RFID Technology and Applications

Are you an engineer or manager working on the development and implementation of RFID technology? If so, this book is for you.

Covering both passive and active RFID, the challenges to RFID implementation are addressed using specific industry research examples as well as common integration issues. Key topics such as performance optimization and evaluation, sensors, network simulation, RFID in the retail supply chain, and testing are covered, as are applications in product lifecycle management in the automotive and aerospace sectors, in anti-counterfeiting, and in health care.

This book brings together insights from the world's leading research laboratories in the field, including MIT, which developed the Electronic Product Code (EPC) scheme that is set to become the global standard for object-identification.

MIT's suite of Open Source code and tools for RFID implementation is currently being developed and will be made available with the book (via www.cambridge.org/9780521880930).

This authoritative survey of core engineering issues, including trends and key business questions in RFID research and practical implementations, is ideal for researchers and practitioners in electrical engineering, especially those working on the theory and practice of applying RFID technology in manufacturing and supply chains, as well as engineers and managers working on the implementation of RFID.

Stephen B. Miles is an RFID evangelist and Research Engineer for the Auto-ID Lab at MIT. He has over 15 years of experience in computer network integration and services.

Sanjay E. Sarma is currently an Associate Professor at MIT, and is also a co-founder of the Auto-ID Center there. He serves on the board of EPCglobal, the wordwide standards body he helped to start up.

John R. Williams is Director of the Auto-ID Lab at MIT, and is also a Professor of Information Engineering in Civil and Environmental Engineering. As well as many years of lecturing, has also worked in industry, and was the Vice President of Engineering at two software start-up companies.

The Auto-ID Lab at MIT has developed a suite of RFID and software specifications for an Electronic Product Code (EPC) network that have been incorporated into EPCglobal and ISO standards and are being used by over 1,000 companies across the globe.

RFID Technology and Applications

Edited by

STEPHEN B. MILES
SANJAY E. SARMA
JOHN R. WILLIAMS
Massachusetts Institute of Technology

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521880930

First published 2008

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data

RFID technology and applications / edited by Stephen B. Miles, Sanjay E. Sarma, John R. Williams.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-521-88093-0 (hardback)
1. Radio frequency identification systems. 2. Inventory control–Automation. I. Title.
TS160.R437 2007
658.7′87–dc22 2007049093

ISBN 978-0-521-88093-0 hardback

Contents

Contributors

Gisele Bennett
Professor and Director, Electro-Optical Systems Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA – Ch. 8

J. T. Cain
Professor, Department of Electrical and Computer Engineering, University of Pittsburgh, Pittsburgh, PA – Ch. 5

J. P. Emond
Associate Professor and Co-Director, IFAS Center for Food Distribution and Retailing, University of Florida, Gainesville, FL – Ch. 11

Elgar Fleisch
Professor and Director, Auto-ID Labs, University of St. Gallen, Institute of Technology Management and Eidgenössische Technische Hochschule Zürich, Zurich, Department of Management, Technology and Economics – Ch. 12

Christian Gorldt
Bremer Institut für Produktion und Logistik GmbH (BIBA), University of Bremen, Bremen – Ch. 14

Bill C. Hardgrave
Associate Professor and Executive Director, RFID Research Center, Sam M. Walton College of Business, University of Arkansas, Fayetteville, AR – Ch. 10

Mark Harrison
Senior Research Associate, Auto-ID Labs, University of Cambridge, Cambridge – Ch. 10

Peter J. Hawrylak
RFID Center of Excellence, University of Pittsburgh, Pittsburgh, PA – Ch. 4

Mohammad Heidari
Center for Wireless Information Network Studies (CWINS), Worcester Polytechnic Institute, Worcester, MA – Ch. 6

Ralph Herkert
Senior Research Engineer, Medical Device Test Center, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA – Ch. 8

Uwe Hinrichs
Bremer Institut für Produktion und Logistik GmbH (BIBA), University of Bremen, Bremen – Ch. 14

