

Computer Communications and Networks

The **Computer Communications and Networks** series is a range of textbooks, monographs and handbooks. It sets out to provide students, researchers and non-specialists alike with a sure grounding in current knowledge, together with comprehensible access to the latest developments in computer communications and networking.

Emphasis is placed on clear and explanatory styles that support a tutorial approach, so that even the most complex of topics is presented in a lucid and intelligible manner.

Also in this series:

An Information Security Handbook

John M.D. Hunter

978-1-85233-180-1

Multimedia Internet Broadcasting: Quality, Technology and Interface

Andy Sloane and Dave Lawrence (Eds)

978-1-85233-283-9

UMTS: Origins, Architecture and the Standard

Pierre Lescuyer (Translation Editor: Frank Bott)

978-1-85233-676-9

Designing Software for the Mobile Context: A Practitioner's Guide

Roman Longoria

978-1-85233-785-8

OSS for Telecom Networks

Kundan Misra

978-1-85233-808-4

From P2P to Web Services and Grids: Peers in a Client/Server World

Ian J. Taylor

978-1-85233-869-5

The Quintessential PIC® Microcontroller 2nd edition

Sid Katzen

978-1-85233-942-5

Ubiquitous and Pervasive Commerce

George Roussos (Ed.)

978-1-84628-035-1

Intelligent Spaces: The Application of Pervasive ICT

Alan Steventon and Steve Wright (Eds)

978-1-84628-002-3

Information Assurance: Security in the Information Environment 2nd edition

Andrew Blyth and Gerald L. Kovacich

978-1-84628-266-9

Peer-to-Peer Computing: Building Supercomputers with Web Technologies

Alfred W.-S. Loo

978-1-84628-381-9

Networked RFID: Systems, Software and Services

George Roussos

978-1-84800-152-7

Problem Solving for Wireless Sensor Networks

Ana-Belén García-Hernando, José-Fernán Martínez-Ortega, Juan-Manuel López-Navarro,

Aggeliki Prayati and Luis Redondo-López

978-1-84800-202-9

Ana-Belén García-Hernando • José-Fernán
Martínez-Ortega • Juan-Manuel
López-Navarro • Aggeliki Prayati •
Luis Redondo-López, MSc

Problem Solving for Wireless Sensor Networks

 Springer

Ana-Belén García-Hernando, PhD
Universidad Politécnica de Madrid
Spain
abgarcia@diatel.upm.es
anabelen.garcia@upm.es

José-Fernán Martínez-Ortega, PhD
Universidad Politécnica de Madrid
Spain
jfmartin@diatel.upm.es
jf.martinez@upm.es

Juan-Manuel López-Navarro, PhD
Universidad Politécnica de Madrid
Spain
jmlopez@sec.upm.es
juanmanuel.lopez@upm.es

Aggeliki Prayati, PhD
ATHENA / I.S.I. Research and
Innovation Center in Information
Communication, and Knowledge
Technologies, Greece
prayati@isi.gr

Luis Redondo-López, MsC
Métodos y Tecnología de Sistemas y
Procesos (MTP), Spain
lredondo@mtp.es

ISBN: 978-1-84800-202-9 e-ISBN: 978-1-84800-203-6
DOI 10.1007/978-1-84800-203-6

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2008926114

© Springer-Verlag London Limited 2008

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licenses issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

The use of registered names, trademarks, etc., in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant laws and regulations and therefore free for general use.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

Printed on acid-free paper

Springer Science+Business Media
springer.com

Preface

Book's Overview and Features

Wireless sensor networks (WSNs) have quickly become an area of great interest in terms of research for both industry and academia. Nowadays, the enormous potential of this technology can be easily seen, along with its inherent difficulties. Just looking at the number of research projects being funded, mainly European- and U.S.-based, the many research papers being published, and the results being put on the market gives clear evidence of the technology's growing importance. In fact, the Massachusetts Institute of Technology recently classified WSNs as one of the 10 emerging technologies that will change the world.

