Chapter 5

RFID Applications and Related Research Issues

5.1. Introduction

RFID technology is one of the leading enabling technologies in building the Internet of Things (IoT), since inanimate objects in daily life will join the network via this technology. For this reason, this chapter provides an overview on RFID applications and ongoing research issues based on the current literature, scientific papers and commercial applications. It provides basic concepts that include the main definitions required in order to understand this technology.

5.2. Concepts and terminology

The following section provides the basic definitions relating to RFID technology. Chapter 2 of this book provided deeper knowledge related to this technology.

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5.2.1. *Radio-frequency identification*

RFID stands for radio-frequency identification and is used mainly for tracking and tracing objects, animals and people. Its major advantage over its predecessor, the barcode, is that the identification is stored electronically and can be retrieved wirelessly via an interrogator or reader with no line of sight required.

The basic hardware through which this technology is implemented is built upon three elements: transponders or tags with or without inbuilt energy that stores an identifier (ID) related to a specific object, readers or interrogators that obtain the ID stored in the tags and servers to perform the processing of collected data following a certain application. This is also called RFID middleware.

The most common frequencies are 860–960 MHz and are termed the ultra high frequency (UHF) band. UHF is also used by the Electronic Product Code (EPC) Gen II/ISO 18000–6c standards. The high frequency band (HF) of 13.56 MHz is also used by ISO 18000-3.

Active tags carry batteries and tiny processors in addition to the memory and antenna system. Generally speaking, passive tags are cheaper than active tags and special tag technologies, such as surface acoustic wave. For active tags, prices may vary between $10 to $500 US per tag. Passive RFID tag costs in May 2009 for the most commercially-used passive tag models are available in [RFI 09, ODI 09] and the models are described below.

The *UHF 4” x 6” tag* or 4” x 6” wide feed is a passive tag with a memory less than 2 Kbytes that is widely used by the US Department of Defense, and the large retail enterprises (Metro, Wal-Mart). The general specifications are:

– UHF Class 1 Gen 2;

– 4” wide x 6” feed;

– thermal transfer paper with general purpose adhesive;

– the price range goes from $0.11 to $0.15 per unit.

The *HF 4” x 6” tag* is the most common passive HF RFID tag on the market to date. The general specifications for these tags are:

– HF 15693;

– 256 bit up to 2 Kbyte memory;

– 4” wide x 6” feed;

– thermal transfer paper with general purpose adhesive;

– the price range goes from $0.41 to $0.55 for the 2 Kbyte memory tag and from $0.37 to $0.52 for the 256-bit memory type.

For passive tags the reading ranges may vary from several centimeters to less than 10 meters for close area tracking applications (HF) and up to 50 m (UHF) for local area tracking. Reading range, however, depends on different factors, such as power of the tag and the reader device, interference objects, and tag density, among others.

Semi-passive and active tags can be accessed from further distances due to the use of batteries.

Cost makes passive tags more interesting for high deployment scenarios, and we expect billions of passive tags to be connected to the network in the near future, building the IoT.

Figure 5.1 shows the prices and fields of operation for different transponders (tags) [MIL 08].

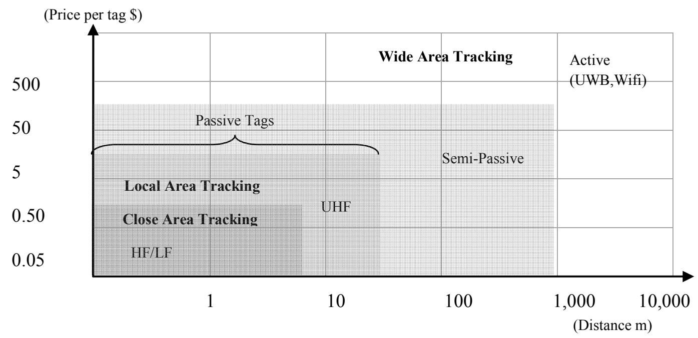

Figure 5.1. *Tags, prices and field operation*

Important institutions involved in RFID research and development include Auto-ID Labs and EPCglobal Inc. Auto-ID Labs is the leading global network of academic research laboratories in the field of networked RFID [AUT 09].

Auto-ID Lab is an independent network of seven academic research labs. These are: MIT (Cambridge US), Cambridge (UK), St. Gallen (Switzerland), Fudan (China), ICU (Korea), Adelaide (Australia) and Keio (Japan). Its mission is to:

> "build a business driven, truly global, sustainable, robust, cost efficient, and future-proof EPC Network Infrastructure that is flexible enough to support future technologies, applications and industries".

