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Introduction

1.1 What is RFID?

Identification is pervasive nowadays in daily life due to many complicated activities such as bank and library card reading, asset tracking, toll collecting, restricted accessing to sensitive data and procedures and target identification. This kind of task can be realized by passwords biometric data such as fingerprints, barcode, optical character recognition, smart card and radar. Radio frequency identification (RFID) is a technique to achieve object identification by using radio systems. It is a contactless, usually short distance, wireless data transmission and reception technique for identification of objects. An RFID system consists of two components:

- tag (also called transponder) – is a microchip that carries the identity (ID) information of the object to be identified and is located on/in the object;
- reader (also called interrogator) – is a radio frequency module containing a transmitter, receiver, magnetic coupling element (to the transponder) and control unit.

A passive RFID system works in the following way: the reader transmits radio waves to power up the tag; once the power of the tag reaches a threshold, the circuits in the tag start to work and the radio waves from the reader are modulated by the ID data inside the tag and backscattered to the reader and finally, the backscattered signals are demodulated at the reader and ID information of the tag is obtained.

RFID technology is quite similar to the well-known radar and optical barcode technologies, but an RFID system is different from radar in that backscattered signals from the tag are actively modulated in the tag (even for a passive tag or chipless tag), while backscattered signals in a radar system are often passively modulated by the scatterers of the object to be detected. An RFID system is different from an optical barcode system in that the information carrying tools are different: the RFID system uses radio waves as the tool, while the barcode system uses light or laser as the tool.

Many applications of RFID or barcode techniques are somewhat exchangeable, i.e., many ID identification tasks can be implemented by either RFID technique or barcode technique. However, optical barcode technology has the following critical drawbacks: (i) the barcode cannot be read across non-line-of-sight (NLoS) objects, (ii) each barcode needs care taken in order

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to be read and (iii) the information-carrying ability of the barcode is quite limited. RFID technology, using radio waves instead of optical waves to carry signals, naturally overcomes these drawbacks. It is believed that RFID can substitute, in the not-too-distant future, the widely used barcode technology, when the cost issue for RFID is resolved.

1.2 A Brief History of RFID

Many people date the origin of RFID back to the 1940s when radar systems became practical. In World War II, German airplanes used a specific manoeuvering pattern to establish a secret handshake between the pilot of the airplane and the radar operator in the base. Indeed, this principle is the same as that of modern RFID: to modulate the backscattering signal to inform the identity of an object. The true RFID, in the concept of modern RFID, appeared in the 1970s when Mario Cardullo patented the first transponder system and Charles Walton patented a number of inductively coupled identification schemes based on resonant frequencies. The first functional passive RFID systems with a reading range of several metres appeared in early 1970s [4]. Even though RFID has significantly advanced and experienced tremendous growth since then [1, 2], the road from concept to commercial reality has been long and difficult due to the cost of tags and readers. A major push that brought RFID technology into the mass market came from the retailer giant Wal-Mart, which announced in 2003 that it would require its top 100 suppliers to supply RFID-enabled shipments by the beginning of 2005[1]. This event triggered the inevitable movement of inventory tracking and supply chain management towards the use of RFID. Up to now, RFID applications have been numerous and far reaching. The most interesting and widely used applications include those for supply chain management, security and tracking of important objects and personnel [3, 5, 6].

Similar to other kinds of radio systems, the development of RFID has also been stimulated by necessity. Even though the progress in the design and manufacturing of antennas and microchips has smoothly driven performance improvement and cost decrease of RFID, booming development for it has not appeared until recently, since optical barcode technology has dominated the market for the last few decades. In recent years, many new technologies, such as smart antennas, ultra wideband radios, advanced signal processing, state-of-art anti-collision algorithms and so on, have been applied to RFID. In the meantime, some new requirements to object identification and new application scenarios of RFID have been emerging, such as simultaneous multiple object identification, NLoS object identification and increasing demand on data-carrying capacity of tag ID. It is this kind of application that calls for the deployment of RFID systems.