Paul Hofmann
Director External Relations, SAP Research Center, Palo Alto, CA – Ch. 7

Hong-Bae Jun
Ecole Polytechnique Fédérale de Lausanne, Lausanne – Ch. 13

Dimitris Kiritsis
Associate Director, Laboratory of Informatics for Design and Production, Ecole Polytechnique Fédérale de Lausanne, Lausanne – Ch. 13

Kang Lee
National Institute of Standards and Technology (NIST), Washington, DC – Ch. 5

Tao Lin
Director of Auto-ID Infrastructure, SAP Labs LLC, Palo Alto, CA – Ch. 7

Michael Lipton
Director of RFID Solutions Management for Healthcare Life Sciences, SAP Labs LLC, Palo Alto, CA – Ch. 7

Duncan McFarlane
Professor and Director, Auto-ID Lab, University of Cambridge, Cambridge – Ch. 10

Krish Mantripragada
Global Lead and Program Director, Supply Chain Solutions, SAP Labs LLC, Palo Alto, CA – Ch. 7

Leonid Mats
RFID Center of Excellence, University of Pittsburgh, Pittsburgh, PA – Ch. 4

Florian Michahelles
Department of Management, Technology and Economics, Eidgenössische Technische Hochschule Zürich, Zurich – Ch. 12

Marlin H. Mickle
Professor and Director, RFID Center of Excellence, University of Pittsburgh, Pittsburgh, PA – Ch. 4

Stephen Miles
Research Engineer and Co-Chair, the RFID Academic Convocation, Auto-ID Labs, Massachusetts Institute of Technology, Cambridge, MA – Ch. 1, 15

Robert Miller
Assistant Professor, Accounting and MIS Department, Dauch College of Business & Economics, Ashland University, Ashland, OH – Ch. 10

Hao Min
Professor and Director Auto-ID Labs, Fudan University, Shanghai – Ch. 3

Kaveh Pahlavan
Professor and Director, Center for Wireless Information Network Studies (CWINS), Worcester Polytechnic Institute, Worcester, MA – Ch. 6

Victor Prodonoff Jr.
Auto-ID Labs, University of Cambridge, Cambridge – Ch. 10

Abel Sanchez
Research Scientist, Auto-ID Labs, Massachusetts Institute of Technology, Cambridge, MA – Ch. 7

Sanjay Sarma
Associate Professor, Massachusetts Institute of Technology, Auto-ID Labs, Cambridge, MA – Ch. 2

Bernd Scholz-Reiter, Ph.D.
Professor and Director, Bremer Institut für Produktion und Logistik GmbH (BIBA), University of Bremen, Bremen, – Ch. 14

Thorsten Staake
Massachusetts Institute of Technology, Auto-ID Labs, Cambridge, MA – Ch. 12

Jan Topi Tervo
Bremer Institut für Produktion und Logistik GmbH (BIBA), University of Bremen, Bremen – Ch. 14

Alan Thorne
Auto-ID Lab, University of Cambridge, Cambridge – Ch. 10

Dieter Uckelmann
Research Scientist and Manager RFID-Application and Demonstration Center, Bremer Institut für Produktion und Logistik GmbH (BIBA), University of Bremen, Bremen – Ch. 14

John R. Williams
Associate Professor and Director, Auto-ID Labs, Massachusetts Institute of Technology, Cambridge, MA – Ch. 7

Paul Xirouchakis
Ecole Polytechnique Fédérale de Lausanne, Lausanne – Ch. 13

Preface

This book is addressed to business management and project managers as well as researchers who are evaluating the use of radio frequency identification (RFID) for tracking uniquely identified objects. In an effort to make RFID project management less of an art form and more of a science *RFID Technology and Applications* brings together pioneering RFID academic research principals to analyze engineering issues that have hampered the deployment of RFID and to share "best practices" learnings from their work. By extending the original work of the Auto-ID Center at MIT and the subsequent Auto-ID Labs consortium led by MIT that now comprises seven world-renowned research universities on four continents, this book seeks to establish a baseline for what RFID technology works today and identifies areas requiring research on which other researchers in academic, commercial, and regulatory agencies can build.

