IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Date of current version January 18, 2018.
Digital Object Identifier 10.1109/ACCESS.2017.2783020

EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: PHYSICAL AND MEDIUM ACCESS CONTROL LAYER ADVANCES IN 5G WIRELESS NETWORKS

It is an exciting time in telecom research, as connectivity becomes the key ingredient of new vertical markets, such as automotive, smart city, smart grid, and healthcare. Fifth Generation (5G) network infrastructure and technologies have to respond to requirements of these verticals as well as mobile broadband services. 5G networks will be challenged by connectivity "everywhere," "all the time" with traffic from "Internet of Things" (IoT). Data rate, latency, and mobility demands are extremely variable and communication mechanisms bring new challenges for network design. 5G networks are not merely considered as an evolution of existing 4G networks, but emphasis on a variety of emerging communication paradigms such as Machine-Type Communication (MTC) and IoT, has changed the design philosophy of future tactile communication. 5G network design will be service driven with billions of new devices generating heterogeneous traffic. The rate and QoS requirements are going to be much stringent and heterogeneous as compared to 4G networks.

The goal of this Special Section in IEEE ACCESS is to provide a comprehensive overview of key theoretical, standardization, and deployment aspects of physical (PHY) and medium access (MAC) layer technologies and techniques, particularly related to 5G networks. Dense networks, millimetre wave (mmWave) frequency bands and massive MIMO are some of the key technologies in focus for 5G network design [item 1) in the Appendix], while techniques like full duplex communication, non-orthogonal multiple access (NOMA), and wireless caching will support these technologies.

Relative to today's mobile communication systems, it is estimated that 5G should have 1000x higher mobile data volume per area. If a 1000x network capacity increase is meant to be achieved in the following years to satisfy gigabit user experiences and offer ultra-low latency, there will be a need to go denser and denser with the cellular deployments to leverage spectrum reuse. Emerging architectural frameworks, such as cloud RAN, software defined networks and network virtualization will play an important role to provide efficient solutions to improve the spectral efficiency in ultra-dense small cell networks, and handle the spectrum crunch expected by 2020.

In anticipation of much more wireless data to be exchanged, it is important to realize the need of communication in other bands. In addition to microwave frequency bands, millimetre wave (mmWave) frequency bands have been proposed as a mean to meet the spectrum scarcity. However, communication in mmWave bands is challenging due to high attenuation loss resulting from atmospheric impairments and sensitivity to blockage. Investigation on channel modelling, solutions to hardware constraints due to more processing power requirements, and development of technology to effectively utilize mmWave bands will play a key role in 5G networks realization.

Massive MIMO is another technology to realize the goals of 5G wireless networks. In addition to achieving diversity by MIMO technology, massive MIMO is the concept, where antenna arrays with tens to hundreds of antenna elements are deployed at the base station (and receivers) to achieve high spectral and energy efficiency. The signal processing techniques and channel state information estimation for such a huge number of antennas require novel physical layer techniques to effectively realize the gains from large antenna arrays, which opens new research challenges. In the context of 5G networks, there are numerous research challenges to design cross layer systems for improved quality of service (QoS). PHY and MAC layers technologies and techniques need to be developed further and integrated well into the emerging frameworks to meet the above mentioned challenges.

We received an overwhelming response for the Special Section. We sincerely thank all the authors for their contributions. After a careful and detailed review process, 21 articles have been accepted for publication in the Special Section which comprehensively cover state of the art PHY and MAC advances in 5G networks.

We accepted two excellent articles which overview the main challenges and technologies under investigation for 5G networks. The invited article by Simsek *et al.* (On the Flexibility and Autonomy of 5G Wireless Networks) provides a broad perspective on the network architecture and design elements for 5G in order to support various novel use cases with heterogeneous requirements, such as industrial automation, autonomous vehicles, e-health. The article elaborates on the main approaches undertaken by 5G standardization bodies regarding the architecture, softwarization, virtualization, MAC and PHY layers.

The second article by Ankarali *et al.* (Flexible Radio Access Beyond 5G: A Future Projection on Waveform, Numerology and Frame Design Principles) discusses the potential directions to achieve flexibility in radio access technologies (RATs) beyond 5G networks. A framework for developing flexible waveform, numerology and frame design strategies is proposed and its potential role to handle various upper level system issues is addressed.

