国外电子信息精品著作(影印版)

IEEE802.15.4系统无线传感器

Sensor Networks with IEEE 802.15.4 Systems: Distributed Processing, Mac, and Connectivity

Chiara Buratti Marco Martalo
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内 容 简 介

本书在数据处理以及无线传感器网络等领域进行了深入的探讨。同时在IEEE802. 15. 4/ZigBee 紫蜂技术中如何实现数据处理给出了实际的展望。本书适合相关领域研究生及高年级本科生使用。

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《国外电子信息精品著作》序

20 世纪 90 年代以来，信息科学技术成为世界经济的中坚力量。随着经济全球化的进一步发展，以微电子、计算机、通信和网络技术为代表的信息技术，成为人类社会进步过程中发展最快、渗透性最强、应用面最广的关键技术。信息技术的发展带动了微电子、计算机、通信、网络、超导等产业的发展，促进了生命科学、新材料、能源、航空航天等高新技术产业的成长。信息产业的发展水平不仅是社会物质生产、文化进步的基本要素和必备条件，也是衡量一个国家的综合国力、国际竞争力和发展水平的重要标志。在中国，信息产业在国民经济发展中占有举足轻重的地位，成为国民经济重要支柱产业。然而，中国的信息科学支持技术发展的力度不够，信息技术还处于比较落后的水平，因此，快速发展信息科学技术成为我国迫在眉睫的大事。

要使我国的信息技术更好地发展起来，需要科学工作者和工程技术人员付出艰辛的努力。此外，我们要从客观上为科学工作者和工程技术人员创造更有利于发展的环境，加强对信息技术的支持与投资力度，其中也包括与信息技术相关的图书出版工作。

从出版的角度考虑，除了较好较快地出版具有自主知识产权的成果外，引进国外的优秀出版物是大有裨益的。洋为中用，将国外的优秀著作引进到国内，促进最新的科技成就迅速转化为我们自己的智力成果，无疑是值得高度重视的。科学出版社引进一批国外知名出版社的优秀著作，使我国从事信息技术的广大科学工作者和工程技术人员能以较低的价格购买，对于推动我国信息技术领域的科研与教学是十分有益的事。

此次科学出版社在广泛征求专家意见的基础上，经过反复论证、仔细遴选，共引进了接近 30 本外版书，大体上可以分为两类，第一类是基础理论著作，第二类是工程应用方面的著作。所有的著作都涉及信息领域的最新成果，大多数是 2005 年后出版的，力求" 层次高、内容新、参考性强"。在内容和形式上都体现

了科学出版社一贯奉行的严谨作风。

当然，这批书只能涵盖信息科学技术的一部分，所以这项工作还应该继续下去。对于一些读者面较广、观点新颖、国内缺乏的好书还应该翻译成中文出版，这有利于知识更好更快地传播。同时，我也希望广大读者提出好的建议，以改进和完善丛书的出版工作。

总之，我对科学出版社引进外版书这一举措表示热烈的支持，并盼望这一工作取得更大的成绩。

中国科学院院士
中国工程院院士

2006 年 12 月

To my parents and my love.

Chiara Buratti

To my parents, the lights that lead my search.

Marco Martalò

To my parents and whom loves me.

Roberto Verdone

To my new twinkling little star.

Gianluigi Ferrari

Foreword

This book provides an in-depth theoretical look at the data processing and communication aspects of wireless sensor networks, as well as a practical look at how data processing can be done in real ZigBee/IEEE 802.15.4 sensor networks. The book provides enough background for the newcomer to the field to understand the fundamentals of wireless sensor networks, while also providing novel analytical frameworks for distributed detection, joint detection and communication, and cross-layer design, making this an excellent choice for those looking for a deeper understanding of the interaction between data processing and communication.

Rochester, September 2010

Wendi Heinzelman
Associate Professor
University of Rochester, NY, USA

When Roberto told me that he was co-authoring a book on Wireless Sensor Networks and asked me if I would be willing to write a foreword for it, my first thought was: "Anything to come back to this beautiful city of Bologna!". So I said "Sure!", before realizing that it is perfectly possible to write a foreword without visiting the authors in their "natural habitat" ever again. My bad. I guess Roberto and I will have to organize together another Joint Workshop and Summer School on Sensor Networks very soon to have an excuse to visit Bologna again.

