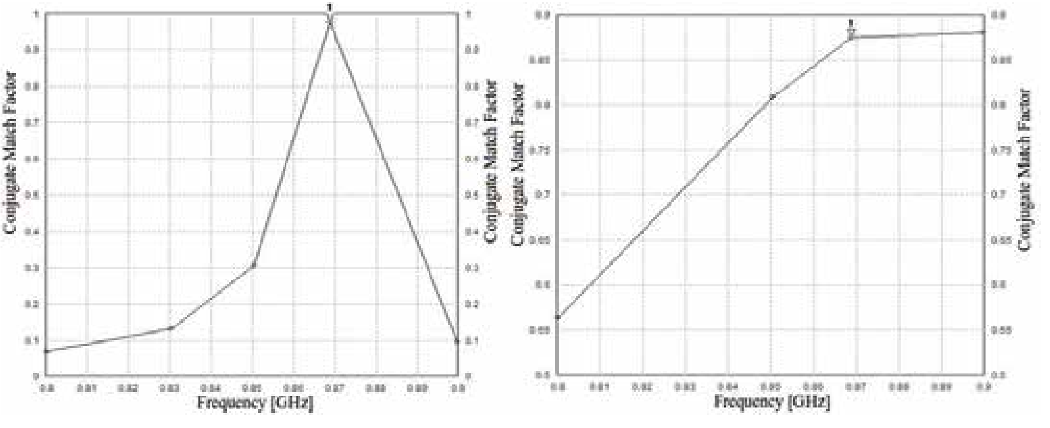


Figure 18. Conjugate match factor plot for TAG 1 and TAG 2 respectively

@869Mhz	TAG1	TAG2
Radiation Efficiency,	57.1%	3.05%
Conjugate Match Efficiency	28.5%	1.52%
CMF	0.975	0.874
Gain	-8.46dBi	-15.25 dBi
Directivity	7.89dBi	8.47 dBi
Size of the Tag Lg x Wg	180x200mm	180x200mm
Antenna impedance, Za	100+j597	206+j472

Table 7. The combined results obtained from the simulation of two tag antenna

6.1.2. Reading range calculation

The read range is obtained as:

$$d_{max} = \frac{c}{4\pi f}\sqrt{\frac{EIRP_R}{P_{chip}}\tau G_{tag}} \tag{8}$$

$$\tau = \frac{4R_{chip}R_a}{|Z_{chip} + Z_a|^2} \leq 1 \tag{9}$$

Here, chip sensitivity is -10 dBm and the maximum radiated power by the reader is 3.2 W EIRP. Thus from the formula the transmission power coefficient for TAG1 and TAG2 is equal to,

$$\tau_1 = 0.97 \tag{10}$$

$$\tau_2 = 0.87 \tag{11}$$

Thus the maximum range obtained is d_{max}= 2 m for TAG1 and d_{max}= 1.2 m for TAG2.

6.2. Comparison when different dielectric substrate used

A comparison is performed in simulation to compare the radiation efficiency of H-slot antenna, when the conductive textile (Cu-Ni) is used as radiating element. The comparison is made by changing the thickness of dielectric substrate (fleece fabric) to 2 mm, 2.56 mm and 4 mm. The simulation is performed for the conductor having the surface resistivity 0.02 Ω/sq to resonate at the frequency 869 MHz. For three different thickness values, three different antenna geometry and CMF and radiation pattern is achieved. The CMF for all the designs were measured to be more than 0.95 when measured in linear scale.

Figure 19 depicts the radiation efficiency obtained from 4 mm thick dielectric substrate is the highest and obtained to be 57.1 %, for 2.56 mm thick dielectric substrate is 43.4 % and that for 2 mm thick dielectric substrate is 35.8 %. The better performance is achieved with the antenna having thicker dielectric substrate.

6.3. Comparison when different dielectric material used

In this case the two dielectric materials are used. One is the fleece fabric with the dielectric constant 1.25 and the other is silicone slab with dielectric constant 11.9. The silicone slab with high dielectric constant is used to reduce the size of antenna and also hydrophobic in nature. This is very useful characteristics of silicon slab. The two antennas with two different materials are depicted in Figure 20 and 21.

As seen from the graph, the radiation efficiency of antenna using silicone slab and having higher dielectric constant, is reduced compared with the one using fleece fabric. Though the

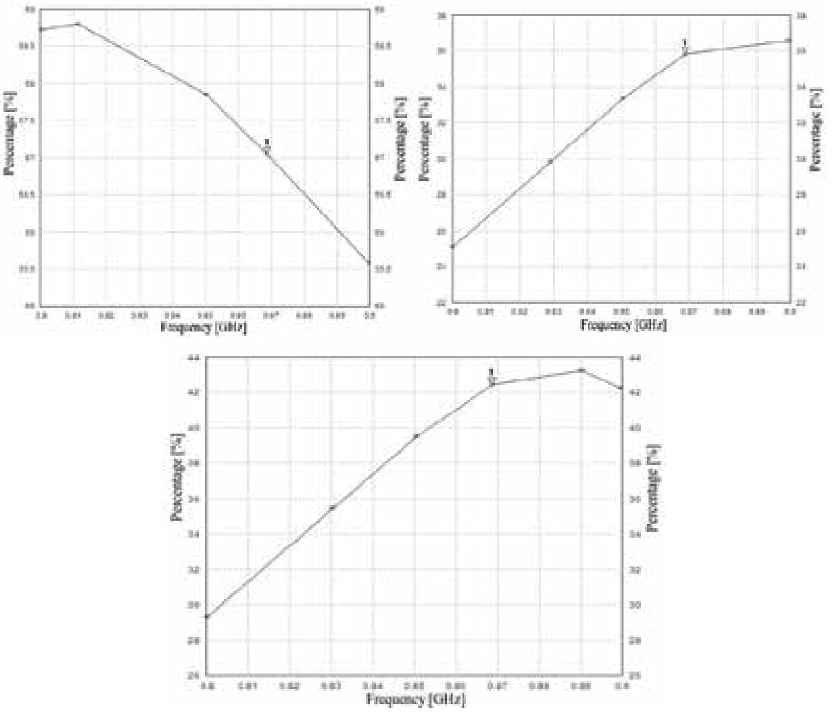


Figure 19. Simulation result of Radiation efficiency plot for Cu-Ni, with the height of dielectric substrate 2 mm, 2.56 mm and 4 mm.

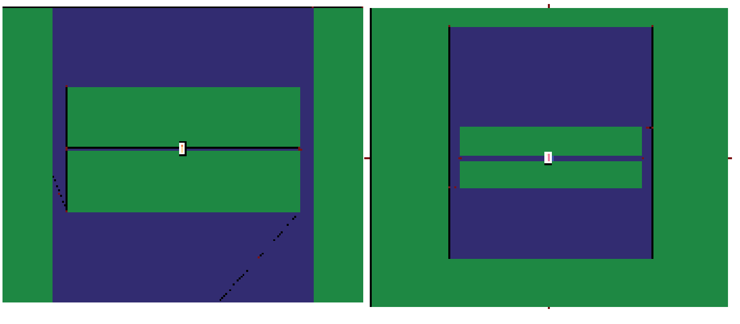


Figure 20. Antenna with Dielectric substrate fleece and antenna with dielectric substrate silicone slab respectively

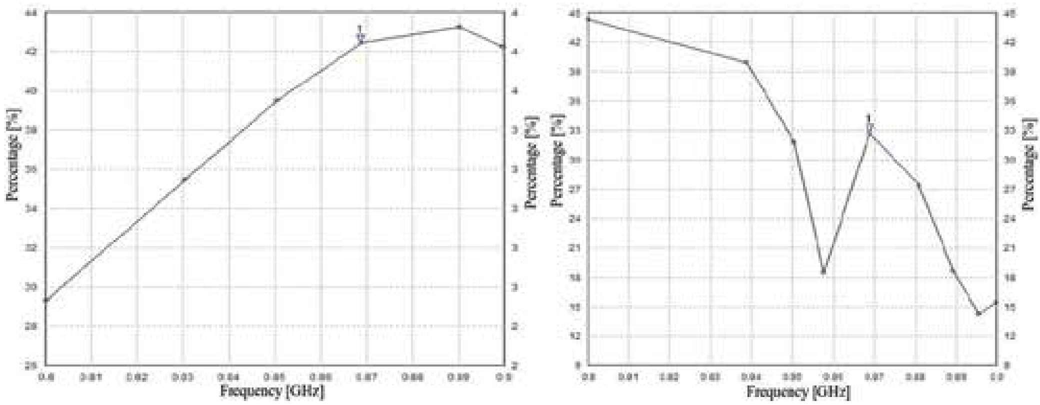


Figure 21. Radiation efficiency of antenna using dielectric substrate fleece (43.4%) and silicone slab (32.7%)

size of antenna was reduced, the efficiency was also decreased drastically. It is due to this reason fleece fabric is preferred.

6.4. Simulation of microstrip patch antenna for RFID application

This is another technique of designing RFID tag antenna. A rectangular parch antenna is used as a tag antenna for RFID. The microstrip patch antenna for RFID is designed for 869 MHz. The manual calculation of microstrip patch is calculated in the similar ways as for the rectangular microstrip patch in chapter 3, however the feeding is different. A T-match is used to match the impedance of the antenna to the chip. The calculated length is 150 mm and the width is 190 mm.

The dielectric material used is Fleece fabric with dielectric constant 1.25 and dielectric height of the substrate 2 mm. The radiating element is simulation of conductive textile material having surface resistivity 0.02 Ω/sq.

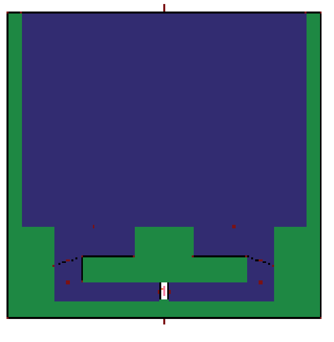


Figure 22. Microstrip patch antenna using T match

Frequency(869 MHz)	TAG3
Radiation Efficiency	41.82%
Conjugate Match Efficiency	20.91%
CMF	0.956
Gain	-7.99dBi
Directivity	8.162dBi
Size LxW	150x190
Imput Impedance , Za	92+j547
Reading distance	2m

Table 8. Simulated output results for TAG 3

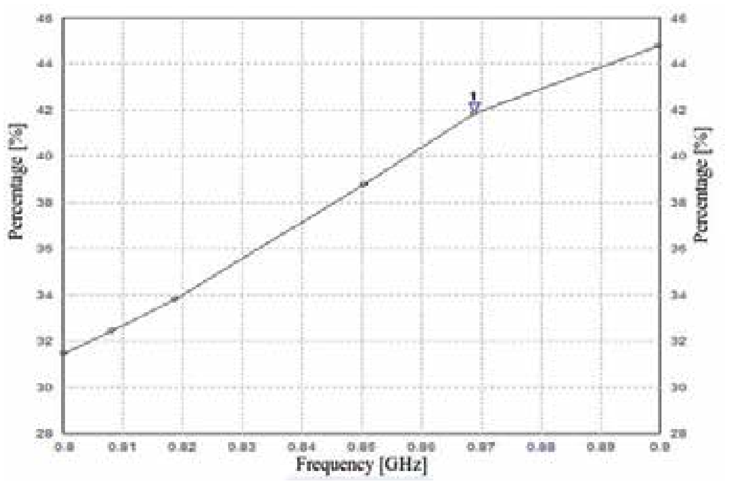


Figure 23. Radiation Efficiency Vs frequency plot for the tag antenna

Figure 23 shows the radiation efficiency obtained is 41.8 %.

7. Fabrication and measurement of H-Slot and patch RFID antenna

7.1. Results of fabrication and measurements of TAG1 and TAG2

For fabrication of these two tag antenna, the available fleece fabric had a thickness of 2 mm, so to have 4 mm thickness two layer of fleece is overlapped by using glue. The conductive material also attached to the substrate by using glue.

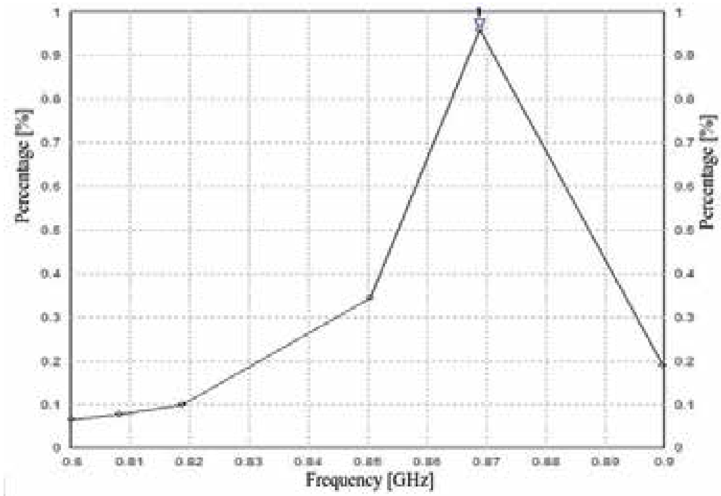


Figure 24. Conjugate match vs frequency for TAG 3 (CMF_{max}=0.956)

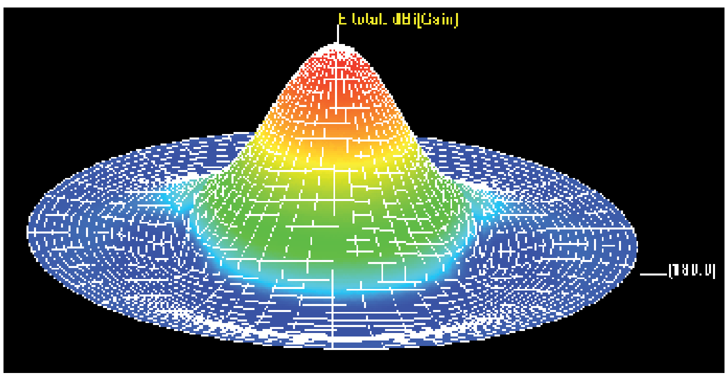


Figure 25. radiation pattern for TAG 3

Figure 26. Fabricated antenna (a), chip connection to slot arm (b) for TAG 1

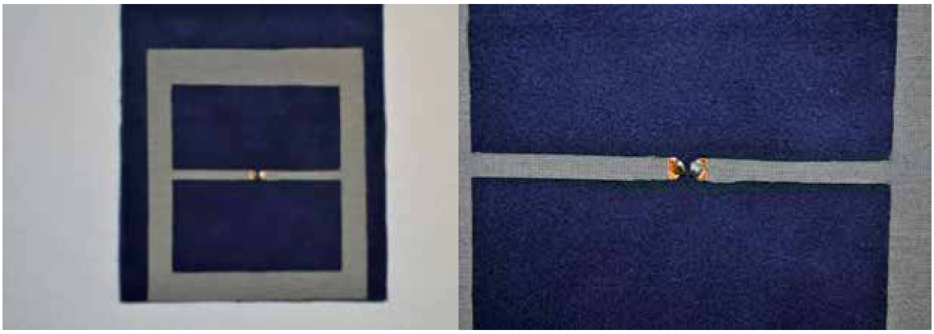


Figure 27. Fabricated antenna for TAG 2 and chip connection

Figure 28. Fabrication and Chip connection for TAG 3

As can be seen from the Figure 27 TAG 2 is constructed from Betex and being very difficult to connect chip by soldering, an alternative way is used. First a copper tape is attached, similar to that with microstrip patch and then the chip is soldered on top of it as shown in Figure. This not done with TAG 1, as it was not necessary.

To measure the tag performance, an RFID reader is connected to the computer.

The reader shown in the above figure generates the frequency signal which is captured by the tag antenna, and retransmit signal back to reader. This signal is received by the reader and is sent to the computer for further processing of the signal.

The RFI21 RFID Reader Demo application program is used in the computer to read the reader. This application uses Python 2.6 programming language in the computer to accomplish this task. The reader is manufactured by METRA BLANSKO a.s.

During the measurement, the reading distance of the TAG1 and TAG2 is measured. Tags are moved towards the reader's antenna till the reader detects the signal from the tag.

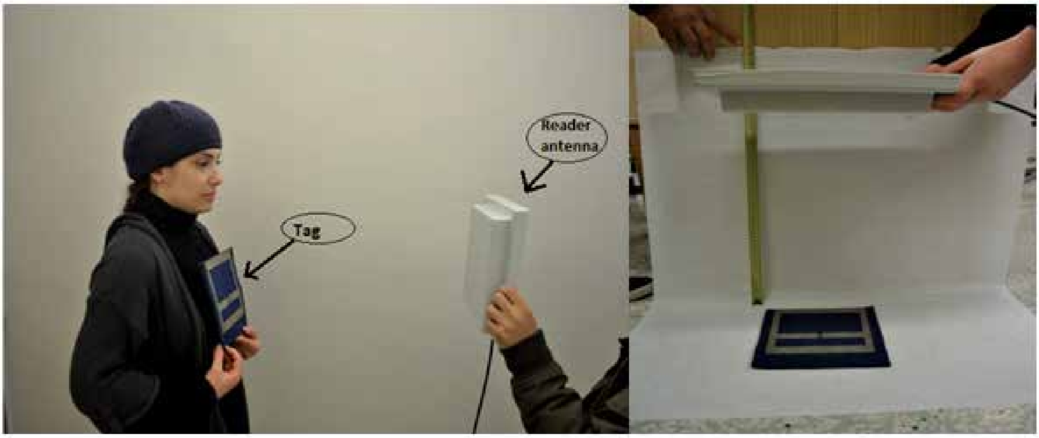


Figure 29. Measuring Reading distance of TAG1

As soon as RFID tag is detected by reader's antenna, the information is displayed on the computer.

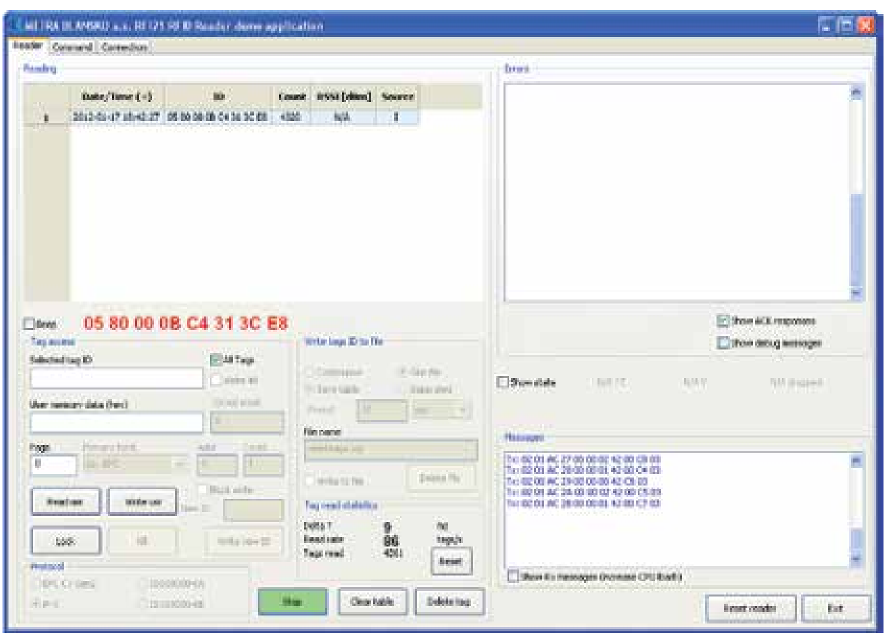


Figure 30. Application program detecting the EM4222 chip ID (in red)

EM4222 chip is used in the tag antenna. When the tag is detected by the reader the tag ID is displayed in the computer. This can be seen in the figure which is the ID of the chip in red color.

From the measurement results, the reading distance for TAG1 is measured to be 50 cm. This is quite smaller then simulated results because of the change in dielectric material due to non-precise determination of permittivity and also soldering process.

The reading distance for TAG2 is quite close the simulation results, 90 cm. The simulated reading distance for this tag is 1.2 m. Thus TAG 2 gave better performance and was very close to simulated values.

Range	TAG1	TAG2	TAG3
Reading range	50 cm	90 cm	60 cm

Table 9. Measured read range from the three designed tag

A short experiment was done to compare working of the fabricated tag and the tag available in the market. To make a comparison of reading distance, two different UHF RFID tag's reading distance were measured. The tags used were UPM Hammer 258-1 and UMP short dipole 211_2. These are the commercially available tag in the market.

Figure 31. UPM Hammer 258-1RFID tag (a), UMP short dipole 211_2 RFID tag (b)

Parameter	UPM Hammer 258-1 RFID tag	UMP short dipole 211_2 RFID tag	H-slot TAG2
Reading Distance	98 cm	152cm	90cm
Chip Protocol	EPS S1 Gento	EPS S1 Gento	IP-X

Table 10. Comparison of read range of manufactured tag with commercially available tag

The measurement was performed in open space in the lab.

8. Conclusion

Implementation of textile antennas for RFID tags represents a realistic developmental assignment, and as shown and practically proved, this arrangement yields good results. The successful operation of such textile antennas mainly requires the mechanical stability of the textile composite, which realizes a RFID tag antenna. A good function of the antenna and thus the sensitivity of the complete tag can be provided for just compliance with the mechanical construction and stability of required dimensions. A good choice of textile material for both electrically conductive structures and the insulating layer of the resultant fabric composite is the most important prerequisite for the successful implementation.

Textile RFID tags find its use at both person marking (marking of athletes, protective clothing and other functional ready-made textile products) and stock-in-trade marking in hospitals, packaging, etc.

Acknowledgements

This work was supported by the project Kompozitex FR– TI4/202 - Composite textile materials for humans and technology protection from the effects of electromagnetic and electrostatic fields. The work was conducted in the Department of Telecommunication Engineering at the Czech Technical University in Prague in the scope of thesis called "Design and performance analysis of purely textile antenna for wireless applications" [12] and other research projects.

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Design and Implementation of RFID-Based Object Locators

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53576

1. Introduction

In the coming decades, an increasingly larger number of baby boomers will grow into old age. This trend has led to an increasing demand for devices and services (e.g., [1-8]) that can help elderly individuals to live well and independently. *Object locator* is such a device. The device can assist its users in finding misplaced household and personal objects in a home or office. Figure 1 shows several object locators offered today by specialty stores and websites. Each of these locators contains an interrogator with a few buttons and an equal number of tags: Even the largest one, the leftmost one in the figure, offers only 8 buttons. The buttons are of different colors, and there is a tag of the color matching the color of each button. By attaching a tag to an object to be tracked, the user can look for the object by pressing the button of matching color on the interrogator. The tag attached to the object beeps and flashes in response and thus enables the user to find the object. Other locators work similarly.

Figure 1. Existing object locators

Existing object locators are not ideal in many aspects: The number of buttons on the interrogator and tags is fixed, and the number is small. Extending the locator to track more objects is impossible. – If the user were to use more than one tag of the same color, the tags would all respond to the search signal for tag(s) of the color from the interrogator. This situation is clearly not desirable. – When a tag breaks, the user must purchase a replacement tag of the same color as the broken one. Tags are battery-powered. A tag might become a lost object itself after it runs out of battery. More seriously, the interrogator itself can be misplaced. Obviously, these are serious shortcomings.

This chapter describes three designs and a proof-of-concept prototype of object locators based on the *RFID (Radio Frequency Identification)* technology. RFID-based object locators do not have the drawbacks of existing object locators. In particular, RFID-based object locators are extensible, reusable, and low maintenance. They are extensible in the sense that the maximum number of tracked objects is practically unlimited and that a RFID-based object locator can support multiple interrogators. The interrogator software can run on a variety of platforms (e.g. desktop PC, PDA, smart phone and so on). A mobile interrogator can be tagged and thus, can be searched via other interrogators when it is misplaced. Reusability results from the fact that all RFID tags used for object locators can have globally unique ids. Hence, tags never conflict, and a tag can be used in more than one object locators. Low maintenance is one of the advantages of RFID technology. One of the designs uses only RFID tags without batteries; the user is never burdened by the concern that a tag may be out of battery.

This chapter makes two contributions: The first is the object locator designs presented here. The designs use different hardware components and have different hardware-dependent software requirements. The information provided by the chapter on these aspects should enable a developer to build a suitable object locator platform, or an extension to one of the commonly used computer and smart mobile device platforms. The functionality of hardware-independent object locator software is well defined, and a C-like pseudo code description can be found in [9].

The hardware capabilities and object search schemes used by the designs lead to differences in search time and energy consumption. We provide here a numeric model that can be used to determine the tradeoffs between these figures of merit. Developers of RFID-based object locators can use the results of the analysis as design guides. Today, object locators based on all designs are too costly: Typical RFID readers have capabilities not needed by our application and cost far more than what is suitable for the application. Through this analysis, we identify the design that is the most practical for the current state of RFID technology and project the advances in the technology required to make RFID-based object locators affordable (i.e., with prices comparable with some of the locators one can now find in stores.) This is the second contribution of the chapter.

The rest of this chapter is organized as follows. Section 2 describes closely related works. Section 3 describes use scenarios that illustrate how a RFID-based object locator may be used. Section 4 presents three designs of RFID-based object locators. Section 5 describes the implementation of a proof-of-concept prototype based on one of the designs. It also describes the reader collision problem [10] encountered in the prototype and the solution we use to deal with the problem. Section 6 describes a numeric model for computing energy consumption and search time and compares the merits of the designs. Section 7 concludes the chapter and discusses future works.

2. Background and related work

This section first presents a brief overview of RFID technology as a way to state the assumptions made in subsequent chapters on state-of-the-art readers and tags. Our object locator resembles location detection systems in its goal: assisting users to locate objects. The section describes existing location systems and compare and contrast them with our object locators.

2.1. RFID technology

RFID technology is now applied to a wide spectrum of applications. As an example, personal identification application is used to provide authentication and authorization to individuals carrying their RFID tags so that they can be automatically identified by a central computer. Card-like RFID tags used as smart cards in public transports is another example: Information on money stored in a tag is automatically deducted when the card holder presents the card in front of a reader while getting on or off a transporter. Other applications include using RFID tags as markings of books for more efficient library management, shipping containers for tracking them by retail industry, and so on.

Figure 2 shows a typical system that uses RFID technology. The host machine uses one or more RFID readers to retrieve digital information stored in RFID tags and processes the information according to the needs of one or more applications. In general, a RFID tag contains a globally unique identification (UID) as well as data fields organized in a standard way [11]. A RFID-based object locator only needs the UID information; other data fields are not used.

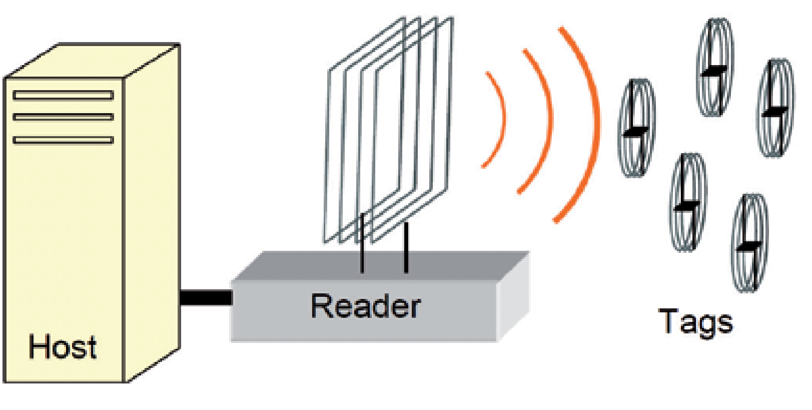

Figure 2. A configuration of RFID system

There are three types of RFID tags: passive, semi-passive and active. A *passive tag* has no internal power source: It gets the power it needs to operate from the incident RF signal radiated by a reader. The readable distance of such a tag ranges from 10 cm to a few meters depending on the frequency of the incident RF signal and its antenna design. In contrast, *semi-passive* and *active tags* have internal power source. Semi-passive tags can increase their readable distances by leveraging internal power. Like passive tags, semi-passive tags respond only after receiving some command from the reader. An active tag, on the other hand, can send RF signals to a reader even when it is not commanded by the reader. Being battery free and having long lifetime (in tens of years) are the major advantages of passive tags over other types of tags for our application.

Each message sent from a reader to tags contains a command code. Among the sets of commands defined by ISO15693 [12], our object locators use only *mandatory* commands and *custom* commands. Standard-compliant tags support all commands in the mandatory set. Commands in the custom set are defined by tag IC manufacturer according to application needs.

The command used to read UID of a tag is the *inventory* command in the mandatory set. This command has only the non-addressed mode, while the other commands have both non-addressed and addressed modes. A command in the *non-addressed mode* is processed by all tags which receive it. A command in the *addressed mode* consists of the command code followed by a UID. When a tag receives an addressed-mode command, it first checks whether the UID is its own. The tag processes and responds to the command only when it is the tag addressed by the UID.

2.2. Location detection systems

Many different location detection systems are available today. Global Positioning System (GPS) [13] is the most well known. Priced at about $ 100 US each, GPS navigators are widely used in cars, buses and so on. However GPS has its limitations. Reflection, occlusion and multipath effects seriously interfere with distance measurement and make GPS ineffective indoors. For this reason, indoor location detection systems use a variety of other technologies.

Active Badge [14] is representative of infrared-based location detection systems. A badge containing an infrared transmitter is attached to each object to be tracked by the system. The transmitter sends periodically messages containing the unique identification of the badge. The messages are caught by some infrared receivers at fixed known locations and relayed by the receivers to a central computer. The central computer resolves the position of the badge based on the locations of the receivers. Shortcomings of systems such as Active Badge arise from the fact that infrared signals cannot penetrate most materials in a building and are easily interfered by other infrared sources.

Ultrasound is used to assist with distance measurement in Bat [15] and Cricket [16]. These systems use both ultrasound and RF signals to measure distances between beacons (transmitters) and listeners (receivers): When a beacon at a known location transmits an ultrasound signal and a RF signal concurrently, a listener can calculate the distance to the beacon from the difference between the arrival times of the signals.

Many indoor location detection systems use RF-based technology to take advantage of the fact that RF signals penetrate most non-metallic materials. RADAR [17] is an example. The system estimates distance by estimating the strength of RF signals. Specifically, the system measures in the initialization phase at a set of fixed locations the strengths of a RF signal sent by a location-known transmitter. The measured strengths are stored in a database to be used later as yardsticks during the working phase. In the working phase, each receiver measures the strength of a RF signal transmitted from a tracked object and sends the strength to a central computer. The computer compares the measured strengths with the information stored in the database and then resolves the possible position of the transmitter (i.e., the tracked object). MoteTrack [18], similar to RADAR, uses empirical distance measurement to estimate positions of objects. WLAN (wireless local area network) can be used to build location detection systems also. SpotON [19] and Nibble [20] are examples.

Compared with the above mentioned location detection systems, an object locator must be a far more low cost solution and must be ultra easy to set up and use. Many indoor location detection systems (e.g. Bat and Active Badge) rely on a big infrastructure or a pre-computed database (e.g. RADAR) to support location estimation. These systems are too costly to deploy and maintain and hence, unsuitable for home use. Cricket system provides a low cost location-aware service. An object with a receiver can determine its location. This is not what an object locator does. A misplaced object does not need to know its own location; the user looking for it needs to know.

3. User scenarios

The routine usage of an object locator requires only three operations: Add, Delete and Query. We describe these operations here to illustrate how a locator may be used. Without loss of generality, we assume that a new object locator kit contains a portable interrogator, a dozen of RFID tags and agents. As illustrated by Figure 3, the interrogator resembles a smart phone. It has a small non-volatile storage and a RF transceiver together with a network address. We will return in the next section to describe how the RF transceiver is used, as well as what agents are and do. Unlike common smart phones, however, the interrogator has a RFID reader. The reader is used for the Add operation described below.

Specifically, Figure 3 shows parts of the user interface on an interrogator with a LCD touch screen and two buttons. The LCD touch screen is used as both input and output user interface. A user can select an item among the items displayed on the screen, the button at the bottom left corner to confirm a selection, and the button at the bottom right corner to cancel the selection. Some operations need text input. The virtual keyboard shown on right is for this purpose.

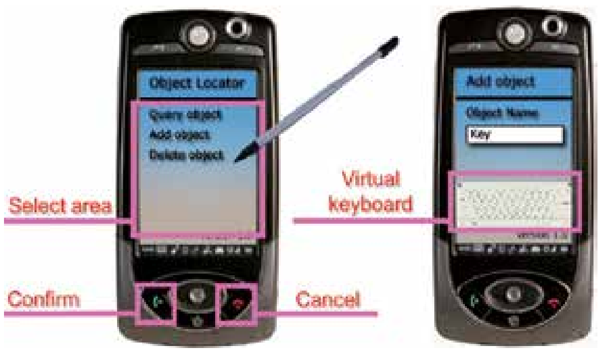

Figure 3. Object locator user interface

Figures 4 and 5 illustrate Add and Query operations, respectively. Add operation works in a similar way as the address book of a smart phone. Using this operation, the user can add the registration of an object to be tracked into the interrogator. By registration, we mean a mapping between the id of the tag attached to an object and the name of the object. The user queries the locations of objects by their names. In response to a query, the interrogator uses the object-name-tag-id mappings to resolve which one of the registered objects to search. Figure 4 shows a scenario: The user picks an unused tag and attaches it to an object to be tracked as shown in Figure 4(a) and (b). Then, the user puts the tag close to the interrogator and selects Add object. This step is shown in Figure 4(c). In response to Add object command, the interrogator reads the id of the tag, displays a new text field and prompts the user to enter a name (e.g., Key). When the user confirms the name, the interrogator creates a mapping associating the name with the id of the tag attached to the object, and stores the mapping in its local non-volatile memory. This is illustrated in Figure 4(d). The user repeats the above steps to register each object until all objects to be tracked are registered.

Figure 4. Add operation

Figure 5. Query operation

Query operation is the work horse of the object locator. The user presses Query object on the touch screen, as illustrated by Figure 5(a), to invoke this operation for assistance in finding misplaced objects. When the names of registered objects are displayed, the user selects the object to be searched; in this example, it is Key. After the user confirms the selection, as shown in Figure 5(b), the interrogator retrieves from its local storage the id of the tag attached to the object with the selected name and starts a search for the tag with that id. Hereafter, we call the tag being searched the *queried tag* and the object attached to the tag the *queried object*. We will describe the search process in the next section.

Object locators of different designs present the result of Query operation in different ways. As examples, Figure 5(c) and (d) shows two different responses. In Figure 5(c), the interrogator directs the user to the place (e.g. bedroom 1) where the queried object is found. In Figure 5(d), the queried tag beeps, allowing the user to look for it by following the sound. This version works like the existing locator described in Section I.

Delete operation removes the registration of an object, i.e., the object-name-tag-id mapping stored in the interrogator: The user can invoke the operation by pressing Delete object on the touch screen. In response, the interrogator displays the list of registered objects, allowing the user to select the object (e.g. Key) to be deleted. The interrogator deletes the mapping after the user confirms the selection. Delete operation frees the tag attached to the now unregistered object and makes the tag free for use to track some other object.

4. Alternative designs

The three designs of object locator are called Room-level Agents, Interrogator and Tags (RAIT) locator, Desk-level Agents, Interrogator and Tags (DAIT) locator and Desk-level and Room-level Agents, Interrogator and Tags (DRAIT) locator. As their names imply, each of the locator consists of tags, agents and at least one interrogator. The adjectives room-level and desk-level describe the ranges of RFID readers used by the designs. The ranges of room-level readers and desk-level readers are sufficiently large to cover a typical-size room or desk, respectively.

The term tag refers specifically to RFID tags. Each tag has a unique id, hereafter called *TID*. One of the designs uses only passive tags. The other designs call for tags that can beep upon receiving query messages containing their TIDs. It is possible to implement such tags using semi-passive RFID tags since the battery in such a tag can be used not only to improve read range but also to drive a beeper.

An *agent* is a device that aids the interrogator in locating the queried object (i.e., the queried tag). Each agent has a RF transceiver, together with a programmable network address, a RFID reader, and a RFID tag. The RFID reader in the agent enables the agent to search for the tags within its coverage area. As stated in Section III, the interrogator also has a RF transceiver with a network address. This allows the interrogator and all agents to form a wireless local area network (WLAN). The network address of the interrogator (or each interrogator in a multiple-interrogator system) is unique and so is the network address of each agent. The interrogator requests assistance from an agent by sending the TID of the queried tag to the agent via the WLAN. We assume that the network provides reliable communication. We do not mention other aspects of the WLAN because they are not relevant to our discussion.

4.1. RAIT locator

A disadvantage of the existing locator is that a user needs to walk around the house when searching an object and the interrogator needs to repeatedly send the query signal until the user hears the queried tag or gives up the search. RAIT locator is designed to eliminate this disadvantage.

RAIT locator uses one or more agents to cover each room, and the house is fully covered by agents as shown in Figure 6. When the user invokes a Query operation, the interrogator sends a query message containing the TID of the queried tag to agents and thus requests the agents to search the queried tag on its behalf. Each agent broadcasts an addressed mode read request with the TID retrieved from the query message to read the tags within range. The tag with id matching the TID beeps upon receiving a read request, in addition to responding to the agent. The agent finding the queried tag reports its network address to the interrogator. This information enables the interrogator to display the results illustrated by Figure 5(c), telling the user to go to the specified room where the queried object has been found.

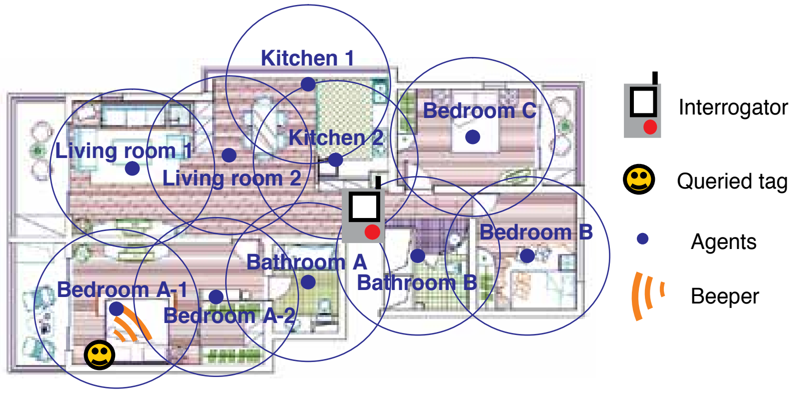

Figure 6. Configuration of RAIT locator

Obviously, the agents must be set up before a RAIT locator can be used. Figure 7 lists the steps carried out by the user and work done by the system during the set up process. The goal of Steps 3-5 is to make sure that there is no blind region. A *blind region* is an area where tags cannot be read by any agent. The corners of a room are the most likely to be blind regions. This is the rationale behind Step 3. When the *TEST READ RANGE* switch of an agent is on, the agent repeatedly broadcasts non-address mode read messages. In this way, the agent enables the user to determine whether any of the corners is a blind region in Step 3.

1. Choose a location near middle of a room and temporarily attach an agent to the ceiling or furniture at the location.
2. Turn on *TEST READ RANGE* switch on the agent.
3. Pick up a tag and check whether the tag beeps at each corner of the room.
4. If no, adjust the location of the agent or add one more agent at another location in the room and turn on *TEST READ RANGE* switch on the additional agent. Then go back to Step 3. If yes, turn off *TEST READ RANGE* switch.
5. Securely attach the agents tested in Steps 2-4 at their respective locations.
6. Put the interrogator near the agent and execute *Register Agent operation*.
7. Repeat step 1 to 6 until all agents covering the house are registered.

Figure 7. Agent set-up process

The Register Agent operation in Step 6 is similar to Add operation described in Section 3. Its goal is to assign a human-readable location name to an agent, so that the interrogator can later generate query results illustrated by the example in Figure 5(c). During the operation, the interrogator prompts the user to provide a unique name for the location of each agent. For example, if the living room needs two agents, Living Room R(ight) and Living Room L(eft) are good names for them.

The interrogator also assigns a unique network address to the agent being registered. The id of the tag in an agent is the product serial number of the agent. The interrogator uses the id to distinguish the agent from previously registered agents. By assigning successive network addresses to agents as they are registered and initialized one by one, successive Register Agent operations enable each initialized agent to join the WLAN and later compute the addresses of other agents by adding or substituting some number from its own address.

Figure 8 depicts the format of messages in a RAIT locator. This format supports multiple interrogators: The src_addr allows agents to identify the interrogator issuing the query message. The dest_addr allows them to address their responses to a specified interrogator. Data field allows interrogators to synchronize their databases created by Add and Register Agent operations. We will discuss how the other fields are used shortly.

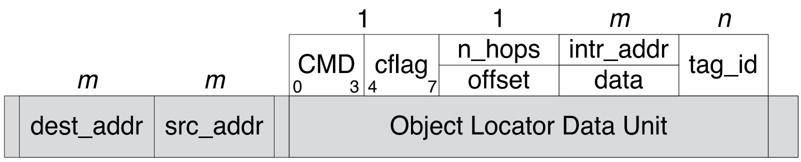

Figure 8. RAIT locator message format

4.2. DAIT and DRAIT locators

DAIT locator, shown in Figure 9, is an extension of RAIT locator. The designs are similar in how the Query operation is handled by the interrogator and agents. DAIT differs from RAIT primarily in the required read ranges of agents. The read range of agents used in a DAIT locator is less than one meter. Agents with such a small range offer higher accuracy in locations of queried tags. Information on the agent that finds the queried tag tells the user the location of the searched object within a small vicinity of the agent. Tags in DAIT locators are passive; they do not beep because a user can easily find the misplaced object even though the tag does not beep. Because tags do not need to beep, they can be battery free. This is a major advantage of DAIT locator.

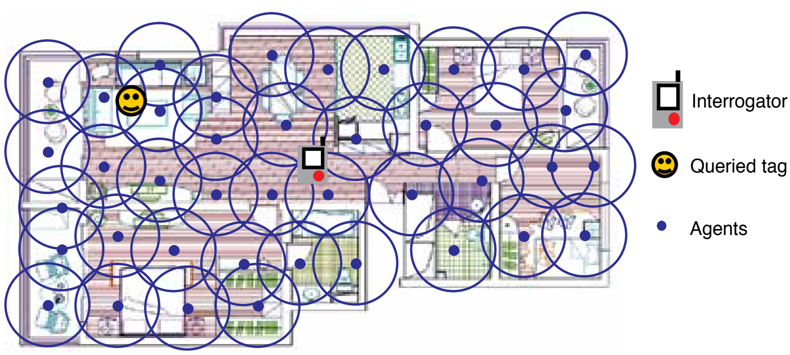

Figure 9. Configuration of DAIT locator

However, it is significantly more complicated to set up desk-level agents. Blind regions of RAIT locator are easy to detect and eliminate because a blind region is typically created by walls and is near the read boundary of an agent. In the case of DAIT locator, a room cannot be fully covered by one or two agents. Any three adjacent agents may create a blind region. Our solution is to give a user a circular thread whose circumference is less than $3\sqrt{3}$ (i.e., the circumference of a regular triangle whose center is one unit away from its corners) times their read range and instruct a user to set any three adjacent agents within the circular thread. By doing so, blind regions never occur.

DRAIT locator has a hybrid design that aims to extend the lifetime of semi-passive tags. A DRAIT locator contains both room-level and desk-level agents. Its interrogator asks desk-level agents to search first. The interrogator asks room-level agents only when no desk-level agent finds the queried object. We set up desk-level agents on furniture in addition to setting up room-level agents as described above. Because misplaced objects are often on furniture or in vicinities of them, the queried object can often be found by a desk-level agent, and the tag on it does not need to beep.

4.3. Search schemes

A queried object can be searched in three ways: broadcast, relay and polling. The *broadcast scheme* is the most straightforward. The interrogator broadcasts a query message with the tag_id field filled with TID of the queried tag. The agents finding the queried tag report their agent ids to the interrogator and the others do not reply.

The knowledge on the agent network addresses and the number of agents enables an interrogator to request assistance from agents one at a time using the *relay scheme*: To search for a queried tag, the interrogator sends a query message containing its own address in intr_addr field, the number of agents to be queried in n_hops and the TID of the queried tag in tag_id to the first agent: The simplest choice is the agent with the smallest address. In response to a query, each agent searches for the tag with the TID in its own cover area. The agent reports its own address to the interrogator if it finds the tag; otherwise it decreases n_hops by one, increments its own network address by one to get the address of the next agent and then forwards the query message to the next agent.

According to the *polling scheme*, the interrogator also sends a query message to the first agent in its polling list, provides the agent with the TID of the queried tag and waits for response from the agent. The agent replies to the interrogator no matter whether it finds the tag or not. If the response from an agent is negative, the interrogator sends the query message to the next agent in its polling list. Advantage of the polling scheme over the relay scheme is that the interrogator can dynamically alter the search sequence.

5. Prototype implementation

We implemented a proof-of-concept prototype of DAIT locator, the design that does not require customized semi-passive tags. Indeed, all components used in our prototype are readily available today. Parts (a) and (b) of Figure 10 show an agent and the portable interrogator of our prototype, respectively. The agent is composed of a microcontroller, a RF transmitter, a RF receiver and a RFID reader module. The microcontroller is ATMEL ATmega128. It runs at 8MHz and has 128k bytes flash / 4k bytes EPPROM. The RF transmitters and receivers interconnecting interrogator(s) and agents are LINX TXM(RXM)-433-LR, which use 433MHz ASK. RFID reader modules are MELEXIS EVB90121, which is ISO15693-compliant and uses a directional antenna. We use TI OMAP5912 and NEC Q-VGA to implement the portable interrogator. The current version of our prototype supports the three operations described in Section II and uses the polling search scheme.

The lack of customized antenna design for tags and readers and the reader collision problem seriously affects the performance of our prototype. Our DAIT prototype uses only tags with directional antennae. (Again, the reason is that such tags are readily available.) When the antennae of tags and readers are directional, the read performance of agents depends on the orientation of the antennae. Clearly, tagged objects may be placed in arbitrary orientations. As a consequence, it is impossible to ensure optimal or near optimal alignment of the tag antennae towards the agents covering their locations. This is the reason that tags in a DAIT object locator should have omni-directional antennae. Agents with omni-directional antennae can be simply set on furniture as shown in Figure 11(a). Agents with directional antennae should be attached to the ceiling as shown in Figure 11(b). This arrangement requires a read range of 2-3 meters. With readers of a sufficiently large read range, RAIT locators can use tags with directional antennae without performance concern.

(a) (b)

Figure 10. Agent and interrogator

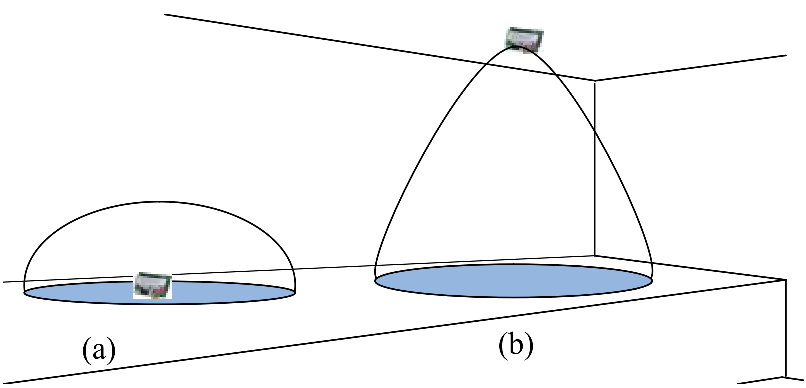

Figure 11. Arrangement of agents

Close proximity of readers (i.e., agents) is necessary in order to avoid blind regions. Our DAIT prototype is no exception. When RFID readers have overlap coverage areas, signals sent at the same time from them to tags in the overlap region interfere with each other. This is called the *reader collision problem* [10]. Fortunately, only the broadcast scheme suffers this problem. Our prototype uses the polling scheme to avoid the problem: According to the polling schemes (or the relay scheme), agents search the queried tag in sequence; signals from readers never interfere.

A DAIT locator that uses the broadcast scheme can circumvent the reader collision problem in many ways. For example, the DAIT prototype can let each agent delay transmitting its query signal by an amount of time that is a function of its network address. In this way, agents try to avoid transmitting query signals at the same time. This solution is practical and easy to implement.

Another solution requires each agent to know the network addresses of its neighbors. Each agent can be viewed as a node in a connected graph. There is an edge between two nodes when the agents represented by them have overlapping coverage regions. A graph coloring algorithm can be used to assign different colors to adjacent nodes. The reader collision problem never occurs as long as agents labeled by different colors do not transmit query signals concurrently. This solution is likely to have a better response time than the solution mentioned above or the relay and polling schemes. However it requires additional hardware for each agent to automatically detect its neighbors or connectivity information entered by the user manually. The additional hardware makes agents more costly, and complicated operations by the user make an object locator hard to use.

6. Relative merits

We use search time and energy consumption of a single query to measure the relative merits of object locator designs. Search time and energy consumption per query depend on many factors including the number of agents, search scheme, search sequence and locations of misplaced objects.

6.1. Search time and energy consumption

The expressions of energy consumption and search time per query according to broadcast, relay and polling schemes are listed in Table 1. The expressions assume that agents and interrogator(s) are battery powered and communicate in the manners described in Section 4. The notations used in the expression are defined in Table 2.

The total energy consumed by the object locator for processing a Query operation according to the broadcast scheme is the sum of the three terms in the first row of Table 1. In this case, the interrogator transmits only one query message per Query operation. The energy it consumes is E_{IA}. The energy consumed by each agent in the search is E_{Arfid}. The total energy consumed by all agents is $N_A(x, y, r)E_{Arfid}$, where $N_A(x, y, r)$ is the number of agents with range r in a rectangular space of dimensions x and y. The agent finding the queried tag consumes E_{AI} to send a response back to the interrogator.

In the expressions, pA_i denotes the probability that the i-th agent in the search sequence finds the queried tag. In general, this probability is a function of the number and location distribution of objects (i.e., tags) in the house. (To keep the expressions simple, our notations do not show this dependency.)

broadcast	E_{total}	$E_{IA} + N_A(x, y, r)E_{Arfid} + E_{AI}$
	T_{avg}	$D_{IA} + pA_1(D_{Arfid} + D_{AI}) + \sum_{i=2}^{n}(\prod_{k=1}^{i-1} 1 - pA_k)pA_i(iD_{Arfid} + D_{AI})$
relay	E_{avg}	$E_{IA} + pA_1(E_{Arfid} + E_{AI}) + \sum_{i=2}^{n}(\prod_{k=1}^{i-1} 1 - pA_k)pA_i(iE_{Arfid} + (i-1)E_{AA} + E_{AI})$
	T_{avg}	$D_{IA} + pA_1(D_{Arfid} + D_{AI}) + \sum_{i=2}^{n}(\prod_{k=1}^{i-1} 1 - pA_k)pA_i(iD_{Arfid} + (i-1)D_{AA} + D_{AI})$
polling	E_{avg}	$E_{IA} + pA_1(E_{Arfid} + E_{AI}) + \sum_{i=2}^{n}(\prod_{k=1}^{i-1} 1 - pA_k)pA_i(iE_{Arfid} + (i-1)E_{IA} + iE_{AI})$
	T_{avg}	$D_{IA} + pA_1(D_{Arfid} + D_{AI}) + \sum_{i=2}^{n}(\prod_{k=1}^{i-1} 1 - pA_k)pA_i(iD_{Arfid} + (i-1)D_{IA} + iD_{AI})$

Table 1. Expressions for search time and energy consumption

- D_{IA}: Delay of a message transmitted from an interrogator to an agent
- E_{IA}: Energy consumption of a message transmission from an interrogator to an agent
- D_{AA}: Delay of a message transmitted from one agent to another
- E_{AA}: Energy consumption of a message transmission from one agent to another
- D_{AI}: Delay of a message transmitted from an agent to an interrogator
- E_{AI}: Energy consumption of a message transmission from an agent to an interrogator
- D_{Arfid}: Time for an agent to use its RFID reader to search a queried tag
- E_{Arfid}: Energy consumption of a RFID reader in an agent per search of a queried tag

Table 2. Notations

The expression of the expected time taken by the locator using the broadcast scheme to respond to a Query operation assumes that agents search the queried tag in sequence in order to avoid the reader collision problem. The first term in the expression is the time taken by the query message from the interrogator to reach all the agents. If the first agent finds the queried tag, which occurs with probability pA_1, the addition delay is $D_{Arfid} + D_{AI}$. This is the reason for the second term in the expression of T_{avg}. In general, the probability that the queried tag is found by the i-th agent is $\prod_{k=1}^{i-1}(1-pA_k)pA_i$. When this occurs, each of the other agents spends D_{Arfid} amount of time to search for the queried tag before the i-th agent can respond to the interrogator. Hence, the delay is $iD_{Arfid} + D_{AI}$.

The average search time of an object locator that uses the relay and polling scheme are estimated by the expressions in the fourth and sixth rows in Table 1, respectively. Relay and polling scheme also lets all agents search the queried tag in sequence. This is why the coefficients in these expressions are the same as the coefficients in the expression of T_{avg} for the broadcast scheme. The expressions of the average energy consumption can be derived from the expressions of the average search time by substituting energy consumption for message transmission delay because sending a message cause both transmission delay and energy consumption.

As stated earlier, Table 1 is based on the assumption that agents and the interrogator are battery powered. Hence, the total energy consumption includes energy consumptions of agents and an interrogator. However, agents can be connected to wall plugs, especially when the number of agents is small, as in the case of RAIT locators. The interrogator using relay and broadcast scheme consumes exactly E_{IA} to search a queried tag. The interrogator using polling scheme consumes at least E_{IA} to search a queried tag. Therefore, the polling scheme is suitable for stationary interrogator(s) and the relay and broadcast scheme are suitable for portable interrogator(s) if we do not need to account for the energy consumption of agents.

6.2. Model of object locality

The probability pA_i of that an agent A_i finds the queried tag, and hence the misplaced object, depends on where the object is at the time. To calculate this probability, we use a locality model of tracked objects. The model gives the spatial probability density of the locations of each object. For the sake of simplicity and without noticeable lose of accuracy, we partitions the space in the search area into unit squares, rather than treating the coordinates of a location as continuous variables. (Except for where it is stated otherwise, the dimension of a unit square is 1 cm by 1 cm.) This allows us to model a house as a finite, discrete and planar search space. We denote the space by $Z = \{Z_{x,y}\} \subseteq N \times N$. Each element $Z_{x,y}$ of the space is a unit square; its location is given by the coordinate (x, y) where both x and y are integers. All agents are at fixed and known locations. A misplaced object may be placed anywhere within the search space.

We call the probability of finding a queried object at $Z_{x,y}$ the (*existence*) *probability* of the object at $Z_{x,y}$. (For example, if we find an object at $Z_{x,y}$ on the average 10 times in 100 searches for the object, the (existence) probability of the object at $Z_{x,y}$ is approximately 0.10. We use $pZ_{x,y}(j)$ to denote the existence probability of an object with a tag of id = j at $Z_{x,y}$. We do not consider the situation where someone has taken some registered object shopping, for example, while someone else is searching for it in the house. Hence, for every object being searched, the sum of the probabilities of it being at all locations in the search space equals to 1.

Figure 12 gives an illustrative example. The figure is not drawn scale, and each unit square in this example is 10 cm by 10 cm in dimension. Two agents A_1 and A_2 are at their locations. The id of A_1 is 1 and the id of A_2 is 2. The rectangle models a desk. It contains 15 unit squares. The number in each square gives the probability of a queried object being at the location. Since the numbers add up to 1, they tell us that the object is surely somewhere in the rectangle. We want to calculate pA_i, the probability that the agent with id = i can find the queried tag. Using Figure 12 as an illustrative example, we see that pA_1 equals to the sum of all existence probabilities within the read range of the agent A_1; in other words, pA_1 is about 0.87. Similarly, we find that pA_2 is about 0.68.

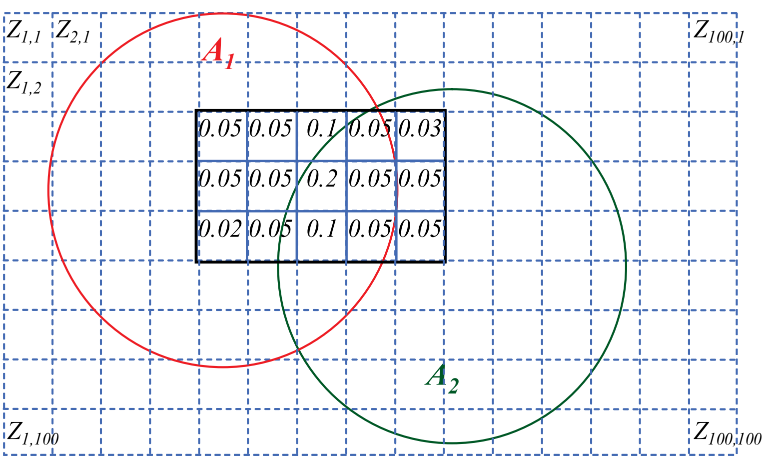

Figure 12. Locality model

We call the area where a misplaced object might be placed an *object region*. The size of an object region is the total area of the region in number of unit squares. We characterize the locality of a misplaced object by the size and shape of its object region and its existence probabilities of being at each unit square within the region. Once we know the locality parameters of an object and coverage area of each agent A_i, the terms pA_i can easily be calculated. We can then calculate the average search time and energy consumption of the object based on the probability pA_i for all agents.

6.3. Evaluation environment and results

The environment we used to evaluate the relative performance of our designs has a 10m by 10m search space, containing 1000 × 1000 unit squares of size 1 cm by 1 cm. Agents are placed according to the arrangement in Figure 13(a). The number of agents is $N_A(1000, 1000, r)$. Again, r is the read range of an agent. The ranges of desk-level and room-level agents are 100 and 350, respectively, the typical number of room-level agents in a RAIT locator is $N_A(1000,1000,350) = 6$, and the typical number of agents in a DAIT locator is equal to $N_A(1000,1000,100) = 42$.

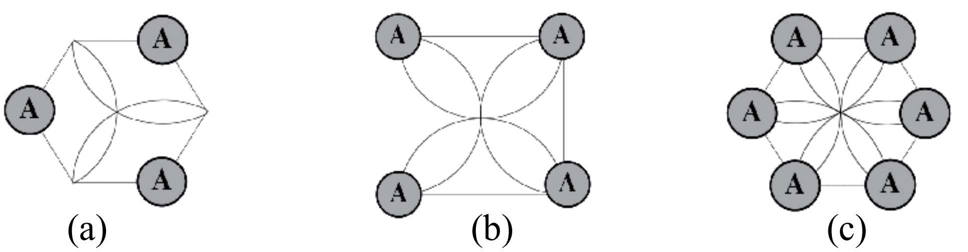

Figure 13. Possible arrangement of agents

In Section 4, we said that the agent with the smallest network address is the first agent and the other agents are asked one by one in order of agent ids to search for the queried object. We call this search order *sequential*. Alternatively, we can ask the agents in non-increasing order of their empirical existence probabilities. This search sequence is called *profiling*.

Our evaluation program assumes that object regions are circular for the sake of simplicity. The center and radius of an object region are randomly generated. The variables D_{IA}, D_{AA} and D_{AI} in Table 2 have the same values because both interrogators and agents use the same kind of RF transceiver. For the same reason, E_{IA}, E_{AA} and E_{AI} have the same value. For convenience, we use D_{Arfid} and E_{Arfid} as base units of delay and energy consumption. The ratio of D_{IA}/D_{Arfid} (D_{AI}/D_{Arfid} and D_{AA}/D_{Arfid}) is called *DRatio* and the ratio of E_{IA}/E_{Arfid} is called *ERatio*. The evaluation program needs only these two parameters rather than all variables.

Figure 14(a) and (b) show the average search time for broadcast scheme, relay scheme, and polling scheme (i.e., polling in sequential order), as well as polling scheme with profiling. The search time of relay and polling schemes is higher than broadcast scheme for all values of DRatio. The search time of polling scheme with profiling is less than that of broadcast scheme when DRatio is less than about 1 (10^0) for N_A = 42 and 1.25 ($10^{0.1}$) for N_A = 6.

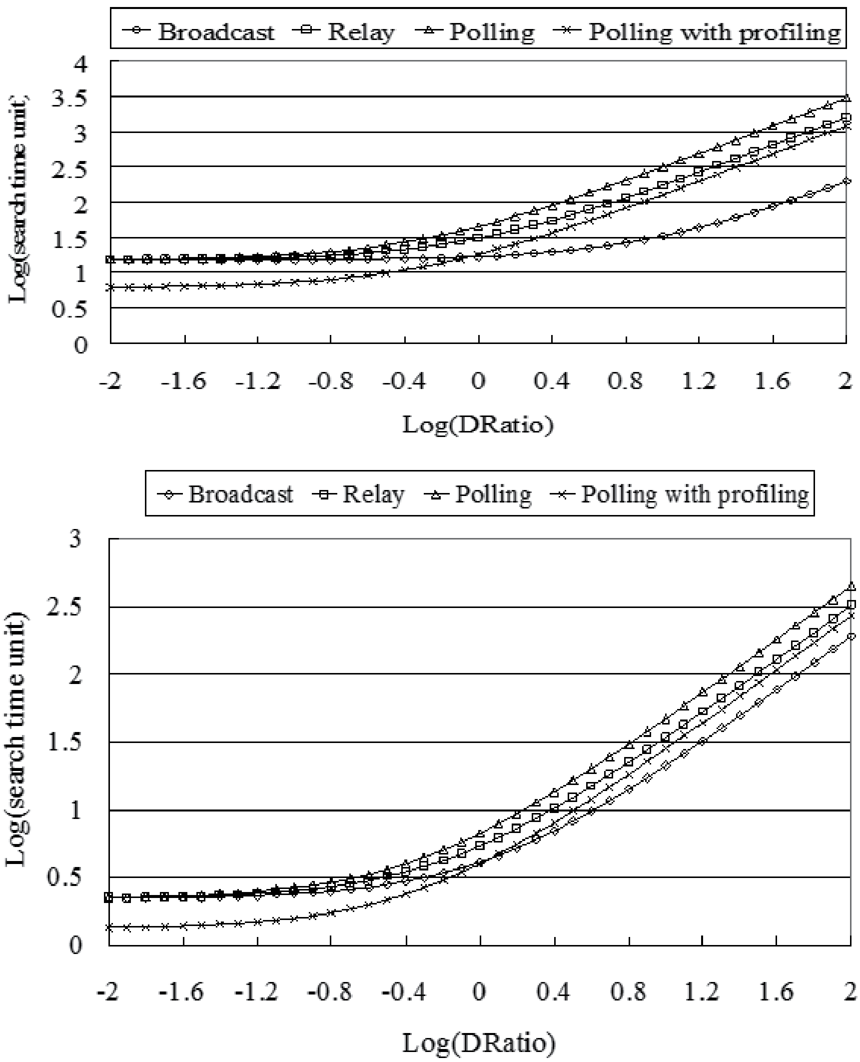

Figure 14. Search time Vs DRatio: (a) top NA = 42; (b) bottom NA = 6

Figure 15 shows the average energy consumption consumed by agents when N_A is 42 and 6. The energy consumption consumed by agents is the same, when the relay and polling scheme is used. As Figure 15(a) depicts, the energy consumption of relay scheme and polling scheme are the same. Their consumptions and that of polling scheme with profiling is less than that of broadcast scheme when ERatio is less than 1.99 ($10^{0.3}$) and 7.94 ($10^{0.9}$), respectively. Values of ERatio at the intersections of the curves in Figure 15(b) are about 3.16 ($10^{0.5}$) and 15.85($10^{1.2}$).

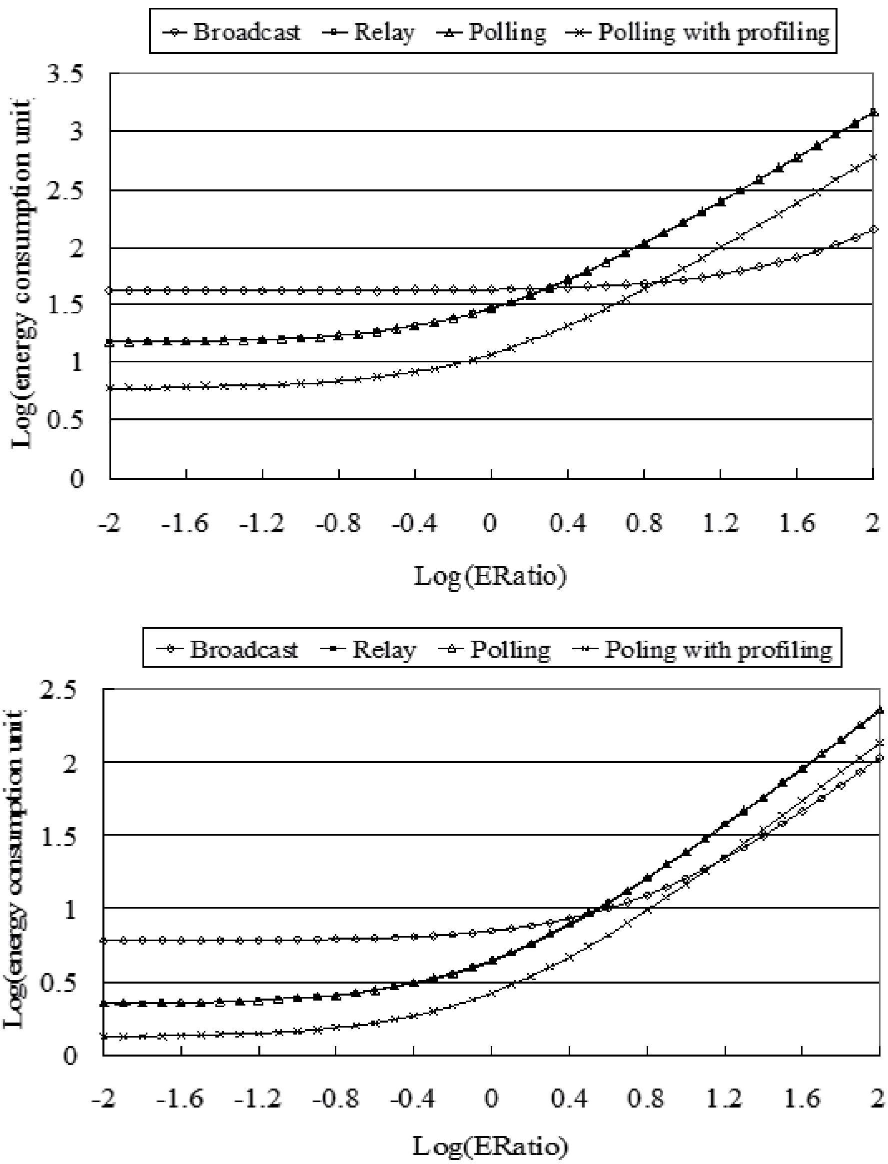

Figure 15. Energy consumption of agents Vs ERatio: (a) top NA = 42; (b) bottom NA = 6

Table 3 gives a summary. The table suggests the broadcast scheme when DRatio is high and search time is more important than energy consumption. When DRatio is low, the differences among the search times of all search schemes are small. Energy consumption becomes the dominant factor for comparison. It is possible for agents in a RAIT locator to connect to power source. For energy saving on interrogators, we suggest polling scheme with profiling for stationary interrogators and relay or broadcast scheme for portable interrogators. As for DAIT locators, we consider energy consumption of an interrogator and agents. We suggest polling scheme with profiling when ERatio is low and the same suggestions as that for a RAIT locator if ERatio is high.

