IEEE RFID 2013 Technical Program

Wednesday

10:00 – 11:30

1A: RFID in BioMed I

1B: Antennas and Propagation I

13:00 – 14:30

2A: RFID in BioMed II / Sensors

2B: Antennas and Propagation II / Localization

Thursday

10:00 – 11:30

3A: Circuits, Devices, and Interrogators I

3B: Protocols and Security I

13:00 – 14:30

4A: Circuits, Devices, and Interrogators II / Applications and Software

4B: Protocols and Security II / Next-Generation Physical Layer I

14:45 – 16:15

5A: Power Harvesting

5B: Next-Generation Physical Layer II

1A: RFID in BioMed I

1A.1: *A Wearable UHF RFID-Based EEG System*

Artem Dementyev, Joshua R. Smith

University of Washington (US)

The wearable electroencephalogram (EEG) monitoring systems are the cornerstone of noninvasive brain-computer interface (BCI) and many medical applications, but state-of-the- art wearable systems are limited by weight, battery life and size. In this paper we present EEGWISP: an EEG monitoring system that is battery-free; is powered by a standard UHF RFID reader; and uses backscatter to transmit the data using an EPC Class 1 Gen2 protocol. Since EEGWISP does not need batteries it can be lightweight, miniature and completely carefree for the user. We designed a low-power EEG acquisition circuit with 62.6 μA current consumption. For validation, EEG signals were shown by distinct appearance of 8-12 Hz oscillations (alpha waves) when wearer's eyes are closed. EEGWISP can record EEG signals at 63 Hz sampling rate, at the distances up to 0.80 m and with 0.1 % data loss. To the authors' knowledge, this is a first UHF RFID based EEG system. With slight modification system can be used for other biopotential signals such as ECG.

1A.2: *Analysis of Wireless Powering of mm-Size Neural Recording Tags in RFID-inspired Wireless Brain-Machine Interface Systems*

Elham Moradi[1], Toni Björninen[1], Lauri Tapio Sydänheimo[1], Leena Ukkonen[1], Jan Rabaey[2]

[1] Tampere University of Technology (FI)

[2] UC Berkeley (US)

This paper provides a full analysis of powering mm-size cortical implants wirelessly. An effective approach for wireless power and data transfer in neurorecording microsystems is the backscattering-based RFID-inspired communication. In this mechanism, an external interrogator powers the implant unit by microwave radiation power, and the implant IC superimposes the neurosignal on top of the signal backscattered to the interrogator. This paper characterizes wireless RF link between an external transmit antenna and an implantable antenna using the two-port model. It presents the design of a novel 1-mm3 implantable loop antenna and four different external loop antennas with various features to analyze aspects and factors limiting the wireless power transfer.

1A.3: *Battery-Free Multichannel Digital ECG Biotelemetry using UHF RFID Techniques*

Jordan Besnoff[1], Travis Deyle[2], Reid Harrison[3], Matthew Reynolds[1]

[1] Duke University (US)

[2] Georgia Institute of Technology (US)

[3] Intan Technologies LLC (US)

We propose to leverage UHF RFID technology to yield a continuously wearable, battery-free wireless multichannel ECG telemetry device that is potentially disposable, low-

cost and suitable for integration with multiple electrodes in a flexible circuit assembly. Such a device could have broad applicability, ranging from initial patient assessment by first responders, to continuous monitoring in various clinical settings. We employ a recently described single-chip data acquisition system including RF power harvesting to eliminate the need for a battery. The single-chip system includes 14 channels of integrated biopotential amplification, an 11-bit ADC, and a 5~Mbps digital backscatter telemetry link. We present an initial characterization of the telemetry chip in this application including battery-free, wireless 3 and 5 channel ECG recordings made from an ambulatory human subject at a range of approximately 1 meter.

1A.4: *RFID Technologies applied to the Design and Implementation of Electro-Mechanical Systems for the Simulation of Medical Scenarios in Neonatal Patients*

Yury Estepa Avellaneda, Edward Julián Ramos Ballesteros, Rubén Stevinson Flechas Lozano, Nicolás Cuervo Benavides, Luis Carlos Méndez Córdoba, Jan Bacca Rodríguez, Gloria Margarita Varón Durán

Universidad Nacional de Colombia (CO)

This document presents the development of simulation systems for clinical scenarios in neonatal patients using RFID Technologies. The systems are intended for their use in the training of personnel in the Health Care industry. They implement possible scenarios of the cardiovascular and respiratory systems and process related to blood pressure. One of the systems also implements the application of a chest massage technique developed at the College of Medicine at Universidad Nacional de Colombia. The system uses two Graphical User Interfaces (GUIs), one for the trainer, where he can program a specific clinical scenario to be resolved, and one for the trainee, where he can get information related to the illness, the patient, and where he can program his treatment.

