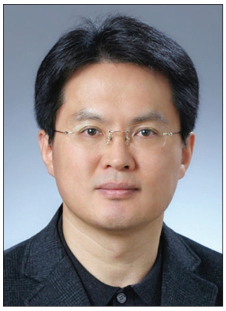
GUEST EDITORIAL

WIRELESS POWERED COMMUNICATION NETWORKS: ARCHITECTURES, PROTOCOL DESIGNS, AND STANDARDIZATION



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The recent advent of wireless energy transfer and harvesting (ETH) technologies has caused an upsurge of research activities directed to the design of novel ETH-based network architectures, protocols, and algorithms. Wireless ETH techniques not only improve the convenience of energy replenishment of electronic devices by obviating the need for physical charging or replacement of a battery, but also become an efficient and economical way to supply energy to a large number of nodes. This controllable one-to-many ETH capability is particularly attractive for many scenarios. For instance, an interesting target scenario for the many ETH-based applications are sensor/actuator networks or, more generally, the so-called Internet of Things (IoT). In this multifarious context, a new networking paradigm, called wireless powered communication networking (WPCN), has been introduced. An ever increasing research interest in this area has been observed in the last few years due to the growing market penetration of both consumer and low-power electronics. The literature on this subject is heterogeneous and characterized by many diverse research directions. This Feature Topic aims at harmonizing the results of these efforts and providing a first comprehensive definition of WPCN, in order to blaze the trail for new tailored designs, novel technical solutions, and clear standardization directions.

Our Call for Papers attracted many submissions worldwide. This gave us the possibility to select for publication, after a thorough review process, the six papers that were best aligned with the aforementioned goal. Tutorial-style introductions to WPCN have been selected for the first part of this Feature Topic, progressively followed by more application-oriented contributions that illustrate a wide range of recent results and key technical challenges associated with WPCN.

The article "Wireless Powered Communication Networks: An Overview" gives an overview of the key networking structures and performance enhancing techniques to build efficient WPCNs. WPCNs eliminate the need for frequent manual battery replacement/recharging, and thus significantly improve the performance and cost over conventional battery-powered communication networks in many aspects, such as higher throughput, longer device lifetime, and lower network operating cost. However, the design and future application of WPCN is essentially challenged by the low WPT efficiency over long distances and the complex nature of joint wireless information and power transfer within the same network. This article provides a detailed introduction to these aspects, and highlights new and challenging future research directions for WPCN.

The article "Some New Trends in Wirelessly Powered Communications" presents important research directions of wireless powered communications that integrate two paradigms: wireless power transfer and wireless communications. While current research focuses on the theoretical aspect, transforming wireless powered communications from theory to practice still faces many challenges such as mobile complexity, power transfer efficiency, and safety. Furthermore, the fundamental limits of wireless powered communications remain largely unknown. The significance of this article lies in introducing a few promising new trends in wireless powered communications research. From the practical perspective, the use of backscatter antennas can support wireless powered communications for low-complexity passive devices, the design of spiky waveforms can improve the power transfer efficiency, and analog spatial decoupling is proposed for solving the power-transfer/information-transfer near-far problem. From the theoretical perspective, the fundamental limits of wireless powered communications can be quantified by leveraging recent results on super-directivity, and the limit can be improved by the deployment of large-scale distributed antenna arrays. Specific research problems associated with these trends are discussed in detail in this article.

