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Networked RFID

Systems, Software and Services

Springer

George Roussos, PhD
Birkbeck College, University of London, UK

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To my daughter, Katerina

Preface

The birth of RFID technology is credited to the 1948 research paper by H. Stockman on "Communication by Means of Reflected Power" [109]. After describing the main principle of communication by reflection and reporting his experiments, he concluded that

> "Evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored."

It turns out that in fact this work required almost 60 years of science and engineering before it was mature enough to find its way into large-scale applications. This is surprising, as at first glance RFID is a simple technology that is straightforward to implement. And yet, its dull appearance hides great complexity: RFID involves several engineering disciplines, including systems, networking and software development, antenna design, radio propagation, integrated circuit techniques increasingly focused on printed electronics, receiver design, encryption and security protocols, and materials technology, to mention but a few.

In this book, I attempt to present the main ingredients for building complete network RFID systems, written for a knowledgable computing audience. I hope this book will help practitioners and researchers alike in establishing a robust framework for thinking about RFID. I also hope that the book will help anyone involved with RFID technology to make informed decisions that are appropriate for their particular problem at hand.

In many ways, I have tried to write the book I wish had been available when in 1999, together with a group of enthusiastic colleagues, we set out to work on the MyGrocer project, a second-generation pervasive retail system. At the time, information about RFID was fragmented and written primarily for a different audience altogether. Building large-scale open software systems for RFID had not been attempted to any significant extent, and experience was

sparse and mostly unpublished. Despite this, MyGrocer succeeded in demonstrating item-level tagging within a real supermarket environment in 2002. To my knowledge, this is the first demonstration of the technology outside the laboratory and thus marks a milestone for RFID.

Nevertheless, recent years there has been an explosion of interest in RFID, and many new technologies have made obsolete the state-of-the-art of 2000. The reason for this is twofold. First is the availability of very low-cost long-range passive RFID tags that require no battery to operate, and second is the wide availability of fixed and wireless communication networks that allow RFID deployments in the field to be linked with software and information services at the network core. These facilities have made possible large-scale commercial applications of RFID in the supply chain, ticketing, asset tracking, maintenance, retail, and personal identification.

Thanks to these applications, RFID today is one of the most popular computing platforms in use. According to some estimates, there are more than 3.7 billion RFID tags in use today, of which more than 1.6 billion were deployed during 2006—and this trend is accelerating. This popularity of RFID permits considerable cost reductions that have sparked further interest in the technology, as it offers unique advantages in instrumenting the physical environment.

Yet the same features that make RFID such a popular technology are also complicating its use. To provide battery-free operation and low cost, passive RFID tags have extremely limited capabilities, often being able to hold (and in fewer cases protect) only a simple entity identifier, which is employed as a means to automatically link physical entities and their stored information. This implies that the majority of system functionality must be supported by the network, for example by mapping an object ID to an entity description and attributes. Note that this intimate linking effected by RFID between real and virtual also creates considerable security and privacy risks that have to be managed so as to guarantee its safe use.

This book is written for readers with a firm grasp of computer fundamentals and experienced in software development. Unlike other books on RFID, it does not make any assumptions about knowledge of other aspects of engineering but only includes appropriate information so the reader can understand common trade-offs and the performance characteristics of different RFID flavors. My guiding principle in selecting material to include in this book is what I would have found useful to understand RFID when I first started working with the technology and exclude all the details that have not been of any practical use.

Contrary to custom, I begin with a quick introduction to RFID basics rather than applications. The reason is that a discussion of applications without a firm grasp of the basics quickly becomes unwieldy and obscures rather than clarifies the issues. My approach may appear somewhat abrupt at first but will pay dividends later in the book. After sorting out the basics, I proceed to discuss three RFID applications that I find of particular interest, especially

in the context of networked systems, namely e-passports, ticketing, and supply chain management. The second chapter concludes with a quick overview of other common applications and some discussion of the numerous standards for RFID.

Chapter 3 discusses in detail the different types of readers and tags and makes particular reference to common technologies used in real systems. It is highly likely that you have already used one or more of these technologies, even though it may not have been clear that this was so, and this chapter also works as a guide to spotting RFID in everyday situations. Chapter 4 takes a step backward and looks at radio waves, how they propagate in space, and how they can be captured by tags. The main reason for covering this material is that it justifies the very different performance characteristics of different RFID systems. Moreover, looking at the fundamentals is rather informative in understanding the design of RFID antennas, which have been considered the "black art" of RFID. This is certainly no longer so, and today the system architect has a wide variety of high-performance commodity designs to choose from.

