A Taxonomy for RFID Systems

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***Abstract*—Ben Clacy and Brian Jennings presented their recently published paper with the title of "service management: driving the future of IT" [1], which highlighted service oriented is very important. How is the situation of RFID systems? There is a proliferation of RFID systems – tags, sensors, readers, middleware and applications - each attempting to solve a specific business need. RFID technology can be found embedded in almost everything from razor blade packages, clothing and books to prescription medicines to parts of an aircraft, indeed it forms a new area titled silent-commerce (s-Commerce). Despite the pervasive nature of RFID, surveys have consistently shown a lack of RFID awareness, an overall lack of understanding and general confusion about what it actually is, its capabilities and limitations. This is due in part to a lack of a comprehensive, principles-based and systematic RFID classification scheme. This paper makes its contribution that first proposes taxonomy of currently available RFID technology and systems. The taxonomy is based on a sound service-oriented RFID architecture framework. It can be used by both novices and RFID practitioners to gain an understanding of the "next big thing" technology, the architectural considerations for designing and implementing a successful RFID system. Moreover, RFID researchers will also benefit from this taxonomy.**

Index Terms— RFID, taxonomy, service-oriented, architecture framework.

I. Introduction

Recently Clacy and Jennungs published a paper titled, "Service management: driving the future of IT" [1], which shows that "moving into 2007 and beyond, it is evident that IT service management (ITSM) adoption will continue to grow, and that its visibility is increasing within all types of organizations." How to look after *service management* in RFID systems? Obviously, the first thing needs to do is to have "a service oriented RFID taxonomy," which drives this paper. In fact, RFID is not new. The foundation was laid many decades ago. In fact the birth of RFID happened when Harry Stockman published his landmark paper titled "*Communications by Means of Reflected Power*" Proceedings of the IRE, pp 1196-1204, October 1948. A lot of progress has been made in the 58 years since Harry Stockman's work. However, RFID has been gaining momentum only in the last few years thanks to initiatives both by the US DoD and by private-sector retailer giant Wal-Mart in the US in mandating RFID requirements in their business dealings with suppliers and service providers. Today, RFID technology comes in a myriad of forms enabling an ever-expanding range of practical applications to transform business operations all over the world. RFID technology can be found embedded in almost everything from razor blade packages, clothing and books to prescription medicines to parts of an aircraft. It has the capability to help track inventory, prevent counterfeiting (of money, drugs ...) and even fight terrorism. Despite the pervasive nature of RFID, surveys have consistently shown a lack of RFID awareness, an overall lack of understanding and general confusion about what it actually is, its capabilities and limitations. This is due in part to a lack of a comprehensive, principles-based and systematic RFID classification scheme. There is a need for a systematic, comprehensive and robust classification scheme to enhance the understanding of this revolutionary technology. Hassan and Chatterjee [2] and other person [4] provided a useful and systematic classification of RFID systems. The classification scheme was based on some broad business principles such as "make it easier to navigate" through the large volume of knowledge on the subject, "to get an overview of which components of the technology can be researched on", etc. It did not seem to be based on any robust scheme or framework. Furthermore, security was not extensively covered, mainly in the Data section only [3], [5], [6]. This work will improve the previous scheme in a number of ways. Firstly, it is founded on a robust and practical service-oriented RFID architecture framework that blends the traditional OSI layers and the service-oriented enterprise architecture components. Due to the paper length limitations, we are unable to provide more details to each subcategory and their inter-dependencies in the taxonomy. Instead we tried to present as much information as appropriate in the more critical subtopics of our taxonomy. The structure of the paper is as follow. In section 2, the service-oriented RFID architecture framework is presented and followed by our taxonomy in section 3. Section 4 checks the applicability of the taxonomy by examining sample real-world cases. Section 4 concludes our paper.

II. Service-oriented RFID architecture framework

A. *Definitions*

Before diving into the framework itself, it would be useful to define what we mean by terms such as *service-oriented* and *architecture framework* in the context of this paper.

Firstly, what is a service? There are many definitions, statements about what it is. Hao He [9] offers one of the simplest definitions: "*A service is a unit of work done by a service provider to achieve desired end results for a service consumer*". It embodies the technical implementation of a logical unit of work with a well-defined interface that can be activated by another service, for example, software service, data service, etc.

