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Technical Program

Mon

10:30 -12:00

1A: [Tag Circuits](#)

1B: [Measurement and Simulation Methods](#)

1C: [Healthcare \(Special Session\)](#)

13:30-15:00 (1:30 PM-3:00 PM)

2A: [Protocol Part I](#)

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2C: [Tag and Reader Testing \(Special Session\)](#)

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3A: [Protocol Part II](#)

3B: [Localization & Active Tags](#)

3C: [Open Source RFID Software \(Special Session\)](#)

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4A: [Privacy and Security Part I](#)

4B: [Reader Design](#)

4C: [Embedding and De-embedding Electromagnetic Structures for RFID Systems \(Special Session\)](#)

14:00-15:30 (2:00 PM-3:30 PM)

5A: [Privacy and Security Part II](#)

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5C: [Chipless RFID \(Special Session\)](#)

16:00-17:30 (4:00 PM-5:30 PM)

6A: [Applications & Networking](#)

6B: [Antenna & Propagation Part II](#)

6C: [Near-Field Electromagnetic Ranging \(Special Session\)](#)

Monday, Apr 27

10:30 - 12:00

1A: Tag Circuits

[Low-power Energy Supply Circuit for Passive RFID Transponder](#)

01

Hong-Zhou Tan (Sun Yat-Sen University, P.R. China); Hu Jian-Guo (Sun Yat-Sen University, P.R. China)

This paper addresses low power design approaches for passive RFID transponder. It proposes a novel low power energy supply circuit, which includes amplitude limiter, rectifier circuit, analog power supply circuit, digital power supply circuit and high voltage power supply circuit. The simulation and measurement results show that proposed voltage rectifier, amplitude limiter and power supply circuit with low voltage checking can provide stable power supply voltage with a small input power and high conversion efficiency. It has been applied to a passive transponder chip design, which was fabricated successfully based on 0.35 μm CMOS process.

[A Low-Power Dual-Clock Strategy for Digital Circuits of EPC Gen2 RFID tag](#)

07

Qiasi Luo (University of Science and Technology of China, P.R. China); Li Guo (University of Science and Technology of China, P.R. China); Qing Li (State Key Laboratory of ASIC & System, Fudan University, P.R. China); Gang Zhang (Fudan University, P.R. China); Junyu Wang (Fudan University, P.R. China)

Power consumption is critical to the performance of EPC Gen2 RFID tags. System clock frequency of tags should be as low as possible to reduce the power consumption and still conform to the protocol. This paper analyses the impact of different clock strategies on digital circuits of EPC Gen2 tag. An error shift approach is proposed to reduce the backscatter link frequency (BLF) errors. A dual-clock strategy with both 1.28 and 2.56 MHz clocks for the digital circuits is developed.

Compared with the 1.92 MHz unitary-clock strategy, the dual-clock strategy offers larger decoding margins and BLF margins, consumes 5.66% to 9.44% less power estimated in CMOS 0.18 μ m technologies, and fully conforms to the EPC Gen2 protocol as well.

Analysis, Design and Implementation of Semi-Passive Gen2 Tag

15

Wenyi Che (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Yuqing Yang (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Conghui Xu (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Na Yan (State Key Lab of ASIC & System, Fudan University, P.R. China); Qiang Li (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Hao Min (State Key Lab of ASIC & System, Fudan University, P.R. China)

An EPCglobal Gen2 compatible semi-passive (or be called battery-assisted passive) tag is proposed. The transmission link is studied to optimize the power distribution in a backscatter RFID system. For long read range consideration, design targets for low power tag are given. The tag chip is implemented in SMIC 0.18 μ m standard CMOS technology. A high efficiency AC-DC charge pump serves as a rectifier. A low power wake-up circuit detects the input energy level and controls a button cell battery to supply the chip. The equivalent tag power is 230 nW by measurement.

Measurement methods for power requirements of high performance UHF RFID tags

20

Stefan Gruber (Infineon Technologies Austria AG, Austria); Hannes Reinisch (Graz University of Technology, Austria); Wolfgang Pribyl (Graz University of Technology, Austria); Gerald Holweg (Senior Manager, Austria)

The sensitivity parameter is one of the most important parameters characterizing UHF RFID tags. This paper presents methods for measuring this parameter. It focuses on the use of non-expensive laboratory equipment. Nevertheless, the proposed methods provide accurate results. Losses and behavior of the setup are calculated and described in detail. Single-ended and differential structures are distinguished and handled separately. Since the antenna plays an important role, its behavior is also considered. Still, the measurement setup is contact based.

1B: Measurement and Simulation Methods

Wideband System-Level Simulator for Passive UHF RFID

28

Daniel Arnitz (Graz University of Technology, Austria); Ulrich Muehlmann (NXP Semiconductors, Austria); Thomas Gigl (Graz University of Technology, Austria); Klaus Witrisal (Graz University of Technology, Austria)

A chip manufacturing process requires extensive support of CAD-tools in order to predict the behavior of the embedded circuitry and to ensure the intended system functionality. Past experience shows that the overall performance of UHF RFID systems is mainly limited by multipath propagation and detuning. In this context, system-level simulations are vital to assess the overall performance and improve the embedded circuit. We present a simulator framework capable of handling chip-level tag models, fading MIMO radio channels, and interrogator building blocks on signal level. It is based on highly flexible behavioral tag-models instead of highly accurate but static ASIC models. In contrast to other UHF RFID simulators, it is explicitly designed to handle wideband signals, fading channels, nonlinearities, and detuning effects. The simulator is currently used to develop and evaluate the performance of ranging and realtime channel estimation systems. The presented results emphasize the feasibility of our framework in the evaluation of a range estimation approach between a standard UHF RFID transponder and an interrogator.

A UHF RFID Channel Emulator Hardware for Playback of Measured Link-Scenarios

34

Holger Arthaber (Vienna University of Technology, Austria); Christian Schubert (Vienna University of Technology, Austria)

This paper introduces a simple and inexpensive approach for emulating recorded radio frequency identification (RFID) link scenarios in the lab. This allows developing and testing of RFID systems, improving their performance... under perfectly reproducible conditions. Hence, it becomes possible to precisely compare the performance of different reader settings (data rate, modulation, arbitration mode...) or to compare different readers and/or tags. This includes statistical analysis of the performance as well. The proposed setup further enables statistical analysis of the results as the emulation of a certain link scenario can be played back arbitrary often. This work discusses the channel emulation for an 815/915 MHz RFID system: The recording of scenarios, the 'connectorization' of RFID-tags, and the channel emulator itself. Finally, exemplary test results of a commercial RFID reader connected to the emulator are presented.

