

Introduction



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Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution.

Albert Einstein, (1879–1955).

1 Mission-Oriented Sensor Networks and Systems: Art and Science

The fast advances in both inexpensive sensor technology and wireless communications over the last two decades have made the design and development of large-scale wireless sensor networks cost-effective and appealing to a wide range of mission-critical situations. These include area monitoring (e.g., deploying sensors for enemy intrusion detection, as well as geo-fencing of gas, oil pipelines, or work area), health-care monitoring (e.g., using implanted, wearable, or environment-embedded sensors for medical applications), environmental/earth sensing (e.g., using sensors for monitoring air pollution and water quality, as well as detecting forest fire and landslide), industrial monitoring (e.g., deploying sensors for monitoring machine health, data center, data logging, water and wastewater, and structural health), to name a few.

Wireless sensor networking has attracted the attention of numerous practitioners and researchers from both industry and academia. These types of networks consist of

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a collection of tiny, resource-limited, low-reliable sensing devices that are randomly or deterministically deployed in a field of interest to monitor a physical phenomenon and report their results to a central gathering point, known as *sink* (or *base station*). These tiny sensing devices suffer from their scarce capabilities, such as bandwidth, storage, CPU, battery power (or energy), sensing, and communication. In particular, the constrained power supplies of the sensors shorten their lifetime and make them unreliable. More precisely, mission-oriented sensor networks and systems are viewed as time-varying systems composed of autonomous (mobile) sensing devices (e.g., using mobile robots) that collaborate and coordinate distributedly to successfully accomplish complex real-time missions under uncertainty. The major challenge in the design of mission-oriented sensor networks and systems is due to their dynamic topology and architecture, which is caused mainly by sensing devices mobility. The latter may have significant impact on the performance of mission-oriented sensor networks and systems in terms of their sensing coverage and network connectivity. In such continuously dynamic environments, sensing devices should self-organize and move purposefully to accomplish any mission in their deployment field while extending the operational network lifetime. In particular, the design of mission-oriented sensor networks and systems should account for trade-offs between several attributes, such as energy consumption (due to mobility, sensing, and communication), reliability, fault tolerance, and delay.

Mission-oriented sensor networks and systems have been able to attract the attention of numerous people from scientific communities in both academia and industry. Indeed, a large number of related innovative research papers to solve challenging problems have been published in high-quality journals, conferences, and workshops. Given the importance of this area of research, I found it is essential that an up-to-date book on the abovementioned topics be provided to our sensor networks and systems research community. This book series, titled “*Mission-Oriented Sensor Networks and Systems: Art and Science*”, includes two volumes, namely, Volume 1 and Volume 2, whose titles are as follows, respectively,

- *Mission-Oriented Sensor Networks and Systems : Art and Science—Foundations*
- *Mission-Oriented Sensor Networks and Systems : Art and Science—Advances*

These two books have been assembled with a goal to address challenging and/or open research problems in traditional as well as new emerging areas of research in mission-oriented sensor networks and systems, including sensor networking, cyber-physical systems, and Internet of things, to name a few. It is worth mentioning that all the book chapters in both volumes have been written as comprehensive review of the state-of-the-art and state-of-the-practice of their associated topics. Precisely, each book chapter is either a survey of existing work in the literature, or a survey with emphasis on the related research done by their corresponding authors. In either case, every book chapter presents a thorough review of the underlying theoretical foundations, along with in-depth overview of the proposed approaches.

This book relates to the second volume, i.e., *Mission-Oriented Sensor Networks and Systems : Art and Science—Advances*. It focuses on advances in mission-oriented sensor networks and systems, including nonconventional sensor networks and sys-