The researchers represented in these pages have gathered on three continents in the course of the RFID Academic Convocations, a research collaboration hosted by the Auto-ID Labs that started in January of 2006, at MIT, and was followed by events co-hosted with the Chinese Academy of Sciences and Auto-ID Labs at Fudan University in Shanghai, as RFID Live! 2007 pre-conference events, and by the event in Brussels organized with the European Commission Directorate-General for Informatics (DGIT) and the Auto-ID Labs at Cambridge University. These Convocations bring together academic researchers with industry representatives and regulatory stakeholders to collaborate across disciplines and institutions to identify challenges faced by industry in adopting RFID technology. As summarized by Robert Cresanti, Under Secretary of Commerce for Technology, United States Department of Commerce in his remarks that day, "the two primary challenges facing this new technology are standards and interoperability issues across various RFID systems, companies, and countries, and privacy and security concerns."[1]

Following an introduction to the history of RFID as it bears on standards and interoperability, the technology chapters that follow (Chs. 2–7) address core engineering issues related to the design of RFID chips and antennas that must be tuned to specific products, the placement, packaging, and density of those tags to

[1] Technology Administration Speech, remarks by Robert C. Cresanti, Under Secretary of Commerce for Technology, United States Department of Commerce, delivered March 13, 2007 at the EU RFID FORUM 2007 (http://www.technology.gov/Speeches/RC_070313.htm).

maximize their readability, and the characterization of downstream RF operating environments, and the reader range and densities for effective (read accuracy and speed) RFID data acquisition and secure information exchange.

In investigating RFID applications (Chs. 9–15) researchers illustrate the challenges of implementing RFID applications today, especially where they are seeking to change current business processes. Sanjay Sarma, co-founder of the Auto-ID Center at MIT and EPCglobal board member, leads the RFID technology section (Chs. 2–7) with an introduction to the technology that he was personally instrumental in developing at the Auto-ID Center and subsequently as interim CTO and Board Member for Oat Systems, a leading RFID middleware company founded by his graduate student Laxmiprasad Putta. Sanjay Sarma sets the stage for the subsequent technology chapters by highlighting the many areas of ongoing research related to RFID (Ch. 2). The introduction to designing RFID tags optimized for low power consumption by Hao Min, Director of the Auto-ID Labs at Fudan University (Ch. 3), is followed by an overview of the physics challenges and performance trade-offs of competing passive HF and UHF RFID systems by Marlin Mickle, Director, and colleagues Peter J. Hawrylak and Leonid Mats from the RFID Center of Excellence at the University of Pittsburgh (Ch. 4). Specifications for active RFID sensors and a proposal to standardize interfaces to active RFID sensors, building on the EPCglobal RFID and IEEE1451 sensor interface specifications, are introduced by Kang Lee of NIST and Tom Cain, Ph.D., University of Pittsburgh (Ch. 5). A test methodology for evaluating real-time location systems with RFID systems, starting with IEEE 802.11g and ISO 24730 Part 1 Real Time Locating Systems (RTLS), is introduced by Mohammad Heidari and Kaveh Pahlavan, Director of the Center for Wireless Information Network Studies at Worcester Polytechnic Institute (Ch. 6). A simulation methodology for modeling the EPC network is presented by John Williams, Director, and Abel Sanchez, Ph.D., of the MIT Auto-ID Labs and colleagues from SAP Research (Ch. 7). In the conclusion we will revisit the question of how passive RFID technology for the supply chain integrates with sensor networking and location tracking, and how these applications complement and/or conflict with current RF infrastructure and applications from aerospace to medical and retail facilities.

