Chapter 6

Case Study: Installing RFID Systems in Supermarkets

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Additional information is available at the end of the chapter

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Abstract

Radio frequency identification technology (RFID) is considered as the reference technology for wireless identification and item traceability. Supermarkets are one of those scenarios where the RFID potential can be harnessed. In theory, RFID in supermarkets shows several advantages compared with traditional barcode systems, offering real-time inventory, stock control, cash queues, among others. In practice, its massive and global implementation is still being delayed due to the high quantity of factors that degrade the RFID system performance in these scenarios, causing uncontrolled items and identification losses and, at the end, economical losses. Some works in the scientific literature studied a single or a set of problems related to RFID performance, mostly focused on a specific communication layer: antennas and hardware design, interferences at physical layer, medium access control (MAC) protocols, security issues, or middleware challenges. However, there are no works describing in depth the set of factors affecting RFID performance in a specific scenario and contemplating the entire communication layer stack. The first challenge of this chapter is to provide a complete analysis of those physical and environmental factors, hardware and software limitations, and standard and regulation restrictions that have a direct impact on the RFID system performance in supermarkets. This analysis is addressed by communication layers, paying attention to the point of view of providers, supermarket companies, and final customers. Some of the most feasible and influential research works that address individual problems are also enumerated. Finally, taking the results extracted from this study, this chapter provides a Guide of Good Practices (GGPs), giving a global vision for addressing a successful RFID implementation project, useful for researchers, developers, and installers.

Keywords: RFID, case study, supermarket, performance, GGP

1. Introduction

For over a decade, radio-frequency identification technology (RFID) has been the benchmark of technological innovation in scenarios of mass identification and traceability. RFID technology allows for identifying thousands of items in a few seconds, without direct line-of-sight between the RFID antennas (reader) and the items to identify (RFID tags), reaching up to 10 m of reading distance.

There are thousands of pilot projects and implementations in use of RFID throughout the world [1–5]. One of them is the identification of goods in supermarkets [6–8]. In these scenarios, the products are items to be identified and, instead of incorporating a barcode, they are labeled with RFID tags, usually working at the ultra-high-frequency (UHF) band. Tags are electronic devices composed of a simple circuit, an antenna, and, in some cases, a battery. The simplest tag models do not incorporate batteries (passive tags) and feed their circuits with the energy extracted from the incident electromagnetic wave generated by the reader antennas. This operating mode is usually called *backscattering* [9]. Every tag stores in a small memory the product identification code (electronic product code (EPC)) [10], which, among other data, includes the provider identification code, the type of product, and the unique serial number of the product in which it is attached to. When a tag is in the coverage range of a reader, it automatically sends its EPC code to the reader, and the reader sends it to a middleware subsystem. This subsystem is in charge of querying to a database (working under EPC-IS [11]) about the product data linked to the EPC code, for example, price or expiration date.

The implementation of RFID in supermarkets allows customers to obtain information about the goods they collect when they are doing the shopping, for example, with RFID *checkpoints* installed in strategic places in the shopping zone or built-in in the shopping trolley [12, 13]. Moreover, with RFID, the customer no longer has to remove the groceries from the shopping trolley and place them into the conveyor belt to be traced in order to make the payment. Instead, the customer passes with the shopping trolley through RFID reader antennas (similar to the anti-theft systems), and immediately all products are tracked and identified. The system calculates the final purchase cost and prints the ticket in a few seconds. Incorporating RFID in supermarkets saves time to customers and offers added-value services that, at present, do not exist in most supermarkets. For those companies in this sector, RFID technology permits them to control inventory in real time and enables product traceability, among others. The downside is that there are many factors that significantly degrade the performance of RFID systems in these scenarios, causing to not being able to identify the products at the expected time or even losing information and identified items due to the hardware and software interferences and limitations, which finally translates into potentially significant economic losses.

With the aim of maximizing the performance of RFID systems in these environments, the engineers and technicians perform multiple measurements in their implementations, varying the antennas orientation, testing different brands of tags, changing the position where the tags are attached to the items, varying the number of tags per pallet, and so on. All these tasks are addressed without following specific implementation rules or a specific Guide of Good

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Practices (GGPs). Consequently, unexplained variations in the performance occur in many cases, which lead to frustration of the implanter, and distrust of the entrepreneur.

The lack of rules and implementation protocols come from the absence of scientific studies encompassing the set of factors that affect and degrade the RFID performance in specific scenarios, works where the set of problems and solutions proposed by the scientific community are identified and listed. Therefore, this chapter is an attempt in this line, presenting a complete analysis on the main factors that degrade the performance of passive UHF RFID systems working in a supermarket. They have been classified according to the communication layer where they occur, distinguishing among those degrading at the physical layer, medium access control layer, and higher layers. The most relevant solutions found in the scientific literature focusing on minimizing or eliminating the identified problems are also enumerated. The results extracted from the study have permitted us to design a GGP for implementing RFID systems, tackling the hardware/software design and requirements that maximize the performance of RFID systems.

2. Scenario description

The scenario under study is a supermarket where an RFID system will be installed. The system will be composed of more than one reader and antennas, a middleware subsystem with some databases, and all products labelled with RFID tags (see **Figure 1**). The scenario has some desirable checking/reading points:

1. *Entrance to warehouse*. In this place, the check-in of goods arriving to the grocery store is performed. Also, the EPC-IS database is updated, since the new inventoried products are added. Then, the available stock is known in real time.