tems, which are not covered in the first volume. Thus, the second volume of this series deals with advanced topics in mission-oriented sensor networks and systems, such as cyber-physical systems, Internet of things (IoT), crowdsensing, wearable computing, robotics, and wireless charging systems. For instance, cyber-physical systems (CPSs) have emerged as a promising technology to provide a bridge between the physical and cyber worlds, where sensors, actuators, and embedded devices are networked to sense, monitor, and control the physical world. Several applications of CPSs, such as health care, transportation, and rescue applications, have been developed. Note that all of these CPSs applications leverage the data gathered by sensors in order to bridge between the physical and cyber worlds. Following Albert Einstein's above-quoted-wise approach of being imaginative, all the book chapters in this second volume emphasize real systems that can be designed mainly based on sensors. These book chapters include up-to-date research work spanning various topics in mission-oriented sensor networks and systems, such as autonomous cooperative routing for mission-critical applications, communication of models and model updates as new paradigm in communication, IoT-based architecture, models for IoT architectures, digital forensics, dependable wireless communication in IoT, localization in IoT, mobile crowdsensing systems, smart cities, privacy and security in wearable computing, wireless transfer of energy, robotics, middleware for robotics, interference mitigation, radiation control, and encryption. Most of these major topics can be covered in an advanced course on mission-oriented sensor networks and systems. I believe that this book will be an excellent reference for graduate as well as senior undergraduate students who are majoring in computer science, computer engineering, electrical engineering, data science, information science, or any related discipline. Furthermore, this book will a great source of information for computer scientists, researchers, and practitioners in academia and industry. I really hope that all readers will find this book very useful, nicely written, clear, exciting, and fascinating. My ultimate goal is that all users of this book will enjoy reading it and using it for any of their favorite research topics, as much as I enjoyed editing it.

2 Book Organization

This book consists of seven parts, each of which has two to four chapters. Next, we provide a short description of each part through a brief summary of each of its chapters.

In Part 1, titled "*Mission-Critical Applications and Cyber-Physical Systems*", Chapter "[Autonomous Cooperative Routing for Mission-Critical Applications](#)" discusses autonomous cooperative routing for mission-critical applications. It presents the underlying networking challenges and practical remedies for this type of routing. Also, it shows that autonomous cooperative routing outperforms other routing schemes. Chapter "[Using Models for Communication in Cyber-Physical Systems](#)" describes a new paradigm in communication, which utilizes communication of models and model updates instead of raw sensed data. Then, it demonstrates the effectiveness of the model-based communication using the example of a vehicular cyber-physical system.

In Part 2, titled “*Internet of Things*”, Chapter “[Urban Microclimate Monitoring Using IoT-Based Architecture](#)” presents various aspects related to Internet of Things-based sensor node development for urban microclimate monitoring. It emphasizes software development, relevant methodologies, hardware modules, and platforms. Chapter “[Models for Plug-and-Play IoT Architectures](#)” reviews plug-and-play architecture along with its corresponding components. Then, it presents a survey of the most important models that feature the capabilities of this type of architecture. Chapter “[Digital Forensics for IoT and WSNs](#)” describes digital forensics challenges in the Internet of Things and wireless sensor networks environments. Also, it analyzes available solutions to overcome some of those challenges from different perspectives. Chapter “[Dependable Wireless Communication and Localization in the Internet of Things](#)” surveys methods to increase the dependability of the Internet of Things. It provides a comprehensive treatment of dependability issues across multiple layers, from signal processing, over microwave engineering, to networking. Also, it proposes to use a switchable ultra-wideband antenna system to enhance communication and localization in the Internet of Things. Moreover, it shows its potential for multipath-resolved positioning.

In Part 3, titled “*Crowdsensing and Smart Cities*”, Chapter “[User Incentivization in Mobile Crowdsensing Systems](#)” identifies basic design issues of mobile crowdsensing systems and investigates some characteristic challenges. Chapter “[Vehicular Ad Hoc/Sensor Networks in Smart Cities](#)” introduces vehicular networks and their challenges. Then, it discusses some existing routing protocols for vehicular networks. Also, it describes some vehicular sensor applications in smart cities.

In Part 4, titled “*Wearable Computing*”, Chapter “[An Overview of Wearable Computing](#)” provides a high-level user-oriented overview of wearable computing. Also, it gives a historical view of wearable computing devices, beginning with an abacus ring from the seventeenth century and progressing to modern wearable computing devices. Then, it discusses the lessons learned from this history and their implications for future wearable devices. Chapter “[Wearables Security and Privacy](#)” discusses security and privacy problems with wearable devices. It describes the components in wearables, such as sensors, processors, software, and communications, and highlights the security issues related to wireless protocols, vulnerabilities, and privacy. Chapter “[Wearable Computing and Human-Centricity](#)” focuses on the principles of human-centric design, which have been used in the context of wearable computers. Those traditional concepts of human-centric computers need to be defined in an adaptable framework. Indeed, wearable devices introduce an additional set of requirements to those traditional concepts. This chapter shows that human centricity is one of the major challenges to the ubiquity and future success of wearable devices.