EPCglobal is leading the development of industry-driven standards for the EPC to support the use of RFID. EPCglobal is the commercial successor of the Auto-ID Center, a global business initiative and academic research program that started at MIT [EPC 09].

The main activities of this group are: assignment, maintenance and registration of EPC manager numbers, participation in development of EPC global standards, EPC global certification and accreditation program testing and training and education on implementing and using EPC technology and the EPCglobal network among others.

5.2.2. *Transponder (tag) classes*

The MIT Auto-ID Center established a tag classification system also used by EPCglobal. Tags can be grouped into passive, semi-passive and active types, as shown in Table 5.1.

5.2.2.1. *Passive tags*

Passive tags are energized by the reader's electromagnetic field. They are of low cost and size because no batteries are needed. Passive tags are divided into Class 0, 1 and 2.

– Class 0: are read-only tags with a simple ID number. The ID is typically a manufacture-programmed 64- or 96-bit number, which can be the EPC and cannot be modified.

– Class 1: are read/write passive tags that can only be written once, either by the manufacturer or the user.

– Class 2: are read/write passive tags that can be written several times. Additional functionalities, like data logging and/or cryptography, may be included.

5.2.2.2. *Semi-passive tags*

Semi-passive tags generally use energy from batteries to work in addition to radio frequency transmission, as in passive tags.

– Class 3: with extra energy the tags can increase their reading distance range as well as providing new functionalities, e.g. sensors.

5.2.2.3. *Active tags*

Active tags are provided with batteries allowing the tag to generate its own radio frequency signals. They might also include additional features like sensors, encryption and data processing, among other functions.

– Class 4: provide communication functionalities with other active tags and have the same features as class 3.

– Class 5: have reader capabilities enabling them to communicate with all types of tags.

In the following table (Table 5.1) the tag classification is presented:

Tag class	Type	Capabilities
Class 0	passive	read only
Class 1		read, write once
Class 2		read/write
Class 3	semi-passive	increased range
Class 4	active	tag communication
Class 5		reader capabilities

Table 5.1. *RFID tag classes*

5.2.3. *Standards*

In Chapter 7, which focuses on standardization, ISO (the International Organization for Standardization) and EPCglobal appear to be the entities that provide RFID technology standards [EPC 09, ISO 09]. In this section, a brief description of common RFID standards published by ISO is provided:

– *ISO 17363:2007*: defines the usage of read/write RFID cargo shipment-specific tags on freight containers for supply chain management purposes. It also defines the air-interface communications, a common set of required data structures, and a commonly organized set of optional data requirements.

– *ISO/IEC TR 24729-2:2008*: describes the potential for the use of RFID as a significant enabler in the recycling of various types of products; notably home appliances and electronics.

– *ISO/IEC TR 24729-1:2008*: provides guidance on the use of RFID-enabled labels and packaging in the supply chain.

– *ISO/IEC 19762-3:2008*: provides terms and definitions unique to RFID in the area of automatic identification and data capture techniques.

– *ISO/IEC 15961:2004 and in ISO/IEC 15962:2004*: In this standard, the data protocol used to exchange information in a RFID system for item management is specified.

– *ISO/IEC TR 24729-3:2009*: provides reference information and practical knowledge in the selection, installation and application of ISO/IEC 18000-6C RFID readers. It includes fixed mounted, handheld and mobile mounted readers.

– *ISO 24631-1:2009*: provides the means of evaluating the conformance with ISO 11784 and ISO 11785 of RFID transponders used in the individual identification of animals.

– *ISO/TS 10891:2009*: establishes:

- a set of requirements for container tags, to permit the transfer of information from a container to automatic processing systems;

- a data coding system for container identification and permanent related information inside a container tag;

- a data coding system for the electronic transfer of both container identification and permanent related information from container tags to automatic data processing systems;

- the description of data to be included in container tags for transmission to automatic data-processing systems;

- performance criteria necessary to ensure consistent and reliable operation of container tags within the international transportation community;

- the physical location of container tags on containers;

- features to inhibit malicious or unintentional alteration or deletion of the information content of container tags on freight containers.

– *ISO 21007-1:2005*: establishes a common framework for data structure for unambiguous identification of gas cylinders and for other common data elements in this sector. It also serves as a terminology document in the area of RFID technology.