The article "On Feasibility of 5G-Grade Dedicated RF Charging Technology for Wireless-Powered Wearables" introduces the concept of endowing future 5G networks with dedicated RF charging capabilities. 5G networks will likely be characterized by heterogeneous integration of multi-radio small cells. This heterogeneity potentially creates several opportunities to realize very efficient wireless energy transfer. This article first describes the general system architecture, setting, and configuration to support practical wireless charging. Subsequently, it discusses the impact of adopting omnidirectional and directional antennas to this end, and proposes a realistic performance evaluation framework that is able to analyze the impact of directional wireless energy transfer on network performance. The framework is based on stochastic geometry. Specifically, the distribution of small cell base stations is modeled according to a Strauss process, the realization of which can include both the Poisson and the hardcore point processes, depending on the adopted interaction parameter. The numerical results clearly show the benefits of the presence of directional antennas at small cell base stations for improving energy transfer efficiency and hence device operating time. Finally, some important research directions are pointed out, such as advanced antenna design, beamforming optimization, and the impact of mobility on energy transfer efficiency and network performance.

The article "Ambient RF Energy Harvesting in Ultra-Dense Small Cell Networks: Performance and Trade-offs" originated from recognizing the increased grid power consumption of large-scale small cell networks (SCNs), especially in view of the foreseen dense deployment of small cells in 5G networks. In this context, the co-channel interference (CCI) from macrocells and overlaid small cells is beneficial for harvesting the energy from ambient RF signals. This article reveals an interesting design trade-off between the improved energy efficiency with ambient energy harvesting from the CCI in SCNs and the link quality in terms of the signal-to-interference-plus-noise ratio (SINR) outage probability of a tagged user in downlink. Additionally, the work demonstrates the feasibility of deploying a mixture of on-grid small base stations (SBSs) (powered by electric grid) and off-grid SBSs (powered by energy harvesting) and optimizes their corresponding portions as a function of the density of SBSs in a geographic area.

The article "Location-Aware Green Communication Design: Exploration and Exploitation on Energy" discusses device-to-device (D2D) techniques to improve spectrum efficiency and take advantage of the neighborhood information. The main focus is on the benefit of energy saving when location-aware devices cooperate. More specifically, the green communication of location-aware devices is discussed from two perspectives: the exploration of energy and the exploitation of energy. The exploration of energy refers to harvesting energy from the transmitted signals, providing a dependable energy source. The exploitation of energy, on the other hand, refers to an efficient strategy to use the accumulated energy based on location-aware clustering techniques. Combining the two aspects, communication among location-aware devices promises to be energy-efficient and highly sustainable.

The article "Secrecy Wireless Information and Power Transfer: Challenges and Opportunities" deals with the conflicting issue between information leakage and power transfer efficiency in secure wireless information and power transfer (SWIPT) settings, which is not observed in conventional secure communication scenarios without energy harvesting. The challenges and opportunities in the design of SWIPT in various scenarios are highlighted. Additionally, effective physical layer security techniques are discussed to provide improved performance of SWIPT, considering the corresponding challenging issues. To this end, massive multiple-input multiple-output (MIMO) techniques are shown to bring significant performance enhancement for SWIPT, thanks to features such as large array gain and high-resolution spatial beams. Finally, several future research directions to identify effective ways of enhancing power transfer efficiency while reducing the information leakage, and thus increasing the performance of SWIPT, are presented.

This Feature Topic has been conceived to provide a comprehensive treatment of wireless energy harvesting and transfer technologies. The six accepted papers outline many open research directions that are useful for researchers in academia and practitioners in industry to shape their future work in this area. As the research in WPCN attracts fast-growing attention, we hope that this Feature Topic will not only serve as a valuable reference for deploying and developing WPCN for various emerging applications, but also encourage readers of *IEEE Wireless Communications* to contribute to discussions on future design, development, and adoption of architectures, protocols, and algorithms for WPCN.

BIOGRAPHIES

DUSIT NIYATO [M'09, SM'15] (dniyato@ntu.edu.sg) is currently an associate professor at the School of Computer Engineering, Nanyang Technological University, Singapore. He received his B.E. from King Mongkuts Institute of Technology Ladkrabang in 1999. He obtained his Ph.D. in electrical and computer engineering from the University of Manitoba, Canada, in 2008. His research interests are in the area of radio resource management in cognitive radio networks and energy harvesting for wireless communication.

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