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Wireless-Powered Backscatter Communications for Internet of Things

Springer

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Foreword

Electromagnetic (EM) waves are fundamental ingredients of modern communication networks. They have enabled connectivity in the so-called Internet of things (IoT) which is an ecosystem of efficient services and smart applications to improve and simplify different aspects of our daily life. The unprecedented scale, massive interconnectivity, and enhanced pervasiveness of IoT also create an environment where the low-power nature of devices becomes a paramount concern. Additionally, how to enable reliable communication among the low-powered devices is a very active research area.

Fortunately, recent research efforts on wireless-powered backscatter communications have shown considerable promise. The low-power nature of backscatter devices renders a very long lifetime and can be used to enable different IoT applications with a low energy footprint. Although the potential of backscatter communication has ignited many research activities all around the world, one must not underestimate the extent of the difficulties that still have to be overcome.

In this regard, this book's arrival is timely, and it will build your knowledge about wireless-powered backscatter communication and IoT networks from the ground up. It will provide you with all you need to refocus your current IoT activities and for starting your backscatter communication endeavors. The book also contains compelling use cases and insights by some of the leading researchers who have played a pivotal role in advancing the state of the art in our times. It is now in your hand to use this book for enabling IoT networks, and by extension, our future.

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Introduction

The evolution in the field of wireless communications requires not only futuristic technologies but also, a change of mindset about how different technologies interact with each other like a well-oiled machine. In this backdrop, the deployment of massive Internet of things (IoT) networks poses significant challenges. While there have been numerous technologies proposed to improve the performance of such low-powered IoT networks, the current state of the art is still not mature enough to deploy commercial and large-scale networks. Rapid energy consumption along with miniature size of energy reservoirs naturally becomes an obstacle as these IoT devices are likely to be untethered when operating. Fortunately, recent research efforts have shown that radio backscatter communication can effectively offer near-zero-power (less than 1mW) connectivity to small devices. In this regard, this book explores the performance evaluation and optimization aspects of backscatter devices in outdoor and indoor environments, where it is not possible to set up a dedicated nearby transmitter. The book also sheds light on different cooperation techniques for backscatter communications. These techniques help analyze the reliability-energy trade-off for backscatter devices. Also, there are in-depth discussions and recent studies on a variety of emerging wireless topics such as physical-layer security, non-orthogonal multiple access (NOMA), age of information, and multi-tone carrier techniques.

Chapter "Cooperative Communication Techniques in Wireless-Powered Backscatter Communication: Preambles and Technical Perspective" studies and analyzes the performance improvement (throughput as well the signal-to-noise ratio (SNR) in a backscatter environment, occurred due to the incorporation of cooperative communication. The cooperation is a key technology to overcome the channel impairments by exploiting spatial diversity, and significantly reduce the interference by employing power control due to the presence of a better channel condition with a relay node. Overall, this chapter serves as an introductory guideline for understanding the basic concept of using backscattering in a cooperative network domain. The authors have also narrowed down some of the key research challenges and open issues that occur due to the use of cooperative communication techniques in a wireless backscatter network. Based on an in-depth simulation analysis, they

have shown that the incorporation of a cooperative network in a backscatter environment significantly improves the throughput as well the SNR, while comparing to a traditional noncooperative network.

Chapter "Physical-Layer Security for Ambient Backscattering Internet-of-Things" provides an analytical perspective for the secrecy performance of a multi-tag ambient backscatter system in the presence of a passive eavesdropper. The main contribution of this work is to provide theoretical tools for inspecting the performance of the system. Consequently, the authors present closed-form analytical expressions for two of the main physical-layer security metrics, namely the secrecy outage probability (SOP) and ergodic secrecy rate (ESR) of an ambient backscatter IoT communications system over Rayleigh fading channels. To gain more insights on the effect of different parameters, the asymptotic SOP, ESR, and diversity order are developed using the residue theorem. The SOP and achievable ESR improve with the increase of both the access point transmit power and the reflection coefficient of the backscatter tag. Additionally, it is shown that the SOP floors to a certain value that depends on the value of mean powers for the tag-to-eavesdropper channel assuming a fixed value of the mean power for the tag-to-reader channel. Finally, the asymptotic behavior of the ESR shows a ceiling at high SNR, which saturates to a value that is inversely proportional to the logarithm of the mean powers for the tag-to-eavesdropper channel.