Service-oriented refers to a concept and an approach to distributed computing and communication that think of computing and communication resources as services available on an information and communication technology (ICT) infrastructure.

What is architecture framework? It is basically a tool for thinking about the information that needs to be captured about an enterprise, to understand how everything interrelates, and to enable the building of information systems that effectively support the business. Examples of well-known architecture frameworks include Zachman and TOGAF frameworks.

B. *Framework overview*

A full treatment of the framework is beyond the scope of this paper. Only a brief discussion is offered to aid the understanding of the taxonomy that is the focus in the main sections.

Successful RFID system implementation is more than just technology and interconnections that can traditionally be satisfied by the use of the 7-layer OSI model. RFID systems are implemented to meet enterprise business needs. To help ensure business – RFID service alignment, a holistic enterprise architecture approach is required. The blending of RFID OSI layer model and enterprise architecture layer concept is quite novel. The framework is shown in Figure 1.

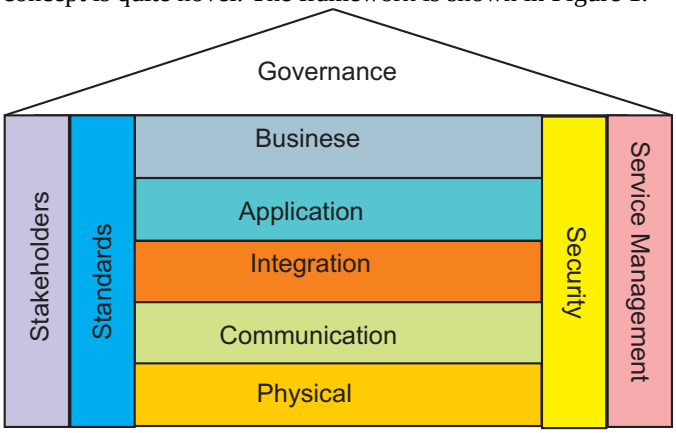

Fig. 1. Service-Oriented RFID Architecture Framework

The hybrid framework recognizes the engineering and computer communications "root" of the RFID technology as well as the enterprise architecture and service-oriented approach necessitated by the business transformation potential RFID will bring to many enterprises.

The benefits of such a framework include:

- bringing the engineers, IT and business groups together
- enhancing the collaboration between these groups
- enterprise-wide (or extended enterprise-wide) focus rather than silo focus
- encouraging an open rather proprietary approach
- assisting customers to evaluate RFID vendors' offerings in a systematic and comprehensive manner
- interoperability between differe3nt RFID technologies and systems

Physical Service Layer

It is equivalent to the Physical layer in the TCP/IP architecture model and comprises of readers, antennas, passive, semi-active, active RFID tags, sensors, motes, etc.

Communication Service Layer

This layer provides the equivalent functions of the Data Link, Network and Transport layers of the TCP/IP architecture model. These include reader networking both wired and wireless. It also handles the communication link and the RF coupling between an Interrogator (Reader) and Transponder (Tag), the Media Access Control (MAC).

Integration Service Layer

This is a new layer that is created for RFID to efficiently handle a huge volume of raw RFID data in real-time. It also provides a means to integrate the back-end enterprise applications with the RFID infrastructure. It is a service-oriented integration layer that will become an important ingredient of the extended enterprise RFID business solutions. In other words, it has the ability to act as a B2B hub for transactions between business partners in the supply chain.

Application Service Layer

This layer consists of various "back-end" enterprise applications that support the business including RFID applications. These back-end enterprise applications that require information from RFID systems include, but are not limited to, Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM), and so on.

Business Service Layer

RFID has the capacity to enable business transformation. To benefit from the implementation of RFID technology, it is often necessary for the enterprise to re-engineer its business processes. This layer deals with enterprise business services, business goals and objectives, business processes, business functions and organizational structure, and so on.

Security Service Layer

Security is one of the most important components of any architecture model in general and in any RFID system implementation in particular. It straddles across all horizontal layers. Having security as a separate component in the framework it will help focus on security service component early and throughout the project. As it touches all layers, it also encourages a holistic, end-to-end and multi-layer defense mechanisms (defense in depth).