1B: Antennas and Propagation I

1B.1: *Staggered Pattern Charge Collection: Antenna Technique to Improve RF Energy Harvesting*

Blake Marshall, Gregory Durgin

Georgia Institute of Technology (US)

This paper introduces the theory of N-by-N staggered pattern charge collectors (SPCC) and a methodology to design and optimize SPCCs for maximum energy harvesting efficiency. The SPCC uses multiple sub-arrays to form an aggregate gain pattern for harvesting RF wireless energy more efficiently than a single antenna or a collection of antennas occupying a similar footprint when the transmitter location is unknown.

1B.2: *Wide-Coverage Array Antenna Using a Dual-Beam Switching for UHF RFID Applications*

Wang-Sang Lee[1], Seung-Tae Khang[1], Won-Seok Lee[1], Hyunsung Tae[1], Moon-Que Lee[2], Jong-Won Yu[1]

[1] Korea Advanced Institute of Science and Technology (KAIST) (KR)

[2] University of Seoul (KR)

Based on a dual-beam switching, the wide-coverage array antenna with a 4X4 proposed matrix which generates three dual-beams is presented for the ultra-high frequency (UHF) radio frequency identification (RFID) applications. The 4X4 proposed matrix generates the three dual-beams which can cover the wide spatial coverage of 180 degree. The main beam directions can be controlled by selecting the appropriate input port of the proposed matrix. Due to the compact structure and very low reflection coefficient, the circular polarized square quadrifilar spiral antenna (QSA) array incorporated with the 4X4 proposed matrix has been configured. The fabricated array antenna operates at the 902--928 MHz band and produces three dual-beams at +-12, +-39, and +-68 degrees.

1B.3: Ultra Low-Profile Metal Tag Antenna Design with an Emphasis on Radiation Efficiency

Jingtian Xi, Terry Ye

Hong Kong R&D Centre for Logistics and Supply Chain Management (HK)

Ultra low-profile metal tags are highly desired for tagging modern IT assets and metallic cylinders. In contrast to most existing research works, this paper focuses on the radiation efficiency of the ultra low-profile tag antennas. The influence of the substrate thickness on the radiation efficiency is studied with both theoretical calculation and full-wave simulation. It is found that the conductor loss takes over from the dielectric loss as the dominant loss mechanism when the substrate thickness becomes extremely small. Furthermore, the influence of the substrate thickness on the radiation efficiency bandwidth is studied based on an ultra low-profile metal tag antenna. The tag antenna takes the form of an inset-fed patch integrated with a short-circuited transmission line, and is implemented at three substrate thicknesses, i.e. 0.855, 0.513, and 0.171 mm. Measurement and simulation results of the proposed tag antenna demonstrate that the feeding structure has a great impact on the radiation efficiency bandwidth. In particular, when the tag antenna is implemented at extremely small thicknesses, the radiation efficiency bandwidth is found to be a more demanding specification than the impedance bandwidth.

1B.4: *Malevolent Object Detection Using Microwave RFID Tags*

Marcin Morys, Muhammad Akbar, Gregory Durgin

Georgia Institute of Technology (US)

Radio Frequency Identification (RFID) tags are gaining popularity in sensing applications. Common implementations rely on backscattering digitally encoded sensor data from an RFID tag to a reader. This paper discusses a unique capability of RFID technology to detect objects in a tag's near vicinity by observing trends in the magnitude and phase of backscattered signal, irrespective

of the information encoded in the data. Computational results and measurements are presented, and demonstrate how to improve sensitivity for object detection near a tag.

2A: RFID in BioMed II

2A.1: *High-Frequency RFID Tag Survivability in Harsh Environments*

Alfonso Gutierrez[1], Clive Hohberger[2], F. Daniel Nicolalde[1], Atul Ingle[1], William Hochschild[3], Rodeina Davis[2], Raj Veeramani[1]

[1] University of Wisconsin – Madison (US)

[2] Blood Center of Wisconsin (US)

[3] University of Wisconsin – Madison & Genrac Power Systems (US)

