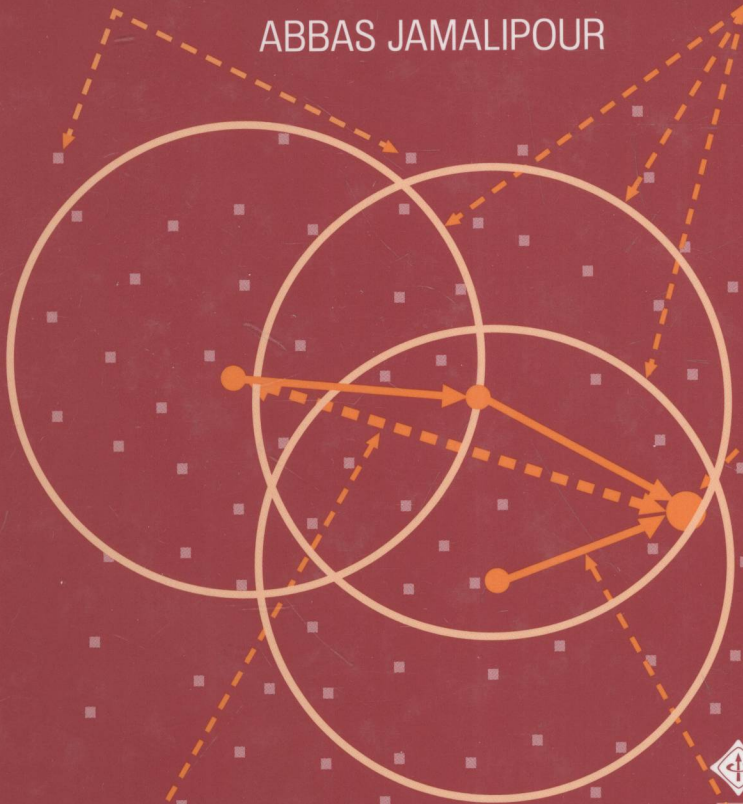
WIRELESS SENSOR NETWORKS

A Networking Perspective

JUN ZHENG
ABBAS JAMALIPOUR



WILEY

IEEE
Celebrating 125 Years
of Engineering the Future

WIRELESS SENSOR NETWORKS

A Networking Perspective

Edited by

Jun Zheng

Abbas Jamalipour

A JOHN WILEY & SONS, INC., PUBLICATION

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-0-470-16763-2

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

WIRELESS SENSOR NETWORKS

IEEE Press
445 Hoes Lane
Piscataway, NJ 08854

To our parents and family

PREFACE

Wireless sensor networking is an emerging technology that promises a wide range of potential applications in both civilian and military areas. A wireless sensor network (WSN) typically consists of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size but are equipped with sensors, embedded microprocessors, and radio transceivers. Therefore, they have not only sensing, but also data processing and communicating capabilities. They communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control. In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful preplanning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. In particular, sensor nodes are typically battery-powered and should operate without attendance for a relatively long period of time. In most cases, it is very difficult and even impossible to change or recharge batteries for the sensor nodes. Distinguished from traditional wireless networks, WSNs are characterized with denser levels of node deployment, higher unreliability of sensor nodes, and severe power, computation, and memory constraints. The unique characteristics and constraints present many new challenges for the development and application of WSNs. Due to the wide range of potential applications, WSNs have received tremendous attentions from both academia and industry all over the world in recent years. A voluminous amount of research activities have been carried out to explore and solve various design and application issues, and significant advances have been made in the development and deployment of WSNs. It is envisioned that WSNs will change the way we live, work, and interact with the physical world in the near future.

The purpose of this book is to provide a comprehensive and systematical introduction of the fundamental concepts, major issues, and effective solutions in wireless sensor networking. Distinguished from other books, this book focuses on the networking aspects of WSNs and covers the most important networking issues, including network architecture design, medium access control, routing and data dissemination, node clustering, query processing and data aggregation, node localization, time synchronization, transport and quality of service, energy efficiency, network security, and sensor network standards.

This book is intended for a wide range of audience, including academic researchers, graduate students, practitioners in industry, and research engineers.

It can be an excellent source of information for academic researchers, industry practitioners, and research engineers who are working in the area of wireless ad hoc and sensor networks to learn the state-of-the-art technologies in the networking aspect of WSNs. It can be used as a textbook or supplementary reading for relevant graduate level courses in electrical engineering, computer engineering, and computer science, for example, wireless sensor networks, wireless ad hoc networks, or wireless networks. It can also be used as a textbook for self-study by professionals who are not working in the field but would like to learn more about wireless sensor networks.

JUN ZHENG AND ABBAS JAMALIPOUR
May 1, 2009

ACKNOWLEDGMENTS

This book would not have been possible without the contribution, support, and encouragement from many people in their different ways.

First of all, we would like to thank all chapter authors for contributing their excellent work to this book. Without their contributions, this book would not have been possible. Thanks are also given to many anonymous reviewers for carefully reviewing all chapters, and providing constructive and valuable comments.

We are grateful to the editors and production group at Wiley-IEEE Press for their enthusiastic support for this project. The publication of this book would not have been possible without the vision and foresight of our Senior Acquisitions Editors, Catherine Faduska and Steve Welch, and Wiley-IEEE Press. Many thanks go to Steve Welch for his efforts throughout the whole process of this project, to our Project Editor, Jeanne Audino, and our Senior Production Editor, Melissa Yanuzzi, for coordinating the production of the book, to our Marketing Manager, Sika Dunyoh, for managing the marketing plan for the book, and to our Copyeditor, Jeannette Stiefel, for carefully copyediting the whole manuscript.