Standards Service Layer

Standards are critical for many RFID applications (or any application for that matter) especially in open supply chains extending across many enterprises (extended enterprise). This layer contains the enterprise's list of preferred standards that it has selected. Adopting approved open international standards will enhance interoperability and reduce costs substantially in the long run.

Service Management Layer

This layer focuses on delivering and managing RFID systems as a service. This notion of an RFID service can be viewed both internally and externally. A typical RFID system implementation consists of a wide range of devices, supporting infrastructures, applications, etc. They need to be managed to ensure service levels are met. For example, there is a need to remotely monitor, configure and update firmware and software of deployed assets such as readers, antennas, servers, etc. Best service management practices such as ITIL, COBIT are recommended. Increasingly in the service-oriented world, business process management (BPM) becomes critical especially in an extended supply chain RFID operation.

Stakeholders Service Layer

Identifying stakeholders and understanding their needs are critical in the development of a service-oriented architecture. In the context of RFID system architecture, there exists a multitude of stakeholders, some of them are obvious, and some are not. They can be our trading or business partners, consumers, our own workers, and so on. Each has its own influence on our architecture.

At the policy level whether it be at the national, regional or international levels, stakeholders consultation and participation are critical. A recent example of this approach is that a stakeholder group will be formed to advise the Commission on the development of its RFID policy [13].

Governance

It is a subset of the corporate governance and includes but does not limit to structure (business and technical committees, steering committees, etc.), processes, rules and procedures. It also involves governance at national, regional and international levels – competition, standards, collaboration, intellectual property (IP) rights, international trade, environment, ethics (RFID implants, labor practices ...), etc.

This component is often overlooked or given a scantily attention.

III. A Service-Oriented RFID Taxonomy

3.1 Definition

The on-line Compact Oxford English Dictionary defines taxonomy as "a scheme of classification". Another definition is from Webopedia website "The science of categorization, or classification, of things based on a predetermined system" [15].

3.2 Automatic Identification and Data Capture (AIDC) and RFID – The Big Picture

The revolutionary RFID is a member of a broad family of AIDC technology as shown in Figure 1. AIDC technologies are used to help machines identify and gather data on humans, animals or objects without human intervention or manual data entry.

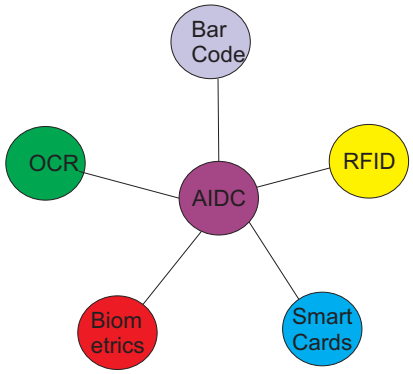

Fig 2: The Family of Automatic Identification and Data Capture Technologies

3.3 Top View

The top tier of the RFID hierarchy is shown in Figure 3.

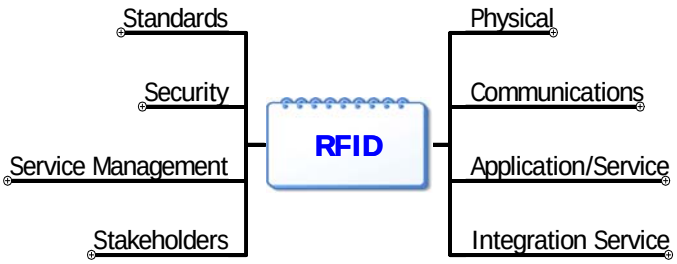

Fig 3: Top Tier

It is note that the governance and business service layers are not included in the taxonomy. It is thought that although RFID systems are very important in the enterprise business model, they might not be the core business for the majority of these enterprises. For example, RFID technology is implemented basically to help Wal-Mart and others to improve their core business bottom line.

It is also debatable whether Stakeholders should be included in the RFID taxonomy. If we want to take a service-oriented enterprise architecture approach to enhance the success of the RFID implementation, it is fundamental that we engage or at least consider our stakeholders right at the beginning. Enterprises that neglect this important enterprise architecture component do it to their detriment.[Ref Wal-Mart and Benetton abortive trials]

We first describe the core RFID OSI layer categories namely the Application, Integration, Communication and Physical Service layers.