	Low DRatio Low ERatio	Low DRatio High ERatio	High DRatio Low ERatio	High DRatio High ERatio
RAIT locator (fewer agents)	PI: ***broadcast*** or ***relay*** SI: ***polling with profiling***	PI: ***broadcast*** or ***relay*** SI: ***polling with profiling***	***broadcast***	***broadcast***
DAIT locator (more agents)	***polling with profiling***	PI: ***broadcast*** or ***relay*** SI: ***polling with profiling***	***broadcast***	***broadcast***

PI: portable interrogator SI: stationary interrogator

PI: portable interrogator; SI: stationary interrogator

Table 3. Summary of suggested search schemes

7. Conclusion

We described here three alternative designs for RFID-based object locator. These object locators are extensible, reusable and low maintenance. They are easy for users to set up and use. Our analysis shows that search time and energy consumption for all designs and search schemes depend the capabilities of RFID readers and RF transceivers used by agents. Roughly speaking, polling and relay schemes are competitive to broadcast scheme only when DRatio or ERatio are less than 10.

We implemented a proof-of-concept DAIT prototype object locator to demonstrate the object locator concept and designs. The prototype uses only readily available hardware components, including readers and tags with directional antennae. The performance of the prototype is far from ideal, primarily for this reason. Because it is impossible to control the orientation of tag antennae, omni-directional antennae are better suited for our application.

The total cost of an object locator depends on many factors. The total hardware cost of a minimum object locator is the sum of the costs of an interrogator and required number of agents and tags. Compared with the costs of interrogator and agent, the hardware cost of tags is significantly lower and, for the discussion here, can be neglected.

Currently, the total hardware cost of an object locator is dominated by the total cost of agents, and the cost of an agent is dominated by the RFID reader in the agent. The number of agents required to fully cover a house depends on dimensions x and y of the house, the read range of the agents and the way agents are placed. To get a rough estimate, we assume that the coverage area of each agent is a circle. Figure 13 depicts three ways to place agents. Putting agents further apart than locations shown in Figure 13(a) can create blind regions. Putting more agents closer than those indicated in Figure 13(c) is not necessary since the space is covered by at least two agents. We need six room-level agents to cover a 10m x 10m space even when we place agents as shown in Figure 13(a) (i.e., as far as possible without creating blind regions). The existing object locator costs $ 50 US. A RAIT locator is not competitive to the existing locator unless the cost per room-level agent is about $ 10 US. As for DAIT locator, the cost per desk-level agent must be much lower. We are optimistic that the cost of agents will become sufficiently lower in the coming decade as the need for more and more products (e.g., Smart pantry [1], dispenser in [4]) containing RFID readers are developed to take advantage of this technology.

Acknowledgment

This work is partially supported by the Taiwan Academia Sinica thematic project SISARL (Sensor Information System for Active Retirees and Assisted Living (http://www.sisarl.org).

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Chapter 11

Object and Human Localization with ZigBee-Based Sensor Devices in a Living Environment

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53366

1. Introduction

Radio frequency identification (RFID) systems are currently widespread in business applications such as inventory management and supply chain management. In particular, the active type of system is often used for total management over a large area because of its long communication range. With the increasing miniaturization and price reduction of RFID tags, the applicable area is expanding from business to consumer. One of the most promising areas is the home environment. In the home environment, object management is as important as that in business areas such as warehouses, because there are many pieces of equipment in daily use. While many objects are accessed often in a warehouse environment, only a few objects are replaced in the home environment. The management of massive objects is thus unnecessary for the home. Another application is in the understanding of the environmental situation. In warehouses, tags with temperature and humidity sensors are often used for quality management. These tags realize not only object identification but also understanding of the object's situation. The next step in situation understanding is behavior recognition for home occupants. Behavior recognition is useful for intelligent home automation, healthcare based on life patterns, and monitoring of people living in remote locations.

To capture human behavior using an active RFID system, the system must measure various information related to human behavior. A typical example of human behavior measurement using a wireless sensing system, which is regarded as a kind of active RFID system, is MITes [1]. MITes can capture home environmental information (e.g. lighting changes and passing people) using wireless sensor devices attached to each of the rooms. MITes can also measure details of human behavior using wearable sensors. Traditional active RFID systems can capture large segments of human behavior, even without the use of a complicated system like MITes. Environmental information can be measured using sensors in the tags. With the addition of the environmental information, the RFID system can easily identify the object with the attached tags. However, while identification alone is suitable for object management, information about object handling and object locations is required to measure human behavior. For object handling, the work of Philipose et al. [2] indicates that the object handling sequence assists with the estimation of human behavior. This information can be captured easily with sensors included in the tags. For the location, as an example of the use of location information for human behavior recognition, the information that a cup exists on a sink indicates that someone is washing the cup. The presence of the cup on a table suggests that someone is drinking from it. Also, if it is known that one specific person uses the cup, this information also identifies the person who is drinking. Although direct information about humans is desirable for behavior recognition, direct measurement is difficult with active RFID systems. If the inhabitants wear tags, some information can be captured. However, wearing the tags constricts the natural behavior. Intille et al. [3] suggested that a rough human location is useful for human behavior recognition. Based on their work, we decided that our measurement target for humans using active RFID systems is sub-room-level human localization without the humans wearing tags. Therefore, our research goal is object and human localization using an active RFID system.

Popular approaches for tag position estimation use radio signal strength indicators (RSSIs) for communication between tags and readers, because RSSI depends on the distance between the tag and the reader [4-6]. The simplest approach uses a triangulation algorithm. However, in the home environment, which contains many obstacles for RFID systems such as furniture and electrical appliances, localization is more difficult because the strength of the radio wave can change easily with the room situation. One solution is the deployment of multiple reference tags, which indicate true position [5] [6]. However, this approach is impractical in a living environment because of the cost and difficulty. Distortion of the radio waves by the occupant's presence decreases the localization performance. When we consider the above applications, accurate position (i.e. x-y-z position) estimation is not necessary, but rough location (e.g., on a table, in a drawer, or in a cabinet) is required. Based on this idea, we have already proposed a method for localization of tag-attached objects [7]. The method uses a machine learning technique and a rule-based algorithm to combine RSSI data and sensor data captured by externally distributed sensors across the room. This combination improves the performance in the presence of humans. However, this method has some disadvantages, including the cost of a commercial RFID system, the necessity for the tag readers to have a local area network (LAN) connection, the additional introduction of distributed sensors and the limitations of the estimation locations (e.g. the system cannot distinguish any drawers that do not contain switch sensors).

To overcome these problems, we must use a new active RFID system instead of the current commercial active RFID systems. We have focused on ZigBee technology for wireless communications. ZigBee has advantages for accurate localization. RSSIs in ZigBee are sensitive to distance because of its high frequency radio wave. Another advantage is that ZigBee provides protocols for sensor devices, which leads to easy transmission of the sensor data from the tags. However, because the ZigBee-based RSSI is more sensitive than a low-frequency RFID system, the presence of humans disturbs the RSSI more severely. The use of sensor data on tags would improve the object localization performance. Rowe et al. [8] have already reported that limitation of the location candidates improves the localization performance. We have expanded the previous algorithm to prevent performance degradation. The algorithm uses the RSSI data, the environmental sensor data, and data from the sensors on the tag to prevent degradation of the performance by human interference.

On the other hand, the sensitivity of ZigBee-based RSSIs to the presence of humans is effective for human localization. Wilson and Patwari developed a human tracking method based on RSSI values from reference nodes at the outside of the walls [9]. Their approach requires many wireless devices to generate tomography data for tracking, and no obstacles exist in the room. For our application, we do not need high-resolution human positioning but require only rough location using a few devices. If human interference with the radio waves is stable, the pattern of the RSSI values among the nodes specifies the human location. Our challenge is therefore to estimate a sub-room-level human location based on this RSSI distortion using a fingerprinting approach, which is the same as object localization.

In this paper, we constructed a prototype active RFID system using ZigBee devices. We also proposed an object localization method using RSSIs among tags and data from sensors attached to the tags. Our experimental results demonstrated the feasibility of our localization approach for both objects and persons in a realistic home environment. The results also show that our approach reduces the performance degradation caused by the presence of humans.

2. ZigBee-based sensor device

To avoid limitations in the sensor variety and the communication protocols, we developed a new ZigBee-based prototype system. The system consists of the target nodes, which are tags in the RFID system, and the reference nodes, which are readers in the RFID system. The difference between this system and the traditional RFID system is that our system enables communication among the readers and can gather RSSI data because the reference nodes are also regarded as a kind of target node. The devices consist of the XBee, which is a commercial ZigBee communication module, and the Arduino or Arduino Fio microcontroller, which is commonly used in prototype device construction because of its compactness and ease of programming. The antenna used for wireless transmission and reception is non-directional to reduce the system performance dependence on device direction. The developed sensors and deployment examples are shown in Fig. 1.

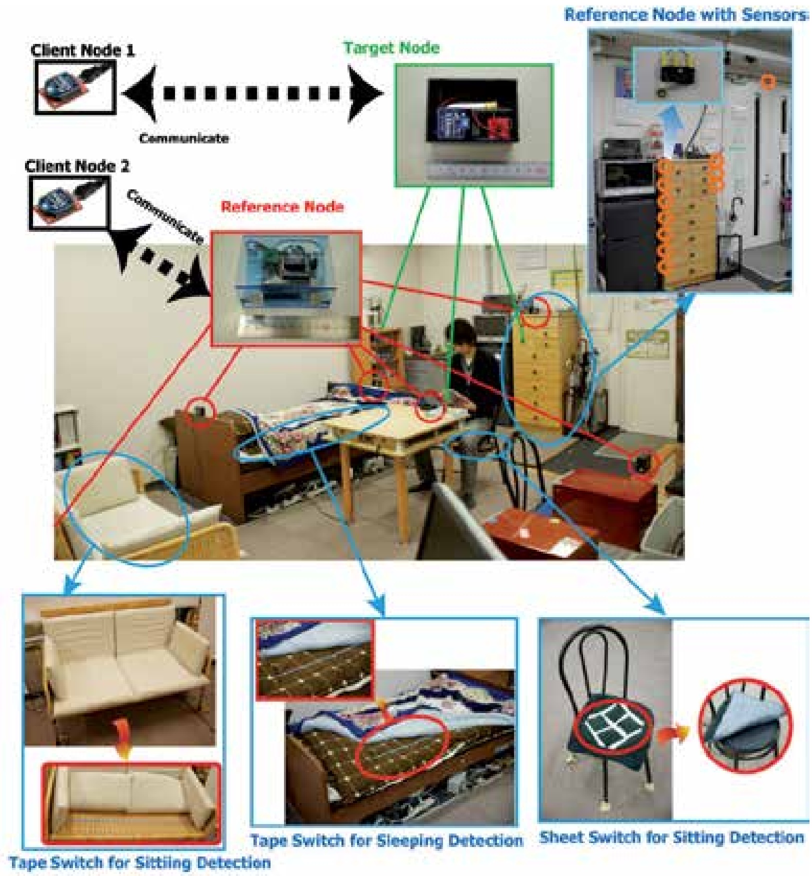


Figure 1. Developed devices and deployment examples.

2.1. Target node

The target node is used for object identification and localization. The node is attached to an object in a room. The node consists of the Arduino Fio and the XBee. The node contains an acceleration sensor (ADXL355) for detection of object handling, along with a luminosity sensor (CdS cell), a humidity sensor (HIH-4030), and a temperature sensor (TEMP6000) for environmental status measurement near the object. The node is battery powered. However, the current device has a battery life of only 3 days, and provision of longer battery life will be part of our future work.

The target node detects the object handling state by using an acceleration sensor, which acts as a trigger to localize the object position. In our research, we estimate the following five motion states by analysis of the acceleration changes:

i. Stable: object is in a stable state;

ii. Start Moving: object begins to move;

iii. Keep Moving: object continues to move;

iv. Ambiguous: object is either in "Moving" state or in "Stable" state;

v. Stop Moving: object stops moving.

To be specific, when a node shows noticeable changes in acceleration beyond a set threshold after a long time in the "Stable" state, our system judges this change to be to the "Start Moving" state. Then, as long as the acceleration sensor continues to respond, the state is regarded as being the "Keep Moving" state. However, in the real case, even if an object is moving, the acceleration sensor attached to the node sometimes does not show any noticeable response because of the way it moves. To avoid mistaken estimation in such cases, where even changes in acceleration cannot be detected, the system does not instantly determine the state to be "Stop Moving". Instead, the system regards such a state as "Ambiguous", which means that the node is either in the "Keep Moving" state or the "Stop Moving" state. If the acceleration sensor does not output any noticeable changes after a fixed period of time, the system decides that the first moment where the acceleration sensor's response disappears is the "Stop Moving" state, and the subsequent moments are the "Stable" state. Typical detection results using this algorithm are shown in Fig. 2.

To examine the validity of this algorithm, we performed some preliminary experiments. Because it is difficult to generalize all possible patterns of object motion, in the preliminary experiments, we simply raise an object with a node and move it for a time, and then set it down somewhere. However, despite the simplicity of the algorithm, the system can distinguish the state of object motion from the other states quite well, with a success rate of more than 90% according to our experimental results.

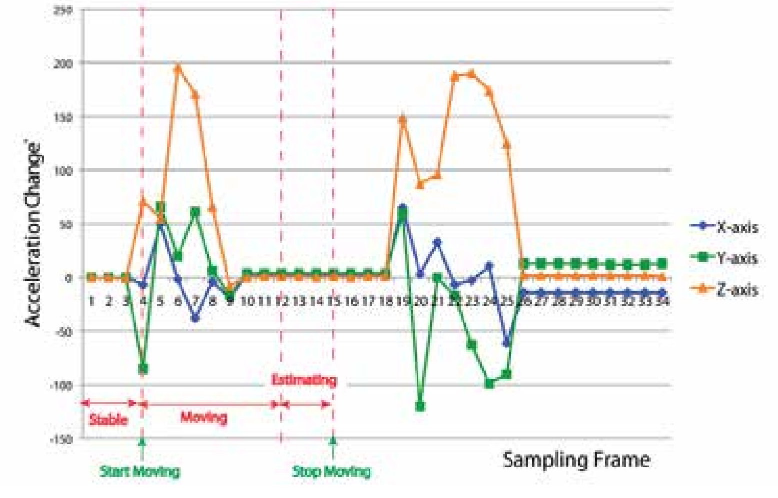


Figure 2. Motion sensing example results with acceleration sensor.

2.2. Reference nodes

A reference node is used for communication with the target nodes and for collection of the environmental sensor data. The node consists of an Arduino and an XBee. The node is capable of connecting to various sensors for environmental data collection. In our experiment, the node contains the same sensors as the target nodes and switch sensors to detect human behavior such as sitting and sleeping. Because the reference nodes cannot move if they are to provide localization reference data, the nodes are attached to fixed objects such as furniture and electrical appliances. The electric power is supplied to these nodes by a power line, because they do not move.

2.3. Communication protocol

The computer for object and human localization collects and controls all the sensor data and the RSSI values. For synchronization and simultaneous data collection, the computer controls the targets and the reference nodes separately with two gateway nodes, which are called client nodes. A typical communication example is shown in Fig. 3. In the figure case, the target nodes and reference nodes transmit sensor data periodically. The reference nodes also regularly gather RSSI values between the reference nodes to estimate human presence and human location based on the algorithm given in section 5 of this paper. When the target node detects object handling using the acceleration sensor, the node transmits a signal to indicate the handling of the object by the occupant. After transmission, the node sends the state of the target node periodically. When the node detects that the object has been put down somewhere, the node broadcasts the putting down action to all reference nodes. Finally, the target node receives each reference node's data with RSSI values and transmits all data to the client node. The computer calculates the object location from the collected RSSIs.

3. Object localization using only RSSI

3.1. Object localization method

While RSSI has a dependence on the distance between the nodes, the RSSI values do not change linearly with the distance. Although the RSSI is sensitive to some types of environmental noise, an RSSI from a fixed location almost always indicates the same value, regardless of the time. Therefore, our main idea is to reduce the environmental effects on the RSSI by not using just a single RSSI, but by using a pattern extracted from several RSSIs. To realize this idea, we must introduce three kinds of pattern recognition method.

The three kinds of pattern recognition method used in our work are the k-nearest neighbor (KNN), the distance-weighted k-nearest neighbor (DKNN) [10], and the three-layered neural network (NN) algorithms. KNN is a method for classification of objects based on the closest training examples in the feature space. The nearest neighbor algorithm, which means that K equals 1, has strong consistency results. As the amount of data approaches infinity, the algorithm is guaranteed to yield an error rate that is no worse than twice the Bayes error rate, which is the minimum achievable error rate given the distribution of the data. KNN is guaranteed to approach the Bayes error rate, for some value of K. DKNN is an extension of KNN, which weights the contributions of the neighbors, so that the nearer neighbors contribute more to the average than the more distant neighbors. We use the inverse of the squared Euclidean distance as a weight function. NN is a kind of classification technique. It is known that NN can demonstrate high discrimination ability for data that has multiple dimensions and is linearly inseparable. We therefore adopted these three methods in our work for object location estimation with RSSIs.

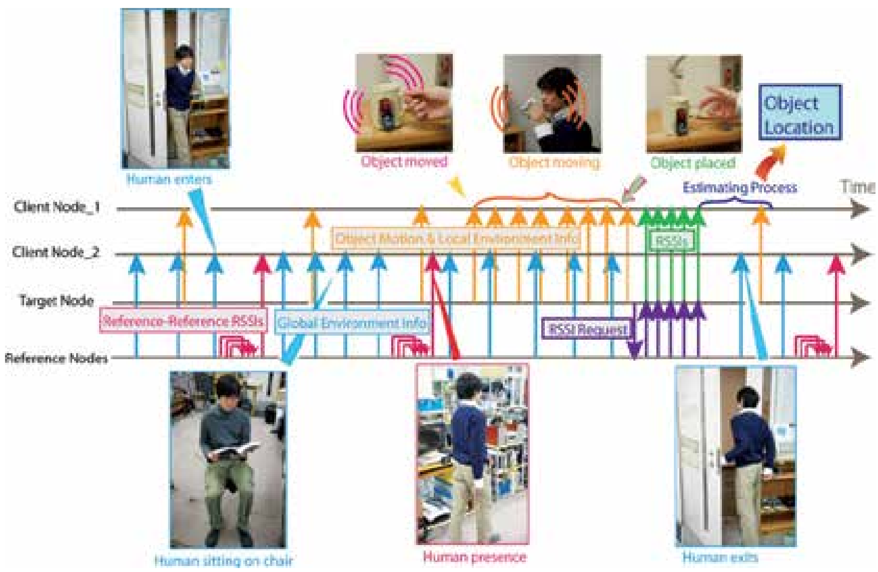


Figure 3. Communication protocol overview.

3.2. Experimental conditions

To investigate the basic object localization performance of the ZigBee-based RFID system, we conducted three experiments. Generally speaking, the classification performance depends heavily on the parameters used in the pattern recognition algorithm. For example, the performance of KNN or DKNN is dependent on the parameters such as the value of k, whereas the performance of the NN depends on parameters such as the number of nodes in the hidden layer. In our experiments, we tried various cases by varying the parameter values and chose the best combination of the parameters according to the estimation performance.

The experimental environment and conditions are shown in Fig. 4. The room contains various articles of furniture. Generally speaking, the largest contributors to reduced localization accuracy are environmental obstacles such as furniture made of metal. This environment provides extreme conditions for localization. However, the difficulty in localization using RSSIs in this environment helps to show that our proposed method is valid in actual living spaces.

To evaluate our estimation algorithm based on pattern recognition methods, we conducted experiments under different conditions: 1) estimation with different numbers of learning data; 2) estimation of different numbers and types of locations; and 3) estimation using different numbers of reference nodes. We collected the same number of RSSI data sets (about 50 to 150) from each of the 17 labeled locations as data sets. The parameters for each of the pattern recognition methods were tuned in advance with the data sets. For performance evaluation, we calculated the estimation accuracy, which is the rate of true positives among the total number of data sets. Ten-fold cross-validation was performed to eliminate any data bias.

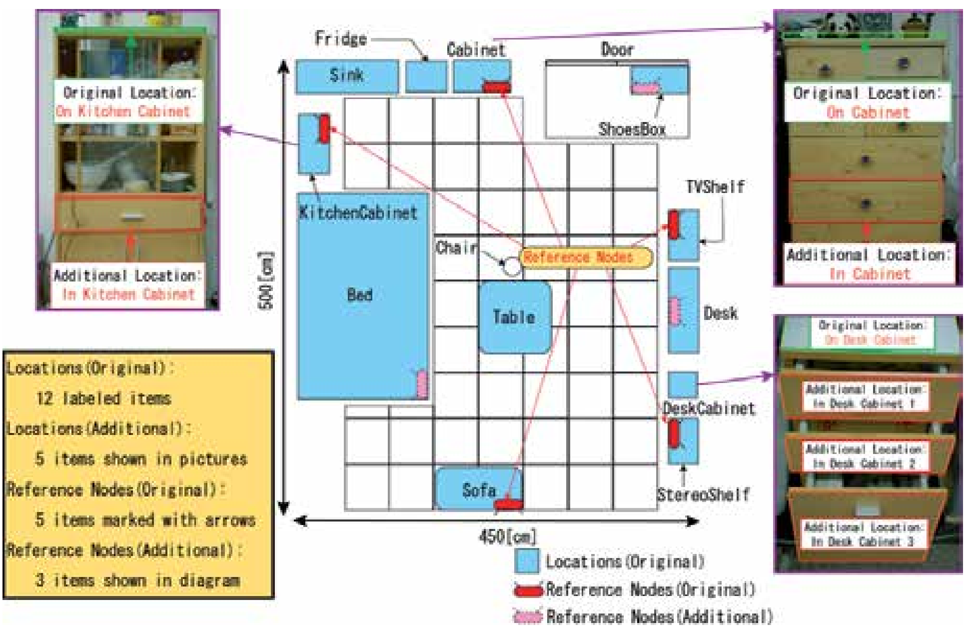


Figure 4. Experimental conditions for object localization using only RSSI.

3.3. Experimental results

3.3.1. Estimation with different numbers of learning data

As mentioned above, we collected RSSI data at each location in the environment and used these data sets to classify objects into particular locations. In Fig. 5a), "n" indicates the number of RSSI data sets collected at each location.

The graph of the results suggests two things to us. The first is that 50 learning data sets per location are sufficient for localization. Therefore, in the following experiments, we used a learning database that contains 50 data sets per location. The other is that as long as the system uses KNN or DKNN as the pattern recognition method, the estimation accuracy is not so heavily dependent on the number of learning data. However, 3-layered NN has increasing difficulty in estimating the object location as the number of learning data increases.

The estimation accuracy at each location with the 3-layered NN is shown in Fig. 5b). The graph demonstrated that the "Table" seems difficult to estimate with the NN. This is because the table is located right in the middle of all of the reference nodes, which means that the table is far from every reference node.

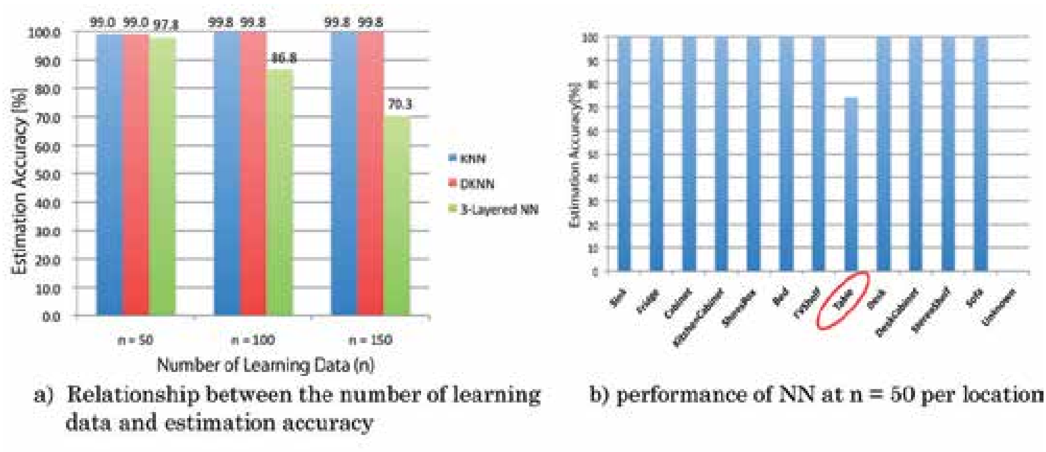


Figure 5. Experimental results with regard to the number of learning data.

3.3.2. Estimation with different numbers and types of locations

We conducted another experiment to investigate how well our proposed method can accommodate an increase in the number of locations. In this experiment, we added 5 new locations, shown in Fig. 4, to the existing 12 locations. We used a learning database consisting of 50 training data sets for each location and 5 reference nodes to measure the RSSIs with the target node.

Figure 6a) shows that our proposed method can estimate object location effectively even when the number of locations increases. In particular, it has been proved that estimation with KNN and DKNN is hardly affected by an increase in the number of locations, whereas estimation with the 3-layered NN becomes worse when the variety of locations increases. In Fig. 6b), we can see a similar tendency to that which appears in Fig. 5b). However, in this case, the estimation accuracy of the "InCabinet" state also drops seriously along with that of the "Table" state. The reason for this phenomenon is thought to be that it is becoming increasingly difficult to distinguish the "OnCabinet" state from the "InCabinet" state.

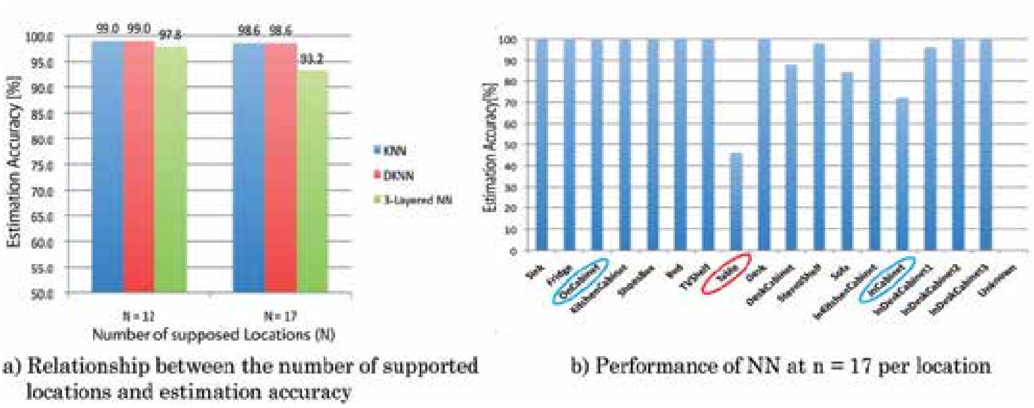


Figure 6. Experimental results with regard to the number of estimation locations.

3.3.3. Estimation by different numbers of reference nodes

We conducted another experiment to investigate the influence of the number of reference nodes on the estimation accuracy. All the experiments above used the 5 reference nodes illustrated in Fig. 4. In this experiment, however, we changed the total number of reference nodes in two ways: one was to subtract two reference nodes from the existing nodes, and the other was to add three nodes to the existing nodes. In the former case, we only used the reference nodes installed at the kitchen cabinet, the TV shelf, and the sofa, while in the latter case we attached reference nodes to the bed, the shoebox, and the desk.

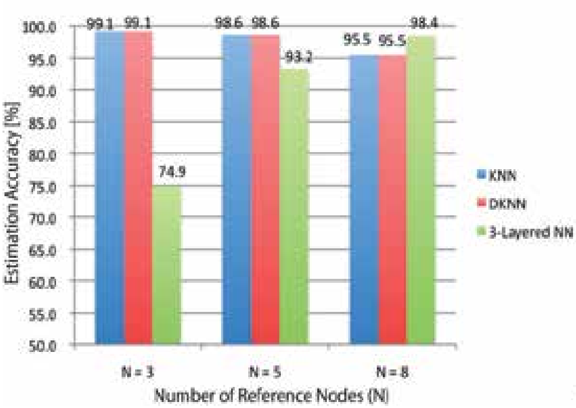


Figure 7. Experimental results with regard to the number of reference nodes.

The graph of the results shown in Fig. 7 suggests two things to us in particular. The first is that there is little difference in the best estimation accuracy with the different numbers of reference nodes. The other is that KNN and DKNN perform strongly with fewer reference nodes, whereas the 3-layered NN has trouble in estimating object locations with fewer reference nodes, although it demonstrates better ability than KNN and DKNN when the number of reference nodes increases.

These results indicate that the ZigBee-based RFID system has the capability for object localization using pattern recognition methods under human-absent conditions.

4. Object localization under human presence conditions

4.1. Object localization using sensor data on target node

The conditions for previous experiments are far from realistic. In a living environment, humans are present and handle the tagged objects. The existence of a human degrades the localization performance because the human body disturbs the radio waves. Our system can measure not only the environmental sensor data but also the sensor data on the target nodes. We extended our previous method [7] to be able to handle the sensor data on the target nodes. Because the previous method limits the location candidates based on estimated human behavior, location candidates are also limited in the new method based on sensor data on target nodes.

In the following algorithm, we use DKNN for RSSI-based localization. Because the sensor data on the target nodes indicates the node location well, the algorithm merges the sensor data on the target nodes into the RSSI-based localization results before combination of the sensor data on the reference nodes.

4.1.1. Integration of target-attached sensor data and rssi-based estimation results

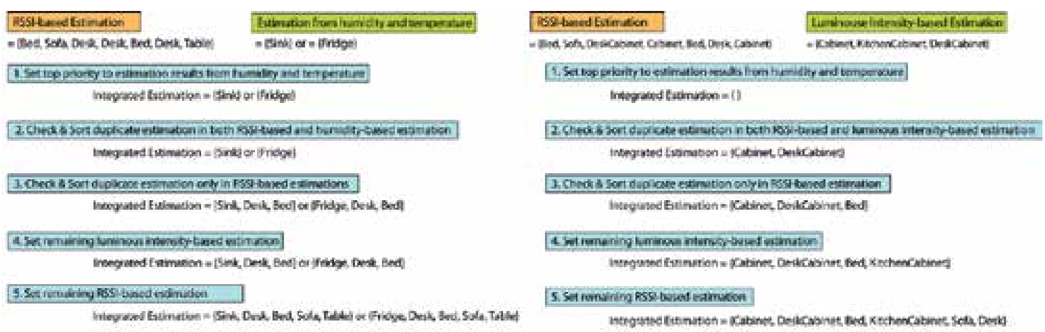
In our system, each target node contains a humidity sensor, a temperature sensor, and a luminous intensity sensor. The humidity and temperature sensors show changes only at specific locations, whereas the luminous intensity sensor is highly sensitive to the environment. This is why the system changes the estimation priority relative to the sensors that have reacted. First, the system integrates the estimation based on humidity or temperature sensors into the RSSI-based estimation. Then, the system integrates the estimation based on the luminous intensity sensor into the results.

- Integration of Humidity and Temperature Sensor Data

Because both the humidity sensor and the temperature sensor change dramatically only at specific locations, the system gives top priority to estimations based on these sensors. For example, because the system can detect object motion through the acceleration sensor, if the humidity rises around the time when an object is set down, it probably indicates that the object has been placed near the sink, because the sink is the only place that can cause a dramatic change in humidity. In the same way, if the temperature drops around the time when an object is set down, it suggests that the object has probably been placed inside the refrigerator, because the preliminary experiments indicate that the temperature only changes dramatically in the refrigerator. The system places its highest level of trust in these sensor reactions because they limit the object location candidates to one in each case. A localization example based on this policy is shown in Fig 8a).

- Integration of Luminous Intensity Sensor Data

The luminous intensity sensor does not limit the object location candidates to only one. This sensor can provide the system with several candidates for the object location. For example, if the luminous intensity drops dramatically around the time when an object is set down, it suggests to the system that the object has been placed in a dark place, such as the inside of a drawer or underneath the bed. Because the luminous intensity changes sensitively depending on the location, the system may even be able to tell the difference between the inside of a drawer and underneath the bed by comparing the sensor's outputs. A localization example based on this policy is illustrated in Fig. 8b).



a) Example where humidity and temperature data limits location candidates

b) Example where luminous intensity data limits location candidates

Figure 8. Typical examples of sensor data integration on target nodes.

4.1.2. *Integration of sensor data on reference nodes into the results*

Because the reference-attached sensor data provide the system with information about human behavior and locations, the system can limit the object location candidates. For example, if a sensor embedded on a sofa continuously reacts around the time when an object is set down, it is easy for the system to guess that the object location is not far from the sofa. In our experimental room, the reference-attached sensors consist of pressure-type switch sensors and microswitch sensors. Pressure-type sensors are installed in the chairs, the sofa, and the bed, whereas the microswitch sensor is installed in the drawer of a cabinet. Each time that an object is set down, the system refers to the reactions of all types of reference-attached sensors around that moment, and keeps track of them. The pressure-type switch sensors, such as those in the chair modules, usually continue to react, not only at the moment when the object is placed, but also during the periods before and after placement, so there is little possibility that the system will fail to detect them. For the microswitch switch sensors such as the drawer modules, however, the sensor reactions usually occur ahead of the moment when the object is placed. If the system only refers to the sensor data within a particular pe-

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riod, it might fail to detect them. However, by tracking the sensor reactions over longer periods, the possibility of missed detection decreases. Thus, the system can use the reference-attached sensors to provide several location candidates, and with the following integration algorithm, shown in Fig. 9, the system integrates reference-based estimation into target-based estimation.

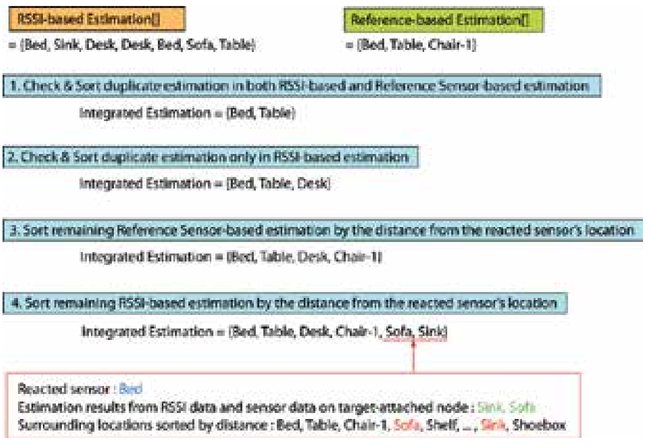

Figure 9. Typical example of sensor data integration on reference nodes.

4.2. Experiment

To evaluate the performance of our system, an experiment was conducted. The experimental room, the sensors for the reference nodes and the deployment locations are the same as those in Fig. 1. The target locations are illustrated in Fig. 10. The total number of target locations is 19. For the training data sets, we collected 400 samples per target location in advance under human absent conditions. For the evaluation, the subject puts down and picks up the object at all of the target locations 5 times, which means 19×5=95 location test data were collected. Strictly speaking, in a single trial, one subject conveyed a target node from location to location in the following order: OnDeskCabinet, InDeskCabinet, StereoShelf, Sofa, Shelf, BedHead, BedBottom, OnKitchenCabinet, InKitchenCabinet, InCabinet, Table, Desk, Chair1, Chair2, TVShelf, ShoeBox, OnCabinet, Fridge, and Sink. For the performance evaluation, we calculated the estimation accuracy in the same way as in the previous experiments. We compared the following five conditions.

1. **RSSI Only:** Estimation based on RSSI data between target node and reference nodes only;
2. **RSSI & Target Sensors:** Estimation directly based on RSSI and target sensor data;
3. **Integration of RSSI and Target Sensor Data:** Estimation based on proposed integration algorithm using the RSSI and target sensor data;

4. **Integration of RSSI and Reference Sensor Data:** Estimation based on proposed integration algorithm using the RSSI and reference sensor data;

5. **Integration of RSSI and All Sensor Data:** Estimation based on proposed integration algorithm using the RSSI and all sensor data (our system performance).

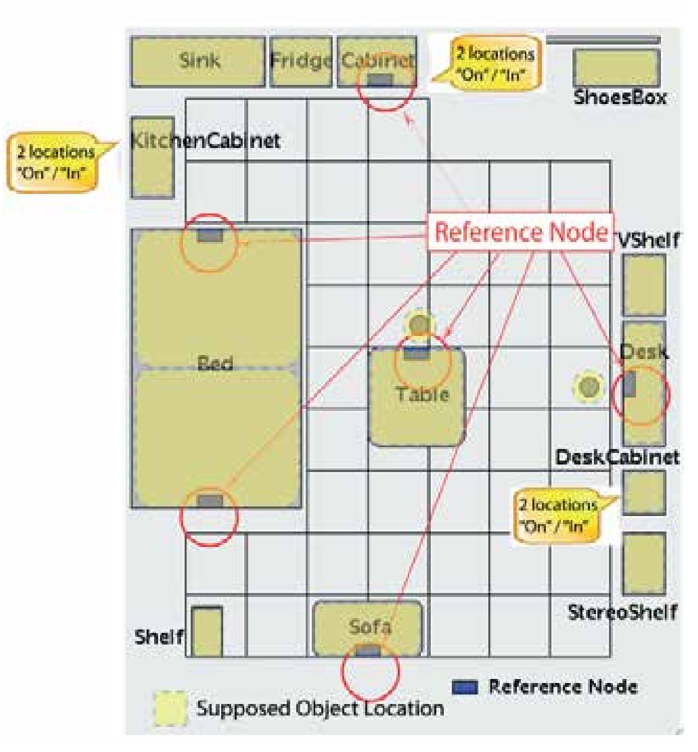

Figure 10. Experimental conditions for object localization with human presence.

The estimation results are shown in Fig. 11. Dynamic interference sources such as a human being had a serious effect on the RSSI-based estimation results. When we use the datasets in our learning database to conduct cross validation, the estimation accuracy is more than 90%. However, in this case, estimation based only on RSSI produced a poor performance.

Estimation based on the RSSI and target sensor data shows lower performance than that of RSSI-only based estimation. In this evaluation, we added another two dimensions (humidity and luminous intensity) to the original RSSI datasets. Because the luminous intensity changes are quite sensitive to the surroundings and to how the target node is placed, they might mislead the estimation to the wrong locations. However, this approach has one point of focus. In the RSSI-based approach, the sink is one of the most difficult places to estimate because it is surrounded by metal. However, by introducing the humidity data, the system estimated the sink correctly through all the scenario tests. This fact indicates that if we integrate target sensor data into RSSI more effectively, then the performance will become higher than that of this simple combination of RSSI and target sensor data.

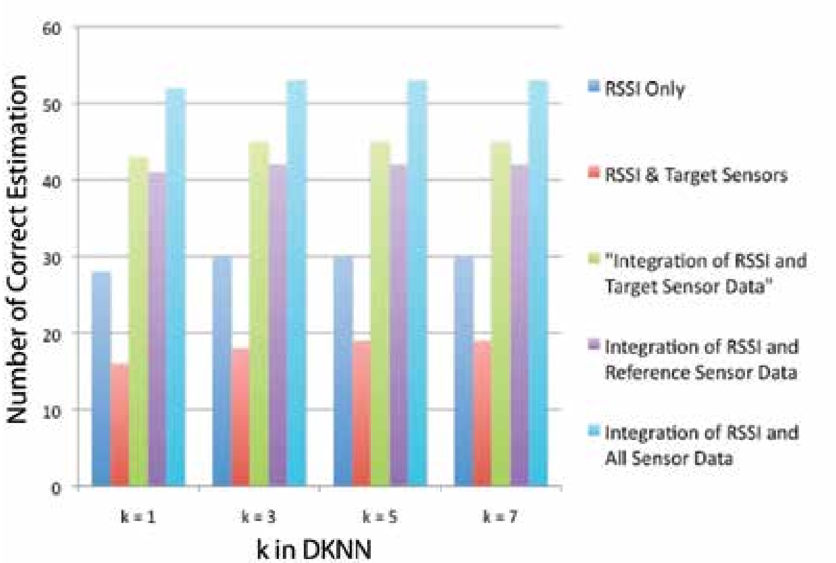

Figure 11. Results for the object localization algorithm at each K in DKNN.

Our proposed integration algorithm based on the RSSI and target sensor data shows much higher performance than the previous two algorithms. It clearly shows the effectiveness of our integration algorithm, which can correct the estimation even if the RSSI-based estimation provides a wrong result. Our proposed integration algorithm based on the RSSI and reference sensor data also shows high performance, similar to that of the RSSI and target sensor data approach. To investigate this in more detail, the contribution of the integration of the reference sensor data is seen to be different from that of the integration of the target sensor data. This therefore indicates that our system should produce a higher performance than these two integration algorithms. The system that integrates RSSI with all kinds of sensor data actually shows the highest performance.

The details of the estimation based on each approach are shown in Fig. 12. These results demonstrate that the use of sensors and limitation of the candidates improves the object localization. The locations where the performance improved are the sinks, the drawers, the bed and the sofa, i.e. locations where the sensor can easily localize the object. These improved locations indicate the effectiveness of the sensor data use. The results also showed that there are several locations that could not be correctly estimated by any of the five algorithms. Any of the five algorithms can estimate an object location based on the results of RSSI-based estimation, but if the RSSIs are heavily distorted by the presence of a human being, even the integration algorithm can hardly correct the mistaken estimation.

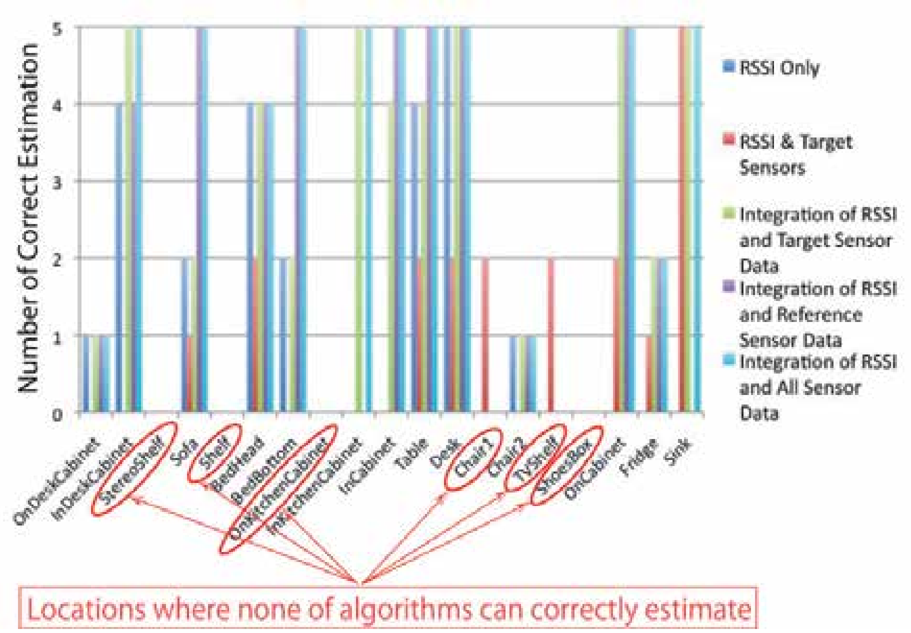

Figure 12. Performance results for each location.

5. Human localization with RSSIs between reference nodes

The human interference with the RSSI values degrades the localization performance. However, because human distortion of the RSSI values is stable, this distortion may be used to indicate the human's location. The human location is estimated by the same approach as that for object localization, using the pattern recognition technique. This is our idea for sub-room-level human localization. While the object location is estimated at the application request time, the human position is always required. Because the continuous use of a target node reduces the battery life, only the reference nodes are used for human localization.

5.1. Experiment on human localization in four areas

To confirm that the distorted RSSI can be used for human localization, we conducted a simple experiment. In this experiment, we make one person stand or sit to cut off the RF signals between two reference nodes. Because this situation drastically disturbs the RSSIs, estimation of the human's location should be easy.

The conditions for the evaluation experiment are described in Fig. 13. The datasets were gathered from 4 reference nodes. When one node is selected to be the base node, as shown in Fig. 13, the node collects RSSI from the three surrounding nodes. In total, 12 (=4×3) RSSIs were used for human localization. In the experiments, the subject sat or stood at the four locations illustrated. Data for the human absence case were also collected. This problem is regarded as 5-class classification. Direct human interference means that the RSSIs between two particular reference nodes are frequently missed, which means that the RF signals could not be received successfully. This data deficit may lead to human location estimation failure. We therefore compensated the part with the data deficit using the average of the successfully collected RSSIs. We evaluated the ratio of the true positive value in all data. Each pattern recognition method adopted the most suitable parameters for the estimation. Ten-fold cross-validation was also used for the evaluation.

The estimation results are shown in Table 1. These results indicate the possibility of estimating the four assumed human locations using the RSSIs among the reference nodes. Estimation with the 3-layered NN algorithm appears to be a little difficult, but estimations based on KNN and DKNN showed high accuracies.

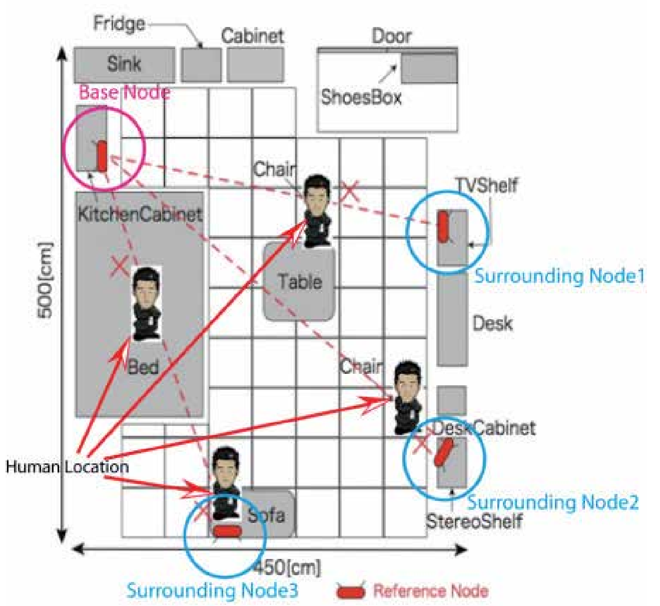

Figure 13. Conditions for experiments on human localization in four areas.

The estimation results suggest two points in particular. The first is that the 3-layered NN algorithm is poor at distinguishing the human presence case from the human absence case. It is also weak at human location estimation when compared with the other two pattern recognition methods. The other point is that KNN and DKNN can not only tell the difference between the human presence case and human absence case, but can also estimate human locations with high accuracy even under the condition where the human presence is unknown.

	Absence	Sofa	Bed	Table	Desk	Total
KNN	96.7%	96.7% (98.3%)	93.3% (88.8%)	91.7% (100.0%)	93.3% (96.7%)	94.3% (95.8%)
DKNN	98.3%	96.7% (98.3%)	93.3% (93.3%)	93.3% (100.0%)	96.7% (95.0%)	95.7% (96.7%)
NN	36.7%	90.0% (98.3%)	95.0% (98.3%)	51.7% (68.3%)	86.7% (95.0%)	72.0% (90.0%)

*Upper selection: Estimation including human absence data.

Lower selection: Estimation excluding human absence data.

Table 1. Results for human localization in four areas with RSSIs among the reference nodes.

5.2. Experiments on sub-room-level human localization

The previous experimental results showed that the direct human interference in communication between two reference nodes contained rich information for human localization. We now address a more complicated case.

The conditions for the evaluation experiment are shown in Fig. 14a). The reference node installed at the table is regarded as the center node, which then receives 14 RSSIs from the remaining surrounding nodes. For human location estimation, we took measurements with each node acting as the center node in turn to cover the whole environment. However, in this case, the same approach will increase the dimensions of the input RSSI data dramatically, which definitely results in the estimation time being too long. Therefore, we only use the reference node on the table as the center node because it is located at the center of the environment and, as Fig. 14a) illustrates, the RSSIs between this center node and other surrounding nodes can cover the majority of the environment.

We divided the environment into 49 grids (0.5 m×0.5 m) as shown in the left part of Fig. 4. We asked a subject to stand or sit on each grid to collect data sets for human localization. Also, human absence was appended to the data sets as one of the conditions. Thus, the problem is regarded as 50 (49+1) class discrimination from 14-dimensional vector data. For the experiment, 50 data sets were collected per location.

In this experiment, we assume an "Unknown" class in the output classes, which is the class to be used when the estimated result is less probable. This means that when the similarity between an input dataset and the most likely dataset in the learning database is smaller than a certain threshold, the system regards the estimated result as wrong and classifies it into the unknown class.

The estimation results are shown in Fig. 14b). The estimation accuracy as a whole is 86.2%, and the discrimination between the human presence case and the human absence case can be discriminated completely, with an accuracy of 100%. The percentage that was estimated as being in the unknown class was 1.3%, which means that almost all of the data is correctly classified.

The results show that RSSIs among the reference nodes can be used as good indicators to localize a human in the environment. It is interesting that although a human standing at the right lower corner of the room does not disturb the radio wave directly, the method estimates the location accurately, which may indicate that the pattern recognition method is sensitive to slight differences caused by human interference.

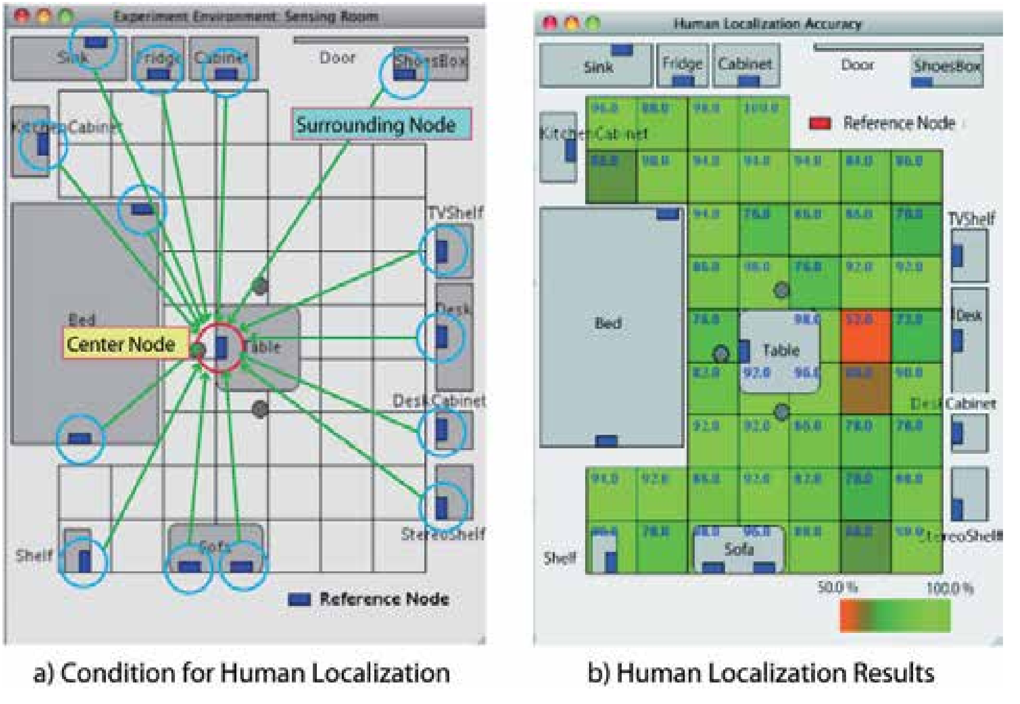

Figure 14. Conditions and results for the human localization experiment

There are some positions that are difficult to estimate with our approach. The worst two estimations are illustrated in Fig. 15. These scattered estimation candidates are the minority of the estimation as a whole and the majority of the mistaken estimation candidates are quite close to the correct location. This result means that loose conditions such as large grid size may improve the localization performance. Human localization using only RSSIs may contain some trade off between spatial resolution and localization accuracy.

These results demonstrated that the system could localize human positions in indoor environments with RSSIs only.

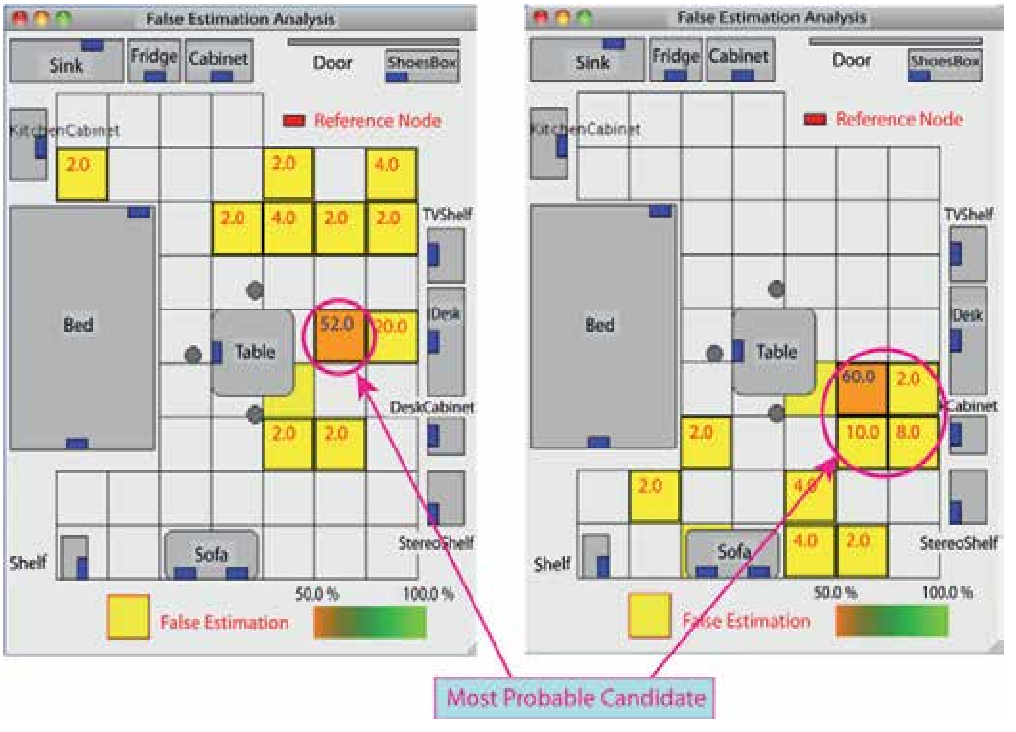

Figure 15. Estimation results at the worst estimation score areas.

6. Conclusion

We proposed methods for object and human localization using a ZigBee-based RFID system. Our method estimates the node locations using a pattern recognition technique from RSSI data among the nodes, environmental sensor data and estimated human behavior to reduce performance deterioration caused by human interference with radio waves. The experiments demonstrated that our method increases object localization accuracy by about 20% under human presence conditions. Considering the fact that human interference with the RSSI is stable, we also performed human localization using pattern recognition based on the RSSI values. Our experimental results showed that our approach is feasible for sub-room-level human localization.

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Chapter 12

Commercial Utilization of Mobile RFID

Ela Sibel Bayrak Meydanoğlu and Müge Klein

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53480

1. Introduction

The basic functionalities of mobile devices (e.g. phone calls, text messages, browsing the internet) are extended to the interaction with physical objects from the real world as a result of the establishment of mobile devices as ubiquitous and personal computing platforms [1]. In this context, mobile interaction with the physical world, the use of mobile devices as mediators for the interaction with the physical world, become more and more popular [2]. Radio Frequency Identification (RFID) technology is one of the enabling technologies that turn mobile devices – commonly mobile phones – into readers of RFID tags attached to physical objects [3]. RFID technology that is used in the context of physical mobile interaction is mobile RFID. This technology enables mobile devices with embedded micro RFID readers to read RFID tags [4]. Via mobile RFID people can contact RFID tagged objects anywhere [5]. The studies in the relevant literature (see Section 2.1) focus mostly on the realization techniques, architecture of the physical mobile interaction and its perception by users and the consequences of this perception. Advantages gained by physical mobile interaction – realized especially by mobile RFID - have not been discussed comprehensively. This study aims to provide an analysis to address this gap and provide a comprehensive discussion. There are indeed a few studies (see Section 3.2.1) in which advantages of using RFID technology in mobile devices are discussed. However, they are discussed briefly while discussing applications of RFID enabled mobile phones and how to use RFID technology in mobile phones.

This study has the characteristics of a review paper. It investigates the studies about physical mobile interaction, mobile tagging and mobile RFID as well as applications of mobile RFID in the relevant literature with the intention of revealing the competitive advantages gained by using mobile RFID.

The study is organized as follows: The next section provides an overview of different studies concerning the physical mobile interaction, illustrates the techniques and the supporting technologies to realize physical mobile interaction. In section 3, mobile RFID is defined. Afterwards commercial applications in the relevant literature are categorized, in order to define the possible B2C applications enabled by mobile RFID. In section 4, commercial advantages gained by application of mobile RFID are illustrated. Section 5 concludes the study.

2. Physical mobile ınteraction

2.1. Related work

The explanations below, which are related to the physical mobile interaction and the techniques as well as supporting technologies for the realization of physical mobile interaction, are outlined based on the explanations of the studies about the physical mobile interaction in the literature. The literature review revealed that studies about the advantages of physical mobile interaction – realized especially by mobile RFID - are limited. This limitation provides an opportunity for the execution of this study.

Various points concerned with physical mobile interaction, have been discussed until now. Reference [2] develops a framework called Physical Mobile Interaction Framework (PMIF) and shows an example of the implementation of mobile interaction with the PMIF. Reference [6] describes a generic architecture that supports mobile interaction, discusses techniques for physical mobile interaction and their integration in their architecture. Reference [7] presents an experimental comparison of four physical mobile interaction techniques: touching, pointing, scanning and user-mediated object interaction. It describes the advantages and disadvantages of these techniques based on the executed comparisons. Context-specific preferences for the techniques are also described. These preferences help application designers and developers to decide the integration technique. Based on a user-study, techniques pointing, touching and direct input for mobile interaction are evaluated in the study of reference [1]. In the study of reference [8] the techniques of pointing, scanning and touching are described. Furthermore, several use-cases concerning the techniques are illustrated. In the study, the touching technique is examined closer, and it is described how it can be realized via RFID or NFC (Near Field Communication). Reference [9] investigates user perceptions on mobile interaction with visual and RFID tags and potential usability risks that are due to the limited or erroneous understanding of the interaction technique. Reference [10] presents an analysis, implementation and evaluation of the physical mobile interaction techniques of touching, pointing and scanning. Reference [11] describes a conceptual system that enables the usage of physical posters as gateways to mobile services and a generic architecture for such a system. The services are related to advertisements and information presented on the posters. In the study, two scenarios are described to illustrate the usage of the developed system. Furthermore, places where posters can be found and behavior of people at stops where posters are observable are analyzed. Additionally, expectations of potential users in mobile and context-aware services are described. In order to prove the developed concept, a prototype is also illustrated. Reference [12] investigates mobile interaction with tagged, everyday objects and associated information that is based on the Internet of Things and its technologies. The study focuses on the implementation, design and usability of physical mobile interactions and applications.

2.2. Definition

"Physical mobile interaction (PMI) describes such interaction styles in which the user interacts with a mobile device (e.g. smart phone, PDA) and the mobile device interacts with objects in the real world [7]." PMI enables mobile devices to interact physically with smart objects (tagged objects) and consequently with associated information as well as services [7], [12]. Smart objects can be things, people or locations. Figure 1 visualizes how the physical mobile interaction functions.

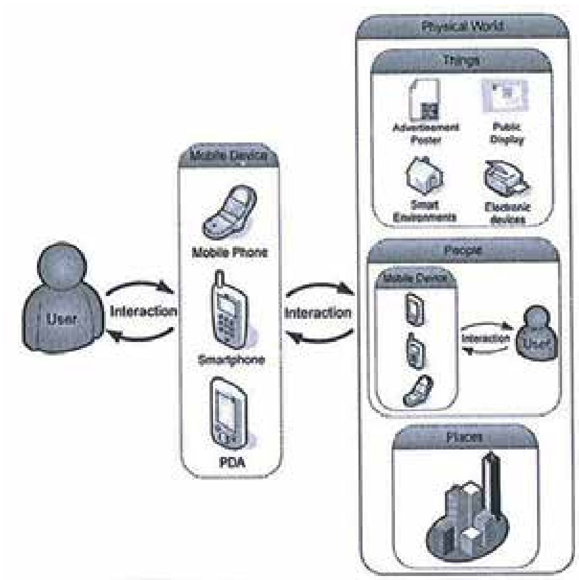

Figure 1. Physical Mobile Interaction [2]

2.3. Techniques for physical mobile ınteraction

Touching, pointing, scanning and user-mediated object interaction are the techniques that are commonly used for the physical mobile interaction [7], [8]. Based on the following determining factors, application designers and developers select the most appropriate technique to integrate into their applications [7], [10]:

- application context,
- location of the object,
- distance between object and user,

- service related to the object,
- capabilities of the mobile device,
- preferences of the user.

Pointing: By means of this technique, user can select or control a smart object by pointing at it with the mobile device [7]. Users of camera-equipped mobile devices point onto visual markers (e.g. QR-Codes (Quick-Response Codes)) on physical objects. In order to access the stored information on markers, visual markers are interpreted by recognition algorithms [13].

Scanning: According to this technique, mobile device scans the environment for nearby objects. Scanning can be triggered by a user, or the environment is scanned permanently by a mobile device. As a result of scanning, nearby smart objects are listed [7]. User is then free to choose the object with which he wants to connect. After the establishment of the connection, direct input from the user is required [8].

Touching: By means of this technique, user touches a smart object with a mobile device or brings them close together (e.g. 0 to 10 cm) [7], [8]. RFID and NFC are the common technologies for touching interaction [10]. Reference [14] is one of the first to present a prototype for touching interaction via RFID. The prototype uses RFID tags and a RFID reader connected to a tablet computer. It enables an interaction with augmented books, documents and business cards, in order to access links to the corresponding services like ordering a book or picking up an e-mail address [7], [10]. This interaction type is relevant for this study. In this context, it is discussed below how this technique is realized.

User-mediated object interaction: By means of this technique the user types in information provided by the object to establish a link between the object and the mobile device. As user is responsible for the establishment of the link, no special technology is needed for linking. Portable museum guides are good examples for the application of this technique. A visitor using portable museum guide has to type in a number to get information about a desired exhibit or a URL printed on an advertisement poster to get access to the corresponding services [7].

2.4. Supporting technologies for physical mobile ınteraction

Typical technologies that support physical mobile interactions are RFID, NFC and 2D Barcodes [15], [16].

2D barcodes and QR-codes: A traditional linear (1D/1-dimensional) code contains data in one direction only. 2D barcode is a graphical image that stores information both horizontally and vertically. That is why it can represent more data per unit area than a linear code. Additionally, it can encode several types of data such as symbols, control codes, binary data and multimedia data [15].

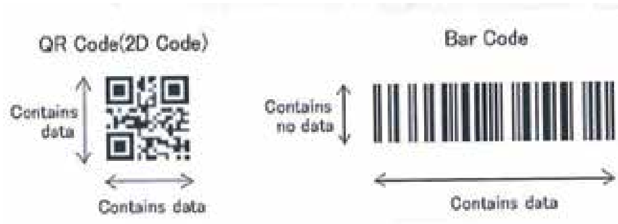

Figure 2. QR-Code vs. linear code [15]

Figure 3 includes some examples of 2D codes.

Figure 3. Examples of 2D barcodes [16]

Among barcodes, 2D barcodes are commonly used for mobile applications. QR-Codes were developed by the Japanese Company Denso Wave Corporation in 1994. It is faster than other 2D codes, because it contains three square position patterns that are used for position detection. These patterns are also used to detect the size, the angle and the outer shape of the symbol. When a reader scans a symbol, it first detects these patterns. Once they have been detected, the inside code can be read rapidly by the scanner. Decoding speed of QR-Codes is 20 times faster than that of other 2D codes [15]. These advantages of QR-Codes are the motives for preferring them for mobile applications.

In order to use barcodes for physical mobile interaction, mobile devices have to be equipped with cameras and image recognition algorithms. Using cameras of mobile devices and applying image recognition algorithms, barcodes – thereby products – are identified [3].

RFID: RFID is an Auto-ID technology that enables to identify tagged items by means of radio waves. Main components of a RFID system are:

- *Tag (Transponder):* It consists of an antenna and a microchip. Microchip stores data about the tagged item. Antenna transmits the data about the tagged item to the reader by means of radio waves [17].
- *Reader (Transceiver):* It is a device that communicates with tags through radio waves and reads data on them [18].
- *RFID Middleware:* It is a type of software that is used to consolidate, aggregate, process and filter raw RFID data, which are received from multiple readers, in order to generate useful information for end-users. It transmits also the processed data to backend enterprise applications [19].
- *RFID System Software:* It is software for the communication between tags and readers in order to read tags, write on tags, detect and fix erroneous data as well as to realize authentication for security [20].
- *Backend Enterprise Service:* This service helps to receive filtered RFID data from the middleware and integrate these with existing applications such as ERP, SCM or CRM systems through Application Programming Interfaces (APIs) [19].