In the RFID applications section of this book (Chs. 8–14) Giselle Bennett, Director, Logistics and Maintenance Applied Research Center, and Ralph Herkert of the Georgia Tech Research Institute at Georgia Institute of Technology expose the challenges of deploying active RFID systems (Ch. 8) from their experience managing projects for the US Navy. Bill Hardgrave, Director of RFID Research Center at the University of Arkansas and Robert Miller, Ph.D., of the Dauch College of Business at Ashland University in Ohio, follow with their assessment of challenges and opportunities for achieving visibility in cross-border international supply chains (Ch. 9). Duncan McFarlane, Director of the Cambridge University Auto-ID Labs and colleagues Alan Thorne, Mark Harrison, Ph.D., and Victor Prodonoff Jr. describe creating an Aero-ID Programme research consortium with the largest US and European exporters who

are using RFID identification and tracking technology in restructuring the aerospace industry supply base (Ch. 10). J. P. Emond, Co-Director of the Center for Food Distribution and Retailing, shares the challenges of using temperature sensors with RFID tags in "cold chain" applications for fresh produce and pharmaceuticals (Ch. 11). Thorsten Staake from the Auto-ID Labs at MIT with colleague Florian Michahelles, and Elgar Fleish, Director of the Auto-ID Labs at St. Gallen, address RFID technology and application problems in anti-counterfeiting (Ch. 12).

When RFID data is shared in the context of new business processes that extend beyond the four walls of the enterprise, entirely new possibilities for visibility emerge. Dimitris Kiritsis describes (Ch. 13) how RFID systems are being designed at Fiat to track products across their lifecycles for managing vehicle disposal, which today accounts for 10% of hazardous waste in landfills in Europe, and how W3C Semantic Web technology can be used to link uniquely identified objects with conceptual objects such as processes, agents, and time stamps using the RDF representation scheme. The RFID applications chapters close with an exploration of autonomic logistics by Bernd Scholz-Reiter and Dieter Uckelmann with researchers Christian Gorldt, Uwe Hinrichs, and Jan Topi Tervo of the Division of Intelligent Production and Logistics Systems, University of Bremen (Ch. 15).

Throughout each chapter we explore how RFID may be used to unlock information from manual entry or "line-of-sight" barcode data acquisition scanning processes, as well as from proprietary enterprise data models, to enable cross-company, cross-industry, and cross-country information services about products, their condition, and where they are. "How does the world change," observes Hao Min, Director of the Auto-ID Lab at Fudan University in Shanghai while working on his contribution to this book, "when the 'Internet of things' contains a profile for every object. If we contrast this to the internet today, information about people and events are recorded and Google is used to search information about people and events. If the information (profile) of every object (include people) is recorded, what will the internet be like?"

The market for RFID technology is growing rapidly, with significant opportunities to add value, but also, because of the challenging engineering issues that are identified in this book, many opportunities for failure. At the 2007 Smart Labels Conference here in Boston, Raghu Das, CEO of IDTechEx, estimated that almost half as many tags will be sold this year as the total cumulative sales of RFID tags for the prior sixty years of 2.4 billion. While approximately 600 million tags were sold in 2005, expectations for 2006 are for sales of 1.3 billion tags in a $2.71 billion market. Of that amount "about 500 million RFID smart labels will be used for pallet and case level tagging but the majority will be used for a range of diverse markets from baggage and passports to contactless payment cards and drugs."[2] The total market for passive RFID tags conforming to international

[2] RFID Smart Labels 2007 – IDTechEx, February 20–23, 2007, Boston Marriott, Boston, MA (http://rfid.idtechex.com/rfidusa07/en/RFIDspeakers.asp).

interoperability standards for supply chain applications has not yet been growing as quickly as anticipated. The challenge of gaining market share for any disruptive technology in an established market such as RFID requires selling much higher volumes of low-cost items to impact industry sales, as is the case for passive UHF RFID tags that are priced at under 15 US cents.

