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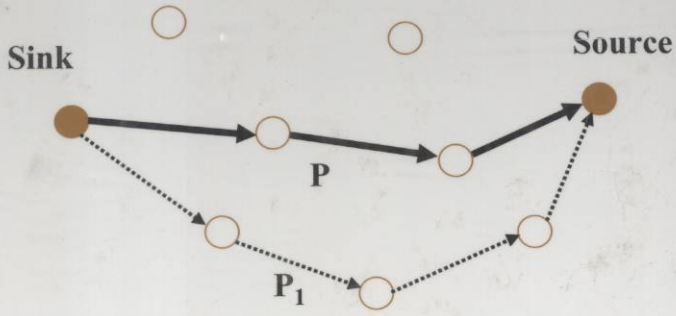
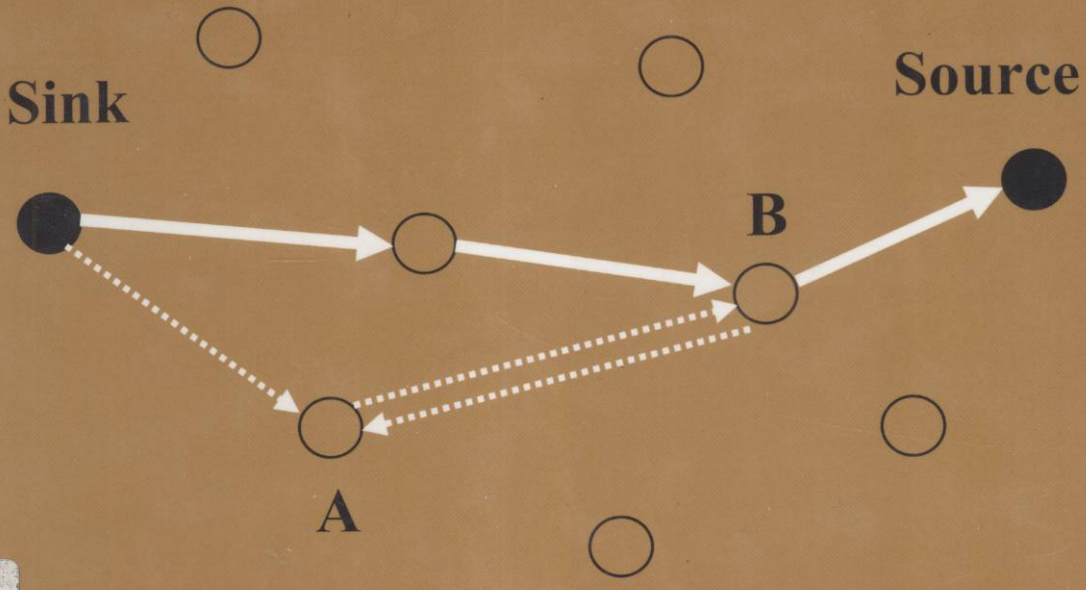


ALGORITHMS AND PROTOCOLS FOR WIRELESS SENSOR NETWORKS

Edited by
AZZEDINE BOUKERCHE



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ALGORITHMS AND PROTOCOLS FOR WIRELESS SENSOR NETWORKS

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WILEY SERIES ON PARALLEL AND DISTRIBUTED COMPUTING

Editor: Albert Y. Zomaya

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This book is dedicated to my parents and my family who have always been there with me. Love you all.