2. *Crossing gate warehouse—sales zone*. At this point, the check-in/check-out of the products entering and leaving the warehouse is made. The goal is to have the EPC-IS database updated, and to get real-time information about the available stock for sale.

3. *Checkpoints in the corridors or built-in the shopping trolley*. This added-value service allows customers for getting data of interest about any product while they are doing shopping: ingredients, nutritional value, expiration date, or recommended recipes, among others.

4. *Cash register system*. Every cash register is an identification point. The products are identified by the RFID system through the antennas installed on these points. The RFID system connects to the EPC-IS database to get the price of the products. Simultaneously, the EPC-IS updates the stock in order to detect if it is necessary to make new orders to suppliers.

5. *Exit doors*. It works as anti-theft system for those not identified products in the cash register system.

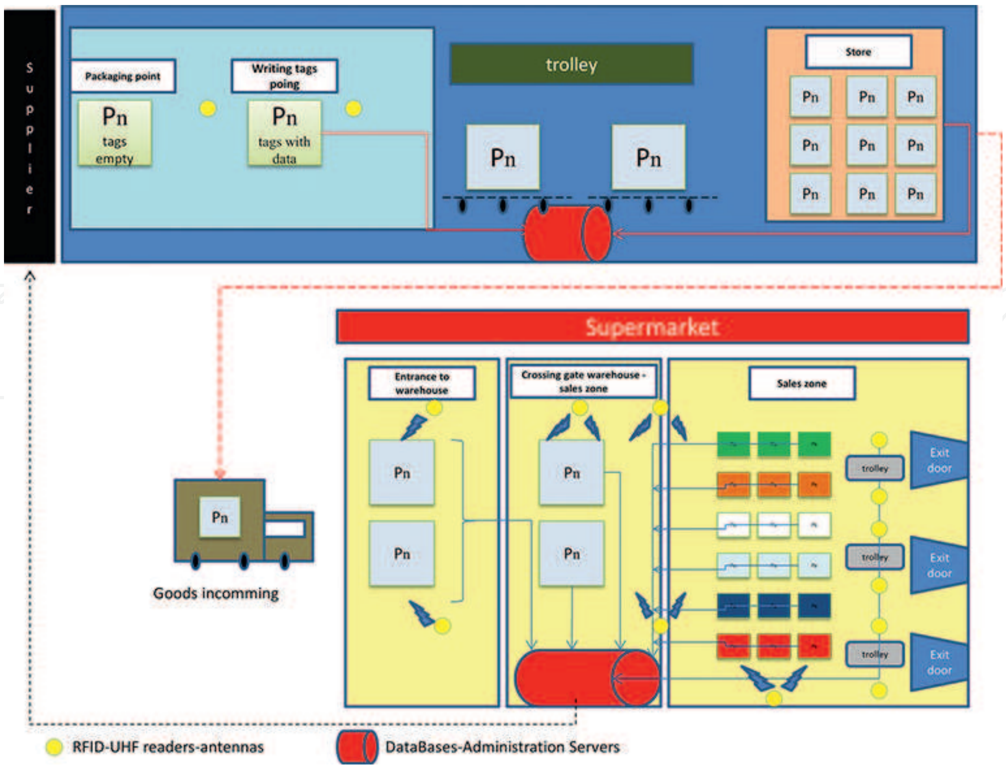

Figure 1. Scenario under study: a supermarket.

In this scenario, some assumptions are taken. First, we require that suppliers label their products with passive RFID tags operating in the UHF band, in the spectrum of the frequencies permitted by the country where the supermarket is located. In addition, tags attached to the goods must store the product's information in EPC code format. Finally, both suppliers and supermarket must connect their databases to an EPCglobal Architecture Framework, called EPCglobal Network [14], which allows product's traceability and localization, in real time, and worldwide.

3. Agents at the RFID physical layer

At the physical layer, the frequencies incompatibility, the electromagnetic noise, and the absorption and reflection phenomena are the agents that have a strong influence in the performance of RFID systems, even triggering the complete loss of information. In the following subsections, each of these issues is addressed, listing the most remarkable and viable solutions found in the current scientific literature.

3.1. Frequencies incompatibility

The International Telecommunication Union (ITU) [15] manages the global radio spectrum by dividing the world into three regions. Each region has a set of frequency allocations. **Figure 2** summarizes the frequency assignments for RFID. For UHF, **Figure 2** shows that tags and

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readers work in different frequency ranges according to the operating region. Assuming that in the case study that concerns us, the RFID-UHF system is installed in a supermarket located in Spain, and only those products labelled with RFID tags operating at UHF-Region 1 (862–870 MHz band) can be identified. Therefore, if a bottle of wine is labelled and marketed in Chile with a tag attached to it operating at UHF-Region 2, it cannot be identified in Spain.

Region	LF	HF	UHF	Microwaves
Region 1	125 KHz	13.56 MHz	862-870 MHz (4 W EIRP)	2.446-2.454 GHz
Region 2	125 KHz	13.56 MHz	902-928 MHz (3.2 W EIRP)	2.40-2.4835 GHz
Region 3	125 KHz	13.56 MHz	950-956 MHz (4 W EIRP, China 2 W ERP, Singapur and Taiwan and Philippines 0.5 W ERP)	2.427-2.470 GHz

Figure 2. ITU regions. Frequencies assignments.