NOMA is a promising solution to accommodate more users by NOMA resource allocation in power or code domains as compared to orthogonal multiple access. Liu *et al.* (Joint Beamforming and Power Optimization with Iterative User Clustering for MISO-NOMA Systems) discuss beamforming, power allocation and user clustering for the NOMA systems. Efficient algorithms for user partitioning, joint beamforming and power allocation are proposed and performance is evaluated as compared to state of the art schemes. In another article by Ali *et al.* (Non-Orthogonal Multiple Access (NOMA) for Downlink Multiuser MIMO Systems: User Clustering, Beamforming, and Power Allocation) investigate the application of NOMA with successive interference cancellation in downlink (DL) multiuser MIMO cellular systems, where the total number of receive antennas at user equipment ends in a cell is more than the number of transmit antennas at the base station. Dynamic power allocation solutions are proposed with an objective to maximize the overall cell capacity. Ding *et al.* (Random Beamforming in Millimeter-Wave NOMA Networks) discuss random beamforming aspects for NOMA mmWave systems. Stochastic geometry is used to characterize the performance of the proposed mmWave-NOMA transmission scheme by using its highly directionality feature. Two random beamforming approaches are proposed to reduce the system overhead, and their performance is studied analytically in terms of sum rates and outage probabilities.

Full duplex (FD) communication achieves better performance in terms of spectral efficiency as compared to half duplex communications. There are some key challenges associated with application of FD communication which are discussed in 3 accepted articles. Yadav *et al.* (Energy and Traffic Aware Full-Duplex Communications for 5G Systems) address resource allocation problem in a multi-carrier heterogeneous network with densely deployed small cells where each cell operates in FD mode. The authors minimize the data buffer length of each user equipment in the network by jointly designing the beamformers, power and sub-carrier allocation and their scheduling. The rate-dependent energy consumed for data decoding of the uplink (UL) user equipments is also taken into account in the total energy consumption at the small cell base stations. Numerical simulations compare the network scenario which accounts for uplink channel rate-dependent energy consumption with that which ignores it. Randrianantenaina *et al.* (Interference Management in Full-Duplex Cellular Networks with Partial Spectrum Overlap) consider a flexible duplex system, and propose a fine-grained bandwidth control for each UL/DL channel pair in each base station (BS). Resulting interference issues are managed by maximizing a network wide rate-based utility function, subject to UL/DL power constraints. This optimization framework jointly determines user-to-BS association, user-to-channel scheduling, UL and DL transmit powers, and the fraction of spectrum overlap between UL and DL for every user. Simulation results show the benefits of the proposed scheme. Qurrat-Ul-Ain *et al.* (Performance Analysis of Compact FD-MIMO Antenna Arrays in a Correlated Environment) analyze the performance of FD-MIMO system for uniform linear array (ULA) and the uniform circular array (UCA) configuration of antenna ports. The authors compare the spatial correlation and mutual information (MI) performance of the ULA and UCA configurations in the 3GPP 3-D urban-macro and urban-micro cell scenarios and study the performance patterns of the two arrays as a function of several channel and array parameters.

Three accepted articles consider application of MIMO technology to various communication systems. Sboui *et al.* (Energy-Efficient Power Allocation for MIMO-SVD Systems) treat the problem of energy efficiency (EE) in MIMO systems. The authors propose a new allocation scheme based on analytical expressions of the optimal power. The numerical results confirm that this scheme results in EE that improves as the number of antennas increases. Sboui *et al.* (Achievable Rates of UAV-Relayed Cooperative Cognitive Radio MIMO Systems) study the achievable rate of an UL MIMO cognitive radio system, in which the secondary user (SU) and the primary user (PU) communicate to the closest primary BS through the same unmanned aerial vehicle (UAV) relay. A special linear precoding scheme is proposed to enable the SU to exploit the PU free eigenmodes, and the optimal power allocation that maximizes the achievable rate of the SU respecting a number of constraints is derived. Numerical results show the gains of the proposed network architecture. Sacchi *et al.* (Millimeter-Wave Transmission for Small-Cell Backhaul in Dense Urban Environment: a Solution based on MIMO-OFDM and Space-Time Shift Keying (STSK)) propose a viable MIMO solution for high bit-rate transmission in the E-band with application to small-cell backhaul based on space-time shift keying (STSK) and orthogonal frequency division multiplexing. The authors consider the most significant channel impairments related to small-cell backhaul in dense urban environment, namely, the correlated fading with and without the presence of line-of-sight, the phase noise, the rain attenuation, and shadowing; and perform a comparative study for STDK against other techniques using simulations.