Flexible Evaluation of RFID System Parameters using Rapid Prototyping

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Christoph Angerer (Vienna University of Technology, Austria); Robert Langwieser (Vienna University of Technology, Austria)

Today's RFID systems are dependent on a wide range of different parameters that influence the overall performance. Such parameters can for example be the selected data rate, encoding scheme, modulation setting, transmit power or different

hardware configurations, like one or two antenna scenarios. Furthermore, it is often desired to optimise several performance goals, like read out range, read out quality, throughput, etc, which are often contradicting each other. In order to achieve a desired performance of an RFID system, it is essential to understand the influences of the single parameters of interest and their interconnection. Due to the multitude, wide range and interdependencies of influencing factors, this however is a complex task. Simulations offer insights in these relations but rely on the correct modeling of the influence of- and between the parameters. With our set-up prototyping system for RFID, we are able to flexibly and accurately explore the influence and interconnection of such parameters in a wide range on a basis of real time measurements.

[Read Range Measurements of UHF RFID Transponders in Mobile Anechoic Chamber](#)

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Wolfram Strauss (Fraunhofer Institute for Integrated Circuits, Germany)

This paper presents a novel and simple method to determine the read ranges of radio frequency identification (RFID) transponders. Range tests in a well defined and accurate stationary anechoic chamber (SC) are awkward and expensive. An extendible mobile anechoic chamber (MC) to produce a large number of repeatable range measurements with minimal effort is proposed. A mobile chamber suitable to reside in our laboratories was designed and built. MC measurements were crosschecked with SC measurements of label transponders. Reading ranges for a number of commercially available metal mount tags, so far not publicly available, were derived. Metal transponders are 3D objects leading to more constraints in applications than labels. Therefore range densities, i.e., reading range per area or volume of the tag, as novel key figures were introduced to make tags more comparable and to determine the optimal transponder for a given use case. The current results are suitable to serve as a relative measure to compare transponders.

1C: Healthcare (Special Session)

Chair: J. Schmidt (Infineon); Chair: Joerg Schmidt (Infineon, Germany)

Talks:

Reliable and secure identification, management and tracing of specimens, Joachim Gerstel, joint analytical systems (jas),

RFID in Healthcare - A Multidisciplinary Perspective, MD Suraj Kapa, Mayo Clinic, Rochester, MN

Tracking of medical implants - from a technical perspective, N.N., Magellan Technology

Panel:

joint analytical systems (jas), Schreiner LogiData, UPM Raflatac, tagstar systems, Mayo Clinic (Rochester, MN), KSW Microtec, RFID in Healthcare Consortium, Magellan Technology, FEIG electronic

Abstract: The RFID market is continuously in motion. New application possibilities and new requirements determine the growth of this technology. Especially the healthcare segment and the pharmaceutical chain have been pointed out as one of the significant growth factors for RFID applications in the past. Unfortunately many projects and applications have been lagging behind expectations. Recommendations from the FDA have lost of its momentum and California has postponed their activities targeting ePedigree. Nevertheless this technology could add value and create significant benefits for the healthcare market – even if these applications will not address the mass market. We will see a slower but continuous growth for RFID in this area. This session will emphasize on the newest trends and current developments regarding the healthcare and pharmaceutical market – technology issues are highlighted just as concrete running applications. The session will show the different opportunities in using different solutions for special applications.

13:00-15:00 (1:30 PM - 3:00 PM)

2A: Protocol Part I

[ALOHA Algorithm considering the Slot Duration Difference in RFID system](#)

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Liu Dan (Fudan University, China, P.R. China); Zhongxiang Wang (Fudan University, China, P.R. China); Hao Min (State Key Lab of ASIC & System, Fudan University, P.R. China); Junyu Wang (Fudan University, P.R. China) when multiple RFID tag identification is becoming a commonplace, the anti-collision technology for multiple RFID tag environment has drawn mounting research interest in the RFID domain. Many published Aloha-based algorithms, assuming that all the slots have the same duration, tend to increase the number of successful slots by tag estimation and dynamic frame scheduling, and thus improve the system efficiency (the ratio of successful slots to all slots in each frame), which is limited by $1/e$ according to the theory of Probability. Whereas, in this paper, the effect of the empty slots and collided slots is analyzed and two novel methods based on the parameters of EPC Gen2 protocol, BIS and Collision Detection, are proposed, to improve the RFID system efficiency by reducing the cost of the none successful slots other than the successful slots. Moreover, a new approach to evaluate the system efficiency for multiple tag identification, taking consideration of the duration difference of the slots, is presented. According to the simulation and test results, the proposed methods, BIS and Collision Detection, can improve the system throughput by 120% and 30~40% respectively.

[Reliable Identification of RFID Tags Using Multiple Independent Reader Sessions](#)

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Rasmus Jacobsen (Aalborg University, Denmark); Karsten Nielsen (Aalborg University, Denmark); Petar Popovski

(Aalborg University, Denmark); Torben Larsen (Aalborg University, Denmark)

Radio Frequency Identification (RFID) systems are gaining momentum in various applications of logistics, inventory, etc. A generic problem in such systems is to ensure that the RFID readers can reliably read a set of RFID tags, such that the probability of missing tags stays below an acceptable value. A tag may be missing (left unread) due to errors in the communication link towards the reader e.g. due to obstacles in the radio path. The present paper proposes techniques that use multiple reader sessions, during which the system of readers obtains a running estimate of the probability to have at least one tag missing. Based on such an estimate, it is decided whether an additional reader session is required. Two methods are proposed, they rely on the statistical independence of the tag reading errors across different reader sessions, which is a plausible assumption when e.g. each reader session is executed on different readers. The first method uses statistical relationships that are valid when the reader sessions are independent. The second method is obtained by modifying an existing capture-recapture estimator. The results show that, when the reader sessions are independent, the proposed mechanisms provide a good approximation to the probability of missing tags, such that the number of reader sessions made, meets the target specification. If the assumption of independence is violated, the estimators are still useful, but they should be corrected by a margin of additional reader sessions to ensure that the target probability of missing tags is met.

An Application Dependent Medium Access Protocol for Active RFID Using Dynamic Tuning of the Back-off Algorithm **72**

Björn Nilsson (Halmstad University, Sweden); Lars Bengtsson (Chalmers University, Sweden); Bertil Svensson (Halmstad University, Sweden)

Active Radio Frequency Identification (A-RFID) is a technology where the tags (transponders) carry an on-board energy source for powering the radio, processor circuits, and sensors. Besides offering longer working distance between RFID-reader and tag than passive RFID, this also enables the tags to do sensor measurements, calculations and storage even when no RFID-reader is in the vicinity of the tags. In this paper we introduce a medium access data communication protocol which dynamically adjusts its back-off algorithm to best suit the actual active RFID application at hand. Based on a simulation study of the effect on tag energy cost, readout delay, and message throughput incurred by some typical back-off algorithms in a CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) A-RFID protocol, we conclude that by dynamic tuning of the initial contention window size and back-off interval coefficient, tag energy consumption and read-out delay can be significantly lowered. We also present specific guidelines on how parameters should be selected under various application constraints (viz. maximum readout delay; and the number of tags passing).