A 2 kilobit memory RFID tag including a 13.56 MHz ISO 18000-3 mode 1 microchip bonded to an etched aluminum antenna on a PET substrate was attached to the upper side of a blood bag with an FDA-compliant adhesive. Tags were subsequently tested for survivability after exposure to three main harsh processing conditions found in blood banks: (a) Three 10-minute cycles of centrifugation at 4750g; (b) -30 °C blast freezing for 72 hours and (c) two consecutive 25 gray (Gy) Cs-137 gamma irradiation exposures. Survivability was measured with three criteria: (a) pass/fail ability to read and write the memory content (partial and full memory) at different distances (0 cm, 5 cm, and 10 cm) within a predefined time threshold, (b) Reliability (pass/fail) of the pre-encoded data (data integrity) and (c) ability to perform the read or write operation successfully (pass/fail) at 5 cm within a predefined time threshold before and after exposure to each test condition. All tests revealed at most 1 read, write, or data integrity failure per test cycle in a sample size of 60. The results of the time-to-read tests for reading the tag ID alone and reading tag data met their respective acceptance thresholds. While some degradation of the RFID tag read/write performance did occur, normal exposure to centrifugation, blast freezing, and gamma irradiation in blood center operations is unlikely to have significant effect on the survivability of 13.56 MHz RFID tags on blood products. Subsequent in-field pilot testing on the processing of 12,000 blood donations at a major blood center showed no tag failures.

2A: Sensors

2A.2: *An Analytical Model for Electromagnetically Coupled UHF RFID Sensor Tags*

Jinlan Gao, Johan Sidén, Hans-Erik Nilsson

Mid-Sweden University (SE)

This paper presents an analytical model for electromagnetically coupled UHF RFID sensor tags where a coupling loop with an embedded sensor is attached to an ordinary UHF RFID tag with a small gap. Electromagnetic coupling is used, in this case, to modulate the properties of the tag antenna in proportion to the values of the embedded sensor. The antenna together with the coupling loop are represented as an equivalent circuit and the analysis of the sensor tag becomes a circuit-level calculation after extracting parameters from full-wave simulations for, respectively, the separated dipole antenna and coupling loop. The results calculated from the equivalent circuit model are compared with the results from full-wave simulations and show a good agreement. The presented model can thus be used for analyzing and predicting the behavior of electromagnetically coupled sensor tags. Based on the analysis with the presented model, the methods for optimizing the sensory performance of this kind of RFID sensor tags are also presented in this paper.

2A.3: *Hybrid Analog-Digital Backscatter: A New Approach for Battery-Free Sensing*

Vamsi Talla, Joshua R. Smith

University of Washington (US)

After comparing the properties of analog backscatter and digital backscatter, we propose that a combination of the two can provide a solution for high data rate battery free wireless sensing that is superior to either approach on its own. We present a hybrid analog-digital backscatter platform that uses digital backscatter for addressability and control but switches into analog backscatter mode for high data rate transmission of sensor data. Using hybrid backscatter, we report the first digitally addressable real-time battery free wireless microphone. We develop the hybrid backscatter platform by integrating an electret microphone and RF switch with a digital RFID platform (WISP). The hybrid WISP operates by default in digital mode, transmitting and receiving digital data using the EPC Gen 2 RFID protocol but switching into analog mode to backscatter audio sensor data when activated by Gen 2 READ command. The data is recovered using a USRP-based Software Defined RFID reader. We report an operating range of more than 2.7 meters for the microphone-equipped hybrid WISP which can be extended to 4.7 meters using a higher output power reader.

2A.4: *A Novel EM Barcode for Humidity Sensing*

Emran Amin[1], Md. Shakil Bhuiyan[1], Bjorn Winther-Jensen[2], Nemai Karmakar[1]

[1] Monash University (AU)

[2] Monash University (US)

In this paper, a novel low cost, compact, printable EM barcode or chipless RFID tag is presented for humidity sensing. The RFID tag sensor is based on planar, single sided resonant scatters operating within the frequency band of 6.5 GHz to 9.5 GHz. Within this frequency range a rectangular patch with a number of slot resonators is designed to designate the data ID. In addition, an electric inductive- capacitive (ELC) resonator is dedicated for humidity sensing. The ELC resonator is modified using polyvinyl- alcohol (PVA) to incorporate humidity sensing. Moreover, the tag sensor can be printed on flexible laminates like plastic and paper for ultra-low cost item level tagging and ubiquitous sensing. The sensor tag has potential of including multiple parameter sensing as the sensing mechanism is independent of data ID generation. It has remarkable application in low cost perishable product process and management.

