RFID Technologies and Their Applications

Technical Report UTDCS-61-06
Department of Computer Science
The University of Texas at Dallas

November 2006
Abinandhan Chandrasekaran and Bhavani Thuraisingham

RFID TECHNOLOGIES AND THEIR APPLICATIONS

Abinandhan Chandrasekaran
axc054100@utdallas.edu

Prof. Bhavani Thuraisingham
bxt043000@utdallas.edu

Data and Applications Security Laboratory
Erik Jonsson School of Engineering and Computer Science
University of Texas at Dallas

ABSTRACT

RFID (Radio Frequency Identifier) tags are transponders that can be used for identification purposes of various entities like day to day goods in cargo, animals and even human beings. They are basically devices that can emit and receive radio waves within a specified region and enable the position identification of a target object. They come in various types. The passive and active ones are the widely known types. A passive RFID device does not possess any internal battery source or power while an active RFID device possesses some form of internal power. RFID devices are used for various purposes like passports, product tracking, automotive parts identification and transport payments like in highway toll tags. This paper describes various technologies related to RFID devices in multiple industries such as supply chain, retailing and healthcare. In addition, security and privacy issues as well as commercial developments and the deployment of RFID technologies are discussed.

Keywords: RFID, Supply Chain, MIT Auto-ID Center, Healthcare, Security, Privacy, Standards

1. INTRODUCTION

RFID devices use the electromagnetic energy to initiate the process of modulated data transfer between systems. These tags are enabled to undertake multiple readings in the sense that an RFIR (Radio Frequency Identification Reader) can read and identify signals from multiple transponders at the

same time without the concept of interference. The advantage with RFID tags is that they are not based on the line of sight concept and can be used in times of adverse weather conditions including snow, fog and ice. Looking at the history of RFID tags, they were initially used in the military for the purpose of missile tracking and occasionally in telemetry. Later, due to the low cost of operation and in-expensive devices availability, they were used in day to day activities. ISO (International Standards Organization) 18000 and its sub parametric rules specify all the requirements and protocols to be followed in terms of standards. They also have sub clauses that mention about the air interface and its usage. RFID tags operate at various frequencies ranging from a few kilo hertz to mega hertz and even in the giga hertz range. Animal Id-ing, secure access applications and product tracking industries use low frequencies while vehicle tracking, smart card applications use more higher frequency ranges. A typical RFID system would have an antenna to emit RFID signals, a reader that would power the antenna and the other filters, an interface which could be serial or TCP/IP (Transport Control Protocol / Internet Protocol) based and finally a tag/transponder which would be a memory device made from EEPROM (Electrically Erasable Programmable Read Only Memory). This survey paper describes RFID technologies utilized in various industries. The sectors examined are Product Tracking, Medical and Healthcare, Manufacturing and Production, Supply Chain Management, Auto-Id and Retailing. In addition, Standards and Regulations, Privacy and Security Issues and the required strategies for the efficient deployment of an RFID system are also discussed. The paper also provides information about the vendors of the RFID system in the real world market. Sections 2 through 12 describe each of the topics listed above. Our analysis is given in section 13. The paper is concluded in section 14.

2. PRODUCT TRACKING

Active tags do not employ back scatter mechanism like passive tags and are hence less vulnerable to environmental factors. The ISO 18000-7 standard is formulated upon the Savi active RFID protocol, which was the first commercial active RFID system employed by the US military in the early 1990's. The 18000-7 standard operates primarily in the 433 MHz frequency band. The advantages are as follows:

- Since the operating frequency is 433 MHz, this technology has no problems

in co-existing with any of the popular wireless technologies such as Bluetooth, WLAN (Wireless Local Area Network) , cordless phones and microwave ovens.

- Based on international frequency regulations, 433 MHz offers the broadest acceptance for Active RFID.
- Good propagation characteristics in crowded environments as signals can move around obstructions by means of diffraction.
- The disadvantages of RFID systems are as follows:
- Compliance with this standard involves the use of four related patents. Although the patent holders are willing to negotiate licensing, the terms are not readily available.
- No specific support for dense reader mode (multiple readers operating in close vicinity).
- No built-in support for reader-to-reader communications. • Susceptible to interference since narrowband signals are used.
- No built-in support for security mechanisms such as encryption or authentication [1].

In [2], the ITS (Intelligent Transportation System), which not only monitors moving traffic but also helps the device drivers in identifying the license plates, is described. The tag is set up in the vehicle and this communicates with the traffic control center through a wireless communication medium. Data processing, toll collection and other traffic related queries are managed by the presence of the tag at the vehicle which constantly communicates with the traffic centre which has a reader to co-ordinate the above mentioned communication. In Greece, RFID tags are being used to monitor taxis [3]. The entire project was developed by *Control and Advanced Technologies Hellas, AEBE.* This project is similar to the one detailed in [2] except that the communication in this is achieved through an exemplary GPRS (General Packet Radio Service) communication. American College of Computer and Information Sciences have developed a tire management solution for the commercial truck tire market [4]. This is a stand alone solution for the tire management system and has system components that are unique when compared to those in existence. Several analysis like the RFID SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis along with cost benefit analysis were conducted by doing comparison with leading tire manufacturers like Good Year and Michelin. In [5], a comparison of smart tokens and smart cards

for limited use ticketing and automatic are collection at mass transits is detailed. Ticket initialization and recycling systems are briefed with the help of flow diagrams. Performance issues like passenger throughput could be found using this analysis and also situation like lost tickets and fare evasions are also considered and reported about. The RFID Sens Net Laboratory developed the AAS (Automatic Attendance System) [6]. The students are given a passive tag each and their attendance is monitored by using an antenna that is present in the class. This antenna is used as the reader and this can also be replaced by a handheld reader. Either way, this reader can be activated by just a click of the mouse by the instructor in the class. The RFID Sens Net Laboratory also developed a custom solution for the garment industry [7]. RFID tags in this context are used for the purpose of inventory control, in the sense that it is used extensively for garment tracking, garment position identification inside the stock yard.