Chapter "Multi-tone Carrier Backscatter Communications for Massive IoT Networks" explores the multi-tone carrier technique to improve the performance of backscatter communications. Backscattering of the wireless signal using ambient RF signals has recently emerged as the most exciting technique to improve a wireless network's performance. This can then be utilized to reconfigure the channel resulting in a better quality of service and to enable ubiquitous connections among small devices. Moreover, since ambient backscatter communication can use instantaneously harvested energy, it does not consume the energy in the storage reserved for active RF transmission. In this context, the authors provide a compelling modification to the existing architecture of the backscatter communications. It was also shown that the multi-tone carrier backscatter RFID system significantly outperforms the conventional approaches in terms of throughput.

Chapter "Time Slot Management in Backscatter Systems for Large-Scale IoT Networks" investigates the time slot management approach in backscatter communications to enable massive IoT networks. The low-power nature of backscatter communication makes it promising to run IoT applications in a battery-free manner. However, the current work faces new theoretical challenges arising from new network topologies. One such challenge pertains to the efficient management of time slots in such networks. In this backdrop, the authors of the chapter convincingly show that their time slot management approach improves the inventory time by 11%. Besides, their results also indicate that the average throughput of 0.614 bps is achieved with a much shorter frame size.

Chapter "Age of Information in Backscatter Communication" sheds light on the importance of age of information for backscatter communications. As one of the key enablers of apprehending the dream of a digital smart world, IoT networks target to connect different objects for real-time exchange of information. Such

devices have a communication interface with unique special addresses, processing, and storage units, which enables them interacting with each other. The concept of the age of information is most relevant to IoT networks since the devices require fresh data for most of the applications. This is extremely challenging requiring a lot of development on the various frontiers from the design point of view. The results provided in this chapter show that efficiency and outage probability for the age of information increase in the number of clusters. Thus, the authors proposed a method to minimize the age of information in the backscatter network. The performance evaluation shows that the proposed method performs better as compared to the random trajectory method.

Chapter "Enhancing Backscatter Communication in IoT Networks with Power-Domain NOMA" concentrates on using the newest backscatter communication technique for a network of sensors deployed in an agricultural farm that transmits the sensed data from plants to the central gateway or reader mounted on top of the farm tractor. The reader reports the collected data to the control center through the Internet for further processing and appropriate actions. This new method has an inheritance from the wireless-powered communication protocol design. However, the key difference is the device transmits data by backscattering the incident carrier RF wave instead of producing and transmitting a signal from its dedicated energy source. To enhance massive connectivity for deployed sensors in the proposed case study, a NOMA principle-based scheme is used which increases the overall spectrum efficiency of a sensors network. It is noted that NOMA is one of the key enabler technique for next-generation 5G cellular networks to increase the system spectrum efficiency. The system performance for all sensors in coverage is analyzed and evaluated in terms of total system outage metrics.

Chapter "NOMA-enabled Wireless Powered Backscatter Communications for Secure and Green IoT Networks" studies the integration of NOMA with backscatter communication. First, this chapter provides the fundamental concepts of NOMA technology, i.e., its key techniques, working principle, features, and integrations with other emerging wireless technologies. Second, this chapter discusses the basics of backscatter communication, its various types, and principles. Then, it also looks into different challenges of NOMA-enabled backscatter communication and their possible solutions. Moreover, this chapter also explains the importance of physical-layer security in wireless communication. Based on the above backgrounds, this chapter investigates the problem of secrecy rate maximization in NOMA-enabled backscatter communication in the presence of multiple eavesdroppers. In particular, an optimization problem to maximize the secrecy rate of NOMA-enabled backscatter communication through efficient reflection coefficient of backscatter tag is formulated. To solve convex optimization, a solution based on dual decomposition is adopted. The performance gap between NOMA-enabled and orthogonal multiple access-based backscatter communication is also confirmed through Monte Carlo simulations.

We hope that this monograph will be helpful for researchers from academia and industries alike. It has been made possible, thanks to contributions from various international experts and research teams. We anticipate that this book will pave the way for future research work on large-scale IoT networks, reconfigurable and software-controlled meta-surfaces, and intelligent reflecting surfaces. It is also hoped that this book will provide a concise picture of the future trends of increasing the efficiency and performance of beyond 5G and forthcoming 6G wireless networks. The book contents will assist the researchers and associated stakeholder communities to narrow down potential ideas for the massive connectivity of IoT networks using backscatter communication.

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