3.4 Application /Service

Application/Service can be expanded as shown in Fig 4.

Currently there is a myriad of interesting applications involving RFID technology in many sectors of our society including private organizations in retailing, manufacturing industry, etc. to government department in law enforcement, health, defense, etc. New innovative applications appear almost every day. There are many ways RFID is invading our daily lives [10] future application categories that we would not even dare to contemplate today

3.5 Integration Service

Integration service is shown in Fig.5.

3.6 Communication Service

For the communication service we can present the diagram as shown in Fig. 6.

3.7 Physical Service

Form factor includes the packaging a tag can be put in. These include thermal transfer labels, plastic cards, key fobs and so on. It is a key factor for the usability of the tag.

3.8 Standards Service

Standards are critical for the successful implementation of an RFID system in the long term. There is a temptation to architect a non-standard or proprietary system in a closed-loop configuration for which there is no need to share the data with any external entities. Such a practice may succeed in the short term, the risks are high in the long term, particularly when the need to share data with external entities, e.g. trading partners arises. Adopting approved and open standards enhance interoperability and reduce costs substantially.

RFID standards development works are generally undertaken at an international level. The main organizations include ISO, IEC, EPC Global and ITU-T. There is much some confusion when EPC Global published its own RFID Air Interface protocol while ISO 1800-6 existed. Regional organizations such as ETSI, EAN and national bodies such as ANSI in the US and Japan's Ubiquitous ID Center also develop a number of standards. China has the world's largest potential RFID market. Its political leaders view the setting of RFID standards as critical to its economic strategy [7]. The People's Daily Online [8] recently reported that more than 70 members of China's top political advisory body backed a proposal to revive a mandatory home-grown standard for radio tag technology. It further added that the move could create a new rift between the United States and China over technology standards.

There are currently no internationally agreed frequencies for RFID operations other than the 13.56 MHz frequency.

3.9 Security Service

Security and Privacy are not the same but related. Both need to be handled with utmost care especially the privacy. There are a lot of real concerns out there not just from the so-called "radical" groups calling for the blanket boycott of RFID technology but also from the seasoned practitioners. Consumer backlash led by CASPIAN forced the major European clothes manufacturer Benetton to back away from a RFID trial [11] in 2003. Similar protest against US retail giant Wal-Mart under the banner "Listen up, Wal-Mart: "No spychips!" occurred in 2005.

Privacy is a concept in disarray. Nobody can articulate what it means. So Solove [15] has developed a comprehensive taxonomy of privacy covering information collection, processing and dissemination and invasion. Not all of the subcategories are directly applicable to RFID privacy.

3.10 Service Management

It is traditionally often considered as an after thought after systems have been implemented. RFID is no exception. Good RFID service management tool is almost non-existent. However, there are vendors and standards bodies who have been actively involved in providing solutions to address service management issues.

An RFID protocol standard that is intended to address reader and RFID system management is being developed by ISO. It is provisionally titled *RFID System Management protocol*.

There is a small number of start-ups [14] and long-established technology providers (e.g. Cisco, IBM, Sun) who start offering devices and software to manage the RFID infrastructure to facilitate the delivery of a vast amount of data from the readers to business applications.

3.11 Stakeholders

No technology can be successfully implemented without the broad acceptance by its users, whether they be individual consumers, industries or workers.

IV. Conclusion

We have presented in the paper a comprehensive RFID taxonomy complete with an exhaustive tree node diagram that is visually easy to follow. The classification scheme is represented by the tree branches in the diagram. It is based on a sound RFID architecture framework that "integrates" the conventional and familiar Open System Interconnections

(OSI) layers in the centre with the best-practice enterprise architecture components.

This taxonomy includes most of the current known RFID technology implementations. However, it is a "living" document hence continues to evolve as the technology evolves, new usage being created and new issues being discovered. Moreover, it will require more "field testing", iterations and fine-tuning before it can be accepted as the definitive RFID classification scheme.