This book is the result of intensive research carried out over several months as part of a European research project. It constitutes a wide review of the current state of the art regarding wireless sensor networks at the time of its writing. Contributions have been made by several researchers from various organizations.

Other research teams and European projects have also made very valuable contributions in the field of wireless sensor networks. However, to the best of our knowledge, this book is the only one encompassing all of the following characteristics:

- It is entirely dedicated to wireless sensor networks and comprises all of the main technological challenges associated with them: from hardware to specific applications, including networking, middleware, and software issues.
- It not only includes a review of commercially available products and solutions, but also examines European research projects concerning WSNs and open issues currently of interest for researchers in this area. Moreover, there is also a chapter devoted to regulatory and safety issues related to this technology.
- It includes a description of several exemplifying application scenarios in which the use of a WSN solution is very attractive, something that may inspire current and future applications.

Target Audiences

All of these features make the book useful for a wide range of potential readers, including researchers in the computer/wireless communications sector, lecturers for advanced communication courses, graduate students beginning research in computer/wireless communications, professionals wanting to offer WSN solutions, and even WSN application designers.

Our aims are to help the reader grasp the main technological issues to be considered when dealing with WSNs, to give a high-level overview of the different technologies available, and to pave the way for an eventual deeper study of specific aspects of this wireless technology.

Acknowledgments

This book has been written mostly as part of the work done in the European research project “Solving Major Problems in MicroSensorial Wireless Networks” (μ SWN), of the Sixth Framework Programme of the European Union. We would like to thank the people of the μ SWN Consortium who have contributed to the quality of this book either by writing specific parts of it or by reading and giving feedback. The figures and technical information related to Wavenis technology and products present in the book have been provided by Coronis Systems and are reproduced with permission.

We would also like to thank the project officer in charge of the μ SWN project (Rolf Riemenschneider) and the project technical reviewers (Prof. Luis Orozco Barbosa, Universidad de Castilla La Mancha, Spain; Dr. Christoph Niedermeier, Siemens AG, Germany; and Dr. Gilles Thonet, Schneider Electric SA, France) for encouraging us to publish this work in order to reach a wider audience.

We acknowledge the support we have obtained from Springer-Verlag London Ltd. to publish the book, particularly Mr. Wayne Wheeler (Senior Editor, Computing & Information Science), who received our proposal and gave us prompt feedback, and Ms. Catherine Brett (Senior Editorial Assistant) who always answered our queries with precision and has been very supportive during the editing process. Ms. Tenmogi Sinnaveerappan, project manager at Integra Software Services, has been in charge of the final production process of the text, and we would like to thank her for her helpful guidance during this last phase.

Editors' and Contributors' Note

Since this book contains mainly a state-of-the-art report on a research field, a wide variety of information from very diverse sources has been read, compiled, and presented. This information includes research papers, books on different subjects, Web pages of varying nature, and manufacturers' products brochures, among other material.

To the best of our knowledge, this information is accurate with respect to what the corresponding authors claim. However, we cannot guarantee its correctness nor accept any responsibility for any damage of any type derived from its use, since we are not the primary source of the information and misunderstandings or errors may have occurred. We encourage those interested in obtaining guaranteed information to contact the sources mentioned directly, especially when dealing with product manufacturers.

Contents

1	Introduction	1
1.1	Executive Summary	1
1.2	Structure of the Book	2
	References	2
2	Radio-Frequency Technologies for WSNs	3
2.1	Bluetooth Technology (IEEE 802.15.1)	3
2.2	Wi-Fi Technology (IEEE 802.11.a/b/h/g)	3
2.3	UWB Technology (IEEE 802.15.3)	4
2.4	Wavenis Technology (EN300–220 and FCC15.247—Coronis Systems)	4
2.4.1	Wavenis’ Main Characteristics	4
2.4.2	Wavenis’ RF ASIC Solution	5
2.5	Wibree Technology (Nokia)	6
2.6	ZigBee Technology	7
2.6.1	ZigBee’s Main Characteristics	7
2.6.2	ZigBee Networks	8
2.6.3	Zigbee Applications	9
2.6.4	ZigBee Promoters and Participants	9
2.6.5	ZigBee System-on-Chip (SoC)	10
2.6.6	Radio-Frequency Integrated Circuit Manufacturers	11
	References	14
3	Hardware Platforms for WSNs	17
3.1	AVIDdirector	17
3.2	WMSNP	17
3.3	SmartMesh-XR	19
3.4	JN5121	20
3.5	MeshScape	21
3.6	SensiNet	23
3.7	EnRoute	26

