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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: NEW WAVEFORM DESIGN AND AIR-INTERFACE FOR FUTURE HETEROGENEOUS NETWORK TOWARDS 5G

Unprecedented levels of spectral and energy efficiency are expected from next-generation wireless networks to achieve ubiquitous communications between anybody, anything, and at any time. Fifth-generation (5G) radio access technology is expected to take a huge leap compared to the previous radio generations by supporting cognitive radio, machine type communication, and the Internet of Things, besides traditional mobile broadband access. The necessity of supporting new services targeted by 5G has made researchers to question the suitability of the orthogonal frequency-division multiplexing (OFDM) waveform as adopted in Long-Term Evolution (LTE). However, the demerits of OFDM are recognized to be its large out-of-band emissions, which affect the coexistence of asynchronous services or devices, as well as its sensitivity to phase noise, Doppler frequency shift, and large peak-to-average power ratio (PAPR). Significant research effort is currently being spent on the design and analysis of alternative solutions aimed at overcoming the inefficiencies of present waveforms. Candidate multicarrier solutions rely on different degrees of filtering to obtain lower sidelobes than OFDM, thus improving robustness to asynchronous transmission. For example, in filter bank multicarrier (FBMC) approaches, universal filter multicarrier (UFMC), and generalized frequency-division multiplexing (GFDM). Even though the mentioned solutions offer undeniable advantages in terms of spectrum containment, their suitability as 5G waveforms when considering complexity constraints, as well as realistic impairments, is still disputable. In particular, the extension to multiple-input multiple-output (MIMO) antenna transmission with multiple streams seems rather cumbersome. Thus, this will lay down an interdisciplinary research agenda that combines energy and time-efficient spectrum schemes into waveform design.

This Special Section on New Waveform Design and Air-Interface for Future Heterogeneous Network Towards 5G was developed with the goal of publishing the most recent results in new waveform design and air-interface for future heterogeneous networks toward 5G. The response to our Call for Papers was overwhelming, with 210 articles submitted worldwide. During the review process, each article was assigned to and reviewed by many experts in relevant areas, undergoing a rigorous one or two rounds of the review process. Thanks to the great support from the Editor-in-Chief of IEEE Access, Prof. Derek Abbott, we were able to accept 64 excellent articles covering various aspects of new waveform design and air-interface for future heterogeneous network toward 5G.

In the article "Evaluating spatial resolution and channel capacity of sparse cylindrical arrays for massive MIMO," by Wu *et al.*, three new arrays, namely co-prime cylindrical array (CCA), nested cylindrical array (NCA), and sparse nested cylindrical array (SNCA), are proposed, which are based on co-prime linear array, nested linear array, and sparse circular array, respectively. Compared with the traditional uniform cylindrical array (UCA), the proposed arrays vastly reduce the number of antennas used at the Base Station.

The article by Wu and Liang, "Coprime interpolation and compressive sensing for future heterogeneous network towards 5G," proposes a co-prime-interpolated compressive sensing approach, which could recover the downsampled data on the receiver side. The co-prime structure, interpolation, and compressive-sensing are combined in order to improve the resolution of reconstructed images through compressive-sensing. This approach provides a potential solution for future heterogeneous networks toward 5G.

The article "On the downlink throughput capacity of hybrid wireless networks with MIMO," by Zhang *et al.*, analyzes the downlink outage throughput capacity in slow fading scenarios and gets the closed-form outage capacity. Then, it analyzes the ergodic throughput capacity over a fast fading channel and gets the ergodic capacity in both low-SNR and high-SNR scenarios. In 5G-based cognitive radio, the primary user signal is more active due to the broad frequency band. The traditional cooperative spectrum sensing only detects one characteristic of PU using one kind of detector, which may decrease the sensing performance when the wideband PU is in a severe fading channel.

In the article by Liu *et al.*, ''Multi-modal cooperative spectrum sensing based on Dempster–Shafer fusion in 5G-based cognitive radio,'' multimodal cooperative spectrum sensing is proposed to make accurate decisions through the combination of multimodal sensing data of the PU signal such as energy, power spectrum, and signal waveform.

In the article ''An identification decision tree learning model for self-management in virtual radio access network: IDTLM,'' by Zou *et al.*, the authors perform research on the redundant problem of traditional packet decision trees and reduce the dimensionality of features by a proximal gradient descent method and cluster the features by Lagrange's multiplier so as to improve the online matching speed between applications and virtual service. In consideration of the independent and nonidentical distribution among online and trained data, and the possible change of virtualized network platforms, a method of transfer learning is proposed to improve the quality of generalization for IDTLM.