The need for an RFID taxonomy stems from the fact that RFID is not just about technology with tags and readers, it is much more complex and encompassing business processes, technology and people. Therefore, an enterprise architecture approach to RFID system planning and development is required. There also exists a wide variety of currently available RFID systems. Moreover RFID technology has become so pervasive and "mutated" into other forms such as in Ubiquitous Sensor Networks (USNs), Mobile Ad-hoc Networks (MANETs). It is also "meld" into personal devices such as PDAs and smart phones. Therefore a systematic organisation of a source of information on RFID technology and systems based on a sound service-oriented framework would be appreciated by novices, enthusiasts, practitioners and academics alike.

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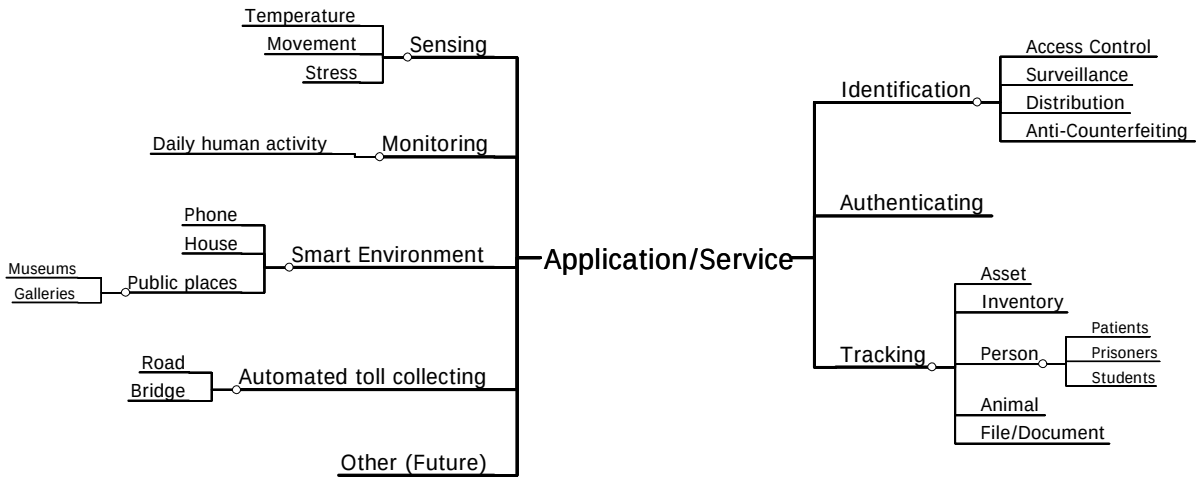