- 3.8 Tmote Sky 27
- 3.9 MICAx 28
- 3.10 BTnodes 33
- 3.11 Embedded Sensor Board 34
- 3.12 Scattergate and Scatternode 36
- 3.13 μ Nodes 37
- 3.14 Smart Tags 37
- 3.15 Wavecard, Waveflow, Wavetherm, Wavesense,
and Wavefront 38
 - 3.15.1 The Wavecard and Waveport Platforms 38
 - 3.15.2 The Wavesense, Wavetherm, and Waveflow
Platforms 40
 - 3.15.3 The Wavefront Platform 41
- 3.16 eyesIFX. 42
- 3.17 WSN Platforms’ Comparative 43
- 3.18 Open Issues in Hardware Platforms for WSNs 48
- References 50

- 4 Software Technologies in WSNs 51**
 - 4.1 Middleware Architectures for WSNs 51
 - 4.1.1 Characteristics of WSN Middleware. 52
 - 4.1.2 Various Middleware WSN Approaches 53
 - 4.2 Agent Technologies for WSN. 61
 - 4.2.1 Agent Technology and Models 61
 - 4.2.2 Use of Agent Models in WSNs 64
 - 4.2.3 Specific Proposals Applicable to WSNs 67
 - 4.3 Design Strategies and Operation of WSN Software 70
 - 4.3.1 Software Design Strategy in WSNs. 70
 - 4.3.2 Software Architecture in WSN 70
 - 4.4 WSN Simulation Platforms 80
 - 4.4.1 Importance and Challenges of WSN Simulators 80
 - 4.4.2 Review of WSN Simulators. 81
 - 4.4.3 Conclusions on the Use of WSN Simulators
for Research. 88
 - 4.5 Open Issues in Software Technologies 91
 - 4.5.1 Software Design and Development for WSNs 91
 - 4.5.2 Low-Level Detail Abstraction. 91
 - 4.5.3 Software Deployment and Operation in WSNs 92
 - 4.5.4 Quality of Service (QoS) 93
 - 4.5.5 Application Software. 94
 - 4.5.6 The Most Important Innovations Considering
the Application Scenarios 94
 - References 95

- 5 Network Aspects and Deployment in WSNs.** 101
 - 5.1 WSN Topologies and Deployment Methodologies 101
 - 5.1.1 Self-Organization. 105
 - 5.2 Communication Protocol Architectures. 108
 - 5.2.1 Physical Layer 108
 - 5.2.2 Data Link Layer 109
 - 5.2.3 Network Layer 119
 - 5.2.4 Transport Layer 125
 - 5.2.5 Application Layer 130
 - 5.3 Routing in WSN. 130
 - 5.3.1 Need for New Routing Protocols 130
 - 5.3.2 Routing Techniques and Protocols in WSNs 131
 - 5.4 WSN Performance: Quality of Service. 139
 - 5.4.1 An Increasing Interest in QoS for WSNs 139
 - 5.4.2 Quality of Service in the WSN Context. 139
 - 5.4.3 QoS MAC Protocols 140
 - 5.4.4 QoS Network Protocols 142
 - 5.5 Open Issues in Network and Deployment Technologies 146
 - References 148

- 6 Standards and Safety Regulations for WSNs.** 153
 - 6.1 Introduction to the Regulatory Aspects of WSNs 153
 - 6.2 Electromagnetic Compatibility. 155
 - 6.3 Biological Effects of Radiation 157
 - 6.4 Environmental Impact 159
 - 6.5 Data Security and Privacy 161
 - References 162

