Principles of Wireless Sensor Networks

Wireless sensor networks are an emerging technology with a wide range of applications in military and civilian domains. The book begins by detailing the basic principles and concepts of wireless sensor networks, including information gathering, energy management, and the structure of sensory nodes. It proceeds to examine advanced topics, covering localization, topology, security, and evaluation of wireless sensor networks, highlighting international research being carried out in this area. Finally, it features numerous examples of applications of this technology to a range of domains, such as wireless, multimedia, underwater, and underground wireless sensor networks. The concise but clear presentation of the important principles, techniques and applications of wireless sensor networks makes this guide an excellent introduction for anyone new to the subject, as well as an ideal reference for students, practitioners and researchers.

Mohammad S. Obaidat, recognized around the world for his pioneering and lasting contributions to several areas, including wireless sensor networks, green ICT, wireless and wired networks, performance evaluation of computer systems and networks, and information and network security, is a Professor of Computer Science at Monmouth University, New Jersey, USA. He is the editor-in-chief or editor of many international journals, and has authored over 30 books and over 600 technical papers to date. He has received numerous awards, including a Nokia Research Fellowship, Distinguished Fulbright Scholar Award, McLeod Founder's Award, SCS Presidential Award, and SCS Modeling & Simulation Hall of Fame Award and Best Paper awards in many conferences. He served as SCS President, Advisor to the President Philadelphia University, and Chair of the Department of Computer Science and Software Engineering at Monmouth University. He is a Fellow of the IEEE and the SCS. He has chaired numerous international conferences all over the world and has been invited to give keynote speeches in international conferences. He served as an IEEE Computer Society Distinguished Speaker and is now serving as an ACM and SCS Distinguished Lecturer/speaker.

Sudip Misra is an Associate Professor at the Indian Institute of Technology, Kharagpur. He has authored over 180 scholarly research papers and has edited 6 books. He was awarded the Canadian Government's prestigious NSERC Post-Doctoral Fellowship and the Humboldt Research Fellowship in Germany.

"The book covers the main aspects regarding modern wireless sensor networks, touching hardware and software platforms, networking architectural organization, and communication protocols and applications. It includes treatment of important issues like localization and tracking, topology management, performance evaluation, security, mobility, and multimedia, as well as of two challenging environments ... underwater and underground.

"The material blends theory and applications, and is presented in a form suitable for students, researchers and practitioners. It provides a comprehensive overview and perspective of the field."

Franco Davoli
University of Genoa

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MOHAMMAD S. OBAIDAT
Monmouth University, New Jersey

SUDIP MISRA
Indian Institute of Technology

CAMBRIDGE
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One Liberty Plaza, 20th Floor, New York, NY 10006, USA

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To Our Families

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Preface

Overview and goals

Small low-cost devices powered with wireless communication technologies along with the sensing capabilities are instrumental in the inception of *wireless sensor networks* (WSNs). Recent years have witnessed a sharp growth in research in the area of WSNs. The characteristics of such distributed networks of sensors are that they have the potential for use in various applications in both the civilian and military fields. Enemy intrusion detection in the battlefield, object tracking, habitat monitoring, patient monitoring, and fire detection are some of the numerous potential applications of sensor networks. The ability of an infrastructure-less network setup with minimal reliance on network planning, and the ability of the deployed nodes to self-organize and self-configure without the association of any centralized control are the smart features of these networks. Leveraging the advantages of these features, the network setup is swift in challenging scenarios such as emergency, rescue, or relief operations. The smart features also enable continuous operation of the network without any intervention in case of any failure.

Along with the above-mentioned attractive features possessed by sensor networks, there are several challenges which hinder hassle-free, autonomous, and involuntary operation of these networks. Some of the challenges are attributed to issues relating to scalability, quality-of-service (QoS), energy efficiency, and security. The protocols should be light-weight enough to be suitable for these networks, which consist of small-sized sensor nodes with limited computation power. Sensor networks are often deployed in large-scale and are expected to function through years. Clearly, battery power is an issue in such cases, and can be achieved with the help of energy-efficient or energy-aware protocols. Finally, QoS is also an issue for applications which demand prompt responses.

There exists vast literature on various issues and dimensions of WSNs. This book attempts to provide a comprehensive guide on fundamental concepts, challenges, problems, trends, models, and results in the areas of WSNs. This book has been prepared keeping in mind that it needs to prove itself to be a valuable resource dealing with both the important core and the specialized issues in the areas. We have attempted to offer a wide coverage of topics. We hope that it will be a valuable reference for students, instructors, researchers and practitioners. We believe this is a particularly attractive feature of this book, as the limited selection of books available on sensor networks are written primarily for academicians/researchers. We have attempted to make this book useful for both the academics and the practitioners alike.