– *ISO/IEC 18000*: defines the operation of RFID air interfaces for item identification and management. The following sections are included:

- ISO/IEC 18000-1:2008 defines the generic architecture concepts in which item identification may commonly be required within the logistics and supply chain and defines the parameters that need to be determined in any standardized air-interface definition in the subsequent parts of ISO/IEC 18000;

- ISO/IEC 18000-2:2004 defines the air interface for RFID devices operating below 135 kHz used in item management applications;

- ISO/IEC 18000-3:2008 relates to systems operating at 13.56 MHz frequency band only;

- ISO/IEC 18000-4:2008 defines the 2.45 GHz protocols that support ISO/IEC 18000-1;

- ISO/IEC 18000-6:2004 defines the air interface for RFID devices operating in the 860 MHz to 960 MHz industrial, scientific and medical band used in item management applications;

- ISO/IEC 18000-7:2009 defines the air interface for RFID devices operating as an active radio frequency tag in the 433 MHz band for item management applications.

– *ISO/IEC 18046:2006*: defines test methods for performance characteristics of RFID for item management, and specifies the general requirements and test requirements for tag and interrogator performance that are applicable to the selection of devices for an application.

The main standard used by EPCglobal for RFID systems is the so-called "Gen 2" standard. It defines the physical and logical requirements for a passive-backscatter RFID system.

Most RFID manufacturers have implemented Gen 2 for RFID product development. It provides an air-interface protocol including physical layer and medium access control (MAC) specifications for UHF RFID passive tags in the frequency range between 860 MHz and 960 MHz. New features are provided including flexibility, security and fast tag identification. Both interrogators and transponders (tags) are included in this standard.

5.2.4. *RFID system architecture*

A basic RFID architecture is based on transponders (tags), interrogators (readers), and back-end servers. In the simplest operation scheme, the tags will communicate their IDs to the reader. The reader then will transfer this information to edge servers in order to be processed. Finally, these edge servers may be connected to integration servers in order to apply business rules and communicate with other companies or institutions.

The tags can communicate with readers by using magnetic or electric fields. For passive tags, the magnetic field is more reliable for powering them but has a limited range of action (a few centimeters).

Electric fields present a greater range (a few meters) but the reader tends to be less effective in the presence of obstacles. Active tags can reach distances up to 12 meters or more, but they are more expensive compared to the passive or semi-passive tags.

There are three different types of readers: hand-held, fixed and mobile. They support different connection interfaces that include Ethernet to wireless links.

On the server's side, all information collected from the readers is processed and interpreted following the application rules. Four main layers describe the basic activities performed:

– the first layer deals with the reader's discovery process;

– the second layer deals with the data captured by the interrogator/reader;

– then, actions are taken regarding the information gathered in the third layer; and finally

– the fourth layer provides an interface to manage the information, business rules and sessions among other functionalities.

In order to interact with other organizations or companies, integration servers may be used. These servers will allow the exchange of information for commercial purposes, statistics, tracing, item location, and so on. In Figure 5.2, the generic RFID architecture model is shown.

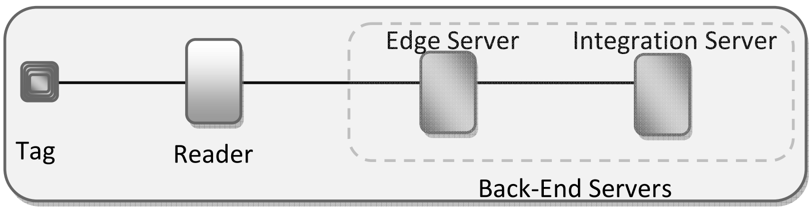

Figure 5.2. *RFID Architecture model*

5.2.5. *Other related technologies*

The following technologies are related to RFID, presenting interesting variations that can be used for new applications.

5.2.5.1. *Near-field communication*

Knowing that RFID technology can be used for short- and long-distance reading, near-field communication (NFC) is a communication technology employed for short-range high-frequency wireless applications. The effective range it is about 10 cm, similar to proximity-card devices. Its direct relation with RFID is that it limits the reading range of RFID for applications requiring security. This technology is an extension of the ISO/IEC 14443 standard for smartcards and readers. Commercial products like the Nokia 6212 mobile phone include this feature and applications can cover contactless payment and ticketing [NOK 09].

Emerging applications will reply on embedded NFC technology connected to a computing device; computer or mobile phones reading surrounding tags, for instance in museums, shopping centre, hospitals, etc. Tool kits are appearing on the market, for instance TouchaTag [TOU] is a kit of RFID reader and a set of RFID tags that can be used to develop applications using the tag information to trigger some action.

5.2.5.2. *Nano-RFID*

This promising technology offers an unlimited range of applications that include not only the traditional RFID features but also measure and sense external variables and possibly have effect on biological functions when used on living beings, including humans [BUR 09].