On the other hand, there is a problem of incompatibility among the RFID systems used by the suppliers. Not all good suppliers are working with RFID-UHF systems. For those products with liquid or with a metal container, the suppliers commonly use tags operating at low-frequency (LF) or high-frequency (HF) band, which are less sensitive to the absorption and reflection phenomena (see Section 3.2). Therefore, if, for example, there are bottles of juice labelled with LF tags, they cannot be read by the UHF reader. To solve these problems, new antennas for tags and readers are being designed in order to operate in the whole UHF spectrum (encompassing the three regions) [16–18] and dual HF/UHF antennas to enable interoperability between different systems RFID [19, 20].

3.2. Electromagnetic noise, absorption, and reflection

In a supermarket, there are many things that cause interferences, affecting the performance of the RFID systems: the metals in the shopping trolleys and shelves, the products with liquids, the refrigeration machines, and even the human body. Some of them are impossible to avoid, such as the electromagnetic or environmental noise generated by the electrical equipment in the supermarket, the alarms, the elevators, the automatic doors, or the interferences from the GSM mobile customers [21, 22].

The absorption and reflection phenomena have also a high influence on the performance. Absorption occurs when the passive tags are attached to products with a high quantity of liquid (e.g., a bottle of milk) or when the labelled products are placed near an item with a high percentage of liquid (e.g., the human body). When a reader tries to communicate with a tag in these situations, most of the tag incident signal is absorbed by the liquid. Then, the tag has not enough energy to power its circuit, being unable to send its EPC code to the reader. Reflection happens when tags are near, or attached to metals. The signal emitted by the reader is reflected by the metal, and again the tag is not able to send its EPC code. An interesting example of reflection in which RFID installers do not pay attention is the reflection caused by the typical fluorescent light tubes in supermarkets. In [23], it was shown how these lamps are able to reflect and modulate the incident signal of a reader, causing a reflected signal with much more power than a tag response, especially when the lamps are less than 5 m away from the reader. In the scientific literature, there are some prominent studies dealing with the design of tags nonvulnerable to the above phenomena [24–30].

4. Agents at the RFID medium access control

In the case study of this chapter, thousands of tags attached to products work together with a high number of readers (at least one reader for each checkpoint and cash register).

When a set of tags is in the coverage area of a reader, all are simultaneously fed by the incident signal of the reader and consequently they try to send their EPC code immediately. When two or more tags transmit their EPC code at the same time, a tag-to-tag collision occurs (e.g., when hundreds of products are in the shopping trolley and go through the reader antenna placed in the cash register system). To minimize the impact of these collisions, the readers in the market implement a medium access control (MAC) mechanism based on the worldwide standard EPCglobal Class-1 Gen-2 [31]. It defines an MAC mechanism for RFID readers working at UHF that organize the tags responses by a Frame Slotted Aloha (FSA) protocol [32], controlled by the reader. This is a very simple mechanism with a low rate of identification, which has led the scientific community to propose new alternatives compatible with the standard that significantly increase the rate of identified tags per time unit [33–36].

When two or more readers are operating in the same environment, reader-to-tag and reader-to-reader collisions occur. The former happens when the tags are located in the overlapping coverage area of two or more readers, for example, in **Figure 3**, when a tag is located in the overlapping coverage area of readers R1 and R2, the tag receives the signal from both readers but, since the tag is a very simple device, is not able to select a reader to send its EPC code, even though readers are working at different frequency. The reader-to-reader collisions occur by the interfering signals of those readers transmitting at the same frequency and time instant (see **Figure 4**). Readers are configured with a specific transmit power (Ptx), defined by the standards and regulations. For instance, in Europe the ETSI-EN 302-208 regulation [37] sets

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the maximum Ptx to 3.2 W Equivalent Isotropic Radiated Power (EIRP), while in the USA is the FCC-Part 15 [38], which sets to 4 W EIRP.