Power Optimized Waveforms for Improving the Range and Reliability of RFID Systems **80**

Matthew Trotter (Georgia Institute of Technology, USA); Gregory Durgin (Georgia Tech, USA); Joshua Griffin (Georgia Institute of Technology, USA)

A major limitation in backscatter radio applications such as passive sensing and RFID is the read range from the reader to tag, which is limited by the power available to the tag. RFID system cost can be decreased by increasing the read range, which reduces the number of readers needed. The Power Optimized Waveform (POW) is a new type of multiple-tone carrier that is designed to improve the read range and power efficiency of charge pump-based passive tags. This paper presents the POW concept; its effects on existing class 1 EPC, generation 2 RFID systems; and several example POWs.

2B: Sensors

Mobile-phone-readable 2.45GHz Passive Digital Sensor Tag **88**

Yann Têtu (CEA-Leti/Minatec, France); Iiro Jantunen (Helsinki University of Technology, Finland); Bertrand Gomez (CEA-Leti/Minatec, France); Stephanie Robinet (CEA-Leti/Minatec, France)

A 2.45GHz passive RFID tag including a digital pressure sensor and its use in a mobile-phone-centric architecture for sensor networks are described. The combination of a low-cost remote-powered sensor tag and an open architecture makes possible a variety of ambient intelligence applications. The tag gathers power from the ISM band at 2.45GHz and wireless pressure measurement is demonstrated at a distance of 42 cm with 0.5 W EIRP transmission power and 110 cm with 4 W. The sensor is able to carry out pressure measurement with a 12-bit-resolution and a 100Hz reading frequency.

Towards Tag Antenna Based Sensing – An RFID Displacement Sensor **95**

Rahul Bhattacharyya (Massachusetts Institute of Technology, USA); Christian Floerkemeier (MIT, USA); Sanjay Sarma (MIT Auto-ID Center, USA)

Displacements can be used as indicators of structural health and are measured by commercially available sensors that need to be accurate and cost effective. In this paper, we examine a technique to utilize a UHF RFID tag antenna as a displacement sensor by mapping structural deformation to a change in RFID tag characteristics. We evaluate how changes in two different parameters, a) tag backscatter power and b) minimum reader transmit power required for RFID chip activation, can be mapped to structural deformation. The theoretical principles of sensor development are first discussed followed by a presentation of the results of experimentation. It is demonstrated that the sensor is sensitive to displacements for a dynamic range of 40 mm.

[A Capacitive Touch Interface for Passive RFID Tags](#)

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Alanson Sample (University of Washington, USA); Daniel Yeager (University of Washington, USA); Joshua Smith (Intel Research Seattle, USA)

This paper presents a novel method for incorporating a capacitive touch interface into existing passive RFID tag architecture without additional parts or changes to the manufacturing process. Our approach is to make the tag's antenna a dual-function element in which the antenna simultaneously acts as both a low frequency capacitance sensor and also as an RF antenna. To show the feasibility of our approach, we have prototyped a passive UHF tag with embedded capacitive sensor using our WISP platform and report on its sensing measurements. Finally, we describe how it can be used for touch interfaces, as well as other user applications with the addition of a LED for user feedback.

[SAW RFID Spread Spectrum OFC and TDM Technology](#)

110

John Pavlina (University of Central Florida, USA); Donald Malocha (University of Central Florida, USA)

SAW based sensors can offer wireless, passive operation over numerous environments, and various device embodiments are used for retrieval of the sensed data. SAW has many unique advantages over possible competing technologies, including the following characteristics: passive, radiation hard?, operable over wide temperature ranges, small, rugged, inexpensive, and identifiable. In a multi-sensory environment, it is necessary both to identify the sensor and retrieve the sensed information. The OFC SAW technology approach has been funded by NASA for possible inclusion in ground, space flight, and space exploration sensor applications. The purpose of this paper is to present the concept of encoding SAW-based sensors for use in a multiple sensor environment. The emphasis will be on orthogonal frequency coded (OFC) devices with a form time division multiplexing (TDM) overlaid on them. It will be shown that in addition to the benefits of OFC such as enhanced processing gain and lower interrogation power spectral density (PSD), the TDM allows for a decrease in overlapping energy and therefore a decrease in intersensory collisions which are shown to cause peak ambiguity. This approach should be applicable to many different SAW based sensors: temperature, pressure, liquid, gas, etc. Measured device results are presented and compared with coupling of modes (COM) model predictions to demonstrate performance. This paper will discuss the use of SAW OFC in a temperature sensor application. Devices are then used in computer-simulated transceiver design, and the results of a possible sensor system are discussed.

2C: Tag and Reader Testing (Special Session)

Chair: Daniel Deavours (Kansas University)

Talks:

Tag Measurement Principles, Pavel Nikitin, Intermec

Tag Measurement Approaches, Jukka Voutilainen, Voyantic

Reader Performance Measurements, Jin Mitsugi, Auto-ID Labs Japan

Panel: Invited speakers

Abstract: Tag and reader testing represents an important topic in the early phase of many RFID projects. Test methodologies have evolved significantly in recent years. This session will analyze the current state of the art in RFID tag and reader testing and discuss future trends.

15:30-17:00 (3:30 PM - 5:00 PM)

3A: Protocol Part II

[Effect of Gen 2 Protocol Parameters on RFID Tag Performance](#)

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Pavel Nikitin (Intermec Technologies, USA); Kodukula Rao (Intermec Technologies, USA)

In this paper, we analyze the effect of Gen2 protocol parameters on RFID tag performance (tag sensitivity and backscatter efficiency). We describe our measurement methodology and perform characterization of several tags with different latest Gen2 ICs available on the market (Monza, UCODE, and Higgs families). We present experimental data and draw conclusions on how some of the protocol parameters (such as pulsewidth) affect the tag performance in forward and reverse links.

[Evaluation of ISO 18000-6C Artifacts](#)

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Nikhil Ayer (University of Texas at Arlington, USA); Daniel Engels (University of Texas at Arlington, USA)

In this paper, we have evaluated the ISO 18000-6 Type-C protocol also known as EPC Class-1 Generation-2 RFID protocol parameters, on the performance of the RFID system. Tari, operating frequency, pulse width and modulation index are evaluated in the protocol at the constant transmitted power. The experiments were designed to eliminate the effects of the tag's antenna design. All the experiments are conducted in the anechoic chamber. The study shows that the slowest tari with half duty cycle, and the higher modulation index receives maximum power from the tag and hence longer reading distance. The fastest tari with the half duty cycle and higher modulation index has the fastest read rate. The Tag respond with the Tari as small as 5usec which provides a 5% read rate increase compared to the fastest Tari requested in the protocol.