5.2.5.3. *Smart dust*

Smart dust originally referred to miniature wireless semiconductor devices made by using fabrication techniques derived from the microelectronics industry. They have embedded sensing, computing and communications modules in millimeter- to micrometer-sized packages [WAR 01].

5.2.5.4. *RFID sensors*

RFID sensors extend the basic identification feature and provide extra capabilities. Applications include external sensing parameters, i.e. temperature, humidity and pressure among others.

5.2.5.5. *Contactless smart cards*

These devices communicate with readers through RFID technology. They follow the ISO/IEC 14443 standard. They require close proximity to an interrogator to perform any transaction. Basic applications cover mass transit systems, credit cards and access control.

5.3. RFID applications

RFID technology is one of the leading enabling technologies of the IoT; it will allow the development of new applications and services, taking advantage of already existing networks. There are wide uses for RFID systems, especially for tracking items, but this technology can also be used for access control, tracing, location and process control among other uses.

In Tables 5.2 to 5.5, the classification of the different RFID applications based on the type of transponder that better suits for the task is provided [WIE 08]. Some real applications are described for each of the different categories presented. [YAN 08] presents some RFID related applications in detail.

5.3.1. *Logistics and supply chain*

The most important and largest application of RFID technology is logistics and supply chains. In distribution and logistics of many types of products, tracking and tracing, concerns a process of determining the current and past locations and other information of a unique item or property. Due to the non-line-of-sight characteristics of RFID, this technology is suitable to replace its predecessor, the barcode. The use of RFID for logistics on the supply chain makes the inventory and tracking of items more efficient and reliable. Due to price constraints, only passive tags are suitable for these applications.

Some of the most important retail companies worldwide have implemented a RFID system to provide a control and management platform. The METRO Group in Germany implemented RFID logistics control and storage management in 2004 by using passives tags [MET 09]. Wal-Mart (US), Tesco (UK), Auchan (FR) and Proctor & Gamble (worldwide) are using RFID technology for the same purpose.

In Table 5.2, the tags suitable for logistics operations are presented.

Application	Subcategory	Tag used		
		Passive	Semi-passive	Active
Logistics tracing and tracking	In-house logistics, closed and open loop[1] logistics, postal applications, dangerous goods logistics	●		
	Manufacturing logistics	●	●	●

Table 5.2. *Tags for logistics and supply chain applications*

5.3.2. *Production, monitoring and maintenance*

Another important application of RFID technology is on production lines. Typically, open systems with no security features can be used. Here RFID gives control on assembly lines, indicating to the personnel where and what parts are to be integrated, minimizing assembly errors and possible delays.

1 Closed loop usually uses a complete proprietary solution, while the open loop might orchestrate systems from different constructors so interoperability rules are necessary.

BMW uses a system designed and installed by Siemens. The system places active RFID tags on finished vehicles as they leave the production line to help BMW workers instantly locate cars before they are shipped to vendors. In Table 5.3, the different subcategories and suitable types of tag to be employed are presented.

Application	Subcategory	Tag used		
		Passive	Semi-passive	Active
Production, monitoring and maintenance	Archive systems, asset management, facility management, airplanes, food and consumable goods	●		
	Vehicles, process control	●	●	●

Table 5.3. *Tags for production monitoring and maintenance applications*

5.3.3. *Product safety, quality and information*

Basically most products can be labeled with RFID tags in one way or another. It provides a platform for tracking and tracing goods that can be applied to a variety of applications, e.g. fighting against counterfeiting where labeling and identifying original products allows them to be traced and tracked. In addition, the use of embedded sensors in RFID devices allows the extension of basic identification capabilities to include environment sensing. A commercial example comes from an Italian company called CAEN [CAE 09]. It sells semi-passive tags, which include a temperature sensor with a capacity of 8,000 samples, suitable for fresh/perishable food control.

In hospital management, RFID can help in tracking patients to reduce prescripton errors and for inventory management and medicines control. Table 5.4 presents the types of tags that can be employed for those applications.

Application	Subcategory	Tag used		
		Passive	Semi-passive	Active
Product safety, quality and information	Consumable goods, electronic goods, textile goods, customer information systems	●		
	Fresh/perishable food		●	●
	Pharmaceuticals, eHealthcare	●	●	●

Table 5.4. *Tags for product safety, quality and information applications*

5.3.4. *Access control and tracking and tracing of individuals*

RFID technology provides a useful approach to track and trace individuals. Non-line-of-sight properties, contactless cards, miniaturization, and nanotechnology are elements that combined with RFID systems provide interesting results. For example, Destron Fearing provides RFID solutions for cattle tracking that is ISO compliant on the frequency band of 134.2 KHz using a 15-digit identification number [DES 09]. Biomark also uses RFID technology to implant chips in animals with models that can measure about 12.50 mm × 2.07 mm in the frequency range of 134.2 kHz with a weight of 0.1020 g [BIO 09].