3. SUPPLY CHAIN MANAGEMENT

Visualization of GeoTime data obtained from RFID tags are used by the Department of Defense (DoD) to provide global in-transit visibility of the DoD supply chain up until the last track of the consignment route. DoD uses RFID tags to monitor the positions and status of their cargos like operational rations, weapons equipment and demand items when they are transported to their defense depots in California [8]. In [9], Tata Consultancy Services, India have used RFID technology for order management systems. They have used RFID tags for retail supply chain and for functions like VMI (Vendor Management Integration), Collaborative Planning, Forecasting and Replenishment (CPFR). Genpact Software released a case study about adopting a techno process model for lean supply chains by incorporating RFID technology. This case study about a new techno model addressed issues like increasing variety of products, decreasing product lifecycles, fragmentation of Supply chain ownership [10]. RFID tags have been used as product codes and it instilled a standardization procedure and enhanced the process altogether [11]. The current RFID ecosystem maps vendors to the evolving ecosystem. It also helps potential players across the industry with adopting the RFID system and also in creating realistic roadmaps for achievements in their corresponding retail supply chain sector [12]. Penn State University has a center for supply chain leadership and research and in their case study released in 2004, usage of RFID

technology in data warehouses is detailed in an exemplary way. Various applications with respect to data warehousing that can deploy RFID as a solution are being discussed along with the difficulties in implementation. In their phased approach, a complete section refers to dealing with mandate compliance and also lists the requirements for implementation [13]. In [14], RFID in the consumer goods supply chain is discussed in detail. The EPC (Electronic Product Code), difference between EPC and EDI (Electronic Data Interchange) data, RFID mandates like slap and ship models, integration models for internal business systems, various issues like data synchronization, technology and process issues and the possible usage in the closed loop systems are also detailed. RFID middleware does the entire integration of the retail supply chain. The design for a simple, cost effective and scalable RFID middleware that will provide a two-way integration between an RFID application and any business application is discussed in [15]. Texas Instruments, a leader in the chip industry very recently released a paper on the security issues concerning the RFID technology when it is used in conjunction with industries like TI (Texas Instruments) itself. They have referred to increasing security in the supply chain market with the help of electronic markers [16]. Patni Computer Systems researched on the required semantics for the RFID technology and also targeted the Demand Planning Systems in which RFID tags could be of more use than anticipated [17]. In [18], the benefits of integrating voice and RFID tags are discussed. Texas Instruments also released a case study recently which urges current players to use RFID tags for their packaging operations. They have discussed about the transition from smart labels to smart packages that has an active tag attached to them [19].

4. AUTO – ID CENTER

Accenture technologies and MIT jointly researched about the future potential of RFID technology in the Auto-Id sector and value chain. In addition to enabling improvements within companies, low cost, open-standards-based Auto-ID infrastructure has the potential to track materials, goods, and assets across the value chain. Based on interviews of Auto-ID Center sponsor companies, Accenture clients, as well as an analysis of prior pilots and cross-industry initiatives the following information can be obtained.

- Potential business benefits of next-generation Auto-ID technologies across a range of value-chain activities

- Important technical and business issues affecting Auto-ID deployment
- Likely scenarios for the deployment of Auto-IDs in the consumer packaged goods (CPG) value chain
- Various business models for Auto-ID deployment for benefits across the value chain [20].

Factors affecting the EPC antennas and readers for supermarket shelves have been studied and grouped in a white paper prepared by the Auto-Id center in Adelaide, Australia. Feasible antenna configurations for high frequency tags are also derived from fundamental theory [21]. The Auto-Id center at MIT did extensive research on Intellectual Property, a term gaining much popularity. For identifying physical objects automatically in the real world in a global open system, a common platform is being attempted by the Auto-Id center at MIT [22]. This center published a technical report on the findings of phase 1 of their field trial. They created a simulation of a Networked Physical World System that would help all the supply chain applications. Their key components included EPC, ONS (Object Naming Service), the Savant, the PML (Physical Markup Language) and cheap RFID tags [23]. In [24], the Auto-Id center at MIT describes an intelligent product driven supply chain management system. This white paper deals with imprinting constantly changing real world data on RFID tags and using them for supply chain purposes. Complete functionalities and the life cycle applications of the intelligent products and the entire proposed system are detailed in this white paper. A simple low level description of technical RFID terms like EPC, ONS and PML are described in [25]. Naming of objects at the RFID scenario required a standardization procedure when the RFID concept was first conceptualized. As in the case of the Internet, where we have unique names for entities like the URL (Universal Resource Locator), we have identification codes to uniquely locate any product. They are called the EPC, and the naming scheme, semantics and rules that need to be followed while formulating an EPC is detailed in [26]. As EPC started to dominate the product tracking and inventory control market, demands surged and required for an extension of the EPC. This lead to the invention of the virtual EPC which addressed issues like unique identification of batch products, component types and physical configurations [27]. ThingMagic LLC and Auto-Id center at MIT jointly developed a unique multi-band RFID reader reference platform which was designed to read tags at

both 13.56 Mega Hertz and in the range 902-928 Mega Hertz. The system had a general purpose analog front end up/down converter for each band and a software radio architecture allowing easy adaptation to new frequencies and protocols. The reader's modular software architecture allows easy expansion while at the same time providing sophisticated networking capabilities including Web configurability, dynamic firmware update, and a TCP/IP reader interface by means of an embedded SQL (Structured Query Language) compatible database engine [28]. In [29], Auto-Id center at MIT released a white paper that discussed details about securing the pharmaceutical supply chain using RFID tags. The healthcare system in North America willingly used the proposed system so as to counter act to the problem of Drug Counterfeiting, which was a problem ever since drugs were transported all through the country in mass amounts. Auto-Id Technologies were used to increase the product availability status in any retail shelf. This technology provided a system for inventory control that had product visibility, transparency and an all together new supply chain management system that behaved based on real time demands [30]. Using the same above mentioned technology in a distribution center scenario is detailed in [31], another white paper written by the same authors. In [32], descriptions about a typical Savant software is provided. A Savant is a middleware software that acts as an application side interface between the various enterprise applications and the actual real world tag readers. It makes possible all the computer functions that the system proposes. Specifications about a class 1 RFID tag (860 – 930 Mega Hertz) and its logical communication interface specification are explained in [33].