2B: Antennas and Propagation II

2B.1: *A UHF RFID Antenna for a Wireless Sensor Platform with a Near-Isotropic Radiation Pattern*

Layne Berge, Michael Reich

North Dakota State University (US)

An antenna designed for a spherical surface with a near-isotropic radiation pattern is presented in this work. The antenna is designed for wireless, UHF RFID sensors. It is electrically small with a diameter of 52 mm and operates in the UHF RFID frequency band. The antenna consists of a spherical ABS plastic shell surrounding a standard FR4 printed circuit board. This allows ample space for sensors and electronic circuitry. A prototype sensor platform has been manufactured and tested. The outer shell was produced using a 3D printer. An Alien Technology Higgs 3 RFID IC was used to test the basic functionality of the antenna. Simulation and measured results are presented.

2B: Localization

2B.2: *An Active Position Sensing Tag for Sports Visualization in American Football*

Darmindra D. Arumugam[1], Michael Sibley[2], Joshua D. Griffin[3], Daniel Stancil[4], David Ricketts[5]

[1] Jet Propulsion Laboratory, California Institute of Technology (US)

[2] Tait Towers (US)

[3] Disney Research Pittsburgh (US)

[4] North Carolina State University (US)

[5] Carnegie Mellon University (US)

Remote experience and visualization in sporting events can be significantly improved by providing accurate tracking information of the players and objects in the event. Sporting events such as American football or rugby have proved difficult for camera- and radio-based tracking due to blockage of the line-of-sight, or proximity of the ball to groups of players. Magnetoquasistatic fields have been shown to enable accurate position and orientation sensing in these environments. In this work, we introduce a magnetoquasistatic tag developed for tracking an American football during game-play. We describe its integration into an American football and demonstrate its use in game-play during a collegiate American football practice.

2B.3: *Inverse SAR Approach for Localization of Moving RFID Tags*

Andreas Parr, Robert Miesen, Martin Vossiek

University of Erlangen-Nuremberg (DE)

This paper presents an inverse synthetic aperture radar approach for localizing standard UHF RFID transponders. The proposed method is a powerful option to estimate the positions of tags that pass RFID gates or read points. A priori information about the relative transponder trajectory, such as the speed of a conveyor belt or a trajectory created by a robotic arm or rotary table, is used to generate an inverse synthetic aperture. Sampled phase data from RFID signals which are backscattered to single or multiple antennas combined with the information on the relative RFID tag trajectory are used to reconstruct the tag's absolute trajectory. The paper describes basic properties of synthetic apertures in RFID systems and methods of evaluating beam patterns based on array beam steering theory. Simulations of a conveyor belt scenario and test data acquired from an industrial rotary table transporting tagged objects are described. The experimental results prove that our novel method enables robust localization of moving RFID tags even in a severe multipath environment.

2B.4: *A Battery-free RFID-based Indoor Acoustic Localization Platform*

Yi Zhao, Joshua R. Smith

University of Washington (US)

The ability to precisely localize RFID tags with low latency and low cost is desirable for applications such as inventory tracking, asset tracking, or robotic-manipulation of tagged items. However, because of multipath effects, traditional RFID positioning methods based on RF Received Signal Strength Indication (RSSI) have limited accuracy (meter-scale) or require large numbers of tags and readers, which increases both latency and cost. Acoustic localization systems can be more precise, but typically require a battery-powered sensor platform, which increases tag size and weight, and reduces tag lifetime. In addition, conventional acoustic localization systems are not integrated with existing conventional RFID infrastructure. This paper presents a working prototype of an RFID-based localization system that locates a custom battery-free, EPC Gen2-compatible UHF tag. The system uses the RFID communication channel for synchronization, and acoustic propagation delays for distance measurement. The system consists of a custom passive tag (WISP) with acoustic detector that receives and times ultrasound signals, an off-the-shelf EPC C1G2 UHF RFID reader, and an array of ultrasonic beacons. By measuring the Time of Arrival (ToA) of the ultrasound, the passive WISP tag can determine its location relative to the ultrasonic beacons. Time synchronization between the positioned tag and beacons is passively accomplished by deploying an active "spy WISP" and the RFID communication protocol. The localization performance of the prototype is characterized, and the tradeoffs among power consumption, accuracy, latency and range are discussed.