NFC: This technology can be seen as an evolution of RFID technology [15]. It is a combination of RFID and interconnection technologies [21]. NFC is compatible with RFID. Both of them use the same working standards and radio frequencies for communication [15]. The differences between these technologies can be listed as follows:

- RFID operates in a long distance range compared to NFC. There is an eavesdropping risk for data exchange. NFC has a short transmission range. That is why NFC-based transactions are inherently secure and there is almost no risk of eavesdropping [8], [15].
- RFID allows only one mobile interaction method, according to which a reader reads or writes a predefined tag. NFC enabled devices allow three different mobile interaction methods. According to the first alternative, NFC enabled mobile device initiates the data transfer by sending a RFID signal to the tag. The tag responds and sends the information it contains back to the mobile device. This type of interaction is congruent with the interaction in RFID systems. According to the second type of interaction, the NFC enabled device acts as a tag (or a smart card). Information on the device can be read by a reader at an interaction point. According to the last type of interaction, direct communication between two NFC enabled mobile devices is possible [8].

NFC has two basic elements: Initiator (called reader in RFID) and target (called tag in RFID). Initiator begins and controls the information exchange. Target responds to the requirements of the initiator. Two modes of operation exist for NFC: active and passive. In the active operation, initiator and target generate their own field of radio frequency to transmit data. In the passive operation, only one of these devices generates the radio frequency field. The other device is used to load modulation for data transfer [21].

http://dx.doi.org/10.5772/53480

3. Mobile RFID

3.1. Definition

Two main ways exist to integrate RFID with a mobile phone, which is a commonly used mobile device for physical mobile interaction: a mobile phone with RFID tags and a mobile phone with a RFID reader [10].

A mobile phone with a RFID tag is a mobile device that includes a RFID chip with some identification information programmed on it. Besides a cell phone antenna used for connection to the network operator, the phone contains a RF antenna for communication with RFID readers. When RF tag equipped phone and reader are within an appropriate range for interaction, the tag information is sent to the reader, and the reader can write some information back to the phone's RFID tag [22].

A mobile phone with a RFID reader is a mobile device that includes a RFID reader. This reader collects data from fixed or mobile RFID tags. The phone also includes an antenna. The phone should have an appropriate reader software for reading and writing tags [22]. The rest of this study focuses on mobile devices that are integrated with RFID readers.

A mobile RFID system works as follows [8], [23]:

- User brings the mobile device equipped with a reader and the object with a tag (smart object) close to each other.
- Reader software in the mobile device activates and decodes tag info, which can be a list of services (e.g. getting more information via an online user manual, changing the state of a smart object such as playing music from the smart phone on your home stereo by simply placing the phone on top of the home stereo) offered by smart object, e-mail address, telephone number, web address, preformatted short message, short text, electronic business card.
- Displaying the decoded info on mobile device.

Below an artificial scenario, that was developed in the context of PERCI-project (PERvasive ServiCE Interaction)[1], is illustrated, in order to highlight how mobile RFID functions. The scenario supports mobile ticketing and payment services. Two posters are used in the scenario that are associated with Web services for mobile ticketing. The first poster allows users to purchase movie tickets for appropriate options like movie title, cinema name, number of tickets and preferred timeslots. The second poster enables to ticket purchases for a public transportation system and offers options like station to start the journey, destination, number of passengers, duration of journey to suggest appropriate tickets. Each option on the posters has a NFC tag and a visual marker. Tags and markers contain or reference the information that the option represents (e.g. name of a cinema) [1], [12]. On the posters action and

1 PERCI-project is a project of the collaboration between University of Munich and NTT DoCoMo Euro-Labs [1] and is funded by the latter. The goal of the project is to investigate and develop new methods for mobile interactions with the Internet of Things [24].

parameter tags are used. Action tags contain URLs of different services. Parameter tags provide parameter-values for the invocation of service. In order to determine the service that is to be used (e.g. ordering a movie ticket), an action tag has to be selected first. Then the corresponding parameter tag has to be selected for the invocation of the previously selected service (e.g. movie title or time slot) [1]. Users interact with the posters with their NFC enabled mobile phones that support interaction techniques pointing, touching and direct input [1], [6]. A user can buy a movie and a transportation ticket by pointing and touching his NFC enabled mobile phone on the posters. His mobile phone displays his selections and presents him a payment form. The user enters his credit card details on his phone to proceed and receives an electronic confirmation. The user shows the electronic confirmation on his phone to the transport controller and cinema officer [6].[2]

3.2. Mobile RFID applications

3.2.1. Related work

Applications of mobile RFID span across multiple areas including enterprises, consumer markets, public sector and even private lives. Among the reviewed references, which studied the application possibilities of mobile RFID, some references have a general classification of all possible application areas and some concentrate on a few, special application areas. In order to analyze the references, the reviewed applications are grouped into a classification framework for mobile RFID that considers three main application groups: *Public*, *Business* and *Private* (see Figure 4). *Public* applications include non-commercial applications for public use such as applications for education and health. *Private* applications are also non-commercial applications of RFID based appliances and focus on using RFID in connection with mobile devices in houses or in offices (e.g. RFID tagged food items in smart refrigerators). *Business* applications cover all commercial and non-commercial applications in a business organization such as applications for Supply Chain Management, Customer Relationship Management or Workflow Management.

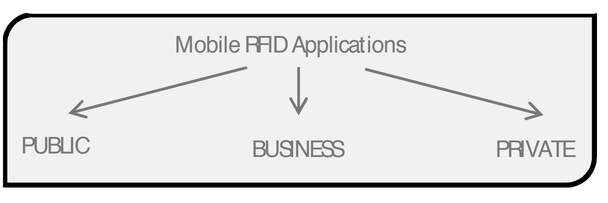

Figure 4. Classification framework for mobile RFID applications

2 As mentioned in Section 2.4, NFC technology is an evolution of RFID technology and besides two additional mobile interaction methods, it uses an interaction method that is also used by RFID technology. According to this method, a reader reads or writes a predefined tag. NFC tags of the illustrated scenario of PERCI-project use the mentioned method. In this context, it can be denoted that NFC tags of the scenario do not differ from RFID tags and the scenario of PERCI-project can be used as an example to highlight how mobile RFID functions.

Applications from thirteen references are reviewed in this study, in order to determine the possibilities concerning commercial utilization of mobile RFID. Below, each work is summarized briefly.

Study of reference [15] is one of the few studies that considers directly the use of mobile RFID and proposes four application categories:

1. Applications for education: RFID tags are used to enable learner to access learning content of an object according to the surrounding context.

2. Applications for health: Using mobile RFID for tagged medicines, RFID based patient smartcards, medical RFID patches enable easy access to patient's information and to monitor the health of patients.

3. Applications for entertainment and culture: Mobile RFID is used to enhance visits to museums and art galleries, particularly for guided visits.

4. Commercial applications: Using mobile RFID for any commercial activity such as ticketing, banking or purchasing goods and services.

Reference [25] groups mobile RFID applications into the following zones:

1. Applications for location based services zone: Services related to customer's current location are provided. Service providers deploy RFID tagged items/devices in a location that provide instant real-time information about services available at that location. Downloading bus routes by scanning RFID tagged buses, downloading prices of RFID tagged goods at stores, downloading movie information, trailers, show timings and the nearest theater locations by scanning RFID tagged movie posters, downloading current menu being served at a restaurant by scanning its RFID tag are some examples for applications concerning location based services.

2. Applications for enterprise zone: Mobile RFID applications support company's mobile staff like inventory checkers, field engineers, maintenance and repair staff, and security guards. It supports them in terms of inventory management in real-time, work attendance log, instructions on how to operate tagged items and demonstrating of staff presence at certain locations etc.

3. Applications for private zone: Mobile RFID assists users in their private spaces like home, garden, garage etc. For example, it helps users to make an instant call or send an instant message by scanning RFID tagged photographs and business cards. By scanning RFID tagged household items with a mobile phone, information (e.g. information about the expiration date of milk in the refrigerator or about the last watering time of a RFID tagged plant) can be obtained quickly.

Report of reference [22] focuses mainly on the enterprise market. However, a few consumer applications are presented to show the potential of the technology in the consumer market. Mobile RFID applications are categorized in five groups:

1. Applications for getting real time product information: For example, a service technician touches the machine to service with his smartphone, and up-to-date service information (for example last service date, instructions for additional service) is downloaded at his device.
2. Applications for collecting real-time information: For example, sending specific time and location information about a position or status for some calculations like meter measurement for pricing (measurement is sent for pricing by touching a tag attached on a meter with the mobile device) or like recording travel expenses (a tag attached on the car dashboard sends the starting and ending mileage for an expense report).
3. Applications for automatic asset tracking: Instead of counting devices manually on remote sites, mobile phone can collect info from RFID tags on equipment (PCs, desks, chairs etc.) and send this information to the centralized tracking application.
4. Applications for consumer marketing: Pointing onto a poster enables buying a video, a song etc.
5. Applications to initiate a call: A tag attached on a person's photo can be used to make an automatic call.

Reference [5] analyses commercial applications based on mobile RFID technology and defines three areas for it:

1. Product ordering: RFID tags are used for getting the latest information about products and for ordering them in case of a positive buying decision.
2. Transportation management: RFID tags are used to provide basic information of transported products and to record exception information.
3. Products receiving: RFID tags are used for checking the expected quality of the received products.

Reference [26] examines the utilization of RFID in mobile supply chain management and groups the application areas as follows:

1. Transport and logistics: toll management, tracking of goods.
2. Security and access control: tracking people, controlling access to restricted areas.
3. Supply chain management: item tagging, theft-prevention etc.
4. Medical and pharmaceutical applications: identification and determining the location of staff and patients, asset tracking, counterfeit protection for drugs.
5. Manufacturing and processing: streamlining assembly line processes etc.
6. Agriculture: tracking animals, quality control etc.
7. Public sector: passports, driver's licenses, counterfeit protection for bank notes, library systems etc.
8. Sports and leisure: tracking runners etc.

9. Shopping: facilitating checkout procedures etc.

Reference [27] defines seven scenarios for mobile RFID applications, which are partly inspired by Nokia:

1. Information retrieval: Mobile device helps to receive information on tagged items. Information would be stored in a database, which is accessed via mobile network. For example, a mobile phone user sees an advertisement on a poster and wants to get more information about the advertised product.

2. Data transmission: Means data transfer, for example for reading of electricity meters via a mobile phone.

3. Automated messaging: Messages will be transmitted when the tags are read (e.g. for reporting presence in the office).

4. Voice services: Through tagged items making phone calls simplifies.

5. Device integration: Information retrieved from tags in the environment can indicate to the mobile phone, which could then activate certain functions. For example, when a mobile phone is placed in a car, support for hands-free can be activated or when the mobile phone is in a hospital, it will be blocked.

6. Presence indication: RFID tag on the phone enables readers in the environment to identify the phone. For example, the location data of a person in a building can be used to provide automatic login to a system.

7. Mobile payment: RFID tags in the mobile device store information for payment.

In reference [8] two scenarios for physical interaction are introduced. The first one is a Smart Environment, according to which the user at home can interact with his personal electronic devices. The second one is about Information Heavy Situations, which can be applied for museum visits and guided tours. Transactions in supermarkets and fashion stores, buying car parking tickets, getting tourist information and using active posters are defined as possible utilization of mobile RFID in this study.

In reference [28], literature on mobile commerce (m-commerce) applications are reviewed. The result of this review reveals that location based services, mobile advertising, mobile entertainment services and games, mobile financial applications, product locating and searching, m-commerce in individual companies or industries are the possible m-commerce applications.

Reference [4] defines mobile RFID as a service using mobile devices to download information from RFID tags containing information of a specific area like stores, restaurants and tour sites.

Reference [29] executes a wide study about the utilization of mobile RFID. It describes many applications for RFID (e.g. buying electronic tickets, mobile payment, getting data about products, transportation, stock-trading, services like car rental, bike rental, car parking, taxi ordering, admissions to museums, musical and sports events, automatic call of a technical service hotline) and demonstrates them with case studies.

Using mobile RFID in B2B sector is considered in references [30], [31], [32]. Reference [30] provides information about a B2B case study in the retail industry supported through RFID technology and demonstrates that the RFID network can improve all relevant supply chain processes. In reference [31], mobile RFID technology is used to track and trace a product during supply chain activities (e.g. mobile product authentication service for consumers or an alert service for manufacturers). In reference [32], mobile RFID is used to manage product arrival inspection and loading in the context of transport management.

In Table 1, all applications found in the reviewed references are categorized according to the framework for mobile RFID applications.

Application Areas	Application Types
Public	**Voice Services** [22, 27], **Identity Management** [29], **City Information** (bus routes, train schedules, restaurants, stores) [4, 8, 15, 25, 29], **Mobile Learning** [15], **Health Services and Information** [15, 26], **Mobile Entertainment Services** [25, 28],**Agriculture Management** [26]
Business	**Mobile Commerce**: *Mobile Advertising* [4, 27, 28] via active posters [8, 22, 27, 29], *Product Ordering* [5, 15, 26, 28, 29] (e.g. electronic tickets for buses, car parking, museums, events, [8, 15, 29]), *Service Ordering* (e.g. taxi, technical service, hotel reservation, ski area acess [29], renting a car, bike etc. [29]), *Mobile Payment* [8, 15, 27, 28, 29], **Asset Management** (inventory control) [5, 8, 22,26], **Transportation Management** (arrival inspection, loading, locating, searching, alert service) [5, 26, 29, 30, 31, 32], **Location Based Services** (data transmission for meter readings/pricing, progress reports, work attendance logs) [22, 25, 27, 28, 29]
Private	**Smart Living Environment** (presence indication, device integration, appliance monitoring) [8, 25, 27, 29], **Asset Tracking** [22], **Voice/Messaging Services** [22, 25], **Sports and Leisure** (tracking runners) [26]

Table 1. Mobile RFID applications in categories

3.2.2. Commercial use of mobile RFID

Public and *Private* applications of the mobile RFID classification framework are out of the scope of this study. In order to define commercial applications and the advantages of mobile RFID, this study focuses on *Business* applications. *Business* applications differentiate among *in-house*-applications, *B2B* and *B2C* applications. *In-house*-applications deal with the execution of internal, non-commercial processes in enterprises. *B2B* applications comprise mainly commercial applications in supply chain management with business partners as well as applications for logistic processes. *B2C* processes aim to sell goods to end-consumers. Figure 5 includes an extended classification framework for mobile RFID applications.

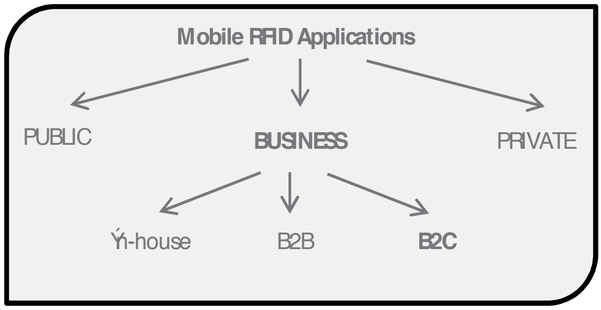

Figure 5. Extended classification framework for mobile RFID applications

As it is seen in Table 1, mobile RFID makes an important contribution to the execution of mobile commerce [5]. M-commerce is a subset of e-commerce and is defined *"as any transaction with monetary value that is conducted via a mobile network"* [33]. Through m-commerce, interaction between supplier and customer is facilitated not only by a mobile network, but also by a mobile customer device. Possible mobile networks for m-commerce are conventional mobile carrier networks, WiFi networks or networks of local frequency technologies for unique identification capabilities for goods (e.g. RFID) (see Figure 6). That is to say, mobile RFID is one of the possible supporting technologies for m-commerce. According to m-commerce supported by mobile RFID, commercial interaction and transaction between suppliers and customers are realized through physical mobile interaction as described above.

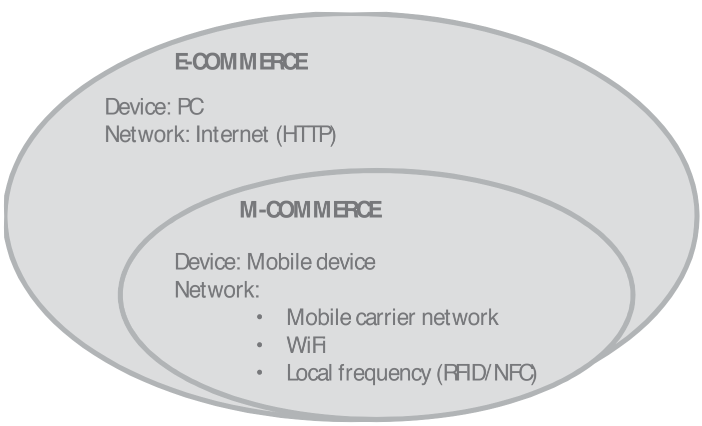

Figure 6. E-commerce vs. M-commerce

This study focuses on B2C m-commerce applications enabled by mobile RFID. As a result of this the m-commerce applications concerning B2C in Table 1 are defined closer:

- **Mobile marketing:** Mobile marketing is a sales approach that helps manufacturers, shopping malls, and service agencies to promote their products and services through interaction with customers via their mobile devices [34]. Kotler [35] defines two basic marketing communications strategies: push and pull strategies. Push-based mobile marketing refers to any content sent by marketers to a mobile device, whether the consumer requests it or not and includes audio, short message service (SMS), e-mail, multimedia messages, or any other pushed advertising content [36]. While push marketing is marketer-initiated, pull marketing is consumer-initiated. Pull-based mobile marketing is defined as any content sent to the mobile consumer upon request [37]. Consumer requests information about products and services that interest him. For classical m-commerce applications enabled by mobile device's Internet or Wifi, both of the mobile marketing communications strategies are applicable. Sending a SMS advertisement to consumer's mobile phone is an example for push mobile marketing. Searching the Internet for a product via a mobile phone is an example for pull mobile marketing. For m-commerce applications enabled by mobile RFID pull marketing strategy is viable. Only if the consumer wants to get more information about a product or a service, or if consumer wants to buy a product or get a service of the RFID tagged item, he can request it. Furthermore, the pull marketing strategy of RFID supported m-commerce is more effective than by classical m-commerce. Because in classical m-commerce, getting information via mobile device's Internet service takes a lot of time and energy of consumer, while through RFID tags information gathering is very quick and convenient [5]. Advertising is an important method for the marketing mix element "communication" (see Section 4). Mobile RFID enables mobile advertising. Through active posters augmented with RFID tags, which advertise a product or a service, or through the tagged items themselves, marketers try to catch consumers' attention. If desired, information about goods is "pulled" very easily via a mobile device. In case of interest, the designated products and/or services can be ordered. Active posters can also be used for location-based mobile advertisements. By using their mobile devices equipped with RFID readers, consumers can read RFID tags, which are placed on boards, and get information about nearby services or products such as restaurants, cinemas [4].

- **Product and service ordering:** Activities concerning product/service ordering do not differ from classical mobile commerce applications. In the context of mobile commerce enabled by mobile RFID, ordering is carried out via a mobile device on Internet or on a product specific network as is done in the classical mobile commerce.

- **Mobile payment:** Payment for product or service ordering occurs also via a mobile device like in classical m-commerce.

4. Advantages gained by mobile RFID

Advantages of using mobile RFID for B2C applications can be grouped as in Figure 7. Mobile RFID is a RFID-based mobile IT application. That is why, the advantages resulted from its characteristics of being an IT system, a mobile solution and a RFID-based technology have to be considered initially.

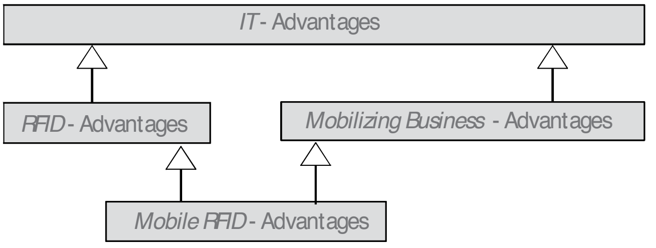

Figure 7. Inheritance classification for mobile RFID advantages

IT-adoption enables organizations to increase efficiency through the automation of processes and information management. As a special IT system, mobile RFID inherits this advantage. RFID technology is a radical innovation in terms of business processes. It does not only automate business processes more efficiently, but it also changes them radically [37]. In addition, it reduces inaccuracy of information caused by transaction errors (e.g. shipment errors, delivery errors etc.) [38], [39]. Substitution of expensive human work through a fully automatic identification system like RFID leads to an increase in information quality, higher data availability and higher speed of process execution, thereby to higher productivity, performance and cost savings [37], [38], [39], [40]. All of these advantages of RFID technology belong also to mobile RFID, which is a RFID-based technology. Mobile business solutions give users the flexibility to operate in a wireless computing environment anywhere [41] and anytime. Users can take advantage of information systems linking business processes among different departments within a company and among companies at remote locations [41]. Ability of accessing a corporate network anywhere and anytime is the primary motive for adopting mobile enterprise solutions [42], [43].

There are also some specific advantages of using mobile RFID in B2C applications. These can be listed as follows:

- **Advantages concerning Marketing Mix:** "*The marketing mix is a combination of tactical marketing tools that a firm uses to satisfy the target market* [44]". Four Cs marketing mix model, which is adopted in this study,[3] groups the marketing tools into four categories: customer needs and wants, cost to customer, convenience and communication. According to the four Cs marketing mix model firms should sell only products that customers need and want. Consumers are more concerned with total costs of ownership of a product rather than its price. Convenience means the ease of buying and finding the product as well as finding information about the product. Consumers should be provided with the most convenient way possible for purchasing. Under communication, any form of communication (e.g. advertising, public relations, personal selling, viral advertising) between a firm and its consumers is understood [45]. Using mobile RFID has a positive impact on the following elements of four Cs marketing mix model:

3 Today's firms tend to execute their activities customer-oriented. Thus, the study adopts customer-focused marketing mix model four Cs instead of product-oriented four Ps marketing mix model.

- *Customer Needs and Wants*: It is essential to offer products that meet customer needs and wants. In order to determine needs and wants of customers, marketers need a good customer database. They may use mobile tags to provide links to specific mobile sites in which through various tools (e.g. questionnaires, voting) information about the needs and wants of customers are collected. The captured information are then analyzed and used to determine offerings for the target customer [46].
- *Convenience*: As mentioned above, ease of finding information about a product is an essential aspect of convenience. Through mobile RFID tags, marketers can provide additional information about their products (e.g. the nutrient content in packaged foods) or events (e.g. concerts, parties, conferences etc.) and facilitate direct downloads (e.g. branded mobile content) [47].
- *Communication*: Advertising is a powerful form of communication and mobile devices are effective communication tools. Consumers use their mobile devices to get tag info that can be an advertisement of a product or a link to a mobile commerce enabled web site. For example, by pointing his/her cell phone onto a poster of a new single, a consumer can get info about the singer, watch the video clip and even buy the song [22]. Mobile RFID enables also location-based mobile advertisements. By using their mobile devices equipped with RFID readers, consumers can read RFID tags, which are placed on boards, and get information about nearby services or products such as restaurants, cinemas [4]. Reference [48] defines using mobile tags within a location-based mobile advertisement publishing system as a convenient way for vendors to create and edit advertisements that include the vendor's location as well as discount coupons stored on a tag.
- **Seamless B2C process:** Mobile RFID enables seamless process flow from advertising to product/service ordering and following to mobile payment with only one mobile device. Thereby, it contributes to solve the media break problem. Off-line products with RFID tags contain information pointers represented as URLs that enable users to access associated on-line contents. For example, a movie poster on a billboard, which is an off-line marketing instrument, can have a RFID tag. This tag enables the user with RFID reader equipped mobile phone to access online information associated with the movie poster (e.g. a short summary about the subject of the movie, comments of movie reviewers), which forms an important online-marketing instrument [49].
- **Ease of information access:** Information access is possible from anywhere to anytime. Information about products or services, which seems interesting for users, can be received immediately via mobile devices [50], [51].
- **Enhanced CRM:** With RFID tagged items and their ordering via mobile devices customer-oriented direct pull marketing strategy is followed. Customers are always able to retrieve valuable product/service information. This customer-oriented characteristic of mobile RFID can increase customer loyalty and lead to repeat purchasing [52].
- **New business models:** Mobile RFID technology leads to new business opportunities for services and products (e.g. the company Flexcar exists only because of its remote vehicle-usage-monitoring system) [22]. Companies that use this technology profile as innovative companies on the market. This is an important competitive advantage for companies [16].

All of the listed advantages have positive impacts on the increase of customer satisfaction, keeping existing customers and thereby increasing customer loyalty as well as on gaining new customers. As customer satisfaction, customer loyalty and an increase in the number of new customers impact directly the revenue of a company, it is not wrong to conclude that mobile RFID has an essential impact on the revenue increase of a company.

5. Conclusion

Although RFID is not a new technology, mobile RFID applications are still in their infancy and their business impact is still unproven. Most of the studies about mobile RFID in the relevant literature are limited to the realization techniques, application possibilities or to case studies. Commercial advantages gained by mobile RFID have not been discussed comprehensively. In this study, based on a literature review B2C applications of mobile RFID are analyzed and commercial advantages of using mobile RFID for B2C applications are illustrated. In this context, first physical mobile interaction concept was defined. Following, mobile RFID was introduced as a supporting technology for physical mobile interaction. After the categorization of mobile RFID applications in the relevant literature, the possible B2C applications enabled by mobile RFID were defined. Finally, commercial advantages of using mobile RFID were illustrated.

This study sheds an insight into the business value of mobile RFID from a commercial viewpoint. Certainly, findings of this theoretical study have to be concretized and validated through case studies in future research.

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Chapter 13

Application of Mobile RFID-Based Safety Inspection Management at Construction Jobsite

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53176

1. Introduction

Jobsite safety management is very important subject special in construction management. Managing jobsite safety-related inspection information plays an important role in the view of safety management. Managing jobsite safety management effectively is extremely difficult owing to various participants and environments in construction jobsite. With the advent of the Internet, web-based information management solutions enable information dissemination and information sharing at the construction jobsite. Generally, jobsite safety-related managers and engineers require access to the important check locations to handle inspection work in construction jobsite. However, jobsite safety-related managers and engineers generally use sheets of paper to handle various types of inspection checklists and entry check record. Consequently, there is serious rework progress regarding the data capture and entry in inspection progress. Furthermore, current desktops and notebooks are not suitable for inspection work at the jobsite because of problems in transportability.

In order to solve the above problems, this study presents a novel system called Mobile RFID-based Safety Inspection Management (RFIDSIM) system for jobsite safety management and providing safety inspection information sharing platform among all participants using web technology and RFID technology. The RFIDSIM is then applied in a construction commerce project jobsite in Taiwan to verify our proposed methodology and demonstrate the effectiveness of safety inspection progress in construction jobsite. The combined results demonstrate that, a RFIDSIM system can be a useful web safety inspection management platform by utilizing the RFID approach and web technology.

Integrating Near field communication (NFC) technology and mobile devices such as NFC Smartphone, Radio Frequency Identification (RFID) scanning and data entry mechanisms, can help improve the effectiveness and convenience of information flow in the safety inspection management. The combined results demonstrate that, an RFIDSIM system can be a useful mobile RFID-based jobsite safety management platform by utilizing the NFC and web technologies. With appropriate modifications, the RFIDSIM system can be utilized at any jobsite inspection and management progress for jobsite safety management divisions or suppliers in support of the RFIDSIM system.

2. Problem statement

Jobsite safety management performance can be enhanced by using RFID technology for information sharing and communication. There are many jobsite safety checkpoints locations need for tracked and inspected for jobsite safety management. Information acquisition problems in inspection management follow from information being gathered from jobsite safety checkpoints locations. The effectiveness of information and data acquisition influences the efficiency of jobsite inspection management. Usually, project managers and safety staff members generally use sheets of paper and/or field notes for jobsite safety inspection progress in Taiwan construction jobsite. Restated, existing means of processing information and accumulating data are not only time-consuming and ineffective, but also compromise jobsite safety management in information acquisition. Such means of communicating information between jobsite safety checkpoints locations and jobsite office, and among all participants, are ineffective and inconvenient. The primary problems in inspection regarding to data capture and sharing based on experts interviews are as follows: (1) the efficiency and quality are low, especially in the safety inspection progress in construction jobsite through document-based media, (2) there are serious rework progress regarding the data capture and input in safety inspection progress, and (3) there are serious problems regarding to inspection information collection and responding during safety inspection progress. However, few suitable platforms are developed to assist jobsite office with capturing and sharing the jobsite safety inspection information when jobsite office needs to handle inspection information and inspection management work. Therefore, to capture data effective and enhance inspection information collection and respond in construction jobsite will be primary and significant challenge in the study.

3. Research objectives

This study utilizes the RFID and web technology to enhance the inspection management progress and effectiveness in jobsite safety management. This system is controlled by the management division, and provides project managers and safety staff members with real-time checkpoints-related information-sharing services, enabling them to dynamically respond to the entire jobsite safety management network. This study develops Mobile RFID-based Safety Inspection Management (RFIDSIM) system to improve efficiency and cost-effectiveness of jobsite safety management, improve practical communication among participants, and increase flexibility in terms of service delivery and response times. RFIDSIM system is a web-based system for effectively integrating managers, safety staff members and relative members, to enhance the jobsite safety management in the construction. Utilizing smartphone with NFC technologies can extend RFIDSIM systems from offices to jobsite safety checkpoints locations. Data collection efficiency can also be enhanced using RFID-enabled smartphone with NFC technology to enter and edit data on the jobsite safety checkpoints locations. By using web technology and RFID-enabled smartphone with NFC technologies, the RFIDSIM system for the management division has tremendous potential to increase the efficiency and effectiveness of information respond and management, thus streamlining services jobsite safety management processes with other participants. The portal and RFID-enabled smartphone with NFC technology enable safety staff members to update data from the jobsite safety checkpoints locations and immediately upload it to the system; project managers can receive inspection information and make better decisions regarding future jobsite safety management and control. The main purposes of this study include (1) developing a framework for a mobile jobsite safety inspection system; (2) applying such a system that integrates RFID-enabled smartphone with NFC technology to increase the efficiency of safety inspection data collection in the jobsite, and (3) designing a web-based portal for jobsite safety management and control, providing real-time information and wireless communication between jobsite office and jobsite safety checkpoints locations. Figure 1 illustrates solutions used in a polite test utilized RFIDSIM system in Taiwan construction jobsite. With appropriate modifications, the RFIDSIM system can be utilized at any jobsite safety inspection and management application in construction.

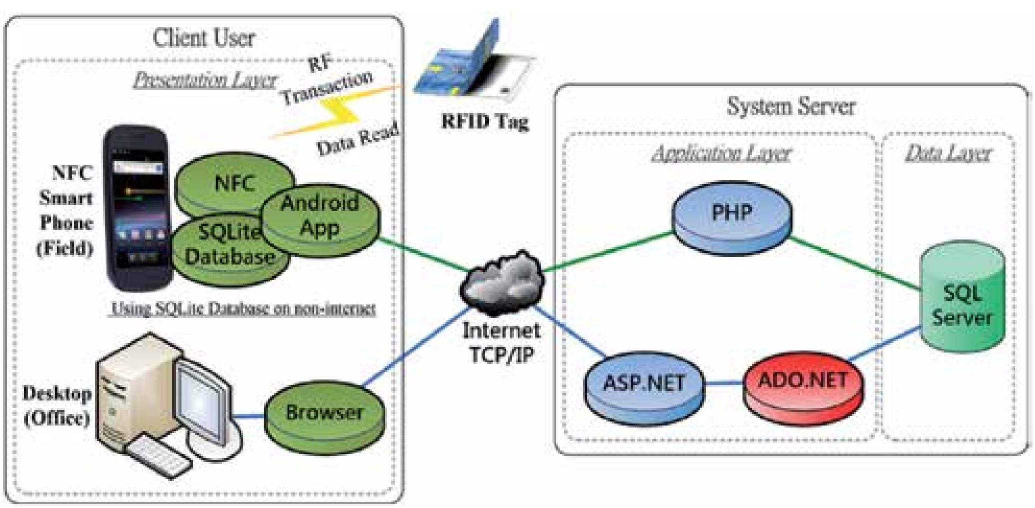

Figure 1. RFIDSIM System Framework Overview

4. Background research

RFID is an automatic identification solution that streamlines identification and data acquisition, operating similarly to bar codes. Automatic identification procedures have recently become very popular in numerous service industries for purchasing and distribution logistics, and in manufacturing companies and material flow systems. Jaselskis and Anderson (1995) investigated the applications and limitations of RFID technology in the construction industry, and attached read/write RFID tags to the surfaces of concrete test that were cast from the job site to test lab. This RFID technology has been widely applied in many areas in the construction industries for the following reasons: (1) to provide owners and contractors with information to enhance operation using RFID technology (Jaselskis and Tarek, 2003); (2) to propose a novel concept of "parts and packets unified architecture" in order to handle data or information related to a product carried by product itself by utilizing RFID technology (Yagi et al., 2005); (3) to apply RFID technology as a solution to problems in pipe spools, and identify potential economic benefits from adopting RFID technology in automated tracking (Song et al., 2006); (4) to apply RFID combined with GIS technology in order to locate precast concrete components with minimal worker input in the storage yard (Ergen et al., 2006); (5) to improve the efficiency of tracing tools and tool availability using RFID (Goodrum et al., 2006); (6) to develop mobile construction supply chain system integrated with RFID technology (Wang et al., 2006); (7) to describe a prototype of an advanced tower crane equipped with wireless video control and RFID technology (Lee et al., 2006); (8) to improve tracing of material on construction using materials tagged with RFID tags (Song et al., 2006); (9) to present strategy and information system to manage the progress control of structural steel works using RFID and 4D CAD (Chin et al., 2008); (10) to enhance precast production management system integrated with RFID application (Yin et al., 2009), and (11) to present a new methodology for managing construction document information using RFID-based semantic contexts (Elghamrawy and Boukamp, 2010).

The use of technology to improve delivery process control is not a novel concept. Many industries have applied barcodes to track materials for many years. Construction companies began to examine the use of barcodes for tool management in the early 1990s. Although barcode is an established and affordable technology, it has presented problems in the construction industry due to the short read range and poor durability of barcodes — a barcode requires a line of sight, and becomes unreadable when scratched or dirty.

An RFID system is composed of an RFID tag and an RFID reader. The RFID tag comprises a small microchip and an antenna. Data are stored in the tag, generally as a unique serial number. The RFID tags can be either passive (no battery) or active (battery present). Active tags are more expensive than passive tags and have a read range of 10–100 meters. Passive tags have a read range of 10mm to approximately 5m (Manish and Shahram, 2005). The vast majority of RFID tags applied in the construction industries are passive.

The RFID reader functions as a transmitter/receiver. The reader transmits an electromagnetic field that "wakes up" the tag and provides the power required for it to operate (Lahiri, 2005). The tag then transfers data to the reader via the antenna. This data are then read by the RFID reader, and transferred to a Pocket PC or computer. Unlike barcodes, RFID tags do not require line-of-sight to be read; they only need to be within the reader's radio range. Additionally, RFID tags can be read through most materials. RFID tags are shrinking, with some measuring only 0.33mm across. Although RFID systems can apply different frequencies, the most common frequencies are low (125KHz), high (13.56MHz) and ultra-high (UHF) (850–900MHz) (Lahiri, 2005).

RFID (Radio Frequency Identification) is a tagging technology that is gaining widespread attention due to the great number of advantages that it offers compared to the current tagging technologies being used today; like barcodes. Near Field Communication, or more commonly known as NFC, is a subset of RFID that limits the range of communication to within 10 centimetres or 4 inches. Compared with Bluetooth and infrared, the main characteristic of NFC is quick, easy, security. Although the NFC data transmission speed is far less than the Bluetooth and infrared, the device only by the unilateral power supply to the operation of the device near to the rapid induction features, and greatly enhance the ease of use. Furthermore of the NFC device requires very short communication distance. NFC technologies help to improve data security because it can reduce the data to the risk of being intercepted or stolen.

In recent years, due to the rapid development and popularization of the smartphone, a growing number of mobile phone NFC functionality into the standard features. The NFC-enabled mobile phone through the sensor to read high-frequency band RFID tags or other NFC-enabled devices for data transmission via a simple touch can, and are widely used in the identification, communication, information obtained, consumption and other purposes provide fast and convenient communication, this study using NFC phones used in patrol operations and identification of the site staff can enhance the operating convenience of mobility and reduce the cost of equipment to build, in order to improve the job the best solution.

Notably, RFID systems are one of the most anticipated technologies that will potentially transform processes in the engineering and construction industries. In the construction industry, RFID technology can be utilized with smartphone, thereby allowing staff members to integrate seamlessly safety work processes in the jobsite, due to the ability to capture and carry data. With a NFC technology plugged into a smartphone, the RFID-enabled smartphone is a powerful portable data collection tool. Additionally, RFID readings increase the accuracy and speed of information communication, indirectly enhancing performance and productivity.

The advantages of using mobile devices in the construction industry are well documented (Baldwin et al., 1994; Fayek et al., 1998; McCullough, 1997). Moreover, mobile devices have been applied in numerous construction industries, to provide the following support: (1) providing wearable field inspection systems (Sunkpho and Garrett, 2003); (2) supporting pen-based computer data acquisition for recording construction surveys (Elzarka and Bell, 1997); (3) supporting collaborative and information-sharing platforms (Pena-Mora and Dwivedi, 2002); (4) using mobile computers to capture data for piling work (Ward et al., 2003), and (5) utilizing mobile devices in construction supply chain management systems (Tserng et al., 2005).

5. System implementation

The RFIDSIM system has three main components, a smartphone, RFID and a portal. Significantly, both the smartphone and RFID components are located on the client side, while the portal is on the server side. All inspection-related information acquired by safety staff members within the RFIDSIM system is recorded in a centralized RFIDSIM system database. All staff members can access required information via the portal based on their access privileges. The RFIDSIM system extends the jobsite safety management from the jobsite office to safety checkpoint locations to assist with safety inspection services, while the RFIDSIM system primarily deals with data transactions in all departments or systems integration. The RFIDSIM system consists of a mobile inspection management portal integrated with RFID-enabled smartphone and RFID technology. Each module is briefly described below.

5.1. RFID subsystem of RFIDSIM system

The RFID technology can be either a passive or active system. The major difference between an active and a passive RFID system is that an active tag contains a battery, and can transmit information to the reader without the reader generating an electromagnetic field. The case study uses HF passive RFID technology due to budget restrictions and short distance read range requirement.

5.2. Mobile device (smartphone) subsystem of RFIDSIM system

The RFIDSIM system adopts Google Nexus S as the RFID-enabled smartphone with NFC technology (see Fig. 2). The Google Nexus S runs the Android operating system. All data in the smart phones are transmitted to the server directly through the web via Wi-Fi. Google Chrome was chosen as the web browser in the RFID-enabled Google Nexus S.

Figure 2. displayed the RFID-enabled smartphone with NFC technology and HF RFID tags using in the study.

5.3. Web portal subsystem of RFIDSIM system

The web portal is an information hub in the RFIDSIM system for a jobsite safety management. The web portal enables all participants to log onto a single portal, and immediately obtain information required for planning. The users can access different information and services via a single front-end on the Internet. For example, a project manager can log onto the portal, enter an assigned security password, and access real-time jobsite safety inspection information and result. The web portal of RFIDSIM system is based on the Microsoft Windows Server 2008 operating system with Internet Information Server (IIS) as the web server. The prototype was developed using ASP.NET, which are easily combined with HTML and JavaScript technologies to transform an Internet browser into a user-friendly interface. The web portal provides a solution involving a single, unified database linked to all functional systems with different levels of access to information.

The following section describes the implementation of each module in the RFIDSIM system.

5.4. Inspection module

Safety staff members can enter inspection results directly via a smartphone. Additionally, smartphone display the inspection checklist in the each jobsite checkpoint location. Safety staff members can record inspection information for conditions, inspection result, descriptions of problems and suggestions that have arisen during the progress. The module has the benefit that safety staff members can enter/edit inspection results, and all records can be transferred between the smartphone and portal by real-time synchronization, eliminating the need to enter the same data repeatedly.

5.5. Progress monitor module

This module is designed to enable project manager and safety staff members to monitor the progress of inspections management. Additionally, project manager and safety staff members can access the progress or condition of jobsite safety checkpoints locations. The progress monitor module provides an easily accessed and portable environment where project manager and safety staff members can trace and record all safety-related inspection information regarding the status of inspections of safety checkpoints locations.

6. Polite test

This study is applied in Taiwan construction jobsite for the polite test. The construction building base was located in the Taipei metropolitan area, near MRT stations and public facilities. The construction project include 30 floors steel reinforced concrete structure buildings, underground parking and five floors of public space. There are three main buildings in the project. The project includes corporate headquarters, office buildings, and a business hotel. This study utilizes an RFIDSIM system in the jobsite safety inspection management. Existing approaches for tracking and managing safety inspection adopt manually updated paper-based records. The most of inspection work were paper-based work by manual entry although construction management system was developed for information management.

However, information collected by staff members using such labor-intensive methods is rework and ineffective in the inspection results entry. Therefore, jobsite safety management division and safety staff members utilized the RFIDSIM system to enhance safety inspection and jobsite safety management in the case study. HF Passive read/write RFID tags were used in the case study. After the critical safety checkpoint locations were selected, each HF RFID tag for the safety checkpoint location was made, and the unique ID of safety checkpoint was entered into the RFIDSIM system database. After the safety checkpoint location was assigned to be monitored for safety inspection, the safety checkpoint location was scanned with a RFID tag to enter the RFIDSIM system. During the setup phase, all the ID of safety checkpoint in the RFID tag had been determined and entered the database for system, and then the RFID tag was attached in the safety checkpoint location (see Figs. 3 and 4). Finally, the tag will be scanned and checked before the inspection work.

Figure 3. Displayed the safety checkpoint location attached UHF RFID tag in the case study. (A)

Figure 4. Displayed the safety checkpoint location attached UHF RFID tag in the case study. (B)

Before the inspection work, the safety staff members can check the inspection list from smartphone, refer the relative information and can make the preparation work without printing any paper document. During the inspection progress, the safety staff member scanned the RFID tag first and to select the inspection result (see Figs. 5 and 6). The system would update inspection information of jobsite safety checkpoints location via browser under wireless circumstance. After the jobsite safety checkpoints locations were inspected, staff members recorded the status and execute the work by procedure. After the operation, safety staff member recorded the result of inspection, edited the description in the smartphone, and provided the updated information to the system (see Fig. 7). Finally, the safety manager and the authorized staff members accessed the updated information from jobsite office synchronously. Fig. 8 displayed the process flowchart of RFIDSIM system. Fig. 9 displayed safety staff used RFID-enabled smartphone to scan RFID tags and edited the description in the smartphone. Fig. 10 displayed project manager entered the RFIDSIM system and accessed the safety inspection result.

Figure 5. Displayed safety staff used RFID-enable smartphone to scan RFID tag. (A)

Figure 6. Displayed safety staff used RFID-enable smartphone to scan RFID tag. (B)

Figure 7. Ssplayed the staff updated the inspection information in jobsite checkpoint location

7. Field tests and results

Overall, the field test results indicate that HF passive RFID tags are effective tools for jobsite safety management in construction. The RFIDSIM system was installed on main server in the jobsite office. During the field trials, verification and validation tests were performed to evaluate the system. The verification aims to evaluate whether the system operates correctly according to the design and specification; and validation evaluates the usefulness of the system. The verification test was carried out by checking whether the RFIDSIM system can perform tasks as specified in the system analysis and design. The validation test was undertaken by asking selected case participators to use the system, and provide feedback by answering a questionnaire. Some comments for future improvements of RFIDSIM system were also obtained from the case participators through user satisfaction survey. Table 1 shows a comparison using a traditional paper-based inspection approach and the proposed system. The next section presents the detailed results of the performance evaluation and the user survey conducted during the field trials.

Item	Traditional Approach	Proposed Approach
	Method	Method
Inspection recording method	Paper forms	Used RFID-enabled smartphone to scan RFID tag
Inspection data search speed	Referring to Inspected item and checklist	Use electronic forms
Inspector location tracking	Paper forms	Real-time Update database
Is inspection on schedule?	Hard to check	The system record automatically
Inspection history management	Paper forms	Access the system and refer directly
Information Dissemination	Paper forms delivering	Access the system directly and share information

Table 1. System Evaluation Result

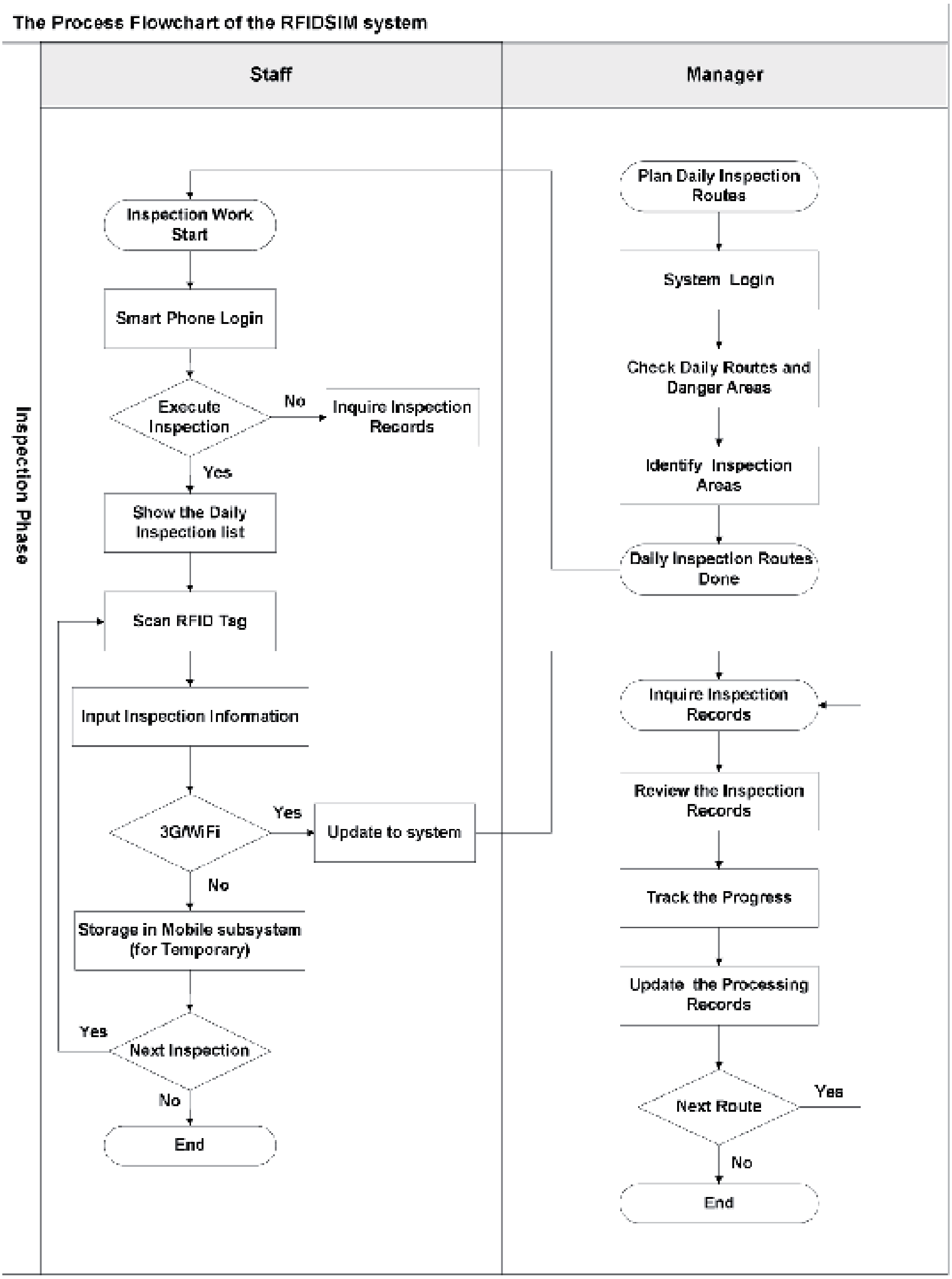

Figure 8. displayed the process flowchart of RFIDSIM system.

Figure 9. displayed safety staff used RFID-enabled smartphone to scan RFID tags and edited the description in the smartphone.

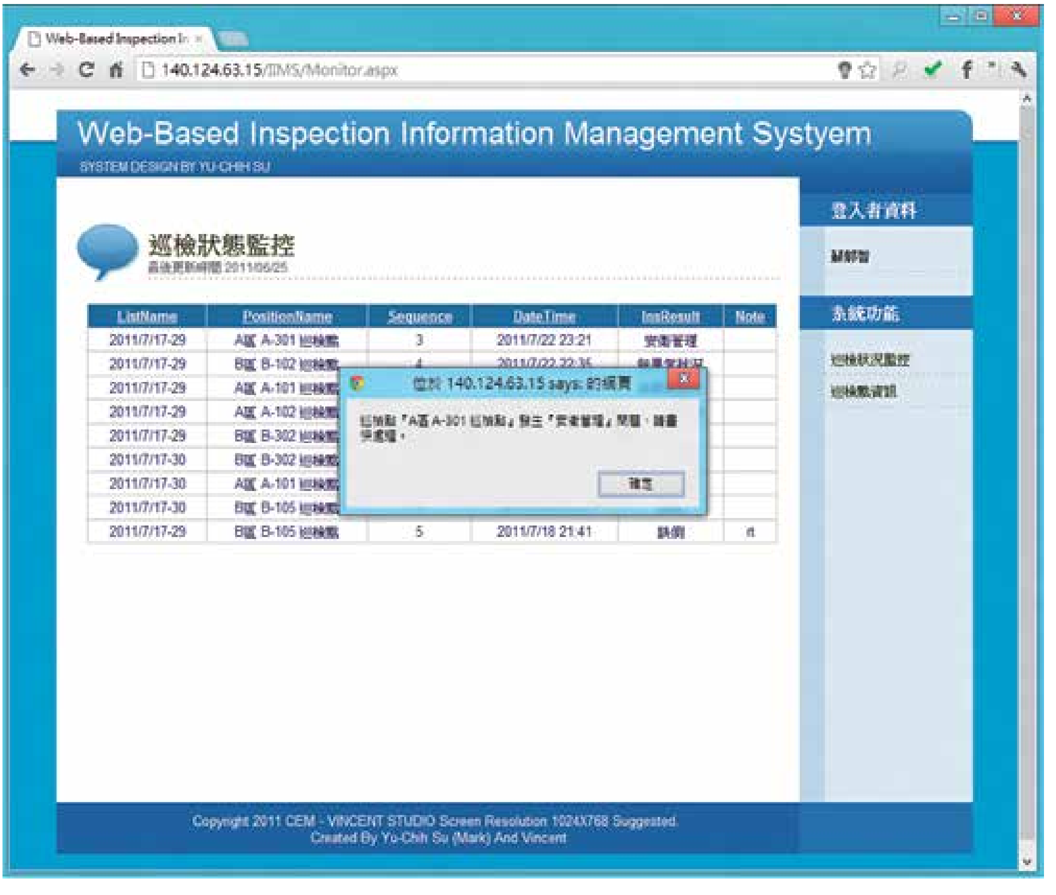

Figure 10. displayed project manager entered the RFIDSIM system and accessed the safety inspection result.

Based on the result obtained from user satisfaction survey indicates that the RFIDSIM system is quite adaptable to the current jobsite safety management practices in construction jobsite, and is attractive to users. This result implies that the RFIDSIM system was well designed, and could enhance the current time-consuming jobsite safety inspection management process. Furthermore, safety staff members just scan the RFID tag and send them electronically to the RFIDSIM system. No additional work was required for any documentation or safety inspection analysis after the data collection.

The advantages and disadvantages of RFIDSIM system identified from the polite test studies application are identified. However, safety staff members' satisfaction survey agree that the RFIDSIM system is useful for improving the efficiency and effectiveness of automated data acquisition and information collection in important check locations, thus assisting safety managers and safety staff members in managing and monitoring the safety inspection processes of the building. Thus, HF passive tags are suited to jobsite safety management.

The use of RFID and web technology to collect and capture information significantly enhanced the efficiency of jobsite safety inspection processes in construction jobsite. Mobile RFID-enabled smartphone with NFC technology and tags are widely thought likely to improve in the future and significantly improving the safety inspection processes efficiency.

In the cost analysis, the HF tags adopted in this study cost under $1 US dollars each in 2012. The cost of these tags is decreasing every year. The total cost of the equipment applied in this study was $3250 US dollars (including RFID-enabled smartphone with NFC technology reader and one server personal computer). Even the reader initial cost is higher, but it is function expandable and really decreases human work. Experimental results demonstrate that RFIDSIM system can significantly enhance the safety inspection processes efficiency. The use of RFID significantly decreases the overall safety inspection operation time and human cost.

The findings of this polite test revealed several limitations of the RFIDSIM system. The following are inherent problems recognized during the case study.

- RFID tags attached to outdoor checkpoint are easily damaged because of external environmental pollution (such as dust, rain, etc.). Therefore, it is necessary to consider and enhance protection and waterproof of RFID tags.
- The cost of system implementation is high because of the non-permanent facilities of the site environment. The required cost increases because that most the temporary facilities, inspection checkpoints always change the location.
- The RFIDSIM is required by the WiFi wireless network or 3G communications to transfer data. Sometime web-based communications in the jobsite safety checkpoints locations are weak and cause information disconnection because of the poor environment (such as underground, corner, etc.).

8. Conclusions

This study presents a Mobile RFID-based safety inspection management (RFIDSIM) system that incorporates RFID technology and mobile devices to improve the effectiveness and convenience of information flow during construction phase of construction project. The RFIDSIM system not only improves the acquisition of data on safety inspection result efficiency using RFID-enabled smartphones, but also provides a real time service platform during safety inspection progress. In the case study, plugging a RFID scanner into a smartphone creates a powerful portable data collection tool. Additionally, RFID readings increase the accuracy and speed of information search, indirectly enhancing performance and productivity. Safety staff members use RFID-enabled smartphones to enhance seamlessly inspection work processes at checkpoints locations, owing to its searching speed and ability to support detail information during the process. Meanwhile, on the server side, the RFIDSIM system offers a hub center to provide jobsite management division with real-time to monitor the jobsite safety progress. In a case study, the application of the RFIDSIM system helps to improve the process of jobsite safety inspection and management work for the construction jobsite in Taiwan. Based on experimental result, this study demonstrated that HF passive RFID technology has significant potential to enhance jobsite safety inspection and management work in construction management. The integration of real-time inspection information from jobsite safety checkpoints helps safety staff members to track and control the whole inspection management progress. Compared with current methods, the combined results demonstrate that, an RFIDSIM system can be a useful RFID-based jobsite safety inspection management platform by utilizing the RFID approach and web technology.

Building information modeling (BIM) is one of the most promising recent developments in the AEC industry. In the future, application of BIM can be considered and integrated for better and advanced jobsite safety inspection and management. Furthermore, the application of BIM will be a viable approach to jobsite safety management during the construction phase of a construction project. The BIM approach, which is utilized to retain visual status of safety condition in a digital format, facilitates effective safety management in the 3D CAD environment. The BIM provides users with an overview of current jobsite safety inspection result during a given construction project, such that users can track and manage jobsite safety inspection result virtually.

9. Recommendations

Recommendations for implementing the proposed system in the future are given below.

- Cost is a currently significant factor limiting the widespread use of RFID tags in the construction industry. Passive tags are cheaper than active tags. Therefore, passive tags are suited to jobsite safety management.
- The smartphone screen is not large enough for operating the RFIDSIM system fluently. The system should be redesigned and developed to be suitable for the smartphone screen.
- In this study, the major characteristic is that users can apply the RFIDSIM system without purchasing additional RFID reader. Currently, this system is developed for Google Android system and will be developed for Apple i-phone system in the future.

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Chapter 14

Interferometer Instantaneous Frequency Identifier

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/52623

1. Introduction

The rapid development of radar, communication and weapons guidance systems generates an urgent need for microwave receivers to detect possible threats at the earliest stage of a military mission. The microwave receivers used to intercept the RF signals must be able to meet these challenges. Thus, microwave receivers have become an important research area because of their applications to electronic warfare (EW) [1].

The instantaneous frequency measurement (IFM) receiver has been mostly incorporated in advanced EW systems. As to perform the fundamental function, which is to detect threat signals and provide information to the aircrafts, ships, missiles or ground forces, the IFM receiver offers high probability of intercept over wide instantaneous RF bandwidths, high dynamic ranges, moderately good sensitivity, high frequency measurement accuracy, real time frequency measurement and relatively low cost.

IFM started out as a simple technique to extract digital RF carrier frequency over a wide instantaneous bandwidth mainly for pulsed RF inputs. It is been gradually developed to a resourceful system for real time encoding of the RF input frequency, amplitude, pulse width, angle of arrival (AOA) and time of arrival (TOA) for both pulsed and continuous wave (CW) RF inputs. For many electronic support measures (ESM) applications, the carrier frequency is considered to be one of the most important radar parameters, since it is employed in many tasks: sorting, even in dense signal environments; emitter identification and classification; and correlation of similar emitter reports from different stations or over long time intervals, to allow emitter location [2,3].

An IFM receiver is an important component in many signal detection systems. Though numerous improvements have been made to the design of these systems over the years, the basic principle of operation remains relatively unchanged, in that the frequency of an incoming signal is converted into a voltage proportional to the frequency. Microwave interferometers are usually base circuits of the IFM systems. These interferometers most often consist of directional couplers, power combiners/dividers and delay lines [4-8]. As a good example, a coplanar interferometer based on interdigital delay line with different finger lengths, will be presented. Another example of interferometers, but now, implemented with micro strip multi-band-stop filters to obtain signals similar to those supplied by the interferometers was published recently and will be presented here as well [9,10].

2. Important concepts

The system is based on frequency mapping, going from analogical signal into digital words. Any frequency value in the operating band of the system corresponds to a unique digital word. In the process, there is no need to adjust or tune any device. The signal is identified instantaneously. The frequency resolution depends on the longest delay and the number of discriminators.

Let us see how the IFMS maps the incoming signal *x(t)* into digital words. First of all, consider a sinusoidal signal $x(t) = \sin(\omega t)$ split into two parts, as shown in Fig. 1.

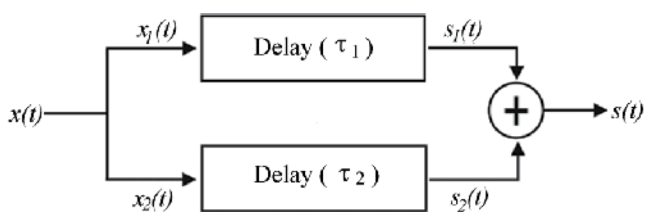

Figure 1. Interferometer used in instantaneous frequency measurement subsystem.

The signals $x_1(t)$ and $x_2(t)$ are then described as

$$x_1(t) = x_2(t) = \frac{\sin(\omega t)}{2} \tag{1}$$

Because of different delays τ_1 and τ_2, one has

$$s_1(t) = x_1(t - \tau_1) \tag{2}$$

and

$$s_2(t) = x_2(t - \tau_2). \tag{3}$$

$S_1(t)$ and $S_2(t)$ are the signals after passing the delay τ_1 and τ_2, respectively. Then the output $s(t)$ is given by the addition of (2) and (3), and after some trigonometric manipulations that sum can be written as

$$s(t) = \sin\left(\frac{2\omega t - \omega(\tau_1 + \tau_2)}{2}\right) cos\left(\frac{\omega(\tau_2 - \tau_1)}{2}\right). \tag{4}$$

From (4), one can see that the frequency interval between two consecutive maxima or minima of $s(t)$ are given by

$$\Delta f = \left|\frac{1}{\Delta\tau_{2,1}}\right|, \tag{5}$$

where $\Delta\tau_{2,1}=\tau_2-\tau_1$ is the delay difference between the two branches of the interferometer. Still from (5), it is noticed that from $\Delta f_{\max}$ one gets $\Delta\tau_{\min}$ and vice-versa.

As in [1], the frequency resolution is given by

$$f_R = \frac{1}{4\,\Delta\tau_{\max}}. \tag{6}$$

A binary code can be generated if

$$\Delta\tau_{\max} = 2^{n-1}\Delta\tau_{\min}, \tag{7}$$

And this way, the resolution f_r of an n-bits subsystem can be rewritten as

$$f_R = \frac{1}{2^{n+1}\,\Delta\tau_{\min}}. \tag{8}$$

Fig. 2 shows the architecture of a traditional instantaneous frequency measurement subsystem (IFMS), where delay lines are used to implement five interferometers as discrimination channels.

Each discriminator provides one bit of the output binary word that is assigned to a certain sub-band of frequency [1]. Wilkinson power dividers are used at the input and output of each interferometer [3]. The output of each discriminator is connected to a detector. The 1 bit A/D converter receives the signal from the amplifier, and attributes "0" or "1" to the output to form the digital word for each frequency sub-band. These values depend on the power level of the received signal. A limiting amplifier is used in IFM input to control the signal gain, to increase sensitivity, and clean up the signal within the band of interest [1], [7].

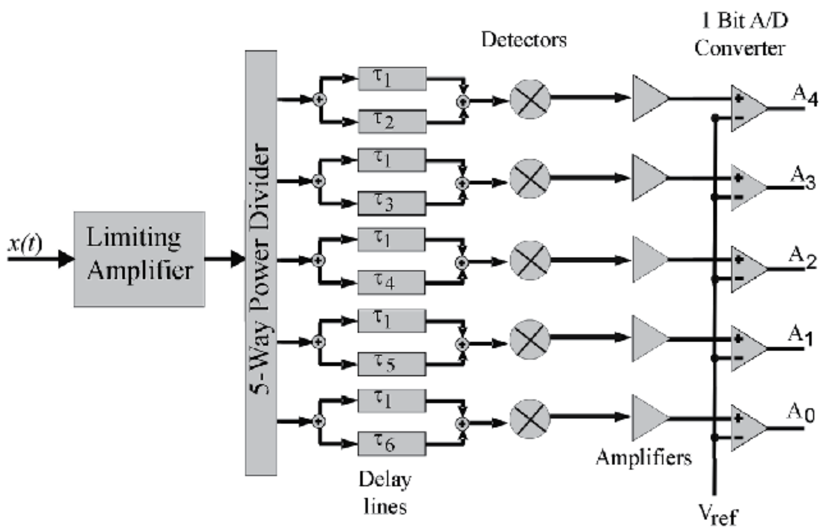

Figure 2. Architecture of a traditional IFM subsystem.

3. Coplanar interdigital delay Line for IFM systems

The schematic drawing of the interdigital delay is shown in figure 3. The particular line consists of 164 interdigital fingers of equal length ℓ, finger width w, finger spacing s and total length L. d is the unit cell length representing the periodicity of the transmission line. If $d \ll \lambda$, an amount of lumped capacitance per unit length C_0/d is added to the shunt capacitance C.

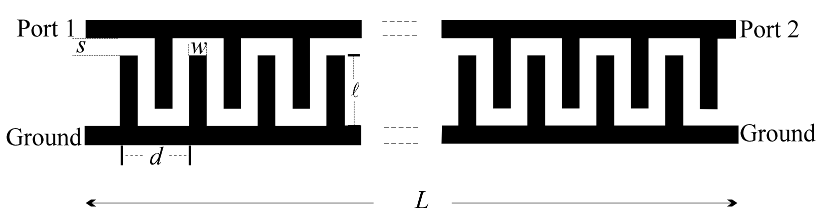

Figure 3. Coplanar interdigital delay line under test.

For the structure shown in figure 3 the phase velocity and the characteristic impedance Z_0, become: $[(C+2C_0/d)\,L_S\,]^{-1/2}$ and $[L_S\,/(\,C+2\,C_0/d\,)]^{1/2}$, respectively. Here, L_S is the series inductance [11]. Due to the fringing electric fields about the fingers, the amount by which the capacitance per unit length increases is greater than the corresponding amount by which the inductance per unit length decreases. In order to exploit the fringing electric fields produced by the fingers, one needs to increase the finger length and keep the finger width fixed.

The *ABCD* matrix of a lossless transmission line section of length *L*, line impedance Z_0 and phase constant β is given by

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\beta L) & jZ_0 \sin(\beta L) \\ (1/Z_0) j \sin(\beta L) & \cos(\beta L) \end{bmatrix} \tag{9}$$

From the above equation one can relate Z_0 to only *B* and *C* elements. If we use the conversion from *ABCD* matrix to *S*-parameters and assume the source and load reference impedance as *Z*, we then have [12]

$$Z_0 = \sqrt{\frac{B}{C}} = \left[Z^2 \frac{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}{(1-S_{11})(1-S_{22}) - S_{12}S_{21}} \right]^{1/2} \tag{10}$$

Note that the *ABCD* matrix is not for a unit cell of the line, it represents the entire transmission line.

Group delay is the measurement of signal transmission time through a test device. It is defined as the derivative of the phase characteristic with respect to frequency. Assuming linear phase change $\phi_{21}(2)\phi_{21}(1)$ over a specified frequency aperture *f(2)f(1)*, the group delay can, in practice, be obtained approximately by

$$\tau_g = -\frac{1}{2\pi} \left(\frac{\phi_{21}(2) - \phi_{21}(1)}{f(2) - f(1)} \right) \tag{11}$$

3.1.Intedigitalinterferometer. design and measurement

The structure shown in figure 3 was etched on only one side of an RT/duroid 6010 with relative permittivity ε_r = 10.8, dielectric thickness h = 0.64 mm, conductor thickness t =35μm, w = 0.3 mm, s = 0.3 mm and L = 99 mm. In order to find the line impedance and delay the simulation was carried out varying the finger length ℓ from 0.6 to 4.2 mm and keeping all the other parameters fixed. The devices were fabricated, measured and simulated.