In Part 5, titled “*Wireless Charging and Energy Transfer*”, Chapter “[Wireless Transfer of Energy Alongside Information in Wireless Sensor Networks](#)” explores techniques to simultaneously deliver energy alongside information during wireless communications. It presents mechanisms to consolidate energy and information transfer in wireless sensor networks. Also, provides an experimental evaluation of the proposed iPoint communication system, which includes novel communication protocols and optimization techniques to ensure efficient delivery of energy and information. Chapter “[Efficient Protocols for Peer-to-Peer Wireless Power Transfer and Energy-Aware Network Formation](#)” investigates interactive, “peer-to-peer” wireless

energy exchange in populations of resource-limited mobile agents, without the use of any special chargers. Then, it discusses protocols that address energy balancing between agents, and distributively forming a network structure with an appropriate energy distribution among the agents. Chapter “[Next-Generation Software-Defined Wireless Charging System](#)” introduces an architecture for next-generation wireless charging systems, called DeepCharge, which realizes a software-defined wireless charging system through separation of controller, energy, and hardware planes. Then, it demonstrates indoor and outdoor prototypes of DeepCharge with extensive experimental measurement.

In Part 6, titled “*Robotics and Middleware*”, Chapter “[Robotic Wireless Sensor Networks](#)” presents a literature survey of an emerging, cutting-edge, and multi-disciplinary field of research in robotic wireless sensor networks. It identifies the core problems, such as connectivity, localization, routing, and robust flow of information. Then, it classifies the existing research on robotic wireless sensor networks. Also, it analyzes what is missing in the literature and identifies topics for future research. Chapter “[Robot and Drone Localization in GPS-Denied Areas](#)” discusses many facets of robot and drone coordination in GPS-denied areas. Also, it addresses issues associated with localization and coordination among multiple agents to accomplish a common goal. Chapter “[Middleware for Multi-robot Systems](#)” surveys state-of-the-art in both distributed multi-robot system and middleware. Then, it provides a taxonomy to classify the MRS middleware and analyze existing middleware functionalities and features.

In Part 7, titled “*Interference Mitigation, Radiation Control, and Encryption*”, Chapter “[Interference Mitigation Techniques in Wireless Body Area Networks](#)” analyzes the issues related to the coexistence amongst wireless body area networks (WBANs) and between WBANs and other wireless networks. Also, it provides a comparative review of the radio co-channel interference mitigation and avoidance techniques that exists in the literature. Chapter “[Radiation Control Algorithms in Wireless Networks](#)” focuses on two problems. The first problem, called minimum radiation path, consists to find the lowest radiation trajectory of a person moving from a source to a destination point within the area of a network of wireless devices. The second problem is to efficiently charge a set of rechargeable nodes using a set of wireless energy chargers, under safety constraints on the electromagnetic radiation incurred. Then, it presents and analyzes efficient algorithms and heuristics for approximating optimal solutions, namely, minimum radiation trajectories and charging schemes, for both problems, respectively. Chapter “[Subspace-Based Encryption](#)” shows the weaknesses from a cryptographic point of view of the concept of blind source separation, which has been used for speech encryption. It proposes to use vectorial subspace concepts, leading to subspace-based encryption systems, which are applied to speech and images. Also, it shows through experiments that the use of subspace-based encryption systems yields performance enhancement.

3 Acknowledgements

This complete two-volume series book, titled “*Mission-Oriented Sensor Networks and Systems: Art and Science*”, is a tribute to the outstanding work of the foremost

leading authorities and scholars in their fields of research in the area of mission-oriented sensor networks and systems. Honestly, it is unfair that my name only appears on the book cover. And, it is really a great pleasure and an honor for me to cordially recognize all of those who contributed a lot to this book and generously supported me throughout this project in order to make this two-volume series a reality. Therefore, it is really a great privilege for me to work with all of these talented scholars. Without them, it would not be possible at all to finish this book and make it available to all the researchers and practitioners, who are interested in the foundations of mission-oriented sensor networks and systems.

First and foremost, I am sincerely and permanently grateful to Allah—the Most Gracious, the Most Merciful—for everything He has been giving me. In particular, I would very much love to thank Him for providing me the golden opportunity to work with such group of outstanding scientists and researchers to put together this book, and for helping me publish it within 3 years. I am extremely happy and so excited to dedicate this modest book to Him, and very much hope that He would kindly accept it and put His Blessings in it. His Saying “**And of knowledge, you (mankind) have been given only a little**” has an endless, pleasant echo in my heart and always reminds me that our knowledge is much less than a drop in the ocean.