The article ''Decorrelating receiver of interference mitigation in mmWave small cells networks,'' by Zhang *et al.*, investigates interference cancellation (IC) with the aim of developing a decorrelating receiver. It begins by suppressing the interference in the multiple antennas mode by means of well-known zero-forcing and a minimum mean square error algorithm. Then, the authors investigate more active IC. To further reduce the impact of interference in HetNets, a hybrid HetNets paradigm is developed.

The orthogonal frequency division multiplexing (OFDM) technique is the most-used approach in various wireless communication technologies due to its implementation advantages. However, OFDM also has some significant drawbacks, such as sensitivity against real-time impairments and poor peak-to-average power ratio (PAPR) performance. In the article by Gokceli *et al.*, ''Superposition coded-orthogonal frequency division multiplexing,'' superposition coding is adopted to OFDM, and superposition coded-OFDM (SC-OFDM) is proposed.

In the article ''On the concatenated transmission scheme with the low-complexity symbol-level watermark decoder for recovering the synchronization,'' by Liu, the author faces high computational complexity for recovering synchronization in the Davey–MacKay (DM) concatenated code and selects a threshold to prevent the paths having very low forward and backward quantities from participating in the calculation of log-likelihood ratios from the watermark decoder.

The article ''ARMA-based adaptive coding transmission over millimeter-wave channel for integrated satellite-terrestrial networks,'' by Gu *et al.*, proposes a practical time-varying rain attenuation prediction model based on the autoregressive-moving-average (ARMA) model. Then, it develops an adaptive coding transmission (ACT) scheme based on the analog fountain codes combined with the ARMA mmWave channel prediction model. The key parameters are selected based on a trade-off between the decoding failure probability, block length, and overhead for its ARMA-based ACT scheme.

The article ''Utilization-oriented spectrum allocation in an underlay cognitive radio network,'' by Zhang *et al.*, considers the problem of spectrum access and assignment in underlay cognitive radio networks (CRNs). The problem is modeled as a global optimization problem by considering the interference between primary and secondary users, and the interference between secondary users and the utilization of the entire network. The utilization of the underlay CRN is maximized in the optimization model. To effectively solve this combinatorial optimization problem, a modified binary artificial bee colony algorithm is proposed.

The article ''Pseudo-noise sequence based synchronization for generalized frequency division multiplexing in 5G communication system,'' by Na *et al.*, designs a pseudo noise (PN)-based preamble and proposes an approach for signal synchronization. The preamble is composed of two identical PN sequences whose autocorrelation and cross-correlation are better than cyclic prefix (CP). Symbol timing offset (STO) can be detected by calculating the correlation coefficient between the local PN sequence of a receiver and the corresponding preamble part of a sliding window. These two adjacent PN sequences can be used to calculate the phase offset value by Fourier transform and then obtain CFO value.

The article ''Beam discovery signal-based beam selection in millimeter wave heterogeneous networks,'' by Yin *et al.*, proposes a mmWave massive MIMO beam selection algorithm based on the beam discovery signal (BDS), where each beam transmitted by the mmWave access point is identified by a specific BDS, and the best beam for the user equipment is then determined by detecting the BDS. In addition, in mmWave heterogeneous networks with densely deployed small cells, strong interference beams are determined through inter-cell cooperation, and orthogonal codes are allocated to the optimal beams and strong interference beams to reduce beam interference from adjacent cells.

The article ''Partial interference alignment for heterogeneous cellular networks,'' by Wang and Liang, proposes a partial interference alignment scheme for heterogeneous network downlink transmission at an intermediate SNR by considering the power imbalance among the macro cell and small cell BSs. The hard partial interference alignment adaptively selects the subspace for transmission and captures the trade-off of the transmission dimensions of small cell users and macro cell users. The soft partial interference alignment is used to further improve the hard interference alignment by iteratively balancing the interference and useful signals on each user side. Also, large dimensional analysis is performed to show that the number of transmit dimensions which can be exploited by the small cell BS is determined by the SNR of the system and singular value distribution of the channel matrix.

The article ''Modeling and throughput analysis of an ADO-OFD based relay-assisted VLC system for 5G networks,'' by Na *et al.*, proposes a novel relay-assisted VLC system based on asymmetrically clipped direct current biased optical OFDM (ADO-OFDM) for 5G networks.