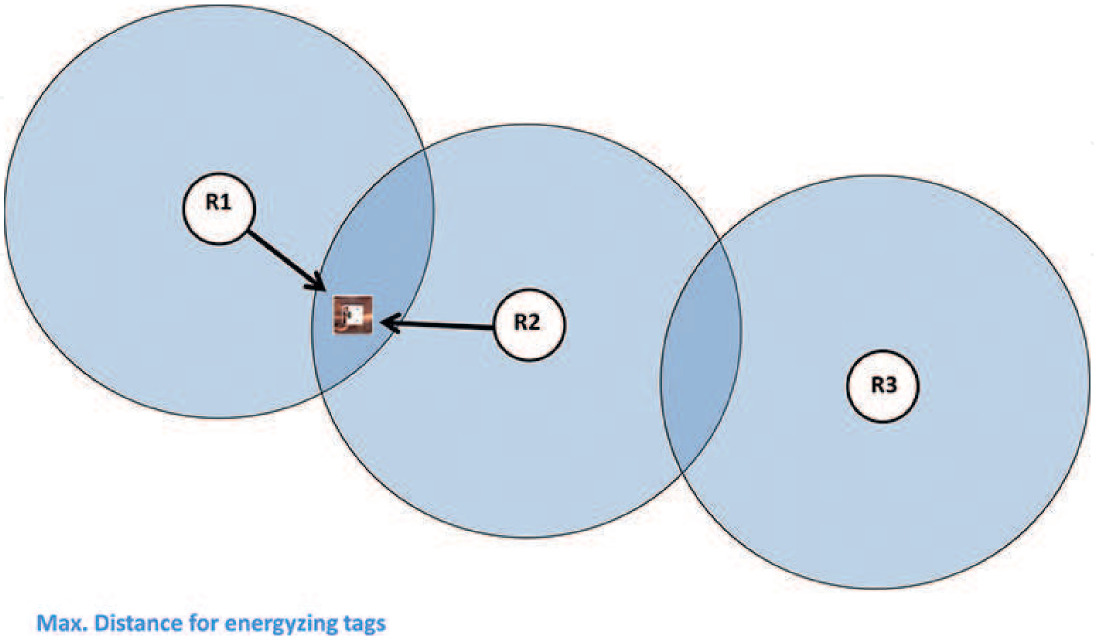

Figure 3. Example of reader-to-tag collision.

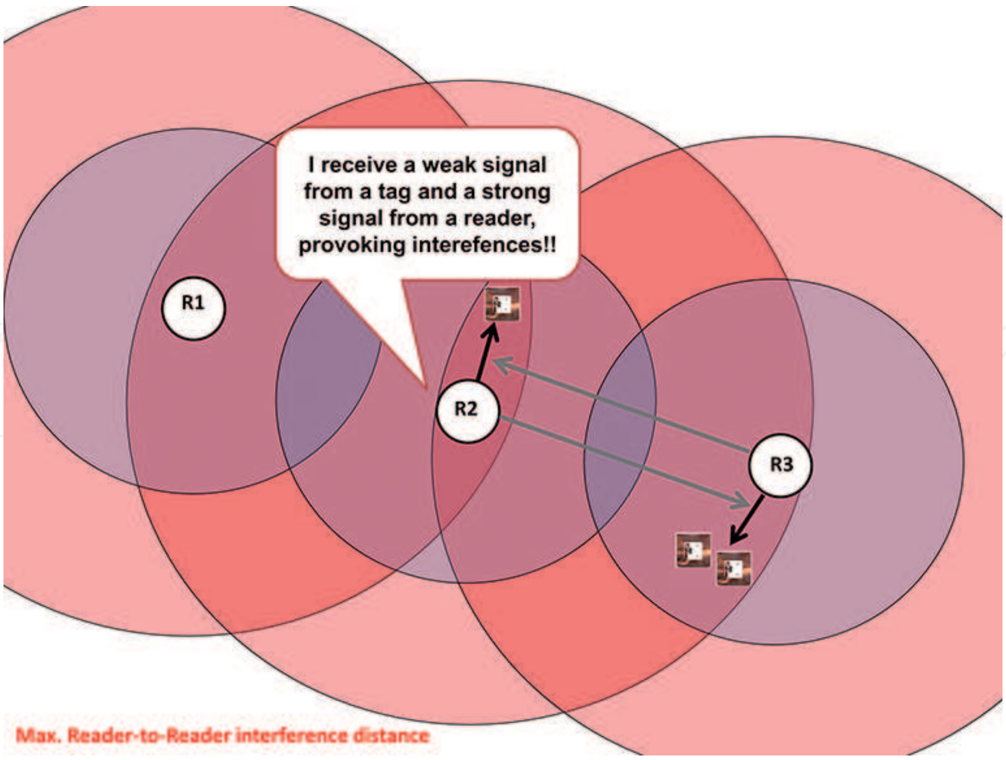

Figure 4. Example of reader-to-reader collision.

The readers' output power limits the maximum reader-to-tag read range, that is, the maximum distance in which readers can feed the tags circuits in order to respond with their EPC codes. But the Ptx also sets the maximum distance in which readers can interfere with each other. In general, in an indoor environment, 3.2 W EIRP allows readers to reach tags placed up to 10-m distance, and interfere with other readers located up to 1000-m distance [39]. In order to minimize the effects of reader-to-reader interferences, the EPCglobal Class-1 Gen-2 standard suggests a communication protocol for scenarios with multiple readers based on the frequency hop spread spectrum (FHSS) mechanism [31]. Readers fix an operating frequency from a set, and they may jump randomly or in a programmed sequence to any frequency set by its ITU region [15]. If the band is wide enough, the probability that two readers were operating at exactly the same frequency is small. This happens in the UHF band in the USA. However, the UHF bands in Europe and Japan are much smaller, so this technique is not effective for preventing reader interferences. The simplicity of this mechanism and its lack of efficiency to address the reader-to-tag collisions have led the scientific community to suggest a number of alternatives to improve the performance of RFID systems in these environments [40–43].

5. RFID middleware

The RFID middleware plays an important role in the global identification and traceability. The EPCglobal Network [14] states the network architecture and the elements in the global RFID traceability network, as well as the communication protocols used among the elements, security issues, and so on.