The simulation used sonnet software in order to find the magnitude and phase of the S-parameters, assuming a lossless conductor. Afterwards, equations 10 and 11 were used to find Z_0 and τ_g, respectively. In the experimental procedure each device was connected with coaxial connectors to a HP8720A network analyzer. After carrying out a proper calibration, the devices were then measured. This way, the group delay measurement was implemented, and figure 4 summarizes the group delay results from both measurement and simulation for a frequency range of 0.5-3 GHz. As the finger length increases the lumped capacitance per unit length increases. It slows down the group velocity leading to an increase in the group delay. The longer the finger length, compared to the finger width, the closer it is to a purely capacitive element.

The experimental data of Z_0 were obtained using a reflection measurement in time domain low pass function of the HP8720A. The same devices were all measured again and the results are summarized in figure 5. Looking at the beginning of the curve on the left hand side, the figure 5 seems to agree with the classical coplanar strips formulation, as we found Z_0= 99 Ω for ℓ=0 [13]. As we expected, Z_0 decreased as the finger length increased, due to the rise in $2C_0/d$, achieving 50Ω at ℓ=3.9mm. As the finger length goes from 0.6 mm to 4.2 mm, τ_g increases about 150% and Z_0 decreases about 45%.

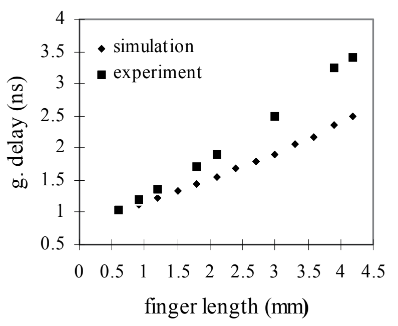

Figure 4. Group delay as a function of finger length at a Frequency range of 0.5-3 GHz.

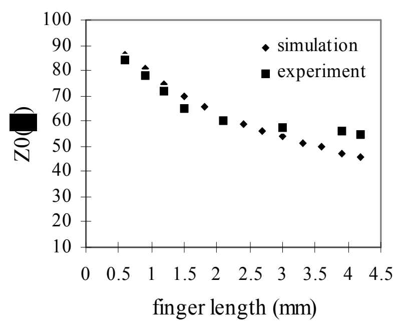

Figure 5. Characteristic Impedance as a function of finger length at a frequency range of 0.5-3 GHz.

These results look promising as far as an IFM application is concerned. Referring to a single stage of a typical IFM, a coplanar unequal output impedance power splitter can be designed to feed two delays with different characteristic impedances. The length of the second delay of each discriminator may be increased to achieve better resolution. The results from figures 4 and 5 may be used together to redesign the coplanar unequal output impedance power splitter to achieve the exact impedance matching. Figure 6 shows a prototype system fabricated based on results of figures 4 and 5. Coplanar wave guide, coplanar strips, coplanar unequal output impedance power splitter and coplanar interdigital delay line are integrated without bends or air bridges. The chip resistors used to increase the isolations between the outputs of the power splitter (and the input of the combiner) are not shown below.

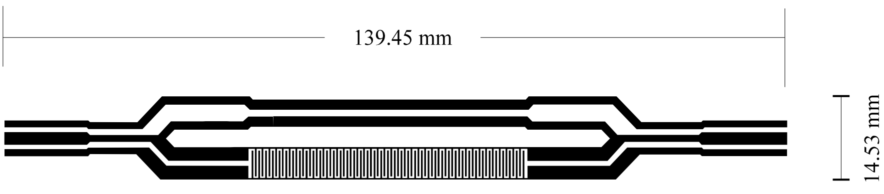

Figure 6. Uniplanar single stage of the IFM under test, scale 1/1

The design has a delay difference of 1.6ns. Two output traces versus frequency from 1.5GHz to 3GHz are presented in figure 7. The theoretical one was obtained using the design equations for a single stage of a typical IFM subsystem [14]. The oscillations in the experimental trace originated from the coaxial connections and the chip resistors bonds.

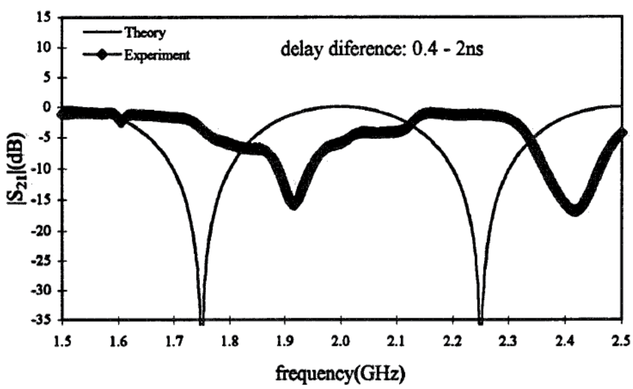

Figure 7. Theoretical interferometer output and measured scattering parameter in dB versus frequency.

4. Interferometer based on band-stop filter for IFM

The IFMS presented now is based on band-stop filter and is shown in Fig. 8. The advantage of using the new architecture is that one has in each channel only multi band-stop filters instead of delay lines and power splitter, as one finds in classical IFMS.

Each word is assigned to only one frequency sub-band to generate a one-step binary code. The response of each multi band-stop filter should be like the one shown in Fig. 9 (a) with discriminators 0, 1, 2, 3 and 4. The discriminator 0 provides the least-significant bit (LSB) and the discriminator 4 provides the most-significant bit (MSB). The form of these responses is suitable to implement the 1 bit A/D converters. Here, let us attribute value 1 if the insertion loss response for the multi band-stop filter is greater than 5 dB, and value 0 for the opposite case. Fig. 9(b) shows the wave form of each 1 bit A/D converter output. According to this example the waveforms at the 1 bit A/D converter outputs are shown in Fig. 9(c). As seen in Fig. 4, this subsystem has its operating band from 2 to 4 GHz, which was divided into 32 sub-bands. Therefore, the resolution obtained was f_R = 62.5 MHz.

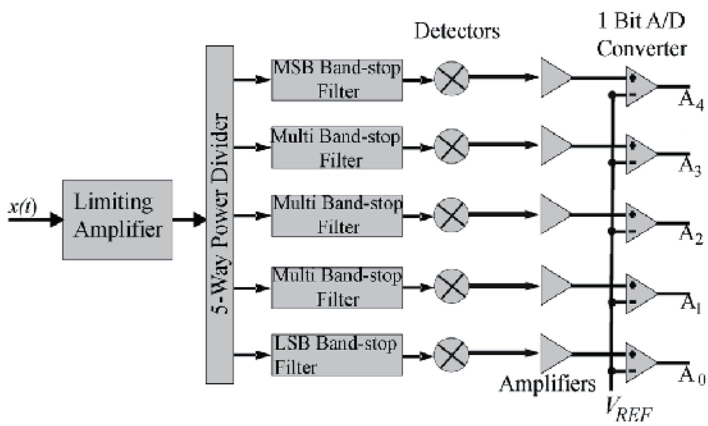

Figure 8. Architecture of an instantaneous frequency measurement subsystem (IFMS) using band-stop filters.

4.1. Multi band-stop filter design and measurement

Rectangular microstrip open loop resonators were chosen to design every discriminator of a five bit IFMS. Frequency response of those resonators presents a narrow rejection band and wide pass band [5] with first spurious out of the working band. Fig. 10(a) shows the top view of a resonator with resonance frequency at 1.9375 GHz. One can see in Fig. 10(b) that the first spurious occurs at 6.140 GHz. Still in this section, it will be shown how this response makes possible the fabrication of a wideband discriminator.

That resonator is placed near to a 50 Ω microstrip transmission line, which was designed with aid of quasi-static analysis and quasi-TEM approximation [8]-[9]. Fig. 11 shows the resonance frequency adjusted by the length l_1 + l_2 + l_3+ l_4 of the resonator, which must be approximately half wavelength long [8]. Additionally, there is a coupling gap g given by l_2 - l_3 - l_4. Moreover, the coupling distance between the resonator and the main transmission line affects this resonance frequency. This distance also affects the bandwidth of the resonator [8].

Despite the narrow band of the isolated resonators, wide rejection bands are created from coupled arrays. Fig. 12(a) presents 3 sketches of one, two and three resonators, whose resonant frequencies are 2.02, 2.07 and 2.12 GHz, respectively. The line width for the resonators is fixed to be 0.5 mm along this chapter. The ideal coupling distance between resonators is obtained varying $d_{i,j}$ using EM full wave software.

Fig. 12(b) shows the frequency response obtained at ideal coupling distance between them. These distances are chosen to obtain the insertion loss greater than 10 dB over rejection band and also to get this band as large as required. One notices that the coupling between non-adjacent resonators is almost zero. This happens because their resonance frequencies are not very close and the distance between them is large enough. Therefore, the insertion of a new resonator does not change the position of the others already inserted.

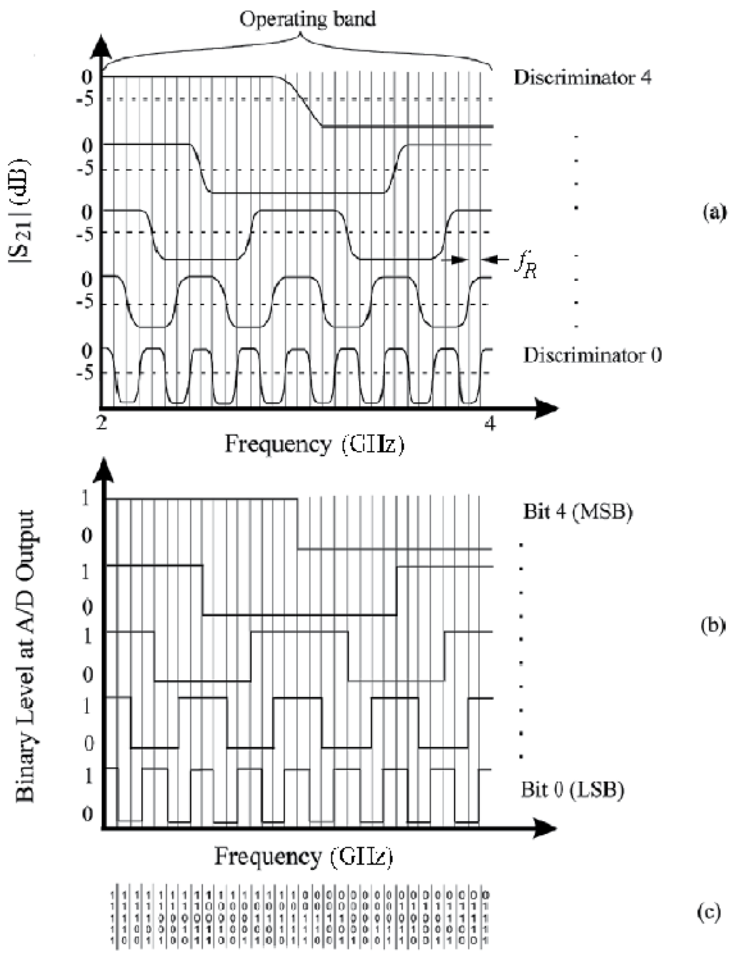

Figure 9. Responses for the IFMS from Fig. 8: (a) desired $|S_{21}|$, (b) A/D converters output, and (c) generated code.

A model of two coupled resonators has been developed by the authors and will be presented in the full chapter.

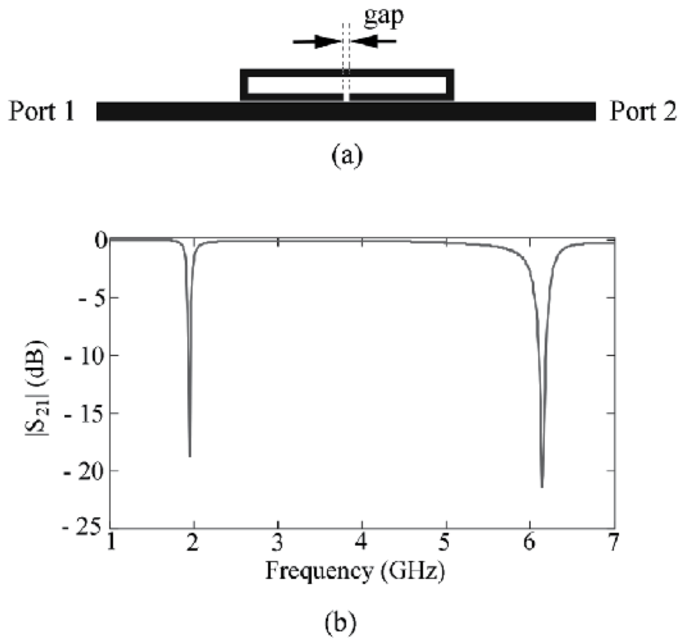

Figure 10. (a) Physical structure of a resonator with resonance frequency at 1.9375 GHz, and (b) frequency response of the resonator over a wideband.

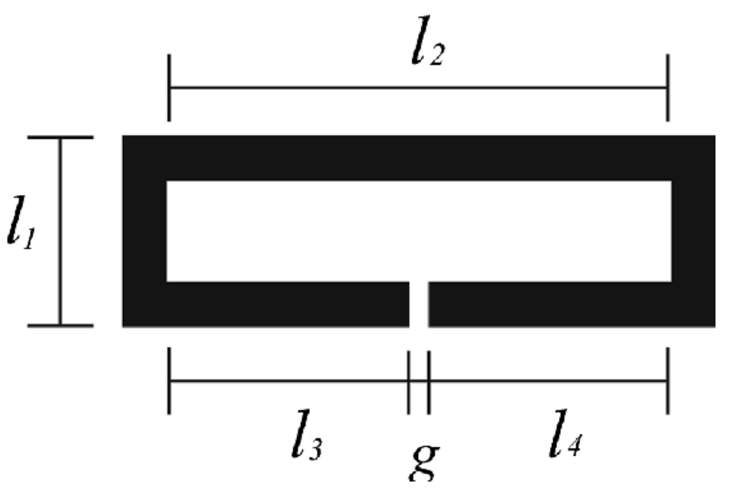

Figure 11. Open loop resonator.

As the desired insertion loss of the discriminator 1 is shown in Fig. 9(a), there must be four rejection bands, where the first one is from 2.125 GHz to 2.375 GHz, regarding the chosen operating band. The resonators are arranged one by one. Fig.13 (a) shows this discriminator with its numbered resonators. The device is designed on a RT6010.2 substrate of relative dielectric constant ε_r = 10.2 and thickness h = 1.27 mm. The 50 Ω transmission line width is 1.2 mm. The gap of every resonator and the distance between the main transmission line and the resonators are kept 0.1 mm for whole structure. Table I shows the coupling distances between the resonators for this device.

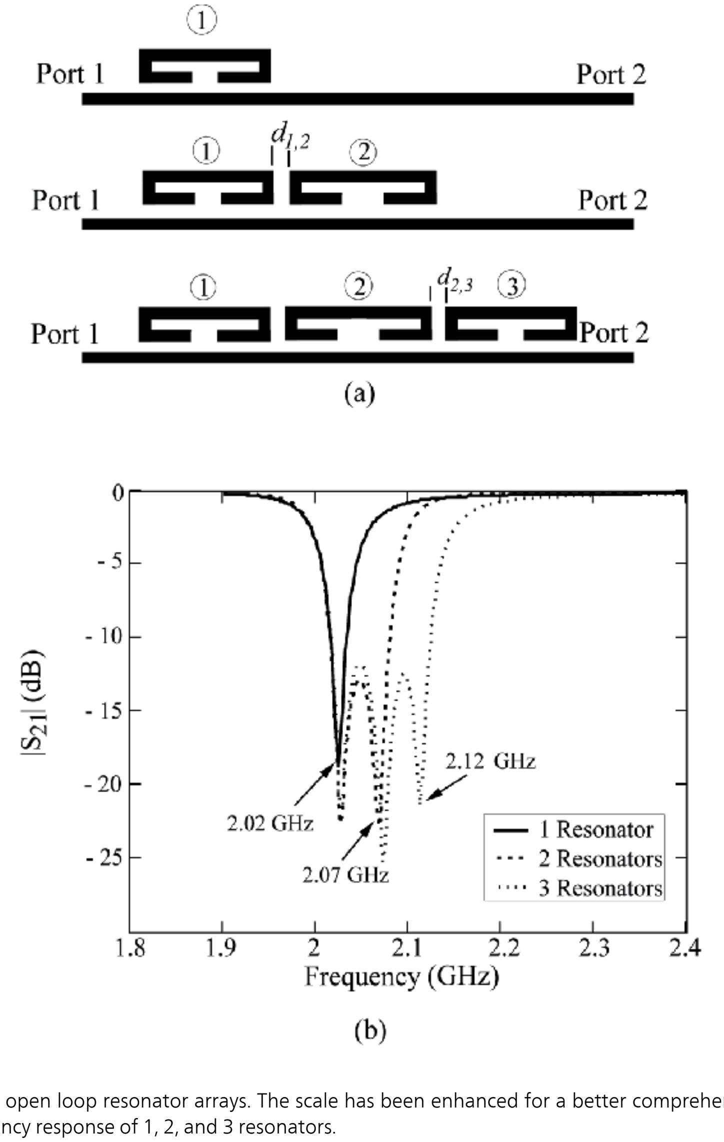

Figure 12. (a) The open loop resonator arrays. The scale has been enhanced for a better comprehension of the devices, and (b) frequency response of 1, 2, and 3 resonators.

Still in Fig. 13(a) one sees four groups of resonators, whose frequency responses and A/D converter outputs are shown in Fig. 15(b). Looking carefully their correlation, Group 1 gives the rejection band over 2 GHz; Group 2 gives the rejection band over 2.5 GHz, and so on. Fig. 13(b) presents the simulated results of the discriminator 1, which agree with the results shown in Fig. 9. One can see the insertion loss level is greater than 10 dB over all rejection bands, and is less than 5 dB over the pass bands. The output A/D converter should generate level zero for $|S_{21}| < -5$ dB and level 1 for $|S_{21}| > -5$ dB. Concerning all the involved $d_{i,j}$, the dimensions of this discriminator are 3 cm wide and 15 cm long. Following the same procedure, the others discriminators are projected, where new resonators configurations will give new desired rejection bands.

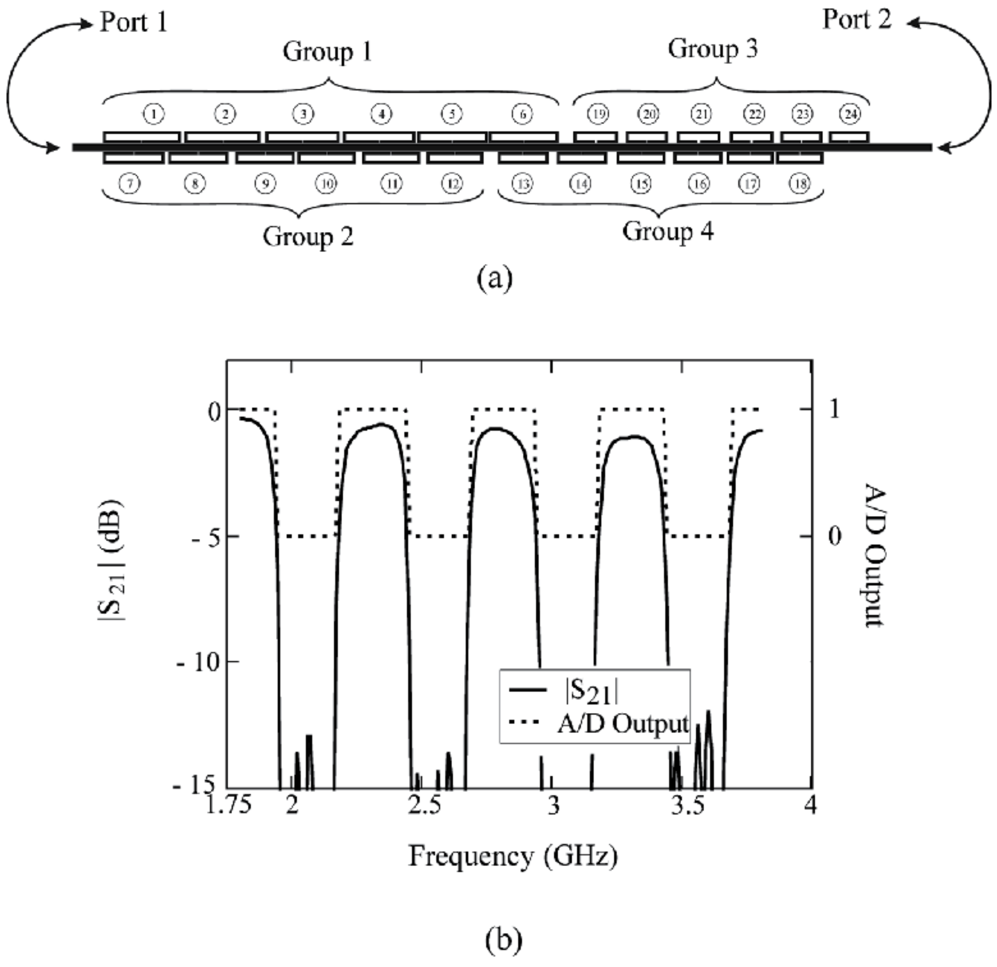

Figure 13. (a) Layout of the discriminator 1, and (b) frequency response of the discriminator 1, and the output of the 1-bit A/D converter; 250 MHz for each rejected band.

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Coupling distance between "i" and "j" resonators (mm)	
$d_{1,2}$= 0.6	$d_{13,14}$ = 1.4
$d_{2,3}$ = 0.8	$d_{14,15}$ = 1.6
$d_{3,4}$ = 0.5	$d_{15,16}$ = 1.3
$d_{4,5}$ = 0.3	$d_{16,17}$ = 0.7
$d_{5,6}$ = 0.2	$d_{17,18}$ = 0.4
$d_{7,8}$ = 0.6	$d_{19,20}$ = 1.3
$d_{8,9}$ = 1.2	$d_{20,21}$ = 1.4
$d_{9,10}$ = 0.4	$d_{21,22}$ = 1.6
$d_{10,11}$ = 1.1	$d_{22,23}$ = 1.2
$d_{11,12}$ = 1.1	$d_{23,24}$ = 1.1

Table 1. Coupling Distances

The Fig. 14(a)-(e) presents all the projected IFMS discriminators from Fig. 8, having between 23 and 25 resonators. The number of resonators depends on the desired rejection bands. Following the same principle, each group gives only one rejection band, so that discriminators with eight groups have eight rejection bands, as shown in Fig. 14(e). The others, without any specified group, have only one as shown in Fig. 14 (a) and (b). Fig. 15 shows that the simulated and measured results of the five discriminators are in reasonable agreement with each other.

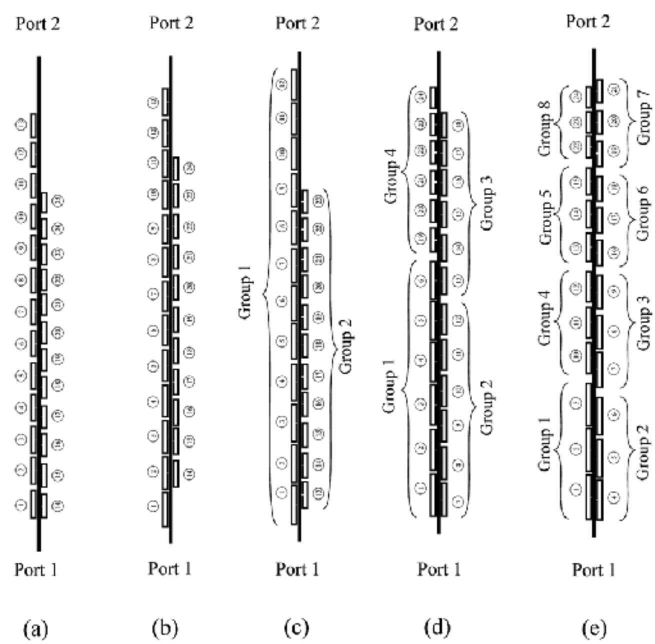

Figure 14. Bandstop filters for implementation of the: (a) discriminator 4 – MSB, (b) discriminator 3, (c) discriminator 2, (d) discriminator 1, and (e) discriminator 0 – LSB.

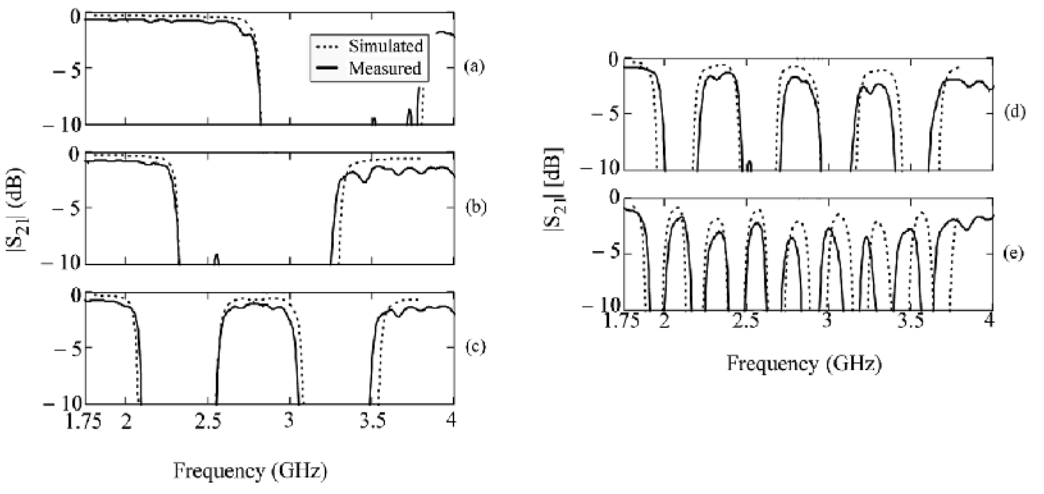

Figure 15. Frequency response of the: (A) Discriminator 4 – MSB, (B) Discriminator 3, (C) Discriminator 2, (D) Discriminator 1, and (E) Discriminator 0 – LSB.

5. Reconfigurable Frequency Measurement (RFM) designs

Fixed IFM designs like the ones discussed in section IV have the advantage of providing instantaneous frequency identification while reconfigurable designs should do a sweep but are very compact in size, making them suitable for portable and handheld systems. RFMs include tuning elements [15] embedded in the designs to produce multibit frequency identification using reconfigurable measurement branches.

An example of RFM architecture is shown in Fig. 16, this design includes a reconfigurable phase shifter used to produce more than one bit. The number of bits will depend on the amount of phase shifts produced by the reconfigurable design; each phase shift will correspond to a specific control voltage in the case of varactors, otherwise switches will be in "on" or "off" state to produce the different phase shifts. The other components shown in Fig. 16 operate in a similar way to the ones exposed in section IV. The RFM can also include reconfigurable bandstop filters [16] instead of the phase shifter to produce a branch that can produce more than one bit as an alternative design.

The switching speed of the tuning elements used in the reconfigurable phase shifter design will mainly determine the detection speed of the subsystem. Solid state components like PIN, varactor diodes, transistors and the use of ferroelectric materials will provide high tuning speeds, (10^{-6} seconds for the PIN and varactor diodes, 10^{-9} seconds for transistors and 10^{-10} seconds for the ferroelectric varactors) while the Micro Electromechanical Systems (MEMS) counterpart will provide slower tuning speeds (10^{-5} seconds) but with the advantage of low power consumption compared with the solid state components. The use of ferroelectric materials results in high tuning speeds with the drawback of having generally high

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dielectric losses. When designing an RFM it is important to decide which type of technology is adequate for a given application in terms of detection speed, power consumption and device size.

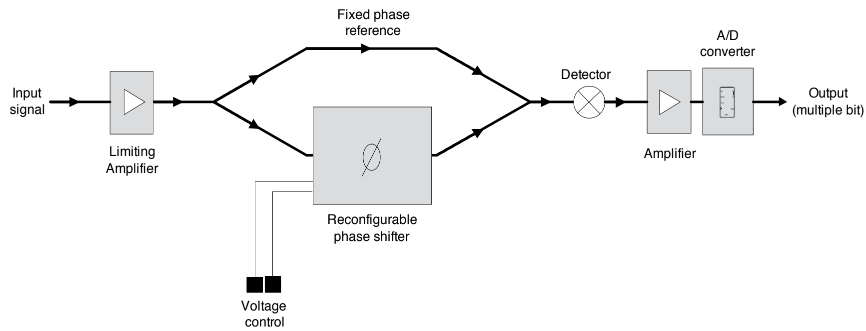

Figure 16. Architecture of a reconfigurable frequency measurement subsystem (RFM) based on phase shifters.

Device size will be mainly determined by the type of technology used to implement the subsystem; the most compact designs can be achieved monolithically, by having the components integrated into a single chip. A monolithic design can include all solid state, MEMS and ferroelectric implementations. Hybrid integrations use microwave laminates or substrates and tuning elements, these include solid state, MEMS and ferroelectric surface mountable components that can be embedded into the design. Hybrid integrations normally involve much larger circuit size compared to the monolithic counterpart, however these components normally involve low cost and simple manufacturing and prototyping techniques.

The most reliable technology is the solid state transistor and the ferroelectric films, followed by the PIN and varactor diode ending with the MEMS components. MEMS packaging can improve device reliability by avoiding contamination or humidity of the movable parts of a switch or varactor. The objective of an RFM is to reduce the size of fixed IFMs by designing branches that can produce more than one bit in the identification subsystem. Size reduction is the main advantage of an RFM over a fixed IFM. A disadvantage over fixed IFMs is that there will be a switching time for the device, so the frequency measurement is not instantaneous.

6. Final considerations

This chapter presented two kinds of interferometers for IFM applications, the first type was a Coplanar Intedigital Interferometer and the second one was based on Multi band-stop filters, which can substitute the interferometers in the IFM Architecture. For the first case, coplanar strips interdigital delay lines were fabricated, simulated and measured at a frequency range of 0.5-3 GHz. As the finger length varied from 0.6 mm to 4.2 mm, keeping all the other parameters fixed, the group delay increased by about 150% and the characteristic impedance decreased about 45%. A prototype of uniplanar IFM with a delay difference of 1.6ns was fabricated and measured based on the results of the characteristic impedance and the group delay.

For the second case, Multi band-stop filters were designed, simulated and measured over a frequency range of 2 GHz. The results show that the use of loop resonators to design the discriminators, instead of delay lines and power splitters, make the simulation and the fabrication easier, as there are no more bends or sloping strips. In addition, one has more control over the resolution, as one can couple the resonators one by one and create the rejection bands. In this process, the association of loop resonators was used to design multi band-stop filters. In light of the above, the use of multi band-stop looks promising as far as planar interferometer identifier is concerned.

The use of loop resonators instead of delay lines and power dividers/combiners, to design IFM systems, decreases the simulating time of the whole structure, as there are no more bends or sloping strips. In addition, one has more control over the resolution, as one can couple the resonators one by one and create the rejection bands. The multi-band-stop filters can substitute interferometers in the IFM system architecture, in a very efficient way. Reconfigurable frequency measurement circuits can considerably reduce the size of the IFMs by using tuning elements embedded into the topologies, resulting in multiple bit circuits by means of reconfigurable frequency measurement branches. RFMs switch between states, thus tuning speed determines the sweep time required for signal detection.

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Chapter 15

Challenges and Possibilities of RFID in the Forest Industry

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Ville Puntanen and Kaj Nummila

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/54205

1. Introduction

Considerable added value in wood and timber production can be achieved via higher yield and quality of the wood products deriving from improved control of the production processes. The key to improve the production is the identification of the individual wood items in order to utilise exact information of their properties. This can be realized by marking and tracking of tree trunks, logs and sawn wood products to allow the information associated with them to be collected and utilised in all stages of the value chain from forest to the wood product.

Marking and traceability technology for forest industry have been investigated for some time and several technologies have been considered. Recently, UHF RFID technology tailored for the needs of the forest industry has been developed. This Chapter will discuss the unique challenges that the forest industry sets for the radio frequency identification technology and will highlight the benefits and possibilities of the RFID use. Recently developed technical solutions and their trials in production conditions are described.

2. Traceability in the wood supply chain

Individual identification of the wood items (tree, trunk, board, pole, etc.) allows detailed information to be associated with them which can be used to optimise the production. The simplified basic wood supply chain is illustrated in Figure 1.

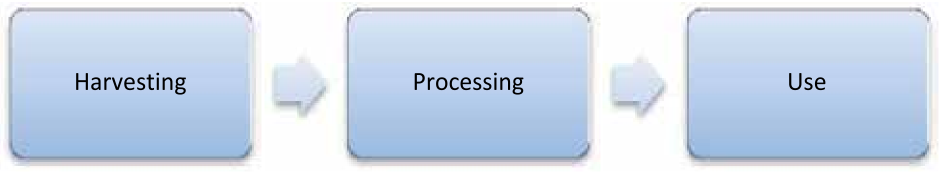

Figure 1. Simplified general wood supply chain.

First the trees are cut down and then they are transported for processing into products. The processed products are then transported to a secondary manufacturer or to an end-user. The supply chain varies in different countries and for different products as does the level of automation – for example the felling of trees can be done manually with a chain saw or by a forestry harvester. The felling is followed by removal of the branches and in some countries the trunks are cut into logs in the forest by the forestry harvester. The trunks or logs are transported to road side for storage and subsequent transportation to an intermediate storage or directly to a processing plant. The processing steps depend on the product in question – the most common ones being pulp for paper or cardboard making, boards, panels, veneer and poles. Each of these products uses different wood as their raw material and wood with different properties. The highest value round wood in the Nordic countries is used for the production of sawn timber such as boards. This supply chain is discussed in more detail in the following Section.

After processing into the primary product (e.g. boards) the wood products are transported via the associated logistics chain to a secondary manufacturer such as a building component manufacturer or a furniture manufacturer or the end-user (e.g. a consumer or a constructor).

If the wood material could be identified at individual level (trees, trunks, logs, boards, poles, etc.) information can be associated with it – and this information can be traced through the supply chain to optimise the production of wood products.

2.1. Nordic wood supply chain for sawn timber

The Nordic wood supply chain is illustrated in Figure 2.

The trees are felled and cut into logs by a harvester. The harvester also carries out a multitude of measurements on the logs such as measuring their dimensions to determine the volume of wood felled. Next the logs are transported to a pile in the road side by a forwarder. A harvester and a forwarder are shown in Figure 3.

The logs are collected from the road side by a timber truck which transports them either directly to a saw mill or to an intermediate storage. From this storage the logs are transported to a saw mill by truck, train or by floating. At the saw mill the logs are received and sorted into different classes – this sorting is usually based on dimensional measurements using a 3-D laser scanner. In addition to the laser scanner, X-rays may be used to characterise the internal properties of the log. After sorting, the logs of a suitable class are sawn into boards which are then sorted based on their dimensions and quality (e.g. number and size of the knots in them). The sawn boards are usually dried in a kiln and graded for quality after the drying. The graded boards are then stored and packaged for shipping to the end user or to a secondary manufacturer.

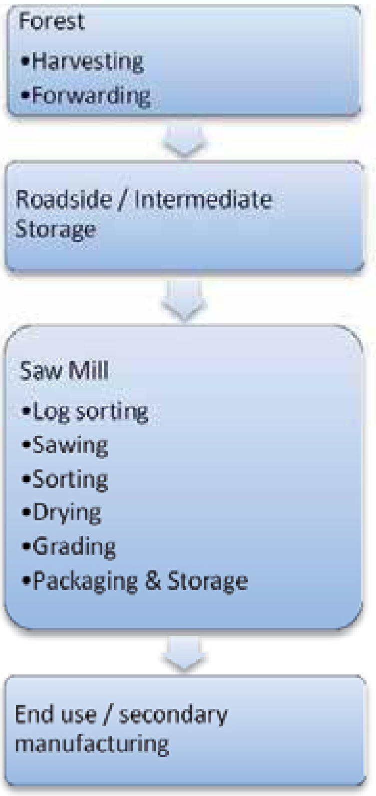

Figure 2. Nordic wood supply chain for sawn timber.

Figure 3. Examples of a harvester and a forwarder [1].

2.2. Possibilities and benefits with wood traceability

Currently, the wood material properties are measured when needed in the wood conversion chain and the gathered data is usually lost between the processing steps as illustrated in Figure 4.

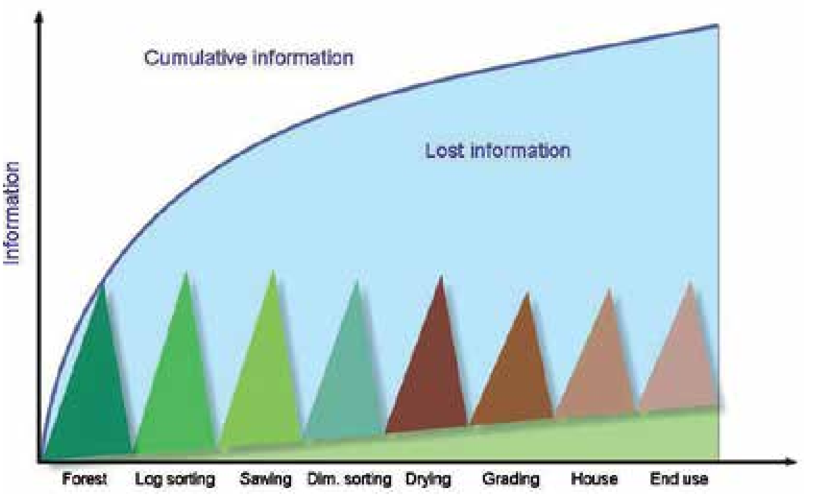

Figure 4. Collection and utilisation of information in the wood supply chain [2].

As the collected information is lost between the processing steps, measurements need to be repeated - such as the measurement of the log dimensions in the forest by the harvester during cutting and the re-measurement of the dimensions in log sorting in the saw mill to determine the volume of the wood for the second time. The lost information also naturally means reduced control over the wood conversion chain from forest to end product as the information related to the wood cannot be traced along the chain.

The traceability of the wood and the associated information can be achieved by identifying the individual wood items – logs and boards, instead of relying on classification of wood and processing in batches of the same class of wood. The benefits of the traceability include:

- Increased quality of the products
- Increased yields
- Reduced production costs.

The quality of the products can be increased with improved control of the production processes by effectively utilising the information collected in the previous stages of the conversion chain. The production process can be optimised based on the individual properties of the wood - processing parameters can be adjusted to better suit the material in question and the most suitable raw material can be used for the product in question.

The yield in the production can be also increased with improved information utilisation and control enabled by the traceability. Downgrading of the boards in the final grading can be reduced when the desired final quality is more consistently achieved. The yield can be also increased by using the right raw material for each product - each type of wood can be used for the most valuable product it is suitable for and less wood material of higher quality is wasted in the production of basic wood products. The production costs can be reduced with improved processing control as the need to 'over-process' the wood is reduced when the actual properties of the wood can be traced instead of relying only on the information on the batch. The improved control over the wood supply and conversion chain together with the more efficient and comprehensive utilisation of the information on the wood material allows also potential new and tailored wood products. Individual identification of the wood items can also be utilised in the logistics – transport planning and control, stock inventory and control in storage, etc.

The traceability in the wood supply chain can also be used to certify the origin of the wood to prevent illegal logging and log theft.

3. Challenges of traceability in the Nordic forest industry

The forest industry presents some unique challenges to the traceability – item marking and identification, and information storage, retrieval and exchange between the different actors in the supply chain. Different supply chains with somewhat different challenges exist for different wood products e.g. pulp and paper, sawn timber, other wood products and energy wood. For simplicity, the discussion is limited here on the sawn timber supply chain with the focus on the round wood.

The wood harvesting takes place in the forest outdoor conditions in rough terrain. The wood is stored outdoors where there is ice, snow, rain, water, dirt, mud, etc. The transportation is by trucks, train or by flotation in bunches from forest to the saw mills. The logs are subjected to impacts with machinery parts, other logs, rocks and the ground. At the saw mill the logs are handled with cranes and conveyors. These conditions are challenging for the log markings and their identification, and for the electronic hardware to be used.

The logs are sawn into boards, which usually destroys the physical markings in the wood and the boards have to be re-marked if full traceability over the chain is targeted. Board marking represents a different challenge from the log marking – the boards are handled in a more controlled industrial environment mostly indoors but the number of boards is larger than that of the logs as each log is sawn in to several boards and the value of each board is lower. Thus the board marking and identification needs to be very inexpensive to be feasible.

In the following Sections, the approaches considered for log marking and identification are discussed together with the specific challenges and limitations related to the use of UHF RFID technology in the forest industry.

3.1. Wood traceability techniques

The traceability can be based on marking and identifying the wood items such as logs and boards. Several methods have been considered for marking tree trunks and logs including painted markings, engraved markings, attached labels with a printed serial number (or other alphanumerical data) or a bar code, fingerprinting techniques based on physical, chemical and/or genetic properties of the wood, and RFID [3]. Markings can be painted or printed on the wood surface and they can be read either by personnel or automatically using machine vision technology (cameras and software). Different coding schemes from simple colour codes to serial numbers and to more advanced codes such as 2D matrix codes have been used. A medium-sized saw mill in Nordic countries typically processes a few million logs per year and thus individual identification of the logs requires a large number of unique codes to be available as the harvested logs may be also transported to several saw mills. Therefore, for unique identification only the more complex codes such as long serial numbers, barcodes or data matrices are feasible. Figure 5 shows examples of a bar code and a matrix code.

(00) 0 0123456 123456789 6

Figure 5. Examples of a GS1-128 code and GS1 DataMatrix [4].

The code markings can be painted, printed, engraved, punched or otherwise imprinted on wood. The main attraction of this kind of markings is the low cost of the marking as each individual marking is inexpensive to make. The most common application of these visual marking codes is printing them onto the boards as the large number of the items and their relatively low value emphasizes the need for low cost marking. The main weakness of the visual markings is their readability – the codes can be obscured by dirt, snow and moisture. A line-of-sight is needed for the camera and optical equipment may need frequent maintenance in dusty industrial environments. Printing of the codes on the surface of wood is also challenging; the surface of wood varies and clear markings are difficult to achieve consistently. For example, markings printed accidentally on dirt or other material on the wood come of when this material comes of the wood. The drying of the wood may distort the shape of the marking and the wood may crack under it.

Multiple techniques have been developed to overcome the problems with visible markings on wood surfaces. One can use attachable labels for smooth printing surface but these labels may also be detached from the wood during the processing steps and the labels can also be covered by dirt, saw dust or other opaque material preventing their reading. Special luminescent inks have been used to improve the readability of the visual markings by increasing the contrast between the markings and the wood surface [5]. Matrix codes allow also for error correction algorithms for improved readability. The achievable identification rate in the board marking with visual codes seems to be in the range of 90-95 % [6].

The use of visual markings on round wood, such as logs and tree trunks, is more complicated than on boards. Logs have to be marked and identified outdoors where the environment is more challenging due to the more frequent occurrence of dirt, water, snow, ice and other materials obscuring the marking. The wood surface also varies more on logs than on sawn boards. In the Indisputable Key –project two log marking methods based on visual markings were tested: luminescent nanoparticle (LNP) ink codes with a handheld marking device and harvester saw integrated printer that sprayed a matrix code or a custom bar code consisting of ink dots or stripes onto the log end [6]. The LNP ink dot or the line markings were read using an infrared camera. The trial achieved 75 % readability of the log markings. The harvester saw integrated marker was tested in marking logs in the forest that we identified using a camera at the log sorting station in a saw mill. Automatic detection rate of the correct identity of the marked logs was nearly 40 % and by eye 74 % of the markings were readable [7].

To overcome the readability problems with visual marking techniques radio frequency identification (RFID) has been tested for log identification. The main advantage of RFID technology is the capability for very high readability – radio waves do not require a line-of-sight and they propagate through most materials excluding highly conductive materials. Thus RFID technology is insensitive to the commonly found dirt, snow, ice and other opaque materials on wood. In the past, RFID trials have used commercial transponders – mainly low frequency (LF, 125 kHz) and high frequency (HF, 13.56 MHz) tags. LF and HF tags have been available much longer and were considered to be better suited for wood marking than UHF (ultra high frequency, ~860-960 MHz) transponders with known problems on moist surfaces e.g. on wet wood and near metal.

Examples of the LF and HF transponder trials are described in [8,9]. In [8] logs were marked by inserting 23 mm long LF tags by Texas Instruments into logs in the forest using a prototype applicator in the harvester. The reading range is reported to have been up to 0.5 m and reading accuracies in the range of 80-90 % were reported at the saw mill. Korten et al [9] report trials with HF transponder cards that were stapled on the logs and read using loop antennas in the forwarder, in a timber truck and at the saw mill. The reported reading range was 0.5-1 m depending on the reading location. Reading is reported to have been reliable.

Reliable automatic log identification is the basis for the traceability in the wood supply chain. UHF RFID technology offers the potential for high readability as the reading range is typically much longer than at LF and HF. Also, a few years ago GS1 introduced standardisation for UHF RFID which facilitates the implementation of the RFID systems. The challenges related to the use of UHF RFID technology in wood supply chain are discussed in the next Section.

3.2. Challenges of UHF RFID technology in wood traceability

Economically viable utilisation of the traceability requires that the wood items can be automatically identified. The item marking should not reduce their value or limit their use as a high quality raw material. The identification of wood items, the marking and reading, should be done without reducing the production efficiency e.g. by slowing it down and the costs related to the traceability should be reasonable to allow the benefits of the traceability to be utilised. The most significant part of the RFID system is the transponder as they are the most numerous component in the system and their performance is the basis of the overall system performance.

Wood is a natural material with varying properties between the trees, logs and boards – and within them. The density of the wood, the grain orientation and the moisture content vary and thus the electromagnetic properties (the complex permittivity) also vary. The varying moisture content has the greatest effect on the permittivity and loss in the wood. The permittivity variation can lead to transponder antenna detuning and the high loss due to the high moisture content attenuates the radio signal. These effects have to be taken into account in the design of the UHF RFID transponder to guarantee a sufficient reading range in all conditions in the wood supply chain. UHF label tags are therefore not suitable for marking fresh wood with high moisture content. In practice, the reading of the tags at saw mills has to be done at distances up to 1 m. The reading range depends mostly on the transponder as the reader operation is governed by the radio regulations defining for example the maximum allowed radiated power.

Reliable identification of the wood items requires that the tags have a high survival rate in the wood processing steps as transponders that have been destroyed or have been detached from the logs or boards cannot be read. In the RFID trials it has been frequently found out that tags glued, stapled or otherwise attached on the logs may be lost in the wood processing – especially during transportation, on conveyors and in debarking. In [9] it is reported that some 75 % of tags attached to the front-end of the log were lost in debarking at the saw mill. In trials carried out by the authors with tags attached onto the surface of the log ends typically up to a few per cent of the transponders were lost in each processing step which results in a significant loss of tags over the supply chain. Therefore, in order to ensure the transponder survival through the whole supply chain the tags has to be inserted inside the wood. Inside the wood the tag is protected from impacts which will improve the transponder survival rate considerable.

The transponder has to be attached on or preferably inserted into the wood by an applicator tool or machine and the tag has to be suitable for reliable and quick application. The application of the transponder should not reduce the production efficiency i.e. the application should not introduce significant delays. The application has to be done automatically where the wood processing is automatic and manual application is possible only if the wood is handled manually, e.g. felled with a chain saw or a reasonably small number of logs are marked. The transponder has to withstand the application to be readable.

In paper making certain materials even in small concentrations are banned from the wood used as the raw material in pulping as they may cause problems in the quality of the paper produced. These materials include most plastics, coal and metal. This represents a challenge in the manufacturing of the transponders as the commonly used materials cannot be used. When round logs are sawn into rectangular boards some of the wood is left over and this wood is commonly chipped and sold to pulp mills. These wood chippings are a high quality raw material for paper making and a valuable by-product for saw mills. As transponders and their pieces may end up into these chippings, the same restrictions on the tag materials apply also to their use in the sawn timber supply. Thus conventional plastics cannot be used in the tags to avoid possible plastics contamination of the wood. The transponder design and materials have to be suitable for inexpensive mass production of the tags as the costs of the transponders typically forms the largest part of a RFID based traceability system.

4. RFID implementation for forest industry

The past RFID trials have focused on using available commercial RFID transponders to mark logs or other wood items. The results of these trials have varied, but in general the transponders intended for other applications have not been optimal for the needs of the forest industry. Therefore, a custom made RFID solution was considered advantageous and was developed in an EU FP6 funded project called Indisputable Key [10]. The following Sections describe the passive UHF RFID solution developed for the supply chain of the forest industry.

4.1. RFID transponder for log marking in sawn timber supply chain

The basis of the traceability utilising RFID is the transponder used to mark the wood items. The requirements for the transponder to be used in log marking in the Nordic sawn timber wood supply chain can be summarised as follows:

- High readability
- Easy attachment into a log
- Harmlessness in pulp and paper making
- Suitability for inexpensive mass production.

These requirements are discussed in Section 3. The required compatibility of the material used with the pulp and paper making processes is perhaps the most constricting requirement for the transponder. Typically a UHF RFID transponder consists of a thin plastic inlay with a metal foil for the antenna to which the microchip is connected and of a hard plastic casing. As common plastics are not accepted in the wood used for pulping, alternative materials were considered. Biopolymers offer an interesting alternative to conventional plastics.

In addition to the chemical compatibility with the paper making processes, the transponder material has to be suitable for insertion into the wood to ensure tag survival in the logs in the wood processing steps in the supply chain. The material has to be mechanically durable; sufficiently hard but not brittle and it may not absorb water. The transponders have to survive several months in the logs. The material should have suitable electromagnetic properties at UHF frequencies – ideally low loss and stable properties. In addition to the suitable chemical, mechanical and electrical properties the material has to be applicable for mass production of the transponders using common plastic fabrication techniques e.g. injection moulding. A suitable bio-composite material meeting these requirements is ARBOFORM® by Tecnaro GmbH [11] and it was selected as the transponder casing material. The ARBOFORM® -material consists of lignin, natural fibres and processing aids. To facilitate the mass production, conventional plastic inlay with aluminium as the antenna pattern material was selected, as the amount of plastic in the inlays ending up into the pulping from the saw mill is negligible. Currently, paper inlays are also available for a non-plastic alternative. The transponder is EPC Class 1 Generation 2 compatible.

The desired high reliability in the wood tracing requires a good survivability of the transponders, which can be only achieved by inserting the tags inside the log. For high readability in the different steps of the supply chain the best location for the tags is in the log end. The transponder size and shape have to be optimised for insertion into the log – several approaches were investigated in the Indisputable Key –project [12] but a wedge-shaped transponder that is punched into the wood was selected [13]. This transponder has the additional advantage of being difficult to remove from the log or to tamper with. The shape of the casing with the inlay inside and the application method are illustrated in Figure 6.

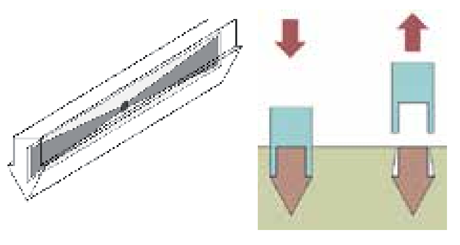

Figure 6. Wedge-shaped transponder and its insertion into the wood.

To achieve good readability in the production conditions on the conveyors, a long reading range is needed. The transponder casing material is somewhat lossy (measured electrical loss tangent is ~0.03 at UHF) which limits the choice of possible transponder antennas to dipole antennas. Wood is a natural material which is not isotropic or homogenous, and the moisture content varies greatly as the wood dries or gets soaked in rain after the tree is felled. The moisture content affects greatly the permittivity and losses of the wood and thus the transponder antenna has to be designed to operate in the wood with varying electromagnetic properties. The moisture content may exceed 100 % of the dry material weight in fresh wood.

The design of the transponder antenna was developed using electromagnetic simulations, laboratory tests and tests in production conditions in saw mills [14]. For electromagnetic simulations, Ansoft HFSS was used. The transponder readability is best when the tag is in the end of the log, as this part is usually exposed in the piles and on conveyor. If the transponder is in the side of the log it may be left under the log or covered by other logs and reading would have to be done through considerable thickness of wood and with the possibility of the tag being pressed against a metal surface. Figure 7 shows the simulator model of the transponder inside the log and the basic layout of the planar dipole antenna inlay.

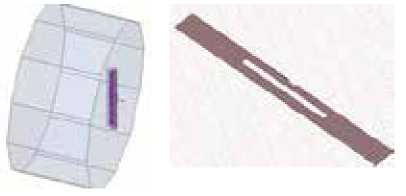

Figure 7. Simulation model of the transponder inside a log and the planar dipole antenna layout.

The planar dipole antenna was optimised for operation inside wet wood with tolerance for varying permittivity caused by varying moisture content in the wood. The electrical properties of wood were measured at UHF and the relative permittivity of the spruce was found to be of the order of 2.3 when fresh and 1.8 after kiln drying. Correspondingly, the loss tangent was 0.08 and 0.03 for fresh and dry spruce. When soaking wet, the relative permittivity of the wood may be even in the magnitude of 10. The final antenna design has the dimensions of 74 mm x 5 mm. Figure 8 shows the reading range measurement in the laboratory together with the measured reading range using TagFormance™ measurement device.

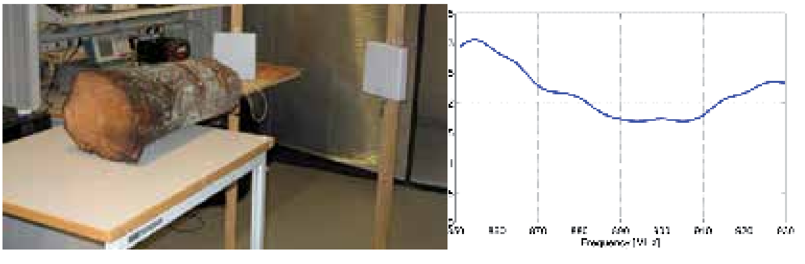

Figure 8. The reading range measurement in the laboratory and the measured reading range.

The reading range from freshly cut wood is approximately 2.5 m at the European UHF RFID frequencies (865.6 - 867.6 MHz) in the laboratory measurements. For inserting the transponder into the log, a simple tool or a manual applicator was developed. The applicator is made from an axe by replacing the blade with a holder for the transponder. Using this applicator, the tag is hit into the end of the log as shown in Figure 9. After some practice an operator may mark up to 100 logs / hour with the first strike success rate of approximately 95 %. In addition to this manual application tool, a prototype for an automatic applicator for a forestry harvester was developed [15].

Figure 9. Application of the tag and the tag inserted into the end of the log.

4.2. RFID readers

Ideally, the traceability in the wood supply chain would reach from the forest all the way to the end user of the wood products - for full coverage of the supply chain RFID transponders would have to be read with RFID readers in every processing step shown in Figure 2. In the Indisputable Key project, the RFID based traceability was used in the round wood supply chain from harvesting in the forest to sawing at the saw mill. RFID readers were used in three processing steps: in the harvesting, at the log sorting and at the sawing where most of the information on the logs is collected and needed – hand-held readers can be used in other processing steps to supplement the fixed readers in the harvester and on the conveyor in the saw mills. The transponders and readers were compatible with the EPC Class 1 Gen 2 air interface standard.

Each reader installation site represents some unique challenges for the RFID reader and for its antennas. The RFID reader has to be able to read the transponders reliably from a practical distance that depends on the location; for example on the conveyor in a saw mill the practical minimum distance from the reader antenna(s) to the transponder in the log is about 1 m as the thickness of the logs varies and sufficient space has to be left to accommodate this variation. The forestry harvester represents the most challenging environment for the RFID readers in the wood supply chain; the reader is subjected to difficult electromagnetic and physical environment in outdoor conditions with rain, snow and ice, vibration, shocks, Nordic four season temperatures and also to occasional impacts. The developed prototype of a vibration and shock resistant RFID reader is described in [14, 15]. The RFID reader features a robust impact resistant IP67 casing, adaptive RF front end for cancellation of reflections from large metal surface in the harvester head and EPC Global Reader Protocol v. 1.1 compatible interface over a CAN-bus to the harvester.

The reader installations at the saw mill were placed in the log sorting where the logs are first received and in the sawing. In these locations the RFID readers are subjected to industrial production conditions – particularly to saw dust and wood splinters, and to the risk of impacts. To protect the readers and to facilitate their installation over the conveyor the commercial readers were enclosed into a robust aluminium casing with the antennas on the outside. The reader used was Sirit Infinity 510 with circularly polarised antennas. Figure 10 shows the reader installations in a saw mill in Sweden in the log sorting station and in the sawing. In the log sorting it was found that antennas in a frame around the conveyor gave more reliable reading of the tags than over the conveyor assembly.

Figure 10. RFID readers in the log sorting and sawing in a saw mill.

RFID readers are used to read the transponders inside the log so that the logs can be identified and information such as measurement data can be associated to the log or the associated data can be retrieved. To identify the individual logs in addition to the reading of the transponder IDs, the ID-code has to be associated with the correct log on the conveyor. In the case of logs in the sawing this is relatively straight-forward as the logs are sawn top first so that the tags in the butt end of the log are always separated by at least the log length. This is based on the automatic applicator always inserting the transponder into the butt end of the log. The speed of the conveyor in sawing is reasonably low as well. In the log sorting the case is more challenging as in some saw mills the logs are not turned before the sorting and the transponders in the log ends can be very close to each other in adjacent log ends on the conveyor. To correctly identify the logs on the conveyor RFID positioning methods such as [16] could be used. In the Indisputable Key projects a simple method based on using the average reading time stamps from several antennas was used to determine the order of the transponders (and logs) on the moving conveyor). When the log separation was larger than about 1 m the logs could be identified reliably but some ambiguity in the log identification remained when the log separation was well below 1 m. The main reason for this was the difficult reading environment in the log sorting shown in Figure 9. There was a flat metal floor under the conveyor that causes reflections; the rapidly changing radio channel causes strong variation in the signal strength and variation of the position where the transponder is read on the conveyor. In the tests in other locations the log identification was significantly more reliable.

4.3. RFID system performance

The RFID system performance in the traceability of round wood in the Nordic wood supply chain was tested in several trials in a saw mill in Sweden and in another saw mill in Finland [15]. In the tests the number of repeated transponder ID readings by the reader was found to be a good indicator of the reading reliability and means to compare reader set-ups. When the tag stays in the field of the reader, the reader keeps reading the ID of the tag repeatedly. With each reading event lasting about one milliseconds, the number of repeated readings indicates how long time the tag has been in the field of the reader. Table 1 shows an example of the observed average number of repeated readings in three tests – in Sweden 164 transponders in 82 logs were run through the log sorting twice, and in a Finnish saw mill 143 test logs with transponders were sawn.

Test	Number of transponders	Reading rate	Number of repeated readings per tag	Standard deviation of the repeats
Log sorting test 1	164	100 %	190	120
Log sorting test 2	164	99.4 %	180	120
Sawing test	143	99.3 %	390	150

Table 1. Reading tests with logs marked with UHF transponders.

Typically the obtained transponder reading rates exceeded 99 % in tests with some 200 logs. In practice, the maximum read rate is 300…600 times per second. As can be seen in Table 4.1 the deviation in the number of repeated ID readings (~120) is rather large compared to the average number of the repeats (180-190) in the log sorting at the saw mill in Sweden, whereas in the other reader location the deviation is smaller in relation to the average number of repeats (150 vs. 390) indicating a more reliable and consistent reading of the transponders. These results also show that for intact normally operating transponders the reading rate can be close to 100 %.

Tests with RFID marked logs were also carried out to determine the log identification rate in the log sorting station in the Swedish saw mill shown in Figure 9 (left-hand side). In this location, reflections from the metal floor caused ambiguity in the reading position on the conveyor and the correct order of logs was unusually difficult to determine. Table 2 summarises the results from three tests where the log marking with RFID tags was carried out both in the forest and in the log yard at the saw mill using the manual applicator or the prototype of an automatic applicator in a forestry harvester.

Log marking	Reader location	Number of read tags in the test	Unique measurement results for the readings	Log identification rate
Automatic in the forest	Log sorting	285	268	94.0 %
Manual in the log yard	Log sorting	218	207	95.0 %
Automatic & manual, all logs for 26 Jan 2010	Log sorting	812	754	92.9 %

Table 2. Examples of identification rates obtained in RFID tests in a Swedish saw mill.

The log identification rate was determined by synchronising the measuring time of the logs by 3D scanner in the log sorting and the RFID tag reading time. Due to the variation in the position of the transponder in the conveyor when it was read by the RFID reader located on the conveyor slightly after the 3D scanner, there was a time window for the time difference the reading timestamp and the 3D scanning timestamp. In the tests, there were also unmarked logs mixed with the RFID marked logs. When there was only one log inside this time window when the RFID tag was read, the log identification was considered successful. The achieved log identification rate was on average about 93 % in the log sorting at this saw mill and in other reading locations the log identification rate was practically the same as the transponder reading rate.

4.4. RFID use in other wood supply chains and processing steps

The promising results in the log identification using UHF RFID in the Nordic round wood supply chain created interest to test the capabilities of the RFID technology in tracing wood in other wood supply chains in the Indisputable Key project. Two other cases were investigated: wooden impregnated poles and sawn timber (boards). Impregnated poles are a product that has a supply chain similar to the round wood supply chain for sawn timber except that the wood used for poles has more stringent requirements and thus a higher value. Additionally, the impregnated wood is not used as a raw material for paper or any other product so there is no limitation for the materials to be used in the RFID transponders. The main challenge in the pole RFID marking is the impregnation process: the poles are impregnated with creosote in high temperatures exceeding +100°C and creosote is a powerful solvent of plastics. The tags are exposed to creosote for an extended time in these high temperatures. The impregnation of the poles destroys most commercial tags as well as the developed biodegradable transponder. After some trials some special materials and high-temperature tolerant commercial tags where found but their high prices made them not feasible for production use. Excluding the destruction of tags in the impregnation, the readability of the UHF transponders in poles was excellent.

The high readability of the RFID tags approaching 100 % caused the desire to try UHF RFID marking of sawn timber, i.e. boards, as the optical marking techniques can typically only reach at best up to 90-95 % readability of the markings in production conditions. The large volumes of the boards sawn and the relative low value of the softwood boards excluded the use of cased transponders (hard tags) due to their price. Thus the only option was to experiment with label tags attached to the boards. The best readability with a label tag on the surface of fresh moist board immediately after sawing was achieved using an inlay indented for near metal applications with good performance in close proximity of detuning materials such as wood – e.g. UPM Raflatac Hammer. The achieved reading range was sufficient for board conveyors to ensure nearly 100 % readability where the reader antenna can be placed approximately 0.4 m away from the boards. However, the application of the label tags on the boards proved to be problematic. Different glues and stapling with plastic staples were tested but the transponder survival on boards in the saw mill in the processing steps from sawing to packing of the dried boards proved to be low - up to 30-40 % of the label tags attached to the boards after the sawing were lost before the packing. Thus the resulting traceability of the boards would be too low for useful applications in the range of some 60 %.

4.5. ICT solution

In the Indisputable Key project an ICT system solution was developed to handle the data storage and transfer to enable efficient utilisation of the collected information by different actors in the value chain.

The ICT System Architecture connects the enterprise business processes to the actual flow of objects. The architecture consist of tags to mark the individual objects, readers to observe the movements of tagged objects, reader data processor to interpret the raw RFID reads to basic observation events and an adapter to create the meaningful business events from the RFID events. The Traceability Services that provides the services to analyse and use the information and the Local ONS that provides the way of publishing the services to the other business partners and the users. Figure 11 presents the overall data flow of the architecture.

The ICT system architecture follows the guidelines set by the EPCGlobal architecture. The EPCglobal Network Architecture Framework is a collection of interrelated standards for hardware, software, and data interfaces, together with core services that are operated by EPCglobal and its delegates, all in service of a common goal of enhancing the supply chain through the use of Electronic Product Codes (EPCs).

Traceability Services Architecture extends the EPCglobal scope by offering the way to use other codes than EPCs and by providing Traceability Services. Traceability Services offers methods to monitor and optimize of the forestry wood supply chain, to research wood property correlations, and of course to trace the wood material throughout the supply chain. By tracing the wood object and processes used to manufacture the wood product the Traceability Services offers the chain-of-custody and environmental product declaration for wood products.

The architecture comprises three modules: Adapter, Collaborative Messaging System and Traceability Services. Adapters are used to acquire traceability information from the processes. The Adapters connect the observations of objects to the process data, generate events and send the events to the Messaging System. The Collaborative Messaging System is re-

http://dx.doi.org/10.5772/54205

sponsible for sending the event messages to the right subscribers. The Collaborative Messaging System is also responsible for authentication and authorization. The Traceability Services is responsible for storing the Traceability Data and presenting it to the users in correct format.