1.3 Motivation and Scope of this Book

Generally, signal processing is the core of a radio system. This claim also holds true for RFID. Several books are available now coping with other topics in RFID, such as basics, fundamentals, smart antennas, security and privacy, but no book has appeared to address signal processing issues in RFID. We aim to complete this task in this book.

The main purpose of this book is two-fold: first, it will be a textbook for both undergraduate and graduate students in electrical engineering; second, it can be used as a reference book

[1] see 'Wal-Mart Draws Line in the Sand' (www.rfidjournal.com/articles/view?462) and also 'Wal-Mart Expands RFID Mandate' (www.rfidjournal.com/articles/view?539).

for practice engineers and academic researchers in the RFID field. Therefore, the contents of this book include both fundamentals of RFID and the state-of-the-art research results in signal processing for RFID. For the former, we will discuss the operating principles, modulation schemes and channel models of RFID. For the latter, we will highlight the following research fields: space-time coding for RFID, blind signal processing for RFID, anti-collision of multiple RFID tags and localization with RFID. Also, due to the two-fold purpose of the book, some attention will be paid to pedagogical methods. For example, some concrete examples on the analysis of transmission efficiency of tree-splitting algorithms will be illustrated in detail before presenting general results in Chapter 7.

The book consists of the following chapters, after this one.

Chapter 2 – Fundamentals of RFID Systems. In this chapter, we will discuss the following issues: (i) operating principles of RFID, (ii) classification of RFID, (iii) analogue circuits for RFID and their basic analysis, (iv) channel models of RFID, (v) a brief review of RFID protocols and (vi) challenges in RFID. This chapter provides a basis for Chapters 3 to 9.

Chapter 3 – Basic Signal Processing for RFID. In this chapter, we will discuss some basic signal processing techniques and their applications in RFID, which include analogue/digital filtering and optimal estimation.

Chapter 4 – RFID-oriented Modulation Schemes. Since a passive RFID tag does not have an 'active' transmitter, some complicated signal modulation schemes in general communication systems cannot be applied to RFID. Instead, only very simple modulation schemes, namely, binary amplitude-shift keying and frequency/phase-shift keying, are suitable for an RFID tag. In this chapter, these modulation schemes, tailored to RFID channels, will be described. The performance of these modulation schemes for RFID channels will be investigated.

Chapter 5 – MIMO for RFID. In this chapter, we will discuss the following issues: (i) channel models of RFID systems with multiple antennas at both readers and tags (MIMO); (ii) signal design at the reader for RFID-MIMO systems (iii) space-time coding at the tag for RFID-MIMO systems and (iv) differential space-time coding at the tag for RFID-MIMO systems. Using multiple antennas in radio systems (especially in communication systems) is a general trend. Actually, employing multiple antennas has been incorporated into many existing communication standards. It is also believed that RFID systems equipped with multiple antennas will be deployed in the near future. Therefore, this chapter will be dedicated to the combination of RFID with MIMO. We will show that, by proper design, the bit-error-rate performance of the system can be greatly improved by using multiple antennas at the reader and tag.

Chapter 6 – Blind Signal Processing for RFID. In practice, one often meets the situation where several or many transponders are present in the reading zone of a single reader at the same time. Therefore, it is important to study the techniques to identify multiple tags simultaneously. In principle, two approaches can be used to do this job. The first one is to use collision avoidance techniques such as Aloha from a networking viewpoint. The second one is to use source separation techniques from a signal processing viewpoint. In this chapter, the second approach will be investigated, while Chapter 7 will be devoted to the first approach. It will be shown that, under a moderate SNR and when the number of measurements to the multiple tags in one snapshot is sufficiently high, the overlapped signals coming from the multiple tags can be separated at the reader receiver if the number of the tags is less than the number of receiving antennas at the reader.