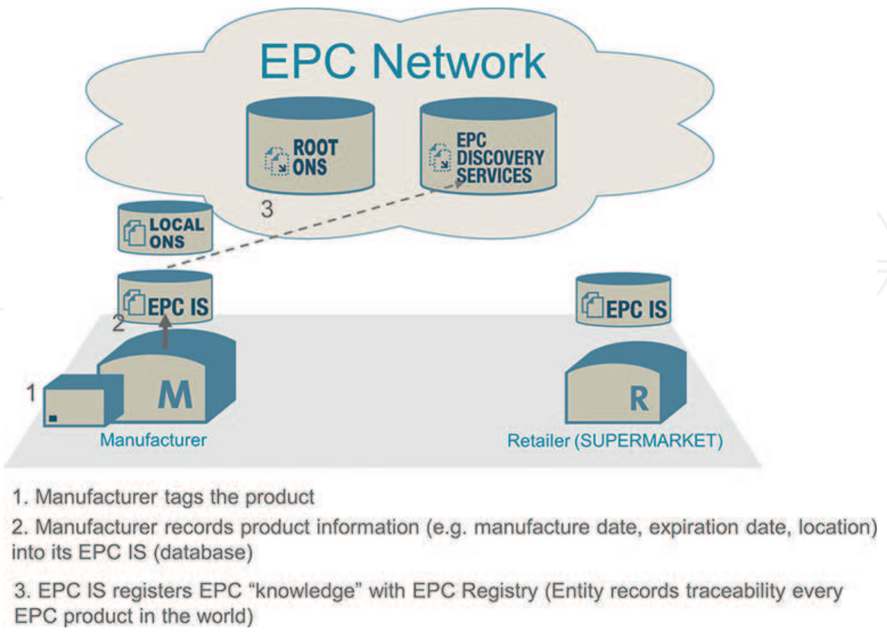

Figure 5. Manufacturer side: recording EPC codes in its EPC-IS and informing to EPC Discovery Services.

When a tag is identified, the reader only gets from it the EPC code [10] of its product (the tag is attached—and customized—to a product). The rest of the data of the identified product is obtained through the middleware, which performs a query to the system database, where all the product data are stored. In the case study that concerns us, this is the database managed by the supermarket. In this case, every EPC code registered is linked to a price. Other data of interest, for example, expiration date, nutritional value, recommended recipes, and so on, are obtained when the supermarket middleware makes a direct query to the manufacturer's EPC-IS (see **Figures 5** and **6**) [11]. For this, the supermarket middleware needs to know the URL or IP that gives access to the EPC-IS. The middleware obtains this sensitive information by querying to a server in the EPCglobal Cloud called root object name server (Root ONS) [44]. This server works like the typical domain name servers (DNS) in the Internet: you ask for a company (sending the company code), and it answers with the IP or URL associated to it (see **Figures 7** and **8**).

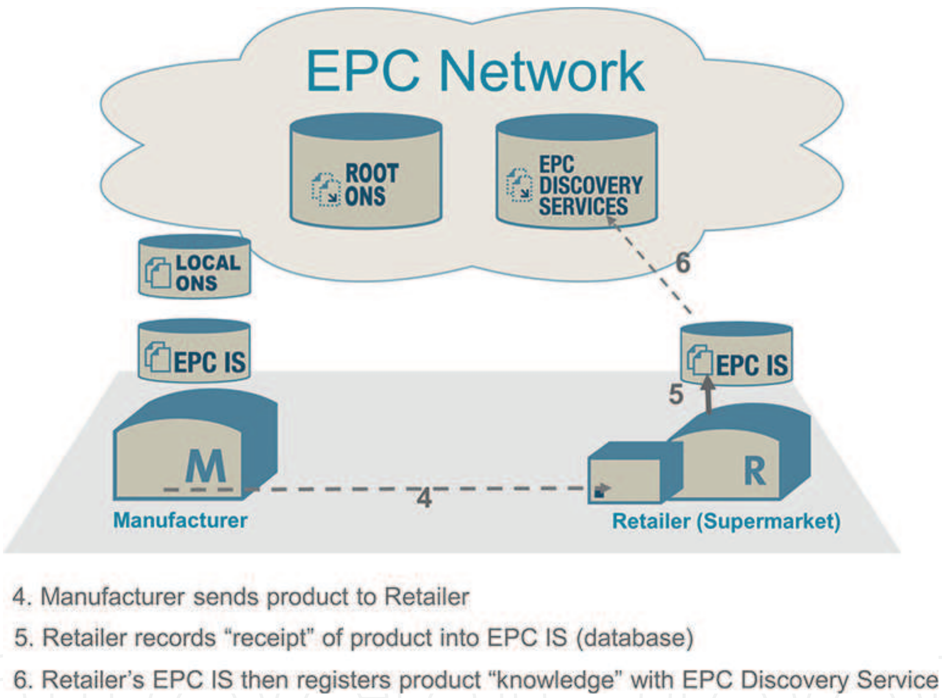

Figure 6. Supermarket side: recording identified tags in its EPC-IS and informing to EPC Discovery Services.

On the other hand, if the data of interest are a record about the product traceability, it is necessary that the middleware makes a query to the EPC Discovery Services [45], a server in the EPCglobal Cloud that stores a traceability record of every product in the world, labelled with RFID tags and storing an EPC code. The EPC Discovery Services stores the locations and other relevant information in the products life, starting at the moment that the product is labelled and recorded at the factory. The products location is updated at the moment that the product is moved, for example, from the factory to the provider, or from the supplier to the supermarket. For instance, when a good enters the supermarket store, it is registered by the middleware in the EPC Discovery Services, indicating its new location.