In fact, not only is the overall number of RFID tags being sold doubling, but also the numbers of technology choices are expanding rapidly. RFID transponders (receiver–transmitter "tags") as part of a class of low-cost sensors are evolving to include more or less intelligence (processors, memory, embedded sensors) on a variety of platforms (from semiconductor inlays or MEMs to inorganic and organic materials that form thin film transistor circuits – TFTCs) across a variety of frequencies (UHF, HF, LF) and protocols (802.11, Bluetooth, Zigbee, EPC GenII/ISO 18000-7). One of the resulting challenges for planning RFID systems is the necessity to keep track of the evolving technology, from semiconductor inlays and printed antenna designs for RFID tags, both passive and active, via high-speed applicators and reader engineering, to sensor networking and the definition of new shared business processes.

Somewhere between an overall RFID market that promises to deliver more tags in the next year than in the prior sixty years since RFID was invented and specific industry sectors where penetration of RFID and, in some cases, even barcode usage is low, there are significant opportunities to use RFID for improving efficiency and visibility. The breakthrough in low-cost RFID tags for everyday products has occurred as a result of the adoption of specifications for interoperable UHF RFID tags that were developed by and licensed from the MIT Auto-ID Center by the barcode associations, now known as GS-1, and the nonprofit EPCglobal industry membership consortium that was formed to promote the use of RFID in today's fast-moving, information-rich, trading networks. The longer read range (several feet at a minimum) requirements for loading dock and warehousing applications, as well as recent UHF near-field research for closer-range applications as presented in this book, make the EPC GenII/ISO 18000-6C specifications a leading contender for passive RFID systems where global interoperability is required. This is clearly the case for supply chains where tags on products manufactured in one country must be read by RFID interrogators (transmitter/receiver "readers") halfway around the world.

In addition to low-cost passive RFID technology, the authors explore active RFID technology for adding telemetry and real-time location system (RTLS) data. During the initial proposal review process with Cambridge University Press for this book, reviewers questioned the usefulness of adding sensor and RTLS technology to a field that, as Dr. Julie Lancashire, Engineering Publisher, describes, is so "massively multidisciplinary." Subsequently the market validated the importance of incorporating active RFID technology for asset tracking and condition-based monitoring applications with the recent acquisitions of Savi Networks by Lockheed Martin and of Wherenet by Zebra Technologies, whereby

RTLS systems now account for up to 30% of RFID systems sold, according to the IDTechEx market study cited above. As a matter of scope, this initial book does not explore RFID systems that work at close (several inches) proximity that are being deployed for access control, personal and animal identification, and payment processing systems based on emerging standards such as IEEE 802.15.4 WPAN and NFC

The chapters that follow address these opportunities from the perspective of principal researchers who have been engaged in the RFID Academic Convocations with senior executives from "first mover" market-leading companies in aerospace and healthcare life sciences, as well as from retail "cold chain" and fast-moving consumer goods supply chains. As Gerd Wolfram, Managing Director of Advanced Technologies at Metro Group Information Technology, said in his address to the EU RFID Forum 2007/4th RFID Academic Convocation,[3] the development of interoperability standards has truly been a community effort with input from academics, industry users, and service providers, as well as from non-governmental and government agencies around the world.

One industry that is establishing benchmarks for how RFID can be used for securing the supply chain and is working to harmonize compliance reporting across jurisdictions is healthcare. At the 5th RFID Academic Convocation pre-conference co-hosted by the Auto-ID Labs and RFID Live 2007 in Orlando,[4] Ron Bone, Senior Vice President of Distribution Planning for McKesson Corporation, and Mike Rose, Vice President RFID/EPCglobal Value Chain for Johnson and Johnson, who serve as EPCglobal Healthcare Life Sciences (HLS) Business Action Group Co-Chairs, spoke about the industry's progress in working proactively with government agencies for a safer and more secure pharmaceutical supply chain. At this gathering the Office of Science and Engineering Labs Center for Devices of Radiological Health at the US Food and Drug Administration (FDA) also presented findings and discussed test methodologies for evaluating the impact of RFID on medical devices. In evaluating EPC network components, from RFID tags to network registries, a common theme emerged from the academic papers that were presented, of an ongoing requirement for fact-based simulation and test methodologies to evaluate various RFID scenarios under consideration, an approach that is pursued in the chapters that follow.

