Wireless-Powered Communication Networks

Architectures, Protocols, and Applications

Learn the fundamentals of architecture design, protocol optimization, and application development for wireless-powered communication networks with this authoritative guide. You will gain a detailed understanding of the issues surrounding architecture and protocol design, with key topics covered including relay-based energy harvesting systems, multiple-antenna systems for simultaneous wireless information and power transfer (SWIPT), performance modeling and analysis, and ambient wireless energy-harvesting-based cellular systems. Current applications of energy harvesting and transfer in different wireless networking scenarios are discussed, helping you to understand practical system development and implementation issues from an engineering perspective.

The first book to provide a unified view of energy harvesting and wireless power transfer networks from a communications perspective, this is an essential text for researchers working on wireless communication networks and wireless systems, RF engineers, and wireless application developers.

Dusit Niyato is an Associate Professor in the School of Computer Science and Engineering at Nanyang Technological University, Singapore. He is the recipient of the IEEE Communications Society Asia Pacific Best Young Researcher Award and the IEEE Communications Society Fred W. Ellersick Prize Paper Award.

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"This is a brilliant piece of work which provides a holistic view of the emerging energy harvesting-based wireless communications and networking technology. Starting with the basics . . . , the book cohesively covers different aspects of this technology, including circuit and antenna design issues for wireless energy harvesting devices and performance modeling and analysis of wireless energy harvesting and transfer-based wireless networks, as well as applications of this technology in different wireless networking scenarios. Standardization activities on wireless energy harvesting and transfer are also discussed. As a valuable addition to the library of graduate students, researchers and practitioners working in this area, this book will equip them for further reading and research on this exciting technology."

Vahid Tarokh, *Harvard University*

"Wireless power transfer and energy harvesting networks have received tremendous attention in both the research community and industry recently . . . This book contains a comprehensive review of the various topics which are nicely organised and blended in a coherent manner. It will be an excellent introductory text to get into this exciting new topic of research."

Vincent Lau, *Hong Kong University of Science and Technology*

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Preface

Recently, there has been an upsurge of research interest in wireless-powered communication networks. These networks are based on energy harvesting and/or energy transfer technology, for mobile devices using wireless propagation media. This technology offers the capability of using different types of wireless medium, such as radio frequency and magnetic induction, to carry energy from dedicated sources to wireless nodes or to harvest energy from ambient sources. Therefore, this has become a promising solution to power energy-constrained wireless networks. Conventionally, energy-constrained wireless networks such as wireless sensor networks have a limited lifetime, which leads to significant deterioration in network performance and usability. By contrast, a network with wireless energy harvesting and transfer capability can be powered without using a fixed power supply. For example, it can harvest energy from environmental sources such as solar and wind energy or from other dedicated or non-dedicated sources which are tetherless. Hence, there is no need to charge or replace the batteries physically, which can improve the flexibility and availability of the network substantially. Wireless energy has many advantages over other energy sources, including indoor support and stable and more predictable supply.

There are three major types of wireless energy harvesting and transfer technique, namely, radio frequency (RF), inductive coupling, and magnetic resonance coupling techniques. In RF energy harvesting, radio signals with frequencies in the range from 3 kHz to 300 GHz are used as a medium to carry energy in the form of electromagnetic radiation. Inductive coupling is based on magnetic coupling that delivers electrical energy between two coils tuned to resonate at the same frequency. The electric power is carried through the magnetic field between two coils. Magnetic resonance coupling utilizes evanescent-wave coupling to generate and transfer electrical energy between two resonators. The resonator is formed by adding a capacitance on an induction coil. Inductive coupling and magnetic resonance coupling are near-field wireless transmission techniques featuring high power density and conversion efficiency. By contrast, RF energy transfer can be regarded as a far-field energy transfer technique. It is suitable for powering a larger number of devices distributed over a wide area. Wireless energy harvesting and transfer have found many applications and have recently been implemented in many devices, including mobile phones, healthcare devices, sensors, and RFID tags. With the increasing number of applications of RF energy harvesting/charging, the Wireless Power Consortium is also making efforts toward establishing an international standard for RF energy harvesting and transfer technology.

Although wireless energy harvesting and transfer can be adopted in different types of wireless network, such as wireless sensor networks, mobile ad-hoc networks, and delay-tolerant networks, to provide the power supply for the wireless nodes, it introduces many challenges. Unlike other forms of energy harvesting, e.g., wind, solar, and vibration, the efficiency of wireless energy harvesting and transfer depends on the relative distances between the energy sources and the harvesting devices of the wireless nodes. Therefore, the locations or placements as well as the density of power sources become a significant architectural issue for such networks. Moreover, with dedicated power sources in a wireless network, issues such as scheduling of users for energy transfer (or charging) as well as data transfer and transmission scheduling of data packets in the energy harvesting wireless nodes become important. Efficient usage of the harvested energy depends on the communication protocols used by these devices as well as other network nodes such as the base stations. Therefore, the schemes and solutions developed for traditional wireless communication networks without or with other forms of energy harvesting have to be revisited. They have to be redesigned and developed to meet the unique challenges that arise due to the distinctive nature of wireless energy harvesting and transfer.

This book entitled *Wireless-Powered Communication Networks: Architectures, Protocols, and Applications* provides a comprehensive treatment of the latest research and technological developments concerning the architectures, protocols, and applications of networks with wireless energy harvesting and transfer capability. It is divided into three parts: Basics of Wireless Energy Harvesting and Transfer Technology (Part I), Architectures, Protocols, and Performance Analysis (Part II), and Applications of Wireless Energy Harvesting and Transfer (Part III). It starts with an introduction to the circuit and antenna design of wireless energy harvesting and transfer devices as well as the standardization efforts toward wireless energy transfer and harvesting technology (Part I). Then, in Part II, the book deals with several issues related to architecture and protocol design for networks with wireless energy harvesting and transfer capability. The topics covered in this part include relay-based energy harvesting systems and the related radio resource management issues, multiple antenna systems for simultaneous wireless information and power transfer (SWIPT), backscattering wireless-powered communications systems, and performance modeling and analysis of dedicated wireless energy harvesting as well as ambient wireless energy harvesting-based cellular systems. Part III of the book deals with applications of energy harvesting and transfer in different wireless networking scenarios, including those in sensor networks, cognitive radio networks, and mobile ad-hoc and delay-tolerant networks. In addition to reviewing the existing approaches for design and operation of energy harvesting wireless networks, the book also outlines the open issues and research challenges in this emerging area which will need to be explored by researchers.

The book provides the following.

- Background on wireless energy harvesting and transfer for RF, inductive coupling, and magnetic resonant coupling methods;
- Introduction to the circuit and antenna design issues for energy-harvesting devices;

- Reviews of several important network architecture and protocol design issues and performance analysis models for wireless energy harvesting and transfer-based wireless networks;
- Applications of wireless energy harvesting and transfer in different wireless networking scenarios;
- Standardization activities on wireless energy harvesting and transfer;
- A comprehensive list of references on topics related to wireless energy harvesting and transfer technology;
- Potential research directions.

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