5. HEALTHCARE

RFID technology is used to create a safe and secure supply chain for the pharmaceutical industry, to streamline reverse logistics and to increase the accuracy and efficiency of distribution of pharmacy and healthcare operations. In [34], architecture for such a stand alone RFID enabled inventory control system is detailed. The reason why UHF (ultra high frequency) is chosen over HF is explained by comparing their material surfaces, read range, tag size and proximity and maturity of the corresponding technology [35]. Aventyn developed CLIP (Clinical Information Processing Platform) that enables the healthcare industry to deliver efficient, low cost and high quality services

with the help of RFID information processing solutions. They also provide medical asset tracking and operate interoperable electronic health care information [36]. Center for Devices and Radiological Health, U.S Food and Drug Administration evaluated the effects of RF electromagnetic fields induced in insulin by exposing it to an RFID system. FDTD (Finite Difference Time Domain) was used to determine the induced fields, the absorption rate and the heating versus time graph. In general, the worst case heating effect and induced electric fields inside Liquid Pharmaceuticals in presence of Radio Frequency Identification Systems were tested and observed [37]. Tata Consultancy Services (TCS) have cited the inefficiencies in clinical trials of drugs taking place at CRO's (Contract Research Organizations). $800 million is spent on an average every year for these clinical trials. TCS verified that usage of RFID can bring in more visibility and help in deducing more information than usual. They proposed a system that has an IEL (Intelligent Edge Layer) that would act as an interface between the RFID system and the existing Clinical Trial Management Systems (CTM) and also for handling the data flow. IEL along with CTM systems and BAM (Business Activity Monitoring) would provide more benefits for the CRO industry [38]. In [39], RFID usage in a medical testing laboratory to create a future Medical Testing Lab that is self aware, adaptive and alert is discussed. The University of Colorado Hospital conducted a case study and concluded that RFID Card Readers helped in their hospital control network access and to achieve HIPAA (Health Insurance Portability and Accountability Act) Compliance [40]. Norwegian centre for telemedicine has probed into possible future applications of telemedicine and also ventured into possible incorporations with the NFC technologies [41]. The University of Minnesota researched the effects of MRI (Magnetic Resonance Imaging) on implanted devices in human organs [42]. They found that an implanted device cannot create any harm and concluded that RFID tags can be used with no sense of fear. This is already in practice currently. Memphis-based systems integrator American Project Services (APS) has teamed up with the University of Memphis' FedEx Center for Supply Chain Management and the Shelby County Regional Medical Center's Trauma Emergency Department to deploy an RFID network [43]. The ultimate aim of the project is to track the time taken by patients at each location in the trauma

center. This data will be provided to the center, which will use it to further streamline its service and improve patients' experience. Texas Instruments, in a white paper released in June 2005, discusses about securing pharmaceutical supply chain using a combination of RFID technologies and PKI (Public Key Infrastructure) technologies [44]. This paper discusses about digitally signed tags and custody event validation of the supply chain.

6. MANUFACTURING

In the Manufacturing domain, incorporation of RFID technology promises improved demand planning and forecasting, faster cash-to-cash cycle, increased labor productivity, stricter quality control, accurate shipment reconciliation, improvement consignment assignment and management [45]. Boeing's IDS (Integrated Defense System), estimated at $27 billion, in Philadelphia, has deployed RFID tag system on many of the spare parts that go into the making of the airplane. They use it for efficient tracking both inside the manufacturing plant and while the consignment is in transit [46]. Dell Inc. also explored the possibilities of RFID tags by studying extensively about Auto-Id. They designed a scoreboard approach for doing financial analysis of Auto-Id applications, another conservative approach, and also went ahead to build a sample business case model [47]. Genpact conducted a case study to evaluate the percentage increase in efficiency of a manufacturing plant after deploying RFID tags. In [48], details about design and development of a closed loop automatic identification and data collection system using Oracle's Sensor Edge Server is discussed. This proposed system could be used in a manufacturing plant to provide better material visibility and to increase labor efficiency. The various ways by which an RFID system could help a business to develop along with incorporation of wireless sensor network technologies is detailed in [49]. RFID technology provides crucial store level promotion execution information and improves post promotion assignment [50]. A novel RPE (real time process execution) methodology is also discussed in the same paper. In [51], the RFID label quality is discussed. Topics discussed include Matching RFID labels with printer/decoder, read range, flexure, adhesion to the fireboard, electrostatic discharge and finally defects in delivered rolls of labels. RFID is also used for tackling product lifecycle management issues. Five major issues wherein RFID technology is supposed to

make an improvement are Product Recall, Just in Time, Service and Maintenance are Repair shops, end of life vehicle issues and asset management [52]. The Metro Group, supposed to be the world's third largest retailer, in its white paper states that RFID technology in its future store at Rheinberg, Germany has produced unprecedented results, majority of the success being owed to the incorporation of RFID technology [53]. The Pyramid creative group released a paper about mastering the conversion of RFID labels. They have a section dedicated to transponder failures which discusses static control inside a RFID circuitry [54]. More problems arising due to static electricity for RFID tags and label converters are discussed in [55].

7. RETAILING

In the retailing industry, RFID systems are used for direct marketing, customer driven marketing and also for obtaining loyalty strategies [60]. In [61], reasons as to why RFID tags and readers will replace bar codes one day are given. More explanations regarding the advantages of using RFID over present day bar codes are also discussed. Infosys technologies, India, in its white paper, states how leveraging RFID technology and other pervasive technologies can increase the transaction efficiency in the consumer retailing market. RFID has features like experience based differentiation that could be of much use to service oriented architecture retailers. Some of the retailing concepts where RFID could be used include SPM (Smart print media) , in store self service kiosks, smart shelves and line busting industries, perpetual check outs, shopping assistance with clientele solutions, remote digital inventories and finally mobile inventorying. RFID in a pervasive computing enterprise can automate data capture, serialize it and provide self reporting systems [62]. RFID has also been used as a validation technique for mobile commerce. In this sphere, it is used for identifying real time transportation data. RFID also helps in gathering information related to products in the M-commerce domain [63]. TR3 solutions have listed the top 10 myths relating to RFID deployment, how to tackle them and deploy RFID technology to attain tangible business value from their own investments [64]. In addition, have included sections on RFID middleware. Apparels and footwear these days are located using item level RFID identification. From the study listed in [65], it is reported that the apparel and footwear industry has made more gains than the CPG (consumer packaged goods) industry by

deploying RFID systems. They were able to automate features like sales floor out of stocks, automated receiving, replenishment from fitting rooms, action against shoplifting, rapid inventory counting, accurate perpetual inventory data, rapid checkout at POS (point of sale) and also in devising the quality of report .