Azzedine Boukerche

PREFACE

With the recent technological advances in wireless communication and networking, coupled with the availability of intelligent and low-cost actor and sensor devices with powerful sensing, computation, and communication capabilities, wireless sensor networks (WSNs) are about to enter the mainstream. Today, one could easily envision a wide range of real-world WSN-based applications from sensor-based environmental monitoring, home automation, health care, security, and safety class of applications, thereby promising to have a significant impact throughout our society. Wireless sensor networks are comprised of a large number of sensor devices that can communicate with each other via wireless channels, with limited energy and computing capabilities. However, due to the nature of wireless sensor networks, we are witnessing new research challenges related to the design of algorithms and network protocols that will enable the development of sensor-based applications. Most of the available literature in this emerging technology concentrates on physical and networking aspects of the subject. However, in most of the literature, a description of fundamental distributed algorithms that support sensor and actor devices in a wireless environment is either not included or briefly discussed. The efficient and robust realization of such large, highly dynamic and complex networking environments is a challenging algorithmic and technological task. Toward this end, this book identifies the research that needs to be conducted on a number of levels to design and assess the deployment of wireless sensor networks–in particular the design of algorithmic methods and distributed computing with sensing, processing, and communication capabilities. It is our belief that this volume provides not only the necessary background and foundation in wireless sensor networks but also an in-depth analysis of fundamental algorithms and protocols for the design and development of the next generations of heterogeneous wireless networks in general and wireless sensor networks in particular. This book is divided into 18 chapters and covers a variety of topics in the field of wireless sensor networks that could be used as a textbook for graduate and/or advanced undergraduate studies, as well as a reference for engineers and computer scientists interested in the field of wireless sensor networks.

The rest of this book is organized as follows. In Chapter 1, we address the several important algorithmic issues arising in wireless sensor networks and highlight the main differences to classical distributed algorithms. Next, an algorithmic perspective toward the design of wireless sensor networks is discussed followed by an overview of well-known algorithms for basic services (that can be used by other algorithms in WSNs), data communication, management functions, applications, and data fusion. Chapter 2 introduces heterogeneous wireless sensor networks where more than one

type of sensor node is integrated into a WSN. While many of the existing civilian and military applications of heterogeneous wireless sensor networks (H-WSNs) do not differ substantially from their homogeneous counterparts, there are compelling reasons to incorporate heterogeneity into the network, such as improving the scalability of WSNs and addressing the problem of nonuniform energy drainage, among others. Chapter 2 also discusses how these reasons are interrelated and how this new dimension heterogeneity opens new challenges to the design of algorithms that run on such wireless sensor networks.

In order to develop algorithms for sensor networks and in order to give mathematical correctness and performance proofs, models for various aspects of sensor networks are needed. In the next three chapters, we focus upon the modeling, design, and analysis of algorithms and protocols for wireless sensor networks. Chapter 3 discusses how biological inspired models, such epidemic models, can be used to design reliable data dissemination algorithms in the context of wireless sensor networks. Recall that reliable data dissemination to all sensor nodes is necessary for the propagation of queries, code updates, and other sensitive WSN-related information. This is not a trivial task because the number of nodes in a sensor network can be quite large and the environment is quite dynamic (e.g., nodes can die or move to another location). Chapter 4 provides an overview and discussion of well-known sensor network models used today and shows how these models are related to each other. While the collaborative nature of the WSN brings significant advantages over traditional sensing, the spatiotemporal correlation among the sensor observations is another significant and unique characteristic of the WSN which can be exploited to drastically enhance the overall sensor network performance. Chapter 5 presents the theoretical framework to model the spatiotemporal correlation in sensor networks and describes in detail how to exploit this correlation when designing reliable communication protocols for WSN.

With the traditional TCP/IP models not suited to routing in wireless sensor networks, the network layer protocol has to be updated to be synchronized with the challenging constraints posed by WSNs. Hence, routing in these networks is a challenging task and has thus been a primary focus with the wireless networking community. The next chapters investigate the major issues to routing with the goals to devise new protocols to keep associated uncertainty under control. Chapter 6 highlights the properties of a wireless sensor network from the networking point of view, and then it presents a description of various well-known routing protocols for wireless sensor networks. The common goals of designing a routing algorithm is not only to reduce control packet overhead, maximize throughput, and minimize the end-to-end delay, but also to take into consideration the energy consumption, especially in a sensor network comprised of nodes that are considered lightweight with limited memory and battery power. In order to achieve high energy efficiency and ensure long network lifetime for routing traffic control, as well as employ bandwidth re-use for data gathering and target tracking, researchers have designed one-to-many, many-to-one, one-to-any, or one-to-all communications, routing, and clustering-based routing protocols. Chapter 7 presents different protocols developed to create clusters and select the best cluster head using Graph Theory concepts. Chapter 8 discusses the merits and challenges of