An amplify-and-forward relay is used in the proposed system to forward the signals from the source terminal and transmit its own signals simultaneously. The signals from the source terminal are allocated to even subcarriers, while the signals from the relay terminal are allocated to odd subcarriers. Then, these two parts of the signals are combined to constitute ADO-OFDM signals. The signals on odd subcarriers do not interfere with the signals on even subcarriers, while the interference of the signals on even subcarriers to the signals on odd subcarriers can be eliminated by the noise estimation in ADO-OFDM system. Finally, both signals can be recovered at the receiver. It derives the formula of system throughput and investigates the impacts of two power allocation factors on system throughput.

In the article ''A novel hybrid access protocol based on traffic priority in space-based network,'' by Jia *et al.*, a novel hybrid access protocol based on traffic priority in the space-based network is proposed, where the frequency–time division multiple access (F-TDMA) is introduced into the space-based network first and for some improvements by joining the time-domain of F-TDMA to meet the specific requirements of the satellite users. Moreover, different traffics in the space-based networks are also considered. The analysis and simulation results show that the hybrid access protocol can obtain a higher throughput and a lower collision probability with a lower average delay compared with the traditional collision avoidance carrier sense multiple access (CSMA/CA).

The article ''Increasing the capacity of cellular network with nested deployed cooperative base stations,'' by Wu and Liang, investigates the capacity of cooperative cellular networks and proposes to use 2-D nested deployment on the base stations. The authors leverage the traditional model of regarding the coverage of base stations as hexagonal blocks and views each hexagon as a macro-cell. One of the theoretical contributions of this article is to use the invariance in the difference co-array to cover the derive the entire set of the channel fading coefficients. Furthermore, this article proves the validity of using the average sum-rate capacity to calculate the capacity of the networks in both Rayleigh fading and nonfading channels.

In the article ''Spectrum resource optimization for NOMA-based cognitive radio in 5G communications,'' by Liu *et al.*, nonorthogonal multiple access (NOMA)-based cognitive radio (CR) has been proposed to allow the secondary user (SU) to access multiple subchannels both at the absence and presence of the primary user (PU). PU-first-decoding mode (PFDM) and SU-first-decoding mode (SFDM) are proposed at the receiver to decode the NOMA signals, respectively.

The article ''A novel diversity receiver design for cooperative transmission system,'' by Gao *et al.*, proposes an efficient two-stage receiver design for a relay-assisted transmission scenario over frequency-selective channels. It is also demonstrated that the receiver can achieve the full diversity order of the system by incorporating linear processing techniques. With this method, the potential spatial diversity and multipath diversity can be obtained by the diversity-combining technique, through which frequency-selective fading channels can be equivalently transformed.

Delay/disruption tolerant networking (DTN) was proposed as an internetworking architecture to accommodate the frequent and lengthy link disruptions and/or long propagation delays that are common in a challenging communication environment. Reliable data delivery and effective mission control, which are critical in space explorations, are some of the common challenges faced in the application scenario of the DTN technology. The article ''Modeling disruption tolerance mechanisms for a heterogeneous 5G network,'' by Wang *et al.*, presents a study of bundle protocol (BP) for reliable data delivery in space communications characterized by multiple link disruption events, accompanied by an extremely long propagation delay and data loss.

The article ''On performance of optical wireless communication with spatial multiplexing towards 5-G,'' by Li, studies the impact of air turbulence on the purities of multiplexed orbital angular momentum (OAM) states. The split-step propagation scheme combined with the Monte Carlo phase screen method is employed to accurately emulate the optical wireless communication (OWC) link with OAM-based spatial multiplexing.

The article ''Design of waveform shaping filter in the UFMC system,'' by Wen *et al.*, puts forward an effective scheme for designing an anti-interference filter for UFMC systems, where the Nyquist condition (or sampling intersymbol interference equivalently), the in-band distortion, and the out-of-band emission are taken into consideration. This article models the filter design as a constrained minimax optimization concerning the abovementioned filter performance indexes. Then, the original nonconvex constraints on the Nyquist condition are approximately transformed into a linear matrix inequation and two linear inequations. Finally, the optimization problem is solved by semidefinite programming.

The article ''Multi-slot spectrum auction in heterogeneous networks based on deep feedforward network,'' by Zhao *et al.*, studies the spectrum auction based on the waveform and air-interface of wireless users, the interests of the channel for the auction, and the interference they suffered during communication as well as their economic capability. The authors adapt the deep feedforward network algorithm to perform waveform and air-interface data analysis and integration for multislot spectrum auction, to address the problem of making the analysis and the integration of such multiple factors for multislot spectrum auction.