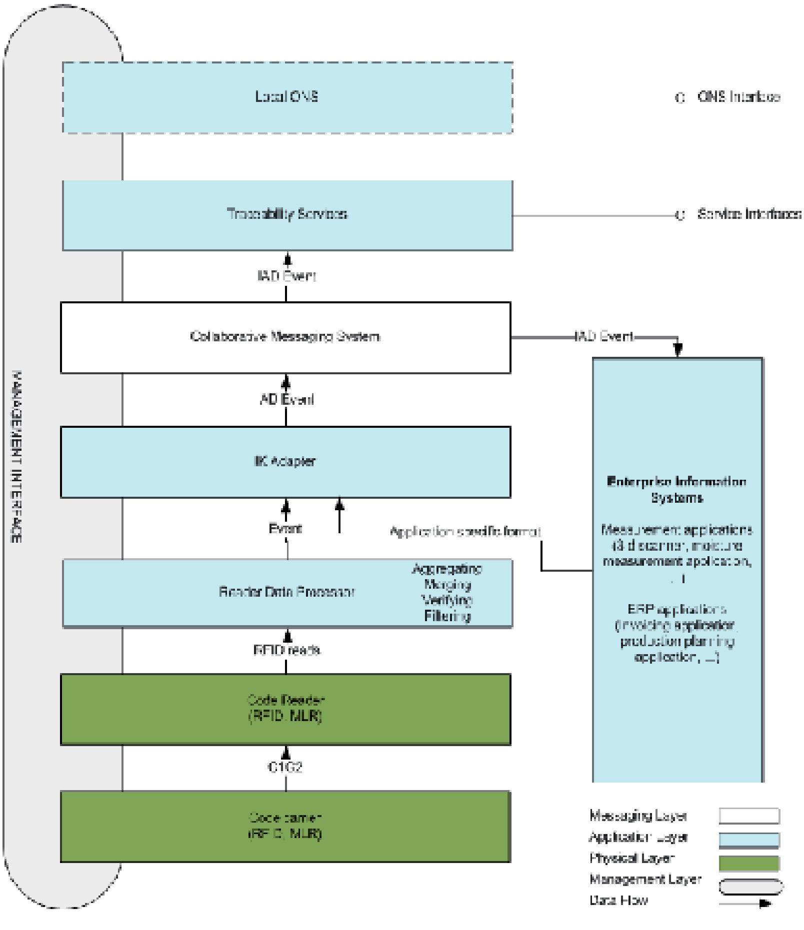

Figure 11. ICT System Architecture.

The interfaces between architecture modules are specified to each message format:

- C1G2, UHF Class 1 Generation 2 Tag Interface standard specifies the interface between RFID readers and RFID tags. The specification describes the interactions between readers and tags and tag operating procedures and commands. The full specification can be found from [18].

- RFID reads are individual reads of a RFID tag. The specification of the protocol used when tag readers interact with upper levels is specified in [19].

- Event is specified to be one observation concerning an individual object. The interface used to transmit the event to the Adapter is EPC global's Filtering & Collection (ALE) Interface, that specifies the delivery of event data to the upper roles. The event in this level could be "At location X in time Y the object with EPC was observed".
- Application specific format is used to connect the business data to the object observations. For example IK Adapter receives a measurements made by 3-D scanner are received as flat-file. The IK Adapter then connects the measurement information to the event information it received from the RFID-reader.
- IAD Event is specified to be one event concerning an individual object.

The Figure 12 presents the architecture when used across enterprises that do not use the same Collaborative Messaging Service. The data flow between enterprises can be realized by using the IAD events. Some application in Enterprise B can subscribe to the events produced in company A. Another connection point is ONS, for example end customers or parties not included into the production chain is to use ONS to look up for the service and use Services provided by the Traceability services to fetch the needed information. For example - customer can fetch a Chain-Of-Custody document or Environmental Product Declaration for object.

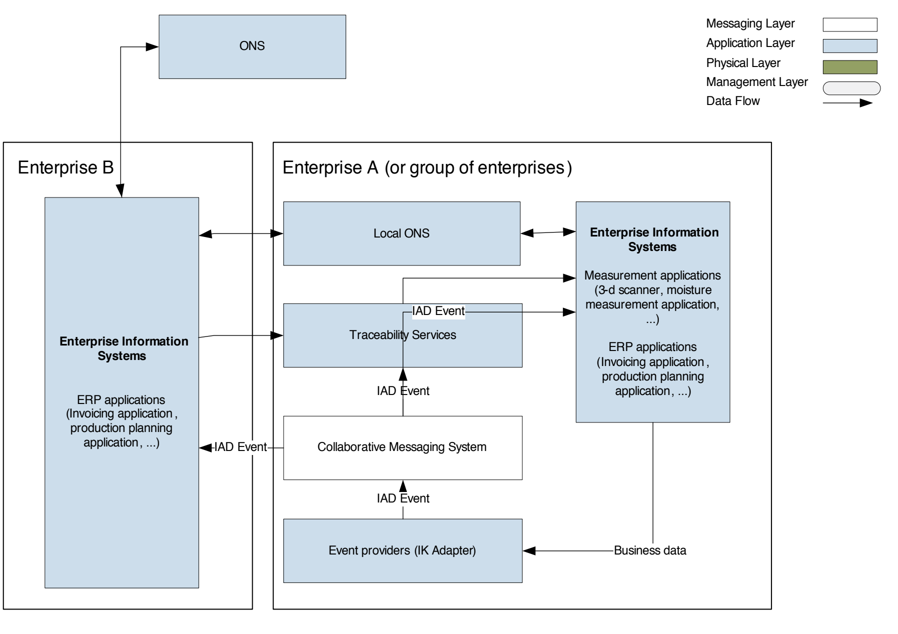

Figure 12. ICT system architecture across enterprises.

The centre of the ICT system architecture is a Collaborative Messaging System that is responsible of transmitting the messages from publishers to correct subscribers. The Publishers are not aware of Subscribers and all the authorization and authentication is performed by the Messaging System.

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The Collaborative Messaging System is realized using publish-subscribe pattern. Publish-subscribe is an asynchronous pattern where publishers of events are not sending the events to predefined subscribers. Instead of sending the message to predefined subscriber, message is published with some topic and content. In forestry-wood production system each event must contain event providers ID, detected object ID and a time stamp. Event can also contain some measurement information. For example in log sorting the event can contain measurements that 3-D scanner read from an object.

Any defined Event provider is an event provider in traceability system. IAD event messages are published about events concerning IAD objects and process information events are published about information concerning processes that can't be focused to an individual object. Each IAD event message must contain id of an event provider, id of an object and an observation time, which is the instant of time when the observation took place. An IAD event message can also contain measurement information about an observed object. For example in log reception station a log is measured with a 3-D scanner. These measurements are included into an IAD event message.

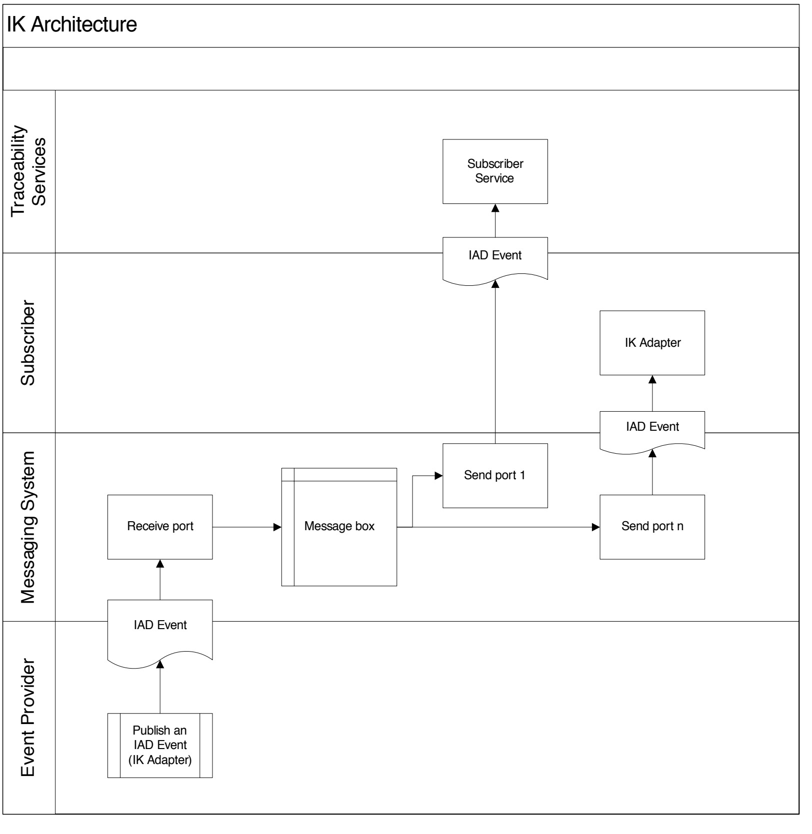

Figure 13. Collaborative Messaging System Data Flow.

Subscription could be topic-based, content-based or a hybrid of these two. In a topic-based subscription a subscriber subscribes for an events published with some topic. In a content based subscription, subscriber receives an event if a content of the event matches to the constraints defined by subscriber. Traceability architecture support hybrid of these two. IAD event providers publish events of a topic and subscribers can define content based subscriptions to one or more topics. For example - as illustrated in Figure 14Example IAD event data flow.

A harvester publishes two events with different topic:

- A LogHarvested event which contains the exact volume, quality and price information about log harvested
- A HarvesterState event which contains information about harvester state (battery, fuel, position, etc…)

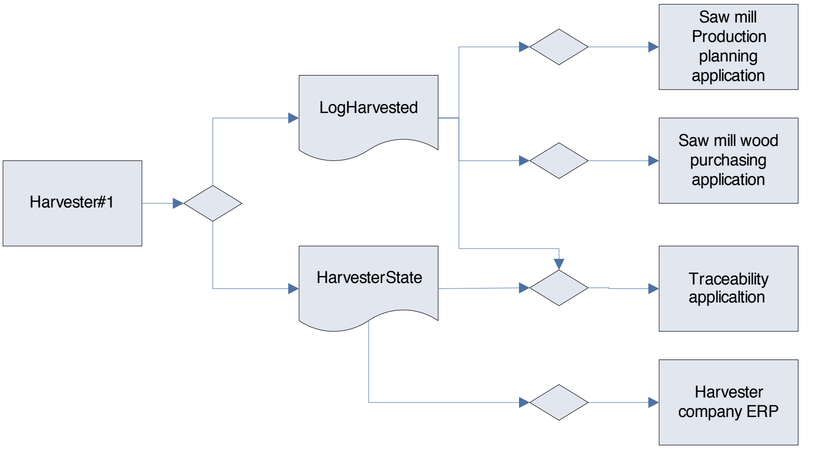

Figure 14. Example IAD event data flow.

There are three different subscribers for the event LogHarvested. Saw mill production planner wants to preplan the production beforehand by knowing the quality and amount of logs that are about to arrive to the saw mill. Saw mill purchaser makes payment based on the log volumes harvested and Traceability application gathers the information for research. For the event HarvesterState there are two subscribers. Traceability application gathers data for research and Harvester company can monitor its harvester status.

By combining information throughout the supply chain the Traceability Services enables new methods of analyzing the wood material. The properties of wood object can be compared between different steps, see Figure 15 Supply chain steps with properties.

For example length in harvesting vs. length in log sorting. Another possibility is to analyze how some property affects some other property. For example, how an area of origin affects the board quality.

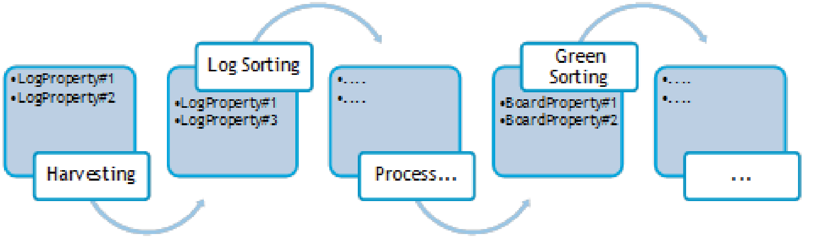

Figure 15. Supply chain steps with properties.

The purpose of Traceability Services is to act as a repository for item level traceability data and process level data and to provide services based on this information. The solution connects the steps of supply chain together and provides a common data model for the whole supply chain. The solution offers services for calculating of Environmental, Economical and Quality KPIs and analysis for the process data that are the basis for the KPI calculations.

5. Discussion

The forest industry represents some unique challenges to the traceability solutions – the data is utilised by different actors in the value chain so that typically the information is produced by one party and the information needs to be utilised by another party that may be outside the supply chain. The basis for the traceability and information utilisation is reliable and affordable identification of the wood. By identifying the wood material and items in the supply chain the associated information can be utilised by different parties. This enables new level of control of the wood conversion chain, tailored and specialised products, and new business models.

The main challenge in enabling the possibilities of the traceability in the forest industry has been the lack of a reliable and inexpensive means to identify automatically the logs and boards in various processing steps along the wood supply chain. The optical marking techniques such as printed markings offer the potential for very low costs but these methods struggle to reach better than 90-95 % success rate in the automatic identification of the wood items in industrial production conditions. The required identification success rate has to significantly exceed 99 % so that the information retrieval becomes a viable option for reacquiring the needed information, e.g. log dimensions. With 90-95 % identification success rate the risk for not being able to retrieve the needed data is some 10 times larger than what is generally considered acceptable – the benefits of the traceability are quickly lost if the information cannot be retrieved for a significant percentage of the wood items.

RFID technology offers the potential for near 100 % success rate in the identification of logs. The main challenge is the cost of the transponders – the acceptable cost for a transponder depends on the value of the wood material in question and on the expected savings and benefits to be obtained through the use of RFID. Currently the acceptable price for RFID varies case by case and there are different opinions on the price level. The price of the tags depends greatly on volumes – large scale mass production lowers the unit price considerably. For a hard tag the price may go as low as a few cents if there is market for sufficiently large volumes – large numbers of tags are needed to push the price down but before the prices are affordable there is not much demand for the tags.

The main challenge in achieving near 100 % identification success rate in RFID based log marking is the application of the tag – the insertion of the transponder into the wood. This has to be done automatically so that the log production efficiency is not significantly reduced by the log marking. Several prototypes of automatic applicators for forestry harvesters have been developed in different research projects but so far no device suitable for long term production use has been successfully built. This is the main technical challenge to be solved before the RFID based log marking can be adopted in large scale in the forest industry. Current solution allows manual tag application for small scale (up to a few thousand logs) log marking, e.g. for marking log batches and piles, or test logs for research and testing purposes, or marking tree trunks or logs when trees are felled manually using chain saws.

6. Conclusion

There are three main types of situations where traceability can be utilized to gain production improvements in forest industry: trouble-shooting, production optimisation and data mining. Trouble-shooting occurs when some end-product or batch deviates from the target quality. With traceability it is possible to trace the defect of quality to its root cause. For example it could be connected to the specific kiln in the saw mill or to a wood batch and its processing history.

Optimisation can be achieved using the traceability information. For example if the spiral grain angle of a log that has been used to produce a board is known, the twist of the board can be estimated. Using this information the board can be placed as a bottom of the drying patch. This can reduce the final twist of these boards by 50%. Traceability information can be used to mine the different correlations between wood properties. For example a window frame producer needs boards with long average distance between knots and wood with this property can be assigned for production of boards for this end product.

The basis of the traceability is reliable identification of wood items to associate and retrieve information on them. To identify the logs in the Nordic round wood supply chain a novel UHF transponder was developed together with robust RFID reader solutions. The novel wedge-shaped transponder is made from pulping compatible materials and it is inserted into the log end. In trials in saw mills the transponder readability was close to 100 % for intact functional tags. An ICT system solution was also developed for the data storage and transfer to utilise the collected information by different actors in the value chain.

The future development of the RFID based traceability should focus on further improving the reliability of the tracing close to 100 % for all logs. The main technical development needed is an automatic applicator suitable for production use in forestry harvesters to achieve high success rate in fast application of tags into logs. For marking high volume lower value items such as boards an inexpensive but sufficiently reliable identification method is needed – currently used printed markings are inexpensive but not highly readable in production conditions. UHF RFID technology has high readability but there are some technical challenges such as the application to the boards to solve – it is also difficult to achieve very low prices for tags if compared to printed markings.

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Interacting with Objects in Games Through RFID Technology

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Víctor M.R. Penichet

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53448

1. Introduction

Interactive games aimed at educational environments are becoming increasingly important in children´s learning. At the same time, technological advances are definitely causing the arrival of new computational paradigms, such as Ubiquitous Computing or Internet of Things. Ubiquitous Computing was defined by Mark Weiser in 1988, which provides the user with advanced and implicit computing, capable of carrying out a set of services of which the user is not aware. Internet of Things is similar to the Ubiquitous Computing paradigm and was introduced by Kevin Ashton in 1999 [7]. The scenario is described as a daily life object network where all of the objects are digitalized and interconnected.

The main objective of this chapter is focused on how to exploit the evolution of technology to improve user interaction in game environments through digitalized objects with identification technology (such as RFID or Near Field Communication). Digitalized objects are used as interaction resources. They are used in conjunction with mobile devices providing the performance of tasks with a simple and intuitive gesture. In the first place, mobile devices offer sophisticated methods to provide users with services to make use of information and to interact with objects in the real world. In the second place, physical objects are associated with digital information through identification technologies such as RFID. In this context, physical mobile interactions allow users to play games through natural interaction with objects in the real world. This chapter has six sections. Section 2 describes some concepts such as: Ubiquitous Computing, the Internet of Things and the types of interaction used in games. Section 3 presents the general infrastructure of RFID systems. In section 4, we describe the development of two RFID games. In section 5 their advantages and disadvantages are presented. Finally, conclusions are set out in Section 6.

2. Related works

Ubiquitous computing involves computers and technology that blend seamlessly into day to day living. Weiser described the concept in the article [8] in 1991.

The idea of a disappearing technology can clearly be applied to the trend in RFID technology development. In recent years, RFID technology was used in retail [2] and logistics [3]. Nowadays RFID Technology is becoming such an ubiquitous technology, it has led to a particular interest in developing a system in smart spaces. The Internet of Things is similar to the Ubiquitous Computing paradigm, which was described by Kevin Ashton in 1999 [7]. This concept refers to the interconnection of everyday objects in a network. i.e., each object such as a table, a chair or a refrigerator may include integrated identification technology. In this way, the Internet evolves from traditional devices to real objects thanks to the use of technologies such as wireless sensors or RFID.

In this chapter we have focused on games as an educational tool for children's learning. A video game is a software programme created for entertainment and learning purposes in general. It is based on the interaction between one or more people and an electronic device that executes the game. Over the past decades, video games have become a mainstream form of entertainment and communication which are highly accepted and successful in the society. People like playing games for several reasons: as a pastime, as a personal challenge, to build skills, to interact with others, for fun, or as tool for learning. In recent years, the advancement of technology has allowed designs to implement intuitive and new forms of interaction between the user and the console. Some of the devices used are: Kinect, Wii, Multi-Touch Technology, Virtual Reality, and Identification technologies such as RFID, NFC. The following describes in detail the devices and ways of interacting that there are between systems and users.

Kinect is a motion sensing input device that is connected to the console and PC video. It allows the user to interact with the game through movement and voice. In order to function, it requires technologies such as sensors, multi-array microphone, RGB camera and an internal processor. Some existing games that incorporate this technology with learning games are: [4][5][6]. These games offer a new and attractive interaction technique based on movement and voice. However, the new interaction needs some getting used to, most especially for children who have either physical or cognitive disabilities, as it can be exhausting to play through movement. Another obstacle is the space requirement and the hardware, such as the camera, is more delicate and expensive. Another device developed to improve the interaction between user and console is the *Wii Remote*, which is used as a handheld pointing device and detects movement in three dimensions. This device incorporates technologies such as: accelerometers, Bluetooth...[21].The main problem is the need for battery.

In addition, there is *Virtual Reality* software using helmets, gloves and other simulators. In this way the user may feel more immersed in the game, and it is very engaging and motivating, but the problem is the high cost of devices, and the difficulty in the use of certain devices. Also, an additional person is required to control the players and devices [9][10]. *Multi-*

touch technology for games allows the users to play on digital tabletops that provide both an embedded display and a computer to drive player interactions. Several people can thus sit around the table and play digital games together. This technology uses infrared LEDs and photodiodes, which are discretely mounted around the perimeter of the LCD. The principle of an infrared touch screen is the combination of an infrared (IR) LED and an IR-sensitive photodiode. As soon as there is an object or finger between the LED and the photodiode, the latter no longer detects the IR light from the LED. This information is the basis for the input detection. You can interact with them through multiple objects (including fingers). Some of the games implemented with touch technology for learning are:[11][12][13][14].

Identification technology such as *RFID* and *NFC* has been used to transmit the identity of an object using radio waves. In this way different types of interaction are allowed, such as touching which involves touching an object to a mobile device and enabling the user to perform the selected task. For example [15][16] show some projects using this technique.

- Scanning: the mobile device or other device is capable of scanning information and interacting with the system to provide a service to the user.

- Approach&remove: [17] this is a style of interaction which allows us to control user interfaces of a distributed nature by making a gesture with the mobile device. Interaction, as mentioned previously, may be absent or may simply consist of approaching the mobile device to digitized objects.

In this chapter we propose another kind of interaction, in which the mobile devices are stationary and the user used physical objects for interacting with the display.

Some systems that use identification technology are described as following: Smart Playing Cards [26] is a game based on RFID; this technology is integrated in cards. Augmented toys are digitalized with RFID technology simulating the real world [18] [19]. Meta-Criket is a kit developed for augmenting objects [25]. Hengeveld described in [20] the value of designing intelligent interactive games and learning environments for young children with multiple disabilities to increase their language and communication skills. In [21] we can find a proposal that digitalizes toys to help deaf children to learn sign language. This system [24] focuses on assessment and training for special children, allowing the user to store data through RFID cards data for processing daily and providing treatment advice. However, this project only focuses on monitoring the child and does not take into account activities to improve their intellectual ability. [22] describes a RFID musical table for children or people with disabilities. The table is designed for people who cannot navigate through menus or by using buttons on an iPod, and serves to enable them to select albums or songs from a music list from an iPod Touch. This system is very specific; it is more focused on entertainment. Logan Proxtalker [23] is a communication device which allows any user to communicate with symbols "PECS" System (Picture Exchange Communication), which is a device to retrieve vocabulary stored in different labels in order to play actual words. These systems provide entertainment and user interaction with the environment. The disadvantage is that are very specific and none of them has focused on the stimulation of the cognitive abilities of people with intellectual disabilities.

The advantages offered by these devices and systems are numerous. They enhance positive attitudes in users. They feel more motivated and encouraged to learn. However, the systems present the following disadvantages:

- The user needs a minimum knowledge of computer use. Not everybody can use a computer and some devices, like a mouse or a keyboard are not intuitive for people with cognitive disabilities. They need someone to help them.

- The system requires highly specialized hardware / software which can be expensive (simulators, virtual reality). In some games, impaired users may have difficulties finding specific information.

On the other hand, RFID technology has many benefits over other identification technologies because it does not require line-of-sight alignment, tags can be identified simultaneously, and the tags do not destroy the integrity or aesthetics of the original object. Due to the low cost of passive RFID tags and the fact that they operate without a battery, this technology is ideal for converting a real object in a physical interface capable of interacting with other devices

3. RFID-games proposal

The main objective of the project was to develop educational games for children that offer easy interaction based on RFID. For this purpose, the advantages offered by games developed in the pre-computer age (traditional games) were combined with the advantages and benefits of computer games.

To begin with, there are many advantages of traditional games. These were designed and carried out in the physical world with the use of real-world properties such as physical objects, our sense of space, and spatial relations.

Pre-computer games interactions consisted of two elements: user-to-physical-world interaction and user-to-user interaction. The physical objects were easily assimilated by the children, allowing users to interact intuitively with them.

There are also many benefits of computer games. These are more popular than traditional games. Some the advantages are the following:

- People create the illusion of being immersed in an imaginative virtual world with computer graphics and sound.

- Computer games are typically more interactive than traditional games, which enables the user to feel more motivated.

- Computer games allow feedback to be easily shown, as well as notifications about the game process and other important information.

Taking advantage of real physical objects and the benefits that new technologies offer us, we have designed a new way to interact with the system. It is based on physical objects that integrate RFID technology and allow us to interact with Graphics User Interfaces.

This kind of the system functions as follows: in the main game an interface is projected on the wall. Users with physical interfaces, i.e., the objects that integrate RFID tags, can interact with the main interface; this requires the mobile device that incorporates the RFID reader to interact with the main interface, which is necessary to bring objects to the mobile device (See Figure 1).

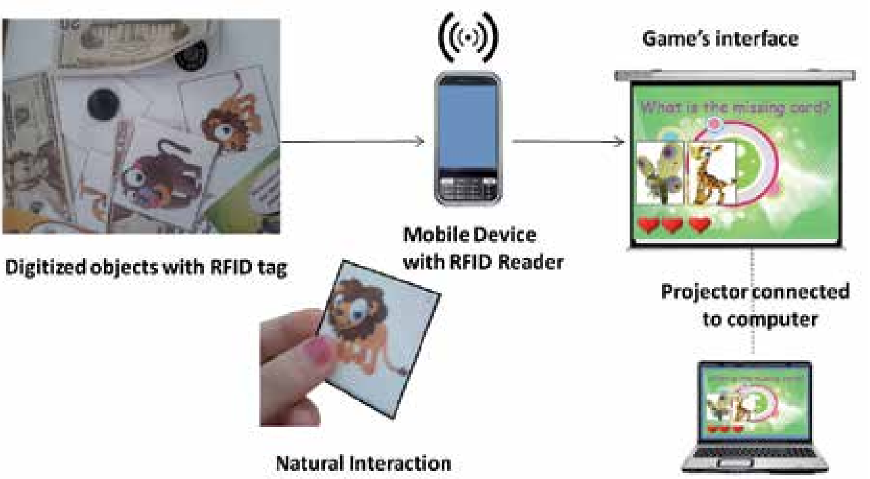

Figure 1. Digitized objects with RFID tags that communicate with the game's interface through the mobile device.

Due to the need to make a simple, accessible and intuitive system and considering the multiple technologies used to develop it, it was decided to follow an architecture based on three layers. The system infrastructure is divided in the following layers: Application Layer, Network Layer and Perception Layer. In the next section, we explain the latter in more detail (See Figure 2).

3.1. Presentation layer

This layer is the intermediary between the user and the system. Its main function is to allow the user to easily interact with the system. In our case study, the games are designed for children and users with special needs and for this reason we must focus primarily on usability and accessibility of the system. The main requirements that have been followed for the development of this type of games are:

Designing simple interfaces so that users do not have to learn to use it, acquire new skills, or need help.

Avoiding distraction and facilitating the interaction so that the user need not know and memorize how the system works.

Avoiding fear of interacting with the system, as well as providing notification of game development and the collaboration of information among players.

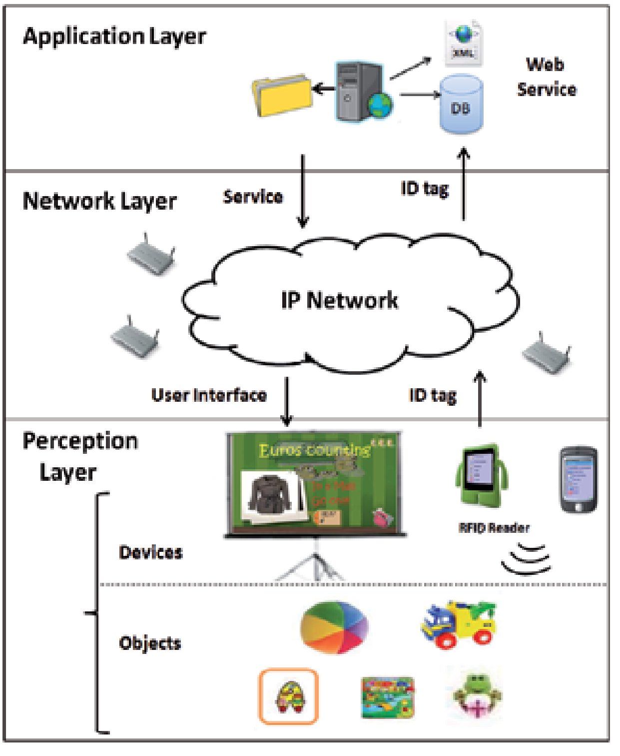

Figure 2. System architecture divided into three layers: Perception, Network and Application

This layer is divided into two parts. Firstly, there are the objects that integrate RFID technology, also called interaction resources, and secondly, there are interaction devices, through which are offered relevant services.

- Objects. Their main function is to facilitate the human-computer interaction. These resources need to have a RFID reader nearby to perform services. The main reason to use objects that interact with the environment is the following: The user uses human factors such as perception in order to interact with the environment. When an object similar to other objects with similar appearance is seen, the mind of the user automatically associates the object with its function.
- Devices. These computing devices are used as input and output of a system. They are communication channels. They are responsible for obtaining information from users

without that them being aware of it. In this particular case, a mobile device has been camouflaged in a toy in such a way that it is more engaging and intuitive to users. The devices available in the system are described as following:

Mobiles devices: These devices internally incorporate the RFID reader, allowing users to communicate with the system through RFID technology.

Projector: This shows the game user interface, the results and feedback. The software is run on a PC or laptop. It returns the information in textual and audio format to facilitate the use of games. It works dynamically and responds to the information sent to web services (Application Layer) through the communication network (Network Layer).

The user communication style with the device is very intuitive, which is why no prior knowledge is necessary (see Figure 3), it is only necessary to move the toy, card or object, depending on the game, closer to the mobile device (hidden in an object). The interaction and the processes that occur below the system are implicitly run by the user.

In this case, the collaborative screen shows the game which is being executed. It may show some objects and to associate that object the user has to interact with it, just by moving the corresponding object closer to the mobile device. From this moment all processes are run implicitly. The collaborative screen displays the pictures, text and sounds, depending on the game executed.

Figure 3. Interaction. The user brings the digitized object closer (interaction resource) to the mobile devices that contain the RFID Reader. This is an interaction device hidden in an object [27].

The communication between interaction devices (mobile devices) and interaction resources (digitalized objects) is the following: The RFID tag (embedded in the object) is a small chip integrated circuit, adapted to a radio frequency antenna that enables communication via radio. The energy to generate communication is received from the reader´s radio waves (integrated into the mobile devices).

The device on the client´s side includes a reader and a controller that is responsible for processing information received by the physical object and transforming it into useful information, such as an XML message that is sent to the server, which will process the message and trigger an action, such as the generation of user interfaces or the information requested at that time. The network technology is then used to notify the customer with through web services, connecting the two components: the client and the server (See Figure 4).

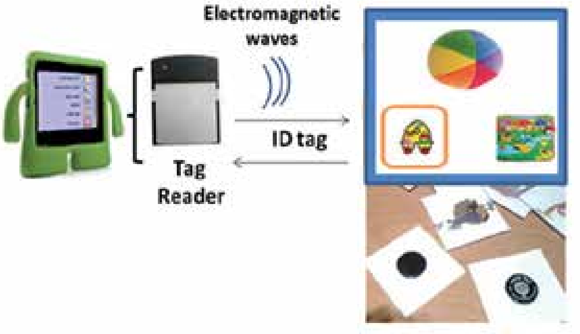

Figure 4. Communication is based on RFID technology. The mobile device has RFID reader inside. It sends electromagnetic waves when a digitalized object is close to mobile device. It processes the information contained in the object and carries out the required action.

3.2. Network layer

This layer enables the information obtained from the perception layer to be transmitted. This layer is composed by different wireless access technologies such as, Wireless Local Area Networks (WLAMs) (IEEE 802.11 variants), Bluetooth (IEEE 802.15.1). Wireless networks are a good option to establish wireless and mobile communications within the Internet of Things. We have used Wi-Fi technology because it allows connection of heterogeneous devices with the system (the computer interface that supports games and mobile devices which communicate with the objects). In addition, it allows user mobility, is highly scalable, efficient and lightweight.

3.3. Application layer

This layer provides services to support the stimulating games. It is consists of a server, which is a computer as part of a network, providing services to the devices which are connected to it. It provides important functions such as Web Services database.

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Web Services are a set of protocols and standards used to exchange data between applications in order to offer services. They facilitate interoperability and enable automated services to be offered, automatically causing the generation of user interfaces, thus allowing user consistency and transparency in use of the technology. Web services are of great importance in the trend of distributed computing on the Internet. To broaden and clarify the concept of Web services, we can quote a presentation by Dr. Marcos Escobar: "A Web Service is a software component that communicates with other applications by coding the XML message and sends this message via standard Internet protocols such as HTTP (Hypertext Transfer Protocol)". Intuitively, a Web Service is similar to a Web site that has a user interface that provides a service to applications, by receiving requests through a message formatted in XML (Extensible Markup Language) from an application, it then performs a task and sends a response message, which is also formatted in XML. The standard protocol for messages is SOAP (Simple Object Access Protocol). A SOAP message is similar to a letter: it is an envelope containing a header with the address of the recipient, a set of delivery options (data encryption), and a body with the information or data of the message. The performance of the web services is as follows: the client application sends an XML message to the server, and then the services contained provide an XML document called WSDL (Web Services Description Language). Its aim is to describe in detail the interfaces so that the user can communicate with the service. XML Web services are registered so that the user can easily find them. This is performed using UDDI (Universal Description Discovery and Integration). The response to the customer is another XML message that is capable of generating the user interface that the device in the client´s side is going to display at that moment. Figure 3 shows the communication that takes place between Web services and client applications.

Database is an organized collection of data, today typically in digital form. The data is typically organized to model relevant aspects of reality. In this case, the database is composed the idtag field. Each idtag is associated with the web service function. Among the functions are the following: execute a method, update information.

The internal operation is as follows: the web service receives the information, which is the output layer, and specifically the id tag which in this application has been read from mobile devices. The system checks the method associated with this id tag in the database. Web Service receives information about the method that it must execute. The execution of this operation depends on the following parameters: the object identifier, the executed game and the current status in the game. A common flow of actions that a user may perform could include:

- Updating the database and results internally in the system.
- The system automatically generates the corresponding game interface. The projector displays it. According to the action carried out, different messages might be shown.
- If the answer is right, a message indicates the outcome of play. This user interface congratulates and encourages the children to continue playing. A few seconds later, the interface related to the game that is running appears, but at a higher level than before.

- If the answer is wrong, a message indicates the outcome of the play. This user interface motivates and encourages them to try again. The next user interface is related to the game that is running at the time, but at the same level as before. Voices and motivating messages sound in every interface to make the user feel actively accompanied and encouraged.
- The system automatically generates the corresponding mobile user interface. It shows feedback and status of the system according to the action carried out.

4. Case studies developed by using RFID technology

In this section we describe two systems built in the University of Castilla-La Mancha (Albacete). The main objective is to take advantage of RFID technology to build systems that improve the user experience.

We used the same architecture for both games, while changing the contents and taking into account the cognitive abilities that we aimed to stimulate in each particular case.

This system functions by projecting an interface on the wall in the main game. Users with physical interfaces, i.e., the objects that integrate RFID tags, can interact with the main interface; this requires a mobile device that allows the RFID reader to interact with the main interface by bringing an object closer to the mobile device to play the game. For example, if in the game an object must be associated with another, the user only has to bring the corresponding object closer to the mobile device for the system to recognize it and display the outcome of the game.

4.1. Train InAb system

Intellectual disability, also called mental retardation, is a disability characterized by significant limitations in intellectual functioning and in adaptive behavior skills manifested in conceptual, social and practical aspects [1].

So far, this group has always had barriers imposed by society and by technology as it has often not been known how to adapt to the personal needs of each of these people.

Gradually, this situation has been improving with technological assistance and that of society. However, many of these people consider the world of technology to be strange and difficult to use.

TrainInAb (Training Intellectual Abilities) is an interactive and collaborative game designed to stimulate people with intellectual disabilities. The game is based on RFID technology; it allows a new form of human-computer interaction to be integrated. The user can interact with the system through everyday objects such as cards, toys, coins, etc. (See Figure 5). For example, if in the game an object must be associated with another, the user only has to bring the corresponding object closer to the mobile device, which the system will then recognize and display the outcome of the game (See Figure 5 and Figure 6)

http://dx.doi.org/10.5772/53448

The package consists of three different types of game, each aimed at stimulating a different cognitive ability such as memory, calculation, attention and auditory discrimination.

- They are divided into different levels to motivate the child when using the game. If the child fails, s/he loses a life and if the user wins, s/he moves on to the next level. Each level is more difficult.
- It displays the external information differently, as it is different for every level.
- The information is displayed as text, voice and graphics. In addition, the game can show the status and game results when the game ends
- The feedback-state messages are motivating for the user who then feels more encouraged to continue playing.
- The user has the possibility of repeating items.

Figure 5. The first image shows the Mobile devices interfaces. The next image shows the Physical user interfaces, that is, objects that integrate the RFID inside.The first objects are cards with images from the game, and the last image shows the notes and coins used for the game.

Figure 6. Main interface of the game designed to stimulate user memory, attention and calculative abilities.

4.2. StiCap

Attention-deficit/hyperactivity disorder (ADHD) is a neurobiological disorder characterized by developmentally inappropriate impulsivity, inattention, and in some cases, hyperactivity. Children who are affected by this disorder have occasional difficulty paying attention or controlling impulsive behavior. This problem affects them in their daily lives at home, at school, at work, and in social settings.

StiCap, Stimulating Capabilities, is an interactive system to improve attention and learning in children with ADHD. It is directed towards psychological therapies, in schools, allowing supervision by professionals, parents, and teachers.

The system consists of three games: two oriented towards memory improvement and another one oriented towards vocabulary enrichment. It is composed of the following devices: cards integrating RFID tags used as interactive resources which allow a one-way transfer of information between a user and the system; mobile devices provide the necessary communication between the cards and the system and a projector or any other big display showing the game interface which is running on any PC or laptop.

Figure 7. Main interface of the game designed to stimulate user memory and attention [28]

5. Benefits and drawbacks

In this section we will discuss the advantages offered by the integration of RFID technology in the new scenarios.

The main advantages of the system are the following:

- Reduction of the cognitive load. This means that users have to rely more on recognition skills than on their memory and that they do not have to remember complicated abbreviations and codes. For this reason, it has been designed in a very graphic way and has also used common objects which can be easily assimilated.
- Flexibility. This refers to the multiple ways in which the user and the system can exchange information. The information exchanged is displayed as text, voice, cheerful

sounds or by using graphics. The goal is to adapt to any user, regardless of any disability or limitation he/she may have.

- Flexibility in the number of users. This is a multi-player game. This allows users to share and exchange experiences with other users. The situation of each user may be complex and variable and for this reason, the game can also be used by one player.
- Flexibility in terms of space. Players can be situated anywhere in the room, the only requirement is that the mobile device is connected to the server.
- Very cheap to develop. Mobile devices will incorporate RFID technology in the short term and passive RFID tags are very inexpensive. In our case, only one mobile device is required, which is why it is low cost.
- Expandable. It offers the possibility to extend the games. The topic can be changed easily. The only requirement is that the RFID must be integrated in the object selected.
- Interaction with the system is simple and intuitive. Common items are familiar and can be easily assimilated by users, making it more predictable to use. They do not need prior knowledge of the system or device.
- The cognitive stimulation of the system can enhance mental abilities such as perception, attention, reasoning, abstraction, memory, language, orientation processes, while optimizing their performance. These games can be used as therapy for the cognitive deficit.

Thanks to this technology, the implementation of new interfaces can be developed for any mobile device, allowing system usability and user-friendly interaction, thus improving user satisfaction.

One possible limitation are that it requires connectivity to another network interconnection. The server needs to contain all the data from RFID tags, so in very complex systems we can find a lot of data, which might be difficult to manage.

6. Conclusions

Educational games are currently making a very positive impact and are extremely successful among society, especially among children.

Emerging technologies and mobility are being inserted without society realising by providing services previously unthinkable. In recent years, devices have been invented that offer new techniques for interaction between humans and game consoles. Nowadays, the user can interact through movement, voice command control, virtual reality, mobile devices, etc... However, there are still some hardware limitations for children and especially people who need special education.In recent years, RFID technology is booming and being used to digitalize spaces and objects easily, so we are getting closer to the new paradigm predicted by Weiser, ubiquitous computing.Exploiting the advantages offered by this technology, this chapter proposes a new form of interaction based on objects that integrate RFID technology.

In this way, anyone can interact with the software(in this case with the games)in an intuitive way.

Acknowledgements

This research has been partially supported by the Spanish CDTI research project CENIT-2008-1019, the CICYT TIN2011-27767-C02-01 project and the regional projects with reference PAI06-0093-8836 and PII2C09-0185-1030. I would like to especially thank to Yolanda Cotillas Aranda y Erica González Gutierrez for their collaboration on this project.

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Chapter 17

Manufacturing Logistics and Packaging Management Using RFID

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53890

1. Introduction

The chapter is centred on the analysis of internal flow traceability of goods (products and/or packaging) along the supply chain by an Indoor Positioning System (IPS) based on Radio Frequency IDentification (RFID) technology.

A typical supply chain is an end-to-end process with the main purpose of production, transportation, and distribution of products. It is relative to the products' movements from the supplier to the manufacturer, distributor, retailer and finally to the end consumer. Moreover, a supply chain is a complex amalgam of parties that require coordination, collaboration, and information exchange among them to increase productivity and efficiency [1, 2]. A supply chain is made up of people, activities, and resources involved in moving products from suppliers to customers and information from customers to suppliers. For this reason, the traceability of logistics flows (physical and information) is a very important issue for the definition and design of manufacturing processes, improvement of layout and increase of security in work areas.

European Parliament (Regulation (EC) No. 178/2002) [3] makes it compulsory to trace goods and record all steps, used materials, manufacturing processes, etc. during the entire life cycle of a product [4]. According to the European Parliament, companies recognize the need and importance of tracing materials in indoor environments.

Traditionally, the traceability system is performed through the asynchronous fulfilment of checkpoints (i.e. doorways) by materials. In such cases, the tracking is manual, executed by operators. Often companies are not aware of the inefficiencies due to these systems of traceability such as low precision and accuracy in measurements (i.e. no information between doorways), more time spent by operators and costs (due to the full-effort of operators who have to trace target positions and movements). According to [5] every day millions of transport units (cases, boxes, pallets, and containers) are managed worldwide with limited or even with lack of knowledge regarding their status in real-time. In order to overcome the lack of data due to traceability, automatic identification procedures (Auto-ID) could be a solution. They have become very popular in many service industries, purchasing and distribution logistics, manufacturing companies and material flow systems. Automatic identification procedures provide information about people, vehicles, goods, and products in transit within the company [6]. It is possible to note several advantages using an automatic identification system such as the reduction of theft, increase of security during the transport and distribution of assets, and increase of knowledge of objects' position in real-time.

Automatic identification procedures can also be applied to packaging products, instead of to each item contained in the package. Packaging is becoming the cornerstone of processing activities [7]. Sometimes products are very expensive and packages contain important and critical goods (for example dangerous or explosive materials) and the tracking of goods – and packaging in particular – is a critical function. The main advantage of automatic system application to packages is the possibility to map the path of all items contained into the packages and to find out their real-time position. The installation of automatic systems in packages allows costs and time to be reduced (by installing, for example, the tag directly on the package instead of on each product contained inside the package).

The purpose of the chapter is to provide an innovative automatic solution for the traceability of *everything that moves* within a company, in order to simplify and improve the process of logistics flow traceability and logistics optimization. The chapter deals with experimental research that consists of several tests, static and dynamic, tracing the position (static) and movements (dynamic) of targets (e.g. people, vehicles, objects) in indoor environments. In order to identify the best system to use in the real-time traceability of products, the authors have chosen Real Time Location Systems (RTLSs) and, in particular, the Indoor Positioning Systems (IPSs) based on Radio Frequency IDentification (RFID) technology. The authors discuss the RFID based system using UWB technology, both in terms of design of the system and real applications.

The chapter is organized as follows: Section 2 briefly describes IPS systems, looking in more depth at RFID technology. After that the experimental research with the relative results and discussion are described in Section 3. Section 4 presents an analysis of RFID traceability systems applied to packaging. Conclusions and further research are discussed in Section 5.

2. Background of Indoor Positioning System (IPS)

This section presents a general description of IPSs. First, the authors describe logistics flows (physical and informative). After that, the section moves on to describing IPSs (methods for determining the position of a target, criteria to evaluate IPSs, classification of IPSs), underlining the advantages of using automatic identification procedures for tracing objects. Finally, the section provides a brief description of RFID and in particular RFID-UWB technology (Radio Frequency IDentification-Ultra Wide Band).

2.1. Logistics flows

Generally, companies provide goods and/or services to customers, purchasing raw materials from suppliers. In order to increase productivity and efficiency within the supply chain, the parties (suppliers, manufacturers, and customers) have to exchange materials and information among themselves.

In a typical supply chain, logistics flows can be classified into *physical* and *informative*. Physical flows include operative activities (e.g. transport, storage of raw materials, semi-finished and finished products, etc.). A great purpose of the optimization of these flows is the reduction of transport and storage costs. Information flows concern the information on the demand, logistics, and production planning. Figure 1 shows a graphical representation of a supply chain, underlining physical and informative flows.

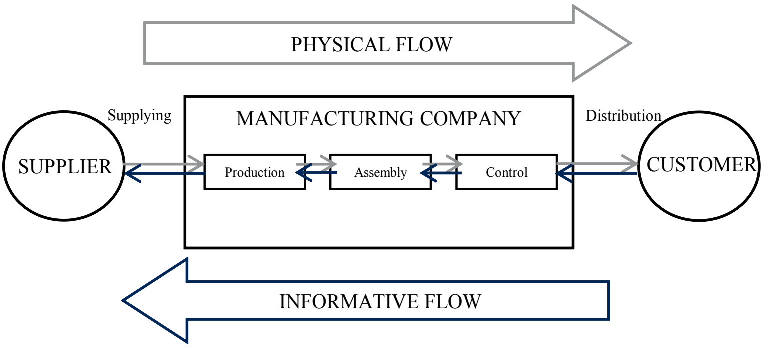

Figure 1. General scheme of a supply chain, underlining materials and information flows

Within the supply chain, it may be essential to know both the position and the movements of operators, pallets, tools, and packages. The traceability of flows within a company is a crucial aspect that has to be optimized.

Traditionally, the process of traceability of goods is performed through the asynchronous and automatic fulfilment of doorways by materials (e.g. bar code reading process) or totally manual by an operator who identifies and measures all movements between work centres, assembly and control workstations, and warehouses (Spaghetti Chart and From-To Chart are two technologies in which the presence of an operator to identify the position and map the movements of goods is necessary). This system implies approximate measurements, full-time effort and wasted time by the operator, and the possibility of human errors. In order to improve performances in the traceability process and to reduce costs optimizing the internal flows, companies are beginning to use automatic identification procedures (Auto-ID). The main advantage of this method is the time reduction in measuring the position and mapping the movements of an object. Real Time Locating System (RTLS) is an automatic system for identifying the real-time position of objects and IPS is the RTLS technology chosen by the authors for developing the experimental research.

2.2. Indoor Positioning System (IPS)

In recent years, indoor location sensing systems have become very popular [8] for locating the position and mapping the movements of goods and people. An Indoor Positioning System (IPS) is a process that continuously determines in real-time the position of something or someone in a physical space (e.g. the location detection of products stored in a warehouse, medical equipment in a hospital, luggage in an airport) [9]. According to [10], an IPS can provide different kinds of data for location-based applications. Any positioning system has at its core the measurement of a number of observable parameters (e.g. angles, velocity, ranges, and range differences) [11]. From the definition by Hightower [9], an IPS works all the time unless the user turns off the system, offers updated position information on the object, estimates position within a maximum time delay, and covers the expected area in which users need to use IPS [10].

In general, a real-time location system is a combination of hardware and software, continuously used to determine and provide the real-time position of assets and resources equipped with devices designed to operate with the system. A location may be described through relative position data with indication of distances, or absolute position data, with some accuracy in any defined grid of coordinates. Generally, location and ranging are reported visually, mostly referring to a map of land, a plan of a building, or in a graph. Alternatively, a change of location may be indicated with sound signals. In particular, a real-time location system uses sensors to determine the real-time coordinates of a tag, everywhere within the area of interest [11]. Curran et al. [11] describe the main industrial applications of indoor location determination systems for companies, in particular the real-time identification of the position of materials, the path control of material flows and warehousing.

Another important industrial application of location positioning system is the *traceability of packages*. Many companies need to track packages, first without the product and after with the products inside, to know the real path (and cost) of their material flows, allowing control of the Work in Progress (WIP) and finally to reduce costs of the system.

2.2.1. Positioning algorithms using IPSs

According to [11], there are several methods for locating and determining the position and movements of an object. A positioning location system can use only one method or combine a number of techniques to achieve better performance. The most commonly used methods are [8]:

- *Triangulation*: this uses the geometric properties of triangles to estimate the target location. It has two derivations: *lateration* and *angulation*.
  - *Lateration* estimates the position of an object by measuring its distance from multiple reference points (it is also called the range measurement technique). According to [8]

this method implies the measurement of the *Time Of Arrival* (TOA, that is the travel time of the distance that divides the receiver and the transmitter, knowing the speed of signal propagation) or the *Time Difference Of the signal's Arrival* (TDOA, that is the distance of the difference between the arrival time of signals sent by the transmitter). The distance is derived by computing the attenuation of the emitted signal strength or by multiplying the radio signal velocity and the travel time;

  - *Angulation* (called also *Angle of Arrival* – AOA) is a method that locates the object to be measured through the intersection of several pairs of angle direction lines, each formed by the circular radius from a base station to the mobile target [8]. The main advantages are that a position estimate may be determined with as few as three measuring units for 2D positioning, and that no time synchronization between measuring units is required. The disadvantages include relatively large and complex hardware requirements and location estimate degradation as the mobile target moves away from the measuring units [8];

- *Scene analysis:* this refers to the type of algorithms that first collect the features (*fingerprints*) of a scene and then estimate the location of an object by matching online measurements with the closest *a priori* location fingerprints [8]. Location fingerprints refer to techniques that match the fingerprint of some characteristics of a signal that is location dependent. The location fingerprint is based on two moments: the offline phase, in which an analysis of the measuring environment is conducted, collecting a large number of coordinates, and the online phase, in which target data is compared with that collected before and the location is identified with the point with the most similar values [8]. This technique is subjected to signal interferences, because of obstacles presented in the environment;

- *Proximity* is the simplest method of positioning, but it can only provide an approximate location of the target, and not an absolute position. Proximity algorithms provide symbolic relative location information. Usually, this relies on a dense grid of antennas, each having a well-known position. When a mobile target is detected by a single antenna, it is considered to be located with it. When more than one antenna detects the mobile target, it is considered to be located at the one that receives the strongest signal. This technique can be implemented over different types of physical media. In particular, systems using RFID are often based on this method [8].

2.2.2. Evaluation criteria for IPS systems

In order to evaluate the performance of an IPS, various system performance and deployment criteria are proposed:

- *Accuracy* (or location error) is the most important requirement of a positioning system [8]. Usually, mean distance error is adopted as the performance metric, which is the average Euclidean distance between the estimated and true location. The higher the accuracy, the better the system. Accuracy alone, however, is not sufficient to completely define the performance of a positioning system and, as such, a trade-off between "suitable" accuracy and other characteristics is needed;

- *Precision* is the success probability of position estimation with respect to predefined accuracy [10] and considers how consistently the system works. Precision is a measure of the robustness of the positioning technique as it reveals the variation in its performance over many trials. In order to measure the precision of a system, the cumulative probability functions of the distance error is used;

- *Complexity* of a positioning system can be attributed to hardware, software, and operational factors. In particular, the software complexity is the computing complexity of positioning algorithms. Elements that influence the complexity are human efforts during the initialization and maintenance phases, and the computing time requested of the tag by the operator to determine the target position [8];

- *Robustness* is the ability of an IPS to keep operating even in serious cases, such as when some devices in the system are malfunctioning or damaged, or some mobile devices run out of battery power [10];

- *Scalability* is the ability to function normally when the positioning scope is large. Usually, the positioning performance degrades when the distance between the transmitter and the receiver increases. A location system may need to scale on two axes: geography (the covered area or volume) and density (the number of units located per unit geographic area/space per time) [8];

- *Cost* of a positioning system may depend on many factors, such as money, time, space, weight, and energy. The time factor relates to installation and maintenance. The space factor is linked to the space and weight constraints of system units. Energy is an important cost factor of a system: some mobile units are completely energy passive and only respond to external fields, therefore could have an unlimited lifetime. Other mobile units have a lifetime of several hours after which they have to be recharged or the battery needs replacing [8].

2.2.3. IPSs classification

According to [10], there are several criteria for classifying an IPS. One criterion is based on whether an IPS uses an existing wireless network infrastructure to measure the position of an object. IPSs can be grouped as *network-based* and *non-network-based* approaches. The network-based approach takes advantages of the existing network infrastructure, where no additional hardware infrastructures are needed. For cost reasons this approach is preferred. However, the non-network-based approach uses dedicated infrastructures for positioning and has freedom of physical specifications by the designers, which may offer higher accuracy.

More generally, IPSs are classified according to the method used to determine the target position. Figure 2 ([12] version modified by [8]) shows the technologies used to determine the target position according to *resolution* (the performance of IPSs) and *scalability* (the environment in which each technology is best suited).

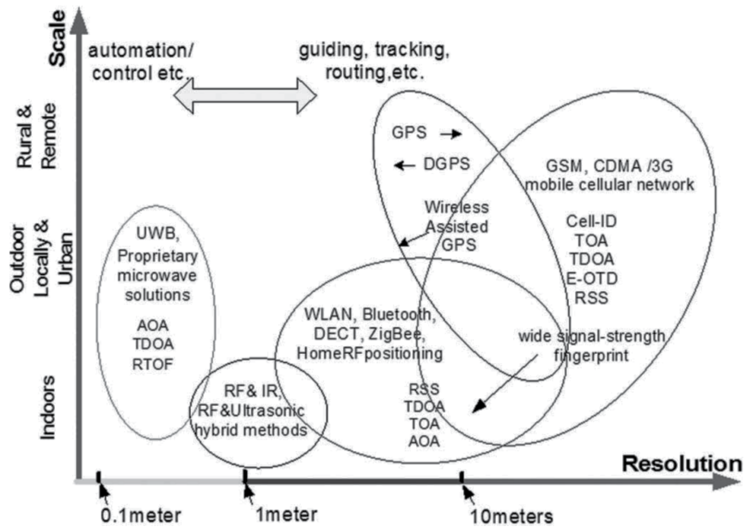

Figure 2. IPSs classification by *resolution* and *scalability* ([12] version modified by [8])

According to resolution and scalability, IPSs can be classified into several groups of automatic positioning systems. The most important are as follows:

- *Infra-Red (IR) based systems* are the most common positioning systems, since IR technology is available on board various wired and wireless devices, such as TVs, printers, mobile phones, etc. [13, 14]. They have several advantages such as wide availability, great positioning accuracy, simple system architecture and light and small tags. In addition, since the whole infrastructure is very simple, it does not need costly installation and maintenance [15]. The line-of-sight requirement and short-range signal transmission are two major limitations that suggest it is less effective in practice for indoor locations [16]. IR systems require the absence of interference and obstacles between the target and the sensor. For these reasons, they cannot be applied to some kinds of indoor scenarios in which the environment is complex;

- *Ultra-sound positioning systems* use diffusion, refraction, and diffraction phenomena, defined by the parameters of frequency, wavelength, speed of propagation and attenuation. Ultra-sound positioning systems are cheap solutions and their accuracy is high, but their precision is low when compared to IR-based systems, because of the reflection influence [15];

- *Radio Frequency (RF) based systems* are technologies used in IPSs, that can uniquely identify people or objects tracked in the system. They provide some advantages as follows. Radio waves can easily travel through walls and human bodies, thus the positioning system has a larger coverage area and needs less hardware compared to other systems. RF-based positioning systems can reuse existing RF technology systems [17]. They can cover large distances, since they use electromagnetic transmissions and are able to penetrate opaque objects such as people and walls. WLAN (Wireless Local Area Network), Bluetooth, Wireless sensor networks and RFID-UWB (Radio Frequency IDentification-Ultra Wide Band) are based on this technology [15], briefly described below.

- *WLAN* technology is very popular and has been implemented in public areas such as hospitals, train stations and universities. WLAN based positioning systems reuse existing WLAN infrastructures in indoor environments, which lower the cost of indoor positioning. The accuracy of location estimations based on the signal strength of WLAN signals is affected by various elements in indoor environments such as the movement and orientation of human bodies, nearby tracked mobile devices, walls, doors. RADAR system, Ekahau positioning system and COMPAS are the main techniques based on the WLAN positioning technology [18];
- *Bluetooth* is a technical and industrial method for transmitting data in a WPAN (Wireless Personal Area Network). It enables a range of 100 m communication to replace the IR ports mounted on mobile devices [19];
- *Wireless sensor networks* are devices exposed to physical or environmental conditions including sound, pressure, temperature and light, and they generate proportional outputs [20];
- *RFID-UWB* is a method for storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [16]. RFID-UWB technology will be explained in detail in the next paragraph.

2.3. Radio Frequency IDentification (RFID)

In recent years, the application of RFID has attracted considerable interest among scientists as well as managers faced with the problem of optimizing production processes in several industries [6]. RFID has enormous economic potential, which many manufacturers (e.g. Wal-Mart, Tesco, Marks & Spencer and other retailers [21-23]) have already recognized and started to use successfully [24].

The main use of RFID systems in industrial applications deals with asynchronous identification. The traditional barcode labels that triggered a revolution in identification systems are inadequate in an increasing number of cases. Barcodes may be extremely cheap, but their limitations are their low storage capacity and the fact they cannot be reprogrammed [6]. A barcode is an optical machine-readable representation of data, which shows data about the object to which it is attached. Unlike an RFID, a barcode represents data by varying the widths and spaces of parallel lines, and may refer to a linear or one-dimension (1D).

Radio frequency identification is a method for storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [16]. RFID positioning systems are commonly used in complex indoor environments and their function is to identify an object through radio frequency transmission. The main purpose of this technology is to assume information about animals, objects, or people identified by small tools in radio frequency associated to them. According to [25] some of the more transparent advantages of RFID are as follows:

- RFID does not require line-of-sight to capture data, hence saving time and labour by eliminating the need for unloading a pallet and identifying the load;
- RFID is able to read the contents of an entire pallet load or SKU (Stock Keeping Unit) in seconds and saves time and labour;
- RFID sensors can read data from tags from several meters away;
- Each RFID tag has a unique code;
- RFID can be a read/write system so data can be updated through the supply chain, providing insight into possible trouble spots in distribution, such as theft and damage.

On the other hand, RFID method is an expensive solution, but this limitation could be overcome with better performances of RFID systems.

By describing RFID components and their functions, it is possible to understand the technology and issues that influence the application of an RFID system. A typical RFID consists of three components:

- *RFID tag* (transponder) is the data-carrying device located on the object to be identified. RFID tags are categorized as either passive or active.
    - *Passive RFID* tags operate without a battery. They are mainly used to replace traditional barcode technology and are much lighter, smaller in volume, and less expensive than active tags. They reflect the RF signal transmitted by a reader, and add information by modulating the reflected signal [8];
    - *Active RFID* tags are small transceivers, which can actively transmit data in response to an interrogation. The frequency ranges used are similar to the passive RFID case except for the low and high frequency ranges. The advantages of an active RFID tag are the smaller antenna and the much longer range than passive tags (which can be 10 m). Active tags are ideally suited for the identification of high-unit-value products moving through a harsh assembly process [8];
- *RFID reader* (interrogator) has the overall function of reading and translating data emitted by RFID tags. Readers can be quite sophisticated, all depending on the type of tags that are supported and functions they need to perform. As a result, the capabilities and sizes of readers depend on the application [25]. A reader typically contains a radio frequency module (transmitter and receiver), a control unit, and a coupling element to the transponder. In addition, many readers are fitted with an additional interface to enable them to forward the data received to another system (PC, robot control system, etc.);
- *Host computer* communicates with the reader and information management system.

The RFID components and their connections are shown in Figure 3 ([6] version modified by [25]).

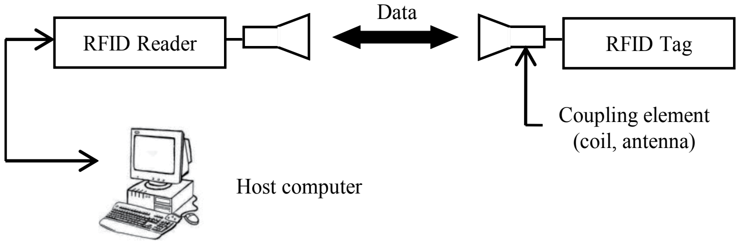

Figure 3. Components of an RFID system ([6] version modified by [25])

2.3.1. RFID – Ultra Wide Band (UWB)

Amongst RFID technologies, Ultra Wide Band (UWB) is the most accurate and fault tolerant system. It can have a widespread usage in indoor localizations.

RFID-UWB is an emerging radio technology marked by accuracy in the estimation of the position, and the precision with which it is possible to obtain that accuracy.

According to the most influential and widespread definition, provided by the *Federal Communications Commission Regulation* [26], an RFID-UWB system is defined as any intentional radiator having a fractional bandwidth greater than 20% or an absolute bandwidth greater than 500 MHz. These requirements mean that a band-limited signal, with lower frequency f_L and upper frequency f_H, must satisfy at least one of the following conditions (Equation 1, 2):

$$\frac{2(f_L - f_H)}{(f_L + f_H)} > 20\% \tag{1}$$

$$f_L - f_H > 500\,MHz \tag{2}$$

According to [27], the main characteristics of an RFID-UWB are the transmission of a signal over multiple frequency bands simultaneously and the brief duration of that transmission. RFID-UWB requires a very low level of power and can be used in close proximity to other RF signals without causing or suffering interferences. At the same time, the signal passes easily through walls, equipment and clothing [27-29] and more than one position can be tracked simultaneously. Moreover, RFID-UWB systems overcome limitations due to reflection, refraction, and diffraction phenomena, using pulses for the broadband transmission. The use of RFID-UWB offers other advantages, such as no line-of-sight requirements, high accuracy and resolution, lighter weight (the weight for each tag is less than 12 g) and the possibility to trace multiple resources at the same time, real-time and three-dimensionally. Furthermore, RFID-UWB sensors are cheaper, which make the RFID-UWB positioning system a cost-effective solution.

An RFID-UWB system comprises a computer and a hub (including a graphical interface), RFID-UWB sensors to record signals in real-time, RFID-UWB tags at low and high power

http://dx.doi.org/10.5772/53890

and shielded CAT-5 cables. A set of sensors is positioned around the perimeter of the measured area. They receive pulses emitted by tags that include a set of data and are subsequently processed by the central hub.

The next section will describe in detail some experimental equipments developed by the authors based on the RFID-UWB system used in on-going research focused on real-time material flow traceability systems.

3. Experimental study

In this section, the experimental study about the traceability of material flows through IPS system based on RFID-UWB technology and its results are presented.

3.1. Components of the RFID-UWB system

The authors chose the RFID-UWB system, among IPS technologies since it is able to ensure the highest accuracy and precision in the measurements thanks to the combined use of AOA and TDOA techniques. The system comprises sensors, tags, and the software location platform, described below.

- *Sensors:* RFID-UWB sensors receive pulses from tags. Each sensor can determine the azimuth point and the arrival angulation thanks to the AOA technique. In this case, if only one sensor receives the signal, the system can determine the 2D location of the tag. Instead, if the signal is captured by more than one sensor, connected each other, it is also possible to find out the TDOA and obtain 3D location of tags. The configuration used reduces the infrastructure requisites, and consequently the costs, and guarantees high reliability and robustness of the system. The main characteristics of the sensors are:
  - *Reactivity in real-time*: each sensor maintains a constant frequency of 160 Hz, which means the tag can be seen every 6.25 ms by each sensor;
  - *Flexible installations*: this kind of infrastructure can be used for both small and large installations. Several sensors can be integrated in a unique system to monitor a big area and manage a large number of tags simultaneously;
  - *Synchronism:* in order to guarantee synchronism, the sensors are cabled with CAT-5 cables. A cell made up of several sensors is able to cover 10,000 m^2 of environment. In order to extend the covered area, the cells can be connected to each other;
  - *Bidirectional communication:* the sensors support bidirectional communication at 2.45 GHz. This allows the system to dynamically manage tags in an optimal way;
  - *Connectionsof sensors:* the sensors can be connected with standard Ethernet cables or through wireless adaptors, using pre-existing infrastructures like access point, switch Ethernet and CAT-5 wiring for communication between the sensors and the server;

- *Ease of maintenance:* the sensors are managed in a remote way through TCP/IP protocols and standard Ethernet for communication and configuration.

Figure 4 shows the sensors used in the experimental application.

Figure 4. Sensors used in the experimental application (courtesy of Ubisense Group plc)

- *Tags:* these are small and robust devices worn by a person or attached to an object to be accurately located within an indoor environment. Tags transmit brief RFID-UWB pulses that are received by sensors and are used to determine their position. The use of RFID-UWB pulses ensures both high precision (approximately 15 cm) and great reliability in complex indoor environments, characterized by noises like reflection from walls or the presence of metallic objects in indoor environments. Each tag is made up of movement detectors for instantaneous activation, LEDs for identification and buttons for executing particular operations. The main characteristics of tags are:
  - *Precise localization*: the tag transmits RFID-UWB radio pulses, used by the localization system for defining the tag position within 15 cm. The precision of the system is also maintained in complex indoor environments thanks to RFID-UWB technology. In this way it is possible to obtain accurate information on 3D positions even when the tag is detected by only two sensors;
  - *Bidirectional communication*: tags use a dual-radio system in addition to the mono-directional RFID-UWB radio communication, used for the spatial detection. The capacity of bidirectional communication allows the system to dynamically manage the update rate of tags, control of LEDs and battery status;
  - *Flexible update rate*: the software platform allows the update rate of tags to be varied. If a tag moves quickly, it can have high upgrading for more precise localization; instead, if it moves slowly the update rate could be reduced in order to save the battery. When the tag is at rest, it is put into energy saving mode thanks to a built-in motion sensor that allows restart in case of movement;
  - *Interactivebuttons*: slim tags have two buttons (while compact tags have only one button) to allow context-sensitive inputs in systems requiring interactivity. The applica-

tions can use tag localization to work according to the events. The application can send feedback to the user through LEDs or acoustic signals;

- *Resistant and suitable*: tags are resistant in critical industrial environments, since they can withstand dust and water. They can also be installed in mechanical and electronic instrumentation safely;

- *Battery life:* the techniques of low-consumption and power management affect the duration of the battery. In a typical application, in which a tag is used to identify an operator every 3 sec, the battery has an average duration of four years.

Figure 5 shows an example of compact tags (on the left) and slim tags (on the right).