The book you have in your hands contains first-class information and crisp explanations about the state-of-the-art in Wireless Sensor Networks. Having done research myself in this field for several years and being the coordinator of CONET, the Cooperating Objects Network of Excellence, that has managed to edit and publish two research roadmaps on sensor networks and related fields, I can only applaud the choice of topics the authors have done. Indeed three of the most fundamental challenges in this area are a proper definition and characterization of

distributed processing, MAC protocols and connectivity and the authors have done a tremendous job at them in this book.

Additionally, the IEEE 802.15.4 MAC protocol is used as the main wireless communication mechanism for the models and analysis performed in each chapter. This protocol is becoming the de-facto standard for Sensor Networks and is gaining importance as we speak (or better said, as you read). Another highlight is the thorough analysis of multi-sink networks that have been traditionally neglected in the literature in favor of simpler problems to tackle. The authors manage to consider multi-sink networks in almost each chapter of the book, which is a tremendous achievement.

Of course, this in-depth analysis of topics also has its price. If you were hoping for a light bedtime read or despise greek letters and formulas, this book is not for you. It is a book written for professionals by professionals and it shows in the quality of each page. It combines not only a theoretical perspective and foundation with numerical analysis, but also with experimental evaluations using simulation tools. Therefore, each chapter contains a performance evaluation of the algorithms that helps in understanding the operating characteristics of each approach. This is extremely important since the field of Sensor Networks is all about practical implementations and solving real-world problems that, sometimes, cannot be approximated by theoretical models.

I can very much appreciate the effort put by the authors in writing this book and the clarity they have achieved in explaining these three fundamental aspects of the Sensor Network field: Distributed processing, MAC protocols and Connectivity. Young researchers willing to understand the intricacies of Wireless Sensor Networks will be thrilled by the insights in this book, and more experienced scientists will surely recommend its read. I definitely do.

Duisburg, September 2010

Pedro José Marròn
Full Professor
University of Duisburg-Essen in Germany
Coordinator of CONET, the Cooperating
Objects Network of Excellence

This book provides a comprehensive overview of the major theoretical and practical issues of IEEE 802.15.4 and ZigBee, which nowadays represent a key technology for wireless sensor networks. The contents are organized into a roadmap which starts with a tutorial-oriented description of the basic foundations, and continues with some chapters offering an in-depth analysis of performance-related problems. This structure makes the book an ideal reference for everyone wants to approach the study of sensor networks and their applications according to a cross-layer design perspective which takes both data processing and communication aspects into the due account: on one hand, Ph.D. students and researchers in the field of wireless sensor networks are

provided with an extensive coverage of major theoretical issues relevant to IEEE 802.15.4 technology, while professionals and networking system developers will also find it an invaluable primer guide.

Catania, September 2010

Sergio Palazzo
Full Professor
University of Catania, Italy

Preface

Wireless Sensor Networks (WSNs) have become an increasingly active field of research in recent years. The very idea of making many small objects with limited capabilities (the sensors) collaborate to create a very versatile and powerful system (a WSN) has stimulated the intellectual and scientific "fantasies" of many researchers. In fact, WSNs can be studied from several perspectives. Moreover, besides their scientific appeal, they hold the promise of playing a key role in future communication and networking systems, such as machine-to-machine communication systems and the Internet of Things.

IEEE 802.15.4 is a Physical (PHY)/Medium Access Control (MAC) air interface commonly considered as a de facto standard for WSNs. While IEEE released the current version of the standard years ago and many books cover issues related to the use of IEEE 802.15.4 for WSNs, there is still a lack in the understanding of the true performance achievable in large WSNs using IEEE 802.15.4 when distributed processing techniques are applied to estimate the values taken by physical instances.

During spring 2009, after years of research performed on the topic of WSNs, Chiara Buratti and Marco Martalò received their Ph.D. degrees from the University of Bologna (under the supervision of Prof. Roberto Verdone) and the University of Parma (under the supervision of Prof. Gianluigi Ferrari), respectively. While research was carried out separately and the two Ph.D. theses were prepared independently, it was immediately clear that the two works were addressing the two faces of the same coin. Therefore, it was decided to put together the contents of the two theses to give birth to a coherent text providing the deepest possible knowledge of how the IEEE 802.15.4 MAC layer can be accurately modeled and of the limits of distributed processing, inherently connected to the MAC behavior, in WSNs. This book is the outcome of that will. However, it is even more.