8. PRIVACY ISSUES

Various privacy issues concern the usage of RFID technology. The frequencies used affect the capability and cost depending upon the application in use. The main advantage of an RFID system would be inventory tracking of applications that are not in the line of sight. We can individually identify items ensuring enhanced safety and convenience. Some of the concerns are the following:

- fear of direct monitoring of individuals by vendors,
- indirect monitoring by third parties,
- anti-RFID advocacy and inquiry and RFID regulations without any specific regulatory new law [56].

The institute of pervasive computing in Switzerland has proposed a new system that has more fair information principles applied onto a RFID system, by which the privacy concerns surrounding the usage of RFID technology can be addressed. They propose to have a watchdog tag by which they secure the entire system including the air interface through which the readers and the tags communicate [57]. The concept of VeriChip, a human implantable RFID device that could be used for medical purposes has been discussed in great detail in [58]. All the security and privacy concerns regarding the patient is detailed and the positive aspects are also addressed. An attempt was made at the University of Central Florida to preserve the privacy in low end RFID tags. They used a physically changing bit to preserve privacy. The PCB or the physically changing bit can be changed either way to activate and deactivate the tag so that it stops communicating with the reader [59].

9. SECURITY ASPECTS

Department of Mathematics and Industrial Engineering and Department of Computer Science and Operations Research, University of Montreal, Quebec, Canada proposed a mobile authentication system called AuthenLink for the M-Commerce domain, more specifically for mobile devices [66]. The proposed system uses a micro chip that is planted within a human skin which would enable in human authentication at all possible locations in a work environment. They have covered all the empirical issues

by doing a comparison with other similar authentication systems such as biometrics, and passwords. AXCESS international Inc developed an automated RFID solution for physical IT management and its protection. They have listed the best practices involved with real time inventory, accountability, security for protecting intellectual property and privacy information in compliance with federal and state laws [67]. In [68], overall security and privacy issues related to RFID tags and readers are detailed. Many proposals and policy suggestions are provided to regulate the risk of threats and security issues, some of which include hash lock, randomized hash lock, cellular automata non-linear feedback registers, secure anti-collision through blinded tree walking, randomized tree walking, assignment key agreement, chaffing and winnowing, detection units, screaming tags, security agents and primary master key.

10. STANDARDS AND REGULATIONS

In [69], Tata Consultancy Services have discussed an enterprise way of approaching the implementation of an RFID system. Explanations as to why an enterprise approach is required for any RFID implementation and what it is in simple terms are parts of the discussion. The various building blocks required to create such a simulation are classified as the industry view, business view and the technology view [69]. Another paper by this company provides facts about the concept of traceability in RFID systems. Traceability is used in achieving food safety which is a chief concern among manufacturers and retailers according to the CIES Top of the Mind Survey in 2002 and 2003. The advantages of traceability that is achieved through RFID systems can be listed as follows: efficient recall system for quicker response to customer needs, builds trust throughout the food chain, allows differentiation and effective marketing of products with undetectable quality attributes [70]. Magellan Technology released a white paper where they performed an extensive comparison of the various existing RFID frequencies and the corresponding protocols. Apart from comparing RFID with bar codes, they have special sections on phase jitter modulation, high data rates, anti-collision functions, un-tuned antenna; high and low power mode and memory capacity [71]. A white paper by Juniper Research visualizes the future of RFID in Western Europe. Countries involved in the European Union have come up with mandates and regulations to standardize RFID usage. The paper also

highlights the factors that are reasons why the European countries are refraining from adopting the RFID technology. Possible benefit attaining scenarios are also discussed [72]. The Department of Defense came up with a RFID labeling scheme for the DFARS (Defense Federal Acquisition Regulations Supplement) clause. They explicitly describe four major requirements and explain the importance of each of those requirements from a system and technology and perspective. The issues regarding addressing the RFID labeling mandate is detailed and the requirements for meeting those mandates are also listed [73]. In [74], a primer for the new RF regulations relating to a passive RFID environment is discussed. The impacts of available bandwidth and RF field power, choice of modulation technique, modulation depth and channel width definitions are also explained. The response of the tag in various scenarios along with its duty cycle is addressed. If we need to develop an RFID system that is in compliance with the Department of Defense specifications, twelve basic steps need to be followed. These steps are detailed in [75]. In [76], guidelines referring to human exposure to RF electromagnetic fields are pointed out. The FCC regulations relating to compliance with mobile and portable devices, the MPE evaluation on mobile devices and protocol issues discussing situations of people near antenna are given.

11. STRATEGIES

RFID and its incorporation with SAP in an enterprise requires lot of planning. In [77], business case based introduction to implementation of RFID technology, RFID core functionality and technology and concepts such as asset oriented computing are detailed. RFID system can be deployed using progressive approach too. Prioritization and requirements of such an implementation, cost associated with it and technical challenges like system integration are discussed [78]. ChannelCorp Consultants conducted an industry wide research and several fire tests in sectors like hardware, software and telecommunication and found out that there were five main challenges that could attacked by using RFID technology. They are Strategic/Architectural/Coverage Challenges, Product Marketing Challenges, Channel Marketing Challenges, Channel Development Challenges, and Channel Management Challenges [79]. RFID systems and sensor based networks means a large amount of data in the sense that they output a lot of information that needs to be maintained and harnessed in the right way so