The following articles discuss various aspects of system design at physical layer. Zhao *et al.* (Peak-to-Average Power Ratio Reduction of FBMC/OQAM Signal Using a Joint Optimization Scheme) consider peak-to-Average Power Ratio (PAPR) problem in the context of the modulation based on Filter Bank Multicarrier with Offset Quadrature Amplitude Modulation (FBMC/OQAM), a candidate for 5G systems. The article introduces a PAPR scheme based on linear and non-linear methods, which is shown to have solid performance. Mahmood *et al.* (Interference Aware Inter-Cell Rank Coordination for 5G Systems) propose an interference aware inter-cell rank coordination framework for the future 5G wireless system. Centralized and distributed implementations of the proposed inter-cell rank coordination framework are presented, followed by exhaustive Monte Carlo simulation results demonstrating the performance. Yan *et al.* (A Dimension Distance-Based SCMA Codebook Design) presents an optimized codebook design for Sparse Code Multiple Access (SCMA), suited for receivers that operate with message passing algorithm. Simulation results show that the proposed design leads to superior performance in terms of Bit Error Rate. Sidrah *et al.* (Asymmetric Hardware Distortions in Receive Diversity Systems: Outage Performance Analysis) study the impact of asymmetric hardware distortion (HWD) on the performance of receive diversity systems using linear and selection combining receivers. The achievable rate performance is analyzed for the ideal and non-ideal hardware scenarios using proper Gaussian signaling (PGS) and improper Gaussian signaling transmission schemes for different combining receivers.

The following 6 articles address system, MAC and resource allocation aspects of 5G. Parida *et al.* (Stochastic Geometry-based Modeling and Analysis of Citizens Broadband Radio Service System) model and analyze a cellular network that operates in the licensed band of the 3.5-GHz spectrum and consists of a licensed and an unlicensed operator. The performance of the spectrum sharing system is characterized using tools from stochastic geometry.

Vilgelm *et al.* (LATMAPA: Load-Adaptive Throughput-MAximizing Preamble Allocation for Prioritization in 5G Random Access) study random access prioritization through separating the random access preambles into non-overlapping priority classes. Based on the obtained insights, the authors develop the Load-Adaptive Throughput-MAximizing Preamble Allocation (LATMAPA) scheme, which adjusts the preamble allocation to the priority classes according to the random access load and a priority tuning parameter. Simulation results indicate that LATMAPA provides effective QoS differentiation across a wide range of random access loads, which are expected in 5G systems. Yu *et al.* (Uplink Scheduling and Link Adaptation for Narrowband Internet of Things Systems) propose a novel UL link adaptation scheme with the repetition number determination to guarantee transmission reliability and improve throughput of NB-IoT systems. Link-level simulations are performed to validate the performance of the proposed UL link adaptation scheme. The results show that the proposed UL link adaptation scheme for NB-IoT systems outperforms the repetition-dominated method. Ferdosian *et al.* (Multi-Targeted Downlink Scheduling for Overload-States in LTE Networks: Proportional Fractional Knapsack Algorithm with Gaussian Weights) design resource scheduling policies for supporting the efficient delivery of heterogeneous traffic in overload states of a cell. The objective of the formulated problem is to meet QoS requirements and provide fairness for all standardized service classes. The authors propose Proportional Fractional Knapsack algorithm for guaranteeing effective utilization of resources for heterogeneous traffic and evaluate its performance. Mi *et al.* (Statistical QoS-Driven Resource Allocation and Source Adaptation for D2D Communications Underlaying OFDMA-based Cellular Networks) consider a cellular network, in which multiple cellular users and device-to-device pairs with delay QoS requirements coexist to share multiple sub-channels. An effective resource allocation and source adaptation policy is proposed, aiming at maximizing the system throughput while satisfying each user's delay QoS requirement. Alternating optimization, successive convex approximation, and outer approximation method are used to solve the complex optimization problem. Hamnah *et al.* (Resource Optimization in Multi-Tier HetNets Exploiting Multi-Slope Path Loss Model) investigate the impacts of multi-slope path loss models, where different link distances are characterized by different path loss exponents and propose a framework for joint user association, power and subcarrier allocation on the DL of a heterogeneous network (HetNet). The authors compare the performance of the proposed approach under different path loss models to demonstrate the effectiveness of dual-slope path loss model in comparison to single-slope path loss model.

The authors would like to thank our reviewers who provided timely and detailed reviews to help us complete review process for the Special Section in time. Finally, the authors appreciate the support of Editor-in-Chief and Staff Members for their guidance and cooperation.

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APPENDIX
RELATED WORK

1) F. Boccardi, R. W. Heath, Jr., A. Lozano, T. L. Marzetta, and P. Popovski, "Five disruptive technology directions for 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 74–80, Feb. 2014.

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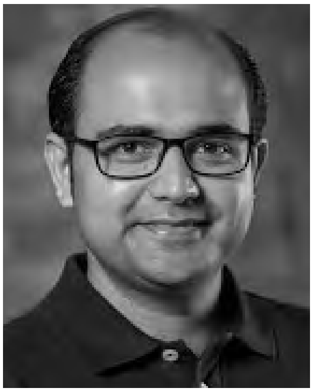

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