This book is indeed composed of four parts. After a short introductory chapter on the fundamentals of WSNs, the second and third parts represent the core of Marco's and Chiara's theses, respectively, after proper alignment was found. More precisely, the second part (Chaps. 2 and 3) is dedicated to distributed processing in

WSNs, whereas the third part is dedicated to MAC and connectivity of WSNs. The fourth part is completely new, as it reports on the outcomes of the effort to integrate the models proposed and validated in the two Theses, to create a novel cross-layer framework for IEEE 802.15.4 system design.

It is our view that the book, in its final form, can assist a WSN designer, whose aim is the estimation of physical instances, in understanding all mechanisms lying behind IEEE 802.15.4 MAC and the application of distributed processing techniques. The book provides many performance charts and all means to generate a complete evaluation tool which is able to compute the performance, in terms of reliability, latency, energy efficiency, of an IEEE 802.15.4-based WSNs for environmental monitoring applications.

We would like to thank Dr. Cristoph Bauman, our Springer Engineering Editor, for immediately supporting our idea and allowing us to finalize this project. We are also indepted to several collaborators, whose help was instrumental. In particular: C. Buratti and R. Verdone would like to thank those scientists whose activities have had an impact on the content of this book: John Orriss, from the University of Manchester, and Flavio Fabbri from the University of Bologna; M. Martalò and G. Ferrari would like to thank Dr. Roberto Pagliari, Dr. Paolo Medagliani, and Marco Sarti for their contributions (while at the University of Parma) to Part II of the book. Authors would also like to thank Flavia Martelli for reading the draft of this book.

Bologna and Parma, September 2010

Chiara Buratti
Marco Martalò
Roberto Verdone
Gianluigi Ferrari

Acronyms

ACK	ACKnowledgement
AODV	Ad-hoc On-demand Distance Vector
AP	Access Point
aU	arbitrary Unit
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BIBO	Binary Input Binary Output
BPSK	Binary Phase Shift Keying
BSC	Binary Symmetric Channel
CAP	Contention Access Period
CDF	Cumulative Distribution Function
CFP	Contention Free Period
CH	Cluster Head
CRC	Cyclic Redundancy Check
CSMA	Carrier-Sense Multiple Access
CSMA/CA	Carrier-Sense Multiple Access with Collision Avoidance
CSS	Chirp Spread Spectrum
dB	deciBel
DML	De-Moivre Laplace
DS-SS	Direct Sequence Spread Spectrum
EC	European Commission
ED	Event Detection
FC	Fusion Center
FEC	Forward Error Correction
FFD	Full Function Device
fm	firing mote
GFSK	Gaussian Frequency Shift Keying
GTS	Guaranteed Time Slot
IF	Intermediated Frequency
IR-UWB	Impulse Radio UWB
ISM	Industrial Scientific Medical

LDPC	Low-Density Parity-Check
LLR	Logarithmic Likelihood Ratio
LQI	Link Quality Indication
MAC	Medium Access Control
MAP	Maximum A posteriori Probability
MFR	MAC Footer
MHR	MAC Header
MMSE	Minimum Mean Square Error
MPDU	MAC Payload Data Unit
MSDU	MAC Service Data Unit
NIST	National Institute of Standards and Technologies
O-QPSK	Offset Quadrature Phase Shift Keying
p.d.f.	probability density function
PAN	Personal Area Network
PBPO	Person-By-Person Optimization
PEG	Progressive Edge Growth
PHR	Physical Header
PHY	Physical
p.m.f.	probability mass function
POI	Phenomenon Of Interest
PPDU	Physical Protocol Data Unit
PPM	Pulse Position Modulation
PPP	Poisson Point Process
PSDU	Physical Service Data Unit
QoS	Quality of Service
r.v.	random variable
RF	Radio Frequency
RFD	Reduced Function Device
RREP	Route Reply
RREQ	Route Request
RSSI	Received Signal Strength Indication
SHR	Synchronization Header
SNR	Signal-to-Noise Ratio
SP	Sum–Product
SPE	Spatial Process Estimation
UMTS	Universal Mobile Telecommunications System
UWB	UltraWide Bandwidth
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
ZC	Zigbee Coordinator
ZED	Zigbee End Device
ZR	Zigbee Router
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