Chapter 7 – Anti-Collision of Multiple-Tag RFID Systems. As already mentioned, there are two approaches to dealing with the multiple-tag identification problem. In this chapter, we will discuss this problem from the networking viewpoint. Basically, the traditional anti-collision algorithms in WLAN, such as tree splitting and slotted Aloha, can be applied to this problem. Since passive RFID systems are highly asymmetric, i.e., the reader is resource-rich, while tags have very limited storage and computing capabilities and are unable to hear the signal transmitted by other tags and to detect collisions, some advanced collision-avoidance algorithms in WLAN, such as carrier sense multiple access are difficult to implement in RFID tags. Therefore, basic tree-splitting and Aloha-based anti-collision algorithms for multi-tag RFID systems will be discussed in this chapter. The methods for the theoretical performance analysis of these algorithms will be addressed. It is found that the static Aloha yields very poor performance in both mean identification delay and transmission efficiency for multiple-tag RFID systems. Therefore, we propose two adaptive frame size Aloha algorithms, which have only a very light computational burden at the reader and no additional computational burden at the tag, but yield significant performance improvement.

Chapter 8 – Localization with RFID. In principle, the problem of localization with the help of RFID is similar to radar ranging problem. However, RFID ranging has its peculiar concerns. Since the distance between the reader and tag is usually short (typically of the order of less than 10 m), the round-trip signal delay is on the order of a few tens of nanoseconds. Because the available bandwidth of typical RFID signals is narrow, it is difficult to measure the time of arrival or time difference of arrival of the RFID signal. Thus baseband phase information is extremely useful for RFID localization problems. In this chapter, we will give an overview for RFID localization algorithms using various methods based on different kinds of information. To use the localization algorithms of the geometric approach, the range between readers and tags or angle of arrival (AoA) should be reliably measured or estimated from the measured information. Two approaches, namely frequency-domain phase difference of arrival (PDoA) approach and spatial-domain PDoA approach for measuring the range and AoA respectively, will be discussed. Finally, the challenging issue, that is, non-line-of-sight mitigation issue in RFID localization, will be addressed.

Chapter 9 – Some Future Perspectives for RFID. RFID systems discussed in preceding chapters belong to the middle class of RFID in the sense that IC chips are integrated inside the tags, but the power needed for signal transmission in the tags of this kind of RFID should be harvested from the reader's transmitted radio waves. This situation can be extended in two extreme ends: chipless tags and active tags. Using active tags, some advanced communication functionalities, such as covert radio frequency identification, can be realized. Using chipless tags, most tags can be printed by inkjet printers, thus greatly reducing the cost of manufacturing and packaging of tags. In this chapter, we will present a brief review for covert RFID and some chipless tags. For the first task, we need to use ultra wideband (UWB) technology and the time reversal (TR) technique. Therefore, some basics for UWB and TR will be also introduced. For the second task, two kinds of chipless tags, namely time-domain reflectometry-based chipless tags and frequency-domain spectral-signature-based chipless tags, will be discussed.

1.4 Notations

Throughout the book, we use $\mathbf{I}$ to denote an identity matrix, whose dimension is indicated by its subscript if necessary, $P_A(x)$ and $p_A(x)$ represent, respectively, the cumulative distribution function and probability density function (pdf) of a random variable A, $\mathbb{E}$ (or $\mathbb{E}_A$ if necessary) stands for the expectation of a random quantity with respect to the random variable A, $\mathbb{E}(\cdot|\cdot)$ denotes the conditional expectation, and Var(A) stands for the variance of A. The notation $\mathcal{N}(0, \sigma^2)$ stands for a Gaussian-distributed random variable with zero mean and variance σ^2. For a matrix or vector, the superscripts ^{T}, *, † denote the transpose, the element-wise conjugate (without transpose), and the Hermitian (conjugate) transpose, respectively, of the matrix or vector. The notations * and † also apply to a scalar. The symbol $\jmath$ is defined as $\jmath = \sqrt{-1}$. The function log is naturally based, if the base is not explicitly stated. We use `diag` to denote a diagonal matrix with the diagonal entries being specified by the corresponding arguments. The real part and imaginary part of a complex variable are denoted by `Re` and `Im`, respectively. We use $|\cdot|$ or $\det(\cdot)$ to denote the determinant of a matrix. Throughout the book, the symbols 0 or $\mathbf{0}$ denote scalar zero, vector zero or matrix zero with corresponding dimensions, depending on the context.

For other notations, we might use the same symbol to denote different things in different chapters or sections. If this case happens, we will explicitly explain what the symbol stands for.

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