Figure 5. Compact tags (on the left) and slim tags (on the right), used in the experimental application (courtesy of Ubisense Group plc)

- *Software Location Platform* is used to control and calibrate the system, to manage the locations of data generated by tags and received by sensors and to analyse, communicate and inform users on the data system. The software platform is made up of the *Location Engine Calibration* and *Location Platform*.

- *Location Platform* is a software that collects and processes data from sensors and tags, viewable thanks to a graphical interface. In this way, it is possible to obtain 2D and 3D maps of the environment and detected assets. The collected data can be sent to other systems for further analysis and stored within the platform to act as a database.

- *Location EngineCalibration* (*LEC*) allows the sensors to be set, calibrated, and configured in cells using a graphical user interface. It is designed to allow the simple coordination of data from sensors and tags in order to be integrated in other applications. The Location Engine is the base component of the software platform since it allows the creation and loading of maps, single cell creation and setup of tags and sensors (deciding master and slave sensors), and the calibration of the system sensitivity (fixing the "noise threshold").

- The Location Engine supports several algorithms to determine tag position through sensor measurements. Each algorithm has a set of parameters that regulate tags behaviour. These parameters are called *filters* and can be applied to a single tag or a group of tags. The Location Engine presents one algorithm without a filter and another four filtered algorithms:

- *No filtering algorithm*: in this configuration, no filters are applied. This means that the position is evaluated only by measuring AOA and TDOA at a specific moment. In this way, any previous data is not processed and the path and speed of movements are not considered. Not using filters does not allow optimal measurements to be obtained.
- Filtered algorithms try to interpret tag movements to predict their positions during further measurements. Information coming from AOA and TDOA techniques is analysed and compared with the expected position that will be used in further measurement. The filter can eliminate measurements that can be deteriorated by reflections or disturbed by external noises. In order to do so, it is necessary to identify a movement pattern for the filter that defines the limitations to which the measured object has to be subjected. The higher the number of applied limitations, the better the robustness of the measurement. The filtered algorithms are presented below:
- *Information filter*: the tag can move along three directions but, if it is not seen for a period, the movement pattern assumes that it is continuing to move according to the last speed value and along the last detected direction. This algorithm is used for assets that move with predictable speed and without direction limitations;
- *Fixed height information filter*: the tag is free to move horizontally, but the vertical movements have to remain close to a predetermined threshold height. In this case, if contact with the tag is lost, it is assumed that it continues to move with equal speed along the horizontal direction, remaining close to the vertical predetermined height. Like the previous algorithm, the level of uncertainty of the location increases with the time. This algorithm is mainly used for vehicles moving at high speed and in two directions;
- *Static information filter*: the tag is free to move in three directions. If the tag is not detected, its position is identified with the last one and the level of uncertainty of localization increases with the time. This algorithm is used for assets that do not normally move or move in an unpredictable way, such as operators. The algorithm does not have any spatial limitations, allowing the detection of 3D movements (for example the movement of people climbing the stairs);
- *Static fixed height information filter:* the tag is free to move horizontally, but it is limited to the vertical direction. If the tag is not seen, it is assumed that its position is the last one detected and the height is close to the prefixed limit. This algorithm is used for targets that do not normally move or move in unpredictable way. Because of its vertical limitation, it is used for vehicles, tools, and people that move in two dimensions.

The parameters that can be regulated by the filtered algorithms are:

- *Handover stickiness*: indicates the tag's adherence to the cell in which it is located. It is measured indicating the maximum number of failed measurements of the tag's position before considering it out of the cell;
- *Handover minimum sensor count*: describes the minimum number of sensors belonging to the cell;

- *Low support reset count*: defines the time in which the tag can be seen with low support modality (the situation in which the measurements rejected by the filter are more than the valid ones) before the reset of the filter;
- *Min reset measurements*: indicates the minimum number of support measurements before the reset of the filter;
- *Tag power class*: the filter can validate the tag's position based on the level of signal power received by each sensor. The filter has to recognize the type of tag that sends the signal, so as to interpret the received power correctly. The value 0 disables the function, value 1 indicates a compact standard tag and value 2 indicates a tag with amplified signal power;
- *Static distance*: describes the minimum distance travelled by a tag compared with the last one;
- *Static alpha*: defines the fraction (0.0 – 0.1) of the current measurement used by the filter when the tag is considered stable. The tag position is computed as follows:
- (alpha * current position) + (1.0 – alpha) * (last position)
- If alpha is close to 0.0, the movement of the tag will be significantly damped;
- *Max position variance*: describes the maximum variation in estimating the position;
- *Max valid position variance*: identifies the maximum variance in estimating the position. This value has to be less than or equal to the "max position variance". The difference between these two parameters is that if the uncertainty is higher than the max position variance, the forecast of the next localization does not change; while if the variance is higher than the max valid position variance, the filter will continue to track the position, but this measurement is not considered valid.

No-static algorithms can regulate other parameters such as:

- *Max velocity*: identifies the maximum velocity at which the object can move;
- *Horizontal velocity standard deviation*: the filter operates with a model of movement in which the tag velocity is considered constant. This parameter indicates the rate of velocity increase in X and Y as the time varies;
- *Vertical velocity standard deviation*: similar to the horizontal velocity standard deviation, but for the vertical velocity;
- *Vertical position standard deviation* (only for the filter with prefixed height): although the height is fixed, this parameter allows the tag to be varied along the vertical movement. If the value of this parameter is 0, the tag will only be detected in two dimensions;
- *Tag height above cell floor* (only for filter with prefixed height): fixes the value of height Z where the tag should always be.

Static algorithms can also regulate another parameter:

- *Horizontal position standard deviation*: the filter operates according to the movement pattern in which the tag's position is considered constant. The uncertainty of the tag's position increases with the time although the tag's forecasting continues to be in the last position. This parameter identifies the increasing rate of standard deviation of position in X and Y as the time varies.

It is possible to underline the difference between static and dynamic filtering algorithms. In the case of dynamic filter, there are long straight lines that identify the moments in which the sensors lose track of the tag and find it again few moments later. Consequently, the measurement's accuracy is low, mainly in the computing of distances travelled, which may be compromised. In the case of static filter, the traced path is very close to the real one, without straight lines, since the tag is always under control. Figure 6 shows an example of tracking of the same path using a dynamic filtering algorithm (on the left) and a static filtering algorithm (on the right).

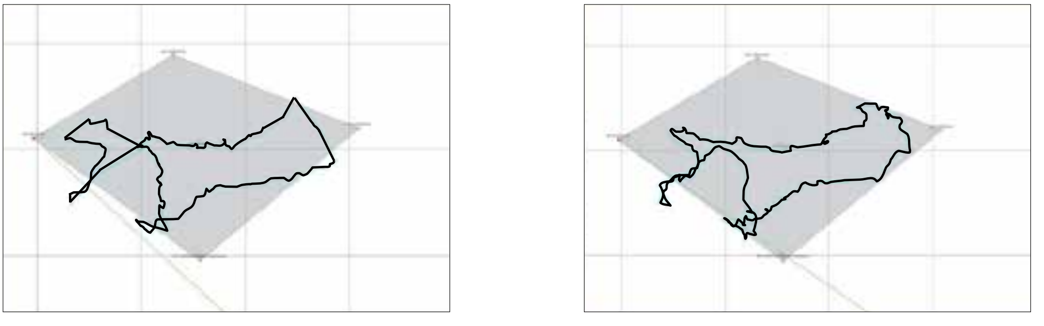

Figure 6. Path traced with dynamic filtering algorithm (on the left) and static filtering algorithm (on the right)

3.2. Installation and calibration of the system

The authors decided to install an IPS experimental system based on RFID-UWB technology in the Laboratory of Manufacturing System of Bologna University that, thanks to the presence of walls, machinery and metal objects, could be representative of a real industrial application.

Figure 7 shows the 2D map (on the left) and the 3D map (on the right) (obtained by LEC platform) of the laboratory, where the white squares indicate the position of the sensors. The optimal configuration needs sensors to be installed in the four corners of the building, but in actual fact, because of the presence of obstacles in the corners of the laboratory, the sensors are installed according to a rhombus distribution, able to guarantee total coverage of the area.

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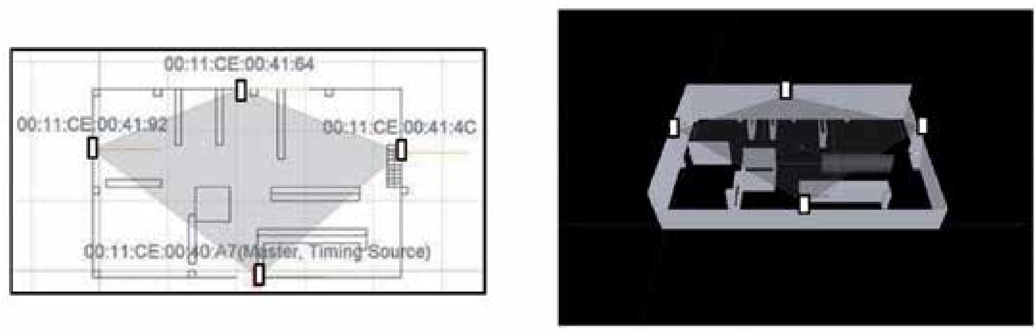

Figure 7. Map (on the left) and map (on the right) of the indoor environment considered in the application

The coordinates of sensors are presented in Table 1:

Sensors name	X [m]	Y [m]	Z [m]
00:11:CE:00:40:A7 (master)	15.618	-0.582	4.336
00:11:CE:00:41:4C (slave)	30.868	11.945	4.545
00:11:CE:00:41:64 (slave)	13.085	18.898	4.336
00:11:CE:00:41:92 (slave)	-0.308	11.039	4.651
STA (reference point)	15.409	10.833	2.100

Table 1. Coordinates of sensors

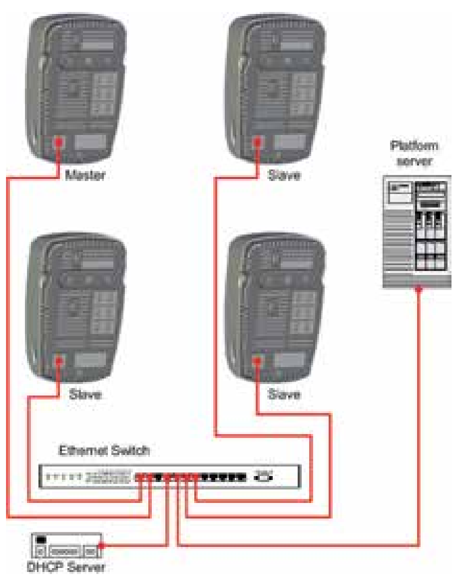

Figure 8. Connection of sensors with the system

The sensors have to be located as close as possible to the ceiling of the building to guarantee maximum coverage of the space and their angulation has to be directed towards the centre of the building. The sensors are grouped into rectangular cells, where they are connected to the switch POE that guarantees the power that is in turn linked with the PC (Figure 8). Each cell is characterized by a main sensor (master) that coordinates the activities of the other sensors (slave) and communicates with the tags. The master sensor has to be connected with the slaves by CAT-5 cables (Figure 9), in order to ensure the time synchronization. When the connection is made, the Location Engine Configurator is set to "Running" mode and the system is ready to work.

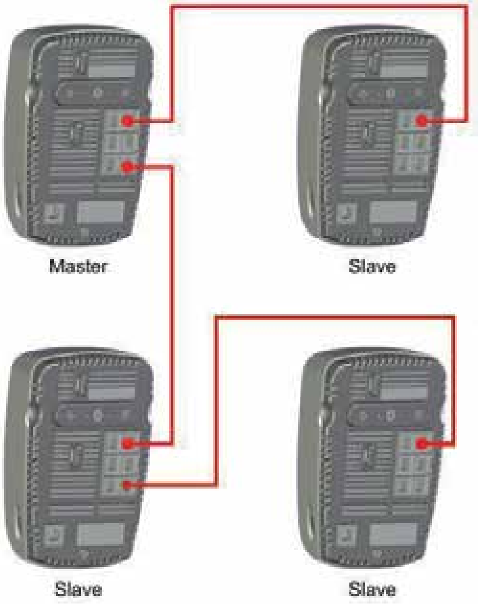

Figure 9. Connection between master and slave sensors

The threshold level of the "background noise" has to be decided, so to allow the system to distinguish valid signals from environmental noises. In order to calibrate the sensors, the power level detected by them is measured, verifying that the "background noise" remains below the threshold level. After that, it is possible to calibrate the sensor orientation. The sensors are oriented to a known tag, taken as reference. Figure 10 shows the sensor calibration through AOA. The green lines connect each sensor to the detected position of the tag.

In order to activate the localization through TDOA, it is necessary to calibrate cables that synchronize all the slave sensors with the master. When the cable calibration is completed, blue strips are added to the green lines, one for each pair of sensors. In absence of obstacles, assets, and reflection phenomena, the blue lines are straight; in actual fact, they are curved lines, with increased bending as interferences and noises increase (Figure 11).

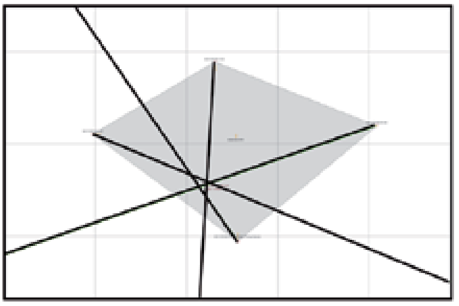

Figure 10. Calibration of sensors

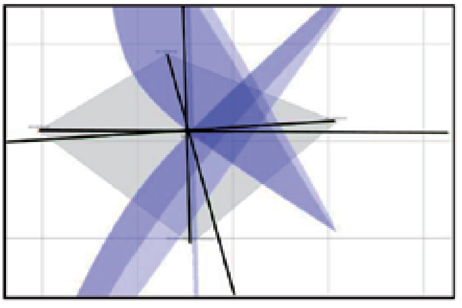

Figure 11. Calibration of cables

The system has to be connected with the layout of the environment to be monitored. A map of the laboratory has to be created, according to the external and internal walls, the columns and any other architecture present in the laboratory (Figure 12).

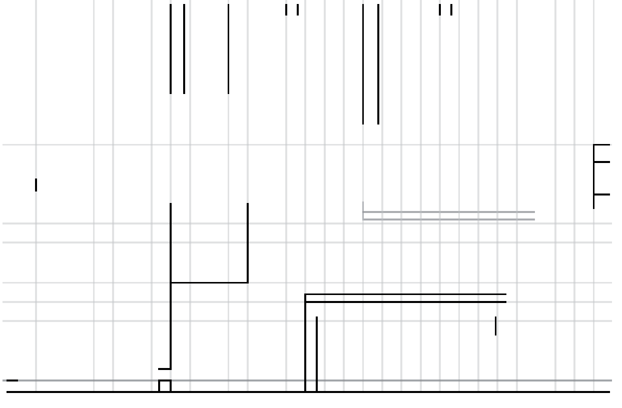

Figure 12. Map of the area controlled by the proposed system

When the map is loaded into the system, the coordinates of the sensors' position and some reference points within the area to be monitored have to be determined. A corner of the building is identified as the axis origin and is indicated by (0;0;0); the other corners will be identified with (X;0;0) and (0;Y;0) where X and Y are the length of the building sides. The level of floor is set as Z=0 so to use the 3D localization capacity of the system. In order to connect the position of the sensors with the laboratory's corner coordinates, the object localizations have to be calibrated, using known points as references. After that, the software will provide a 3D image of the area to be monitored.

In order to complete the calibration and verify the absence of errors, it is important to test the system, moving a tag within the area and ensuring that the sensors work correctly and that all necessary data is displayed.

3.3. Experimental evidence

The experimental research consists of several tests, static and dynamic.

The static tests consist of the identification of different points (to which tags are applied) within the area to be monitored. The sensors have to detect the coordinates of the tags to compare the estimated and detected coordinates of every point.

The dynamic tests consist of the application of a tag to an operator that goes around the monitored area. The operator follows prefixed paths, and the route and distance travelled by him are compared with the estimated values, measured in advance.

3.3.1. Static tests

In order to undertake the accuracy and precision of the proposed RFID-UWB system, the first test is the measurement of known point coordinates through a laser. 16 points within the monitored area, chosen according to the characteristics of visibility, proximity to metal objects and position, are identified.

The static tests are performed according to the variation of some tag parameters, such as:

- Filter used (*No-filter, Information Filter, Fixed Height Information Filter, Static Information Filter, Static Fixed Height Information Filter*);
- Update each four time slot;
- Frequency: 37 Hz;
- All tests are performed by putting the asset on a support 0.5 m high, except point 13, which is placed 2 m high.

Figure 13 shows the considered 16 points represented in the map of the laboratory.

For each point, four tests are performed in order to understand the average error between the estimated and detected coordinates.

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Test 1

- Filter: *Static Fixed Height Information Filter;*
- Update each four time slot;
- Frequency: 37 Hz.

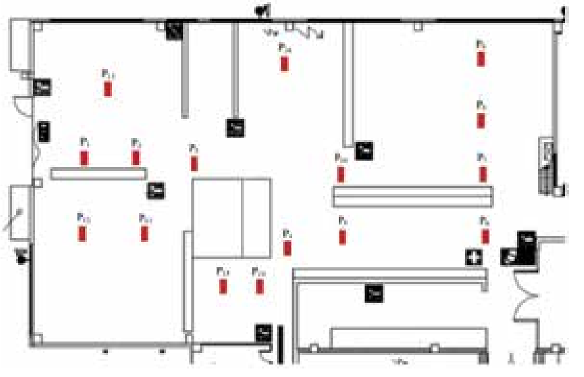

Figure 13. Reference points for static tests

Table 2 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.1007	11.0112	0.2930
2	7.976	10.991	7.6250	10.7717	0.4138
3	11.389	11.207	11.5024	11.0014	0.2347
4	15.693	7.138	15.9791	7.2085	0.2946
5	18.627	7.138	18.6374	7.1973	0.0602
6	26.39	7.138	26.1077	7.4651	0.4320
7	26.39	11.204	26.5720	10.8224	0.4227
8	26.39	14.028	26.2713	13.4417	0.5980
9	26.39	16.6	29.1303	18.6123	3.3998
10	19.347	11.207	19.5315	10.5318	0.6999
11	8.17	7.113	7.8618	7.2394	0.3330
12	3.415	7.05	3.7401	8.0534	1.0548
13	3.399	15.739	3.3871	14.3100	1.4289
14	16.397	2.748	14.9795	3.2646	1.5085
15	11.367	2.748	11.7532	4.3628	1.6602
16	15.637	15.187	15.8656	14.9317	0.3426

Table 2. Analysis of static *Test 1*

The average error of *Test 1* is 0.8236 m.

The points situated in the best positions (excluding points 9, 12, 13, 14 and 15) are located with high accuracy and present an average error of 37 cm. The worst result of point 9 is due to the presence of numerous obstacles around the considered area that make the tag visible to only one sensor. The same causes also influence the detection of points 12, 13, 14 and 15, although with lower impact.

Test 2

- Filter: any filter applied;
- Update each four time slot;
- Frequency: 37 Hz.

Table 3 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	5.8597	10.9974	0.1203
2	7.976	10.991	7.9914	11.1263	0.1362
3	11.389	11.207	11.4886	11.1252	0.1289
4	15.693	7.138	15.8387	7.2311	0.1729
5	18.627	7.138	18.4915	7.0736	0.1499
6	26.39	7.138	21.3617	3.6867	6.0987
7	26.39	11.204	28.4824	11.4226	2.1038
8	26.39	14.028	25.6281	13.6126	0.8676
9	26.39	16.6	28.6270	9.2454	7.6872
10	19.347	11.207	19.4776	10.3303	0.8863
11	8.17	7.113	7.7177	7.6014	0.6656
12	3.415	7.05	6.5425	5.6330	3.4335
13	3.399	15.739	3.5185	14.9626	0.7855
14	16.397	2.748	14.7514	2.9406	1.6567
15	11.367	2.748	10.9230	4.2645	1.5800
16	15.637	15.187	15.7053	15.1101	0.1028

Table 3. Analysis of static *Test 2*

The average error of *Test 2* is 1.661 m.

The absence of filters means that the oscillations of the tag positions are not damped. This leads to the worst result of all the tests. It is possible to note that the easily reachable and visible points present low error values, while for the most critical points the system performance is worse, even reaching high error values (in the order of metres).

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Test 3

- Filter: *Static Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz.

Table 4 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.0484	10.8824	0.3203
2	7.976	10.991	7.4876	11.0006	0.4884
3	11.389	11.207	11.3885	10.9646	0.2423
4	15.693	7.138	15.9165	6.9975	0.2640
5	18.627	7.138	18.6268	7.0524	0.0855
6	26.39	7.138	21.5961	4.4598	5.4912
7	26.39	11.204	26.5539	10.9868	0.2720
8	26.39	14.028	25.7937	13.2303	0.9959
9	26.39	16.6	22.0670	9.2817	8.4996
10	19.347	11.207	20.3456	10.0280	1.5450
11	8.17	7.113	7.1760	7.0652	0.9950
12	3.415	7.05	3.4986	7.7185	0.6737
13	3.399	15.739	3.1959	14.0444	1.7067
14	16.397	2.7481	14.9009	2.8403	1.4989
15	11.367	2.7481	12.5534	3.8802	1.6399
16	15.637	15.187	15.8690	14.8410	0.4165

Table 4. Analysis of static *Test 3*

The average error of *Test 3* is 1.5709 m.

Like the other two tests, points 6 and 9 present largely incorrect values, because of the condition of the area in which they are located. The other values are in line with the estimated measurements.

Test 4

- Filter: *Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz.

Table 5 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [m]
1	5.826	11.113	6.1134	10.8474	0.3913
2	7.976	10.991	7.4098	11.1165	0.5798
3	11.389	11.207	11.4637	11.0003	0.2197
4	15.693	7.138	15.7641	7.0616	0.1043
5	18.627	7.138	18.7090	7.1121	0.0860
6	26.39	7.138	20.3066	4.3934	6.6738
7	26.39	11.204	26.5290	10.9065	0.3283
8	26.39	14.028	22.7547	9.2591	5.9963
9	26.39	16.6	27.3837	17.1635	1.1424
10	19.347	11.207	19.5325	10.7986	0.4484
11	8.17	7.113	5.5139	7.2697	2.6607
12	3.415	7.05	4.0360	7.3234	0.6786
13	3.399	15.739	3.4861	14.5849	1.1573
14	16.397	2.7481	14.9694	3.0857	1.4668
15	11.367	2.7481	11.8527	3.4522	0.8554
16	15.637	15.187	15.7347	15.1152	0.1212

Table 5. Analysis of static *Test 4*

The average error of *Test 4* is 1.4319 m.

In this case, the results are better than *Test 2* and *Test 3*, but the problems regarding the presence of obstacles in the area to be monitored, noted during the other tests, remain.

From a comparison between the four static tests (Table 6), it is possible to note that the best algorithm in terms of the lowest average error between estimated and detected tag position is *Test 1* that uses a *Static Fixed Height Information Filter*.

Filter used	Average error [m]
Static Fixed Height Information Filter	0.8236
Any filter applied	1.661
Static Information Filter	1.5709
Information Filter	1.4319

Table 6. Comparison between the average errors of static tests

3.3.2. *Dynamic tests*

Dynamic tests are performed by applying a tag to an operator that goes around the laboratory following prefixed paths. The length of these paths, measured in advance, is compared with the real distance travelled by the operator. In this way, it is possible to see the precision of each known point and test the capacity of the system to reconstruct the trajectory.

The first part of the paragraph presents the results obtained by dynamic tests, using a static filter (*Static Information Filter*), while the second part shows the same results using a dynamic filter (*Information Filter*), underlining the differences between them.

3.3.2.1. Dynamic tests using Static Information Filter

Four tests are performed, according to the following parameters:

- Filter: *Static Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/sec;
- Velocity of tag: 2 m/sec at a constant height of 1.5 m.

In order to cover the whole interested area, several proof paths are decided and measured in advance.

Test 1

The path is 28.8 m long: the first part is made up of an area with good coverage by sensors without obstacles, while in the second part the operator has to cross an area with numerous obstacles and metallic materials. Figure 14 shows the estimated path (Figure 14a) and the detected path travelled by the operator, obtained using LEC software (Figure 14b).

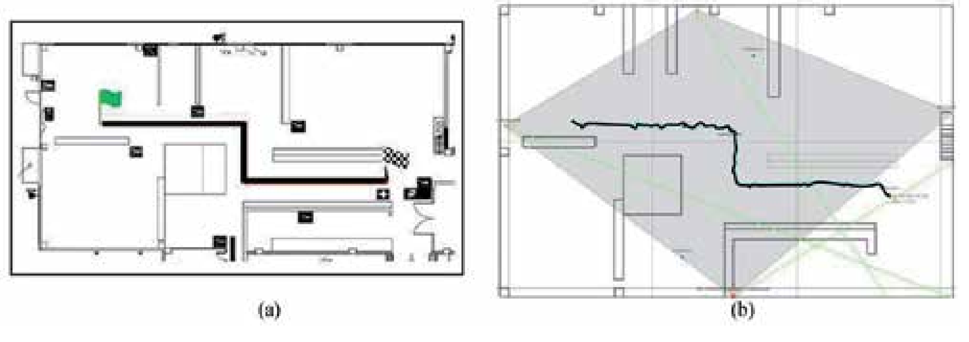

Figure 14. a. Estimated path of dynamic *Test 1* b. Detected path of dynamic *Test 1*

Table 7 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
28.8	31.22	2.421	8.408

Table 7. Synthesis of dynamic *Test 1*

Test 2

The path is 30 m long and it travels around a metallic shelf in the centre of the laboratory. Figure 15 shows the estimated path (Figure 15a) and the detected path travelled by the operator, obtained using LEC software (Figure 15b). As can be seen from Figure 15b, the blue-sky line representing the path, presents some noises, due to the momentary loss of the signal.

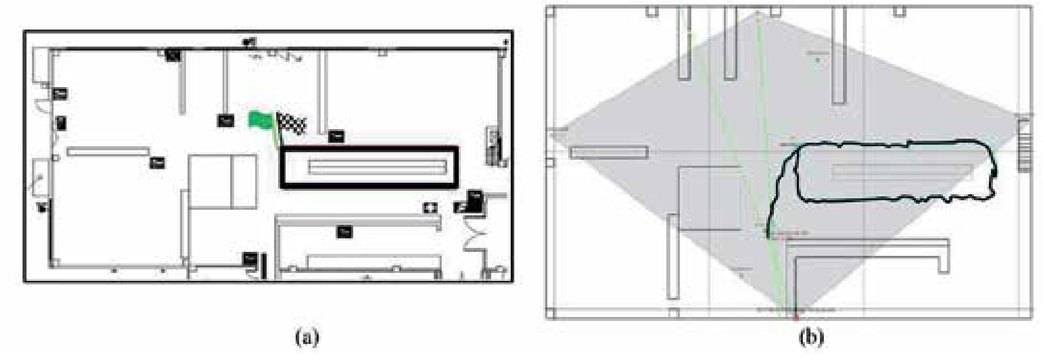

Figure 15. a. Estimated path of dynamic *Test 2* b. Detected path of dynamic *Test 2*

Table 8 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
30	30.45	0.4594	1.5315

Table 8. Synthesis of dynamic *Test 2*

Test 3

The path is 23.5 m long: the first part is made up of an area with low coverage, because of the presence of walls, shelves and several metallic machines and objects. In the final part, the path is made up of an area surrounded by machineries and this makes the correct localization of the tag difficult. Figure 16 shows the estimated path (Figure 16a) and the detected path travelled by the operator, obtained using LEC software (Figure 16b).

Table 9 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
23.5	24.02	0.5199	2.2125

Table 9. Synthesis of dynamic *Test 3*

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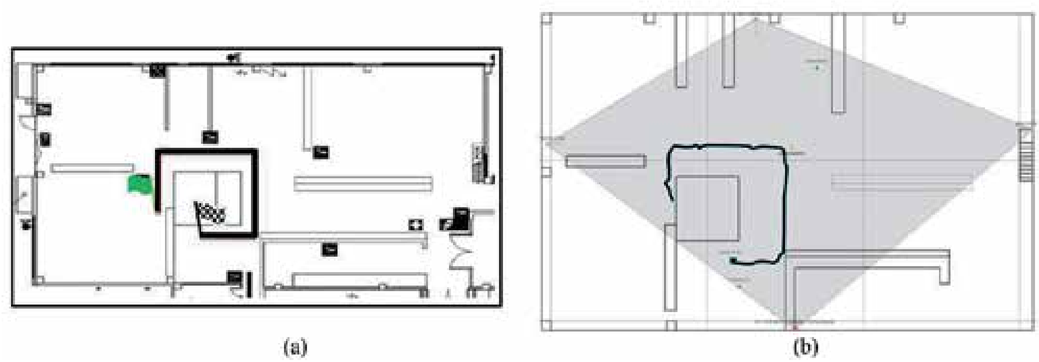

Figure 16. a. Estimated path of dynamic *Test 3* b. Detected path of dynamic *Test 3*

Test 4

The path is 11.5 m long. It is situated in a complex environment, characterized by the presence of walls and several machines that strongly hinder correct signal reception by the sensors. Indeed, it is possible to observe the irregular trend that causes problems in the correct evaluation of the distance travelled. Figure 17 shows the estimated path (Figure 17a) and the detected path travelled by the operator, obtained using LEC software (Figure 17b).

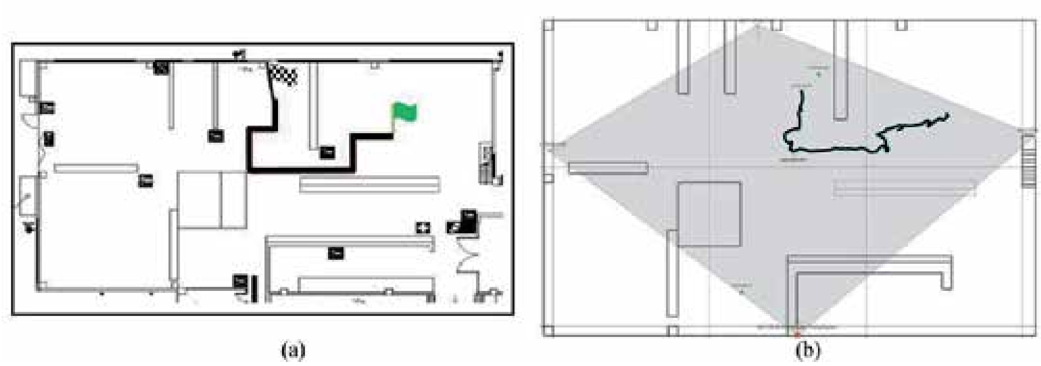

Figure 17. a. Estimated path of dynamic *Test 4* b. Detected path of dynamic *Test 4*

Table 10 shows the detected and measured distances and the difference between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
11.5	14.42	2.9285	25.465

Table 10. Synthesis of dynamic *Test 4*

3.3.2.2. Dynamic tests with Information Filter

The authors decide to re-apply the same tests applying a dynamic filter, called *Information Filter*, to the algorithm, in order to compare the results with those obtained by using a static filter. If the sensors lose the signal, the static filter maintains the last detected position and updates it when a valid signal arrives. The dynamic filter, instead, stores the velocity and the direction of the tag moment all times and, in case of absence of valid signals, it assumes that the target continues to move in the same direction and at the same velocity as the last measurement. The use of a dynamic filter results in lower performance of operations for the reconstruction of trajectories, since the paths do not reflect the real tag movements.

The tests are performed according to the same parameters as the dynamic tests with a static filter:

- Filter: *Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/sec;
- Velocity of tag: 2 m/sec at a constant height of 1.5m.

The paths are the same as the dynamic tests with static filter.

Test 1

The application of a dynamic filter does not heavily modify the results, except for the central stretch and the last part of the path, since it is made up of metallic materials. Figure 18 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 18a) and dynamic filter (Figure 18b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.

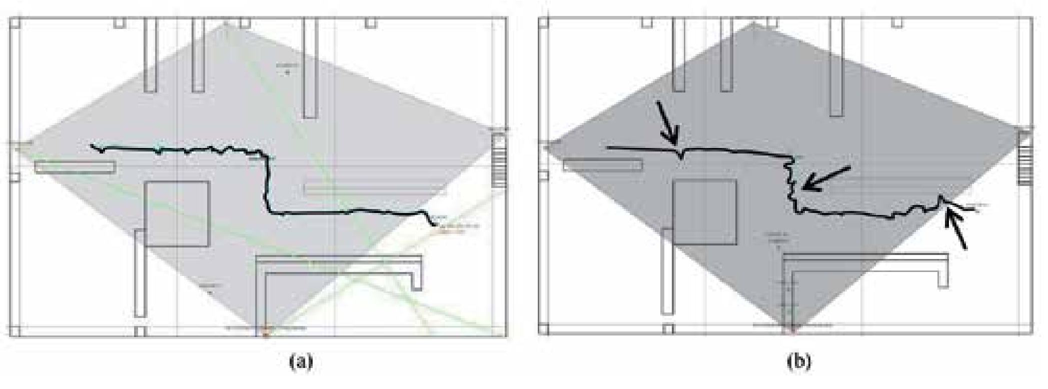

Figure 18. a. Path travelled using static filter b. Path travelled using dynamic filter

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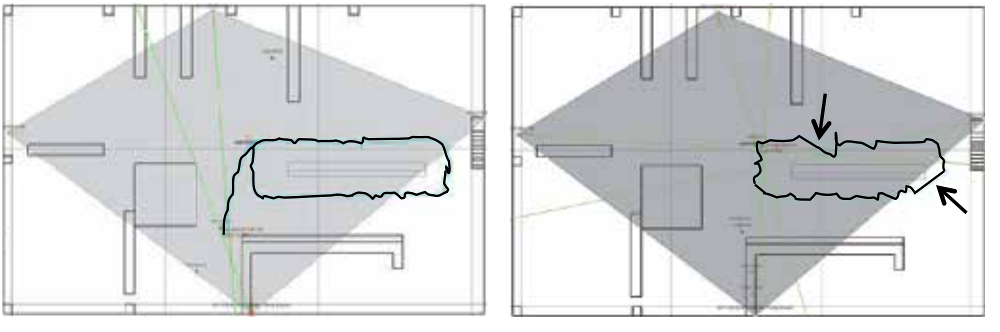
The path travelled by an operator in the laboratory using a dynamic filter, presents more noise than that travelled using a static filter. It is possible to note some peaks along the path, due to loss of signal. Indeed the *Information Filter* allows the target to move along the three dimensions, but, if it is not seen for a period, the system assumes that it is moving along the same direction and at the same velocity.

Test 2

In this case, the path is strongly modified at the point where the signal is lost. In particular, it is possible to observe the formation of straight lines that indicate that sensors were not able to detect the tag presence for some seconds. In this way, the last trajectory is maintained, but it does not reflect the real path travelled by the target. Figure 19 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 19a) and dynamic filter (Figure 19b). The arrows show straight lines formed because of the loss of signal by the sensors, unlike the case of a static filter.

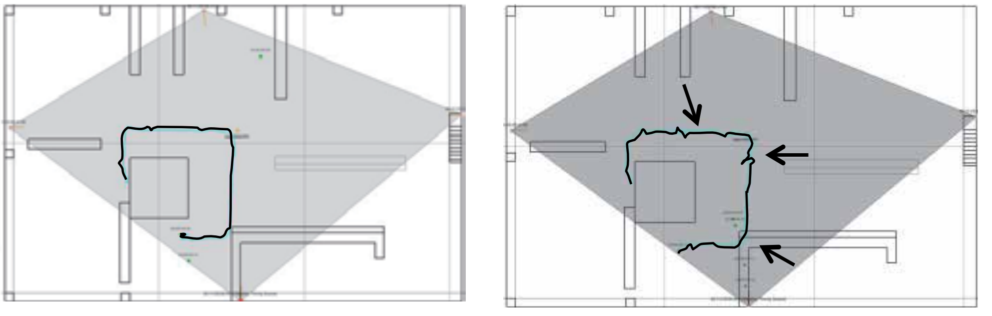


(a) (b)

Figure 19. a. Path travelled using static filter b. Path travelled using dynamic filter

Test 3

In this case, the errors in the traceability of the path are less evident than in the last case, but it is possible to note that the line appears more indented. This is an indication of more noises during localization. Moreover, in the final part, the trace overlaps with a wall, underlining the limits of the localization with the dynamic filter. Figure 20 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 20a) and dynamic filter (Figure 20b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.

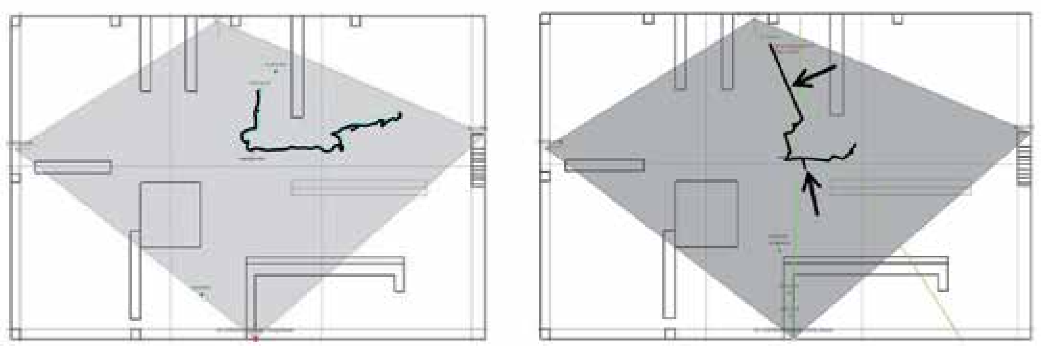


(a) (b)

Figure 20. a. Path travelled using static filter b. Path travelled using dynamic filter

Test 4

In this case, the errors in the traceability of the path are evident, because of the critical environment in which the path is travelled. In the middle of the path the signal is lost and found again only in the proximity of the final part of the path. This leads to the creation of a straight line that does not reflect the real movement of the tag. Figure 21 shows the comparison between the maps obtained using LEC software, in the case of static (Figure 21a) and dynamic filter (Figure 21b). The arrows show the main differences between the paths travelled using a static and a dynamic filter.



(a) (b)

Figure 21. a. Path travelled using static filter b. Path travelled using dynamic filter

The algorithm using a static filter provides better results than that using the dynamic filter. A comparisons between the two algorithms show that if the sensors lose the tag signals for a period, the system assumes that the tags continue to move according to the last velocity value and along the last direction of movement. The greater the moment of no-detection of tag's position, the higher the inaccuracy of the system, causing a distortion of the path.

3.4. RFID technology applied to packaging system

RFID technology is introduced in the packaging sector due to the logistics advantages regarding the utilization of automatic identification systems. This introduction mainly focuses on the secondary and tertiary packaging levels because the utilization in the item level (product identification) has been difficult to justify in economic terms [30]. Specifically, 250-300 millions of tags were used in 2006 in the tertiary level [31]. Furthermore, Thoroe et al. [32] have predicted that in 2016 there will be 450 times more RFID tags in use than today. Therefore, a rapid increase in RFID tag consumption is expected in the packaging sector.

Technological developments in recent years, along with a reduction in tag price and emerging standards have facilitated trials and rollouts of RFID technology in packaging. A study conducted by IDTechEx Limited [33] stated that the main benefits of RFID technology in packaging are better service and lower costs.

Packaging incorporating RFID technology is usually referred to as *smart packaging* (called also *active* or *intelligent packaging*) and it is commonly used to describe packaging with different types of value-adding technologies, for example placing in the package a smart label or tag. The term smart packaging was used by Yam [34] in 1999 to emphasize the role of packaging as an intelligent messenger or an information link. According to the Smart Packaging Journal [35], smart packaging is described as *packaging that employs features of high added value that enhances the functionality of the product* and its core is responsive features. These high-value features have a variety of characteristics, but are mainly made up of mechanical or electronic technology features such as mechanical medicines, dispenser of packaging tagged with electronic devices like RFID technology. Smart packaging is often used to refer to electronic responsive features where data is electronically sensed on the package from a distance, using an automatic identification system as the RFID technology. Schilthuizen [36] pointed out that identification and sensor technology enable intelligent functions in packaging.

Usually packages – and the products contained within them – are traced with systems obtained through asynchronous fulfilment of doorways by materials. In such cases, the tracking is totally manual, executed by operators. These manual activities could be eliminated or replaced by an automated identification activity, using an RFID system. The application of RFID to packaging allows more frequent and automated identification of packages (e.g. pallets, cases, and items) increasing the accuracy of the system, reducing the labour and time needed to perform the identification of packages and enabling near real-time visibility, which in turn facilities the coordination of activities within and between processes. The costs of RFID technology in packaging and potential benefits will vary, according to the packaging level that is tagged. Figure 22 (modified version of [25]) illustrates the influence that tagging different packaging levels has on the retail supply chain processes.

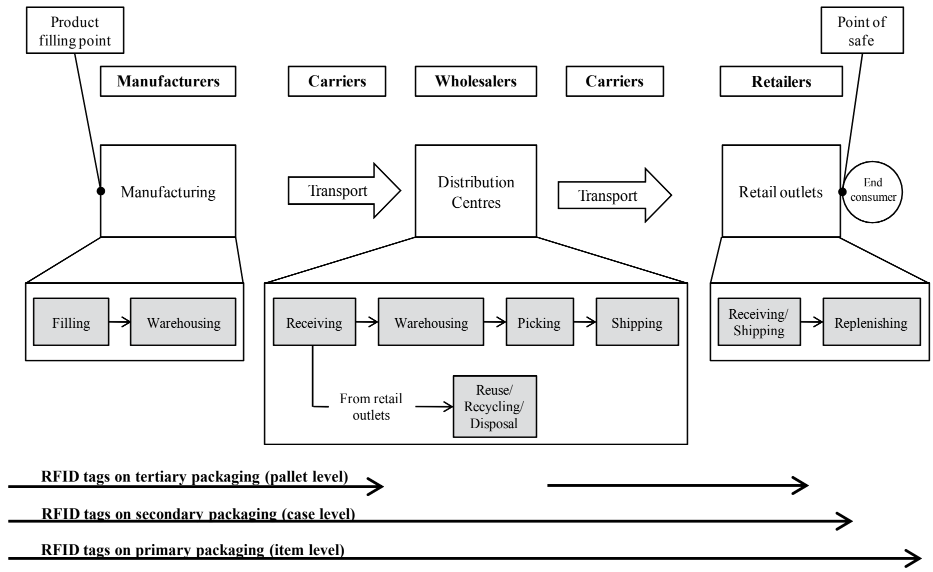


Figure 22. The influence of tagging different packaging levels along the supply chain (modified version of [25])

As can be noted in Figure 22, RFID tags on tertiary packaging may be used from the filling to the storing process. Furthermore, the tags on tertiary packaging may be used from the shipping process of the distribution centre to the receiving and shipping process of the retail outlet. RFID tags on secondary packaging could be used further downstream in the supply chain than tagged tertiary packaging, i.e. from the filling process and all the way to the replenishing process. Irrespective of the activities within the replenishment processes, tagging of primary packaging may be used in the whole supply chain, from the point of filling by the manufacturer to the point of sale in the retail outlet. Tagging of primary and secondary packaging could also provide opportunities beyond the point of sale in retail outlets e.g. recycling, reusing, and post-sales service and support. Although tagging on the primary packaging level will bring about the greatest level of benefits for the retail supply chain, tagging on secondary and tertiary packaging levels could provide valuable benefits for the supply chain. The model presented in Figure 22 indicates that a manufacturer who applies the tags to packaging can gain direct benefits from primary and secondary packaging tagging. According to [25], the average time to pick an order decreases by roughly 25% when RFID technology is used in secondary packaging. This means that the workforce conducting the picking activity, which is the core and the most labour-intensive activity in distribution centres could be reduced by approximately 25%. Hellström [25] also stated that the ability to automatically generate orders by capturing the inventory levels through tagging of primary packaging could reduce out-of-stock situations by approximately 50%.

Figure 23 shows the traceability of a primary package patterns within a manufacturing company (in particular in an assembly station) using the RFID-UWB system.

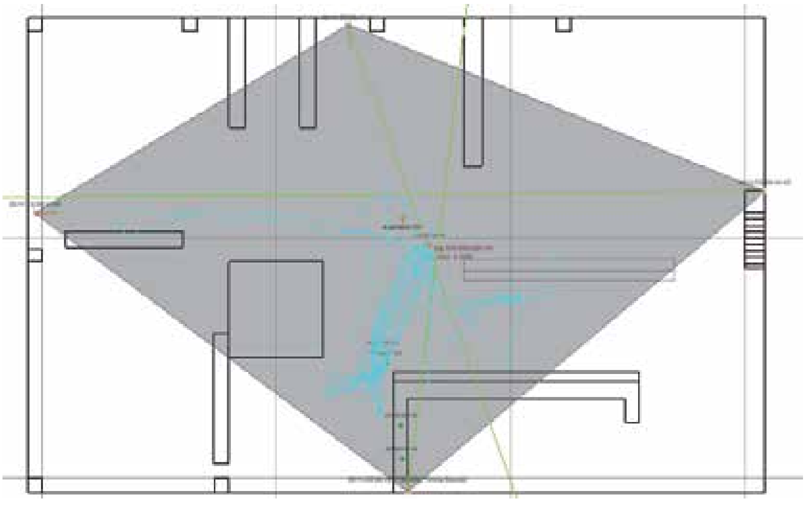


Figure 23. Traceability of a package with RFID-UWB system (Spaghetti Chart)

The traditional approach provides the well known *Spaghetti Chart* (manually realized). In addition, the data is approximate and does not provide precise values. In order to overcome the difficulty in analysing data from a traditional tracking method, Real Time Location System is perfect for the traceability of goods.

The framework on RFID and packaging shows the importance of tracing packages since several benefits can be achieved (e.g. reduction of costs and time, increase of efficiency and effectiveness, accuracy of the activities along the supply chain, security of the products, etc.). The RFID-UWB system presented in the chapter is perfectly aligned with the problem of package traceability.

3.5. Results and discussion

The results obtained during the static tests show that the average error between the estimated and the detected measurements is approximately 1 m. However, it is important to consider the non-optimal installation of the sensors. In fact, the most suitable arrangement to obtain the maximum coverage of the area is obtained by placing the sensors at the corners of the area to be monitored. Because of the presence of obstacles and metallic objects, the authors have had to opt for an alternative solution, placing each sensor in the middle of each wall. This causes the incomplete coverage of the monitored area.

Despite this limitation, the authors have chosen to include in the tests some points located outside the optimal coverage area. In these cases, the obtained accuracy is much lower than that obtained by points located where the coverage is maximum. For example, in some cases, there are errors of several meters, not compatible with the project needs and that affect the estimation of the average error that increases greatly. For this reason, these points are eliminated in the computing of the average error estimation, obtaining a considerable improvement in the accuracy, reaching an average error of 40 cm.

Regarding dynamic tests, the problems connected with the layout of the area are the same as the static ones. The authors have set the tests to simulate paths all around the area. Several critical points cannot be seen by the sensors. In particular, in some areas, the tag is seen only by one or two sensors, which results in inaccuracies in the traceability of the path travelled by the target.

Unlike the static tests, during the dynamic tests, it is necessary to control the typology of filters used. The results show that the best performance is obtained using a static (*Static Information Filter*), rather than a dynamic (*Information Filter*) filter, with an error of 5% between the estimated and the real distance travelled. If the sensors lose the signal and the filter is dynamic, the system continues to see the tag moving along the same direction and at the same velocity as the previous measurement. On the contrary, if the sensors do not see the signal and the filter is static, the system assumes that the position of tag is the same as the last measured. In conclusion, systems using dynamic filters provide less accurate results than systems using static filters.

In order to improve the performance of the system, several changes could be made:

- Install sensors according to the optimal layout, locating them in the corners of the monitored area, so to obtain greater coverage and eliminate points in which the intensity of the signal is low;
- Locate sensors as high as possible so that each point is in the line-of-sight of at least two sensors;
- Customize the filter configuration, finding a combination of parameters, better suited to the characteristics of the monitored area, and type of application (velocity of movement, static or dynamic detection, etc.) to be achieved.

4. Conclusion

In recent years, more and more companies are recognizing the importance of tracing logistics flows in indoor environments (e.g. factories, warehouses, production plants, etc.). One of the best ways to analyse internal flows of materials is the Real Time Location System (RTLS) and in particular the Indoor Positioning System (IPS). IPS is a process that continuously determines in real-time the position of something or someone in a physical space [9]. RFID-UWB (Radio Frequency IDentification-Ultra Wide Band) technology is the best method to use for tracing targets within a company, among others. The main advantages of RFID-UWB technology are that it requires a very low level of power and can be used in close proximity to other RF signals without causing or suffering interferences. At the same time, the signal passes easily through walls, equipment, and clothing [27-29] and more than one position can be tracked simultaneously. The use of RFID-UWB offers other advantages, such as no line-of-sight requirements, high accuracy and resolution and the possibility to trace multiple resources in real-time. Furthermore, RFID-UWB sensors are cheaper, and this makes the RFID-UWB positioning system a cost-effective solution.

In order to trace the position and to map the movements of targets (e.g. people, materials, products, vehicles, information), the authors have developed an experimental IPS system based on RFID-UWB technology in the Laboratory of Manufacturing System of Bologna University which, thanks to the presence of walls, machineries and metal objects, can represent a real industrial application. The system is made up of active tags – positioned on forklifts, packages, or operators –, sensors that receive the signal from tags, and a software platform that collects data in order to present, analyse and communicate information to the final customer. The tags, which must be positioned around the tested areas, transmit short pulses to the sensors, organized in rectangular cells. Each cell is characterized by a main sensor (*master*) that coordinates the activities of the other sensors (*slave*) and communicates to the tags the detected position within the cell. The software platform carries out the positioning calculations based on information by the sensors and then analyses the results.

The experimental research consists of several tests, static and dynamic. The results present useful conclusions in terms of system performance, accuracy, and measurement precision.

The static tests give good results in terms of average error (approximately 40 cm) between the estimated and detected position of all considered points. The dynamic tests are performed using filters that regulate the behaviour of tags. The filters can be static or dynamic. The tests performed by applying a static filter produce better results compared with dynamic filter. If the sensors lose the signal and the filter is dynamic, the system continues to see the tag moving along the same direction and at the same velocity as the last measurement. On the other hand, if the filter is static, the system assumes that the position of tag is the same as the last measured. In conclusion, systems using static filter provide more accurate results (with an average error between the estimated and detected real distance travelled of 5%) than systems using the dynamic filter.

RFID technology can be also applied to packaging. Although the use of RFID technology in packaging is still limited, more and more companies are recognizing the importance of tracing packaging products moving within indoor environments. During recent decades, the importance of packaging and its functions is been increasing. Packaging is considered an integral element of logistics systems and its main function is to protect and preserve products. More often companies have to transport and distribute particular goods (e.g. dangerous or explosive products) or expensive products, such as some kinds of medicines. Since companies need to reduce thefts, increase security, and reduce costs and time spent on the traceability of products, they are starting to use RFID in packaging.

Rapid advances in factory automation in general and packaging operations in particular have posed a challenge for engineering and technology programs for educating a qualified workforce to design, operate and maintain cutting edge techniques such as RFID systems [37]. The system proposed by the authors tries to play this challenge.

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Chapter 18

RFID Under Water: Technical Issues and Applications

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53934

1. Introduction

While RFID technology is nowadays very common in many commercial and industrial sectors, from items tracking to personal identification, few studies have dealt with the chance to use RFID systems in marine or fluvial environments for underwater monitoring operations. While the technical limitations for these scenarios can be in some cases insurmountable, ad-hoc studies have proven that in some cases RFID technology can work even under water.

RFID, like all radio technologies, in unsuitable to work in presence of water. Still water is not a natural conductor, but the presence of dissolved salts or other materials turns it into a partial conductor. Electromagnetic waves cannot travel through electrical conductors: this means that in most cases radio waves cannot be used to communicate under water. Anyway, studies have proven that the chance to transmit radio signals under water mainly depends on two factors: the conductivity of water and the frequency of the radio wave. While the conductivity of water is a factor that cannot be modified to increase the possibility to use radio waves under water, the only factor that can be modified to increase the performances is obviously the radio frequency.

This factor has already been employed when using the electromagnetic fields for the common radio transmissions: Very Low Frequency radio waves (VLF – 3-30kHz) have proven to be able to penetrate sea water to a depth up to 20 meters, while Extremely Low Frequency radio waves (ELF - 3-300Hz) can travel in sea water up to hundreds of meters. Anyway, these frequency bands present severe technical limitations. First of all, their extremely long wavelengths require antennas of very big dimensions: frequencies lower than 100Hz have wavelengths of thousands of kms, forcing to use antennas covering wide areas. Secondly, due to their narrow bandwidth, these frequencies can be used to transmit only text signals al slow data rates.

Some of these considerations can be applied also to RFID systems. First of all the use of active technologies is discouraged by many factors: at lower frequencies only passive systems can be found; moreover, the use of active systems is also impeded by the required dimensions of the antennas. Due to these limitations, only two RFID technologies can be employed for underwater applications: the High Frequency systems, operating at 13.56MHz and the Low Frequency systems, operating in the 125-134kHz band. The first solution (13.56MHz) still presents some severe limitations due to the reduction of the reading range: with common desktop antennas the reduction in the range is up to 80%, forcing to bring the transponder practically in contact with reader antenna. For the second solution (125-134kHz) the reduction is lower (around 30%) and the reading at a distance is still achievable. Laboratory tests proved that, with long-range antennas, a 50cm reading range is still achievable.

Both these two solutions can be anyway employed to set up RFID systems working in under water environments. Some solutions can already be found in some parts of the world [1]. USS Navy is testing the use of RFID technology for their applications based on the use of Unmanned Underwater Vehicles. Other applications foresee the use of RFID for the monitoring of underwater pipelines, with RFID transponders employed as markers to guarantee the integrity of the pipes. RFID has also been employed in aquariums to identify fishes, in the same way as Low Frequency RFID capsules are employed in cattle breeding. Finally RFID has been employed as a way to track the movement of pebbles on beaches, in order to analyse the impact of coastal erosion during sea storms.

The chapter will be subdivided in four main sections.

In the first section, the transmission of radio signals in water will be analysed. Details will be given on how the presence of water affects the electromagnetic fields, and examples of applications working in the VLF and ELF bands will be provided.

The second section will focus only on RFID. Technical data will be provided concerning the signal attenuation due to the presence of water. Some results will be given to prove the agreement of experimental data with the theoretical analysis.

In the third section the state of the art concerning under water RFID applications already existing all around the world will be provided. The few already tested applications will be described in detail.

Finally, in the fourth section some future applications based on this technology will be proposed.

2. Underwater radio signals

2.1. Water electric and magnetic properties

Water molecule is composed by two oxygen atoms and one hydrogen atom bonded together by a covalent bond. Oxygen has a negative charge, while the two hydrogen atoms have a positive charge: this means that the vertex of the molecule has a partial negative charge, while the two ends have a partial positive charge. A molecule with such a charge equilibrium is called electric dipole, and is characterized by its dipolar momentum μ, defined as the product between the absolute value of one of the two charges and the distance between them. This value indicates the tendency of a dipole to orientate under the effect of a uniform electric field.

While still water has a very low electrical conductivity, this value increases in presence of ionized molecules, in proportion to their concentration. When a salt is melt in still water, the single molecules are equally perfused in the whole liquid so that each single volume portion of the solution dissociates, creating many positive and negative ions that remain in the solution together with all the other molecules that aren't dissociated. This phenomenon is called electrolytic dissociation, and the so created solutions are called electrolytic solutions. These solutions can be crossed by an electrical current, in contraposition with still water that acts as a pure insulator.

2.2. Marine water

The chemical composition of marine water is influenced by several biological, chemical and physical factors: one simple example is the presence of rivers that add every day new chemical materials to the water. On the other side, other materials are removed by the action of organisms and due to erosion. Anyway, the most part of the salts dissolved in marine water remains almost constant due this continuous interchange phenomenon. The most important factors that influence the chemical composition of the marine water are the following:

- The draining of materials deriving from human activities;
- The interaction between the sea surface and the atmosphere;
- The processes between the ions in solution;
- The biochemical processes.

The elements that can be found is marine water are around 70, but only 6 of them represent the 99% of the total. These predominant salts are:

- Chloride (Cl): 55.04 wt%
- Sodium (Na): 30.61 wt%
- Sulphate (SO42-): 7.68 wt%
- Magnesium (Mg): 3.69 wt%
- Calcium (Ca): 1.16 wt%
- Potassium (K): 1.10 wt%

The symbol (wt%) stands for the mass fraction, and represents the concentration of a solution or the entity of the presence of an element in a solution. The quantity of these ions is proportional to the salinity of water, a parameter describing the concentration of dissolved salts in water. Due to the evaporation, this value is lower at the poles (around 3.1%) and higher at the tropics (around 3.8%), with the highest value for an open sea reached by the Red Sea (4%, with a peak of 4.1% in the Northern parts). Moreover, salinity is lower close to the coasts due to the inflow of fresh water by the rivers. Salinity affects the conductivity of water: while this parameter also depends from the water temperature and pressure, it ranges from around 2 S/m to around 6 S/m. Anyway, in most cases it can be considered constant, with a value of 4 S/m. Water is then a conductor.

Once the value of water conductivity is known, it can be used to calculate the values of the penetration depth and of the attenuation.

The penetration depth δ is the distance where the electrical and magnetic fields are reduced of a *1/e* factor, and it can be calculated using the following formula:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \; m$$

where f is the frequency of the electromagnetic wave, μ is the absolute magnetic permeability of the conductor and σ is the conductivity. While water is a diamagnetic material, their absolute magnetic permeability can be considered the same as the vacuum magnetic permeability, i.e. $\mu_0 = 4\pi{*}10$ H/m. This means that, with the conductivity considered constant, the penetration depth only depends on the frequency: the higher is the frequency, the lower is the penetration depth.

The attenuation α can be calculated using the following formula [2]:

$$\alpha = 0.0173\sqrt{f\sigma} \; dB/m$$

where f is the frequency of the electromagnetic wave and σ is the water conductivity that, as said before, can be considered constant. Attenuation is then in inverse proportion with the frequency and then obviously also with the penetration depth.

2.3. Fresh water

Around 97% of the water of the world is found in seas and oceans, while two thirds of the remaining 3% of fresh water is retained as ice in glaciers and at the poles. This means that the most part of studies that can be found concerning the chance to communicate under water using the electromagnetic fields focuses on the marine environment.

Anyway, similar considerations as the ones made for salt water apply to fresh water. The biggest difference derives from the different values of salinity that are detected in fresh water. While the salinity of salt water is around 3.5% (See section 2.2), in fresh water this value decreases down to 0.05%. Anyway, unlike marine water, a general analysis concerning the quantity and typology of salts that can be found in fresh water is impossible to carry out due to the single peculiarities of rivers, lakes, and the chemical and geological composition of the territories that they pass through and where they are located.

A different value in salinity also means a different value in conductivity. In particular, conductivity of fresh water ranges from 30 to 2000μS/cm: these are nevertheless extreme values; river water conductivity usually ranges from 50 to 1500$\mu S/cm$, while rivers supporting a

http://dx.doi.org/10.5772/53934

good wildlife usually range from 150 to 500$\mu S/cm$. This value is notably lower than the average one for marine water. The main consequence of this fact is that for fresh water the penetration depth is higher and the attenuation is lower.

2.4. Underwater radio communication

Some easy calculations prove that the electromagnetic fields can be used to transmit radio signals under water (Especially under the sea) only when their frequency is very low. As an example we can calculate the penetration depth for an electromagnetic wave traveling through salt water at frequency of 10kHz, using the average values for μ and σ:

$$\delta_{10kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 10^4 \bullet 4\pi \bullet 10^{-7} \bullet 4}} \approx 2.5m$$

This value allows a short range communication, while long range communication requires even lower frequencies.

Looking at fresh water the situations is a little bit better. The previous calculation can be made, using a very low conductivity value of 30 μS/cm (3mS/m):

$$\delta_{10kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 10^4 \bullet 4\pi \bullet 10^{-7} \bullet 3 \bullet 10^{-3}}} = 92m$$

Anyway, while this value is higher, long range communication is not allowed when the operative frequency is higher than some kHz.

As a consequence of the previous analysis, the only bands that have been used for underwater radio communication have been the ELF (Extremely Low Frequency) band, ranging form 3 to 300 Hz, with the sub-band ranging from 30 to 300 Hz called SLF (Super Low Frequency) band, and the VLF (Very Low Frequency band).

The ELF band was used for the communication with submarines both by the US and the Russian Navies. The US system, called Seafarer, operated at the frequency of 78Hz, while the Russian one, called ZEVS, operated at the frequency of 82Hz. These systems had a penetration depth in the order of 10km, allowing thus a communication from a fixed station on the sea surface with a submarine traveling close to the ocean floor. Anyway, the realization of a communication channel at these frequencies presents several technical limitations that are extremely difficult to be overcome. One of the biggest problems to be solved is the size of the antenna: its dimension has in fact to be a substantial fraction of the wavelength, but at these frequencies the dimension of the wavelength is in the order of the thousands of kilometres. The solutions found by the US and Russian Navies were complex and expensive, making prohibitive their use for civil applications.

The VLF band ranges from 3kHz to 30kHz: this means that the penetration depth of electromagnetic waves at these frequencies is in the order of ten meters. This value allows a communication with submarines positioned few meters below the sea surface. The limitations on the antenna dimensions, deriving from the big wavelength, have to be taken in account also in this case. Moreover, due to the limited bandwidth, this communication channel cannot be used to transmit audio signals, but only text messages.

3. Underwater RFID

RFID, being a radio technology, suffers from the same limitations of the standard communication channels. This means that the higher is the frequency, the lower are the chances to have a reliable communication {3-7}.

RFID systems are usually subdivided in the following bands:

- Low Frequency (LF) – 120-150kHz;
- High Frequency (HF) – 13.56MHz;
- Ultra High Frequency (UHF) – 433MHz, 868-928MHz;
- Microwave – 2.45-5.8GHz.

3.1. Salt water

As underlined in section 2, significant differences occur according as the RFID system has to be used in salt or fresh water. Starting from salt water, some calculations show that only LF RFID can be used for systems requiring a long reading distance (over 50cm). In particular at a frequency of 125kHz, the average value (Using the salinity value of 4S/m) for the penetration depth is:

$$\delta_{125kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 1.25 \bullet 10^5 \bullet 4\pi \bullet 10^{-7} \bullet 4}} \approx 71cm$$

This value is just lower than the maximum achievable reading range for a Low Frequency system, which is usually lower than 1m. This means that Low Frequency RFID can be theoretically used for the underwater identification of items.

Moving at higher frequencies, the use of these systems for long range identification becomes virtually impossible. The calculation for the penetration depth provides an extremely low value. Starting from the High Frequency band, where all RFID systems work at the standard frequency of 13.56MHz, with the same conditions as in the previous case, the obtained value for the penetration depth is:

$$\delta_{13.56kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 13.56 \bullet 10^6 \bullet 4\pi \bullet 10^{-7} \bullet 4}} \approx 68mm$$

This result proves that High Frequency RFID can be used under water only for short range solutions. In particular, due to the fact that the effectiveness of every RFID system is notably influenced by the performances of the hardware devices employed, it's possible to affirm that the chance to use High Frequency systems is limited to the applications where the tag is in close contact with the reader.

The UHF band is currently employed in many different systems and probably represents the best solution for many applications due to its good performances in terms of reading range, costs and bitrate. Anyway, its frequency is too high to allow its use also for underwater contactless applications. The calculation of the penetration depth, using an average frequency value of 800MHz (varying this value from 433MHz to 930MHz the order of magnitude remains quite constant), provides the following result:

$$\delta_{800MHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 800 \bullet 10^{6} \bullet 4\pi \bullet 10^{-7} \bullet 4}} \approx 9mm$$

This value is obviously too short to use this technical solution for other than contact applications. Only bringing a transponder in contact with the antenna of the reader, the reading becomes possible. While this fact strongly limits the possible uses of these systems, in some cases UHF systems can still become a good choice.

Finally, the Microwave band is obviously the one that provides the worst results. The value of the penetration depth is provided only for completeness, even if currently no application can be found worldwide using this technical solution:

$$\delta_{2.45GHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 2.45 \bullet 10^{9} \bullet 4\pi \bullet 10^{-7} \bullet 4}} \approx 5mm$$

Before moving to the next section a clarification has to be made. In the previous analysis no differentiation has been done on the powering method of the transponders. In fact, while active transponders usually provide higher reading ranges, they are generally used only at higher frequencies (UHF and Microwave bands): anyway, at these frequencies the penetration depth is so short that even with the most powerful active transponder no improvement in the performances of the systems would be noticeable. Moreover, even at lower frequencies, the value of the penetration depth is anyhow lower than the reading range achievable using passive transponders: therefore, a study for the use of active transponders also at these frequencies would be useless and wouldn't provide any improvement.

3.2. Fresh water

The analysis for fresh water is similar to the one carried out for salt water. The main difference derives from the fact that, while the range of the conductivity values of salt water is very short, it becomes wider in the case of fresh water. As anticipated is section 2.3, fresh water conductivity roughly varies from 30 $\mu S/cm$ to 2000 $\mu S/cm$. While both these values are notably lower than the conductivity of salt water, the differences between the obtained values for penetration depth are less distant. In order to provide an accurate set of data, the penetration depth value will be calculated both for the best (30 $\mu S/cm$) and the worst (2000 $\mu S/cm$) case.

As in the case of salt water, the analysis will begin from the Low Frequency band. In this case, at the frequency of 125kHz, with a conductivity value of 30 $\mu S/cm$ (3 mS/m), the value of penetration depth is:

$$\delta_{125kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 1.25 \bullet 10^{5} \bullet 4\pi \bullet 10^{-7} \bullet 3 \bullet 10^{-3}}} = 26m$$

With a conductivity value of 2000 $\mu S/cm$ (0.2 S/m) the penetration depth becomes:

$$\delta_{125kHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 1.25 \bullet 10^{5} \bullet 4\pi \bullet 10^{-7} \bullet 0.2}} = 3.2m$$

Both these values are high enough to allow a reliable long range RFID communication channel.