VeriChip [VERI] is a tag that looks like a rice grain that can be inserted under the human skin for tracking people. Current applications include tracking emergencies in hospitals where injured people cannot talk. More applications are expected if the issue of privacy is solved.

MIFARE is a technology that has been selected for most contactless smart card projects. Its product portfolio includes products for applications, such as loyalty cards, road tolling, access management and gaming. The cards support dynamic download of Java applications [MIF 09]. Metro systems like Tokyo's have implemented "Suica" cards for access control and ticket sales machines [SUI 09]. In Paris and London the metro access control works with contactless prepaid cards (Navigo pass and Oyster card).

An RFID application for inmates' surveillance has been implemented and commercialized Tsiprism, proposing safe and reliable security control in prisons [TSI 09].

All types of tags can be used for access control, tracking and tracing (see Table 5.5).

Application	Subcategory	Tag used		
		Passive	Semi-passive	Active
Access control, tracking and tracing of individuals	Access control systems, person and animal tracking	●	●	●

Table 5.5. *Access control and tracking and tracing of individuals*

5.3.5. *Loyalty, membership and payment*

Contactless smart cards allow information to be stored that can be used to identify clients for loyalty and/or membership affiliations. The main advantage is the fast and automated identification done by the readers. In June 2009, the American food chain Dairy Queen deployed a mobile rewards loyalty program using RFID tags to send coupons and offers to consumers' handsets. Metro in Germany also provides RFID cards for its membership/loyalty program. MasterCard (PayPass) has provided a new contactless card to perform common transactions in stores. Passive tags are used for these applications.

5.3.6. *Household*

Controlled environments and smart homes in home networking benefit from RFID technologies that identify and track objects, provide security solutions, inventory tracking and location features. A commercial example is the RFID fridge (developed by Samsung in 2007) that allows inventory tracking of products available in it and communicating via Internet or short message service with its users. All types of tags are suitable for these applications.

5.3.7. *Other applications*

Any application or system that mainly requires the identification, tracking and tracing of its elements can benefit from RFID technology. Some examples of these systems could be public transportation, libraries, tree identification and ecologically-related monitoring systems among others. Reader's should look at [YAN 08] book and [FLO 08] conference proceedings for more examples of applications.

Other applications can use the identification information stored in the RFID and match it with a semantic specific to an application. For instance, using RFID to improve network functionalities such as the location and mobility support of nodes as presented in Chapter 6. Combining location-based services with the RFID system is also a very promising application, assuming that the privacy issue is solved. In fact the RFID technology will be successful in public applications only if users accept RFID technology; this means that privacy must not be an issue.

5.4. Ongoing research projects

RFID technology is an old technology that dates from the early 1940s. There is interest in using this technology in different applications and building the envisioned IoT augmented over the last decade. Several research issues have arisen, however, depending on the technological limitation or specific application requirements. Here we present some of the research issues appearing in scientific papers in 2009 that show the scientific trend in the RFID field. Some works are published in the conference proceedings of IoT 08 [FLO 08].

5.4.1. *Hardware issues*

The research efforts can be grouped in the following categories: reader-related research, tags, chips and antenna.

5.4.1.1. *Reader-related research*

Readers or interrogators perform the identification of tags and are basically conformed of the following modules (see Figure 5.3).

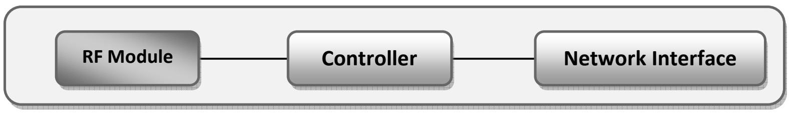

Figure 5.3. *Reader modules*

Some research topics cover the multimode and multiband RFID interrogators [CHI 09]. The readers will operate in different frequency bands allowing the implementation of new interference and collision solutions. Some other works propose to separate the interrogation and response channels (uplink and downlink) in order to increase the range of interrogation to energize more tags in a zone, and put the response capability closer to the tag. This information might then be forwarded on a hop-by-hop basis.

5.4.1.2. *Tags*

Tags or transponders are basically composed of the antenna part and a chip module (see Figure 5.4).