Rushikesh Khasgiwale (University of Texas Arlington, USA); Rohan Adyanthaya (University of Texas, Arlington, USA); Daniel Engels (University of Texas at Arlington, USA)

In this paper, we develop techniques to extract information from communication collisions involving passive UHF RFID tags. Our goal is to extract information that can enhance the performance of existing anti-collision protocols. Present RFID anti-collision protocols detect a collision at the Medium Access Control (MAC) layer and take appropriate measures to avoid further collisions detectable at this level. However, the physical layer signal received during collisions is discarded. This signal contains valuable information, such as the number of tags communicating, that can be used to augment the anti-collision algorithms and the algorithms that utilize them. Collecting and utilizing this currently discarded information would provide performance improvements to existing protocols and provide insights that can be used to guide the development of future protocols. We analyzed communication collisions from ISO 18000-6C compliant tags in their response to a Query command. Our techniques enabled us to reliably identify the exact number of tags in the collided slot for up to 4 tags communicating in that slot and the existence of at least 5 tags communicating in a slot with more than 4 tags communicating in that slot.

Separation of Multiple Passive RFID Signals Using Software Defined Radio

Dawei Shen (Massachusetts Institute of Technology, USA); Grace Woo (Massachusetts Institute of Technology, USA); David Reed (MIT Media Lab, USA, ?); Andrew Lippman (MIT Media Laboratory, USA); Junyu Wang (Fudan University, P.R. China)

We present a practical design of an RFID reader that is capable of reading multiple passive tags through joint decoding. The reader is implemented and analyzed using the GNU Software Defined Radio system. We use low frequency (LF) 125kHz commodity MIT ID cards in the experiment, and discuss extensions to decoding high frequency (HF) tags. This design reconsiders opportunities available in the lower layers of RFID design. Physical layer communication is analyzed rigorously and a complete system design is introduced as a result. We demonstrate this by exploring the differences in amplitudes and phase offsets among signal components, multiple tags can be separated and efficiently decoded using joint decoding. System performance is analyzed with both implementation and simulation. Based on these results, we summarize opportunities for improving industrial auto-collision algorithms with multiple-tag decoding capability.

3B: Localization & Active Tags**Multifrequency-Based Range Estimation of RFID Tags**

Xin Li (Villanova University, USA); Yimin Zhang (Villanova University, USA); Moeness Amin (Villanova University, USA)

Radio frequency identification (RFID) is a rapidly developing wireless communication technology for electronically identifying, locating, and tracking products, assets, and personnel. RFID has become one of the primary means to construct a real-time locating system (RTLS) that tracks and identifies the location of objects in real time using simple, inexpensive tags attached to or embedded in objects and readers that receive the wireless signals from these tags to determine their locations. Most RFID tag localization techniques heavily rely on precise estimation of the range between a reader and the tags. Traditionally, range information is obtained from the received signal strength indication (RSSI). Such approach is inaccurate, particularly in a complicated propagation environment. Recent development on phase difference of arrival (PDOA) allows coherent signal processing for improved range estimation performance. PDOA based approaches share the same concept as the dual-frequency techniques for range estimation being applied in radar systems where signals with two basic frequencies are used, and the phase difference observed at the two frequencies is used to estimate the range of the reflecting objects. Exploiting multiple frequencies may further improve the range estimation performance. In this paper, we focus on multifrequency-based techniques to achieve several important advantages in the range estimation of passive or semi-passive RFID tags. The use of well designed multiple frequencies allows effective phase unwrapping and elimination of the range ambiguity problem which may be encountered in PDOA methods. In a complicated propagation environment, the multifrequency-based techniques provide frequency diversity for robust range estimation when signals are highly faded at some frequencies. These advantages not only yield improved range estimation accuracy of RFID tags in various applications, but also enable robust range estimation in challenging scenarios.

Hybrid Ultrasound-RFID Indoor Positioning: Combining the Best of Both Worlds

Sverre Holm (University of Oslo, Norway)

Existing hybrid ultrasound/RF positioning systems usually measure ultrasonic time-of-flight. This operation requires a wide bandwidth and this makes it rather noise sensitive, limiting the useful range. Therefore a new system is proposed where only the room-indicating capability of ultrasound is utilized and combined with RF. A portable tag obtains the room location by receiving a narrow bandwidth signal from a stationary ultrasound transmitter. The result is then relayed back over RF. This combines the high accuracy of ultrasound to pin-point exactly the room location with the high communications capacity of RF that enables tracking of hundreds of simultaneously moving tags. Secondary parameters that may aid in refining the position such as ultrasound signal level and velocity may also be measured. In addition to the increased capacity, the use of portable receivers instead of transmitters, as in ultrasound-alone indoor positioning systems, also has the advantage of reduced user exposure to ultrasound due to the larger distance to the transmitters.

[A Novel Localization Scheme for Passive RFID Tags; Communication Range Recognition \(CRR\)](#)

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Tomotaka Wada (Kansai University, Japan); Norie Uchitomi (Kansai University, Japan); Yuki Ota (Kansai University, Japan); Toshihiro Hori (Kansai University, Japan); Kouichi Mitsuura (Shinshu University, Japan); Hiromi Okada (Kansai University, Japan)

This paper focuses on the localization technology of passive RFID (Radio Frequency IDentification) tags. By this technology, we will be able to detect some target, to get information on it, and to find the position and the distance of it. This paper proposes a novel scheme named Communication Range Recognition (CRR) in order to localize RFID tags effectively. This scheme finds the edges of the communication range of the RFID reader antenna when its position is moving by the robot appropriately. We evaluate the performance of the estimated position error through numerous experiments. We show that our proposed scheme can reduce the moving distance of the RFID reader without degrading the accuracy of localization in comparison with the conventional schemes.

[Verification Methodology for Battery Lifetime Requirements of Higher Class UHF RFID Tags](#)

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Christoph Trummer (Graz University of Technology, Austria); Christoph Kirchsteiger (Graz, University of Technology, Austria); Alex Janek (Graz, University of Technology, Austria); Christian Steger (Graz University of Technology, Austria); Reinhold Weiss (Graz University of Technology, Austria); Markus Pistauer (CISC Semiconductor Design+Consulting GmbH, Austria); Damian Dalton (Neosera Systems Ltd., Ireland)

Today's higher class tags usually are powered by batteries. The battery's capacity and the application's power demand influence the operational lifetime of the tag. Therefore, the designated application and lifetime requirement have to be kept in mind when designing a higher class tag. Moreover, the lifetime requirement needs to be verified in order to ensure the application will be successful. However, verification of the lifetime requirement is usually a very complex task. A verification environment for the application and its lifetime requirement needs to be created manually. After simulation with a battery model the results can be compared to the requirements document. Due to the complex and time-consuming nature of verification this often results in later time-to-market and increasing costs. In this work we present a novel, highly automated methodology to verify battery lifetime requirements. From the requirements document of the higher class UHF RFID tag a verification environment is created automatically. After power estimation is performed a battery model can be connected to the automatically generated lifetime verification environment. Finally, simulation is performed to verify whether the higher class UHF RFID tag fulfills the lifetime requirement of the application. The main benefit of our methodology is a decrease in the verification effort due to the high degree of automation in the creation of the verification environment. Moreover, simulation time is decreased which enables faster exploration of various batteries. This results in faster time-to-market and a reduction of costs.