3A: Circuits, Devices and Interrogators I

3A.1: *A Passive UHF-RFID Tag with Inkjet-Printed Electrochromic Paper Display*

Jue Shen[1], Li Xie[1], Jia Mao[1], Lirong Zheng[2]

[1] KTH Royal Institute of Technology (SE)

[2] Fudan University (CN)

In this paper, an inkjet-printed electrochromic (EC) paper display integrated with passive UHF-RFID tag is introduced as a solution for passive electronic shelf labels (ESL). To address the system challenges of the limited power budget of passive UHF-RFID tags and the material aging of EC display, an feedback comparator integrated digital display driver is proposed based on the study of electrochromic, bi-stable and aging features of the EC display. Modularized baseband with different enable conditions and clock domains is implemented in the system design level. Moreover, to maintain the system

functions when the input power is lower than the display refresh power, a duty-cycled power management unit (PMU) is activated to accumulate the UHF power and drive the display in burst mode, enabling the fast charging of the voltage rectifier and the correct output of the regulator for the core circuit. The design is fabricated in a 0.18-um CMOS process with an area of 2.25 mm^2. Fed with EPC C1G2 protocol write command, experiments demonstrate correct refresh of EC display with 4 cm^2 effective area. The system sensitivity is basically immune to the display load at the antenna reference point. Further sensitivity improvements can be achieved with careful chip-to-antenna impedance matching.

3A.2: *Modulation and Sensitivity Limits for Backscatter Receivers*

Gregory Durgin, Christopher Valenta, Muhammad Akbar, Marcin Morys, Blake Marshall, Yanpao Lu

Georgia Institute of Technology (US)

This paper discusses how a low-powered RFID tag or sensor mote's backscatter modulation scheme -- limited in ways that conventional digital wireless systems are not -- may be adapted to the peculiar non-white noise properties of a backscatter receiver's radio frequency electronic chain to maximize detection. The analysis and results in this paper enable longer-range operation of today's passive, or semi-passive RFID tags as well as future backscatter sensor links that operate in higher frequency bands.

3A.3: *Bulk Acoustic Wave True Time Delay for UWB Passive Backscatter RFID*

Ryan Westafer, Kyle Davis, James Maloney, William Hunt

Georgia Tech Research Institute (US)

An electrically small bulk acoustic wave true time delay is proposed for use in a coherent, passive, and transistorless RFID tag operating around 2.45 GHz. The active area of the time delay component is just 100x100 microns, and a delay of about 10 ns is achieved. Experimentally, a maximum power transfer was obtained near 1.4 GHz. A link budget for the realized device is presented, and RCS modulation is quantified by measurements conducted in an indoor anechoic range.

3A.4: *Passive UHF RFID Interrogation System Using Wireless RFID Repeater Nodes*

Sithamparanathan Sabesan, Michael J. Crisp, Richard Penty, Ian White

University of Cambridge (GB)

This paper presents a new wireless radio frequency identification (RFID) repeater system, facilitating remote interrogation without the need for arrays of wired antennas, despite using entirely passive, low-cost ultra high frequency (UHF) RFID tags. The proposed system comprises a master RFID reader with both transmit and receive functions and multiple RFID repeaters to receive, amplify and retransmit tag-to-reader and reader-to-tag communications. This expands the area over which the master RFID reader may provide coverage for a given maximum transmit power at each antenna. We first demonstrate a single hop wireless repeater system to allow similar read performance to a standard commercial passive UHF RFID reader. Finally, a proof of principle system demonstrates that a single wireless repeater node can allow an extension in range.

3B: Protocols and Security I

3B.1: *On Security with the New Gen2 RFID Security Framework*

Daniel W. Engels[1], You Sung Kang[2], Junyu Wang[3]

[1] Southern Methodist University (US)

[2] ETRI (KR)

[3] Fudan University (CN)

Radio frequency identification (RFID) systems compliant to the EPCglobal Generation 2 (Gen2) passive UHF RFID protocol are being deployed in a broad range of applications including access control, automated tolling, anti-counterfeiting, and supply chain management. As Gen2 RFID systems have moved into applications beyond supply chain management, the on-tag functionality requirements have moved from a simple identifier to higher functionality including more user memory and on-tag sensors. With the broadening applications and the increased on tag functionality, security on the tag has become a critical enabling functionality in many applications. To address this growing marketplace need, EPCglobal has developed a standard security framework within which security functionality may be integrated seamlessly into the Gen2 protocol. We review the proposed Gen2 security framework and introduce cryptographic suites that utilize this framework to provide a range of security functionality. We analyze the security of this new functionality and conclude that the new security framework allows for the efficient integration of secure functionality; however, we further conclude that using the delayed response of the new Gen2 security functionality creates new vulnerabilities to timing based attacks such as replay attacks and man-in-the-middle attacks.