as to make the best use of it. Managing such data, considering their implications and finally coming up with an integrated RFID data management system architecture is the ideal solution. Such a design is proposed in [80]. Very similar to managing the obtained data from RFID systems, the devices involved like the RFID tags and readers/transponders also need to be maintained and constant information about them needs to be logged or reported for future references. Managing devices is explained in more detail in [81]. Business models currently vary from older versions in the sense that they are no more CRM strategies, but follow the EDGE technology, which propose decisions on the fly based on real time feasible decisions. A framework for such an edge computing environment and an example shipping transaction is highlighted in [82]. Managing processes inside an already existing business case model is taxing and can be time and cost consuming. Incorporating such a complex task with RFID technology and the methodology to achieve significant impact is shown in [83]. Compliance alone does not guarantee perfect functioning of an RFID system. Therefore, additional strategies that are required to be in place so as to derive some meaningful value beyond RFID compliance is discussed in [84]. In [85], the practical feasibility of implementing a B2C (Business to Commerce) RFID service through the mobile system is detailed. Most of the current systems do not extend to the private sector. Adopting the strategy explained in [85] could prove fruitful. PLM (Product Life Cycle Management) is a strategic business approach that applies a consistent set of business solutions which support collaborative creation, management, dissemination and use of product definition information. PLM and RFID can be combined to produce more benefiting solutions to many business issues as observed by Tata Consultancy Services [86]. In [87], the new world of opportunities brought about in the mass transit system through contact less ticketing is discussed. In a white paper released in June 2006, facts about high volume and low cost production of RFID tags that have an operating range of 900 Mega Hertz are provided. The operating mode descriptions along with state of the art improvements and the wavezero strategic approaches are discussed in [88]. In [89], the RFID center discusses issues related with competence, advice, support, development and certifications associated with the RFID ecosystem. A testing framework called test pyramid for consistent evaluation of RFID

tags from design and manufacture to end use is detailed in [90]. RFID systems generate large amounts of data, most of which are dumped in repositories for later usage and references. When an RFID system is successfully merged with an upstream system like ERP or supply chain software, we can see advantages beyond tags and readers [91].

12. VENDOR WHITE PAPERS

MPI Label Systems, in its white paper, has highlighted the benefits of automating the slap and ship operation. A fully automated system suffers hugely when the tags begin to fail. Subsequently they developed a solution called RFIDirect, which is a solution that is not fully automated. The proposed process is reliable in the sense that the frequencies never mismatch and hence most of the tag burns and non-responses are nullified [92]. In [93], a brief explanation of class 1 Gen 2 system is provided. Furthermore, its behavior compared to systems using the existing EPC Protocols is also discussed. They start by providing an overview of the class 1 Gen 2 system specification, discuss the flexibility in the read rates and then describe concepts like "Q" protocol and symmetry, and mitigating reader interference. The purpose of combining smart labels with RFID technology for special applications like pallet pilot situations is illustrated in [94]. The theoretical anatomy of a smart label, label certification and steps involved in choosing the right label for the right job is a task by itself. When an information technology company tries to switch to RFID technology, the information it needs to know so as to make a smooth transition is detailed in [95]. An exhaustive account about a typical managerial architecture of an RFID system, the system components, the collaborating IT infrastructure and RFID security aspects are also provided in the same vendor white paper. In a cargo transportation system that uses airplanes for its freight transfer, integration with RFID technology brings in more visibility, a fact confirmed by ACISS Holding [96]. Processing raw data into information that makes sense in an RFID ecosystem is a complex task, but one that needs to be carried out. Process information management is a critical session in RFID systems which involves the following steps: data source identification, data source mapping, packaging level attribute identification, information extraction and filtering, information normalization, item state management and collaborative transaction management which in turn comprises of certification, synchronization

and syndication [97]. A detailed account of the EPC value model for the healthcare and life sciences sectors is provided in [98]. The percentage increase in value of the whole system after incorporating RFID technology and EPC global standards with the existing system is assessed using a methodology described in [98]. Tata Consultancy Services provided a detailed overview of the implementation aspects and benefit calculation proportions for companies in its white paper called RFID Foglifter [99]. EPC protocols were released in updated Gen 2 versions. It promised more speed compared to Gen 1 versions, better bandwidth efficiency, range, reliability, security and cost benefit features. It also had extra features like dense reader operation, write verification, persistence and better range characteristics including tag kill. Questions regarding the abovementioned promises and a more detailed account are provided in [100]. To explain the details of Gen 2 systems, a new primer explaining the available features was given in [101]. In particular, a description of the RPC Gen 2 protocol along with market timings and development, comparison with other classes and operations, and explanations about the promised future proof RFID infrastructure are listed. ODIN technologies also gave a detailed account of the Gen 2 EPC protocol, and provided answers to general questions like what can it do to one's business if chosen to be incorporated? Information about pseudo-compliance and the licensing fees is also accounted [102] [103]. In [104], the advantages of RFID and wireless solutions in a healthcare provider scenario are listed. A standalone RFID enabled patient identification and information system along with a demonstration is also provided. It also has explanations on medical item/asset tracking/identification based on RFID sensor based temperature monitoring applications. Though there are many performance measures that can be used to find the quality output of an RFID system, the metric called receptivity of the tag is the most important one as suggested in [105]. The acceptable degree of receptivity of a tag is measured using concepts like inventory sensitivity and interference rejection. Infosys technologies, India, identified "Inbound Logistics" as the most neglected area in retail and supply chain management. When a marketing department is concerned about outbound logistics, which we call supply chain, the purchase or procurement department is concerned about inbound logistics. Most of the times, higher outbound costs are just to compensate the increase in

inbound logistics management. In [106], a detailed account of managing inbound logistics so as to strike a tradeoff between cost measures in both inbound and outbound logistics is detailed. Infineon technologies, in its white paper, discusses how chips can be used to identify documents in the first place and then in making it more secure [107]. Infochip systems have used RFID systems for tracking of critical components and states that the RFID system can perform actions like proactive maintenance, inventory management, operate mobile data and process web based applications softwares [108]. In [109], IBM, a giant in the RFID industry, illustrates facts about the power and benefits of information integration. Information regarding value generation through information integration, event specification and possible real world benefits are listed too. Apart from item level tracking in the retail supply chain industry, there are many other benefits that can be obtained by the usage of RFID technology. Seven of those are pointed out in [110]. RFID systems have equal usage in the manufacturing and distribution industry as in the supply and retail chain industry. Processes like yard management, asset management, WIP tracking, replenishment and value unlocking are executed with ease in an RFID enabled scenario [111]. General overview of RFID technology and information regarding the implementation are detailed in [112] [113] [114] [115]. Functional requirements regarding the automation of a supply chain environment, project definition and the various layers involved like edge processing layer, operations layer and the enterprise layer are briefed in [116].