3C: Open Source RFID Software (Special Session)

Chair: C. Floerkemeier (MIT/Fosstrak)

Talks:

Rifidi, Prasith Govin, Primari

LLRP Toolkit, Daniel Bowman, Impinj

Fosstrak, Christian Floerkemeier, MIT/Fosstrak

Panel:

Abstract: Open Source RFID Software is becoming increasingly popular. Tools such as Rifidi's IDE, the LLRP Toolkit or Fosstrak's software suite facilitate RFID application development significantly. These software tools begin to emerge as core components around which custom RFID solutions are built. This session will discuss current trends in RFID open source software projects. Representatives from prominent open source initiatives such as Rifidi, LLRP Toolkit and Fosstrak will present recent developments in the field and a discussion panel will analyze future opportunities.

Tuesday, Apr 28

11:00 - 12:30

4A: Privacy and Security Part I

[Untraceable RFID Authentication Protocols: Revision of EC-RAC](#)

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Yongki Lee (University of California at Los Angeles, USA); Lejla Batina (Katholieke Universiteit Leuven, Belgium); Ingrid Verbauwhede (University of California at Los Angeles, USA)

Radio Frequency IDentification (RFID) systems are steadily becoming paramount due to their vast applications such as supply chains, inventory, tolling, baggage management, access control etc. While they have potentials to improve our lives, they also present a privacy risk. Privacy is often overlooked in many applications, but due to pervasiveness of RFIDs the issue has to be taken into account. However, additional security always comes at price and the scarceness of resources on a tag makes

conventional privacy-preserving protocols infeasible. In this paper we propose several authentication protocols that are all made of the same building blocks. More precisely, we first revise the EC-RAC (Elliptic Curve Based Randomized Access Control) protocol and we expand it into several authentication protocols. All the proposed protocols satisfy the basic requirements, which are the system scalability, un-traceability and security against cloning attacks and replay attacks, but each protocol has different security properties. The security proofs are implied by means of cryptographic reductions i.e. they are based on the security of the Schnorr protocol and the hardness of the decisional Diffie-Hellman problem.

HB-MP++ Protocol: An Ultra Light-weight Authentication Protocol for RFID system

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Bongno Yoon (Korea University, Korea)

Since Hopper and Blum suggested the HB protocol which is based on the conjectured hardness of the LPN (Learning Parity in the Presence of Noise) problem in 2001, a family of light-weight authentication protocols has been developed for RFID (Radio Frequency Identification) system by many engineers. It was found that each algorithm had own weakness against new attacks so that more advanced protocols have been expanded in order to overcome the attacks. In this paper, we enhance the HB-MP and HB-MP+ protocol, called HB-MP++. Ultra low-weight and concrete function will be used to eliminate vulnerability of the conventional methods. We also provide the security and performance analysis of the proposed protocol.

How to Improve Security and Reduce Hardware Demands of the WIPR RFID Protocol

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Jiang Wu (University of Waterloo, Canada); Doug Stinson (University Waterloo, Canada)

In this paper, we analyze and improve WIPR, an RFID identification scheme based on public key techniques with efficient hardware implementation. First we analyze the security and privacy features of WIPR. We show that WIPR may be vulnerable to short padding attacks and reset attacks, and discuss countermeasures to avoid these attacks. Then we propose two variants, namely WIPR-SAEP and WIPR-RNS, to improve its security and to further reduce its hardware cost. Using an additional hash function, WIPR-SAEP achieves provable security in the sense that violating the security properties leads to solving the integer factoring problem. WIPR-RNS uses a residue number system (RNS) for computation, and reduces hardware costs of WIPR. WIPR-RNS may also provide a better security guarantee in that it uses standard cryptographic primitives instead of the non-standard ones in WIPR. WIPR-SAEP and WIPR-RNS can be combined into one scheme.

Preserving RFID Data Privacy

200

Benjamin Fung (Concordia University, Canada); Khalil Al-Hussaeni (Concordia University, Canada); Ming Cao (Concordia University, Canada)

Radio Frequency IDentification (RFID), a technology for automatic object identification, has wide applications in many areas including manufacturing, healthcare, and transportation. Yet, the uniquely identifiable objects pose a privacy threat to individuals carrying the objects. Most previous work on privacy-preserving RFID technology, such as EPC re-encryption and killing tags, focused on the threats caused by the physical RFID tags in the data collection phase, but these techniques cannot address the privacy threats in the data publishing phase, when a large volume of RFID data is released to a third party. In this paper, we study the privacy threats caused by publishing RFID data. Even if the explicit identifying information, such as name and social security number, has been removed from the published RFID data, an adversary may identify a target victim's record or infer her sensitive value by matching a priori known visited locations and timestamps. RFID data by default is high-dimensional, so applying traditional anonymity model to RFID data suffers from the curse of high dimensionality, and would result in poor data usefulness. We define a new privacy model, develop an anonymization algorithm to address the special challenges on RFID data, and evaluate its performance in terms of data quality and efficiency.

4B: Reader Design

Broadband Suppression Properties of Active Leaking Carrier Cancellers

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Gregor Lasser (Vienna University of Technology, Austria); Robert Langwieser (Vienna University of Technology, Austria); Arpad Scholtz (Vienna University of Technology, Austria)

In passive UHF RFID systems backscattering is used for tag to reader communication. This technique relies on a continuous wave signal being transmitted by the reader during the tag's data transfer. In order to separate transmission and reception paths circulators, directional couplers or disjoint transmit and receive antennas can be used. Perfect isolation is not achievable with any of those approaches. So a leaking carrier is present at the receiver in any case. It is possible to reduce the interference from this signal by some kind of leaking carrier cancellation. Such a cancellation prevents receiver blocking and reduces the baseband hardware's requirements, depending on the receiver concept. Usually, the narrowband properties of carrier cancellers are studied. This is only sufficient for conventional RFID systems, if the transmitter noise can be neglected. Broadband RFID systems, as recently discussed in literature, also require broadband leaking carrier cancellers. In this paper the broadband suppression properties of carrier cancellers are first investigated theoretically. Further a hardware implementation is presented and characterized. Finally, measurement results are compared to the theoretical findings.

