Introduction to the Issue on Signal Processing Advances for Non-Orthogonal Multiple Access in Next Generation Wireless Networks

RECENT years have witnessed the explosive growth of mobile data traffic, which has led to ever-increasing demand for high system throughput, massive user access, heterogeneous data traffic, high bandwidth efficiency, and ultra-low latency. Non-orthogonal multiple access (NOMA) has received considerable attention in both industry and academia as an efficient multiple access scheme to meet this demand. The concept of NOMA is to encourage spectrum sharing and to accommodate multiple users in the same orthogonal resource block, such as a time slot, a frequency band, and a spatial direction. By doing so, high bandwidth efficiency and massive connectivity can be attained. Because of its superior performance, NOMA has already been included in the 3rd generation partnership project long-term evolution advanced (3GPP-LTE-A) standard and the next generation digital TV standard (ATSC 3.0), while new proposals for including NOMA in the 5G New Radio (NR) have been put forward. While the principle of NOMA has been well-accepted by both academia and industry, there are still many open issues related to the required signal processing. The aim of this special issue is to present solutions for signal processing and practical implementation problems related to NOMA, in order to close the gap between theory and practice. In fact, this special issue presents innovative solutions to advanced signal processing designs for of NOMA systems.

As Guest Editors of this special issue, we aimed to showcase the variety of topics outlined in the Call for Papers. We were very encouraged by the fact that this special issue attracted a large number of submissions, which allowed us to select an excellent set of papers, representatives of that diversity. Nevertheless, unfortunately we had to reject many high quality papers because of lack of space. In particular, after a rigorous review process, 27 out of 79 submissions were accepted for publication. These papers cover a wide range of topics in the area of advanced signal processing for NOMA.

A. Resource Management in NOMA Networks

Broadly speaking, resource management refers to user scheduling and resource allocation, which have been targeted by several research contributions in this special issue. In particular, the paper "Delay-Minimization Nonorthogonal Multiple Access enabled Multi-User Mobile Edge Computation Offloading" by Wu *et al.*, proposes a novel NOMA-enabled computation offloading scheme, where NOMA users can offload their computing tasks to a mobile edge server in a more spectrally efficient manner, compared to orthogonal multiple access (OMA). The work "A General Framework for Temporal Fair User Scheduling in NOMA Systems" by Shahsavari *et al.*, applies a new user scheduling scheme for NOMA systems, by considering temporal fairness constraints for the optimal system utility to be achieved. The next paper is "Rethinking Outage Constraints for Resource Management in NOMA Networks" by Cui *et al.*. It first redefines the outage probability of NOMA systems, and then, this probability is used to formulate a joint optimization problem for user scheduling and power allocation. Lin *et al.* in the paper "Cache-Aided Non-Orthogonal Multiple Access: The Two-User Case" propose a two-user case cache-aided NOMA scheme by exploiting the data cached at the users for interference cancelation. More particularly, the achievable rate region of the considered scheme is characterized. Tang *et al.* in the paper "Energy Efficiency Optimization for NOMA with SWIPT?", propose a joint power allocation and time switching control scheme and investigate a wireless powered NOMA network in order to increase the energy efficiency. The next work by Wen *et al.*, "Interference Pricing Resource Allocation and User-Subchannel Matching for NOMA Hierarchy Fog Networks," demonstrates the applicability of NOMA to hierarchical networks and fog computing, where the associated resource allocation problem is solved by using a two-stage Stackelberg game. The last paper on this topic is "A Green Coordinated Multi-Cell NOMA System with Fuzzy Logic Based Multi-Criterion User Mode Selection and Resource Allocation" by Zeng *et al.*, where a coordinated NOMA scheme in multi-cell systems is studied, in which the user mode selection and resource allocation problems are jointly investigated to improve the spectral efficiency.

B. Transceiver Design for NOMA

Several papers in this special issue are devoted to the transceiver design for NOMA. The paper "Non-Orthogonal Multiple Access with Improper Gaussian Signaling" by Tuan *et al.*, proposes the use of improper Gaussian signalling (IGS) in NOMA systems in order to enhance the system throughput, where the additional degrees of freedom provided by IGS are exploited. "Delay Guarantee and Effective Capacity of Downlink NOMA Fading Channels" by Xiao *et al.*, exploits a stochastic network calculus to derive closed-form expressions for the delay violation probability in downlink NOMA systems for

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both Nakagami-m and Rician channels. In the work "Hybrid NOMA/OMA with Buffer-Aided Relay Selection in Cooperative Networks," Nomikos *et al.* propose a novel relay selection scheme for cooperative hybrid NOMA networks, where the outage performance is improved by exploiting relays with buffers.

C. The Application of NOMA to Internet-of-Things (IoT) Networks

NOMA is a promising technique for addressing the massive connectivity requirements of IoT networks, and thus, several papers in this special issue are devoted to this topic. In the paper "Design of Non-Orthogonal Beamspace Multiple Access for Cellular Internet-of-Things," Jia *et al.* propose a novel non-orthogonal beamspace multiple access framework for channel state information (CSI) acquisition and beam design in IoT networks with massive connections. The next work, "Delay Minimization for Massive Internet of Things with Non-Orthogonal Multiple Access" by Zhai *et al.*, investigates the joint optimization of user scheduling and power allocation with the aim to minimize the access delay in IoT networks.