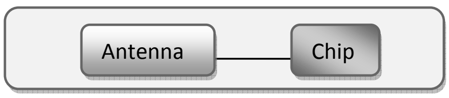

Figure 5.4. *Tag modules*

5.4.1.2.1. Chip

The main objectives from a research point of view are design optimization, new materials testing and performing protocols. This is done in order to obtain better performance and cost reduction [PAR 09]. New techniques, such as the spread spectrum, are also considered [QIU 09].

Some other research also goes towards the chip-less RFID systems [SHR 09] where the ID generation uses different alternatives, such as surface acoustic wave [HAR 09], transmission lines and left-handed delay lines. This is useful, especially for applications where electromagnetic waves are considered as a hazardous factor. This chip-less approach does not use silicon devices and the main advantage is that they can be printed directly on products.

5.4.1.2.2. Antenna

A considerable number of studies have been conducted on RFID tag design for metallic objects [KIM 07, KWO 05, SON 07] in recent years, including antenna miniaturization [CHE 09].

An interesting topic is the chip-less RFID utilizing inkjet-printed antennas. This kind of device works in the electromagnetic-sensitive applications field [RID 09, YAN 09]. Implementation is based on low-cost paper substrates and conductive ink which consists of nano-silver particles.

5.4.2. *Protocols*

The main research topics are related to effective and efficient security mechanisms as well as the collision problem. In fact, from the security point of view, the resource limitation of the tags makes it hard to use existing access control, cryptography and other security systems. In addition, the issue of privacy has to be considered as very high priority. With the collision problem, the issue is about maximizing the correctness of tag reading and minimizing the collision of requests or answers in the RFID architecture.

5.4.2.1. *Security*

In order to protect the information exchange between tags and readers it is necessary to provide security mechanisms to avoid possible attacks on an RFID system, especially if sensitive information is managed.

One of the most frequently used standards on RFID technology is EPCglobal class-1 generation-2 (Gen2) [AUT 09]. It was approved as ISO18000-6C in July 2006, and one of the security problems it faces is that it transmits the EPC code as plain text. Many researchers have proposed hash-based protocols [CHI 09, WAN 09, WEI 03] that consume less computational resources than cryptographic primitives, such as data encryption standard or advanced encryption standard, hash functions. The asymmetric method is even more resource intensive and is mainly used for key management in RFID systems.

5.4.2.2. *Collision*

It is important to avoid the problem of collision, especially in counting items in a retail chain as every tag needs to be detected correctly. Multi-tag-parallel reading presents a drawback due to the interference generated by multiple responses (tags to reader) or multiple readers trying to request IDs from tags. To reduce the effect of collisions and in order to minimize the identification delay, anti-collision protocols are used. The anti-collision protocols preferred for RFID are those that are time division multiple access (TDMA)-based [KLA 09] (see Figure 5.5). Approaches such as space division multiple access and code division multiple access are too complex and expensive to be applied for commercial usage.

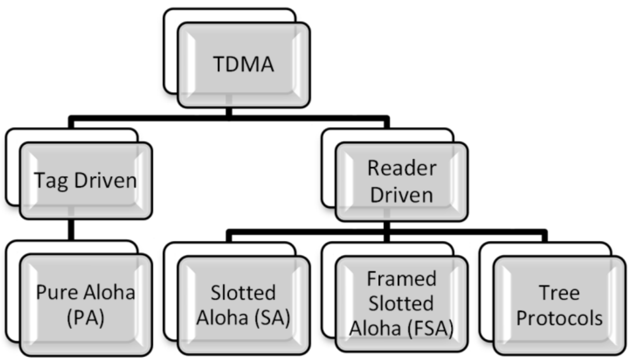

Figure 5.5. *TDMA anti-collision algorithms*

In pure aloha (PA) algorithms, the tags transmit their IDs randomly after receiving power from the reader. The tags have a random counter that sets a delay and once the time is expired they will try to send their IDs again if collision occurred. PA variants (see Figure 5.6) include: slow down, muting, fast mode, and combinations of them. In slow down, tags are ordered to reduce their transmission rate and, for instance, reduce the probability of collision. The muting variant mutes the successfully identified tags, reducing the reader's identification load. The fast mode silences the tags that are not being identified.