Fig. 4: Diagram for Application /Service

Fig. 5: Integration Service

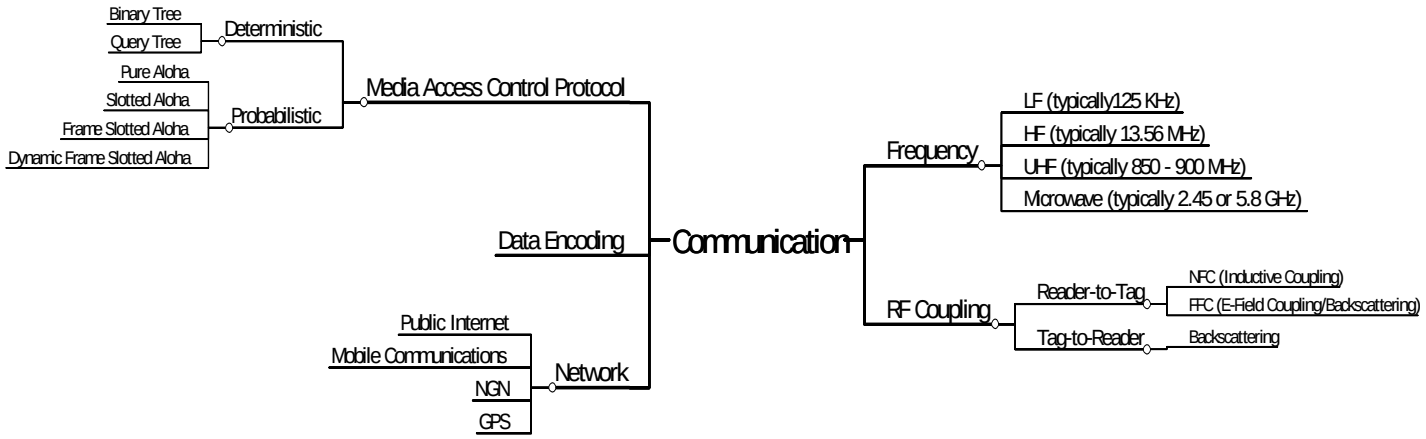

Fig.6: Communication service

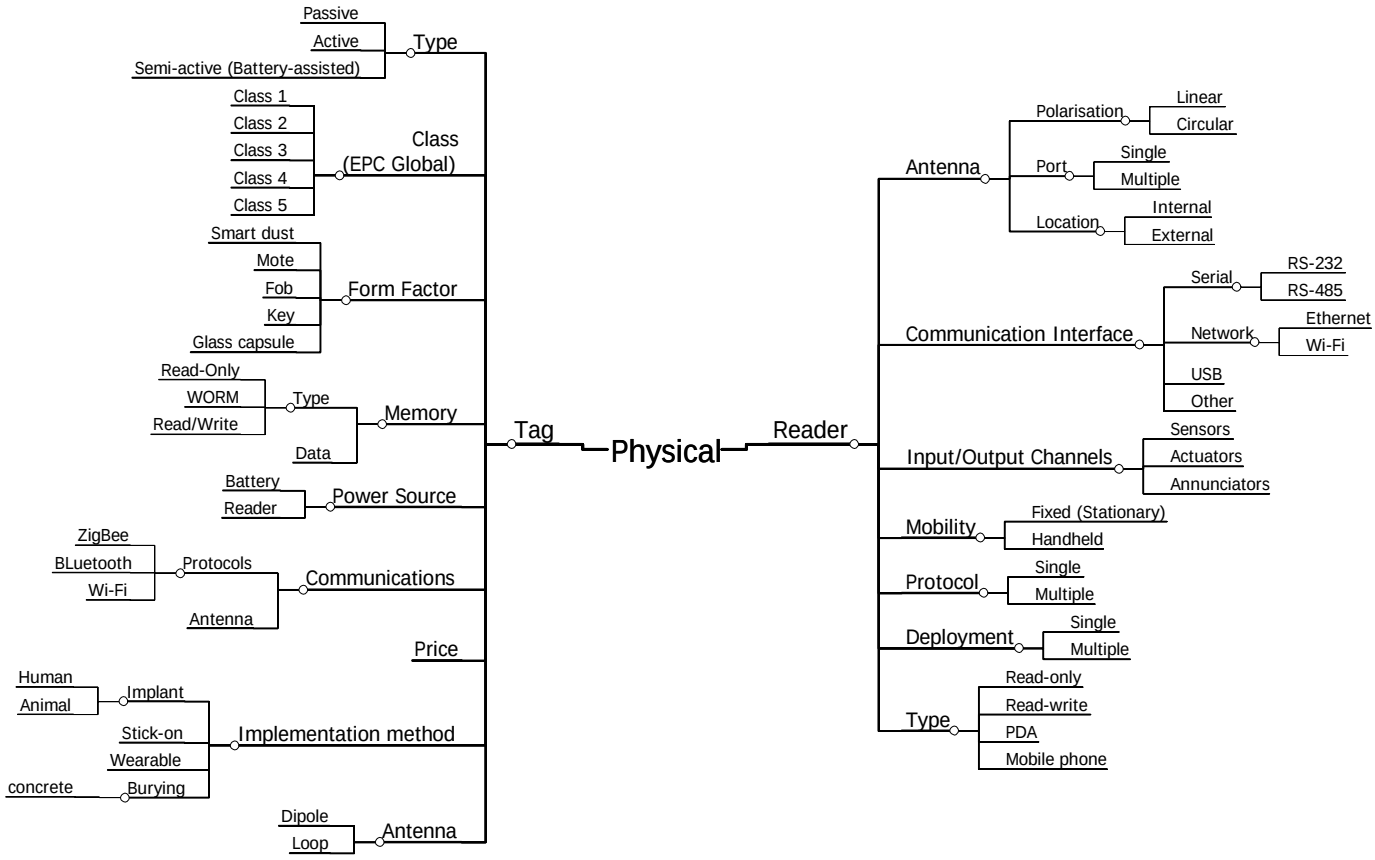

Fig.7: Physical Service

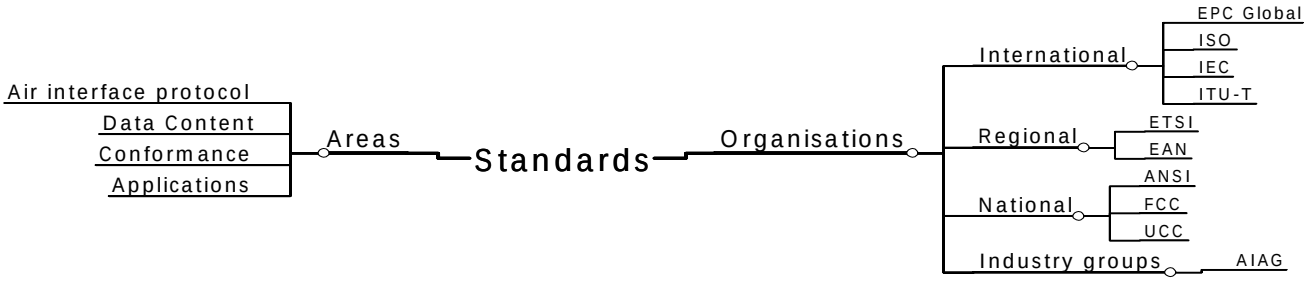

Fig. 8: Standards Service

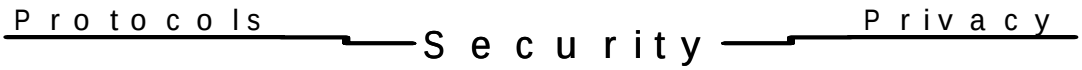

Fig. 9: Security Service

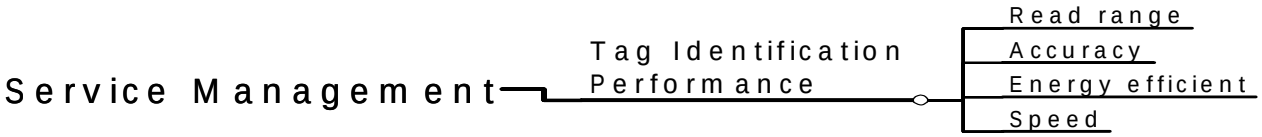

Fig.10: Service Management

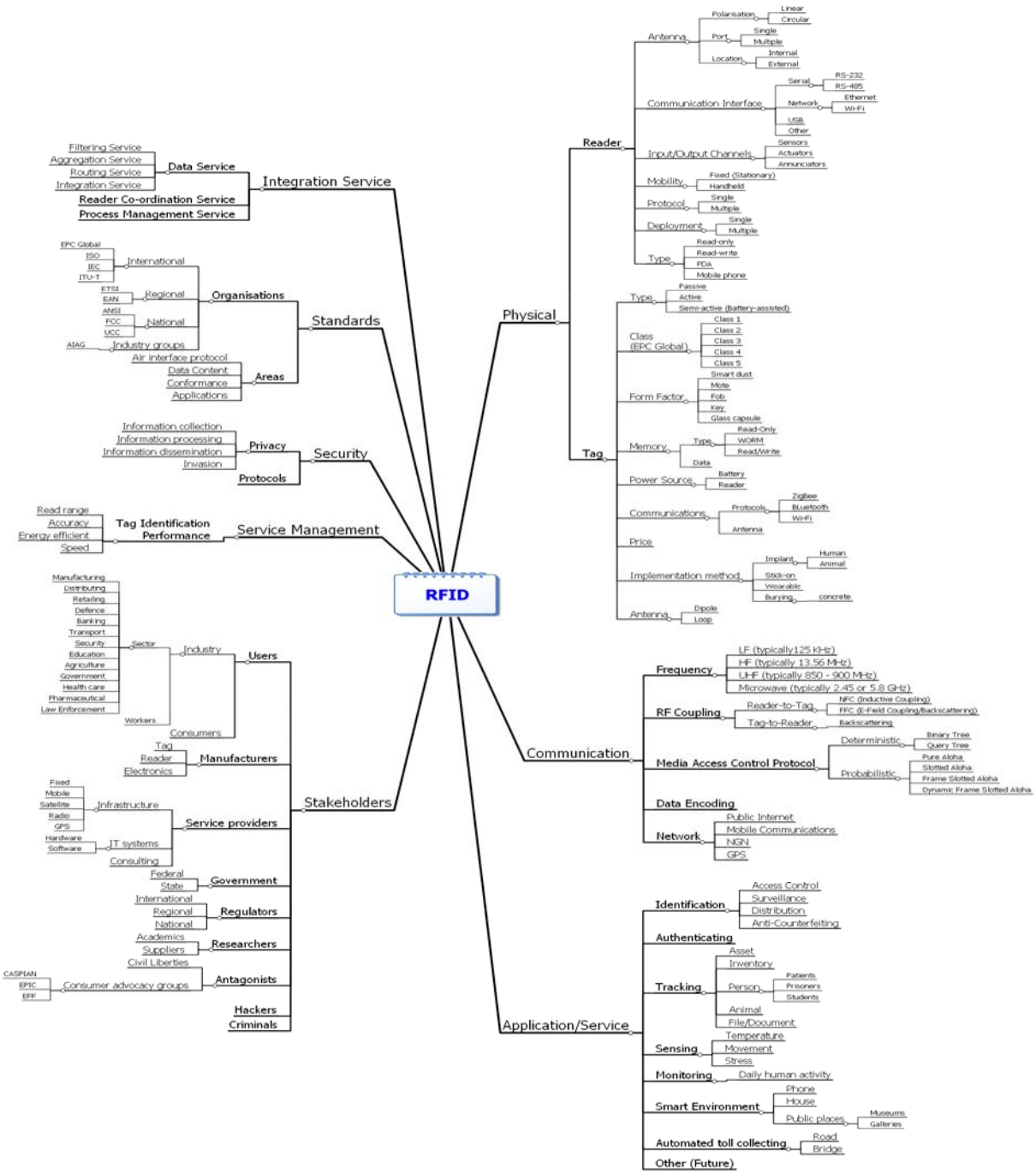

Fig. 11: Diagram for Service-Oriented RFID Taxonomy

RFID technology basics. Radio Frequency Identification (RFID) is the wireless or contactless transfer of a digital ID and additional data between an RFID tag and a reader by means of electromagnetic waves. Tagging of physical objects allows businesses, organizations and consumers to assign a unique digital identity -- a digital twin -- to identify, authenticate, track, sense and engage with each object seamlessly.