3B.2: *LLCPS and SISO: A TLS-Based Framework with RFID for NFC P2P Retail Transaction Processing*

Pascal Urien[1], Selwyn Piramuthu[2]

[1] Télécom ParisTech (FR)

[2] University of Florida (US)

The introduction of smartphones enabled with Near Field Communication (NFC) technology facilitates transformation of processes that involve manual intervention such as payment transaction processing in an automated manner. Although payment for transaction using NFC technology is not new, the possibility to use smartphones for payment either through stored payment information in the smartphone or in the cloud allows for seamless integration of associated processes. We consider advances in identification and communication technologies such as RFID (Radio Frequency IDentification) and smartphones as well as the ability to respond in real-time for automated check-out in a retail shopping environment with NFC-enabled smartphones. Using a recently proposed protocol (LLCPS) as an envelope for communication between the smartphone and the NFC reader, we develop a suite of authentication protocols (SISO) for secure payment processing in a retail store environment.

3B.3: *Nested Error Correcting Code Based Highly Reliable Data Reading for UHF RFID*

Yong Yuan[1], Dan Yu[2]

[1] Siemens (CN)

[2] Siemens AG (DE)

In the current UHF RFID standards, the data transfer on reverse link, from tag to reader, is unreliable in nature since there is only error detection code (CRC) used. With the continuous improvement of sensitivity for tag chip, the unreliable reverse link may become the bottleneck for the whole system. In this paper, a nested error correcting code (ECC) based data transfer method is proposed to enhance the reliability of reverse link while maintaining the acceptable read efficiency. The information bits are encoded in the nested way to get the redundant bits for each layer. The reader writes the original information bits and all redundant bits into the tag. During the reading process, the reader gets the redundant bits at different layer in an incremental manner. The purpose is to correct the errors by requiring as less redundant bits as possible. According to the numerical results, the reliability in terms of residual error probability is improved significantly compared to the normal scheme with only CRC check. However, the efficiency in terms of average time to get information bits is much better than the single code protection scheme. Therefore, the proposed scheme can get a good tradeoff between reliability and efficiency. On the other hand, the proposed scheme can be implemented in software, requiring no modifications on the reader hardware and tag.

3B.4: *Cloud-based RFID Authentication*

Wei Xie, Lei Xie, Chen Zhang, Quan Zhang, Chaojing Tang

National University of Defense Technology (CN)

Along with the development of cloud computing, cloud-based RFID is receiving more and more attentions of researchers and engineers. However, there is no research in which cloud computing is applied to RFID authentication schemes. Most current works lay emphasis on functionalities, lacking considerations about security and privacy. Classical RFID authentication schemes fail to meet the special security and privacy requirements of cloud-based RFID. The basic postulates of traditional backend-sever-based RFID authentication, i.e. secure backend channel and entirely trustworthy database, are no longer natively tenable in cloud-based RFID scenarios. In this paper, a virtual private network agency is suggested to build secure backend channels and to provide readers with anonymous access to the cloud. The cloud database is structured as an encrypted hash table. The first cloud-based RFID authentication protocol preserving tag/reader privacy to database keepers is proposed. Comparing with classical schemes, the proposed scheme has advantages in deployment cost saving, pervasiveness of authentication, scalability of O(1) complexity to verify a tag, mobile reader holders privacy preserving, and database security.

4A: Circuits, Devices and Interrogators II

4A.1: *Design and Realization of Stretchable Sewn Chipless RFID Tags and Sensors for Wearable Applications*

Arnaud Vena[1], Elham Moradi[1], Karoliina Koski[1], Abdul Ali Babar[2], Lauri Tapio Sydänheimo[1], Leena Ukkonen[1], Manos M. Tentzeris[3]

[1] Tampere University of Technology (FI)

[2] Tampere University of Technology, Rauma Research Unit (FI)

[3] Georgia Institute of Technology (US)

This paper presents the design of a sewed chipless RFID tag and sensor, on a fabric for wearable applications. The proposed design is based on three sewn scatterers on cotton textile. The tag is realized using a computer-aided sewing machine and electro-thread plated with silver. The simulation and frequency-domain measurement results validate the design from 3 to 6 GHz. The tag's static backscattered response can be identified in free space and on the human body. Some preliminary results from a sewn stretchable sensor are also given to demonstrate the potential for biomedical applications. Finally, we discuss the main challenges concerning the practical implementation of this technology.

4A: Applications and Software

4A.2: *A network architecture for fast retrieval of user memory data from sensor RF tags*

Yuki Igarashi, Keita Miyazaki, Yuki Sato, Jin Mitsugi

Keio University (JP)

The use of user memory data together with the unique ID of RF tag has been expanding in various industrial applications. Therefore, the fast reading of user memory data from sensor RF tags is required. In this paper, a network architecture for fast retrieval of user memory data is proposed. The architecture features the network based memory layout resolving and the optimization of read command according to the characteristics of interrogator. We implemented the proposed network architecture and evaluated the performance with commercial interrogator and commercial RF tags both of which are comfortable to the fundamental specification of ISO/IEC 18000-6 Type C. The experimental evaluation reveals that the network based memory layout resolving is effective particularly for interrogators which have large inventory overhead before reading user memory data. In our experiment, 3.3 times read speed up is achieved with the network based resolving. The optimization of read command is effective regardless of the protocol implementation of interrogator. We achieve 2.5 times speed up in the experiment.