The article ''A KNN learning algorithm for collusion-resistant spectrum auction in small cell networks,'' by Zhao and Tang, proposes a collusion-resistant spectrum auction algorithm based on K-Nearest Neighbor (KNN) learning in small cell networks. The algorithm can satisfy the increasing requirements of broadband services, improve the utilization of spectrum, and also enhance the power-transmitting

efficiency in small cells. Considering the interference among small cells, the KNN algorithm is used to classify all the small cells based on the small cells' geographic locations and interference radius, which can improve the collusion-resistance ability of spectrum auction and improve the spectrum allocation efficiency.

The article ''Comparative performance evaluation of intrusion detection methods for in-vehicle networks,'' by Ji *et al.*, analyzes potential security threats to 5G vehicular networks and focuses on intrusion detection methods for in-vehicle networks. The authors selected four experiment scenarios from potential attacks to in-vehicle networks and collected real car data to compile various attack databases for the first time. In order to find appropriate methods to identify different attacks, four light-weight intrusion detection methods are presented to recognize abnormal behaviors of in-vehicle networks. Furthermore, this study undertakes a detection performance comparison between four detection methods while considering comprehensive evaluation metrics.

The article ''Performance analysis of non-orthogonal multiple access with underlaid device-to-device communications,'' by Madani and Sodagari, investigates the impact of the integration of D2D communications with a downlink NOMA system. In a cluster of two cellular users and a D2D pair, it extracts power control strategies for the base station (BS), which allows for cellular users to achieve a higher sum rate and higher individual rates in NOMA compared to orthogonal multiple access (OMA). The D2D link has the same rate in both OMA and NOMA systems in the proposed scheme. It further derives the probability that both users obtain higher rates in NOMA under a fixed power control strategy.

In the article ''Circularly pulse-shaped precoding for OFDM: A new waveform and its optimization design for 5G new radio,'' by Huang and Su, a new circularly pulse-shaped (CPS) precoding orthogonal frequency division multiplexing (OFDM) waveform, or CPS-OFDM for short, is proposed.

The article ''A base station DTX scheme for OFDMA cellular networks powered by the smart grid,'' by Wang *et al.*, considers distributed smart grids which can power cellular networks using renewable and conventional energy. It jointly optimizes the discontinuous transmission (DTX), resource allocation, and smart grid energy procurement to maximize the profit of the network operators and minimize the GHG emission. It formulates the joint optimization problem as a mixed integer programming problem.

In the article ''Joint rate and BER scheduling resource allocation for wireless communication systems,'' by Guan *et al.*, the relationship between rate and bit error rate (BER) was established by considering both the communication channel decay and the error control mechanism. A resource allocation based on joint rate and BER scheduling (JRBS) was proposed to satisfy the transmission power requirement generated by the quality change in communication channels.

The article ''Experimental testbed of post-OFDM waveforms toward future wireless networks,'' by Zayani *et al.*, provides details and design guidance to improve the energy efficiency and robustness of the studied waveforms through new approaches of digital predistortion (DPD) and peak-to-average power ratio (PAPR) reduction in the presence of RF power amplifier (RF PA), and addresses the impact of the lack of synchronism between transmitters on the performance of the selected waveforms, which is of special relevance for future 5G massive machine type communication applications.

In the article ''Distributed antenna allocation scheme for massive MIMO cellular backhaul networks,'' by Kuo and Chen, a distributed mechanism termed hierarchical distributed adjustment is proposed. On the basis of the links' channel conditions, BS' available antennas, users' service requirements, and neighbors' allocation decisions, the transceiving antennas of each link are adjusted to both fulfill the quality-of-service constraints and maximize the total utility of the best-effort traffic.

The article ''Energy efficiency optimization for OFDM based 5G wireless networks with simultaneous wireless information and power transfer,'' by Lu *et al.*, studies the energy efficiency optimization problem for the orthogonal frequency-division multiplexing-based 5G wireless networks with SWIPT, in which the subcarrier and power allocation are jointly optimized to maximize the system energy efficiency for single-user and multiple-user cases.

The article ''Green coexistence for 5G waveform candidates: A review,'' by Hammoodi *et al.*, proposes an assessment of various 5G waveform candidates (filtered orthogonal frequency-division multiplexing (OFDM), universal filtered multicarrier (UFMC), filter bank multicarrier (FBMC), and generalized frequency-division multiplexing) under the key performance indicators (KPIs). It assesses the main KPI factors such as computational complexity, peak-to-average-power ratio, spectral efficiency, filter length, and latency.

The article ''Performance analysis and transceiver design of few-bit quantized MIMO systems,'' by Ling and Wang, analyzes and optimizes the achievable rate of the multi-input multi-output channel with low-resolution ADCs at the receiver by assuming that the channel state information is known at both the transmitter and the receiver.