As a conclusion, if the supermarket is going to operate under the EPCglobal Network, it is necessary to set the agreements between the supermarket and the suppliers, in order to have access to the products information stored in the EPCglobal Network. On the other hand, there are still latent problems in the EPCglobal Network architecture that must be solved to reach a proper functioning: global network synchronization, scalability, security access to the EPC-IS and ONS, and so on. There are some outstanding works in the scientific literature that attempt to minimize and address these problems [46–50].

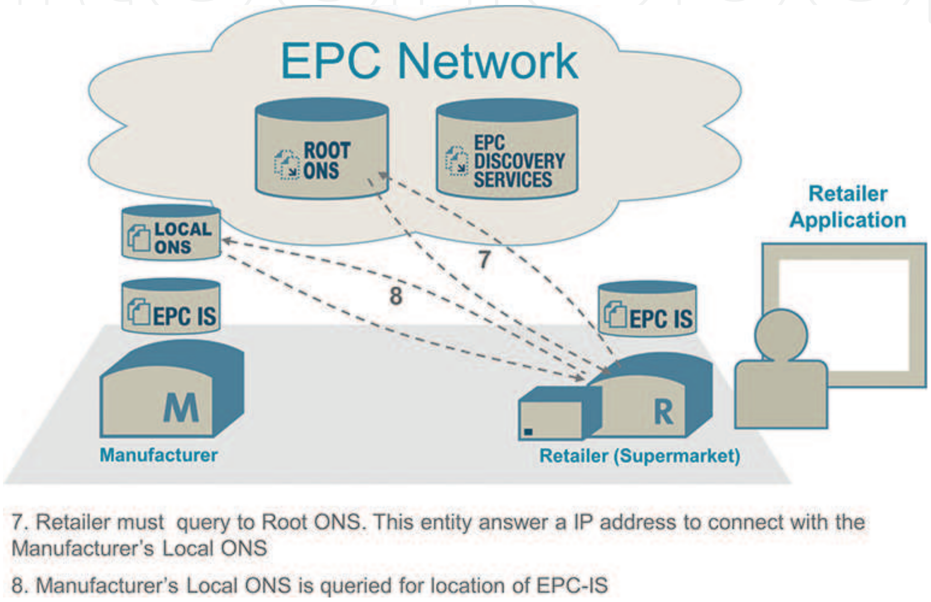

Figure 7. Supermarket queries about the EPC collected to the ONS.

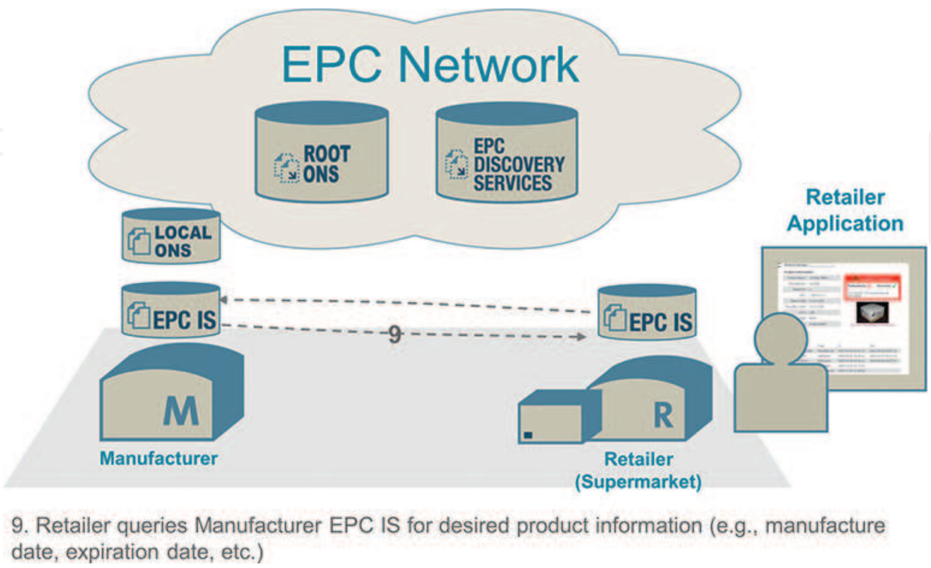

Figure 8. Supermarket gets the added-value information about the EPC collected.

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6. Security and privacy issues

In addition to the security issues to solve in the EPCglobal Network, it is necessary to clarify the doubts about data security and privacy of customers, suppliers, and companies in general. Corporations feel vulnerable to the following:

1. Spoofing (industrial espionage). It may happen when there are unauthorized reading products to know their type, composition, quantities, among others.

2. Tampering data that means to destabilize the supply chain or to disturb the operations by rewriting or deleting the EPC codes in tags by a malicious reader, for example, changing the EPC code of a tag by other linked to a product with lower price.

Customers also feel vulnerable to the following:

1. Tracking: customers fear that malicious readers can identify them, for example, with the RFID passport or an identity card, with the aim of being controlled (their habits or movements) by a higher entity (e.g., the government).

2. Hostlisting/profiling: customers fear they can be traced and classified according to the items labelled with RFID that they buy or they have.

The current security and privacy challenges focus on the establishment and management of keys, certificates of authorization, and the use of cryptographic algorithms for encrypting reader-to-tag communications [50–52].

7. Guide of Good Practices for implementing an RFID-UHF system in a supermarket

After reviewing the factors influencing the performance of RFID in supermarkets, this section proposes a Guide of Good Practices (GGP) for the design and implementation of RFID-UHF passive systems in supermarkets. Note that the rules described in this section must be applied once the scenario is defined, as well as the traceability/identification zones/points, for example, like the description addressed in Section 2.

