Chapter 1

# INTRODUCTION

Radio Frequency Identification (RFID) is a technology that uses communication through radio waves to transfer data between a reader and electronic tags attached to the object either to be identified or tracked. RFID technology has benefits with respect to (wrt.) other identification technologies [[Intro\_RFID](" \l "LyXCite-Intro_RFID)], such as no line-of-sight connection, fully automotive identification process, robustness, identification speed, bidirectional communication, reliability in different environment conditions, bunch detection and secured communication. Thus, RFID became particularly optimum solution for several applications where other identification technologies such as bar-codes are unsuitable in, for example, inventory tracking, supply chain management, automated manufacturing, etc [[Barcodes\_VS\_RFID\_1](#LyXCite-Barcodes_VS_RFID_1), [Barcodes\_Vs\_RFID\_2](#LyXCite-Barcodes_Vs_RFID_2), [Barcodes\_vs\_RFID\_3](#LyXCite-Barcodes_vs_RFID_3), [Barcodes\_vs\_RFID\_4](#LyXCite-Barcodes_vs_RFID_4)]. Due to the crucial significance of the RFID system in different real applications, RFID systems have received large attention from both, research groups and industry. Recently, a lot of work has been published on the area of RFID systems either in hardware and software design or in protocols and applications, etc [[2017\_RFID\_1](#LyXCite-2017_RFID_1), [2017\_RFID\_2](#LyXCite-2017_RFID_2), [2017\_RFID\_3](#LyXCite-2017_RFID_3), [2017\_RFID\_4](#LyXCite-2017_RFID_4)].

In this chapter, research motivation will be clearly presented. In addition, thesis contributions and outline will be highlighted.

## 1.1 Motivation

During the past few years, the number of applications that use RFID has increased, and their number will potentially further grow in the near future. One of its main applications, is logistics, where, for example, many tags (transponders) may be closely placed on pallets. Thus, in such systems, we have a single RFID reader responsible to identify a bunch of tags in the reading area as shown in figure [1.1](#fig_RFID_System). This naturally requires fast RFID readers (interrogators), in order not to slow down the delivery process of the actual goods. According to [[EPC\_1](#LyXCite-EPC_1), [EPC\_2](#LyXCite-EPC_2), [EPC\_3](#LyXCite-EPC_3)], ISO 18000-6C [[standard](#LyXCite-standard)] is the most commonly used RFID standards in logistics based on Time Division Multiple Access (TDMA), which leads to a certain probability of tag-collisions on the communications channel. Owing to their low price and simple design, tags can neither sense the channel nor communicate with the others. Hence, the readers are responsible for coordinating the network, and avoiding collisions using anti-collision algorithms.

Figure 1.1: Dense RFID network with single RFID reader

According to the previously published RFID work, Frame Slotted ALOHA (FSA) [[FSA\_2012](#LyXCite-FSA_2012), [FAS\_1](#LyXCite-FAS_1), [FSA2](#LyXCite-FSA2), [FSA3](#LyXCite-FSA3), [FSA4](#LyXCite-FSA4)] is the most widely used Medium Access Control (MAC) anti-collision protocol for RFID systems due to its simplicity and robustness. In FSA, the communication timing between the reader and the tags is divided into TDMA frames, each frame includes a specific number of slots. The frame length is function of the existing number of tags in the reading area. During the reading process, each active tag randomly assigns itself to one of the available slots in a frame. Therefore, each slot can take one of the three different states: 1) Successful Slot: Only one tag chooses this slot, is fully identified, and then deactivated by the reader. 2) Collided Slot: Multiple tags reply, resulting in a collision. The collided tags normally remain in their active state and retry their transmission in the next frame. 3) Empty Slot: No tag responds and the slot remains unused. Therefore, the reading efficiency is limited by the effect of two main parameters:

1. The accuracy of FSA frame length: If the frame length is bigger than the optimum value, many empty slots in this frame will be present, which is time-wasting. If the frame length is smaller than the optimum value, this will result many collided slots, which is also a waste of time. Thereby, choosing the optimum value in FSA frame length is the most crucial optimization parameter in such application.
2. The robustness of number of tags estimation: FSA frame length strongly depends on the actual number of tags in the reading area. However, in real applications, the number of tags in the reading area are unknown. Therefore, the more precise number of tag's estimation algorithm given, the better reading efficiency achieved.