The article ''An energy efficient Internet of Things network using restart artificial bee colony and wireless power transfer,'' by Zhang *et al.*, attempts to study an IoT network containing wireless sensors and base stations. To save electrical energy, data transfer of the discussed IoT network scenario is expressed as a minimization problem. A three-stage method is proposed to handle the optimization problem. A restart artificial bee colony (RABC) method is proposed to solve the subproblems of the data transfer model.

The article ''An adaptive coverage enhancement scheme based on mmWave RoF for future HetNets,'' by Chen *et al.*, focuses on the spectrum sharing and energy consumption problems with millimeter-wave radio over fiber (mmWave RoF) utilized to enhance the coverage of the system.

The proposed adaptive scheme includes several steps which are addressed in the article.

The article ''Analysis on the empirical spectral distribution of large sample covariance matrix and applications for large antenna array processing,'' by Lu *et al.*, addresses the asymptotic behavior of a particular type of information-plus-noise-type matrices, where the column and row numbers of the matrices are large and of the same order, while signals have diverged and the time delays of the channel are fixed.

In the article ''Computation offloading optimization based on probabilistic SFC for mobile online gaming in heterogeneous network,'' by Jin *et al.*, a component-based approach is proposed to model online games based on the probabilistic service function chain. In order to obtain the optimal virtual function placement in the fog-enabled heterogeneous radio access network, the cost minimization of computation offloading on the data plane is formulated as an integer linear programming problem considering the constraints of application maximum tolerable latency, resource limitation, and user behavior.

The article ''Joint spectrum and power allocation for NOMA enhanced relaying networks,'' by Wang and Zhao, investigates the joint resource allocation for non-orthogonal multiple access (NOMA)-enhanced relaying networks involving the subcarrier pair, subcarrier-user assignment, as well as power allocation. To maximize the system throughput, the joint resource allocation problem is formulated as a mixed-integer nonlinear programming problem.

The article ''Performance investigation of DFT-spread OFDM signal for short reach communication systems beyond NG-PON2,'' by Li *et al.*, investigates the performance of a discrete Fourier transform (DFT)-spread OFDM signal in an intensity-modulation/direct-detection system. The authors find that DFT-spread OFDM could reduce the peak-to-average power ratio effectively and, hence, improve the nonlinearity tolerance.

In the article ''Multi-carrier waveform design for directional modulation under peak to average power ratio constraint,'' by Zhang *et al.*, multi-carrier-based waveform design for directional modulation (DM) is studied. To solve the problem of multicarrier design in the high peak-to-average-power ratio (PAPR) of the resultant signals, the PAPR $\leq \rho$ ($\rho \geq 1$) constraint is considered in the design, and a solution called wideband beam and phase pattern formation by Newton's method (WBPFN) is proposed.

The article ''Positional modulation design based on multiple phased antenna arrays,'' by Zhang and Liu, studies a multiple antenna array model, which could solve the problem of eavesdroppers. The principle of the design is that the eavesdropper located in the same direction as the desired user for one antenna array may not be in the same direction for another antenna array.

In the article ''Bandwidth allocation based on personality traits on smartphone usage and channel condition, '' by Chen *et al.*, a bandwidth allocation method based on smartphone users' personality traits and channel condition is studied in a unified mathematical framework. Personalizing bandwidth allocation could be done by analyzing smartphone users' personality traits, resulting in business intelligence as well as smarter and more efficient usage of the limited bandwidth while taking channel fading conditions into account.

In the article ''Orthogonally polarized dual-channel directional modulation based on crossed-dipole arrays,'' by Zhang *et al.*, signal polarization information is exploited, and a new DM scheme is designed which can transmit a pair of orthogonally polarized signals in the same direction at the same frequency simultaneously, resulting in doubled channel capacity. These two signals can also be considered as one composite signal using a 4-D modulation scheme across the two polarization diversity channels.

The article ''Performance investigation of a cost- and power-effective high nonlinearity tolerance OFDMA-PON scheme based on sub-Nyquist sampling rate and DFT-spread,'' by Li *et al.*, investigates the performance of a cost- and power-effective high-nonlinearity tolerance orthogonal frequency-division multiple access passive optical network scheme based on sub-Nyquist sampling and discrete Fourier transform spread.

The article ''Power allocation in 5G wireless communication,'' by Chen and Liang, forecasts the Fifth-Generation (5G) channel based on the Granger causality and transfer entropy, and then uses the water filling algorithm to allocate power for the forecasted 5G channel.