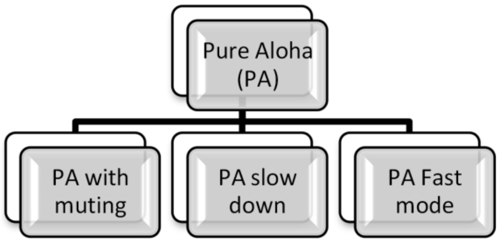

Figure 5.6. *Pure aloha variants*

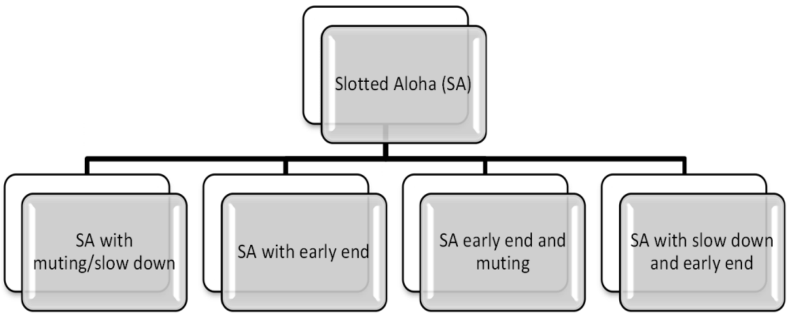

Figure 5.7. *Slotted aloha variants*

The slotted aloha (SA) works in synchronous mode, defining transmission periods or slots. There are four variants: muting and slow down, early end, early end and muting, and slow down and early end (see Figure 5.7). The muting and slow down work as mentioned before for PA algorithms, however synchronous slots are used to detect tags. The early-end feature allows us to end a transmission slot and prevent other tags colliding with a successful identification process in progress.

Frame slotted aloha (FSA) tags can transmit their IDs only once per frame. The basic and dynamic classification refers to the size of the frame defined from the reading process. For basic FSA, muting and no-muting is possible. The early-end feature described before can also be applied, generating two more variants (see Figure 5.8).

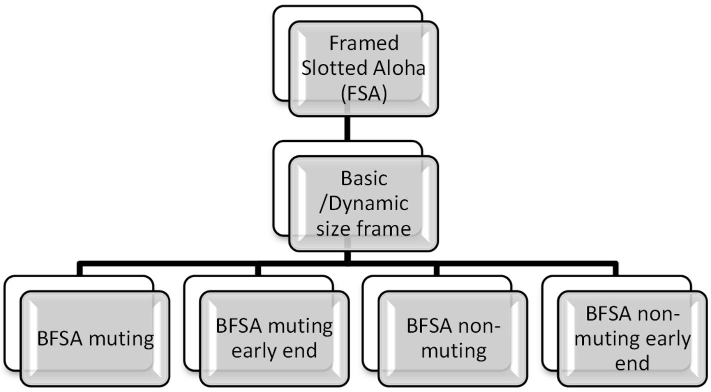

Figure 5.8. *Frame slotted aloha variants*

Tree protocols divide the tag space in order to perform the identification process. There are four categories: tree splitting, query tree, binary search and bitwise arbitration. In Figure 5.9 the tree-based protocols are shown.

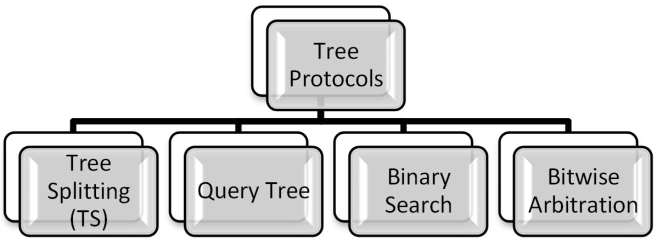

Figure 5.9. *Tree protocols*

Tree splitting is divided into: basic tree splitting (BTS), adaptive tree splitting (ABTS) and enhanced tree splitting (EHS), see Figure 5.10. Tree splitting divides the collided tags into *n* disjoint subsets. BTS minimizes the subset until only one tag is present. The tags provide one counter to keep track of the tag position in the tree. ABTS reduces the idle timeslots obtaining a fast tag identification process. It requires two counters in the tags. Enhanced BTS keeps track of ID bits transmission, indicating a colliding bit by a pointer. Tags will later transmit only the bits that start from the collided one marked with the pointer.

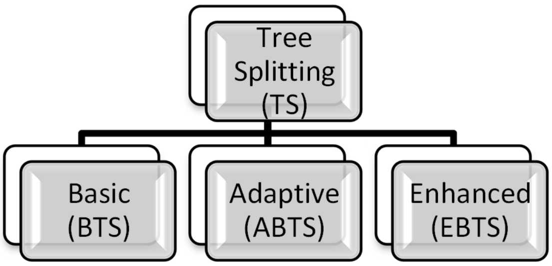

Figure 5.10. *Tree splitting algorithms*

Query tree algorithms [LAW 00] rely on the processing power at the reader side (see Figure 5.11). It will keep an appending queue registry, in order to identify tags that match with the binary sequence required. Some variants include query tree shortcutting, where the redundant queries are deleted, and query tree aggressive enhancement, which involves appending multiple bits instead of one to the identification queue.

