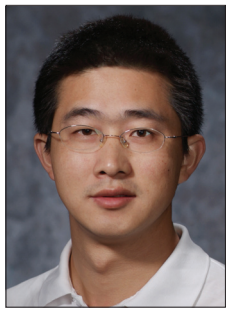
ENHANCING SPECTRAL EFFICIENCY FOR LTE-ADVANCED AND BEYOND CELLULAR NETWORKS







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The rapidly growing demands for bandwidth-intensive mobile broadband services have triggered tremendous efforts to develop the long-term-evolution (LTE)-Advanced and beyond cellular networks, which are widely deemed as a major advancement of the existing LTE networks. Constrained by limited spectral resources, wireless communication researchers and engineers have proposed a number of technologies to efficiently utilize spectral resources in multiple dimensions. Specifically, with a large number of transmit antennas deployed at a base station, massive multiple-input multiple-output (MIMO) (also called full-dimension MIMO [FD-MIMO] in the Third Generation Partnership Project [3GPP] community) is expected to achieve enormous spectral efficiency by exploiting degrees of freedom in the spatial domain. Recent theoretical and experimental findings highlight that massive MIMO is a promising solution to improve data rates , link reliability, and power savings for cellular networks. Another attractive technology, small cells, has also shown great potential for enhancing system throughputs of LTE-Advanced and beyond cellular networks. In the small cell solution, lower-cost base stations are densely deployed, and the size of a cell is substantially reduced, thus enabling great improvement of frequency reuse ratios in the geographical domain and significant enhancement of the spectral efficiency of cellular networks. Also, other technologies such as device-to-device (D2D) and cognitive radio have also emerged as promising solutions to boost the spectral efficiency of cellular networks in various scenarios.

The objective of this Feature Topic is to showcase the recent research and development of spectrally efficient technologies for LTE-Advanced and beyond cellular networks. Our Call for Papers attracted many submissions worldwide. After a rigorous review process, nine papers, which best fit the theme of this Feature Topic and cover a broad spectrum of research topics including massive MIMO, small cell solution, D2D communications, and cognitive radio, were selected for publication.

In the first article, "Enhancing Spectral-Energy Efficiency for LTE-Advanced Heterogeneous Networks: A User's Social Pattern Perspective" by Xing Zhang *et al.*, the authors propose a new paradigm to improve the performance of LTE-Advanced heterogeneous network (HetNet) systems from the point view of users' characteristics. The concept of a user social pattern (USP) is used as an optimization basis for network performance enhancement, which characterizes the general behavior, pattern, and rules of a group of users as a social manner. The proposed USP model is further testified based on the large-scale traffic traces of current cellular networks, and USP-based spectral efficiency and energy efficiency enhancement schemes are also proposed and evaluated.

In the second article, "An Overview of Load Balancing in HetNets: Old Myths and Open Problems" by Jeffrey G. Andrews *et al.*, the authors rethink several long-standing assumptions about cellular networks in the context of a load-balanced HetNet, and further dispel three deeply entrenched myths. In terms of load balancing for HetNet, several primary technical approaches are investigated and compared to draw design lessons for orthogonal frequency-division multiplexing (OFDM)-based cellular systems, and some thoughts on open problems for future exploration are provided.

The third article, "Full Dimension MIMO (FD-MIMO): The Next Evolution of MIMO in LTE Systems" by Younsun Kim *et al.,* explores the characteristics and potential of FD-MIMO technology for evolution toward beyond 4G and 5G cellular networks. Fundamental features and performance benefits of FD-MIMO, together with the ongoing standardization efforts in 3GPP to incorporate FD-MIMO features in the next evolution of LTE, are discussed. Additionally, the design of a 2D antenna array for supporting FD-MIMO is elaborated, and the system-level evaluation results are provided.

In the fourth article, "Spectral and Energy-Efficient Two-Stage Cooperative Multicast for LTE-Advanced and Beyond" by Yiqing Zhou *et al.*, the authors focus on two-stage cooperative multicast to support multimedia services with high spectral and energy efficiency. Their design leverages a mobile relay arrangement scheme based on sector ring structure, which shows significant superiority

over traditional multicast technique with respect to the ability to improve the spectral efficiency in Watts.

The fifth article, "Local Cooperation Architecture for Self-Healing Femtocell Networks" by Wei Wang *et al.*, presents the distinct features of the two-tier macro-femto system necessity dedicated architectures for self-healing femtocell networks. With extensive investigation of the advantages and limitations of three different architectures, the authors call attention to the local cooperative architecture with proper design, which is a better fit for the practical requirements imposed by the salient features of femtocell networks. The proposed outage detection and compensation schemes further manifest the potential benefits of the local cooperative architecture.