Â Simply put, RFID systems consist of three components: RFID tags or intelligent labels; RFID readers (also called interrogators); and software (also called middleware) to feed the captured data into IT systems or the Internet of Things (IoT). RFID systems come in a myriad of forms, each catering to a specific need. However, a systematic classification to reduce the confusion of potential adopters, researchers and enthusiasts is still lacking. This article proposes and evaluates a taxonomy of various RFID systems currently available. The taxonomy can be used for gaining an understanding of this technology, the factors for implementation of a successful RFID system, its strengths and weaknesses as well as scalability options. Both novice as well as experienced RFID researchers will benefit from this classification. Published in: Proc Radio-frequency identification (RFID) uses electromagnetic fields to automatically identify and track tags attached to objects. An RFID system consists of a tiny radio transponder, a radio receiver and transmitter. When triggered by an electromagnetic interrogation pulse from a nearby RFID reader device, the tag transmits digital data, usually an identifying inventory number, back to the reader. This number can be used to track inventory goods. There are two types of RFID tags: There is a proliferation of RFID systems â€“ tags, sensors, readers, middleware and applications -each attempting to solve a specific business need. RFID technology can be found embedded in almost everything from razor blade packages, clothing and books to prescription medicines to parts of an aircraft, indeed it forms a new area titled silent-commerce (s-Commerce).Â Reference [5] presents a taxonomy for RFID system. There are many researches on standardization of the RFID middleware system. An Approach to Design and Implement RFID Middleware System over Cloud Computing. Article. Full-text available.