13. ANALYSIS

We have discussed different sectors in which RFID technologies find its usage. To summarize, we can state that its use in the supply chain industry is of foremost importance when compared to the other sectors. It opens up more avenues of opportunities with respect to visibility in the chain, extending to management of supply chain. It increases the scalability calculations in the product tracking environment, enhances the effectiveness of the management process as a whole. Most of the companies that have deployed the technology have not restricted themselves to using the standardized available procedure, but have gone ahead and customized the technology to suit their own business needs. For example, the retailing industry has numerous advantages by incorporating the tag based tracking and marking system. The

auto-id sector which is rather new to RFID and has more or less inherited most of its features from the standard set of policies already available for the RFID system. The manufacturing industry proposes more revenue by looking at RFID involvement in their assembly line units. Most of the vendor written papers compliment this fact. Healthcare records in mass transits are also using RFID tags, and so are some of the big scale industries that produce and maintain whole sale medical equipments. The research front in the medical arena uses tags as implant substitutes and radio back information regarding the concerned organ. Their importance and usage in future applications involving the above mentioned industries and many more cannot be denied and is estimated at a humongous rate, even exponential.

In summary, while areas like supply chain and retailing are using RFID technologies extensively it is expected that numerous other areas including finance, defense and intelligence, homeland security, and telecommunications will be major users of this technology in the near future.

14. CONCLUSION

A complete review about existing RFID technologies, the different ways in which they are deployed in multiple industries ranging from retailing to asset tracking is provided in this survey paper. Along with this, an account about the rules, regulations and strategies with respect to the security and privacy issues are highlighted. In addition, a large number of vendor written white papers are reviewed to complete the survey. Methodologies used in various real world industries along with critical observation examples are listed. In conclusion, more than one hundred papers were surveyed in order to provide a thorough discussions and analysis of RFID technology, along with its diverse usage scenarios in multiple industries. Our next step is to select a few areas and conduct in depth research. Some of our possible research directions include the following: Security and privacy for RFID technologies, Management and mining RFID data, Building warehouses for RFID tags, Data streaming and RFID technologies, and Traceability of RFID tags. We have begun an investigation of some of the areas and our research will be reported in future papers.

15. REFERENCES

[1] "Active Tag Zoo" - *Deva Seetharam and Richard Fletcher.*

[2] "Intelligent Transportation System" – "Application of RFID" - *YouLong Zhou.*

[3] "Monitoring Taxi's via RFID tags in Greece" - *Project developed by Control and Advanced Technologies Hellas AEBE.*

[4] "RFID Technology Offers a Cost Effective Tire Management Solution to the Commercial Truck Tire Market" - *Randy A. Jansen, raj@imiproducts.net, American College of Computer and Information Sciences, MGT599 – MBA Thesis, January 31, 2006, Running head: RFID Technology.*

[5] "A Comparison of Smart Tokens and Smart Cards for Limited Use Ticketing and Automatic Fare Collection in Mass Transit" - *White paper prepared by Steven H T Wong, Product Development Director, China Elite Technology Co. Ltd.*

[6] "Automatic Attendance System" - *Grant Hornback, Alex Babu, Bobby Martin, Ben Zoghi, Madhav Pappu, Rohit Singhal.*

[7] "RFID Solutions: The Custom Specialty Garment industry" - *Chad Stone, Ruben Garcia, Alfonso Lujan, Ben Zoghi, Rohit Singhal.*

[8] "GeoTime Visualization of RFID Supply Chain Data" - *David Shuping (FC Business Systems) and William Wright (Oculus Info, Inc).*

[9] "RFID in integrated order management systems" - *Tata Consultancy Services.*

[10] "Lean Supply Chain: A case for the adoption of a techno-process model" - *Rajeev Bajaj Sr. Projects Manager, RFID Practice Lead Supply Chain Management Track Genpact Software.*

[11] "Leveraging Product Codes" - *for Internet Commerce - Ross Stapleton-Gray, Ph.D., CISSP Stapleton-Gray & Associates, CommerceNet Labs Technical Report #04-06 November 2004.*

[12] "Industry developments and models – The RFID Ecosystem for the retail supply chain" - *Christopher Boone.*

[13] "The RFID-Enabled Warehouse" - *Mr. Gino Capone, Mr. David Costlow, Mr. W. L. (Skip) Grenoble, Ph.D., Mr. Robert A. Novack, Ph.D., Penn State 2004.*

[14] "Radio Frequency Identification (RFID) In the Consumer Goods Supply Chain: Mandated Compliance or Remarkable Innovation?" - *Larry Shutzberg, Vice President & Chief Information Officer October 2004.*

[15] "RFID Middleware – Integration to the Entire Supply Chain" - *Kirit Goyal, Deep Krishna.*

[16] "Increasing Security in the Supply Chain with Electronic Security Markers" - *Joseph Pearson, Business Development Manager, Texas Instruments Radio Frequency Identification (TI-RFid™) Systems.*

[17] "Semantics and Internet of things" - *Sapan Shah, Technical Lead, Patni Computer Systems Ltd.*

[18] "Moving Toward the Talking Tag, The integration of voice and RFID offers benefits that neither one alone can provide." - *Tom Kerr, Director of Applied Research,*
Elise Yoder, Software Product Manager – New Markets and Larry Sweeney, Co-Founder and Vice President – Product Management – Vocollect.

[19] "RFID Packaging Innovations: From Smart Labels to Smart Packages" - *Prashant Upreti, Product Marketing, Texas Instruments Radio Frequency Identification (TI-RFid™) Systems Tony Sabetti, Director, UHF Retail Supply Chain, Texas Instruments Radio Frequency Identification (TI-RFid™) Systems.*

[20] "Auto-ID across the Value Chain: From Dramatic Potential to Greater Efficiency & Profit" - *Ajit Kambil & Jeffrey D. Brooks.*

[21] "A Study of Factors Affecting the Design of EPC Antennas & Readers for Supermarket Shelves" - *Peter H. Cole.*

[22] "Executive briefing - Towards an Approach to 'Intellectual Property" - *Kevin Ashton.*

[23] Technical report – "Auto-ID Center Field Trial: Phase I Summary" - *Silvio Albano & Daniel W. Engels.*

[24] "The Intelligent Product Driven Supply Chain" - *Alia Ahmad Zaharudin, Chien Yaw Wong, Vivek Agarwal, Duncan McFarlane, Robin Koh, Yun Y. Kang.*

[25] "The new network - Identify any object anywhere automatically"

[26] "The Electronic Product Code (EPC) - A Naming Scheme for Physical Objects"
David L. Brock.