The article ''Real-valued orthogonal sequences for iterative channel estimation in MIMO-FBMC systems,'' by Zhang *et al.*, presents a novel sequence design for efficient channel estimation in multiple input multiple output filterbank multicarrier (MIMO-FBMC) systems with offset QAM modulation. The proposed sequences, transmitted over one FBMC/OQAM symbol, are real-valued in the frequency domain and display zero-correlation zone properties in the time-domain. The latter property enables optimal channel estimation for a least-square estimator in frequency-selective fading channels.

The article ''Generalized discrete Fourier transform for FBMC peak to average power ratio reduction,'' by Aboul-Dahab *et al.*, proposes the use of generalized DFT (GDFT) spreading as an alternative to DFT spreading for PAPR reduction in systems employing FBMC. It derives the conditions at which the GDFT can totally make use of the single carrier effect of DFT spreading and hence reducing the PAPR. The authors also propose an enhancement algorithm that is utilized in the GDFT for further PAPR reduction without any additional complexity overhead.

The article ''Optimizing MEC networks for healthcare applications in 5G communications with the authenticity of users' priorities,'' by Lin *et al.*, investigates the optimization of end-to-end delay of wireless users in a cellular network with the authenticity of their priorities by blockchain consensus, and proposes an algorithm of allocating communication and computation resources to minimize the delay of data transmission and computation.

The article "Modeling and calibrating the ground-surface beam pointing of GEO satellite," by Sun *et al.*, provides a comprehensive calculation approach for the actual beam pointing on the ground of a satellite multi-beam, which is also validated via theoretical analysis of the measurement from a ground-based calibration station. On this basis, a simple yet effective data-driven model is established to characterize the dynamical deviating trends induced by various unexpected influences.

In the article "Vehicle lighting recognition system based on erosion algorithm and effective area separation in 5G vehicular communication networks," by Yi *et al.*, a design scheme for a vehicle lighting recognition system for 5G vehicular communication networks is proposed. First, a camera is used for image acquisition. Then, the acquired RGB image is converted in to a hue-saturation-lightness (HSL) image in a dedicated cloud. Second, a 3×3 convolution kernel is constructed, and the threshold of this HSL is used to create a mask.

In the article "The design of microstrip array antenna and its optimization by a memetic method," by Zhang *et al.*, a novel design of 2.45-GHz microstrip array antenna is proposed. The novel array antenna is composed of a planar layout of elements, coaxial feeders, and circular feed points. The array antenna is designed to satisfy practical requirements, including frequency channel, voltage standing wave ratio, impedance matching, and signal loss rate. A memetic of genetic algorithm and the quasi-Newton method is proposed to effectively solve the design model.

The article "Near optimal timing and frequency offset estimation for 5G integrated LEO satellite communication system," by Wang *et al.*, investigates time and frequency synchronization for the downlink transmission of 5G-NR signals over LEO satellite channels. Starting from the maximum log-likelihood criterion for timing offset estimation given the observation of the received primary synchronization signals (PSS), it derives an upper bound of the objective function for simplicity.

The article "Robust beamforming and user clustering for guaranteed fairness in downlink NOMA with partial feedback," by Al-Wani *et al.*, investigates beam design and user clustering from the throughput-fairness trade-off perspective. To enhance this trade-off, two proportional fairness (PF)-based scheduling algorithms are proposed, each with two stages.

The article "Optimal and robust interference efficiency maximization for multicell heterogeneous networks," by Xu and Li, investigates the robust resource allocation (RA) problem for maximizing the interference efficiency of users (i.e., total rate/sum interference) in heterogeneous networks. Under perfect channel state information (CSI), the considered RA problem is formulated as a multivariate nonlinear programming problem with constraints on the maximum interference power of MUs, the minimum rate requirement of each femto user, and the maximum transmit power of the femto base station.

The article "Power control for full-duplex D2D communications underlaying cellular networks," by Han *et al.*, investigates the power control for full-duplex D2D communications underlaying cellular networks. Specifically, it formulates the power control problem by maximizing the achievable sum-rate of the full-duplex D2D link while fulfilling the minimum rate requirement of the cellular link under the maximum transmit power constraint of the cellular users and D2D users.

In the article "Fuzzy reinforcement learning for robust spectrum access in dynamic shared networks," by Fan *et al.*, the authors interpret the estimated CSI with uncertainty as fuzzy number, and adopt a novel framework referred to as a noncooperative fuzzy game (NC-FG), whereby the user utility is mapped as a fuzzy value via the user-defined fuzzy utility function.