The first step (Task 1 in **Figure 9**) is to decide the operating frequency, since it will determine the entire system. As it was explained in Sections 1 and 3.1, UHF is the most extended and used frequency band in these environments, offering the maximum reading distances between passive RFID tags and readers. Hence, the supermarket and its suppliers should agree about the operation mode, that is, if they will work at the same UHF band under the ITU region (see **Figure 2**). If a provider works with LF or HF, it should use tags with dual antennas, which are able to transmit/receive in HF/UHF or LF/UHF [19, 20]. Moreover, if the supermarket sells products labelled outside the ITU-working region, they must be labelled with tags that work in the whole UHF band [16–18]. On the other hand, the suppliers should address measurements about the absorption and reflection effects in their products labelled with RFID tags

(Task 2 in **Figure 9**). Suppliers must verify the successful identification of their products with liquids or metals. It is necessary something like a certificate of "*quality of identification,*" where suppliers officially state that the tags used to label their products are not susceptible to the absorption and reflection phenomena [23–25].

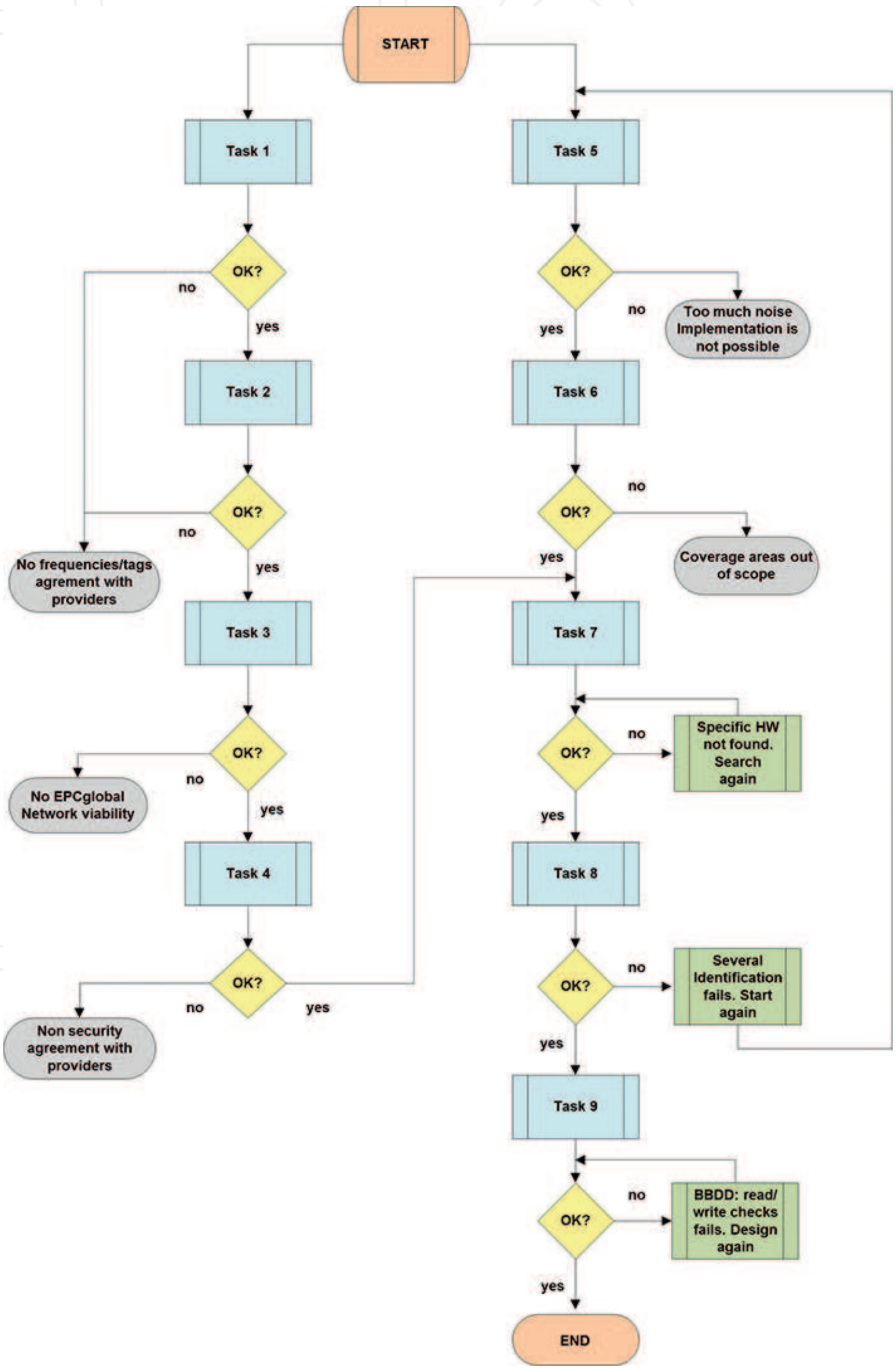

Figure 9. Guide of Good Practices: an RFID-UHF system implementation in a supermarket.