Organization and features

The book is broadly divided into three sections – the first part discusses the basics of WSNs, the second part focuses on the networking aspects and protocols of WSNs, and the third part deals with the advanced issues and topics such as localization, topology management, security, modeling, and simulation. There are 14 chapters in the book, of which the first part has three chapters, the second part has three chapters, and the third part has eight chapters.

In the first part, we provide an introduction to WSNs to the readers in Chapter 1. In this chapter, we provide an up-to-date treatment of the fundamental techniques, applications, taxonomy, and challenges of such networks. We also explain the basic components of a wireless sensor node, and classify the sensor networks. Finally, we discuss the differences between WSNs and wireless mesh networks and RFID systems.

Chapter 2 elaborates on components, structure, and operations of a wireless sensor node. We discuss the limitations and the design challenges of WSNs. The hardware architecture and the operating systems of a sensor node are discussed with examples of sensor nodes. This chapter also includes the effects of the infrastructure on the performance evaluation of WSNs. We also discuss the MEMS technology used to manufacture low-power inexpensive sensor nodes.

Chapter 3 reviews the major WSNs applications to various areas including environmental monitoring, health care, intelligent and smart home, homeland security, underwater applications, agriculture and greenhouse monitoring, and military applications.

Chapter 4 is dedicated to discussions about medium access control (MAC) in WSNs. We first discuss the problems of the traditional MAC schemes. In this chapter, the major MAC schemes for WSNs are discussed in detail.

In Chapter 5, we review the aspects, related advantages, and disadvantages, as well as challenges, of routing in WSNs. We classify the existing routing schemes into various categories, and explain a few schemes from each of the categories.

Chapter 6 deals with the transport protocols and quality-of-service (QoS) issues of the WSNs. We first address the transport protocol requirements for WSNs, and discuss the applicability of the Internet transport protocol in WSNs. Finally, the transport protocols are classified into various categories, and schemes from each of the categories are discussed.

Chapter 7, the first chapter of the third part of the book, presents the localization and target tracking schemes of WSNs. First, we discuss the basics of localization and the various distance estimation techniques. Next, the taxonomy of the existing localization schemes is presented with a few schemes from each category investigated in detail. Similarly, the target tracking schemes are also classified into various categories, and we discuss a few existing schemes as well.

In Chapter 8, the aspects and importance of topology management and control are discussed. A taxonomy of the existing schemes is also presented. Finally, we present a few existing schemes from each of the categories.

In Chapter 9, we provide an up-to-date treatment of the techniques that can be used to evaluate the performance of WSN systems. We discuss modeling and simulation techniques for WSNs, which are important when performance evaluation of these networks is needed. The performance metrics and fundamental models associated with performance evaluation are also discussed.

Chapter 10 discusses the security issues related to WSNs. We present a comprehensive study of the challenges, vulnerabilities, attacks, existing solutions, and then compare the major security techniques related to WSNs.

Chapter 11 presents the issues and aspects related to mobile wireless sensor networks. The authors investigate various issues such as coverage, connectivity, and deployment in mobile WSNs.

In Chapter 12, the authors discuss another variant of WSNs named wireless multimedia sensor networks (WMSNs). The challenges and specific applications of WMSNs are also discussed. This chapter also includes the network and node architecture and the communication layers of WMSNs.

Chapter 13 presents the underwater counterpart of WSNs. It is named as Underwater Sensor Networks (UWSNs). We present the challenges and characteristics of UWSNs, and the underwater physics and dynamics associated with UWSNs. The UWSN sensor nodes, their components, the network architectures, and few localization services are also studied in this chapter. We go through each layer of the protocol stack for UWSNs, and briefly discuss the schemes related to each layer.

Chapter 14 deals with another variant of WSNs, the Wireless Underground Sensor Networks (WUGSNs). The applications, challenges, network architectures of WUGSNs are presented. We also shed some light on the protocol stack, communication channels, and routing schemes for such networks.

Target audience

The book is written primarily for the student community. This includes students of all levels – those being introduced to these areas, those with an intermediate level of knowledge of the topics, and those who are already knowledgeable about many of the topics. In order to achieve this goal, we have attempted to design the overall structure and content of the book in a manner that makes it useful at all learning levels.

The secondary audience for this book is the research community, which includes researchers working in academia, industry, or government. To meet the specific needs to this audience group, most chapters of the book also have a section in which attempts have been made to provide directions for future research.

Finally, we have also taken into consideration the needs of those readers, typically from the industry, and those practitioners who wish to gain insight into the practical significance of the topics, i.e. how the spectrum of knowledge and the ideas are relevant for real-life workings of sensor networks.

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