Carolyn Walton, Vice President of Information Systems for Wal-Mart, stated in her address at the 5th RFID Convocation that healthcare costs are growing more quickly than company profits and threaten to overcome national healthcare programs such as Medicare. Citing the $11 billion in excess costs identified by the Healthcare Information and Management Systems Society (HIMMS) study of

[3] EUROPE RFID Forum 2007, organized in conjunction with the 4th RFID Academic Convocation in Brussels (http://ec.europa.eu/information_society/policy/rfid/conference2007_reg/index_en.htm).

[4] 5th RFID Academic Convocation – Pre-conference to RFID Live! April 30, 2007, Disney Coronado Springs Resort, Orlando, FL (http://www.rfidjournalevents.com/live/preconfer_academic_convocation.php).

hospitals,[5] where supplies consume 40% of operating costs and administration exceeds 25% of supply chain costs, and especially where barcode technology has not been implemented, Carolyn said that there is an opportunity for supply chain management best practices including RFID.

RFID together with wireless sensors and actuators are extending the reach of the internet in ways that promise to transform our ability to communicate about, and interact with, things in the physical world. These chapters are written from the very different perspectives of principal investigators from their diverse areas of research interest. Nonetheless, the authors share an interest in and vision of RFID technology that facilitates communication and enables better visibility and management decisions. The challenge that we face – and would like to invite readers of this book to explore – is one of finding out how we can combine data related to unique IDs to create applications that add value to our communities and to commerce. An acknowledgment of individuals who have supported this collaboration follows this preface.

Stephen Miles, Sanjay Sarma, and John R. Williams
Massachusetts Institute of Technology, Auto-ID Labs,
Cambridge, MA

[5] The Healthcare Information and Management Systems Society (HIMSS) breaks down savings into four categories: $2.3 billion inventory management, $5.8 billion order management, $1.8 billion transportation, and $1.1 billion physical distribution; 14th Annual HIMSS Leadership Survey.

Acknowledgments

This book is the direct result of the research collaboration initiated at the RFID Academic Convocation in January of 2006 hosted by the Auto-ID Labs at MIT that was organized with the support of co-editors Sanjay Sarma, co-founder of the Auto-ID Center, and John Williams, Director of the Auto-ID Labs at MIT, and that subsequently evolved to include events in Shanghai and Brussels with co-sponsorship from the Chinese Academy of Sciences and the Ministry of Science and Technology (MOST) and the European Commission Directorate General for Informatics (DGIT). I would like to thank the authors included in this book who served as Conference Committee members during this process for their input and support.

On behalf of the Conference Committee, special thanks go to industry leaders Simon Langford, Director at Wal-Mart, and Mike Rose, Vice President RFID/EPC Global Value Chain at Johnson and Johnson, with Ron Bone, Senior Vice President Distribution Planning at McKesson, for taking the time from their busy schedules and leadership roles within the EPCglobal Healthcare Life Sciences community to investigate issues requiring broader research collaboration. I would like to personally acknowledge Convocation Co-Chairs Bill Hardgrave, Director of the RFID Lab at the University of Arkansas, and John Williams, Director of the Auto-ID Labs at MIT, as well as Co-Sponsors Yu Liu, Deputy Director of the RFID Laboratory of the Institute for Automation at the Chinese Academy of Sciences, Dr. Zhang Zhiweng, Department of High-Technology Development & Industrialization of the Chinese Ministry of Science and Technology, and Hao Min, Director of the Auto-ID Lab at Fudan University, for their support.