Circularly Polarized Patch Antenna with High Tx/Rx-Separation

213

Lukas Mayer (Vienna University of Technology, Austria); Arpad Scholtz (Vienna University of Technology, Austria)

In this contribution an antenna is described that allows simultaneous transmission and reception in the same frequency band. Circular polarization is employed for a most reliable communication with radio frequency identification (RFID) transponders that typically have linearly polarized antennas. To achieve high separation between transmitted and received signals, a square patch antenna originally transmitting horizontally and vertically polarized radiation is combined with a 3 dB-hybrid circuit. With this hybrid circuit the antenna can simultaneously radiate a right-hand circularly polarized wave and receive a left-hand circularly polarized wave. Furthermore, the transmit signal that is unintentionally leaking into the receive path can be compensated by tuning the hybrid circuit with two variable capacitance diodes. At 866 MHz a maximum Tx/Rx-separation of 65 dB was achieved in a static scenario. In a time variant indoor scenario with a metal object moving on a conveyor belt a Tx/Rx-separation of more than 52 dB was achieved by continuously tuning the hybrid circuit with a minimum-search algorithm.

Demonstration of Improved Passive UHF RFID Coverage using Optically-Fed Distributed Multi-Antenna System

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Sithamparanathan Sabesan (University of Cambridge, United Kingdom); Michael Crisp (University of Cambridge, United Kingdom); Richard Penty (Cambridge University, United Kingdom); Ian White (University of Cambridge, United Kingdom)

Optically-fed distributed antenna system (DAS) technology is combined with passive ultra high frequency (UHF) radio frequency identification (RFID). It is shown that RFID signals can be carried on directly modulated radio over fiber links without impacting their performance. It is also shown that a multi-antenna DAS can greatly reduce the number of nulls experienced by RFID in a complex radio environment, increasing the likelihood of successful tag detection. Consequently, optimization of the DAS reduces nulls further. We demonstrate RFID tag reading using a three antenna DAS system over a 19m range where 100% of the test points can be successfully read. The detected signal strength from the tag is also observed to increase by an average of approximately 10dB compared with a conventional non-DAS RFID system. This improvement is achieved at +31dBm isotropically radiated power (EIRP) power from all three antenna units (AUs).

4C: Embedding and De-embedding Electromagnetic Structures for RFID Systems (Special Session)

Chair: Darmindra Arumugam (University of Pittsburgh & Carnegie Mellon University, USA)

Talks:

Practical Passive UHF RFID Systems: Design and Characterization Challenges within Computational Electromagnetism, Darmindra D. Arumugam, CMU

Design of UHF RFID Systems with the aid of Computational Electromagnetics, C.J. Reddy, EMSS USA - FEKO

Panel: Darmindra D. Arumugam, CMU; C.J. Reddy, EMSS USA – FEKO; Pavel Nikitin, Intermec; Leonid Mats, Tego

Abstract: It is widely known that designing passive RFID systems using CEM methods are somewhat precise, but differ in accuracies as compared to real-world results based on the algorithms, methods, and meshing guidelines used, as well as devices utilized for measurement and characterization of systems. By embedding electromagnetic structures such as measurement and/or characterization devices/systems into the CEM environments, we are able to visualize electromagnetic modeling results that are much more accurate than previously known, thus allowing an original design to perform exceedingly similar in the CEM environment as it would in the real world. This special session would incorporate modeling of designs for devices and/or connection systems which are typically used during the measurement and characterization stages that would allow for the de-embedding of these structures from the realworld measurements. We will also concentrate on the application, utility, and physics of electromagnetic structures used for the purpose of de-embedding.

16:00-15:30 (2:00 PM - 3:30 PM)

5A: Privacy and Security Part II

Serialized TID numbers – A headache or a blessing for RFID crackers?

225

Mikko Lehtonen (ETH Zurich, Switzerland); Antti Ruhanen (Confidex Oy, Finland); Florian Michahelles (ETH Zurich, Switzerland); Elgar Fleisch (ETH Zurich & University of St. Gallen (HSG), Switzerland)

Though Transponder ID (TID) numbers of Radio Frequency Identification (RFID) tags were originally introduced to identify the chip model, serialized TID numbers are currently advertised as security features of UHF chips. Serialized TID numbers do not provide any cryptographic protection, but they do introduce a hurdle against adversaries who want to clone RFID tags today. Furthermore, serialized TID numbers are very relevant for end-users who want to protect their UHF from cloning today since cryptographic chips are not yet commercially available in that frequency range. In this paper, we analyze the suitability of TID numbers for security applications by evaluating the effort to bypass the TID check by exploiting various vulnerabilities, and we compare this effort to the needed level of protection in an example of anti-counterfeiting in the tobacco industry. The analysis suggests the hurdle that TID checks provide is not high enough for industrial scale security applications and it will get lower and might even diminish due to commodification of the RFID technology. However, end-users of security applications can still benefit from the increased tag cloning resistance that serialized TID numbers provide before migrating to more secure solutions.

Cryptography is Feasible on 4-Bit Microcontrollers - A Proof of Concept

233

Markus Vogt (Embedded Security Group, Germany); Axel Poschmann (Ruhr-University Bochum, Germany); Christof Paar (Ruhr-University Bochum, Germany)

The RFID technology in combination with cryptographic algorithms and protocols is discussed widely as a promising solution against product counterfeiting. Usually the discussion is focused on passive low-cost RFID-tags, which have harsh power constraints. 8-Bit microcontroller have very low-power characteristics (100-200 μW) and are therefore an interesting platform for active and passive low-cost RFID-tags. To the best of our knowledge there are no implementations of cryptographic algorithms on a 8-bit microcontroller published so far. Therefore, the main contribution of this work is to demonstrate that cryptography is feasible on these ultra-constrained devices and to close this gap. We chose PRESENT as the cryptographic algorithm, because contrary to many other ciphers, PRESENT uses a 4x4 S-Box. Our implementation draws a current of $7\ \mu\text{A}$ at a supply voltage of $0.8\ \text{V}$ and a frequency of $0\ \text{KHz}$ and requires less than $0\ \text{ms}$ for the processing of one data block.

Security Considerations in the Design and Peering of RFID Discovery Services

241

Trevor Burbridge (BT Research, United Kingdom); Mark Harrison (Cambridge University, United Kingdom)

There is growing interest in Discovery Services for locating RFID and supply chain data between companies globally, as well as for locating sources of product lifecycle information for individual objects. Discovery Services are heralded as a means to find serial-level data from previously unknown parties, however more realistically they provide a means to reduce the communications load on the information services, the network and the requesting client application. Attempts to design a standardised Discovery Service will not succeed unless security is considered in every aspect of the design. In this paper we clearly show that security cannot be bolted-on in the form of access control, although this is also required. The basic communication model of the Discovery Service critically affects who shares what data with whom, and what level of trust is required between the interacting parties.