4A.3: *Sensor Enabled Wearable RFID Technology for Mitigating the Risk of Falls Near Beds*

Roberto Luis Shinmoto Torres[1], Qinfen Shi[1], Alanson Sample[2], Damith C. Ranasinghe[1]

[1] The University of Adelaide (AU)

[2] Intel Labs (US)

The increasing aging population around the world, associated with their increased risk of falling, challenges society and technology to find better ways to mitigate the occurrence of such costly and detrimental events as falls in elderly population. The most common activity associated with falls is bed transfers; thus, the most important high risk activity. Several technological solutions exist for bed exiting detection using a variety of sensors which are attached to the body, bed or floor. However, lack of real life performance studies, technical limitations and acceptability are still key issues. In this research, we present and evaluate a novel method for mitigating falls high risk for bed exits which is inexpensive, privacy preserving and light process. Our approach is based on an classification system based on conditional random fields that requires almost no preprocessing of sensorial and RF metrics data extracted from an RFID platform. We tested our approach on elderly patients (66-86 years old). The results of our trials are compared with performance metrics from previous bed exit classification studies. We also present the acceptability of RFID technology in an elderly population.

4A.4: *Expressive RFID Data Access Policies for the Pharmaceuticals Supply Chain*

Miguel L. Pardal[1], Mark Harrison[2], Sanjay Sarma[3], José Alves Marques[1]

[1] IST – Technical University of Lisbon (PT)

[2] Cambridge University (GB)

[3] MIT Auto-ID Center (US)

The Pharmaceuticals industry is at a crossroads. There are growing concerns that illegitimate products are penetrating the supply chain. There are proposals in many countries to apply RFID and other traceability technologies to solve this problem. However there are several trade-offs and one of the most crucial is between data visibility and confidentiality. In this paper, we use the TrakChain assessment framework tools to study the US Pharma supply chain and to compare candidate solutions to achieve traceability data security: Point-of-Dispense Authentication, Network-based electronic Pedigree, and Document-based electronic Pedigree. We also propose extensions to a supply chain authorization language that is able to capture expressive data sharing conditions considered necessary by the industry's trading partners.

4B: Protocols and Security II

4B.1: *Minimum Energy Source Coding for Asymmetric Modulation with Application to RFID*

Farzad Hessar, Sumit Roy

University of Washington (US)

Minimum energy (ME) source coding is an effective technique for efficient communication with energy-constrained devices, such as sensor network nodes. In this paper, the principles of generalized ME source coding is developed that is broadly applicable. Two scenarios - fixed and variable length codewords - are analyzed. The application of this technique to RFID systems where ME source coding is particularly advantageous due to the asymmetric nature of data communications is demonstrated, a first to the best of our knowledge.

4B.2: *A Novel Paradigm to Exchange Data in RFID Piconets*

Ivan Farris, Antonio Iera, Silverio Carlo Spinella

University Mediterranea of Reggio Calabria (IT)

In this paper a new paradigm is proposed, according to which a group of RFID readers establishes a piconet, called RAN (RFID Area Network), similarly to Bluetooth or ZigBee devices and exchanges data by only using RFID tags as a common "virtual channel". The proposal represents an interesting enabling factor of pure RFID ecosystems, wherein RFID enabled devices (such as mobile RFID readers, RFID reader cards embedded into cellular/mobile devices, etc.) only rely on the RFID technology for identification, for sensing and, now, for low-bitrate data exchange as well. Suitable algorithms to handle interference and collision problems during the data exchange within a piconet are proposed and the performance of the introduced paradigm is assessed.

4B.3: *Hybrid ARQ Improvements for RFID Systems*

Colby Boyer, Sumit Roy

University of Washington (US)

This paper investigates potential Hybrid ARQ (HARQ) improvements to the RFID ISO 18000-6C standard. Theoretical models that capture the baseline performance in terms of tag read rate are developed, and a new protocol capable of using HARQ or rateless codes is described. Existing HARQ algorithms such as Chase combining (CC) and incremental redundancy (IR) are studied via simulations and the performance quantified in terms of tag read rate. These empirical results show that CC allows for graceful system degradation and IR achieves read rates close to the capacity limit.