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In the globalized world, it seems obvious that both supermarkets and suppliers want to be part of the global network of traceability, the EPCglobal Network. In such case, both must register their EPC-IS [11], designing their databases and middleware compatible for operating with the EPCglobal Network, according to the standard defined in [14] (Task 3 in **Figure 9**). Besides, they must have read/write access in the EPC Discovery Services [45] and they must be registered in order to query to the ONS Root [44]. If a provider does not belong to the network, it cannot ensure global traceability of its products, nor can it provide information about the manufacturer, product type, and so on. However, the products can be identified by the supermarket and a price can be assigned to them through the internal database used in the supermarket.

Regarding secure communications, both the RFID system installed in the supermarket and the suppliers should use security systems to avoid spoofing and/or tampering, but without neglecting the global products visibility (Task 4 in **Figure 9**). This entails that both parties have to manage certificates of authorization for accessing to the EPC-IS, ONS, among others. In addition, for the reader-to-tag communications, a data encryption algorithm must be used and shared by the parties, suppliers, and supermarket [50–52].

If the above points are satisfactorily achieved, it means that both, suppliers and supermarket, can work together under a global identification RFID-UHF system. The following steps (which can be addressed in parallel to the above) are

1. Studying the electromagnetic noise (Task 5 in **Figure 9**). It is necessary to analyze the noise environment where the reader antennas will be installed, detecting all elements of the area which are the source of interferences. This comprises, for instance, the use of a spectrum analyzer connected to a half-wave dipole antenna and to a PC. The analyzer captures the interfering signals and the data are stored on the PC. It is desirable to make measurements at times of the day where there is more work activity, and when more electronic devices are working. In [53], it is described in detail how to perform these measurements.

2. Designing the identification areas (Task 6 in **Figure 9**). Although the starting point is the plan with the ideal deployment described in Section 2 (see **Figure 1**), the results of the previous step determine the final reader antennas location. Those zones where the effects of interferences are the lowest will be the initial identification zones. In each of them, a one-fourth wave dipole antenna, put on the center of a metal plate, will be placed, using a tripod. A signal generator and a PC will be used to capture the measurement data. The aim is to create a coverage map to decide how to properly orient the antennas and how to align them to offer the best performance. In [53], it is described how to perform these measurements in detail. If the measurement results are optimistic, it is time to choose the hardware, installation, startup, and identification tests.

3. Selecting RFID hardware (Task 7 in **Figure 9**). This task encompasses having an extensive knowledge about how the RFID readers and tags work (physical and logical operation). It is recommended to use bistatic antennas, with circular polarization, and a distance between the reader and the reader antennas (cable) less than 5 m. The reader will have at least 4 I/O ports, and it will work to the maximum output power according to the ITU

region where it is operating. The reader-to-tag communication protocol must be EPCglobal Class-1 Gen-2 [31] or an improved version, compatible with the standard, that permits to modify the frame-length parameter (*Q*) [32–34]. Readers must implement a reader-to-reader anti-collision protocol based on FHHS or a similar technique, being compatible with the current standard [31]. Finally, readers should be able to run the *EPCKill* command, defined by the EPCglobal standard. This command enables that those readers placed at the exit doors of the supermarket can automatically disable tags leaving the supermarket. Then, those tags cannot be read anymore, preventing customers from *Tracking* and *Hostlisting*.

4. Installation and identification tests (Task 8 in **Figure 9**). It is recommended to make the installation antenna by antenna. For every new reading point installed, the coverage range must be tested, and an intensive reading identification test is required. The performance is usually measured by the number of identified tags per time unit. The testing procedure will be conducted by varying the following parameters: frame-length (*Q*), number of tags per pallet/shopping trolley, speed pallet/trolley, tag-antenna distance, tag position according to the antenna, and so on.

5. Write/Read database/EPC-IS (Task 9 in **Figure 9**). If, after performing the previous steps the identification results are acceptable, it is time to implement the databases, the middleware, and the EPC-IS, to enable the supermarket operations through the EPCglobal Network. Note that the supermarket can use a unique database with all products data, distinguishing those data that will not be shared by the EPCglobal Network, for example, price of product, in/out-of-stock, for sale, sold, and so on. The databases must be tested (read/write operations), as well as the readings in the EPC-IS of the suppliers, Root ONS, and EPC Discovery Services.

If all the above steps are addressed and the testing results are satisfactory, the system is ready to operate. **Figure 9** shows a specification and description language (SDL) diagram with the GGP explained here.

8. Conclusions

This chapter has addressed a complete analysis of those hardware, software, and environmental factors that degrade the performance of passive RFID systems, focusing the study on a scenario of great potential for RFID technology and of interest to the society: a supermarket. In general, in the scientific literature these factors are studied individually or only a set of them and most of the works are usually focused on a communication layer. By contrast, this chapter provides a study in-depth about the set of factors affecting RFID performance in a specific scenario but contemplating the entire communication layer stack, and taking into account the requirements and needs of suppliers, supermarket companies, and final customers.

Throughout this chapter, the most remarkable works in the scientific literature that address how to eliminate or minimize the impact of the problems at physical, communication, or

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middleware layer have been reviewed: frequencies incompatibility, electromagnetic noise, reader-to-reader and reader-to-tag collisions, data security, scalability, global synchronization, and so on. As a result of this study, a protocol for implementing RFID systems in supermarkets is proposed as a Guide of Good Practices composed of nine defined tasks. It gives a complete vision for addressing, step by step, a successful RFID system implementation project, being useful for researchers, developers, and installers.

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