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 an object, either to be identified or tracked. The RFID technology has benefits with respect to (wrt.) other identification technologies [1], 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 the optimum solution for several applications where other identification technologies such as bar-codes are unsuitable, for example, inventory tracking, supply chain management, automated manufacturing, etc [2–4]. Due to the crucial significance of the RFID system in different real-world applications, RFID systems have received large attention from both, research groups and industry. Recently, many work has been published on the area of RFID systems either in hardware and software design, or in protocols and applications, etc [5–7]. In this chapter, the research motivation will be presented. In addition, the 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

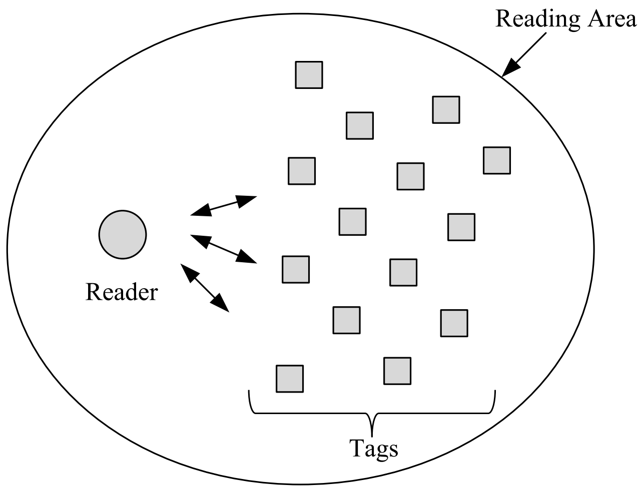

Figure 1.1: Dense RFID network with single RFID reader

RFID reader responsible to identify a bunch of tags in the reading area as shown in figure 1.1. This naturally requires fast RFID readers (interrogators), in order not to slow down the delivery process of the actual goods. According to [8–10], the EPCglobal C1 G2 [11] is the most commonly used RFID standards in logistics. It is 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.

According to the previously published RFID work, Frame Slotted ALOHA (FSA) [12, 13] 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 a 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 higher than the optimum value, many empty slots in this frame will be present, which reduces the reading efficiency. If the frame length is lower than the optimum value, this will result many collided slots, which again reduces the reading efficiency. Thereby, choosing the optimum value in FSA frame length is the most crucial optimization parameter in such application.

2. The robustness of the number of tags estimation: The optimum FSA frame length strongly depends on the actual number of tags in the reading area. However, in real-world applications, the number of tags of the reading area is unknown. Therefore, the more precise the number of tags estimation, 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 [14, 15]. This decreases the losses which result from collisions. 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 [16, 17], 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 the 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 EPCglobal C1 G2 standard [11]. Moreover, results are compared to the theoretical lower limit for this standard. Finally, compatible upgrades of the EPCglobal C1 G2 standard are proposed, thus granting additional improvements for the overall performance. The main contributions of this thesis can be summarized as follows:

1. A novel number of tags estimation method was developed, 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 methods presented in 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 the 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 was 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 other proposals.

5. Further, a new closed-form solution for the optimal Frame Slotted ALOHA (FSA) frame length was created. 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 the EPCglobal C1 G2 standard are proposed. They require some compatible modifications in the UHF RFID tags/readers, to be capable of acknowledging more than a single 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 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 the EPCglobal C1 G2 standard. In this system, such modifications to tags/readers, can acknowledge more than single tag per slot. Finally, chapter 7 concludes this document by highlighting the main issues addressed in this thesis and outlining some of the future research aspects.