In the article by Wang *et al.*, "Energy efficiency optimization for NOMA-based cognitive radio with energy harvesting," a nonorthogonal multiple access (NOMA) system with simultaneous wireless information and power transfer (SWIPT) for the CR network is studied. The frame structure is designed with two subslots. In the downlink subslot, the secondary users (SUs) harvest wireless energy from radio frequency (RF) signals and sense the spectrum state simultaneously. In the uplink subslot, SUs transmit their independent information to the base station (BS).

The article "Phase corrections with adaptive optics and Gerchberg-Saxton iteration: A comparison," by Li, studies phase corrections with adaptive optics (AO) and Gerchberg–Saxton (GS) iteration to mitigate the air turbulence effect under various turbulence conditions. The improvement in performance is comprehensively compared between both schemes.

In the article "Performance of D2D aided uplink coordinated direct and relay transmission using NOMA," by Xu *et al.*, a D2D communication-assisted uplink CDRT using NOMA is proposed, in which a base station (BS) directly communicates with a cell-center user (CCU) while communicating with a cell-edge user (CEU) with the aid of a relay.

The article "On the feasibility of 5G slice resource allocation with spectral efficiency: A probabilistic characterization," by Escudero-Garzás *et al.*, addresses the feasibility of forming 5G slices, answering the question of whether the available capacity (resources) is sufficient to satisfy slice requirements.

The article "The local delay and the throughput in cooperative cognitive radio ad hoc networks," by Gao and Zhang, studies the local delay and the throughput in cooperative cognitive radio *ad hoc* networks. In order to forward the packets of primary users, a τ-slotted ALOHA protocol is adopted by secondary users in which a slot is divided into the first τ-slot and the latter $(1 - \tau)$-slot.

In the article "Outage throughput capacity of hybrid wireless networks over fading channels," by Wang *et al.*, two types of transmission modes in hybrid wireless networks, i.e., intra-cell mode and infrastructure mode, are considered. To effectively overcome the fading impairment, the optimal

multiple access technique is applied, allowing opportunistic sources to transmit concurrently with the scheduled source.

The article ''Enhanced frequency stability over fiber link with improved phase discrimination scheme,'' by Wang *et al.*, demonstrates a phase-stability radio-frequency (RF) dissemination system via fiber link with direct phase discrimination. The phase fluctuation of the RF signal is identically transferred to a 10-MHz intermediate frequency (IF) by using dual-heterodyne phase error transfer.

Finally, the invited article ''Integrated use of licensed- and unlicensed-band mmWave radio technology in 5G and beyond,'' by Lu *et al.*, develops a mathematical queuing-theoretic framework that is mindful of the specifics of mmWave session dynamics and may serve as a flexible tool for the analysis of various strategies for the integrated use of licensed and unlicensed mmWave bands in terms of the session drop probability and system utilization.

We express our gratitude to the authors for their excellent contributions to this Special Section. We are also thankful to all the reviewers who dedicated their efforts to review these articles and for their valuable comments and suggestions that significantly improved the quality of the articles. We hope that this Special Section will serve as a good reference for researchers, scientists, engineers, and academicians in the field of new waveform design and air-interface for future heterogeneous network toward 5G.

QILIAN LIANG, *Guest Editor*
Department of Electrical Engineering
The University of Texas at Arlington
Arlington, TX 76019, USA

TARIQ S. DURRANI, *Guest Editor*
Department of Electronics and Electrical Engineering
University of Strathclyde
Glasgow G1 1XQ, U.K.

XUEMAI GU, *Guest Editor*
Graduate School Harbin Institute of Technology
Harbin 150001, China

JINHWAN KOH, *Guest Editor*
Department of Electronics and Electrical Engineering
Gyeongsang National University
Daegu 52828, South Korea

YONGHUI LI, *Guest Editor*
School of Electrical and Information Engineering
University of Sydney
Sydney, NSW 2006, Australia