How to detect cloned tags in a reliable way from incomplete RFID traces

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Mikko Lehtonen (ETH Zurich, Switzerland); Florian Michahelles (ETH Zurich, Switzerland); Elgar Fleisch (ETH Zurich & University of St. Gallen (HSG), Switzerland)

Cloning of RFID tags may lead to considerable financial losses and deteriorated reputation in many commercial applications, while being attractive for adversaries. One way to address tag cloning is to use the visibility that RFID traces provide to detect cloned tags as soon as they enter the system. However, RFID data always presents historic events without giving certainty where the traced objects currently really are. Furthermore, imperfect read rates can lead to missing reads. As a result, the visibility is not always perfect, which makes detection of cloned tags harder and less reliable. This paper proposes and investigates a series of probabilistic techniques to enable reliable detection of cloned tags in cases where the visibility is incomplete. Our hypothesis is that the events generated by cloned tags cause rare or abnormal events that can be detected when the process that generates the legitimate events is understood. The proposed techniques are studied in a comprehensive simulator study of a real-world pharmaceutical supply chain. Our findings suggest that reliable detection of cloned tags is possible if missing reads are addressed and the supply chain is precisely modeled.

5B: Antenna & Propagation Part I

A Circularly Polarized Planar Antenna Modified for Passive UHF RFID

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Daniel Deavours (University of Kansas, USA)

The majority of RFID tags are linearly polarized dipole antennas, but a few use a planar, dual-dipole antenna that facilitates circular polarization, but requires a three-terminal IC. In this paper, we present a novel way to achieve circular polarization with a planar antenna using a two-terminal IC. We present an intuitive methodology for design, and perform experiments that validate circular polarization. The results show that the tag exhibits strong circular polarization, but the precise axial ratio of the tag remains uncertain due to lack of precision in the experimental system.

UHF RFID Transponders Antenna Design for Metal and Wood Surfaces

262

Riad Kanan (University of Applied Sciences, HES-SO Valais, Switzerland)

In this paper, metal and wood support effect on UHF RFID transponders are investigated. New antennas designed for passive UHF RFID transponders mounted on metal and wood surfaces are described. Simulation results are presented which are in good agreement with measurement data. The transponder reading distance measurement shows good performance. In particular the reading distance obtained with the tags designed for metal surfaces is higher compared to the available commercial Metal Mount UHF tags.

Optically Transparent Conductive Polymer RFID Meandering Dipole Antenna

270

Nicholas Kirsch (Drexel University, USA); Nicholas Vacirca (Drexel University, USA); Elizabeth Plowman (Drexel

University, USA); Timothy Kurzweg (Drexel University, USA); Adam Fontecchio (Drexel University, USA); Kapil Dandekar (Drexel University, USA)

In this paper, we present optically transparent flexible conductive polymer antennas for radio frequency identification systems. The designs for these antennas are presented along with simulated and measured results of antenna radiating properties. These conductive polymer antennas are compared to antennas with the same design fabricated out of copper. Finally, we include an analysis of the optical transparency of the conductive polymer antennas.

[Analysis and Design of Wideband Passive UHF RFID Tags Using a Circuit Model](#)

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Daniel Deavours (University of Kansas, USA)

The great majority of commercial UHF RFID tags are based on dipole antennas using a modification of a T-match as a matching circuit. The literature contains examples of wideband matching, but provides little insight as to how wideband behavior is achieved. Here, we present a simple circuit-based theory to describe the antenna, matching circuit, and IC behavior; we present an approach for developing an impeding matching strategy to maximize bandwidth; and we present a concrete example and analysis using a method of moments (MoM) numerical solver. The results show very good agreement with theory.

5C: Chipless RFID (Special Session)

Invited Talks & Discussion Panel: Chair: Rich Fletcher (Tagsense, USA)

Talks:

Short Review of Chipless RFID, Rich Fletcher, Tagsense Inc.

Design of Global SAW Tag RFID Devices, Clinton S Hartmann, RF-SAW

Nanobers: Printed Microwave Tags made from Carbon Nanotubes, Morton Green, Inkode

Panel: Invited speakers

Abstract: The ability to perform wireless identification and sensing with passive material structures has enabled a variety of applications where the use of traditional chip-based RFID is not possible. In addition to offering extreme low-cost, chipless RFID is capable of operating in extreme environments and provides a rich variety of physical phenomena that has proven useful for security and sensing applications as well as identification. With new growth in the general RFID market, there has been renewed interest in chipless technologies to complement chip-based RFID. In this session, we review key features of chipless RFID technologies and discuss niche markets and emerging applications.

4:00 PM - 5:30 PM

6A: Applications & Networking

[A Passive SAW Based RFID System for Use on Ordnance](#)

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Paul Hartmann (RF SAW Inc., USA)

Automatic RFID tracking of ordnance in transport or storage has been difficult or impossible due to the dangers that arise from possible accidental actuation of electro-explosive devices due to RF electromagnetic fields. Limits on the maximum RF power densities that meet Hazards of Electromagnetic Radiation to Ordnance (HERO) emission standards preclude many passive RFID systems from operating safely in the vicinity of ordnance due to the high level of RF radiation needed to power the electronics onboard the RFID tag. This paper describes a Surface Acoustic Wave (SAW) based RFID system that allows safe operation of an RFID system with no standoff or separation distance between the reader antenna and the item of ordnance. Surface Acoustic Wave RFID systems are a "chipless" technology that utilize the piezoelectric properties of certain monolithic crystal materials to provide a truly passive RFID technology which can be operated at RF power levels well below those established for safety near ordnance.

[Inference of Product Quality by using RFID-enabled Traceability Information -A Study on the US Pharmaceutical Supply Chain-](#)

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Tatsuya Inaba (Keio University, Japan)

We present a stochastic model to infer a product quality index by using product traceability information. We propose a model by using Bayesian Network and apply it to the US pharmaceutical supply chain where regulations to mandate exchanging of traceability information for individual prescription drugs are being studied. In supply chains where traceability information of only a few products is available, consumers simply take the quality of products with traceability information is higher than those without traceability information. But when traceability information of many products become available, consumers need to understand the difference and choose the products that have a sufficient quality for them. Our model can be used in this situation. We show that our model successfully differentiate product quality indices by using a numerical study with a hypothetical scenario.

[Load Shedding Based Resource Management Techniques for RFID Data](#)

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Nova Ahmed (Georgia Institute of Technology, USA)

RFID based systems are enjoying widespread adoption in a variety of application scenarios. Item tracking in a supply chain environment is one such application. Despite the widespread adoption there are a number of challenges that need to be handled in an RFID deployment. From an application perspective, there are two challenges: (a) the data rates for large deployments are growing by leaps and bounds; (b) the demands placed on the system for query processing in real time are also on the rise. Meeting these challenges in large-scale deployments is non trivial. The hardware base for RFID based systems compound these challenges due to the fact that RFID readers are error-prone and reliable reading of RFID tags is hampered by a number of physical limitations such as environmental conditions, and contents of the items carrying the tags. Naturally, the reliability of these systems become even more questionable when both the data rates increase and the need for real time processing of queries increases. We propose load shedding mechanisms that use the spatial and temporal properties of RFID deployments to combat the challenges due to increased demands for tag and query processing in real time. These mechanisms are piggy-backed on top of a middleware Reliable Framework for Radio Frequency IDentification (RF²ID) that uses redundancy to improve the reliability of RFID deployment. The basic idea in RF²ID is to use the spatial notion of a path taken by items flowing from source to destination. By cumulatively aggregating the tags collected by entities called Virtual Readers (VR) that are placed along the path, the total reliability of the system is enhanced. The VRs cooperatively shed the load under heavy load conditions. The built-in redundancy in the RF²ID system allows the VRs to shed load with reasonable system performance thus enhancing the overall reliability of the deployment. Two different load shedding strategies are proposed in the literature: space based approach and time based approach. These strategies have been implemented in the RF²ID middleware and performance results show the efficacy of these mechanisms for dealing with increased data rates.