Categorization implies prior knowledge of a tag’s IDs to classify the queries. Short-long separates the queries into short (one bit appending) and long (whole ID). Adaptive query tree requires the reader to keep track of the past prefix required to be identified. The improved version of the query tree reduces the number of bits sent back by the tags when collision occurs. Randomized hashing from a predefined hash function leads to each tag generating a random number. An intelligent query tree exploits tag’s prefix patterns.

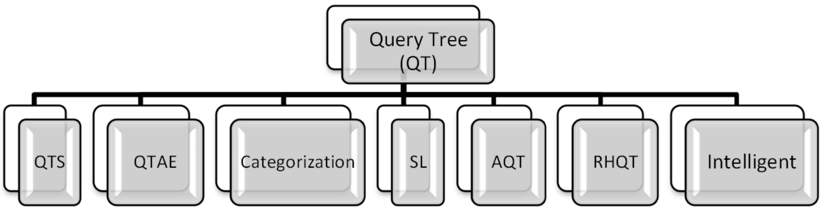

Figure 5.11. *Main query tree protocols*

Binary search algorithms are based on the transmission of binary digits that tags will compare with their IDs, enabling them to transmit them when the comparison result is positive or when the digits are less than the IDs themselves. We can find two variants: enhanced binary search algorithms (EBSA) and dynamic binary search algorithms (DBSA), see Figure 5.12. On EBSA, the reading process is not restarted after successful tag identification. DBSA does not require the whole ID to identify the tags and it can be divided to optimize a tag's identification.

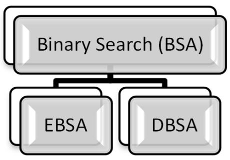

Figure 5.12. *Binary search algorithms*

Bitwise arbitration algorithms request a tag's IDs in a bit-by-bit manner. The main variants are:

– ID-binary tree stack;

– bit-by bit (BBT);

– modified and enhanced BBT; and

– bit query (see Figure 5.13).

ID-binary tree stack splits the ID creating a tree bit-by-bit and the tags keep track on the bits in order to transmit them when their IDs have been fully identified. They then go into a sleep state. BBT uses separate channels to transmit the binary digits. In Multiple BBT slots are not used to obtain the binary digits. Enhanced BBT require tags to send their entire IDs and then the reader observes the bits that have collided. Finally, a binary query scheme transmits a binary query to tags that respond based on a prefix.

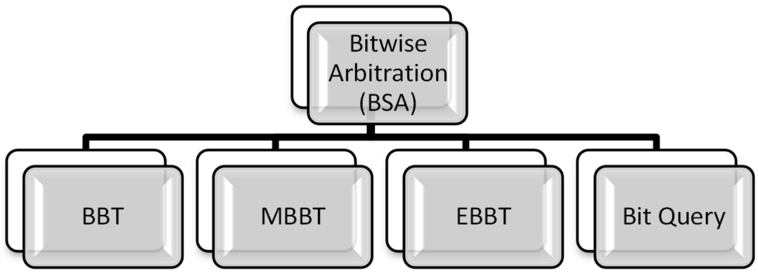

Figure 5.13. *Bitwise arbitration protocols*

Finally, hybrid protocols combine tree and aloha protocols. Some variants are: hybrid randomized protocol, tree slotted aloha and hybrid query tree.

5.5. Summary and conclusions

RFID technology started more than 100 years ago, but has gained more attention during this last decade, especially in building the envisioned IoT. Although already used, this technology needs to be improved from security and performance points of view. Main RFID applications are used for tracking and tracing items on production lines and distribution chains. However, a variety of applications can be built based on this technology. Some recent examples show the development of a system to help vision-impaired people to be guided on buses [ZIK 09]. Enhancing museum visits with smart phones and RFID is shown in [MOD 09]. In [DU 09] we observe how RFID and web services can be integrated. In order to assist logistics on e-commerce applications in [PAN 09], a combined RFID system is proposed.

RFID technology will enable more applications to contribute to building the IoT [ITU 09]. Several research projects are ongoing in Europe [FUT], the US [GEN] and all over the world, seeking new applications and services orchestrating these tiny technologies; RFID, sensors, etc. to increase automation in everyday tasks and to better monitor nature and the planet. Besides these emerging applications, a new communication model beyond the IP model is expected to better adapt to the resource limitation of tiny objects and provide a better scale for the billions of objects expected to be connected.

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