It is worth mentioning that all the contributing authors were invited to contribute to this book, and that no Call for Book Chapters had ever been sent out through any mailing list. All of those authors whom I invited were chosen very selectively to cover most of the foundational topics in mission-oriented sensor networks and systems. They have been contributing to the growth and development of the field of mission-oriented sensor networks and systems. This book would never have been written without their great contributions, support, and cooperation. Thus, my cordial recognition is due to all of my friends and colleagues (faculty and—the ones whom I invited to contribute with their book chapters to this book—whose names are listed in the alphabetical order: Drs. Kemal Akkaya, Mohamad Jaafar Ali, Mohamed-Slim Alouini, Constantinos Marios Angelopoulos, Ahmed Bader, Mustafa S. Bakr, Md Zakirul Alam Bhuiyan, Adel Belouchrani, Jorge Blasco, Carlo Alberto Boano, Wolfgang Bosch, Jiannong Cao, Thomas M. Chen, Kaushik R. Chowdhury, Yaser Fallah, Andrea Gasparri, Fabrizio Gentili, Pradipta Ghosh, Philipp Greiner, Jasmin Grosinger, Bernhard Großwindhager, Hooman Javaheri, Mukesh Jha, Shan Jiang, Jiong Jin, Umit Karabiyik, Bhaskar Krishnamachari, Adelina Madhja, Prashanth Reddy Marpu, Troy McDaniel, Ahmed Mehaoua, Atef Mermoul, Hassine Mounsla, Ufuk Muncuk, M. Yousof Naderi, Sotiris Nikolettseas, Guevara Noubir, Sethuraman Panchanathan, Harsh Kupwade Patil, Christian Poellabauer, Theofanis P. Raptis, Christoforos Raptopoulos, Michael Rath, Jose Rolim, Kay Römer, Yuvraj Sahni, Josh Siva, Chao Song, Arash Tadayon, Ramin Tadayon, Dimitrios Tsolovos, Alexandros Tsoupos, Gary M. Weiss, Klaus Witrisal, Daniel Wolff, Jie Wu, and Mohamed Younis. I am really honored to have worked with such an amazing crew of scholars and scientists. I learned a lot from them throughout this project, and it was an incredible experience for me in finishing this book.

Each book chapter has undergone two rounds of reviews. Moreover, in each round, every book chapter received 2–5 reviews by experts in the scope of the chapter. Our ultimate goal is to provide the readers with a high-quality reference on the founda-

tions of mission-oriented sensor networks and systems. Precisely, all book chapters were carefully reviewed in both rounds by all the contributing authors. I would like to express my sincere gratitude to all the contributing authors for their constructive feedback to improve the organization and content of all book chapters. My special thanks go to Drs. Damian M. Lyons (external reviewer), Flavia Delicato, and Mohamed Younis for their generous offer to review several book chapters of both books of this two-volume series. Also, my original plan was to publish only one book, titled “*Mission-Oriented Sensor Networks and Systems: Art and Science*”. But, I ended up with 42 book chapters, which I split into two volumes along with their book chapters and titles. Moreover, I am very grateful to Dr. Bhaskar Krishnamachari, Professor and Director, Center for Cyber-Physical Systems and the Internet of Things Viterbi School of Engineering, University of Southern California, Los Angeles, California, for his great foreword, kindness, and outstanding support to me.

I started this project on Monday, September 5, 2016 at 12:42 AM when I contacted the Publishing Editor, Dr. Thomas Ditzinger, who approved my proposal for an edited book. All book chapters for both volumes were uploaded on the website of Springer and made accessible to the Project Coordinator, Mr. Gowrishankar Ayyasamy, on August 21, 2019. Hence, this project lasted about 3 years. During all this period of time, I exchanged a few thousands of emails with all contributing authors with regard to their book chapters. I would like to thank all the contributing authors for their invaluable time, flexibility, and wonderful patience in responding to all of my emails in a timely manner. Please forgive me for your time, and I hope that the readers will appreciate all of your great efforts and love all the materials in this book. We all have devoted a considerable amount of time to finish this book, and I hope that all of our efforts will be paid off in the future.

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