- 7 European Research Projects Related to WSNs** 165
 - 7.1 UbiSec&Sens 165
 - 7.2 CoBIs 165
 - 7.3 WINNER 166
 - 7.4 AWARE 167
 - 7.5 Sensation. 167
 - 7.6 e-SENSE. 169
 - 7.7 WASP 169
 - 7.8 MIMOSA 170
 - 7.9 E2R. 170
 - 7.10 CRUISE 170
 - 7.11 RUNES 171
 - 7.12 Smart Messages 171
 - 7.13 EYES 173
 - 7.14 Embedded WiSeNts 173
 - 7.15 μ SWn 174
 - References 174

- 8 WSN Application Scenarios** 177
 - 8.1 Application Fields for WSNs 177
 - 8.1.1 Environmental Monitoring 177
 - 8.1.2 Health Care 180
 - 8.1.3 Security Domain 182
 - 8.1.4 Additional Domains 185
 - 8.2 The Three Most Prevailing WSN Application Scenarios. 188
 - 8.2.1 Multiple-Target Tracking 189
 - 8.2.2 Surveillance 193
 - 8.2.3 Vital Sign and Environmental Parameters 197
 - 8.2.4 Technical Requirements 203
 - References 207
- Index** 211

Contributors

Christos Antonopoulos
Industrial Systems Institute, Greece

Fabrice Auzanneau
CEA LIST, France

Yannick Bonhomme
CEA LIST, France

Mickael Cartron
CEA LIST, France

Iván Corredor-Pérez
Universidad Politécnica de Madrid, Spain

Ausra Dagilyte
Birstonas Municipality, Lithuania

Antonio da Silva-Fariña
Universidad Politécnica de Madrid, Spain

Guillermo de Arcas-Castro
Universidad Politécnica de Madrid, Spain

Ana-Belén García-Hernando
Universidad Politécnica de Madrid, Spain

Valentin Gherman
CEA LIST, France

Spilios Giannoulis
Industrial Systems Institute, Greece

Vicente Hernández-Díaz
Universidad Politécnica de Madrid, Spain

Eduardo Hernández-Pérez
Universidad de las Palmas de Gran Canaria, Spain

- Fotis Kerasiotis
Industrial Systems Institute, Greece
- Christos Koulamas
Industrial Systems Institute, Greece
- Agnius Liutkevicius
Kaunas University of Technology, Lithuania
- Álvaro Llorente-Alonso
Universidad Politécnica de Madrid, Spain
- Javier Longares-Abaiz
Edosoft Factory, Spain
- Mario López-Marcos
Universidad Politécnica de Madrid, Spain
- Juan-Manuel López-Navarro
Universidad Politécnica de Madrid, Spain
- Lourdes López-Santidrián
Universidad Politécnica de Madrid, Spain
- Fernando D. Lorenzo-García
Universidad de las Palmas de Gran Canaria, Spain
- Emily Louisa Manning
Métodos y Tecnología, Spain
- José-Fernán Martínez-Ortega
Universidad Politécnica de Madrid, Spain
- Christophe Maugenest
CORONIS, France
- Juan L. Navarro-Mesa
Universidad de las Palmas de Gran Canaria, Spain
- Aggeliki Prayati
Industrial Systems Institute, Greece
- Daniel Quijano-Díaz
Edosoft Factory, Spain
- Pedro J. Quintana-Morales
Universidad de las Palmas de Gran Canaria, Spain
- Manuel Ramiro-Mauleón
Métodos y Tecnología, Spain
- Miguel Ramos-Herrero
Métodos y Tecnología, Spain

Luis Redondo-López
Métodos y Tecnología, Spain

Luis-Daniel Rosado-Poveda
Universidad Politécnica de Madrid, Spain

Mariano Ruiz-González
Universidad Politécnica de Madrid, Spain

Tsenka Stoyanova
Industrial Systems Institute, Greece

Juan-Alberto Vera-Gómez
Edosoft Factory, Spain

Arunas Vrubliauskas
Kaunas University of Technology, Lithuania