Moving on to higher frequencies, the second evaluation is made for the High Frequency band. The calculation is made using the standard frequency of 13.56MHz. The penetration depth value with a conductivity of 30 $\mu S/cm$ (3 mS/m) is:

$$\delta_{13.56MHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 13.56 \bullet 10^6 \bullet 4\pi \bullet 10^{-7} \bullet 3 \bullet 10^{-3}}} = 2.5m$$

With a conductivity value of 2000 $\mu S/cm$ (0.2 S/m) the penetration depth drops to:

$$\delta_{13.56MHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 13.56 \bullet 10^6 \bullet 4\pi \bullet 10^{-7} \bullet 0.2}} \; 30cm$$

While at lower conductivity values the realization of an efficient long range RFID system could still be possible, when the water conductivity grows the penetration depth drops down to values that make this solution difficult to be implemented or even totally impossible. Anyway, the chance to use HF RFID in particular environments like rivers or lakes has to be carefully evaluated case-by-case. An additional remark has to be made: in terms of performances, LF and HF systems are similar. This means that, if the system doesn't present specific requirements, the use of LF technology is however strongly suggested.

At higher frequencies the value of penetration depth drops down to values that allow the use of these systems only for contact or short range applications. At 800MHz the penetration depth with a conductivity value respectively of 30 $\mu S/cm$ (3 mS/m) and 2000 $\mu S/cm$ (0.2 S/m) is:

$$\delta_{800MHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 800 \bullet 10^6 \bullet 4\pi \bullet 10^{-7} \bullet 3 \bullet 10^{-3}}} \approx 32.5cm$$

and

$$\delta_{800MHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 800 \bullet 10^6 \bullet 4\pi \bullet 10^{-7} \bullet 0.2}} \approx 4cm$$

For Microwaves, these values drop down to:

$$\delta_{2.45GHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 2.45 \bullet 10^9 \bullet 4\pi \bullet 10^{-7} \bullet 3 \bullet 10^{-3}}} \approx 18.6cm$$

$$\delta_{2.45GHz} = \frac{1}{\sqrt{\pi f \mu \sigma}} = \frac{1}{\sqrt{\pi \bullet 2.45 \bullet 10^9 \bullet 4\pi \bullet 10^{-7} \bullet 0.2}} \approx 2.3cm$$

A remark is necessary: the values obtained for the penetration depth are ideal values and represent mainly an upper bound. This means that in most cases the effective system will present real reading ranges notably lower and in some cases it won't work at all.

	Low Frequency 125kHz	High Frequency 13.56MHz	Ultra High Frequency 800MHz	Microwaves 2.45GHz
Salt Water 4S/m	71cm	68mm	9mm	5mm
Fresh Water 30$\mu S/cm$	26m	2.5m	32.5cm	18.6cm
Fresh Water 2000$\mu S/cm$	3.2m	30cm	4cm	2.3cm

Table 1. The penetration depths for the considered frequencies for both salt and fresh water

In conclusion, while theoretical data suggest that several solutions are possible when RFID is required for under water applications, it's possible to affirm that to obtain reliable results the operative frequency as to be the lowest possible. In particular:

- For salt water long range reading is obtainable only using Low Frequency systems;
- In salt water, short range or contact reading could be possible also at higher frequencies. Anyway, also in these cases a reliable reading level could be very difficult to be achieved at frequencies higher than 13.56MHz;
- For fresh water long range reading could be obtained not only with Low Frequency systems, but also with the use of High Frequency devices operating at 13.56MHz. Anyway, also in this case the use of Low Frequency is strongly recommended due to their higher reliability;
- When short range or contact reading is required in fresh water, quite all the frequencies could be efficient, even if there is a lack of studies proving the effectiveness of UHF frequencies.

4. RFID applications under water

RFID is currently one of the most widespread technologies for the automatic identification of items. There are countless fields where RFID is used for access control, items tracking, people and animal identification and many other different applications. Anyway, few applications exist where RFID is used under water.

The question of the transponders waterproofing is crucial for many applications and several devices providing a high protection level against the contact with water have been realized. Plastic tags are inherently waterproof devices, while items like wristbands have been customized to be worn also under water. Anyway, all these devices have been designed only to resist against water intrusion, and not to be read directly under water. Moreover, no reader has been realized to be used under water. Readers providing a high protection level against water can be easily found: anyway, they are designed only to be positioned on the outside, for example on building walls for access control, and then to resist against bad weather.

A step ahead is the development of transponders realized ad-hoc to be positioned on bottles or other items containing liquids. In this case the solution mainly deals with the introduction of a dielectric layer that simply separates the transponder and the liquid allowing thus its reading.

Anyway, the number of applications where the data exchange happens totally underwater is nowadays very little: the most part of these applications deals with animal tracking and environmental monitoring, mainly in marine environment.

4.1. Animal tracking

The chance to track animals, crucial for industrial stock-breeding activities, using RFID technology has probably raised for the first time the question whether is possible or not to read RFID tags immersed in water. The body of most part of living beings is mainly composed by water: as an example, around 65% of human body is composed by water. The necessity to guarantee the integrity of the tracking device (In this case the transponder) has encouraged its positioning in a place where it cannot be removed, i.e. inside the body of the animal to be tracked. While the body of the animal is mainly composed by water, to read the transponder from the outside it’s necessary to find a technological solution avoiding the insulating effect of the water layer.

The use of RFID for animal tracking is nowadays very common, and has also led to the realization of two ad-hoc standards, the ISO 11784 and ISO 11785 standards, that regulate the use of RFID devices, in particular implantable transponders, for the identification of animals. Standard RFID systems for animal tracking operate at the frequency of 134.2kHz (Low Frequency band). The transponders used for this purpose are generally glass cylinder tags that are modified to be applied under the skin of the animal, to be clasped to the ear of the animal or to be ingested by the animal.

Even if these applications deal with the interaction with water, they are not properly under water systems. Anyway, RFID technology has been employed also to track animals under water. In particular, Low Frequency RFID technology has been used to identify fishes in the aquariums [8]. At the Underwater World Singapore Oceanarium, at Underwater World Pattaya, Thailand and at Virginia Aquarium & Marine Science Center, Low Frequency cylinder glass tags have been applied under the skin of a number of fishes.

The tagged fishes are identified when they come close to a long range antenna positioned on the glass of the tank where the fishes are kept. When the fish passes in front of the antenna, the identification code stored inside the transponder is read and the fish is identified. Once the fish has been identified the visitors of the aquarium can receive an interactive set of information concerning the animal. In particular, an ad-hoc software provides on a screen a picture of the fish and a description: these data are kept on the screen until a new fish passes close to the antenna.

http://dx.doi.org/10.5772/53934

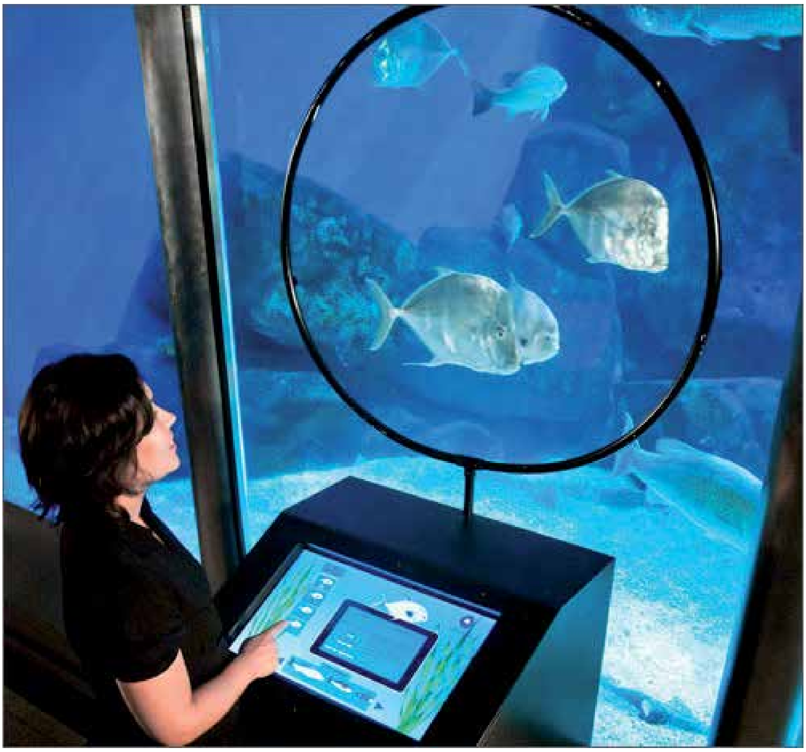

Figure 1. The Virginia Aquarium and Marine Science antenna identifying fishes.

4.2. Pipeline monitoring

Another interesting application that foresees the use of RFID technology under water focuses on the monitoring of pipelines used to carry oil [9]. This solution has been currently only tested, while no information has been retrieved on possible effective applications nowadays working. In this kind of applications Low Frequency RFID tags were applied directly on the pipeline, keeping a fixed distance between one tag and the other.

The tags operated the frequency of 125kHz and they were customized to fit exactly on the pipe: in particular, standard Phillips Semiconductor Hitag transponders were introduced inside a protecting case, shaped on the curvature of the pipe.

Enertag, which tested the system, also developed an ad-hoc underwater reader: this was a handheld waterproof device connected with a cable to a PC positioned on a boat on the sea surface.

This system was employed to monitor the conditions of the pipeline. In practice, the transponders acted as milestones, used to identify the exact portion of pipeline. This was combined with the data concerning repairs that the pipeline had undergone, and suggesting which portion of the pipeline required assistance.

Figure 2. The Enertag system for the pipeline monitoring

4.3. Underwater navigation

US Navy analysed a possible use of RFID technology as a support for the navigation of autonomous underwater vehicles [10]. In this application tags are positioned directly on the sea bottom, and they contain information related to their position inside the area where the vehicle is moving.

The reader is embedded directly inside the vehicle: every time that a transponder comes inside the interrogating range of the reader, the information stored inside it is read and then used by the vehicle to manage its movements.

While no data has been found about an effective application of this solution, the possible uses of such a kind of system are many. Even if this solution has been proposed by the US Navy, it could be employed also in many civil applications, from the environmental monitoring to the harbour management.

4.4. Environmental monitoring

RFID technology has been used for the monitoring of coastal dynamics. The University of Siena and the University of Pisa, in Italy, have realized the so-called "Smart Pebble" system, where Low Frequency transponders are used to trace the movements of a set of pebbles along a pre-defined span of time, in order to study the dynamics of the shoreline [11].

In this system different typologies of 125kHz transponders have been employed in the last 4 years, from plastic disc tags to cylinder glass tags. These tags were inserted inside real pebbles picked up directly on the beaches where the system had to be employed: in order to allow the housing of the transponder, the pebbles were drilled. The transponder was then glued on the bottom of the small hole realized in the pebble and then it was covered with the small rocky cap extracted during the drilling operation.

Once a large set of pebbles was realized, it was positioned on the beach to be studied, following a grid pattern covering both the emerged and the submerged portion of the beach. Through an ad-hoc waterproof reader realized modifying a common reader used for access control, the pebbles were then localized after a pre-defined span of time. The starting and final positions were recorded using a GPS total station: with these data the path followed by the pebble swarm was traced, allowing geologists to easily understand the dynamics of the shoreline and the erosive effects of the meteorological events.

This application proved to be very interesting because its biggest requirement was to achieve the largest reading range possible. This constraint forced to test different hardware solutions in order to obtain the best performances especially for salt water, which was the environment where the system had to be employed. A few tests were made with HF (13.56MHz) devices but the results achieved discouraged from using this solution. In particular, the reading range obtained with a common desktop reader under salt water was lower than 3cm. This result is in accordance with the theoretical data and excludes the use of this technology for long range under sea applications.

The following experimentations were carried out on LF 125kHz systems: the theoretical analysis on this technology foresaw the chance to use them for long range applications also under sea. The tests were carried out using a long range reader usually employed for access control. Several kinds of transponders were used for the tests, from plastic discs to glass tags. The tests tried to simulate as much as possible the real environmental conditions: to achieve this result a model of the sea bottom was realized using a plastic tube. The results of the laboratory tests are shown in Table 2 and demonstrate that, using Low Frequency, long range reading is possible also under sea. Note that the experimentation was carried out in two times, and the results are then divided in two sub-sets: the first three results provide an average value from the best and worst coupling value, while the second three provide these two values separately [12]. The results are in accordance with the theoretical analysis: the achieved reading range is lower than the penetration depth, that acts then as an upper bound.

Tag Typology	Ideal Reading Range	Real Conditions
Nylon disc	55cm	41cm
ABS Plastic disc	63cm	51cm
PVC disc	49cm	36cm
Transparent disc	50cm	28-47cm
Long Glass tag (34mm)	65cm	48-63cm
Short Glass tag (14mm)	42cm	30-41cm

Table 2. Reading ranges of different Low Frequency transponders under water

The first experimentations on the Smart Pebble system were carried out in 2009 and this solution has been since then employed in several on-site applications on different beaches in Italy. The effective use of the system has roughly confirmed the results recorded in the laboratory tests: during the localization process, the transponders embedded inside the pebbles were localized even from distances higher than 50cm.

Figure 3. A Smart Pebble. On its surface is possible to notice the hole housing the transponder

Figure 4. A moment of the localization operations

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While this application is interesting because sea is probably the most complex environment for the underwater use RFID, this technology has also been employed several times for the study of sediment transportation in rivers [13-14].

All these solutions are based on the use of Low Frequency technology. 125kHz or 134.2kHz transponders are introduced inside pebbles that act as tracers in the same way as the marine application.

Anyway, differences occur in the way transponders are detected. In some applications, a reader carried by hand is employed: this means that in most cases the reader is kept outside water and used as a sort of metal detector along portions of the river where the depth is very low. Other interesting solutions are based on the deployment of an array of antennas directly on the river bed. In this case, the tagged pebbles are detected only when they pass over one of the antennas.

5. Future applications

The systems described in the previous sections represent a good starting point for the development of many other possible applications, in the same applicative fields but also in totally new ones.

Starting from the animal tracking application, the extension of this solution to other scenarios is limited mainly by the reading range, which forces the fish to come close to the reader antenna to be identified. Anyway, the chance to track animals also under water suggests a possible use of RFID technology also in the sector of fish breeding. In this case, the use of such a solution could be used to trace the production process and to guarantee the quality of the final product. On the opposite side, the use of RFID technology to trace the movements of wild fishes is notably more difficult. The RFID reading range makes the possibility to trace fishes in the sea (or even in a lake) virtually impossible because the chances that a fish will come close to some antenna positioned elsewhere are close to zero. On the other hand RFID could be used to monitor the movements of fishes along a river. In this case, antenna arrays could be structured as a sort of RFID barrier in locations where the river depth is low enough to allow the detection of every transponder passing over it. In this case, such a system could be for example useful to study the migration processes of fishes like salmons.

The technique set up for the pipeline monitoring could be easily extended to other typologies of industrial monitoring. In particular, it could be applied to monitor the state of harbour infrastructures, ship hulls, oil platforms and all the other offshore industrial plants. In all these scenarios, RFID could be useful to keep trace of the maintenance interventions performed in specific locations. The operators could use RFID transponders as a sort of electronic note where the state of the site could be read and then updated every time that any sort of intervention is performed.

The underwater navigation application could be a good starting point to develop applications where RFID is used to manage the movements of boats inside the harbours. In this case, RFID transponders could be used as a sort of electronic trail, with a reader positioned directly on the boat analysing the information stored on them and using it to move inside the harbour. On the other side, it could be possible to deploy transponders directly on the boat, and to use them as a sort of electronic license plate. This could allow the boat to be automatically identified by a reader positioned on the pier without the direct intervention of a harbour operator.

The field of environmental monitoring probably opens the way to the widest range of possible applications. Together with the geological applications concerning the sediments tracking, RFID could also be useful for the monitoring of biological activities both is rivers and in the sea. The application concerning the tracking of pebbles has in fact suggested a possible extension for this technique. The pebbles recovered at the end of the experimentation presented a lot of organic sediments left on them: this fact suggests then their possible use also as probes to analyse the impact of pollution on the biological activity of the portion of littoral under study. This technique could also be extended to be employed in other scenarios where sediments tracking is required: a similar system could be for example deployed in the city of Venice to monitor the condition of the canals. In general, such a solution could be used in those water environments where the dynamics are slow enough to keep the tracers in an area small enough be manually scanned using a reader. In this sense, such a system could be used for example to analyse in detail the dynamics of a glacier.

Together with these possible applications, deriving from the existing systems, other possible solutions could be studied every time that an under water monitoring or tracking system is required.

6. Conclusions

In this chapter the chance to use RFID technology for systems operating under water has been analysed.

The composition of salt and fresh water has been described, together with the influence that the salinity has on the conductivity of water and then on key parameters like water attenuation and penetration depth. The value of this second parameter has been calculated for the standard RFID systems: the results show that only at Low Frequencies it's possible to develop solutions where a long reading range is required, both for salt and fresh water. Anyway, moving at higher frequencies, while for fresh water the chances to set up efficient solutions are still high, especially for short range applications, for salt water RFID becomes virtually unusable.

However, the chance to use the lower frequency bands has led to the development of some applications that use RFID technology for specific purposes, both in marine and in fresh water environments. These applications range from animal tracking solutions to environmental monitoring systems, and represent a good starting point for a wider diffusion of this technology even in a sector traditionally precluded to technologies relying on electromagnetic fields for their functioning.

http://dx.doi.org/10.5772/53934

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Possibility of RFID in Conditions of Postal Operators

Juraj Vaculík, Peter Kolarovszki and Jiří Tengler

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53285

1. Introduction

Radio frequency identification is becoming a modern trend in many sectors. It provides a contactless identification, tracking and tracing of goods, property and people in real time. Increase efficiency, performance and competitiveness. One area of application of RFID technology is also postal processes. In this context there are several question of feasibility of the use of identification of letters. In addition to the costs associated with the introduction of technology is necessary to examine the feasibility of using RFID technology in the field of postal processes.

Today, postal operations have implemented RFID in various closed-loop systems to measure, monitor, and improve operations. For example, RFID is being used to monitor international mail service between major hubs. By randomly "seeding" tagged letters into trays, elapsed delivery time can be measured. This allows service issues to be identified and addressed in a reliable and cost-effective manner.

Other postal operations have piloted tracking mail containers to measure trailer utilization and to track container locations. Manual container tracking systems tend to break down when volumes are high and there's a deadline to meet departure times. By allowing information to be captured automatically, RFID makes sure it is done, even under stressful conditions. Postal managers can rely on the information to make decisions that improve transportation costs and to relocate containers when needed. RFID-tracked mailbags, which provide delivery status, have already been created for priority mail services. Tagged mailbags are automatically read at specific points in the network to provide this automated track-and-trace capability. Four additional areas can benefit from the cheap, accurate, and pervasive information obtained using RFID. Each of them has the prospect for returning substantial monetary benefits, as well as having the potential to significantly upgrade postal service capabilities, an ever more important consideration in the competitive delivery market.

Chapter is divided on several parts. We will be talk about basic of RFID, possibility of technology in postal and logistics processes, other mobile technology in processes, security of technology with contents to postal services, impact of operational characteristic on the readability and finally results of testing RFID technology in our laboratory of Automated identification and data capture (AIDC Lab) of University of Žilina.

2. Basic of RFID technology architecture

The RFID system architecture consists of a reader and a tag (also known as a label or chip). The reader queries the tag, obtains information, and then takes action based on that information. That action may display a number on a hand held device, or it may pass information on to a POS system, an inventory database or relay it to a backend payment system thousands of miles away. Let's looks at some of the basic components of a typical RFID system.

2.1. RFID tag/label

RFID units are in a class of radio devices known as transponders. A transponder is a combination transmitter and receiver, which is designed to receive a specific radio signal and automatically transmit a reply. Transponders used in RFID are commonly called tags, chips, or labels, which are fairly interchangeable, although "chip" implies a smaller unit, and "tag" is used for larger devices. The designator label is mainly used for the labels that contain an RFID device. Tags are categorized into four types based on the power source for communication and other functionality (Figure 1):

- A passive tag uses the electromagnetic energy it receives from an interrogator's transmission to reply to the interrogator. The reply signal from a passive tag, which is also known as the backscattered signal, has only a fraction of the power of the interrogator's signal. This limited power significantly restricts the operating range of the tag. Since passive tags are low power devices, they can only support data processing of limited complexity. On the other hand, passive tags typically are cheaper, smaller, and lighter than other types of tags, which are compelling advantages for many RFID applications. [3]
- An active tag relies on an internal battery for power. The battery is used to communicate to the interrogator, to power on-board circuitry, and to perform other functions. Active tags can communicate over greater distance than other types of tags, but they have a finite battery life and are generally larger and more expensive. Since these tags have internal power, they can respond to lower power signals than passive tags. [3]
- A semi-active tag is an active tag that remains dormant until it receives a signal from the interrogator to wake up. The tag can then use its battery to communicate with the interrogator. Like active tags, semi- active tags can communicate over a longer distance than passive tags. Their main advantage relative to active tags is that they have a longer battery life. The waking process, however, sometimes causes an unacceptable time delay when tags pass interrogators very quickly or when many tags need to be read within a very short period of time. [3]

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• A semi-passive tag is a passive tag that uses a battery to power on-board circuitry, but not to produce return signals. When the battery is used to power a sensor, they are often called sensor tags. They typically are smaller and cheaper than active tags, but have greater functionality than passive tags because more power is available for other purposes. Some literature uses the terms "semi-passive" and "semi- active" interchangeably. [3]

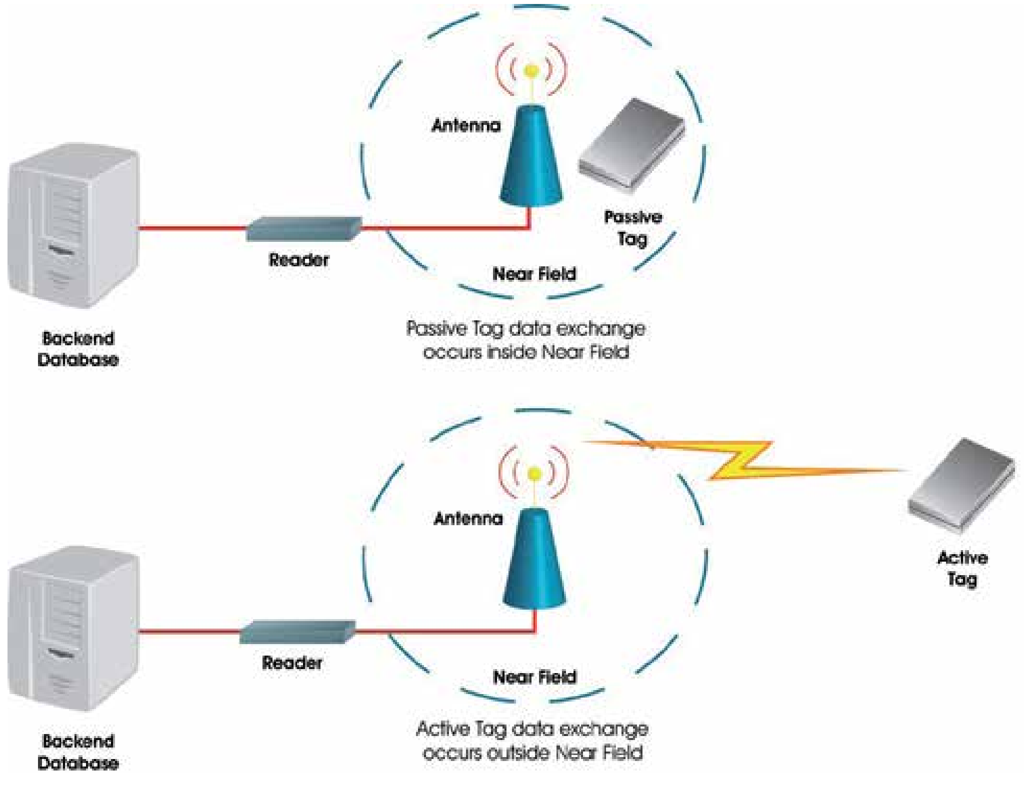

Figure 1. Passive and Active Tag Processes

Like bar codes in an earlier time, RFID is the next revolution in AIDC technology. Most of the advantages of RFID are derived from the reliance on radio frequencies rather than light (as is required in optical technology) to transmit information. This characteristic means that RFID communication can occur:

• Without optical line of sight, because radio waves can penetrate many opaque materials,

• At greater speeds, because many tags can be read quickly, whereas optical technology often requires time to manually reposition objects to make their bar codes visible, and

• Over greater distances, because many radio technologies can transmit and receive signals more effectively than optical technology under most operating conditions. [3]

2.1.1. Carrier frequencies

Today, there are four carrier frequencies implemented for RFID that are popular globally: 125 KHz, 13.56 MHz, UHF ranging from 866 to 950 MHz depending on national radio regulations, and microwave frequencies of 2.45 GHz and 5.8 GHz. There is also the frequency range 430-440 MHz, which is allocated to amateur radio usage around the world. The ISM band 433.05-434.790 MHz is located near the middle of the amateur radio band. The amateur radio band has emerged as an RFID channel in a number of applications. The frequency range has been called the 'optimal frequency for global use of Active RFID'. [1]

2.1.2. Functionality

- The primary function of a tag is to provide an identifier to an interrogator, but many types of tags support additional capabilities that are valuable for certain business processes. These include:
- Memory - memory enables data to be stored on tags and retrieved at a later time. Memory is either write once, read many (WORM) memory or re-writeable memory, which can be modified after initialization. Memory enables more flexibility in the design of RFID systems because RFID data transactions can occur without concurrent access to data stored in an enterprise subsystem. However, adding memory to a tag increases its cost and power requirements.
- Environmental sensors. The integration of environmental sensors with tags is an example of the benefit of local memory. The sensors can record temperature, humidity, vibration, or other phenomena to the tag's memory, which can later be retrieved by an interrogator. The integration of sensors significantly increases the cost and complexity of the tags. Moreover, while many tag operations can be powered using the electromagnetic energy from an interrogator, this approach is not workable for sensors, which must rely on battery power. Tags typically are only integrated with sensors for high-value, environmentally sensitive, or perishable objects worthy of the additional expense.
- Security functionality, such as password protection and cryptography. Tags with onboard memory are often coupled with security mechanisms to protect the data stored in that memory. For example, some tags support a lock command that, depending on its implementation, can prevent further modification of data in the tag's memory or can prevent access to data in the tag's memory. In some cases, the lock command is permanent and in other cases, an interrogator can "unlock" the memory. EPCglobal standards, International Organization for Standardization (ISO) standards, and many proprietary tag designs support this feature. Some RFID systems support advanced cryptographic algorithms that enable authentication mechanisms and data confidentiality features, although these functions are most commonly found on RFID-based contactless smart cards and not tags used for item management. Some tags offer tamper protection as a physical security feature.
- Privacy protection mechanisms. EPC tags support a feature called the kill command that permanently disables the ability of the tag to respond to subsequent commands. Unlike

the lock command, the kill command is irreversible. The kill command also prevents access to a tag's identifier, in addition to any memory that may be on the tag. While the lock command provides security, the primary objective of the kill command is personal privacy. RFID tags could be used to track individuals that carry tagged items or wear tagged articles of clothing when the tags are no longer required for their intended use, such as to expedite checkout or inventory. The ability to disable a tag with the kill command provides a mechanism to prevent such tracking.[1]

2.2. RFID reader (Interrogator)

The second component in a basic RFID system is the interrogator or reader, which wirelessly communicate with a tag. Readers can have an integrated antenna, or the antenna can be separate. The antenna can be an integral part of the reader, or it can be a separate device. Handheld units are a combination reader/antenna, while larger systems usually separate the antennas from the reader.

The reader retrieves the information from the RFID tag. The reader may be self-contained and record the information internally; however, it may also be part of a localized system such as a POS cash register, a large Local Area Network (LAN), or a Wide Area Network (WAN).

There is also Middleware, software that controls the reader and the data coming from the tags and moves them to other database systems. It carries out basic functions, such as filtering, integration and control of the reader. [1]

RFID systems work, if the reader antenna transmits radio signals. These signals are captured tag, which corresponds to the corresponding radio signal (Figure 2).

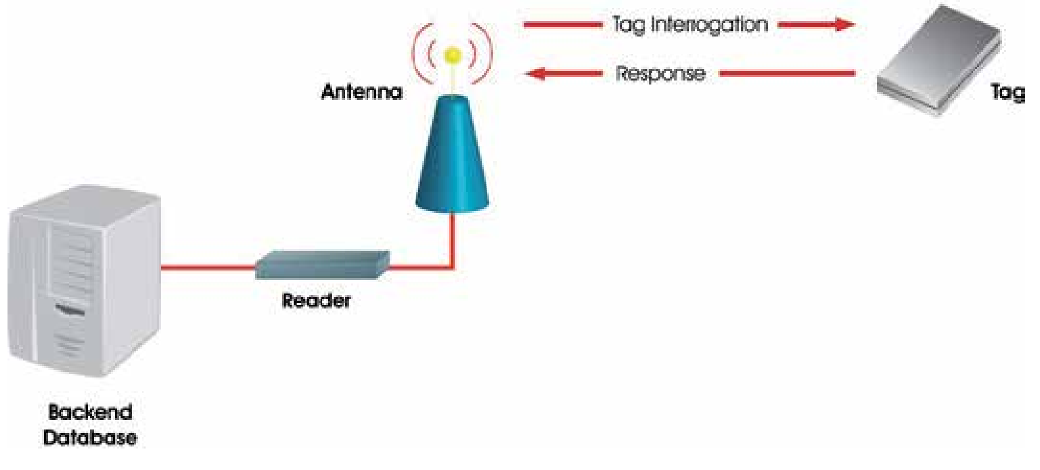

Figure 2. The interaction between the reader and RFID tag [2]

2.3. Security of RFID technology

Let's start with the first question: What are the security risks with RFID? The information inside [passive] RFID tags is vulnerable to alteration, corruption, and deletion due to low processing speed and low memory. In contrast, some high-end active RFID readers and tags tend to improve security through use of cryptography, challenge-response protocols, rotating passwords, and tamper detection technology. These devices have more processing power and more memory than their passive counterparts. They are more expensive and need a battery to give a boost to the processing power. The passive RFID devices do not need a battery. The tags wake up when they receive a signal from a reader.

Now let's go the second question: How can we categorize the attacks on RFID technology? The management can start with the four categories of the attacks that are unique to the RFID infrastructure: war-walking and lifting, counterfeiting, denial-of-service, and weak cryptography.

2.3.1. War-walking and war-lifting

War-driving, also known as the wireless LAN driving is a technique of using a Wi-Fi-based laptop or PDA to detect Wi-Fi wireless networks while driving in a vehicle, such as a small truck or an automobile. Legitimate war-drivers do not use services without proper authorization.

In the RFID technology arena, we add the wireless RFID driving to the description of war-driving. It is not necessary to have a LAN as an access point that a remote wireless device can pick up. A war-driver can use the device to pick up the information from unsecured tags affixed to an item, case, or pallet. What is more is that the war-driver could disable the RFID deactivation mechanisms when the items leave the retail stores.

In addition, the war-driver can read and get the information from the RFID tags of purchased goods that a passerby carries in a shopping bag. This can happen only if the tags are not properly deactivated when they leave a retail store or a warehouse.

War-walking is more bold than war-driving. War-walkers do not need a wireless device to find the RFID tags. With fake credentials or cards, they can bypass physical checks and find the system that uses RFID tags to monitor the movements of conference attendees.

Let's assume the cracker goes beyond finding the system. The cracker either runs away or removes the passive RFID tags from the objects, say, inside one case by sawing or etching the tags away. The cracker replaces them with the counterfeited tags, and reattaches the tag with original RFID data to the like objects in another case, all without being detected. This technique is known as lifting.

In another instance, a corporate spy walks around, scans the entire stock of a competing retail outlet, rewrites the tags of cheap products and replaces with better product labels and even hides products in a metal-lined tag and replaces with new tags on shelf. Passive tags do not work very well when they come into contact with a metallic surface.

Another privacy issue that has raised is what flashes up on a scanner as someone walks near the interrogator (especially the active interrogators that have a much wider scanning region than those of passive interrogators). The scanner could show:

- Clothing origins
- Contents of origins
- Contents of briefcase or handbag
- Which credit cards being carried
- Linkage to RFIDs that identify the user of passport in suit pocket

Make sure the RFID infrastructure is secured with physical security control mechanisms. If the company can afford it, it could use, for example, AXCESS's ActiveTag system, a single-system approach to automatic monitoring and tracking applications right from your desktop computer, including Asset Management, Personnel and Vehicle Access Control, Personnel Monitoring, Production and Process Control, and Inventory Tracking.

2.3.2. Counterfeiting

It is the semi-conductor companies who manufacture RFID tags. Unlike security firms, the semi-conductors have practically no experience in security. These companies are more interested in getting the customers to buy their products rather than in the discussion of product vulnerabilities and countermeasures. Another problem is the vendors who become too overconfident that their products will not be easy to break.

With a switched reader, you will be not able to read the tags. An adversary can defeat an encryption by switching readers after gaining physical access to the location that sends encrypted communications.

Now, how does an adversary make the switch? One possibility is to switch with a fake reader. Another possibility is to tamper with the original reader. It is so easy to do so with a portable handheld device, particularly the ones that can fit into the palm of most hands. The tampered or replaced reader can be modified to allow the adversary to control a legitimate reader nearby from a distance and write counterfeit serial numbers on the RFID tags. It also can be modified to automatically change the original RFID numbers stored in the reader's database and replace it with invalid numbers.

That is why it is important to secure custody for the reader even when a RFID handler is not using the device. It is also important for the organizations to ensure that a legitimate reader can reject an invalid RFID number counterfeited on the tag or in the reader's database.

You should determine what countermeasures you need to mitigate the risks of counterfeiting threats before RFID is fully implemented.

2.3.3. Denial of service

RFID radio signals area also very easy to block or jam. This can cause denial-of-service not only to the RFID tags but also at the data and network level.

Hackers and crackers can launch a denial-of-service attack by using electromagnetic fog to block RFID scanning and flooding a retail outlet with radio waves at the same frequencies as RFID scanners, thus causing chaos at check-outs. They also can hide a transmitter in a cat at a parking lot. This transmitter can block radio signals, causing an RFID-enabled store to close, and send a malicious virus to an EPC IS server containing the RFID data.

2.3.4. Weak cryptography

Although we expect the price for passive tags to drop below five cents per unit in a few years, we must acknowledge that these tags are computationally weak for the standard basic symmetric key cryptographic operations. Because more expensive RFID tags have more processing power and memory they can perform advanced cryptographic functions. Most low-cost tags are readable; many have limited writeable capability. This is because these tags are designed with basic functionality to keep the costs low.

Although we can get around this problem in a limited way via minimalist cryptography and Elliptic Curve Cryptography (ECC), they are more appropriate for other RFID devices, smart cards.

To overcome some of the confusing policies on when to use the kill command, the AUTO-ID Center and EPCglobal have proposed to put thef chip tags to sleep for a while rendering them inoperable temporarily and: then wake up these tags later on with a pair of sleep/wake commands.

As mentioned previously, the basic functionality of the low-cost RFID tags does not allow the basic cryptographic operations, due to limited processing power and little memory and size of the chip. To make it work, the tag must have memory of several megabytes and be rateable. The scheme for this cryptography is pseudonym throttling. It sores a short list of random identifiers of pseudonyms and goes into a cycle. Very little computation, if any, is involved, as contrasted to standard cryptography that requires quite a bit of computation and more complex circuitry.

The ECC is widely accepted for its efficient deployment of the public key mechanism. ECC is known for its compactness due to the novel way it uses arithmetic units to perform complex computations. It is much more compact then RSA, allowing the low-cost tags to be RFID-enabled. To get the ECC to work properly in RFID tags, we cannot overlook three important things: an adequate memory, the size of the area into which the ECC is installed, and the amount of power the tag can consume and emit signals to perform a simple computation. If the memory is too low, the ECC will not work. If the memory is adequate but the circuitry does not give enough power to consume, the ECC will not work. If the size of the area is too small regardless of memory size or the amount of power consumption, the ECC will not work. The memory, the area size, and power consumption, must be set properly in order for all three to get the computation to work properly.

2.3.5. Defence in depth

Let's assume light-weight cryptography for the RFID tag is well designed and is one of the protection mechanisms to defend the RFID infrastructure from attacks. In reality, 100 percent protection from cryptography is not possible. What is possible is the mitigation of risks to cryptographic attacks to an acceptable level. Another possibility is to let other protection mechanisms take over at the software/hardware level if one protection mechanism degrades or fails. They include firewalls, intrusion detection systems, scanners, RFID monitoring, failover servers, VPNs, and PKI.

As shown in Figure 3., these protections form the core of the Defense-in-Depth model of three rings. The middle ring focuses on access and audit controls. Access controls are best achieved with a WSSO for each user via SAML Auditing is accomplished with an examination of security practices and mechanisms within the organization.

Overlapping the core and middle rings are the operating systems that include both, for example, firewalls and access controls, such as Windows 2000 security, Windows 2003 Server Security, UNIX and Linux security, and Web security. Also included are the automated tools and devices to assess network vulnerabilities.

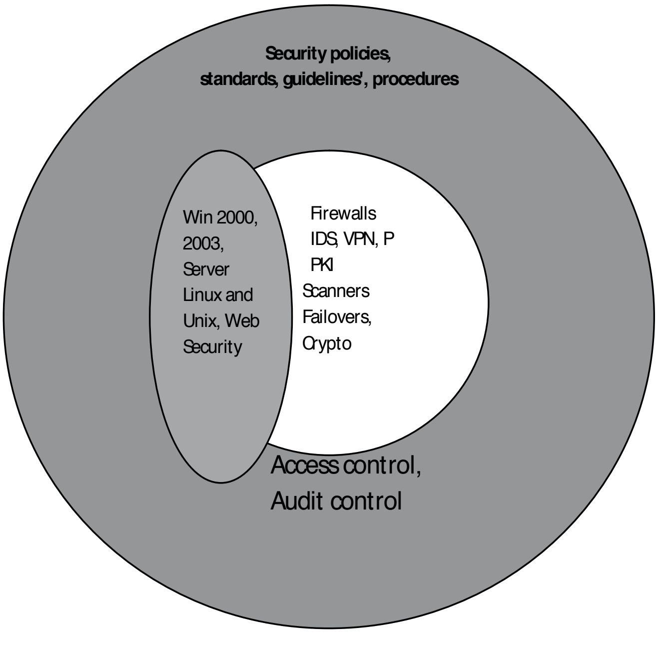

Figure 3. RFID Defence-In-Depth

The outer ring is a set of security policies including business continuity policy, risk assessment policy, password protection management policy, and server security policy.

Implementing the Defense-in-Depth is not as easy as it seems. Administrators must often choose from among a dizzying array of specialized hardware and software products to meet their organizations' need for network security.

To realize both best-of-breed application choice and full management integration, network administrators should consider an enterprise security solution built on an open architectural platform. With well-defined interfaces, this enables third-party security applications to plug in seamlessly with the overall security policy. In addition, an open architecture can leverage Application Programming Interfaces (APIs) to develop and deploy custom applications to meet specific network security needs.

2.4. RFID data collection tool-backend communication attack

Middleware and backend communication occur using JMS, SOAP, or HTTP. There are two types of attacks that can have an impact on the backend: MIM application layer attack and a TCP replay attack.

2.4.1. MIM Attack

A MIM attack occurs when someone monitors the system between you and the person you are communicating with. When computers communicate at low levels of the network layer, they may not be able to determine who they are exchanging data with. In MIM attacks, someone assumes a user's identity in order to read his or her messages. The attacker might be actively replying as you to keep the exchange going and to gain more information. MIM attacks are more likely when there is less physical control of the network (e.g., over the Internet or over a wireless connection).

2.4.2. Application layer attack

An application layer attack targets application servers by deliberately causing a fault in a server's operating system or applications, which results in the attacker gaining the ability to bypass normal access controls. The attacker takes advantage of the situation, gaining control of your application, system, or network, and can do any of the following:

- Read, add, delete, or modify your data or operating system,
- introduce a virus program that uses your computers and software applications to copy viruses throughout your network,
- introduce a sniffer program to analyze your network and gain information that can eventually be used to crash or corrupt your systems and network,
- abnormally terminate your data applications or operating systems,
- disable other security controls to enable future attacks.

- The best way to prevent MIM and application layer attacks is to use a secure way.

2.4.3. TCP replay attack

A replay attack is when a hacker uses a sniffer to grab packets off the wire. After the packets are captured, the hacker can extract information from the packets such as authentication information and passwords. Once the information is extracted, the captured data can be placed back on the network or replayed. Some level of authentication of the source of event generator can help stop TCP replay attacks.

2.4.4. Attacks on ONS

ONS is a service that, given an EPC, can return a list of network-accessible service endpoints pertaining to the EPC in question. ONS does not contain actual data regarding the EPC; it contains only the network address of services that contain the actual data. This information should not be stored on the tag itself; the distributed servers in the Internet should supply the information. ONS and EPC help locate the available data regarding the particular object.

2.4.4.1. Known threats to DNS/ONS

Since ONS is a subset of Domain Name Server (DNS), all the threats to the DNS also apply to ONS. There are several distinct classes of threats to the DNS, most of which are DNS-related instances of general problems; however, some are specific to peculiarities of the DNS protocol.

- *Packet Interception—Manipulating Internet Protocol (IP) packets carrying DNS information* Includes MIM attacks and eavesdropping on request, combined with spoofed responses that modify the "real" response back to the resolver. In any of these scenarios, the attacker can tell either party (usually the resolver) whatever it wants them to believe.
- *Query Prediction—Manipulating the Query/Answer Schemes of the User Datagram Protocol (UDP)/IP Protocol* These ID guessing attacks are mostly successful when the victim is in a known state.
- *Name Chaining or Cache Poisoning* Injecting manipulated information into DNS caches.
- *Betrayal by Trusted Server* Attackers controlling DNS servers in use.
- *Denial of Service (DOS)* DNS is vulnerable to DOS attacks. DNS servers are also at risk of being used as a DOS amplifier to attack third parties.
- *Authenticated Denial of Domain Names*

2.4.4.2. ONS and confidentiality

There may be cases where the Electronic Product Code (EPC) of an RFID tag is regarded as highly sensitive information. Even if the connections to EPCIS servers were secured using Secure Sockets Layer (SSL) /Transport Layer Security (TLS), the initial ONS look-up process was not authenticated or encrypted in the first place. The DNS-encoded main part of the EPC, which identifies the asset categories, will traverse every network between the middleware and a possible local DNS server in clear text and is susceptible to network taps placed by internet service providers (ISPs) and governmental organizations.

2.4.4.3. ONS and integrity

Integrity refers to the correctness and completeness of the returned information. An attacker controlling intermediate DNS servers or launching a successful MIM attack on the communication could forge the returned list of Uniform Resource Identifiers (URIs). If no sufficient authentication measures for the EPCIS are in place, the attacker could deliver forged information about this or related EPCs from a similar domain.

2.4.4.4. ONS and authorization

Authorization refers to protecting computer resources by only allowing the resources to be used by those that have been granted the authority. Without authorization, a remote attacker can do a brute-force attack to query the corresponding EPCIS servers until a match is found. In case the complete serial number is not known, the class identifier of the EPC may be enough to determine the kind of object it belongs to. If using the EPCglobal network becomes ubiquitous and widespread, the attacker could add fake serial numbers to the captured, incomplete EPC and query the corresponding EPCIS servers to find a match. This can be used to identify assets of an entity, be it an individual, a household, a company, or any other organization. If you wore a rare item or a rare combination of items, tracking you could be accomplished just by using the object classes.

2.4.4.5. ONS and authentication

Authentication refers to identifying the remote user and ensuring that he or she is who they say they are.

2.4.4.6. Mitigation attempts

- *Limit Usage* Use the ONS only in intranet and disallowing any external queries.
- *VPN or SSL Tunneling* With data traveling between the remote sites, it needs to be exchanged over an encrypted channel like VPN or SSL Tunneling.
- *DNS Security Extensions (DNSSEC)* ensure the authenticity and integrity of DNS. This can be done using Transaction Signatures (TSIG) or asymmetric cryptography with Rivest, Shamir, & Adleman (RSA) and digital signature algorithms (DSAs).

2.5. Risk and vulnerability assessment

The assessment of risks and vulnerabilities go hand in hand. To begin evaluating your system, you need to ask questions regarding the assessment and tolerance of the risks: what types of information are you talking about at any given point in the system and what form is it in? How much of that information can potentially be lost? Once these risks are evaluated, you can begin to plan how to secure it. A good way to evaluate the risk is to ask five classic investigative questions: "who?", "what?", "when?", "where?" and "how?"

- **Who** is going to conduct the attack or benefit from it? Will it be a competitor or an unknown group of criminals?
- **What** do they hope to gain from the attack? Are they trying to steal a competitor's trade secret? If it is a criminal enterprise, are they seeking customers' credit card numbers?
- **When** will the attack happen? When a business is open 24 hours a day, 7 days a week, it is easy to forget that attacks can occur when you are not there.
- **Where** will it take place? Will the attack occur at your company's headquarters or at an outlying satellite operation? Is the communications link provided by a third party vulnerable?
- **How** will they attack? If they attack the readers via an RF vulnerability, you need to limit how far the RF waves travel from the reader. If the attacker is going after a known vulnerability in the encryption used in the tag reader communications, you have to change the encryption type, and, therefore, also change all of the tags.

2.5.1. Type of RFID risks

RFID technology enables an organization to significantly change its business processes to:

- Increase its efficiency, which results in lower costs.
- Increase its effectiveness, which improves mission performance and makes the implementing organization more resilient and better able to assign accountability, and
- Respond to customer requirements to use RFID technology to support supply chains and other applications.[16]

This section reviews the major high-level business risks associated with RFID systems so that organizations planning or operating these systems can better identify, characterize, and manage the risk in their environments. The risks are as follows:

Business process risk - direct attacks on RFID system components potentially could undermine the business processes the RFID system was designed to enable. For example, a warehouse that relies on RFID to automatically track items removed from its inventory may not be able to detect theft if the RFID system fails.

Business intelligence risk - an adversary or competitor potentially could gain unauthorized access to RFID-generated information and use it to harm the interests of the organization implementing the RFID system. For example, an adversary might use an interrogator to determine whether a shipping container holds expensive electronic equipment, and then target the container for theft when it gets a positive reading.

Privacy risk - the misuse of RFID technology could violate personal privacy when the RFID application calls for personally identifiable information to be on the tag or associated with the tag. For example, if a person carries products that contain RFID tags, those tags may be surreptitiously read by an adversary. This could reveal that person's personal preferences such as where they shop, or what brands they buy, or it might allow them to track that person's location at various points in time.[16]

Externality risk - RFID technology potentially could represent a threat to non-RFID networked or collocated systems, assets, and people. For example, an adversary could gain unauthorized access to computers on an enterprise network through Internet Protocol (IP) enabled interrogators if the interrogators are not designed and configured properly. Multiple RFID interrogators operating in a confined space may cause hazards of electromagnetic radiation to fuel, ordinance or people in the vicinity.

2.5.2. Risks in supply chain management and tracking applications

Tracking applications are used to identify the location of an item, or more accurately, the location of the last interrogator that detected the presence of the tag associated with the item. An example of an intentional attack on an RFID business process is cloning, which occurs when an adversary reads information from a legitimate RFID tag and then programs another tag or device to emulate the behavior of the legitimate tag. Another attack on an RFID business process would be removing a tag from the item it is intended to identify and attaching it to another unrelated item.

Supply chain management involves the monitoring and control of products from manufacture to distribution to retail sale. Supply chain management typically bundles several application types, including asset management, tracking, process control, and payment systems. Supply chain systems record information about products at every stage in the supply chain. Ideally, tags are affixed to products during the manufacturing process or soon afterward. As a product moves through the supply chain, to the customer, and to post-sale service, the tag's identifier can be used by all supply chain participants to refer to a specific item.

In addition, supply chain systems that use active tags can track larger objects such as cargo containers. Tags on these containers can store a manifest of the items shipped in each container. This manifest can be automatically updated when items are removed from the container. Potential problems are not just limited to the RF subsystem. If the network supporting the RFID system is down, then the RFID system is likely down as well. In supply chain applications, network failures at any point in the chain have the potential to impact the business processes of any subsequent link in the chain. For example, if a supplier is unable to write manifest data to a tag, then the recipient cannot use that data in its operations even if its RFID interrogators and network infrastructure are fully functional. Servers hosting RFID middleware, databases, analytic systems, and authentication services are all points of failure.

Any efforts to assess business process risk need to be comprehensive, because such a wide variety of potential threats exist. All of these threats have the potential to undermine the supported business process and therefore the mission of the implementing organization.[3]

3. RFID in procedural conditions of logistic operators

Supply chain can be defined as the parts that are involved, directly or indirectly, in fulfilling a customer request (Chopra and Peter 2007). By this definition, it can be seen that a supply chain consists of manufacturers, warehouses, retailers, transporters, and customers. The purpose of a supply chain is to maximize the value generated for the customer; namely, maximizing the difference between the final product worth and the total expended by the supply chain to provide the product to the customer.

In order to succeed, the supply chain must be conducted to minimize the costs incurred. Supply chain management (SCM) is responsible for optimizing the flows within its operational stages which include raw materials, manufacturing, distribution, and transportation in order to minimize the total cost of the supply chain. SCM is a unification of a series of concepts about integrated business planning that can be joined together by the advances in information technology (IT) (Shapiro 2007), yet many companies have not completely taken advantage of this process.

In today's world, the competition between companies, more demanding customers, and reduced margins make the scenario more difficult for companies to succeed, to this context, SCM is an important practice for companies that want not only to keep in business but also have their results optimized and meet the clients' expectations.

Responsiveness in the supply chain has gained importance and it is a trend that apparently will dictate future decisions regarding supply chain design. According to Kovack, Langley, and Rinehart (1995), the themes that will have influence on logistics on the near future are:

- Strong corporate leadership will enhance logistics value through focusing on efficiency, effectiveness, and differentiation.
- Value realization requires marketing of logistics capabilities within the company and to external customers.
- Emphasis on the "scientific" aspect of logistics management in order to enhance the "art" of creating customer satisfaction. Enhancing logistics value through integrating product, information, and cash flows for decision-making linking external and internal processes. Logistics value enhanced by ownership of responsibility internally and externally to the firm.
- Focus of successful companies is to create internal value for their organizations and external value for their suppliers and customers.

From these themes, it can be seen that SCM plays and will continue to play an active role in successful companies' routines. In order to achieve better results in the supply chain and better responsiveness to customers' necessities, new techniques such as real-time inventory and dynamic supply chain need to be developed.

3.1. Transportation in logistics and SCM

As a supply chain driver, transportation has a large impact on customer responsiveness and operational efficiency. Faster transportation allows a supply chain to be more responsive but reduces its efficiency. The type of transportation a company uses also affects the inventory and facility locations in the supply chain. The role of transportation in a company's competitive strategy is determined by the target customers. Customers who demand a high level of responsiveness, and are willing to pay for the responsiveness, allow a company to use transportation responsively. Conversely, if the customer base is price sensitive, then the company can use transportation to lower the cost of the product at the expense of responsiveness. Because a company may use transportation to increase responsiveness or efficiency, the optimal decision for the company means finding the right balance between the two.

The transportation design is the collection of transportation modes, locations, and routes for shipping. Decisions are made on whether transportation will go from a supply source directly to the customer or through intermediate consolidation points. Design decisions also include whether multiple supply or demand points will be included in a single run or not. Also, companies must decide on the set of transportation modes that will be used.

The mode of transportation describes how product is moved from one location in the supply chain network to another. Companies can choose between air, truck, rail, sea, and pipeline as modes of transport for products. Each mode has different characteristics with respect to the speed, size of shipments (parcels, cases, pallet, full trucks, railcar, and containers), cost of shipping, and flexibility that lead companies to choose one particular mode over the others. Typical measurement for transportation operations includes the following metrics:

- Average inbound transportation cost, or the cost of bringing product into a facility as a percentage of sales or cost of goods sold (COGS). Cost can be measured per unit brought in but is typically included in COGS. It is useful to separate this cost by supplier.
- Average incoming shipment size measures the average number of units or dollars in each incoming shipment at a facility.
- Average inbound transportation cost per shipment measures the average transportation cost of each incoming delivery. Along with the incoming shipment size, the metric identifies opportunities for greater economies of scale in inbound transportation.
- Average outbound transportation cost measures the cost of sending product out of a facility to the customer. Cost should be measured per unit shipped, oftentimes measured as a percentage of sales. It is useful to separate this metric by customer.
- Average outbound shipment size measures the average number of units or dollars on each outbound shipment at a facility.
- Average outbound transportation cost per shipment measures the average transportation cost of each outgoing delivery.

- Fraction transported by mode measures the fraction of transportation (in units or dollars) using each mode of transportation. This metric can be used to estimate whether certain modes are overused or underutilized.
- The fundamental trade-off for transportation is between the cost of transporting a given product (efficiency) and the speed with which that product is transported (responsiveness). Using fast modes of transport raises responsiveness and transportation cost but lowers the inventory holding cost.

3.2. Information technology and SCM

It is no surprise that IT played a big role in enabling many processes and ideas in Supply Chain Management (SCM) that seemed impossible in earlier years. The first advance was the decreasing of inventory levels by managers abandoning rules of thumb and adopting the setting of inventories based on service level desired and historical demand (Shapiro 2007). IT allowed the analysis of a great quantity of units and the process of recalculating the inventory level as the demand changed. This ability to analyze inventory needs made the companies more agile while decreasing inventory levels and increasing service levels.

Another important fact that gave a great contribution to SCM was the electronic interchange (EDI). This technology allows the direct data interchange between companies using computers. EDI changed the relationship between the company and customers, with its suppliers, and also with the employees. The ability of trading data almost instantly across the supply chain gave companies the ability to manipulate more up-to-date information in a shorter period of time. This reduced the need for printing and transporting papers, enabled just-in-time practices, and helped to restructure logistics supply chain relationships. Together with EDI we can also mention the importance of the Internet in global business (Johnson et al. 1999).

Artificial intelligence systems are responsible for many advances achieved by society and by SCM as well. Computers can be programmed to execute routine functions and according to the rules imposed to the computer it can be capable of behaving an intelligent system that can execute complex activities in reduced time. This brought to logistics a much larger capacity of processing information and executing tasks. Many activities can operate without human interference and this converges to a more responsive and accurate supply chain (Johnson et al. 1999).

Some technologies, discussed later in this chapter, can be used to make real-time adjustments to the supply chain. Those adjustments could be due to many events such at manpower shortages or equipment breakdowns. For example, if a problem occurs with a truck or the road conditions change due to weather, the system, supplied with this updated information, should be able to make the necessary corrections to the transportation routes of other trucks to compensate for the truck failure.

This system would be very useful for natural disasters such as Hurricane Katrina. With real-time information, the system would reallocate transportation and production. This kind of modeling would reduce the response time for such events from months or weeks to days or even hours. This system can also be expanded to urban transportation within a city or long distances between two cities.

3.2.1. Real-time technologies

Radio frequency identification (RFID) and global positioning systems (GPS) are emerging technologies that will allow for real-time data collection to assist with decision support in SCM. RFID has a wide variety of applications. Some examples of RFID uses are library checkout stations, automatic car toll tags, animal identification tags, and inventory systems. Real-time data collected using RFID allows a supply chain to synchronize reorder points and other data. Real-time information can also be used to design and operate logistical systems on a real-time basis. GPS is currently used solely as a means to locate equipment and derive navigation directions.

An RFID system consists of a reader, tags, and an air interface. The reader, also known as an interrogator, sends out a signal through an antenna. This signal is usually in the form of an electromagnetic wave, so a direct line of sight is not needed to read the information on the tag. This is a major advantage of RFID. The signal is received by the tag and a response signal is sent back to the reader. This response signal contains a unique identifier associated with a tag. The response signal can be powered in two ways corresponding to the type of tag. Passive tags utilize the energy of the original signal to send a response signal back to the reader. Passive tags have a limited amount of energy to power the response signal. Therefore, the amount of information transmitted by a passive tag is fairly small, quite similar to the information carried in a bar code. Active and semi-active tags use energy from an attached battery to power the response signal. The use of the embedded battery allows the response signal to contain more information and travel farther. The reader receives the response signal, decodes it, and sends that information to a database. Often the information in the response signal is connected to additional information in the database.

RFID technology can be used throughout the supply chain in order to promote visibility. This visibility helps coordinate actions between entities in the supply chain. Figure 4 shows the relationships within the supply chain that can be affected by the implementation of the RFID technologies. An example of RFID implementation is the use of active tags for detecting tampering and monitoring security of maritime containers. Those types of tags also have the tracking advantages of RFID and can be used to improve operations management. Those tags can be seen in Figure 5.

GPS systems consist of a series of receivers and satellites that orbit the Earth-GPS works by calculating the distances from a receiver to a number of satellites. With each distance between a receiver and satellite, the number of possible locations is narrowed down until there is only one possible location. A receiver must calculate its distance from at least three satellites to determine a location on the surface of the Earth. However, four satellites are usually used to increase the location accuracy (Dommety and Jain 1996). This process of location would be controlled by the positioning module of GPS system. An average GPS positioning and navigation system would also have the following modules:

- **Digital map database,**
- **Map matching,**
- **Route planning and guidance,**
- **Human-machine interface,**
- **Wirelesscommunication.**

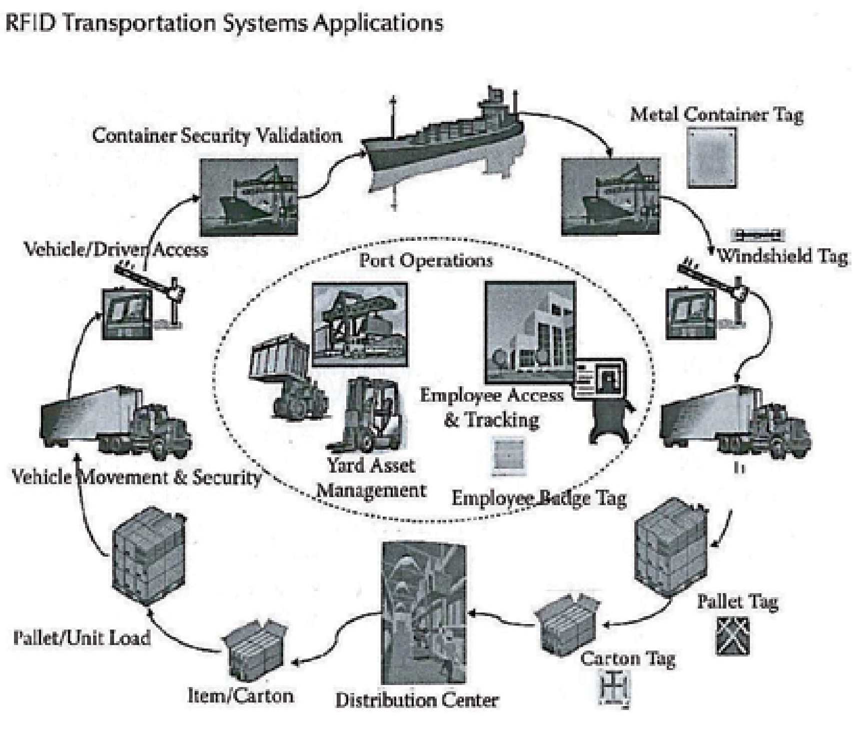

Figure 4. Integrated supply chain with RFID (Source: SAVI Technology)

There are three positioning technologies that can be used: radio wave-based positioning, dead-reckoning, and signpost. The use of GPS for navigation can have direct and indirect impacts on intelligent transportation systems. GPS navigation systems can provide information about local surroundings. Also, emergency personnel can be provided with a precise location for situations, thus reducing response times. Asset tracking is one of the most popular uses of GPS. One of the limitations of GPS is that receivers cannot communicate with satellites when indoors (Feng and Law, 2002).

RFID and GPS are radio wave-based technologies that are currently used by many organizations. RFID is primarily used in inventory and material handling processes. Tags are placed on items. When these items pass by checkpoints where readers are located, the tag is read and the appropriate action can be taken. Real-time inventory can be kept by monitoring tag reads at strategic points like loading docks. RFID can also be useful in material handling. Items on a conveyor can be diverted at the appropriate times based on the information received from the RFID tag. GPS is primarily use to track assets such as vehicles and other expensive equipment. For example, if a truck breaks down, it is possible to locate the truck and get the shipment moving again in a fraction of the time it would take with a GPS receiver.

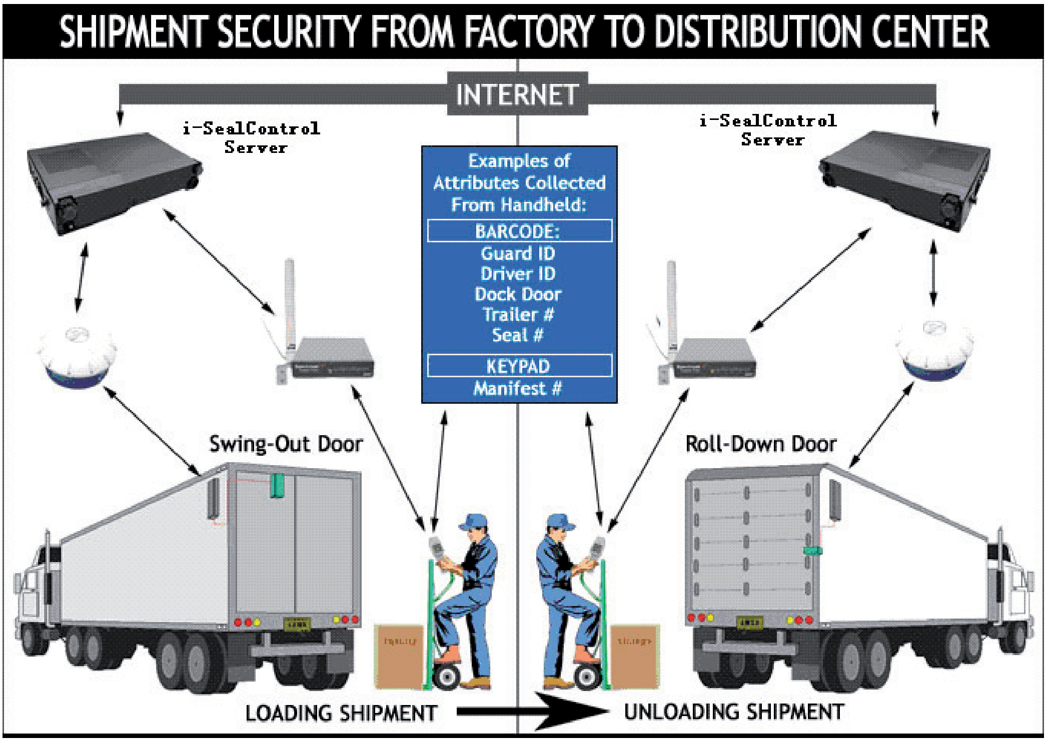

Figure 5. RFID Container Seal (Source : SAVI Technology)

Summary of RFID and Information Enablers

This section provides understanding of key technologies and how all the technologies differ and how they can be integrated to work for operational effectiveness. This will allow warehouse management system algorithms such as "bucket brigade" calculations, picking route optimization, and other effective system updates that will improve operations. Further insights into safety stock minimization, customer order optimization, and pick/stock labor minimization will be affected and discussed later.

3.2.2. RFID Provides timely visibility in logistics

RFID supports information in the supply chain by enabling visibility. The concept of visibility describes the ability of anyone, including customers, to have access to inventory, orders, raw materials, and delivery points at any time. Visibility is currently [provided by a mixture of automatic identification, or auto-ID, technologies such as bar codes, smart labels, ISBN, and UPC codes, along with others. The opportunity for RFID is that its non-line-of-sight scanning, the integration of the aforementioned auto-ID identifiers into RFID nomenclature, and the push for standardized technology protocols will provide large supply chain savings.

The real-time nature of RFID is considered a benefit and currently a challenge. The benefit is that you have the latest information to make the best decisions; the drawback is that the amount of data currently presents a data storage problem for operational systems.

Better visibility provides reduced inventory, labor and assets management using inventory policies, scheduling, and decision support system information. This is exemplified by the fact that:

- RFID supports reduced inventory costs with more effective labor policies
- RFID supports labor reduction with more effective scheduling
- RFID supports the reduction of expensive assets such as facilities, trucks, containers, and railroad time because of more accurate information in decision support systems. The ability for RFID to provide timely information and visibility into the supply chain are based on three components of RFID technologies. They are
- **Automatic data capture,**
- **Real-time information**
- **Real-time location system.**

The RFID enabling technologies diagram shown in Figure 6 represents these components as interconnecting orbits.

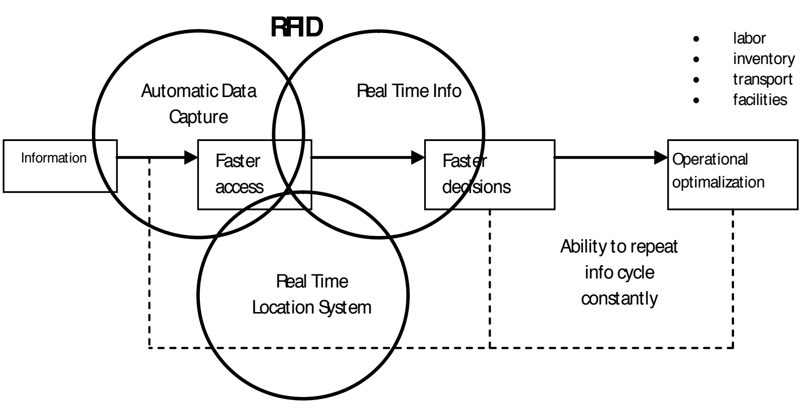

Figure 6. RFID-enabling technology

The figure also shows how RFID supports timely information in the supply chain by enabling information to be accessed faster. This implies that faster decisions can be made, which produces operational optimization that can be effectively repeated. In the figure, one of the boxes represents the RFID information flow. The ability to allow resident information collected automatically in real-time leads to faster, more effective decisions is where RFID shows future promise. Business costs are reduced as operations become more productive by reducing labor, transportation, and facility cost of moving inventory in the supply chain and postal services.