Special thanks are given to a number of friends and colleagues for their support and encouragement during the editing of the book. We will not forget their gentle reminding messages that there are more beautiful things in life beyond working.

Last but most, we would like to express our deep gratitude to our family for their invaluable love, and continuous support and encouragement throughout the whole editing process of this book.

ABOUT THE EDITORS

Jun Zheng is a Full Professor with the School of Information Science and Engineering of Southeast University, China. He received his Ph.D. degree in Electrical and Electronic Engineering from The University of Hong Kong, China. Before joining Southeast University, he was with the School of Information Technology and Engineering of the University of Ottawa, Canada.

He is an Associate Technical Editor of IEEE Communications Magazine, an Editor of IEEE Communications Surveys & Tutorials, and an Associate Editor of IEEE/OSA Journal of Optical Communications and Networking. He is also the founding Editor-in-Chief of ICST Transactions on Mobile Communications and Applications, and an Associate Editor of several other refereed journals, including Wiley Wireless Communications and Mobile Computing, Wiley Security and Communication Networks, Inderscience International Journal of Communication Networks and Distributed Systems, and Inderscience International Journal of Autonomous and Adaptive Communications Systems. He has guest-edited eight special issues for different refereed journals and magazines, including IEEE Network, IEEE Journal on Selected Areas in Communications, Wiley Wireless Communications and Mobile Computing, Wiley International Journal of Communication Systems, and Springer Mobile Networks and Applications, all as Lead Guest Editor.

He has served as the founding General Chair of AdHoctNets'09, General Chair of AccessNets'07, TPC Co-Chair of AccessNets'08, Symposium Co-Chair of IEEE GLOBECOM'08, IEEE ICC'09, and IEEE GLOBECOM'10 respectively. He is also serving on the steering committees of AdHocNets and AccessNets, and has served on the technical program committees of a number of international conferences and symposia, including IEEE ICC and IEEE GLOBECOM.

Dr. Zheng has conducted extensive research in the field of telecommunications and computer communication networks. The scope of his research includes design and analysis of network architectures and protocols for efficient and reliable communications, and their applications to different types of communication networks, covering wireless networks, optical networks, and IP networks. His current research interests focus on wireless ad hoc and sensor networks. He has co-authored (first author) a book published by Wiley-IEEE Press, and has published a number of technical papers in refereed journals and magazines as well as peer-reviewed conference proceedings. Dr. Zheng is a senior member of IEEE.

Abbas Jamalipour holds a Ph.D. from Nagoya University, Japan. He is the author of the first book on wireless IP, two other books, and has co-authored 7 books and over 190 technical papers, all in the field of mobile communications network. He is a Fellow of IEEE (for contributions to next generation networks for traffic control), a Fellow of Institute of Engineers Australia, an IEEE Distinguished Lecturer, the Editor-in-Chief of the IEEE Wireless Communications, and a Technical Editor of several scholarly journals including IEEE Communications, Wiley International Journal of Communication Systems, Journal of Communication Network, and so on. His areas of research are wireless data communication networks, wireless IP networks, wireless sensor networks, next generation mobile networks, traffic control, network security and management, and satellite systems. He was one of the first researchers to disseminate the fundamental concepts of the next generation mobile networks and broadband convergence networks as well as the integration of wireless LAN and cellular networks; some of which are being gradually deployed by industry and included in the ITU-T standards. Dr. Jamalipour has authored several invited papers and been a keynote speaker in many prestigious conferences. He served as the Chair of the Satellite and Space Communications Technical Committee (2004–2006), and currently is the Vice Chair of Communications Switching and Routing TC, and Chair of Chapters Coordinating Committee, Asia-Pacific Board, all from the IEEE Communications Society. He is a voting member of the IEEE GITC and IEEE WCNC Steering Committee. He has been a Vice Chair of IEEE WCNC2003 to 2006, Program Chair of SPECTS2004, Chair of symposiums at IEEE GLOBECOM2005 to 2007 and IEEE ICC2005 to 2008, among many conference leadership roles. He has received several prestigious awards, for example, 2006 IEEE Distinguished Contribution to Satellite Communications Award, 2006 IEEE Communications Society Best Tutorial Paper Award, and 2005 Telstra Award for Excellence in Teaching.

CONTRIBUTORS

Dharma P. Agrawal University of Cincinnati, USA
Nayef A. Alsindi Worcester Polytechnic Institute, USA
Habib M. Ammari Hofstra University, USA
Nirwan Ansari New Jersey Institute of Technology, USA
Torsha Banerjee University of Cincinnati, USA
Stefano Chessa University of Pisa, Italy
Sajal K. Das University of Texas at Arlington, USA
Yuguang Fang University of Florida, USA
Edwin Hou New Jersey Institute of Technology, USA
Abbas Jamalipour University of Sydney, Australia
Bo Li Hong Kong University of Science and Technology, China
Tommaso Melodia State University of New York at Buffalo, USA
Kaveh Pahlavan Worcester Polytechnic Institute, USA
Nikolaos A. Pantazis Technological Educational Institute of Athens, Greece
Dario Pompili Rutgers, The State University of New Jersey, USA
Fikret Sivrikaya Rensselaer Polytechnic Institute, USA
Kazem Sohraby University of Arkansas at Fayetteville, USA
Dimitrios D. Vergados University of Piraeus, Greece
Mehmet Can Vuran University of Nebraska-Lincoln, USA
Chonggang Wang University of Arkansas at Fayetteville, USA
Guoliang Xue Arizona State University, USA
Bülent Yener Rensselaer Polytechnic Institute, USA
Baoxian Zhang Chinese Academy of Sciences, China
Chao Zhang New Jersey Institute of Technology, USA
Jun Zheng Southeast University, China
Yun Zhou University of Florida, USA

CONTENTS