D. NOMA Assisted Millimeter-Wave (mmWave) Communications

Two contributions in this special issue illustrate the high potential of integrating NOMA and mmWave, both of which have been recognized as key enabling technologies for the next-generation wireless networks. In the paper "NOMA for Hybrid mmWave Communication Systems with Beamwidth Control," Wei *et al.* consider a novel NOMA-mmWave scheme applying beamwidth control, which enables a single radio frequency chain to serve more than one user. By doing so, the system energy efficiency can be significantly increased. The work "Channel Estimation and Transmission Strategy for Hybrid MmWave NOMA Systems" by Fan *et al.* proposes a novel channel estimation strategy for the considered mmWave-NOMA systems. Moreover, based on the designed strategy, multi-user scheduling and power allocation are jointly investigated for maximizing the achievable data rate.

E. Massive MIMO and NOMA

Massive MIMO is a compelling technique, which significantly increases the performance of wireless networks. The application of NOMA in massive MIMO networks is explored in this special issue in the following two papers. In "What Role Can NOMA Play in Massive MIMO?," Senel *et al.* compare the performance of NOMA and multi-user beamforming. It is shown that multi-user beamforming is capable of outperforming NOMA in massive MIMO setups. The work "NOMA-Aided Multi-Cell Massive MIMO Downlink" by Kudathanthirige *et al.* proposes novel user clustering and pilot assignment schemes for massive MIMO multi-cell NOMA networks. Numerical results demonstrate that the proposed schemes are capable of leveraging the users' spatial covariance matrices.

F. NOMA for Aerial-to-Ground Communications

Aerial-to-ground communication is an emerging research area where application of NOMA is also benefical. In "Angle Feedback for NOMA Transmission in mmWave Drone Networks," Rupasinghe *et al.* aim to reduce the system overhead caused by full CSI feedback. In this direction, it proposes several limited feedback schemes for NOMA-mmWave aided unmanned aerial vehicle (UAV) networks. The paper "Uplink Cooperative NOMA for Cellular-Connected UAV" by Mei *et al.* proposes a NOMA-aided uplink communication system, where one UAV is capable of communicating with several cellular BSs, while sharing the spectrum with ground users. The next work is the "Joint Beamforming and Power Allocation for Satellite-Terrestrial Integrated Networks with Non-Orthogonal Multiple Access" by Lin *et al.*. It proposes the application of NOMA in satellite to terrestrial communications. Specifically, a satellite can utilize the mmWave spectrum to communicate with ground users, and the paper investigates the joint optimization problem for beamforming design and power allocation is investigated.

G. Security Provisioning for NOMA

Several works in this special issue focus on security provisioning for NOMA. The paper "Secure Users Oriented Downlink MISO NOMA" by Wang *et al.*, considers secure transmissions for the multiple-input single-output NOMA downlink with the objective to optimize the achievable minimum secrecy rate, where zero-forcing beamforming techniques are proposed to cancel the interference among users. The work "Securing Downlink Massive MIMO-NOMA Networks with Artificial Noise" by Zeng *et al.*, proposes the application of artificial noise for enhancing the physical layer security of massive MIMO enabled NOMA networks. The last paper on this topic is "Physical Layer Security in Cognitive Radio Inspired NOMA Network" by Xiang *et al.* It investigates the physical layer security of cognitive radio inspired NOMA networks by designing a novel secure NOMA transmission strategy to improve the security performance.

H. Coding and Modulation for NOMA

Several research contributions related to the design of advanced coding and modulation for NOMA are included in this special issue. The work "Spatial Modulation-Aided Cooperative NOMA: Performance Analysis and Comparative Study" by Li *et al.*, investigates the coexistence of spatial modulation (SM) and NOMA, by proposing a novel cooperative SM-aided NOMA scheme. The paper "NOMA Aided Precoded Spatial Modulation for Downlink MIMO Transmissions" by Yang *et al.*, proposes a NOMA-aided SM scheme for overloaded downlink transmission, which inherits the advantages of both techniques, i.e., low transceiver complexity due to SM and high spectrum efficiency due to NOMA. The next paper is "Joint Active User Detection and Channel Estimation in Massive Access Systems Exploiting Reed-Muller Sequences" by Wang *et al*. It investigates the use of Reed-Muller sequences for detecting active users and estimating the channel for machine type communications.

The work "Iterative Gaussian-Approximated Message Passing Receiver for MIMO-SCMA System" by Dai *et al.*, proposes two novel message passing algorithms, by using the extended factor graph for joint multiuser and MIMO detection. The paper "TCM-NOMA: Joint Multi-User Codeword Design and Detection in Trellis-Coded Modulation-Based NOMA for Beyond 5G" by Di *et al.*, proposes to map multiple users' data streams jointly to one superposed codeword. By doing so, the proposed novel NOMA-based trellis-coded modulation schemes are capable to increase the system coding gain.

We would like to thank all authors who have submitted manuscripts to this special issue, as well as the large number of reviewers, whose feedback helped to facilitate a special issue of the highest quality. We would like to thank the Editor-in-Chief, Professor Shri Narayanan, and the entire IEEE JSTSP editorial board for guidance. Furthermore, we would like to thank the journal coordinators, Allison Fisher and Rebecca Wollman, who have provided effective support throughout the reviewing process. We hope that this NOMA-related special issue will become a stepping stone for future developments and advancements in terms of signal processing techniques for NOMA-based systems. We also hope that the readers will find articles of interest in this special issue that are useful for their future research.

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