In the sixth article, "Beamforming for Small Cell Deployment in LTE-Advanced and Beyond" by Giulio Bartoli *et al.*, the authors separately discuss two major small cell deployment approaches: sharing the same frequency bands with the macrocell or using a separate higher frequency band. The benefits of beamforming in each approach are elaborated, with focus on the discussion of suitable beamforming schemes dedicated to combat the main impairments for different interference scenarios. Solutions based on LTE-Advanced, together with possible challenging solutions in systems beyond LTE-Advanced, are also discussed.

In the seventh article, "Device-to-Device Communications Achieve Efficient Load Balancing in LTE-Advanced Networks" by Jiajia Liu *et al.*, the authors highlight a D2D communication-based load balancing algorithm, which is able to offload traffic among multi-tier cells efficiently according to their real-time traffic distributions. Simulation results show the performance gains improved by the proposed algorithm, indicating its great potential for future application. In addition, the potential challenges in further research and applications of D2D communications are identified.

In the eighth article, "The Role of Mobility for D2D Communications in LTE-Advanced Networks: Energy vs. Bandwidth Efficiency" by Dan Wu *et al.*, the authors study the role of mobility for D2D communications in LTE-Advanced networks from the perspective of energy efficiency (EE) and bandwidth efficiency (BE). By exploiting the parameter of device density to describe the device mobility, a simple but practical mobility model is deployed to capture the track of the mobile services. Based on the relationship between EE and BE, an EE-BE-aware scheduling scheme with a dynamic relay selection strategy is proposed to make the transmission decision flexibly. Also, the authors characterize a precise EE-BE tradeoff curve for various device density theoretically, which enables the network operators to make a quantitative decision on choosing the right parameters with respect to EE and BE.

In the last article, "Spectrum Sharing Using Licensed Shared Access (LSA): The Concept and Its Work Flow for LTE-Advanced Networks" by Marja Matinmikko *et al.*, the authors review different types of spectrum band for LTE/LTE-Advanced and beyond networks and focus on shared spectrum bands using the LSA concept as a potential spectrally efficient solution for spectrum access in the future. Specifically, motivated by a life cycle model from process theory, a work flow for the LSA concept is developed consisting of LSA preparation, licensing, deployment, and release phases, with tasks of the key stakeholders for different phases of the LSA work flow detailed. Moreover, the adaptive ability of the LSA concept for the changing LSA band availability supports its further applications in mobile communication networks.

In conclusion, the Guest Editors would like to thank all the authors who submitted their papers for this Feature Topic, and all the reviewers for their time and effort. Their careful reviews and valuable comments helped us select the appropriate papers and improve the quality of this Feature Topic. Finally, we hope that this special issue will serve as a useful and informative reference for interested readers, and stimulate further research and development activities on spectral efficiency technologies.

BIOGRAPHIES

SHAOWEI WANG [SM'13] received his Ph.D. degree in electronic engineering from Wuhan University, China, in 2006. From 1997 to 2001, he was a research scientist at China Telecom. He joined the School of Electronic Science and Engineering of Nanjing University, China, in 2006, where he has been an associate professor since 2008. From 2009 to 2011, he was also with LAMDA Group, Nanjing University, China. From 2012 to 2013, he was with Stanford University, California, and the University of British Columbia, Canada, as a visiting scholar/professor. His research interests are mainly in wireless communications and networks, optimization, and machine learning. In these areas he has published more than 60 papers in leading journals and conference proceedings.

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WEIYI ZHANG is currently a research staff member of the Network Evolution Research Department at AT&T Labs Research, Middletown, New Jersey. Before joining AT&T Labs Research, he was an assistant professor in the Computer Science Department, North Dakota State University, Fargo, from 2007 to 2010. He received his Ph.D. degree in computer science and engineering from Arizona State University, Tempe. His research interests include routing, scheduling, and cross-layer design in wireless networks; localization and coverage issues in wireless sensor networks; survivable design; and quality-of-service provisioning of communication networks. He has published more than 80 refereed papers, including papers in *IEEE INFOCOM*, *ACM MobiHoc*, *ICDCS*, *IEEE/ACM Transactions on Networking*, *ACM Wireless Networks*, *IEEE Transactions on Vehicular Technology*, and *IEEE Journal on Selected Areas in Communications*. He has served on the Technical or Executive Committees of many internationally reputable conferences, such as IEEE INFOCOM. He was the Finance Chair of IEEE IWQoS '09 and Student Travel Grant Chair of IEEE INFOCOM '11. He received the Best Paper Award in 2007 from IEEE GLOBECOM. He won the AT&T Labs President Excellence Award in 2013.

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