[27] "The Virtual Electronic Product Code" - *David L. Brock.*

[28] "Multi-Band, Low-Cost EPC Tag Reader" - *Matthew Reynolds, Joseph Richards, Sumukh Pathare, Harry Tsai, Yael Maguire, Rehmi Post, Ravikanth Pappu, Bernd Schoner.*

[29] "Securing the Pharmaceutical Supply Chain" - *Robin Koh, Edmund W. Schuster, Indy Chackrabarti, Attilio Bellman.*

[30] "Focus on Retail: Applying Auto-ID to Improve - Product Availability at the Retail Shelf" - *Keith Alexander, Garry Birkhofer, Kathryn Gramling,*
Herb Kleinberger, Stephen Leng, Dhaval Moogimane, Maurice Woods.

[31] "Focus on the Supply Chain: Applying - Auto-ID within the Distribution Center"
Keith Alexander, Tig Gilliam, Kathryn Gramling, Mike Kindy, Dhaval Moogimane, Mike Schultz, Maurice Woods.

[32] "Auto-ID Savant Specification 1.0" - *Sean Clark (Sun Microsystems) sean.clark@sun.com, Ken Traub (ConnecTerra, Inc.) kt@connecterra.com, Dipan Anarkat (Uniform Code Council) danarkat@uc-council.org, Ted Osinski (Uniform Code Council) tosinski@uc-council.org.*

[33] "860MHz–930MHz Class I Radio Frequency - Identification Tag Radio Frequency & Logical, Communication Interface Specification, Candidate Recommendation, Version 1.0.1" - *Auto-ID Center.*

[34] "An Industry Working Group Report on Jumpstarting RFID/EPC in the Pharmaceutical Supply Chain"

[35] "RFID and UHF: A Prescription for RFID Success in the Pharmaceutical Industry."

[36] "Clinical Information Processing Platform – RFID Solutions for delivering efficient, high quality healthcare."

[37]" Liquid Pharmaceuticals and 915 MHz Radiofrequency Identification Systems, Worst-Case Heating and Induced Electric Fields." - *Howard Bassen, Leader, Electromagnetics and Wireless Laboratory, Division of Physics, Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, U.S. Food and Drug Administration, 12725 Twinbrook Parkway, Rockville, MD 20852*

[38] "RFID in Clinical Trials" – *Tata Consultancy Services*

[39] "Medical Testing that is Adaptive, Alert and Aware" - Hanns-Christian Hanebeck, Director Enterprise Applications, GlobeRanger, Ines Dekker, Consultant, Atos Origin, Erik Cramer, Director *of Global RFID, Atos Origin.*

[40] "Case Study: University of Colorado Hospital, RF Ideas Card Readers Help Hospital Control, Network Access, Achieve HIPAA Compliance."

[41] "What about Near Field Communication technology? An overview with possible future telemedicine applications." - *Enrico M. Staderini, Norwegian Centre for Telemedicine, Tromsø, Norway.*

[42] "Magnetic Resonance Imaging & VeriChip™, RFID Human Implant at 1.5 Tesla" -
James Lamberg, University of Minnesota Twin Cities.

[43] "RFID In Hospitals – Issues and Solutions" - *Madhav Pappu, Ph.D., Rohit Singhal,*
Ben Zoghi, Ph.D.

[44] "Securing the Pharmaceutical Supply Chain with RFID and Public-key infrastructure (PKI) Technologies" - *Joseph*

Pearson, Pharmaceutical Business Development Manager, Texas Instruments Radio Frequency Identification (TI-RFid™) Systems.

[45] "Communications, Consumer, Industrial and Technology Beyond Compliance: The future Promise of RFID"

[46] "Radio Frequency Identification: Making a Difference at Boeing" - *By: Kash Bhaya, The Boeing Company, and William Duncan, Computer Sciences Corporation.*

[47] "Building a Business Case for RFID at Dell" - *Mark Dinning, Dell, Inc., Edmund W. Schuster†, Research Consultant to Auto-ID Labs.*

[48] "Using RFID In Manufacturing – A Pilot Case Study - Kirit Goyal, Genpact"

[49] "Helping Organizations realize the business benefits of RFID and wireless sensor network technologies."

[50] "OATSystems – Real time promotion execution (RPE)."

[51] "Practical Guide To RFID Label Quality" - Paxar.

[52] "RFID - Tackling Product Lifecycle Management issues" - *By Rajaravisankar Shanmugam, September 2004.*

[53] "Real World RFID" - *White Paper.*

[54] "Mastering RFID Label Converting *Where Understanding Static Control Can Help Prevent RFID Transponder Failures."* - *By Mark Blitshteyn, Ion Industrial.*

[55] "*Shock*ing problems for RFID Tag & Label Converters from Static Electricity!"

[56] "RFID Tags and Privacy: How Bar-Codes-On-Steroids Are Really a 98-Lb. Weakling" - *by Jim Harper*.*

[57] "Scanning with a Purpose _ Supporting the Fair - Information Principles in RFID Protocols" - *Christian Floerkemeier, Roland Schneider and Marc Langheinrich, Institute for Pervasive Computing, ETH Zurich, Switzerland.*

[58] "Is the verichip: friend or foe?" - *a paper submitted in partial fulfillment for thesis work by a student in Dallas – more details at RFIDjournal.com.*

[59] "PCB: Physically Changeable Bit for Preserving Privacy in Low-End RFID Tags". *Cliff C. Zou, School of Electrical Engineering and Computer Science, University of Central Florida.*

[60] "Loyalty programs redesign among rfid lines, some examples from industries" – *by freddy brofman.*

[61] "White Paper - Diagraph - an ITW Company - RFID is to Cellular as Barcode is to Phone Booth."

[62] "Leveraging RFID and other Pervasive Technologies to achieve transaction efficiency in consumer retailing" – *Infosys.*

[63] "Mobile Commerce with RFID" - *ZulkharNain , Researcher, JNTUH, India.*

[64] "Top 10 myths about RFID Data Analytics."

[65] "Moving forward with item – level radio identification of apparel and footwear."