4B: Next-Generation Physical Layer I

4B.4: *Rich-Media Tags: Battery-Free Wireless Multichannel Digital Audio and Image Transmission with UHF RFID Techniques*

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In this paper we present the first fully passive (battery-free) wireless transmission of multiple digital audio channels and images via modulated backscatter. We leverage a previously reported single chip, passive transponder that can digitize and uplink up to 10 analog input channels sampled at a rate of 26.1 kHz. Given a

base station transceiver operating at a frequency of 915 MHz and a transmit power of +36 dBm EIRP, the transponder has a demonstrated operating range of ≈1.4 m. The transponder data uplink uses binary phase-shift key (BPSK) modulated backscatter operating at a total link throughput rate of 5 Mbps, with an uplink energy consumption of only 3.7 pJ/bit. The transponder was initially designed for biomedical telemetry of neural and EMG signals. We present a new application of this tag for multichannel, high fidelity digital audio recording, as well as color image transfer using a slow-scan television (SSTV) modulation (PD290) with a resolution of 640 by 493 pixels. Additionally, we demonstrate fully-passive digital recording of ambient sound using a microphone powered by the chip's harvested energy at an operating range of 0.72 m. The passive, digital microphone is sensitive enough to record human speech within approximately 5 m of the device. We believe these results will serve as a first step toward media-rich battery-free (wirelessly powered) devices that take advantage of the high speed, low power nature of modulated backscatter communication links.

5A: Power Harvesting

5A.1: *Rectenna Performance Under Power-Optimized Waveform Excitation*

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Power-optimized waveforms (POWs) have been shown to increase the power-conversion efficiency in energy harvesting circuits. This paper is the first attempt to study the effects of a POW on these circuits and determine how its design can affect circuit performance. As an example, a 5.8 GHz single-shunt rectenna was designed to investigate the variation of POW parameters. It was shown that there is an optimal range of subcarrier spacing to maximize POW gain and minimize voltage ripple. Furthermore, a relationship between the maximum number of equal energy subcarriers, ripple voltage, and circuit parameters has been determined.

5A.2: *Wireless Power Transfer Optimization for Nonlinear Passive Backscatter Devices*

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We present a method for enhancing far-field wireless power transfer (WPT) to nonlinear, passive UHF RFID backscatter transponders using a multi-input multi-output (MIMO) base station. The proposed method does not require on-tag power measurements or on-tag channel estimation, either of which would add significant complexity and power consumption for microwatt-class wirelessly powered devices such as passive UHF RFID tags. We show in a measurement-based proof of concept that WPT optimization to nonlinear backscatter transponders is possible solely based on the backscatter signal, without knowledge of the incident power level at the tag or prior knowledge of the tag's characteristics. Using an 8x8 MIMO transceiver array to optimize power delivery, we observed an average WPT enhancement of 8.9 dB relative to an un-optimized 8-transmitter configuration across a 50 m^3 volume in an office/lab environment. We also show that power to a given tag can be selectively denied, with a notch depth of -106.4 dB (noise floor of the presented measurements). These results are comparable to values previously observed for linear backscatter transponders, and suggest that the use of MIMO interrogators could lead to improved forward-link performance and thus efficiently provide power for sensors or other new power-hungry functions on passive transponders.

5B: Next-Generation Physical Layer II

5B.1: *Precise Ranging and Simultaneous High Speed Data Transfer Using Active mm-Wave Backscatter Tags*

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For precise ranging in dense indoor RFID applications, a large absolute bandwidth is required for effective multipath suppression. Since UHF bands are severely limited in bandwidth, mm-wave tags are proposed as an attractive option in combination with high capacity data storage and high speed data transfer (>>10 MBit/s) e.g. in short range (1-10 m) augmented reality and multimedia applications. Regarding tag architecture, a regenerative active backscatter tag based on a pulsed injection-locked oscillator is suggested in order to achieve a sufficient reader SNR for high bandwidth communication. It is demonstrated that a 34.3-34.8 GHz frequency modulated continuous wave (FMCW) RFID ranging approach can be seamlessly integrated with simultaneous data transmission from the modulated active backscatter tag to the reader at 37.5 MBit/s. Mutual distortions between FMCW ranging and data transmission are prevented by line encoding and quadrature mixing.

5B.2: *THID, the Next Step of Chipless RFID*

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This paper discusses recent advances in chipless RFID technology. It describes coding methods and storage capacity in RF domain, where the information is coded in the surface of the tags. It extends the concept of chipless RFID to THz domain where the information is coded into the volume of the tag. Several examples of RF and THz tags are reported and their design and performance carried out and discussed. Many remarkable results are obtained.