algorithms and protocols that provide point-to-point services through position-based routing, where forwarding decisions are made by maximizing or minimizing some function of node locations within a coordinate system. Sensors can generally be placed in an area of interest either deterministically or randomly. However, controlled node deployment is viable and often necessary when sensors are expensive or when their operation is significantly affected by their position. Chapter 9 investigates the effect node placement strategies on the dependability of WSNs, and it presents the various sensor and base-station positioning protocols that have been developed to enhance further the performance of WSNs and extend its network lifetime.

The next generation of wireless sensor networks are envisioned to support mobile sensor devices and a variety of mobile robot sensor devices and a variety of wireless multimedia sensor services. Chapter 10 presents several techniques for exploiting the mobility of network components in large networks of resource constrained devices, such as wireless sensor networks, and improving the performance of these networks without significantly affecting data routing and end-to-end latency. A number of mobility issues in WSNs as well as the pros and cons of providing mobility to the normal nodes, relay nodes, and/or sink nodes are analyzed. Also in this chapter, solutions that use mobility to alleviate the problem of energy depletion of nodes near the sink are shown. However, this mobility as well as the random deployment of the nodes in a WSN imposes another problem to the network: how to discover the current physical position of the nodes. Chapters 11 and 12 focus on the different aspects of this problem known as the localization problem. In Chapter 11, the localization systems are divided into different components—distance estimation, position computation, and localization algorithm—and several techniques employed by these components are explained. On the other hand, Chapter 12 deals with more specific problems, such as using the signals' angle of arrival to estimate the position of the nodes.

Quality of service (QoS) provisioning in wireless sensor networks (WSNs) is an important concept to enable mission-critical and real-time applications. In Chapter 13, the necessity to support QoS in WSNs, QoS-based communication protocols, and research directions to support QoS in WSNs is discussed. Chapter 14 presents some background topics in network information theory relevant to the efficient collection, compression, and reliable communication of sensor data. Then, it discusses how a QoS perspective enables scalability in classical flat sensor networks. Finally, a number of practical QoS approaches for high-fidelity data extraction in large-scale sensor networks are explored. Chapter 15 focuses on several important aspects of energy efficiency, like minimizing the total energy dissipation, minimizing the number of transmissions, and balancing the energy load to prolong the system's lifetime. Several characteristic protocols and techniques in the recent literature that explicitly focus on energy efficiency are presented. Such techniques include clustering and probabilistic forwarding, adaptive transmission range management, and local optimization.

WSNs are supposed to be deployed in critical scenarios to be used in safety, emergency, and military applications. In these cases, security is a key technology in order to make the gathered data a reliable information. Thus, we believe that a WSN book would not be complete without a good review of the proposed techniques that aim to provide the secure operation and communication in WSNs. Thus, the next chapters

of this book investigate different aspects of providing security in WSNs. Chapter 16 focuses on general aspects of the problem, showing how WSNs are vulnerable to several attacks in the different network layers. Cryptography techniques for WSNs such as cryptographic systems, authentication methods, and key distribution and management protocols are then studied and analyzed as a countermeasurement for a number of the identified attacks. Also in this chapter, secure routing protocols that are resilient to these attacks are discussed and explained. Besides securing the routing, it is also important to secure other key protocols in WSNs such as the synchronization and localization protocols. Chapter 17 provides a good overview of the proposed solutions for securing a time synchronization protocol to be used in critical applications of WSNs. This chapter shows the importance of a secure synchronization system, how current synchronization solutions are vulnerable to a number of attacks, and the proposed techniques to secure these protocols. Finally, Chapter 18 takes the security issue to the localization protocols. This chapter shows how the different components of the localization systems–distance estimation, position computation, and localization algorithm–are vulnerable to a number of attacks and then shows the proposed techniques and countermeasurements to secure these components and provide a secure localization system that are able to work in the presence of hostile nodes and compromised environments.