[66] "ASEMC: Authentication for a SEcure M-Commerce" - *Christina Braz1 and Esma Aïmeur2, 1 Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal, C.P. 6079, succ. Centre-Ville, Montreal (Quebec) Canada H3C 3A7 Christina.Braz@polymtl.ca, http://www.polymtl.ca/fr/fr/index.php, 2 Department of Computer Science and Operations Research, University of Montreal, C.P. 6128, succ. Centre-Ville, Montreal (Quebec) Canada H3C 3J7, aimeur@iro.umontreal.ca, http://www2.iro.umontreal.ca/~aimeur/.*

[67] "An Automated RFID Solution for Physical IT Asset - Management and Protection

A Best Practice for Real Time Inventory, Accountability, and Security for Protecting Intellectual Property and Privacy - Information in Compliance with Federal and State Laws."

[68] "Security and Privacy in Radio-Frequency Identification Devices" – *by Stephen August Weis - Submitted to the Department of Electrical Engineering and Computer*

Science - in partial fulfillment of the requirements for the degree of Master of Science in Computer Science.

[69] "Compliance and Beyond – an enterprise approach to RFID implementation" - *Tata Consultancy Services.*

[70] "Enabling Traceability in RFID" - *Tata Consultancy Services.*

[71] "A comparison of RFID frequencies and protocols" - *Magellan Technology.*

[72] "RFID Futures in Western Europe" - *Juniper Research.*

[73] "Requirements for Meeting the DoD RFID Labeling DFARS Clause" - *Miles Technologies - 1150 Heather Drive - Lake Zurich, IL 60047 - 800-783-2132.*

[74] "Passive Radio Frequency Identification (RFID) – A Primer for New RF Regulations" - *By Kevin Powell, Senior Director, Product Development, Matrics Inc.*

[75] "12 Basic Steps for DoD RFID Compliance" - *Paxar.*

[76] "Briefing paper for EPCGlobal on - The need to Demonstrate Compliance with FCC - Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields - (RFID)" - *Magellan Technology.*

[77] "RFID and SAP: A Strategic Vision - *Leading Edge Forum Technology Grant* Jonathan Gregory" - *Computer Sciences Corporation - May 2006.*

[78] "Deploying RFID using progressive approach" – *By Sapan Shah – Patni Computer Systems Ltd & Teo Ruscin – GE Transportation, Aircraft Engines.*

[79] "Fire Test Findings and Fixes" - *Channel Corp.*

[80] "Managing Data from RFID & Sensor-based Networks - Implications and Considerations for Data - Management Challenges" - *Christian Hanebeck - Director Enterprise Applications.*

[81]"RFID and Sensor-based Device and Network Management - Building the Intelligent Network of Connected – Items" - *Christian Hanebeck - Director Enterprise Applications.*

[82] "Edge Computing Platforms - Enabling Real-Time Decisions at the Edge" - *Hanns-Christian Hanebeck - Director Enterprise Applications.*

[83] "Processes Management and RFID - Implications and Considerations for Process Management" - *Hanns-Christian L. Hanebeck - Director Enterprise Applications.*

[84] "Strategies for Deriving Value Beyond RFID – Compliance - Ideas, Metrics, and Business Case Development, for Wal-Mart Suppliers" - *Christian Hanebeck - Director Enterprise Applications.*

[85] "Opening Strategy for Mobile RFID Service in Korea" - Boo-*man Cheong - (Director, RFID/USN Team, and National Computerization Agency)*

[86] "PLM – RFID combined solutions to solve new business issues" – *Tata Consultancy Services.*

[87] "Smart ticketing for mass transit - The new global opportunity created - by low-cost, contactless ticketing" - *Innovision Research & Technology plc.*

[88] "High Volume, Low Cost Production of RFID Tags - Operating at 900 MHz." - *Fabrizio Montauti, PhD - WaveZero, Inc.*

[89] "Center for Competence" – *RFID Center.*

[90] "The test pyramid: a framework for consistent evaluation of RFID tags from design and manufacture to end use" - *David J. Puleston and Ian J. Forster Avery Dennison RFID Division - (rfid.info@averydennison.com) -*

[91] Upstreaming RFID – beyond tags and readers – Tata Consultancy Services.

[92] "The Benefits of Automating a Slap and Ship Operation" - *MPI Label Systems.*

[93] "EPC Class 1 Gen 2 Specification" – *Alien.*

[94] "From bar codes to smart labels" – *PrintRonix.*

[95] "RFID White Paper - Technology, Systems, and Applications - An overview for companies seeking to use RFID technology to connect their IT systems directly to the "real" world."

[96] "Safe and Secure Air Cargo Containers with Integrated RFID Visibility System" – *ACISS.*

[97] "Product Information Management" – *Comergent.*

[98] "Safe and Secure Air Cargo Containers with Integrated RFID Visibility System."

[99] "An RFID Foglifter" – *Tata Consultancy Services.*

[100] "Will your Gen 2 system be up to the standard?" - *Intermec.*

[101] "Generation 2 – A user guide" – *ThinkMagic.*

[102] "Understanding the Evolution: How Gen 2 Will Impact You - A guide for dealing with the Complexities of Gen 2 RFID".

[103] "Gen 2"– *by John Burnell.*

[104] "Radio Frequency Identification (RFID) and Wireless Solutions for Healthcare Service Providers" – *Alvin Systems.*

[105] "Receptivity - a tag Performance metric" – *by Impinj.*

[106] "Driving costs out of the Supply Chain – inbound logistics" – *by Infosys.*

[107] "The Role of Chips in Making Identification Documents More Secure" - *A white paper produced by Infineon Technologies N.A., based on AeA's Secure ID CyberForum, Washington, DC, July 14, 2005.*

[108] "Managing Critical Equipment with RFID" - *Improving Certification, Maintenance & Tracking (CMT) Processes – InfoChip.*

[109] "Information Infrastructure – delivering the advantage of information integration today" – *IBM.*

[110] "7 Places Retailers Can Benefit from RFID Without Item-level Tagging" – *Intermec.*

[111] "Beyond the Tag – Finding RFID Value in Manufacturing and Distribution Applications" – *Intermec.*

[112] "RFID Overview" – *Intermec.*

[113] "A basic introduction to the RFID Technology and its use in the Supply Chain" – *Laran RFID.*

[114] "The RFID Software Conundrum" – *Markem Corporation.*

[115] "RFID basics – updated" – *Monarch Services.*

[116] "Supply Chain Automation- Project Definition" – *Modular Computing Systems.*