Many organizations see that the benefit of using RFID is that they can effectively manipulate inventory. Inventory exists in the supply chain because of the variance between supply and demand. This variance is necessary for manufacturers where it is economical to manufacture in large lot quantities and then store for future sales. The variance is also present in retail stores where inventory is held for future customer demand. Oftentimes businesses suggest that inventory is a marketing vehicle creating demand by passing customers. The main role inventory plays is to satisfy customer demand by having product available when the customers want it. Another significant role that inventory plays is reducing cost by exploiting economies of scale that may exist during production and distribution. Given that economy of scale is believed to have such a large impact on inventory, we will present some relevant information regarding inventory in the supply chain.

RFID is essentially in the same position occupied by mobility and wireless technology a few years ago. It is poised to spark a global revolution—in supply chain visibility and management. Using RFID in pivotal points in the supply chain can help enable a vision of having goods available to customers at the right place and at the right time. RFID technology is an enabler of this vision aiding the synchronization between physical and information flow of goods across the supply chain from Manufacturer to Retail Outlet, represented on figure 7. [1]

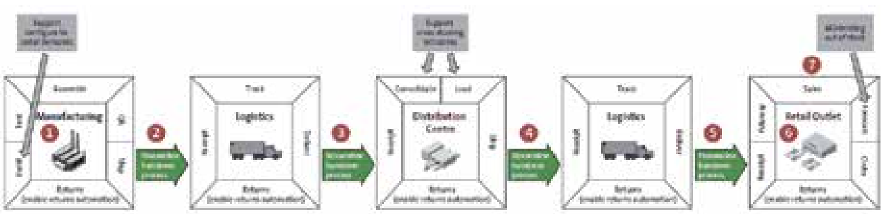

Figure 7. Supply chain containing RFID technology

Manufacturing

As goods travel down the production line, RFID tags are physically applied and a unique ID is written and then validated for quality assurance purposes. The unique ID is automatically associated to the product/order details to facilitate further tracking and exception management.

During the pallet build process; goods (e.g cases) are automatically identified to aid with customer order configurations. Finally, pallets are identified and tracked as they are delivered to the staging area ready for shipment.

http://dx.doi.org/10.5772/53285

Manufacturer – Logistics pickup

As the logistics vehicle arrives at the loading dock, the RFID reader positioned at the loading dock communicates with the unique RFID tag to confirm that the logistics vehicle is authorised to pickup goods. Upon approval, pallets leaving the loading dock communicate with the RFID reader to alert B2B systems (ASN) and ERP systems to initiate electronic transactions, proof of pickup and potentially shipment invoicing.

Logistics delivery – Distribution centre (dc)

As the logistics vehicle arrives at the Distribution Centre, the RFID reader and middleware initiates an event that captures the unique ID from the RFID tag, triggering the arrival of the manifest to initiate automatic routing of the goods to the next logistics vehicle (load consolidation).

Distribution centre – Logistics delivery

As pallets are loaded onto the logistics vehicle the RFID reader positioned above the loading dock communicates with the RFID tags. The RFID tags broadcast their unique ID to the reader and via the RFID middleware transfer information to ERP systems indicating that the manifest is loaded.

Logistics delivery – Retail outlet

As the shipments of goods arrive at the receiving dock (again being detected by RFID readers), Retail ERP systems are updated to manage inventory levels (automatically, accurately and at low cost) and initiate B2B messages to Suppliers to commence invoicing.

Retail outlet – Customer

As items are removed at shelf level, the RFID reader can automatically detect the event and via the RFID middleware, initiate additional product supply requests. With such a system in place, the need to maintain costly volumes in remote warehouses is almost eliminated. At this point of the process, the customer is initiating direct demand generation on the supply chain management process.

Customer

Rather than wait in line for a cashier, the customer simply walks out the door with the purchase. A reader built into the door recognises the items in the cart by unique ID's. A swipe of the debit or credit card and the customer is on their way.

3.2.2.1. Future technologies

Current applications of RFID and GPS systems have allowed for more effective tracking of inventory and assets. These technologies can be used in conjunction, but the data has to be captured and written to a database to be correlated to other tags or receivers. If these technologies can be combined to produce hybrid systems, greater gains can be achieved. One focus of research is the nesting of GPS receivers and various RFID tag types. If tags and receivers were able to communicate with one another, even more accurate real-time data collection could be achieved during transportation. This would also reduce equipment costs because fewer readers would be required. The nesting would follow the form in Figure 8.

If these technologies can be nested, it will allow the information in a bar code or a passive RFID tag to be collected by an active tag. This information could then be combined with the information contained within the active tag and transferred to a GPS receiver. The GPS receiver could then send not only its location but all of the information about the cargo being shipped (Reade and Lindsay 2003). A possible application of this nested technology approach would be in the railroad industry. Currently, there are two passive RFID tags attached to the sides of all railcars in the United States. In addition, most railroads use GPS receivers to track locomotives. If nesting became possible, implementation would be easy. Active tags could be used to capture the information correlated to the cargo in all of the railcars and transmit it to the GPS receiver and thus to the inventory databases.

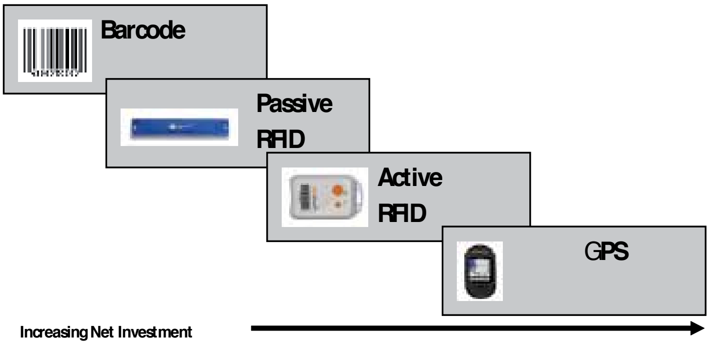

Figure 8. Nesting diagram

In addition to nesting technologies, more advanced tags can be developed to allow more detailed data collection. Tags that utilize sensors to capture and write data to the tag are being developed. Some tags have been developed but are still very unreliable. These sensor tags could be used to monitor physical parameters, like temperature and humidity, as well as security parameters. The main problem faced by these passive sensor tags is the limited power supply. The sensor cannot use any energy while outside the range of the reader. Also, the amount of energy available while in read range is very small. This limits possible measurement techniques (Want 2004). With these sensor tags, perishable goods could be monitored to guard against possible safety issues. This could include salmonella outbreaks caused by frozen chicken reaching too-high temperatures for too long and medications being held at temperatures that reduce potency.

4. AIDC and mobile technologies in postal sector

This part primarily deals with identification of postal items and transport units in logistic chain of postal operators. Nowadays, the identification is carried through barcodes and optical character recognition. In this article we would like to specify, how can be transport units identified in the transmission process by RFID technology. In the carriage of postal items is necessary to decide what type of transport is used for that purpose, what the flows of items are and what their intensity is.

The part described scheme of the transport process, including planned technology and there is also simulated a real postal process in conditions close to operational.

An unavoidable part of today is a dynamic development in the field of mobile technologies, their everyday use and application of the processes, which largely supports the level of quality of postal services and thereby strengthening the market positions of individual postal operators. This area is even more pertinent that in all countries of the European Union since 1 January 2013 approved the postal market and postal services. In this respect, it is necessary to include postal processes embarked on new technologies to ensure the competitiveness of the national postal operator and alternative providers.

RFID technology has been selected by an international post corporation (IPC) to test deliverability (transit time) of items in 55 countries of the world (Slovak republic including). The requirement of transit time is defined by Universal Postal Services and applicable also for Slovak Post. Despite the RFID technology is being known and being improved for a long time, it is essential to define the standards and security requirements.

Besides efficiency, consolidation and globalization within the European Union, interoperability is one of key elements. It is the ability of information and communication systems (including the supported processes) to exchange data, share information and knowledge, which leads to standardization.

4.1. Methods and aims

For understanding of issue is should be analyze terms used. The availability of RFID components, GPS devices and possibility of using satellite navigation there is possible to create a relative effective infrastructure for improving management of transport process by post.

There is true, that personal correspondence is on the wane, the main reason is development of information technology especially Internet, but large part of using a postal services have a companies and therefore the services will remain an indispensable part of society.

4.2. Structure

When we focus on these connections, external influences on postal sector and potential current technologies there is important to analyze possibilities of automation individual processes, improve a transportation operating activities and ensure continuity in fulfilling the goals. These aims lead to satisfying of customers in area of provide post services at phase in the delivery of mail.

The aim of this part is refer on possible improve in this area. The most important term of category, which will use in individual chapters are: mobile technology, definition of means transport.

4.2.1. Mobile technology

The classification of wireless technologies based on the distance or reach of the broadcast signal provides insight on their potential use. A condition of transport a date in broadcast systems and networks is communication without physical contact.One of the possible division of this system is on range of coverage:

- **Global system –** These systems coverage of territorial area. There we can speak on worldwide operating systems, which aren´t dependent on a concrete application and their communication is carried through different protocol. (for example: Satellite communication systems, GPS)
- **Metropolitan systems** – These systems operate on lower geographic area. They usually operate at state level. (For example: The system based on wireless technology, Wi-Fi)
- **Local systems** - These systems operate at a distance, which include a several cm up to several hundred meters (For example: Bluetooth, RFID)

4.3. Postal transport network

The postal transport is most important part of process from submission of mail after its delivery to addresses with consistent set of quality standards for different types of mail. These standards are also based on the postal license and the requirement for quality by the universal postal services.

The postal transport network includes postal courses and infrastructure. While constructions of postal transport network are use a different systems and tools. The postal transport network is divided into three basic levels:

- **district transport network (OPS**) - this network connecting establishment with other facility of processing center area.
- **regional transport network this(RPS**) – this network connecting the main processing centers with district processing centers of own district.
- **main transport network (HPS) –** this network connecting the main processing centers, the main processing center with the district processing centers from different district of HSS. This network includes transport conclusion in international relations.

In the carriage of postal items is necessary to decide what type of transport used for that purpose, what are the flows of items and what is their intensity. Way to connect and type of vehicle depends on the following factors:

- density and organization of the postal network,
- flows of different types of postal items and their size,
- the carrying capacity of vehicles used,
- transport time of each species of postal items,

- safety and effectiveness of postal traffic.

Processing of items is implemented in the workplace of the Slovak Post:

- **HSS - main processing center** - the facility providing treatment and quest items posting its area of perimeter, mail items addressed to your district and in transit in its dealings with OSS circuit, in contact with other HSS and OU,
- **OSS - regional processing center** - post office responsible for preparing and quest items posted at post offices in his own constituency and in transit in contact with your postal district and interacted with the HSS, the facility responsible for receiving, processing and quest items express postal services,
- **selected post** - post office responsible for preparing and quest items selected species within a specified range (usually as OSS),
- **Exchange post** - processing the shipment and ensure shipments to post offices exchange foreign postal administrations,

Regional hub as department of express service - establishment is responsible for receiving, processing and quest items express postal service.

4.4. Characteristics of transport units and processes

Characteristics of transport units - Slovak Post, a. s. used in the transport process shipments following shipping units: containers, leaf containers and postal bags. Containers are used in the transport process at HSS and OSS, on the local network using only postal letter case and postal bags.

Basic flow of transport processes are show on next figure including use a basic mobil technology in relevant stages.

The postal courses represent connection, which is set by transportation route with time data movement of vehicles used for carrying of postal mails. The postal courses are divided by the following criteria:

- **The rail transport –** used on carrying of postal mails through rail network. The conclusions are transport in wagon, which owned SP, a.s.
- **The road transport –** used road infrastructure for carrying conclusions. The conclusions are transport by vehicle, which own of SP, a. s.
- **The fly transport –** this type of transport is most advantageous for fast speed and overcoming large distance. The SP, a.s. used this type of transport on agreements with individual airlines. It only use for international postal mail transport.

The greatest part of transport postal mail is ensured by the road transport between main transport network (HPS), regional transport network (RPS) and district transport network (OPS).

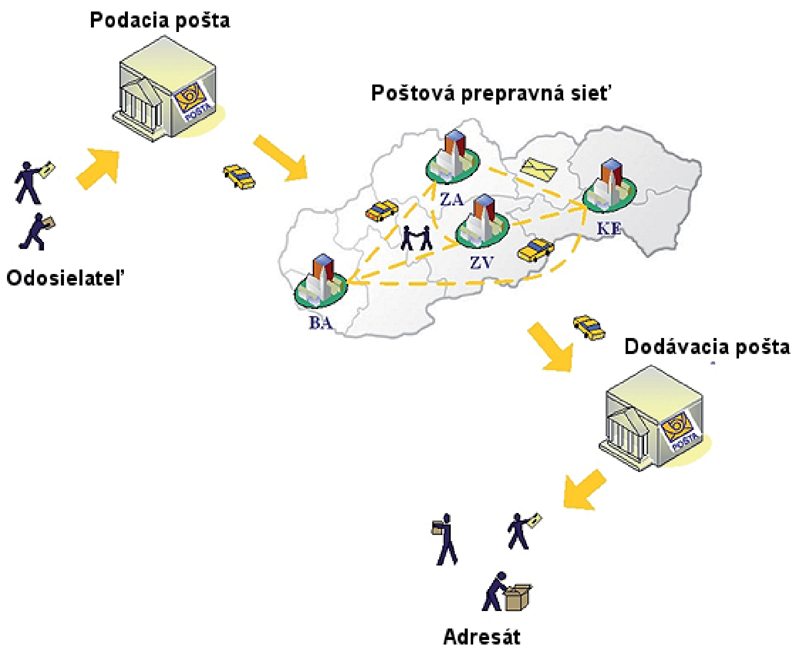

Figure 9. Simplified diagram of movement of the consignment of transmission network in Slovak

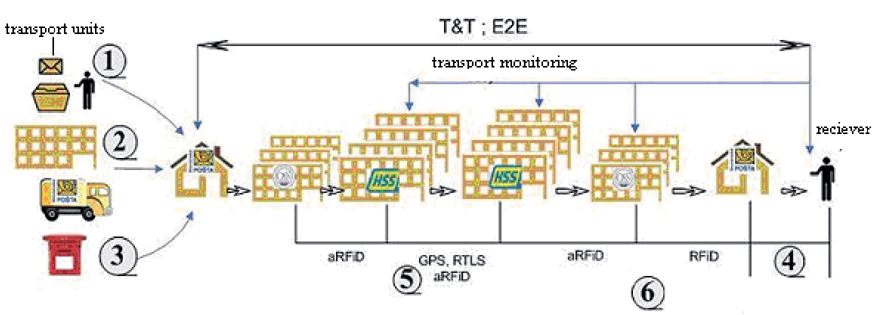

Figure 10. Scheme of the transport process, including planned technology

1. sender pass the post office at the counter
2. collecting expedition posting or accumulating courses,
3. pass through postal box,.
4. mobile technology - monitoring the transport process,
5. possibilities for optimizing routes for mail delivery
6. communication with the addressee.

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4.4.1. Transport units

The Slovak Post used the following transporting units in the transport process:

- container
- letter boxes
- bags

The postal operator has four types of containers for transport of letters and bags:

- platform truck – made by aluminum profiles connecting by PVC parts. This container is equipped by securing straps,
- stable structure track with rear wall and two side panels with wire grid 100x100mm,
- truck shipments on a very stable structure, floor frame and rugged steel profile galvanized steel thickness 1mm,
- folding platform truck made of steel profiles welded together by fasteners.

The containers are used in the transport processing at HSS and OSS. In the local postal network used only containers and bags.

4.5. Design applications

It is obvious that these systems are in a lot of cases combined and interrelated. In this design is emphasis on technology, which their using isn´t common. There is mean GPS, Wi-Fi, GSM and more. On the figure, there are plans with this technology. Some of these technologies the postal operators used now and this is reason, why was this design focused on mail monitoring in transport processes on passive RFID technology.

For possible future use of the possibilities currently offered by some mobile technologies, we have tried outline Figure 11 scheme of the transport process, including the applicable technologies selected and purpose of their use:

aRFID such as active RFID technology – application within HSS and OSS use on monitoring containers a transporting units, optimization process and better evaluation quality of postal services,

- **pRFID** such as passive RFID technology – application between post office and sender/addresses of postal mails. There is a lot of option of using,
- **BC** – bar code – barcode using by SP, a, s. at present,
- **RTLS** – monitoring mails, which are important or contain perishable content,
- **GPS –** route monitoring, possible specifying of delivery place for some type of mails,
- **GSM –** communication through mobile phone, information about mails, possible locate a place for delivery mails, possible pay for service through mobile phone

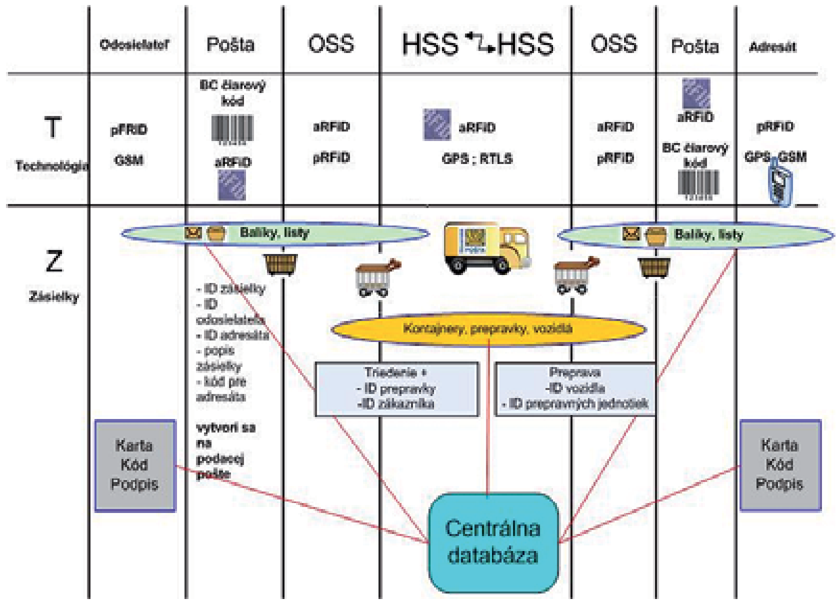

Figure 11. Scheme of the transport process, including the anticipated technologies

4.6. Types of RFID application in conditions of postal processes

The AMQM[1]™ Platform provides postal operators with a complete overview and effective traceability of mail volumes, parcels, mail bags, mail items, trucks, roll-containers and letter trays across the entire logistics chain. One key feature is automatic consignment system that associates the mail items to the containers carrying these items and to the trucks transporting these.

This solution can be based on various technologies such as: RFID, disposable RFID labels and bar codes, as well as combinations thereof. It also enable objective documentation of times of arrival and departure of vehicles, which postal containers are loaded/unloaded, vehicle load space management, real-time information on types of mail, quantities, times of arrival, delays or changes in transport times etc. With regard to postal operational systems, the following conditions must be taken into account:

- Rough industrial environments.
- Large volumes of goods and mail.
- Short time available for processing.
- High labor costs in connection with the daily operations.
- Large potentials in automation and streamlining of manual processes.

1 AMQM – Automatic Mail Quality Measurement

4.6.1. RFID-based vehicle management

Tracking vehicles and trailers throughout the entire transport logistics chain provides considerable benefits to all parties involved, e.g. management, users and customers. The Vehicle and Trailer Tracking System is an advanced and effective IT system for monitoring and managing precise arrivals and departures of vehicles at specific points in the logistics chain.

The system is built on the experience and know-how acquired from supplying the world's largest and most widespread RFID network stretching across about 60 countries.

Implementing this system offers unique values. Examples of benefits:

- Fully automatic registration of vehicles - i.e. no manual work involved.
- Improved yard and vehicle management.
- Precise and objective record of exchange of goods between parties.
- Early warning on delays in transport to all parties.
- Precise feedback to transport planning systems.
- Improved vehicle maintenance routines.
- Cost savings in centers with real-time information available.

4.6.2. Roll cage tracking and managing

One of the main issues being addressed by the roll container tracking and managing project is need to take control of and better manage transportation assets. Another primary project requirement is to ensure that the required containers will be always available at the customers' premises and within postal operator facilities. This should overcome the tendency for planned or unplanned hoarding of roll containers that causes shortages elsewhere, especially at peak times.

Additionally, the lack of visibility of roll container whereabouts led to unnecessary loss since it was not possible to identify where the roll containers disappeared and hence forced expensive purchase of new roll containers to meet the customer service level agreements. System of the monitoring and managing roll cages includes tag (active or passive, it depends of application), that is placed on a side or on the bottom of the container (Figure 12), it also includes a handheld terminal solution for consignment of roll container, product and destination enabling load control on all roll containers (Figure 13).

The result is avoiding miss-sending and has real-time *t* volume forecasting into all facilities in the network providing efficient and on time production and distribution. Also a handheld terminal solution designed for track and trace of all individual parcels is a part of the solution providing key customers with shipment visibility throughout the whole logistic network. Miss-shipments are prevented by load-control.

Figure 12. RFID tag placed on the container

Figure 13. Handheld terminal

When a roll container is ready for dispatch, the roll container is scanned for destination and product type. If the roll container is lead through a gate not matching the destination, an alert will immediately help correct the mistake. Solution must include Asset Management software platform enabling full, real-time transparency of the location of each roll container and can be also used to track specific mail and parcel transports. [6]. Implementing this system offers unique values. Examples of benefits:

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- Improves availability and load balance throughout the logistics chain.
- Prevents hoarding of roll-containers.
- Minimizes losses.
- Helps to improve supply chain efficiency.
- Provides the ability to monitor the transported delivery time of goods.
- Helps to improve service and maintenance.

4.6.3. Letter tray tracking

Tracking and tracing letter trays throughout the entire postal logistics chain provides benefits to postal customers, employees and management. The trays are automatically registered in the postal logistics by means of RFID technology. Each letter tray has a tag that communicates and transmits information to the reader in Real-time load control (Figure 14). Now it is possible for the postal operators to reuse the same RFID network to track & trace postal letter trays. This new opportunity is a fast pay-back investment with many unique advantages to postal operators worldwide.

Figure 14. RFID tags on letter trays and Real-time load control

Key Benefits:

- Better utilization of postal letter trays.
- Possibility to analyze though-put times of mail and letter trays at distribution centre.
- Knowing the location of trays improves their availability throughout the entire logistics chain.
- Knowing the location and contents of trays improves the possibility of managing the tray sorting process right on time.
- On automatic handling systems, such as tray sorters, the reading rate can be improved dramatically compared to that of bar codes - reducing manual intervention.
- Being able to identify trays helps to improve service and maintenance.

4.6.4. Mail bag tracking

Mail bags are widely used all over the world for transporting letters. The use of the mail bags differs between postal operators from transporting standard letters, to added value letters or to being used in closed customer loops. Each mail bag has a passive RFID tag that contains information about letters, which are inside the bag and some other additional information useful for sorting and other postal processes (Figure 15).

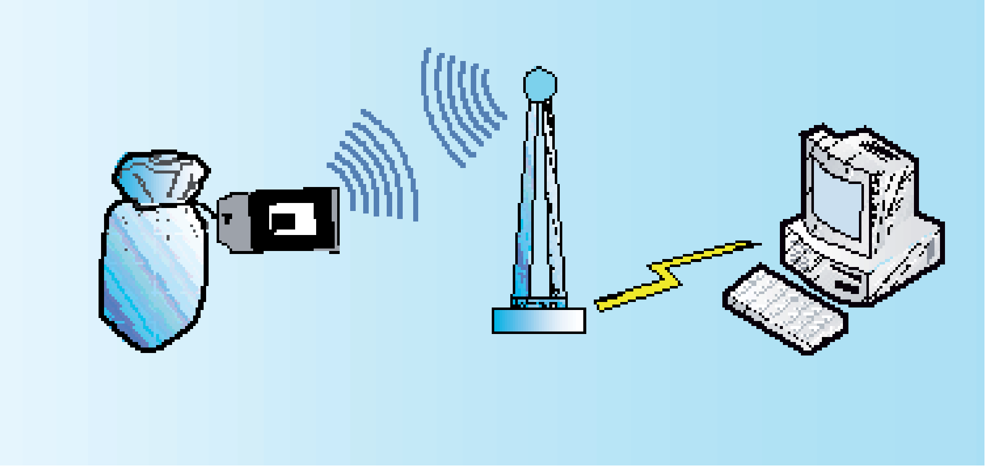


Figure 15. RFID tag placed on Mail Bag

Independent of how each postal operator is using the mail bags, tracking them can improve their competitiveness by means of:

- Optimization of processes.
- Optimization of routes.
- Control of Quality of Service.
- Internal documentation of handovers.
- Customer documentation.

Tracking solution is based on:

- Bar codes.
- Active RFID tags.
- Passive RFID tags.
- Hand-held terminals or PDAs.
- Automatic scanners.

5. The impact of the operational characteristics on the readability in postal sector

In this part we show the reality of using RFID technology to identify the letter by specific analysis of the legibility of letters in the crate. The goal was to assess whether it is possible to achieve 100% legibility of letters stored in the crate using a postal RFID technology.

To determine the success of reading measurements were performed on letter mail stored in the actual postal crate using the RFID reader and two antennas from Alien, label affixed to objects and middleware management program. Under review was to create RFID systems and perform test measurements to evaluate the success of the load of letters stored in crates and stored the measurements are properly presented and evaluated in the framework to create web application related to middleware program that is designed to manage RFID reader.

For the purposes of measurement was the technical background of Alien - RFID reader, RFID tags, and two antennas, which was created by the RFID gate. Used middleware program provided by the Italian company Aton, s.p.a. web application was developed in an environment with a PHP MySQL database system. Principle of RFID technology is as follows:

- the base of the system is reading device (reader) RFID systems and serves as a transmitter and a receiver of radio waves
- part of the reader are one or more antennas through which the reader is able to transmit electromagnetic waves to a radiofrequency, and transmit the encoded information,
- using RFID transponder tag is received electromagnetic waves with information encoded converted into an electric charge is stored on RFID tags,
- transformation of electromagnetic waves into an electrical charge is possible that the RFID tag is able to broadcast their own radio waves with its own unique encoded information,
- reader receives the signal modulated with disabilities. The information thus obtained is further processed and sent to the superior information systems.

5.1. Orientation and location of identifier

Identifiers are polarized as well as antennas. For optimal performance RFID read range and the polarization must be parallel to the polarization of the antenna. For most of the current is the polarization parallel to the longer side. Ideal antenna alignment and location identifier is an identifier in front of the antenna and the longer side oriented parallel to the polarization of the antenna. Real but it is virtually impossible to guarantee. In all applications, but it is important to align the antenna with the antenna system identifier reader. Same alignment orientation identifier in phase with the direct model antenna returns optimal results. However, the general rule is that the identifier may be disoriented by about 15 ° angle in any direction with negligible performance degradation. Correct adjustment of the system may allow an even greater tolerance. This tolerance to disorientation system allows you to read the label orientation and angle of presentation changes depending on their trajectory through reading.

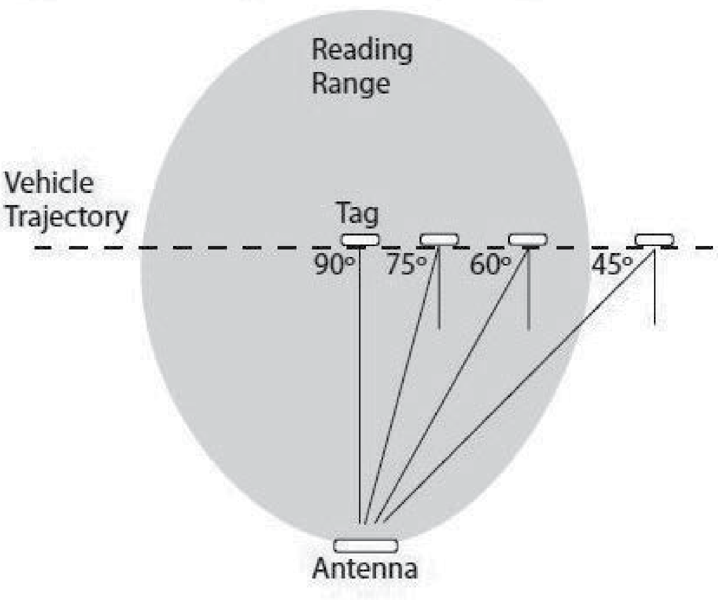


Figure 16. This is illustration shows the identifier transmitted by antennas around the reader.

This illustration shows the identifier transmitted by antennas around the reader. As shown in figure 17. range reading is weaker if the identifier to a greater angle to the antenna.

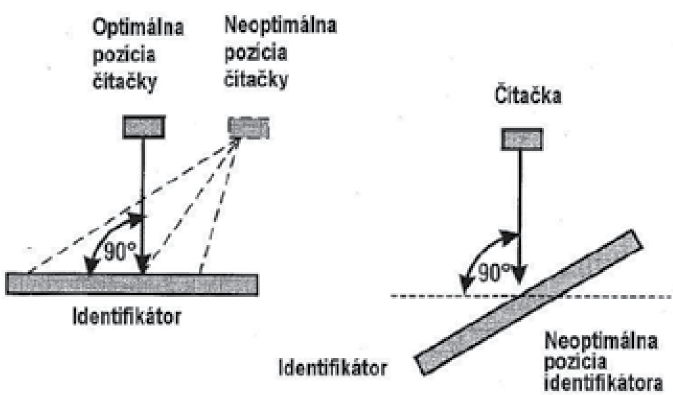
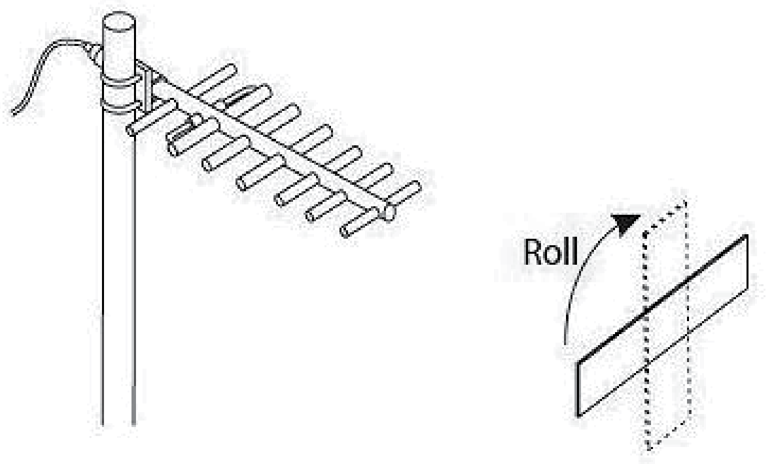
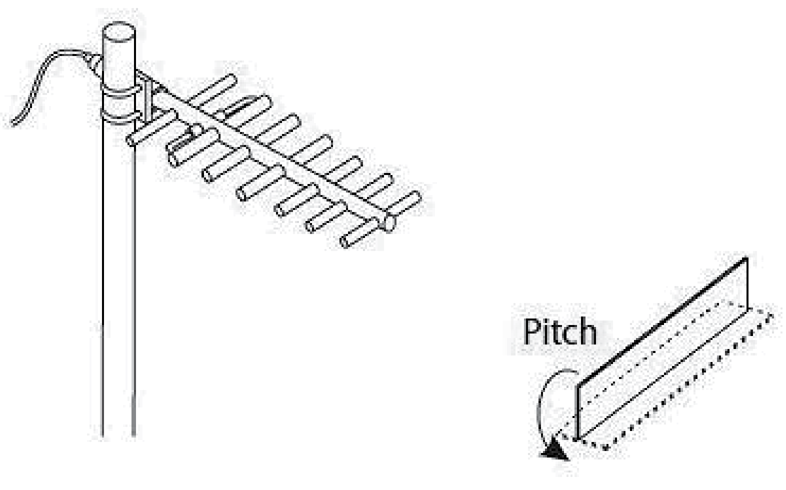


Figure 17. The optimal position of antenna and tag (identifier)

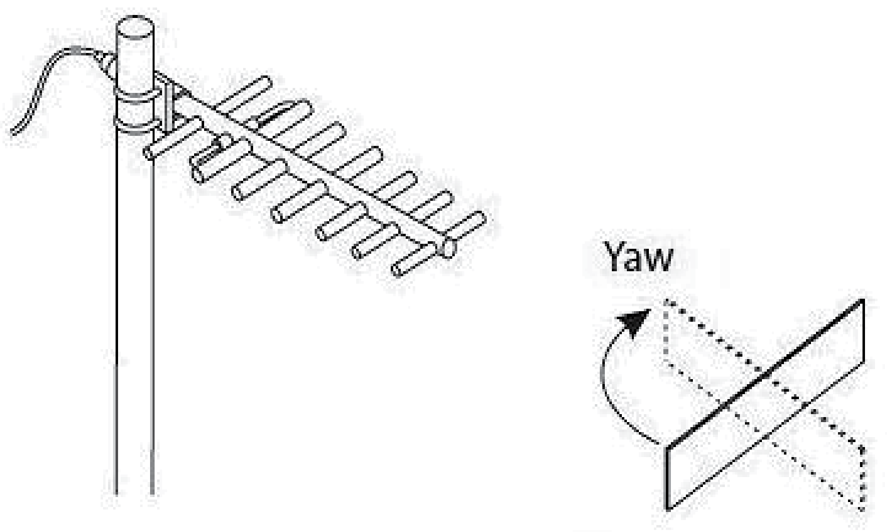
Reading range may be affected by pitch, roll or diverting of identifier. In a further assume that the antenna polarization is parallel to the long side identifier.



Scheme 1. Rotation (roll) the identifier in a clockwise or counterclockwise direction will cause loss of performance. This loss increases with expanding angle of rotation - the optimum approach angle is 90 °. That may be why the orientation of the identifier used to avoid reading other remote signals from any recources.



Scheme 2. Inclination or tilt (pitch) of identifier - the rear rotation (*front to back*) around a horizontal axis) affects performance only slightly.



Scheme 3. Rotation (yaw) facing each other (end on end) about its vertical axis is for further consideration. As the angle of identifier rotation increases from the antenna, area identifier's internal antenna, which is within the reader field is shrinking. With this reduction is also associated identifier readability.

Differences in surface mounting, the angle and height of placement, as well as changes in the angle of the transition identifier reading area are compensated if allowed a sufficient margin for optimal orientation and alignment

5.2. Evaluation of test success

The main purpose of making measurements and the creation of applications was to evaluate the success of the measurements and draw conclusions about the most significant and important impacts that affect the success of reading. The effects have been studied for measurements are as follows:

- save correspondence with the measurements
- the use of crates,
- free storage correspondence,
- number of measured items.

5.2.1. Impact of the imposition of letters

During performing measurements correspondence can be letters stored in several ways to create a number of test locations. Basis to build positions in the imposition items vertically or horizontally as shown next figure.

At horizontally aligned storage correspondence can be created as the following positions:

- items stored horizontally narrow side facing the antenna,
- items stored horizontally wider side facing the antenna,
- items stored horizontally, in the gate rotated 360 degrees.

At a vertical aligned correspondence can be created as the following positions:

- Items stored vertically, towards the flat antenna
- items stored vertically, perpendicular to the flat antenna
- items stored vertically in the gate rotated for about 360 degrees.

Other than those specified positions were also carried out tests on unaligned shipments. At vertical alignment shipment is possible to distinguish whether the letter is placed RFID tags glued upward or downward. Depicting the imposition of letters is shown in the following table. In order to determine the optimal storage correspondence tests were performed in all these positions.

Description deposit of letter items	Reading success (%)
Aligned vertically toward the surface of the antenna, the tags below	29,03
Aligned vertically toward the surface of the antenna, the tags above	64,98
Aligned vertically, perpendicular to the flat antenna, the tags below	4,15
Aligned vertically, perpendicular to the flat antenna, the tags above	11,98
Horizontally aligned, wider side facing the antenna	26,27
Horizontally aligned, narrow side facing the antenna	11,06
Aligned vertically, rotate the gate about 360 degrees	65,44
Aligned horizontally, rotate the gate about 360 degrees	42,40
Misaligned, randomly placed	85,25

Table 1. The impact of the imposition of letters

As shown in table above the highest percentage was reached at a loading unaligned accidentally saved letter. Saving is but random, and in greater numbers there is no guarantee that the RFID tags do not overlap more than one shipment. We can assume that for larger numbers, this percentage declined.

When comparing the measurements of success with storing correspondence RFID tags up and save measurements made with RFID tags can be seen down a significant difference. Greater success is achieved when depositing RFID tag upwards, which is due to greater freedom for the RFID tags. Large differences are visible when you turn the leaf surface shipments towards RFID tag antenna. Compared to the stored correspondence surface perpendicular to the RFID tag antenna is the difference in the success of loading more than 50%.

Measurements were carried out with the type of gate in which both antennas are on the sides. Gate type significantly influenced the success of horizontal loading and shipments compared to a vertical were significantly lower. Rotate the trays in the gate 360 degrees slightly increased readability vertically or horizontally stored correspondence. Optimal solution in terms of deposit of letters on the measurements is to store:

- vertical,
- flat plate toward the RFID antenna,
- Implementation in gate turned 360 degrees.

5.2.2. The impact of the use of containers

To determine the impact of the imposition of letters in the crate measurements were not made only in the crate, but also in bulk correspondence without containers. With the settings and save the items in the same position was achieved the following results:

	Reading success (%)	
Imposition of letter items	**use crate**	**without crate**
aligned, horizontally placed	82,95	84,79
aligned, vertically, tag surface to side antenna	91,71	63,59
aligned, vertically, tag surface upright to side antenna	53,46	46,08
aligned, vertical rotation	90,32	80,18
aligned, horizontally rotation	83,41	93,09
unaligned, random stored	98,16	96,31
overall	83,35	77,34

Table 2. The impact of the use of containers

The table shows that the use of containers has not a significant impact on the success of improvement or deterioration reading of letter items. When using containers to store the correspondence is achieved even greater average success on reading. This is probably due to the freer depositing correspondence in containers than in the same position simulations without containers, especially in the upright position. At horizontal position, where it was easy to simulate the same position was achieve slightly higher readability without the use of crates.

5.2.3. The impact of free scope of stored letter items

By examining the different variations of the deposit of letter mail has proved an important factor affecting the success of slackness between RFID tags glued to the letter. It was had done testing with the following settings of slackness between the letter post:

- separate correspondence by carton;
- the bulk correspondence (classical)
- letter correspondence pressed together.

Degree of freedom between the letter items	Successful reading (%)
pressed together	68,66
stored slackness	69,59
separate by carton	100,00

Table 3. The impact of free scope of stored letter items

The table shows that the separation of the carton shipments has a significant impact on the success of loading achieved is 100% readable. Crushed shipments only slightly worse compared to the readability of bulk shipments.

5.2.4. The impact of other elements

Unit shipments for the cardboard several measurements were carried out to confirm 100% readability:

Studied impact	Successful reading (%)	
speed of running by gate	4 sec.	100,00
	2 sec.	100,00
	quickly	100,00
antenna distance	80 cm	100,00
	60 cm	100,00
antenna intensity	90%	100,00
	75%	100,00
	60%	100,00
	40%	100,00
	20%	95,85
optimal storage of letter		97,24

Table 4. The impact of other elements

By separating mail boxes are reaching nearly all settings by 100% readable. Mild impairment occurred only at very low intensity at 20% and save correspondence area perpendicular to the antenna. But even in these cases is very high loading percentage. But the question remains questionable real use in practice.

5.3. Model 1 – Evaluation of the feasibility of using RFID technology

At real-saving correspondence to crates are stored in the manner:

- aligned vertically,
- unseparated to each other as shown next figure.

Figure 18. Postal crate

By a given type of deposit correspondence, the maximum load value of the success achieved in the following settings:

- **intensity** of the RFID reader to a maximum value,
- **type of gate** - one antenna on the side, a top antenna,
- **remain** in the gate at least 2 seconds,
- **freely** save letter items.

After several performed in those settings with 31 letter items were obtained the following results:

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Measurement count	Number of reading items	Successful reading (%)
1	30	96,77
2	29	93,55
3	30	96,77
4	30	96,77
5	24	77,42
6	25	80,65
7	31	100,00
Overall	199	91,71

Table 5. Results of measurement

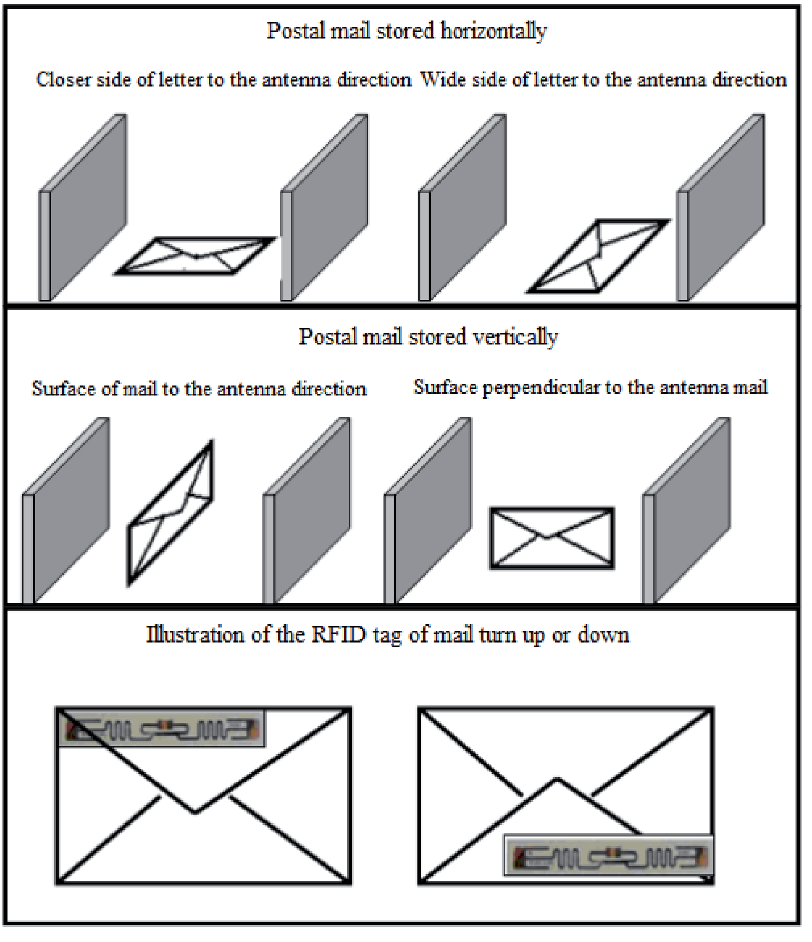

Figure 19. Position of mail while reading

At horizontally stored correspondence, following positions can be created:

- items stored horizontally narrow side facing the antenna,
- items stored horizontally wider side facing the antenna,
- items stored horizontally, in the gate rotated in 360 degrees.

At a vertically stored correspondence, following positions can be created:

- items stored vertically, surface towards the antenna
- items stored vertically, surface perpendicular to the antenna
- items stored vertically in the gate rotated in 360 degrees.

Except for those specified positions, tests were also realized on unaligned shipments. Within vertically aligned shipment, it is possible to distinguish whether an RFID tag is placed upward or downward on letter. Depicting the imposition of letters is shown in the following table.

In order to determine the optimal storage of correspondence, the tests were performed in all mentioned positions.

Description deposit of letter items	**Success of reading** (%)
Aligned vertically toward the surface of the antenna, tags placed on bottom	29,03
Aligned vertically toward the surface of the antenna, tags placed on top	64,98
Aligned vertically, perpendicular to the flat antenna, tags placed on bottom	4,15
Aligned vertically, perpendicular to the flat antenna, tags placed on top	11,98
Horizontally aligned, wider side facing the antenna	26,27
Horizontally aligned, narrow side facing the antenna	11,06
Aligned vertically, rotate the gate about 360 degrees	65,44
Aligned horizontally, rotate the gate about 360 degrees	42,40
Misaligned, randomly placed	85,25

Table 6. The success of reading the different position of mail

5.4. Model 2 – Test of readability of postal items through the RFID technology

One of the methods that could significantly make the process of identifying postal items in transport condition more effective is above mentioned RFID technology. As a wireless technology, without visual contact with the shipment, it tracks and identifies the contents without the need of manual handling from the crate. This allows easier and more efficient handling of supporting documents (creating the list of items, checking the presence of item) of postal sacks/bags and containers. With regard to price and the quantity of items processes, a question arrives: Is RFID technology effective and should be used for all shipment, including letters? As already mentioned - due to the large quantities of letter items and still quite high price of RFID tags - the method could be appropriate only for registered letters/mail. The actual implementation design of RFID technology, as shown in Figure 3 could be divided into the following phases:

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1st phase - tracking between the HSS

2nd phase – tracking between the HSS and OSS.

3rd phase – tracking between the OSS and final post office (point of delivery).

Because of our basic interest is in the RFID technology we tried to test of readability RFID tags placed on postal items in various situations. Basic assumption is the use of RFID gates at the entrance and output to the processing unit as show next figures.

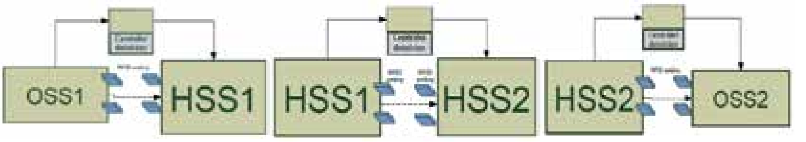


Figure 20. RFID gates at the entrance and output to the processing unit

In order to verify the practical applicability of this technology we have dealt with the preparation and implementation of practical activities through which we examined reading RFID tags. The object of these measurements was to determine the statistical characteristics of reading success and reading passive tags, placed on postal items, located in the mail bag. The aim was to provide sufficient information as accurately measured under different conditions that can occur in a real situation, including a draft measure, which would lead to the improvement of measured data.

Therefore we try to simulate a real postal process in conditions close to operational and test this technology on next component set configuration:

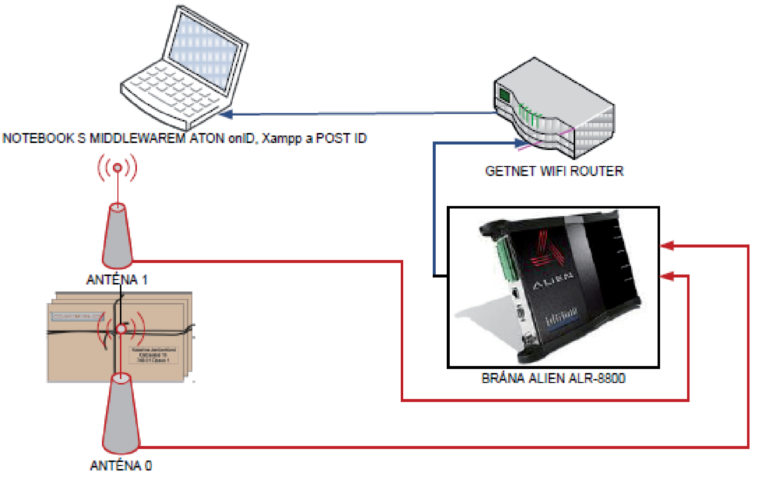


Figure 21. Principle component links

When some bundle or bundles placed in a bag entry into the detection field begin to transfer the identification data from the RFID tag to the antennas of gate. The gate extends the data (by adding date, time, number of particular antenna,…) and send them to system. Thus processed data are transmitted through the wifi router middleware Aton onId into notebook.

Figure 21 (figure located in next section) describes the principle of software components and their cooperation - communication between web applications POST ID, MySQL database server and middleware onid Aton.

5.4.1. Description of the model

There was used a software from Italian company Aton, also known as middleware, which provides the management, organizational and communication operations between different applications. In our case, the firmware Alien Gate and other applications, particularly database server. Onid Aton itself is not monolithic program, but it is a functional connection Java service console (java server) and the graphic manager called Qflow. Itself Qflow intuitive and easy enabled an interactive creation and administration of custom processes.

Major elements are program elements, called the processor to implement elementary operations (reading from the gateway, filtering, record the output, etc..)

- The first step is to enter the configuration data to POST ID. From there shall be deposited directly into database tables. The subject of this storage is data on the number of configuration items and numbers.
- In a second step, after the start of broadcasting alien element and their detection by InlineProcesor made load measurement numbers, the number of items and the configuration number and attach it to information from the antennas.
- In third step, the data are extended by the information about time and date using TimeFormatter processors. The first two into generators of text and xml files with a resolution by the uniqueness of the registration data. The third way into InsertProcessor, where the data are entered into the database. Fourth way turns itself to LackEvents processor. In the case that in a defined time there is here not recorded any new message from the gateway, it sends a new message to next two processors, which on the basis of the received message (MessageGenerator) to increase the value of measurement number by 1 and this value by updating the database InsertProcessorA.
- The second CommandExecutor processor on receipt of a report by running the alarm indicates the new number of measurements. The measurement consists of setting values in POST ID and physical adjustment of antennas. The effort was to make sure if it was possible the most accurate and smoothest possible transition from the beginning to the end of the runway. After making the transition waiting for the time needed for detection of zero, which means the CPU and LackEvents CommandExecutor will sound, indicating the end of measurement and readiness for the next measurement. At the same time processor MessageCounter increased number of first measurement after finishing the sound detection is possible again to make the switch between the antennas to the selected track.

http://dx.doi.org/10.5772/53285

Full application part is shown in Figure 22.

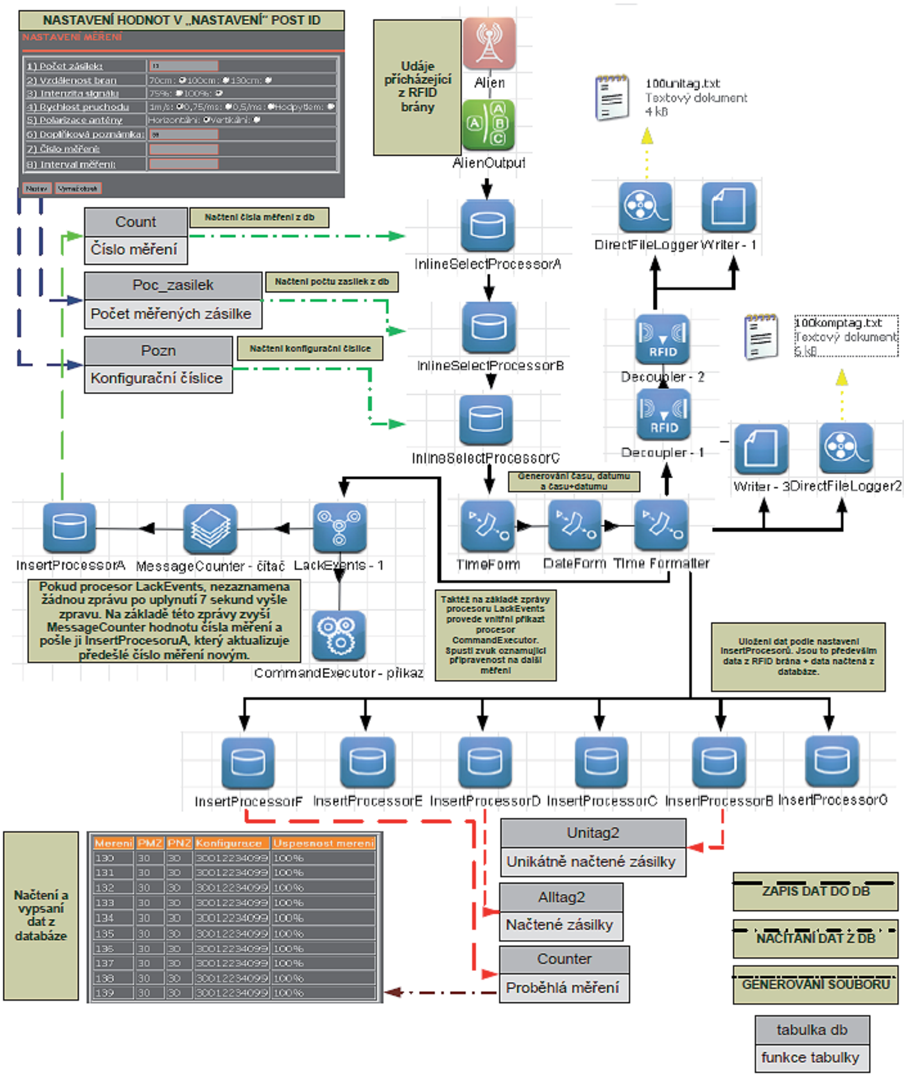


Figure 22. Final configuration model based on ATON onID

5.4.2. Test of readability of postal items

Measurements carried out in an improvised laboratory in the premises of the computer lab of the University of Žilina. There were measured passive tags placed uniformly on all mail in the middle of the upper left corner. Tags were placed so strictly because simulate challenging situation that could occur in real practice, so that all shipments under the labels overlap, the close neighbours. This arrangement could cause the EM waves emitted by RFID tags will interfere with each other. For each item was then transcribed RFID tag number and serial number marked for later processing easier statistical information. The object of measurement items were deposited into the mail bags, which are grouped into a bundle. To determine the characteristics of reading and expanding sub-measure was introduced by another character, and that is the position of the beam due to the antennas. These positions are defined (according to Figure 23):

1. boundle horizontally - the length of the area enclosing antennas,
2. boundle horizontally - the width of the area enclosing antennas,
3. boundle vertically - party address shipments parallel flat antennas,
4. boundle vertically - mail address side perpendicular to the plane antenna.

Likewise, in our measurements were sequenced according to the serial number of items, grouped into bundles, according to the size of the consignments as shown in Figure 23.

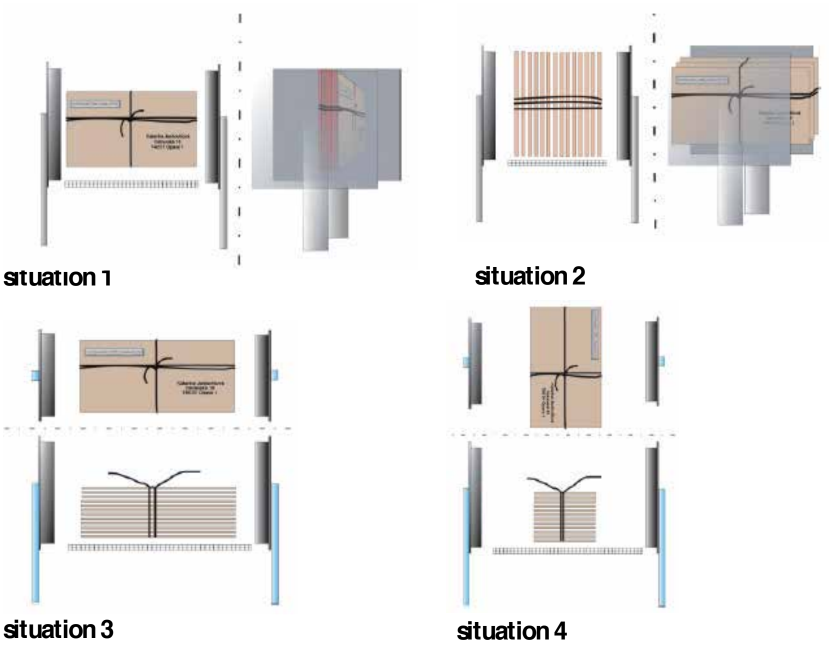


Figure 23. Configurations of letters bundles

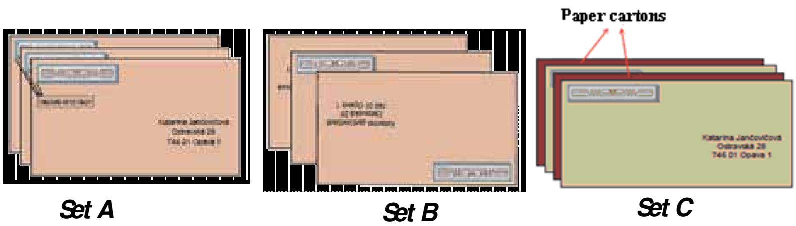


Figure 24. Several set of letter bundles

We have used two ways of transporting items via gate:

1. Static transfer through the postal truck or conveyor, also examined the transport unit volumes, which are in relative peace in terms of positioning items
2. Dynamic hand, respectively manual transfer using human power - move with a rate shocks, which could help to better read the labels in bundles.

All data recorded after the measurement time was subject of evaluation, and because of the large scale of the recorded data was be evaluated only average and cumulative results Determining the accuracy of measurements based on the statistical characteristics - it is a statistical description, which expresses the degree of statistical variability of the file, it indicates the letter R, It indicates the difference between the largest and smallest value and in some extent we are able to denounce both the large inaccuracies in the measurement occurred. It is expressed by the formula$R = X_{\max} - X_{\min}$. In percentage terms inaccuracies modified formula looks as follows:

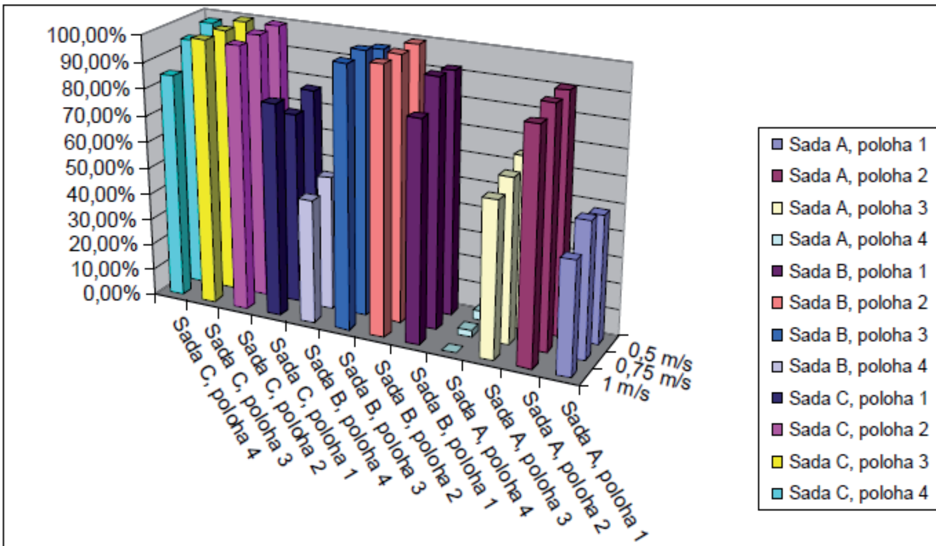
$$Z = ((X_{\max} - X_{\min}) / number\_of\_items) * 100$$

Based on this formula was compiled by chart positions inaccuracies sets.

Since the evaluation of this quantity of data with the graphic processing is substantially opaque (a sample can be figure 25 with a graphical evaluation, which is a preview of kits depending on the speed of transition between the antennas) and it is not possible to present all the results of measurements on such a small space of this contribution will sum up only the basic results of the measurements and focus only on some important findings.

The measurement is made clear that that some parameters are irrelevant in terms of readability, such as speed of shipments run through the transition zone readers are relatively independent (readability in an average of about 76% to 2% deviation, the readers distance is taken with a 77% deviation around 6% use conveyor with 80% deviation around 4%, or manual switch (94% with a deviation of about 2%.

It is interesting that in an evaluation of readability situations of the consignment given the readers runs through the gate (table 1 upper), in some cases is sufficient and relatively uniform (situation 2 and 3 value of 100%), while what for example situation 4 is the readership in wide range of 2% up 92%.



	1 m/s	0,75 m/s	0,5 m/s
Sada A, poloha 1	42,56%	51,28%	48,21%
Sada A, poloha 2	87,18%	90,26%	90,77%
Sada A, poloha 3	58,97%	62,05%	65,13%
Sada A, poloha 4	0,00%	2,56%	3,59%
Sada B, poloha 1	83,08%	93,85%	92,31%
Sada B, poloha 2	100,00%	100,00%	100,00%
Sada B, poloha 3	98,46%	99,49%	96,41%
Sada B, poloha 4	46,67%	50,77%	55,90%
Sada C, poloha 1	80,51%	72,31%	77,44%
Sada C, poloha 2	99,49%	100,00%	100,00%
Sada C, poloha 3	100,00%	100,00%	100,00%
Sada C, poloha 4	85,13%	94,87%	97,95%

Figure 25. Final test results

Set	situation 1	situation 2	situation 3	situation 4	average
A	47,35%	89,40%	62,05%	2,05%	50,2%
B	89,74%	**100,00%**	98,12%	51,11%	84,7%
C	76,75%	99,83%	**100,00%**	92,65%	92,3%

Table 7. Basic dependency between sets of readability and situations

The overall success of the method of transition as the distance of antennas for different speed ranges from 81% - 87%, and has a major impact on readability, similar to the way the transition between sets of antennas is relative stable (81% to 95%)

Based on the evaluation of measurement data cannot be identified unambiguously exclude or recommend the use of this technology in practice. These measurements may be partly conditional on imprecision caused by a provisional Laboratories. There is unable to clearly provide the desired stable speed and position of shipments due to the antenna. The end result is therefore a lack of readability of RFID tags in a traditional way-now commonly used in practice in the post measurement known as the set A. Although in other cases, the readability is very high and almost 100% (set C or B), there were other aspects that significantly affect its use.

6. Conclusion

RFID technology is still growing up and there is several type of application, which you can use in condition of the postal processes. This chapter deals with type of application that are common uses in postal sector such as mail bag, letter trays, roll cages and vehicle tracking and managing application. All these application are useful for the track and trace system and it presents added value for costumers. Most postal services provide at least a limited form of track and trace, particularly for premium delivery services. Today, tracking uses bar codes. Switching to RFID tags can lower tracking labor by eliminating the need for most manual piece handling. RFID is a very useful and exciting technology. It seems that everywhere one looks there is some article about RFID and the huge benefits its technology promises. Moreover, there are many examples that demonstrate how this technology is fulfilling its potential.

Based on the measurements it can be concluded, with some exceptions that prove the rule, the closer they are to each antenna, the greater the success of reading RFID tags. Given the large dispersion of values it can be concluded that some elements are simply eliminated They can, for example using multiple counting gates, respectively antennas (eliminating the position of shipments), or the use of such specialty (bubble) envelopes for magnification air gap between consignments (as by set C)

This article deals with identification of postal items and transport units in logistic chain of postal operators. It described scheme of the transport process, including planned technology and there is also simulated a real postal process in conditions close to operational. Article is part of the projects described below, which, together with the afore-mentioned application, will improve the learning process at the Department of Communications.

The benefits of RFID technology can be reaped if RFID events give realtime visibility to the business processes either already in place or to new ones. The backend systems give a business context to the RFID events collected from the RFID data collection tools and then invoke the right business process in real time (or near real time). Protecting the backend system is vital from the various security threats at the network level (attacking ONS or network communication between data collection tool and backend system) or at the data level (spurious events).The network level attacks can be prevented by using secured communications between various processes. The data attacks are hard to deal with, and application designers must take special care to differentiate spurious events from good events and then act on the good ones almost in real time. Since data is collected using automated data collection techniques, application designers must clean the repository where good RFID events are stored.

Costs of the security regarding RFID technology got implemented in a company´s infrastructure still presents relatively expensive attribute in the eye of CEO´s. Although the price of active and passive tags is still being reduced and RF technology becomes continuously more and more popular in a field of logistics, supply chains, toll systems, postal services, retailers or asset management, the relevance has to be put on a confrontation of costs of RFID implementation and its explicit use towards the eventual probability of attack.

In the relation on main aim of this article was focus on options of implementation mobile technology includes RFID technology into postal transport area. The content of introductory chapter is approximation the best terms of category and theoretical knowledge, which is used in this article. Further there are characterized the postal transport network, individual transport units, which is use in this area.

By optimal settings in real conditions the average maximum reading percentage is about 91.71%. Significant effect to increase the readability, RFID tags have been pointing toward a flat antenna and the antenna by sensing the top. Very significant impact on increasing or reducing the readability of the number of letters had the crate. For the purposes of measurement was used in 31 letters. The real use of the crate contained a much higher number of letters, which would likely significantly reduce readability.

Based on these results, identification of letters in the crate, RFID technology is not yet, given the technical conditions for real. Achievements, however, were relatively high. Some uncertainties should be possible to eliminate appropriate technical configuration (number of gates and Antennas, their location, etc.). On the other side some, particularly the operating elements (separation of cardboard) can be solved as special packaging elements (bubble envelope to increase the air gap), etc.) can ensure a desired level of reliability required reading. Therefore, we expect that further testing with a larger number of antennas other types of antennas, readers and RFID tags in our AIDC laboratory.

Acknowledgement

This work was supported in part by grant and research project VEGA 1/0421/12 - Modeling diffusion of knowledge in business value chains (60%), Centre of excellence for systems and services of intelligent transport II., ITMS 26220120050 supported by the Research & Development Operational Programme funded by the ERDF (20%) and institutional projects: 3/KS/2012 - Supporting education through educational multimedia applications [10%] and 1/KS/2012 - Sensitivity analysis of contact points to the costs arising from the provision of UPS [10%]

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Edited by Mamun Bin Ibne Reaz

RFID based application creates tremendous new business opportunities such as the support of independent living of elderly and disabled persons, efficient supply chains, efficient anti-counterfeiting and better environmental monitoring. RFID data management, scalable information systems, business process reengineering, and evaluating investments are emerging as significant technical challenges to applications underpinned by new developments in RFID technology. This book presents the contributions from world leading experts on the latest developments and state-of-the-art results in the RFID field to address these challenges. The book offers a comprehensive and systematic description of technologies, architectures, and methodologies of various efficient, secure, scalable, and reliable RFID and RFID based applications.

ISBN 978-953-51-6347-3

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