From the EU RFID Forum/4th RFID Academic Convocation I would like to acknowledge Organizing Committee members Henri Barthel, Director of the European Bridge Project and Technical Director of EPCglobal Europe, Duncan McFarlane, Program Committee Chair and Director of the Auto-ID Lab at Cambridge University, Dimitris Kiritsis of the EPFL, and Co-Sponsors Peter Friess, Florent Frederix, and Gerard Santucci, Head of the European Commission Directorate General for Informatics (DGIT), Networked Enterprise & Radio Frequency Identification (RFID), for their leadership. Finally the Auto-ID Labs have benefited from the continued engagement of the original Board of Overseers of the MIT Auto-ID Center and current EPCglobal Board of Governors members who are engaged in Asia and Europe as well as the

Americas. Several of these executives, including Dick Cantwell, Vice President of Procter and Gamble, who serves as Chairman, and Sanjay Sarma, co-founder of the MIT Auto-ID Center and co-editor of this book, continue to serve on the EPCglobal Board of Governors and to provide examples of "RFID advantaged" applications.

It has already been three years since the Auto-ID Labs were formed, together with the creation of EPCglobal and their commitment to fund academic research to support the RFID technology licensed from the MIT Auto-ID Center. At the MIT Auto-ID Labs inception, I organized the Auto-ID Network Research Special Interest Group (SIG) to investigate requirements for Electronic Product Code (EPC) data exchange, with principal investigators who served in succession, co-founders of the Auto-ID Center Sanjay Sarma, David Brock, Ph.D., and current MIT Auto-ID Labs Director John Williams. We would like to acknowledge sponsors Jim Nobel, CIO of the Altria Group, and his Global Information Services team leaders Stephen Davy and Brian Schulte, Tom Gibbs, Director of Global Solutions at Intel, Ajay Ramachandran, CTO of Raining Data, and David Husak, CTO of Reva Systems, for their support of a sponsored research initiative to use web protocols for communicating about things. CIO Ramji Al Noor and Steve Stokols in their roles at Quest (prior to transitioning to British Telecom), Matt Bross, CTO of British Telecom, with Peter Eisenegger, Steve Corley, and Trevor Burbridge of the R&D group in Martlesham Health, and Dale Moberg, Chief Architect of Cyclone Commerce (now Axway), were instrumental in validating the opportunity for creating Auto-ID/RFID services, as was Alan Haberman, a father of the barcode movement and an early instigator of this research initiative. Special thanks are due to Tim Berners-Lee and to Steve Bratt from W3C for their continued support and vision of a world where information can be retrieved and re-used in ways that had not been envisioned when it was created.

From the Management of Technology (MoT) Program at the MIT Sloan School I would like to thank MoT Program Director Jim Utterbach for reviewing an early version of my chapter and for his teachings that bring an historical perspective to disruptive technologies – including the rediscovery of a nineteenth-century export trade in ice blocks based in Boston – and Tom Eisenmann of the Harvard Business School for his best practices case studies in "Riding the Internet Fast Track," whose company founders he brought into the lecture hall to present their case studies to classmates who had survived the dot.com "bubble."

I would also like to express my gratitude to colleagues who worked with me in designing internet solutions for data communications including VoIP, MPLS core routers, and mobile IP telephony at Officenet, NMS Communications, Ironbridge Networks, and Wireless IP Networks, respectively, as we worked the world over to deploy infrastructure for adding value through IP networks. Special thanks go to my family Ingrid, Garth, and Stephen, who grew up in the turbulent world of high-technology businesses. It is my hope that this book will pave the way for people to use Auto-ID technology to apprehend and actuate

better decisions for our work, our entertainment, and the world environment in which each one of us plays a unique role.

Stephen Miles
Auto-ID Labs, Massachusetts Institute of Technology,
Cambridge, MA