Recent research groups have focused upon using the PHY (Physical) Layer properties, in the so-called Collision Recovery phenomena, to convert part of the collided slots into successful slots [[PHY1](#LyXCite-PHY1), [PHY2](#LyXCite-PHY2)]. This decrease the losses which come from the collision. Moreover, modern RFID readers have the ability to identify the type of the slot (successful, collided, or empty). Thus, the RFID readers are able to terminate the slot earlier as soon as they recognize the absence of a tag reply [[PHY3](#LyXCite-PHY3), [PHY4](#LyXCite-PHY4)], which eliminates the effect of the empty slots.

According to the previous discussion, the number of tags' estimation algorithm and the optimum FSA frame length strongly depend on the PHY-layer properties of the used system.

## 1.2 Thesis Contribution

This thesis aims to improve the performance of existing UHF RFID systems, mainly by minimizing the total identification delay. The accomplished work focused on optimizing FSA frame length and the number of tags' estimation algorithm for dense RFID networks, taking into consideration the MAC/PHY-layer parameters. All modifications are on the reader side, as the improved system has to follow the EPC global C1 G2 standard [[standard](#LyXCite-standard)]. Moreover, results are compared to the theoretical lower limit for this standard. Last but not least, compatible upgrades of UHF standard are proposed, thus granting extreme improvement for the overall performance. The main contributions of this thesis could be summarized as follows:

1. A novel tag's estimation method was created, taking into consideration the collision recovery capability of the system. The main advantage of the proposed method is that it provides a novel closed-form solution for the tag population estimator, which considers the collision recovery probability of the used system. Simulation results indicate that the proposed solution is more precise compared to the literature. Timing comparisons presented in the simulation results show the reduced identification delay of the proposed estimation method compared to other proposals.
2. A closed-form solution for the optimum frame length for FSA was provided, by optimizing the Time-Aware Framed Slotted ALOHA reading efficiency, which considers the differences in the slot durations. Simulations indicate that the proposed solution gives the most accurate results with respect to the exact solution.
3. Another closed-form solution for optimum frame length for FSA was settled, by optimizing the Time and constant collision recovery coefficients Aware reading efficiency. The proposed solution gives a novel closed form equation for the frame length considering the different slot durations and the collision recovery capability with equal coefficients. Moreover, a new method is introduced to calculate the capture probability per frame. Simulations indicate that the proposed solution gives accurate results for all relevant parameter configurations without any need for Multi-dimensional look-up tables.
4. A novel closed-form solution for the optimal FSA frame length was established, which considers the differences in the collision recovery probabilities. The values of the collision recovery coefficients are extracted from the physical layer parameters. Timing comparisons are presented in simulation results to show the mean reduction in reading time using the proposed frame length compared to the other proposals.
5. Another new closed-form solution for the optimal Frame Slotted ALOHA (FSA) frame length was generated. The novel solution considers the multiple collision recovery probability coefficients, and the different slot durations. Timing comparisons are presented in the simulation results to show the reading time reduction using the proposed frame length compared to other the state-of-the-art algorithms.
6. Finally, compatible improvements of UHF standard are proposed. In this system, there are some compatible modifications in the UHF RFID tags/Readers, to be capable of acknowledging more than a sole tag per slot.

## 1.3 Document Outline

A brief outline of this document is presented as follows. Chapter 2 introduces the historical background and literature survey of RFID systems. Chapter 3 presents the collision problem in the RFID systems and the existing anti-collision algorithms. Moreover, the concept of proposed cross-layer anti-collision algorithm will be defined. Chapter 4 reports the most commonly used number of tags' estimation algorithms in the RFID system. Afterwards, the proposed collision recovery aware Maximum likelihood estimation algorithm is discussed. In this part, a closed-form solution for the estimated number of tags in the reading area is suggested taking into consideration the collision recovery capability of the used system. Chapter 5 shows different case studies for FSA frame optimization. Each case depends on the PHY-layer parameters. Hence, in every case, a closed-form solution for the optimum FSA frame length is an analytically derived function of the estimated number of tags and the PHY-layer parameters. Chapter 6 provides compatible improvements of UHF standard. In this system, such modifications in the UHF RFID tags/Readers, can acknowledge more than single tag per slot. Last but not least, chapter 7 concludes this document by highlighting the main issues addressed in this thesis and outlining some of the future research aspects.