It is our belief that this is the first book that covers the basic and fundamental algorithms and protocols for wireless sensor networks, making their design and analysis accessible to all levels of readers.

Special thanks are due to all contributors for their support and patience, as well as to the reviewers for their hard work and timely reports, which make this book truly special. Last but not least, we wish to extend our thanks to Paul Petralia and Whitney Lesch from John Wiley & Sons for their support, guidance, and certainly their patience in finalizing this book.

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Azzedine Boukerche is a Professor and holds a Canada Research Chair position at the University of Ottawa. He is the Founding Director of Paradise Research Laboratory at the University of Ottawa. Prior to this, he held a Faculty position at the University of North Texas, and he was working as a Senior Scientist at the Simulation Sciences Division, Metron Corporation, located in San Diego. He was also employed as a faculty member at the School of Computer Science, McGill University, and he taught at Polytechnic of Montreal. He spent a year at the JPL/NASA-California Institute of Technology, where he contributed to a project centered around the specification and verification of the software used to control interplanetary spacecraft operated by JPL/NASA Laboratory. His current research interests include wireless ad hoc and sensor networks, wireless networks, mobile and pervasive computing, wireless multimedia, QoS service provisioning, large-scale distributed interactive simulation, parallel discrete event simulation, and performance evaluation and modeling of large-scale distributed and mobile systems. Dr. Boukerche has published several research papers in these areas. He was the recipient of and/or nominated for the Best Research Paper Award at IEEE/ACM PADS '97, IEEE/ACM PADS '99, IEEE ICC 2008, ACM MSWiM 2001, and MobiWac'06, and he was the co-recipient of the 3rd National Award for Telecommunication Software 1999 for his work on distributed security systems on mobile phone operations.

Dr. A. Boukerche is a holder of an Ontario Early Research Excellence Award (previously known as Premier of Ontario Research Excellence Award), an Ontario Distinguished Researcher Award, and a Glinski Research Excellence Award. He is a Co-Founder of QShine International Conference on Quality of Service for Wireless/Wired Heterogeneous Networks (QShine 2004) and has served as a General Chair for the 8th ACM/IEEE Symposium on Modeling, Analysis, and Simulation of Wireless and Mobile Systems, the 9th ACM/IEEE Symposium on Distributed Simulation and Real-Time Application, and the 6th IEEE/ACM MASCOT '98 Symposium; he has also served as the Vice General Chair for the 3rd IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS '07), Program Chair for IEEE Globecom 2007 and 2008 Ad Hoc, Sensor and Mesh Networking Symposium, and a Program Co-Chair for ICPP 2008, the 2nd ACM Workshop on QoS and Security for Wireless and Mobile Networks, ACM/IFIPS Europar 2002 Conference, IEEE/SCS Annual Simulation Symposium '02, ACM WWW '02, IEEE MWCN 2002, IEEE/ACM MASCOTS '02, IEEE Wireless Local Networks 03-04, IEEE WMAN 04-05, and ACM MSWiM 98-99.

Dr. A. Boukerche is an Associate Editor for *ACM/Springer Wireless Networks*, *IEEE Transactions on Vehicular Networks*, *IEEE Wireless Communication Magazine*, *IEEE Transactions on Parallel and Distributed Systems*, Elsevier's *Ad Hoc Networks*, *Wiley International Journal of Wireless Communication and Mobile Computing*, Wiley's *Security and Communication Network Journal*, Wiley's *Pervasive and Mobile Computing Journal*, Elsevier's *Journal of Parallel and Distributed Computing*, and *SCS Transactions on Simulation*. He also serves as a Steering Committee Chair for the ACM Modeling, Analysis and Simulation for Wireless and Mobile Systems Symposium, the ACM Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, and the IEEE/ACM Distributed Simulation and Real-Time Applications Symposium (DS-RT).

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