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EDITORIAL

IEEE Access Special Section Editorial: Ultra-Dense Cellular Networks

To satisfy the significant demand for wireless traffic growth in the near future, ultra-dense cellular networks have been extensively investigated recently in both academia and industry. Many techniques, such as massive MIMO (multiple-in multiple-out) antenna arrays, millimeter wave communication, small cells, and heterogeneous networks, have been proposed for the design of future ultra-dense cellular systems. For example, Massive MIMO technology enables the reduction of antenna transmission power, and millimeter wave channels are suitable for short distance communications in outdoor environments. Motivated by these new technologies, cell coverage has also been correspondingly reduced so as to improve the area spectrum usage. To realize seamless coverage, a large number of small cells will be deployed.

Currently, small cells, heterogeneous networks, massive MIMO antenna, and millimeter communications technologies have been investigated separately, whereas significant benefits may be derived by integrating the development of these technologies. Therefore, designing ultra-dense cellular networks using new transmission technologies is both promising and challenging. This Special Section in IEEE *Access* focuses on emerging technologies in the field of ultra-dense cellular networks. Eight high-quality papers have been accepted from leading groups around the world after rigorous peer-review processes.

In the first paper, millimeter wave (mmWave) communications greatly exploit the available transmission bandwidth, which is much wider than today's microwave frequency bands. It has been recognized as an important component of future 5G wireless networks. However, the use of mmWave transmission in cellular channels needs further research in channel propagation measurements, especially in dense cellular networks. In the work by MacCartney et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7181638), "Millimeter-wave omnidirectional path loss data for small cell 5G channel modeling," the authors present mmWave propagation measurement results are obtained in New York City during the summers of 2012 and 2013 and in downtown Austin during the summer of 2011. Large-scale path loss data measured at 28 GHz, 73 GHz, and 38 GHz are presented. Measurement layout maps with transmitter and receiver locations and GPS coordinates are also presented for the further use of other researchers.

It is important for future 5G systems to support highly mobile and dense users in ultra-dense networks with sufficient throughput and QoS requirements. In the article by Kela et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7214194), "Borderless mobility in 5G outdoor ultra-dense networks," a novel scheduling algorithm is proposed to achieve a more uniform distribution of mobile user throughput in ultra-dense networks based on a new frame structure similar to IEEE 802.11ac and LTE-A. The results obtained for a high density of mobile users indicate that the proposed scheduling schemes achieve 77% higher median user-throughput than the maximum-throughput scheduler at the cost of 17% lower area-throughput. Furthermore, the proposed strategy performed better on a UDN deployment than on a micro-cell deployment using more massive planar antenna arrays.

In the third paper, link transmission scheduling plays an important role in millimeter wave communications and mmWave technologies networks based on small cells. In the paper by He et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7210127), "On link scheduling under blockage and interference in 60-GHz ad hoc networks," the authors address the problem of link transmission scheduling in 60GH mmWave ad hoc networks while considering a generic link model. Both single-hop and multi-hop mmWave ad hoc networks are investigated and effective scheduling algorithms are proposed. The findings in this paper are instrumental to enabling future ultra-dense mmWave small cell networks.

The fourth paper describes how small-cell base stations can theoretically achieve the anticipated future data bandwidth demand of 10,000 fold growth in the next 20 years by using large-scale antenna systems and mmWave high-bandwidth spectra. In the article by Muirhead et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7226781), "Insights and approaches for low-complexity 5G small-cell base-station design for indoor dense networks," small cell distances are leveraged to simplify SBS design, particularly considering dense indoor installations. Based on a link budget analysis, theoretical results are compared with the simulation results of a densely deployed indoor network using appropriate mmWave channel propagation conditions.

As discussed above, to enable the use of mmWave communication in mobile cellular networks, the mmWave propagation measurements conducted at 28 GHz and 73 GHz in New York City provided an abundance of valuable results. In the fifth paper, an invited submission by MacCartney et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7289335), ''Indoor office wideband millimeter-wave propagation measurements and channel models at 28 GHz and 73 GHz for ultra-dense 5G wireless networks,'' details of this measurement are presented. The results show that novel large-scale path loss models provided in this paper are simpler and more physics-based compared to previous 3GPP and ITU indoor propagation models. Moreover, multipath time dispersion statistics for mmWave systems using directional antennas are presented.

The sixth paper covers how to implement caching at small cells in an energy-efficient way in view of the explosive growth of mobile data traffic and rapidly rising energy prices. In a work by Zhou et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7268835), ''Energy-efficient context-aware matching for resource allocation in ultra-dense small cells,'' the authors study an energy-efficient context-aware resource allocation problem. To tackle this mixed integer nonlinear programing problem, an energy-efficient matching algorithm based on the Gale-Shapley algorithm is proposed. The simulation results demonstrate that the proposed algorithm achieves significant performance and satisfaction gains compared with the conventional algorithms.

As described in the seventh paper, for ultra-dense cellular networks, diverse proprietary network appliances increase both the capital and operational expenses of service providers while at the same time causing network ossification. Network Function Virtualization (NFV) is proposed to address these issues by implementing network functions as pure software on commodity and general hardware. In the work by Li et al., ''Software-defined network function virtualization: A survey,'' a thorough investigation of the development of NFV under the software-defined NFV architecture is presented. The software-defined NFV architecture as a state-of-the-art NFV technology, significant challenges and relevant solutions of NFV, and future research directions in this field are also provided and discussed.

In the last paper, for future 5G systems, different kinds of networks will work together to form ultra-dense cellular networks. Therefore, the network will be heterogeneous. In the work by Pervaiz et al. (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7270991&tag=1), ''Energy and spectrum efficient transmission techniques under QoS constraints toward green heterogeneous networks,'' a joint energy efficiency and spectrum efficiency tradeoff analysis is proposed as a multi-objective optimization problem in two-tier heterogeneous networks subject to QoS constraints. The results show that the achievable energy efficiency and spectrum efficiency increase with an increase in network densification and user density.

The above papers exemplify the deep technical depth and wide span of this Special Section. However, we recognize that it cannot cover all of the aspects of ultra-dense cellular networks. Finally, we sincerely thank all the authors and reviewers for their efforts, and of course the Editor-in-Chief and Staff Members for their guidance.

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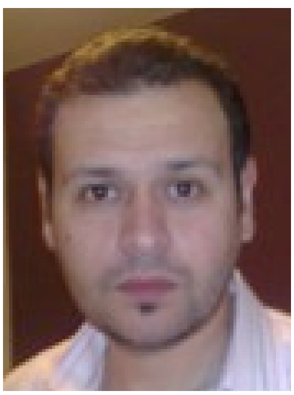

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