XIN WANG, *Guest Editor*
LinkedIn Corporation
San Jose, CA 94085, USA

QILIAN LIANG (Fellow, IEEE) received the B.S. degree from Wuhan University, in 1993, the M.S. degree from the Beijing University of Posts and Telecommunications (BUPT), in 1996, and the Ph.D. degree from the University of Southern California (USC), in 2000, all in electrical engineering. He is a Distinguished University Professor with the Department of Electrical Engineering, The University of Texas at Arlington (UTA). Prior to joining the Faculty of The University of Texas at Arlington in August 2002, he was a Member of the Technical Staff at Hughes Network Systems Inc., San Diego, CA, USA. He has published more than 320 journal articles and conference papers, and seven book chapters. His research interests include wireless sensor networks, radar and sonar sensor networks, wireless communications and networks, signal processing, and machine learning. He received the IEEE TRANSACTIONS ON FUZZY SYSTEMS Outstanding Paper Award in 2002, the U.S. Office of Naval Research (ONR) Young Investigator Award in 2003, the UTA College of Engineering Outstanding Young Faculty Award in 2005, 2007, and 2009, the U.S. Air Force Summer Faculty Fellowship Program Award in 2010, the UTA College of Engineering Excellence in Research Award in 2012, and the UTA Outstanding Research Achievement Award in 2013. He was inducted into the UTA Academy of Distinguished Scholars in 2015.

TARIQ S. DURRANI was the University Deputy Principal from 2000 to 2006, with major responsibility for university-wide strategic developments in computing/information technology infrastructure, entrepreneurship, staff development, and lifelong learning. He has supervised over 40 Ph.D. degree theses. He joined the University of Strathclyde as a Lecturer in 1976. He was a Professor in 1982 and the Department Head of one of the U.K.'s largest EEE Departments from 1990 to 1994. He was the Chair of the Institute for Communications and Signal Processing from 2006 to 2007 and the Head of the Centre of Excellence in Signal and Image Processing from 2008 to 2009. He was the Director of the U.K. Government DTI Centre for Parallel Signal Processing from 1989 to 1991 and the U.K. Research Council/DTI Scottish Transputer Centre, Strathclyde, from 1991 to 1995. He was the Vice President of natural sciences from 2007 to 2010, the Vice President (international) of the Royal Society of Edinburgh-National Academy of Scotland from 2012 to 2013, and a Council (Board) Member of the Scottish Funding Council, which distributes U.S. $3.0 billion equivalent funding annually to universities and colleges. He is currently a Research Professor in electronics and electrical engineering with the University of Strathclyde. He has authored six books and over 350 publications. His research interests include communications, signal processing, technology management, and higher education management. He is a Foreign Member of the U.S. National Academy of Engineering (NAE) and a Fellow of the Royal Academy of Engineering and the Royal Society of Edinburgh.

XUEMAI GU received the M.Sc. and Ph.D. degrees in information and communication engineering from the Harbin Institute of Technology, in 1985 and 1991, respectively. He is currently a Professor and the Dean of the Graduate School, Harbin Institute of Technology. His research interests include integrated and hybrid satellite and terrestrial communications, and broadband multimedia communication techniques. He is a Fellow of the Chinese Institute of Electronics.

JINHWAN KOH received the M.S. and Ph.D. degrees in electrical engineering from Syracuse University, Syracuse, NY, USA. He is currently a Professor with the Department of Electronics Engineering, Engineering Research Institute, Gyeongsang National University, Jinju, South Korea. His current research interests include radar signal processing and electromagnetic measurements.

YONGHUI LI (Fellow, IEEE) received the Ph.D. degree from the Beijing University of Aeronautics and Astronautics, in November 2002.

Since 2003, he has been with the Centre of Excellence in Telecommunications, University of Sydney, Australia, where he is currently a Professor and the Director of the Wireless Engineering Laboratory, School of Electrical and Information Engineering. He holds a number of patents granted and pending in his research fields. His current research interests include wireless communications, with a particular focus on MIMO, millimeter-wave communications, machine-to-machine communications, coding techniques, and cooperative communications. He was a recipient of the Australian Future Fellowship in 2012 and the Australian Queen Elizabeth II Fellowship in 2008. He received the Best Paper Award from the IEEE International Conference on Communications (ICC) in 2014, the IEEE Wireless Days Conferences (WD) in 2014, and the IEEE PIRMC in 2017. He served as the Guest Editor for several IEEE journals, such as the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, the IEEE INTERNET OF THINGS JOURNAL, and IEEE ACCESS, and *IEEE Communications Magazine*. He is currently an Editor of the IEEE TRANSACTIONS ON COMMUNICATIONS and the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY.

XIN WANG received the B.S. degree from Shanghai Maritime University, Shanghai, China, in 2007, the M.S. degree from Tongji University, Shanghai, in 2010, and the Ph.D. degree from The University of Texas at Arlington, in 2013, all in electrical engineering. He is currently a Senior Engineer with LinkedIn Corporation, Sunnyvale, CA, USA. His research interests include wireless communications, hybrid wireless networks, wireless sensor networks, and smart grids. He was the Organizer of the IEEE INFOCOM in 2016 and the Workshop on 5G and Beyond-Enabling Technologies and Applications in 2017.