Chapter 5 is by far the most tedious of this book, as I go into the details of different identifier systems, how they encode unique serial codes for tagged entities, and how codes are assigned to particular organizations. Although this is a rather esoteric issue, it is nonetheless necessary to have an in-depth understanding of such schemes when working with RFID, as this is the only way to interpret codes. To brighten up the discussion, I also include a bit of history on how we have arrived at the current situation.

Chapters 6 and 7 are intimately related. In the former, I present what I call the RFID stack; that is, a layered description of the structure and the functionality of modern RFID systems. Due to the fact that large-scale RFID is relatively recent, each system and vendor uses different terms and different subsystem boundaries to describe what are essentially identical components. The stack is my attempt to organize all such elements into a unified system architecture that provides a blueprint shared between all systems and platforms. I also outline how the systems of the major RFID vendors fit into this view. The next chapter complements the description of the stack by describing RFID middleware, which provides the glue that makes such unification possible. Note that middleware is without doubt the hottest area of RFID software, and for this reason I also include some material on forthcoming developments that may not currently be part of commercial systems or standards.

Chapter 8 discusses the different types of network services required for RFID support. In particular, I highlight the main elements of code resolution solutions and their limitations and the emerging class of repository services. I review several systems that provide solutions to this problem with a view toward providing common patterns of RFID systems and software that can be modified and reused as appropriate to fit the requirements of diverse domains and applications. In the short term, such services are unlikely to become as pervasive or ubiquitous as the common network services that form the

internet infrastructure. Before this happens on any significant scale, many data management and trusted operation issues would have to be resolved.

Chapter 9 deals with the issues that have given RFID its current notoriety, namely privacy and security. I use several cases where RFID has been used in a haphazard way to motivate the discussion of specific technologies and privacy protection approaches. Nevertheless, these issues have less to do with technology and everything to do with the choices we collectively make as a society and codify in law and culture, and RFID places considerable strain on both. Of course, our business is technology, but despite what many may claim, technology also shares the same context as the rest of society and has to be guided by ethics as much as curiosity about what is technically possible.

The final chapter of this book takes a look to the future. I start with a discussion of several improvements to RFID already in the pipeline that hold the promise of even lower-cost tags and extended capabilities. Many of these developments are due to mature in the relative short term and offer exciting enhancements to current RFID functionalities. Lowering the cost of the individual tag may also allow widespread item-level tagging of consumer products. This development will directly affect the end user—that is, the consumer—and it can potentially bring about fundamental changes in the shopping experience.

I discuss these changes and the potential opportunities and risks they may cause using the findings of the MyGrocer study, which outlined the main issues and explored specific consumer concerns. Moreover, I set the discussion of RFID in the wider context of pervasive computing, the next-generation computing paradigm that is gradually emerging from research, and link one to the other, identifying applications of particular promise. Pervasive computing is my own research specialization, and RFID provides a low-cost entry into a world where the physical and the digital are no longer separate.

Throughout the book, I have attempted to provide as many examples based on real case studies as possible and follow them up with detailed explanations and photographs that hopefully help to clarify the issues. My intention has been to provide narratives around my experiences with RFID and the experience that others have shared with me, rather than discuss the minutia of standards and specific programming interfaces. The emphasis is on developing an arsenal of techniques and designs that can be mixed and matched to fit the needs of new systems and applications.

Before concluding, I would like to express my gratitude to all those who have worked with me on RFID over the years as advisors, clients, colleagues or students. First, I thanks my companions in the MyGrocer experiment, in particular Panos Kourouthanassis and Juha Tuominen, both of whom played a critical role in the success of that project. Many thanks go to Roger Till and other staff at GS1 UK for valuable advice and guidance. Thanks are also due to the following persons for discussions, advice, or both: Alessandro Acquisti, Christof Bornhövd, Sastry Duri, Simson Garfinkel, Anatole Gershman, Vassilis Kostakos, Matthias Lampe, Olli Pitkänen, Tony Salvador,

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Last, but not least, my thanks go to my wife, Theano, and my daughter, Katerina, who gave up their time with me so that I could work on this book.

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George Roussos
University of London

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