[A Real Options Approach for Strategic RFID Investment Decision](#)

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Xiaodan Wu (Hebei University of Technology, P.R. China); Chao-Hsien Chu (Penn State University, USA); Dianmin Yue (Hebei University of Technology, P.R. China); Junbo Bai (Hebei University of Technology, P.R. China); Yunfeng Wang (Hebei University of Technology, P.R. China)

One major roadblock for RFID adoption is to justify its return on investment. Most researchers used cost/benefit analysis, discount cash flow, or net present value method to support the decision; however, these methods does not consider uncertainties and lack flexibility when valuate the investment in RFID. In this paper, we examine the uncertainties and risks associated with RFID investment and propose the use of real options approach to consider them. We demonstrate how can a real options method be used and suggest a process for making strategic RFID investment decision. The results were evidenced and supplemented with a sensitivity analysis.

6B: Antenna & Propagation Part II

[Multipath Fading Measurements for Multi-Antenna Backscatter RFID at 5.8 GHz](#)

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Joshua Griffin (Georgia Institute of Technology, USA); Gregory Durgin (Georgia Tech, USA)

UHF and microwave backscatter RF tag systems, including radio frequency identification (RFID) and sensor systems, experience multipath fading that can be more severe than that found in a conventional transmitter-to-receiver channel. Previous work has shown that multipath fading can be reduced on the modulated backscatter signal received from the RF tag in a non-line-of-sight (NLOS) channel if more than one RF tag antenna is used to modulate backscatter. This paper presents the first multipath fading measurements for backscatter tags using multiple antennas at 5790 MHz -- the center of the 5725-5850 MHz unlicensed industrial, scientific, and medical (ISM) frequency band that may offer reliable operation for future, miniature RF tags. NLOS measurement results are presented as cumulative density functions (CDF) and fade margins for use in backscatter link budget analysis and a detailed description of the custom backscatter testbed used to take the measurements is provided. The measurements show that gains are available for multiple antenna RF tags and results match well with gains predicted using analytic fading distributions derived previously.

[Performance Analysis of Stacked RFID Tags](#)

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Terry Ye (Hong Kong R/D Center for Logistics and Supply Chain Management, Hong Kong)

Most RFID tag performance analysis is based on the assumption that the tag is stand-alone when interacting with the readers. However, in the real world, RFID tags are often stacked together when deployed, i.e., RFID-labeled carton boxes stacked on the pallet. When multiple RFID tag antennas are placed close to each other, each antenna behaves like a shielding and reflecting object to others and the radiation pattern and other EM properties will be detuned. The stacking impact often leads to performance degradation and in many cases, read and write failure. In this paper, we first derive an RCS model to generalize a loaded antenna as a shielding and reflecting object. We then introduce a normalized mutual impedance matrix of multiple antennas to formulate the coupling effects among stacked antennas. To quantify and visualize the stacking impact in a real world scenario, we also construct a 3-D EM model in Agilent® AMDS consisting of 27 (3 × 3 × 3) stacked carton boxes, each with Alien® tags attached on the surface. Our theoretical calculation agrees with AMDS simulation and shows that both tag radiation pattern and other EM properties will be greatly altered by neighboring tags. Compared with tags in stand-alone scenarios, the degradation at different positions and directions could be very significant (more than 6dB).

Yu Tanaka (Tokyo University of Science, Japan); Yohtaro Umeda (Tokyo University of Science, Japan); Osamu Takyu (Tokyo University of Science, Japan)

In this paper, we discuss change of read range between a passive UHF RFID tag and reader when a tag is close to another tag. The read range is determined by the strength of forward link and reverse link, which are represented by received power at a tag and reader, respectively. Approaching of tags causes electromagnetic interference between antennas of tags and results in change in impedance matching condition between an antenna and IC of a tag. This change in impedance matching condition decreases in read range. Therefore, we measure the change in received power of a tag and reader experimentally so as to identify which link limits read range and to restrict the existence range of IC impedance. In addition, a technique for extending read range when tags are close is proposed.

On the Measurement of the Delta Radar Cross Section for UHF Tags

Saad Skali (Grenoble-inp/esisar, France); Christophe Chantepy (Grenoble-inp/esisar, France); Smail Tedjini (Grenoble-inp, France)

This paper presents a methodology for the practical measurement of the variation of the Radar Cross Section (Δ RCS) for the RFID UHF tags. This is a very critical parameter, and will govern the tag performance. It also influences both the reading distance as well as the sensitivity of UHF tag. The experimental procedure is based on the measurement of baseband I and Q signals. Measurements are carried out in an anechoic chamber under bistatic antennas configuration. I and Q signals are measured twice: with and without the tag into the anechoic chamber. This allows the measurement of the difference of re-radiated power issued from the tag only, and thus the Δ RCS is obtained. The paper includes the analysis procedure and the experimental setup. The later is based upon an anechoic environment, a vector signal generator and a vector signal analyzer. The delta RCS is obtained as a function of the reader power. The paper describes the proposed procedure as well as its application to some tags of type ISO/IEC 18000-6C (EPC Class 1Gen2) tag.

6C: Near-Field Electromagnetic Ranging (Special Session)

Chair: Hans Schantz (The Q-Track Corporation, USA)

Talks:

A Technical Primer on Near-Field Electromagnetic Ranging, Hans Schantz, Q-Track

Near-Field Electromagnetic Ranging Versus Ultra-Wideband, Kai Siwiak, TimeDerivative

Radiation Worker Dosimetry Training System, John Unden, Q-Track

Panel: Invited speakers (Schantz, Siwiak, Unden)

Abstract: Near-Field Electromagnetic Ranging is an emerging indoor wireless location technology using narrowband (CW tone) signals operating at low frequencies (~1MHz) and long wavelengths (~300m). By exploiting the excellent propagation behavior of low frequency signals' near-field phase characteristics, these systems typically achieve 30cm-1m (1-3ft) accuracy at ranges of 30-60m (100-200ft) even in cluttered industrial environments. The pilot commercial deployment of near-field electromagnetic ranging is in the nuclear industry (see <http://www.q-track.com/VideoALARMS.htm>), but other applications include military training, miner tracking, and supply chain management.