Introduction to the Special Issue on Array Signal Processing for Angular Models in Massive MIMO Communications

IN RECENT years, there has been tremendous research progress in massive MIMO from communications theory viewpoint. An emerging trend is to explore the angular models of the propagation channels and design the massive system with array signal processing techniques. Particularly, fundamental concepts in array signal processing (e.g., direction of arrival/departure - DOA/DOD), can be conceptualized and exploited. To implement such angular models in massive MIMO systems, several critical issues must be addressed, which range from angle-based channel estimation and channel tracking, to angle domain hybrid beamforming and interference control, to spatial division multiple access and power efficiency, and to data-driven approach for 5G wireless communications. It is expected that array signal processing techniques could explore the structure of the environment and provide enhanced performance compared to those directly obtained from the communication viewpoint. This special issue starts with the survey paper by M. Wang, F. Gao, S. Jin, and H. Lin, which presents a comprehensive overview of state-of-the-art research on merging array signal processing into massive MIMO communications as well as its promising future directions. Then, 21 technical papers with original contributions are included, addressing each of the aforementioned challenges.

Channel estimation has long been deemed as a bottleneck for massive MIMO systems, especially for the downlink case. Instead of estimating the channel matrix directly, one could apply array signal processing techniques to estimate the parameters, i.e., angles, delays, Doppler shifts, complex gains, then reconstruct the channels. This special issue has seven papers related to parametric channel estimation making use of array signal processing techniques. The paper by K. Wu, W. Ni, Tao Su, R. P. Liu, and Y. J. Guo exploits the spatial-wideband effect and develop an accurate AoA estimation approach for lens antenna arrays. The paper by W. Cui, Q. Shen, W. Liu, and S. Wu studies the underdetermined DOA estimation problem for wideband off-grid sources and shows that complexity reduction can be achieved via a dynamic dictionary based off-grid DOA estimation method. In the contribution by Z. Zhou, L. Liu, and J. Zhang, a tensor based DOA estimation algorithm is introduced in the multi-user FD-MIMO systems with pilot-data superposition. The paper by X. Wang, L. Wan, M. Huang, C. Shen, and K. Zhang estimates the polarization massive MIMO channels consisting of DOA and polarization parameters under coexistence of circular and noncircular signals. The paper by C. Qian, X. Fu, and N. D. Sidiropoulos proposes a low overhead structural training sequence for the downlink channel estimation, and the parameters of downlink channels can be provably identified when the number of paths largely exceeds the number of receive antennas. To extend the angle aided channel estimation to the regime of 3D irregular arrays, the paper by L. Cheng, C. Xing and Y.-C. Wu proposes a two-stage angular channel estimation algorithms for an irregularly shaped array. In the contribution by P. Dong, H. Zhang, and G. Y. Li, a spatial frequency deep convolutional neural network (SF-CNN) is proposed for mmWave massive MIMO channel estimation by exploiting both the spatial and frequency correlation.

The hinderance in channel estimation is further aggravated by practical hardware constrains, including an arbitrary array geometry, hybrid hardware structure, and one-bit analog-to-digital converters (ADCs) systems. Four papers in this special issue touch upon this topic. The paper by Y. Wang, Y. Zhang, Z. Tian, G. Leus, and G. Zhang seeks to design a angle-based super-resolution channel estimation framework that not only utilizes the sparsity of mmWave massive MIMO propagation, but also fully considers the nonideal array geometry and practical hardware limitations. In the contribution by S. Rao, A. Mezghani, and A. L. Swindlehurst, the Bayesian Cramér-Rao performance bounds (CRBs) for channel estimation in one-bit mmWave massive MIMO systems are both explored and compared in parametric channel models as well as generic finite impulse response filter channel models. By exploiting the sparse nature of the mmWave channels, V. Suresh and D. J. Love studies the problem of successive one-bit feedback-assisted beam alignment, where both adaptive (closed-loop) and non-adaptive (open-loop) channel sounding techniques are considered to pose the optimal beams. In the contribution by M. Shao, W. K. Ma, Q. Li, and L. Swindlehurst, a spatial Sigma-Delta modulation is applied to one-bit MIMO precoding, which adapts the user angle for achieving nearly zero quantization noise.

Moreover, the sparsity of mmWave massive MIMO channels originates from the high correlation in angle domain, which makes it possible to track the channel state with much reduced resource requirements. Three papers in this special issue touch upon this topic. By leveraging the delay and angular reciprocity between the uplink and downlink FDD massive MIMO channels, Y. Han, Q. Liu, C. K. Wen, M. Matthaiou, and X. Ma propose a frequency-independent parameter tracing module for each user's uplink channel. Based on the lens antenna array and the

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spatial sparsity of the mmWave massive channels, Z. Gong, F. Jiang, and C. Li propose a data-aided channel tracking scheme for high mobility vehicle-to-infrastructure (V2I) communication systems. In the contribution by W. Peng, W. Li, W. Wang, X. Wei, and T. Jiang, the downlink channel matrix can be quickly tracked and predicted from the real time uplink channel state information by three components: steering matrix, fading coefficients, and time delays.

With channel state information at the transmitter, preprocessing such as precoding, beamforming, interference control, and multiple access can be performed in the angle domain to optimize the performance of massive MIMO systems. Four papers in this special issue touch upon this topic. Considering perfect channel state information at the base station, the paper by Y. Song, C. Liu, W. Wang, N. Cheng, M. Wang, W. Zhuang, and X. Shen presents a 2D downlink precoding scheme for single-cell 3D massive MIMO systems, which shows that either the elevation or azimuth domain can be used for interference cancellation. In the contribution by S. Schwarz, M. Rupp, and S. Wesemann, a Grassmannian product codebook is designed for channel quantization and feedback in two-tier precoding architectures, which is especially effective if the massive channels can be decomposed in the angular domain. The paper by E. Vlachos, G. C. Alexandropoulos, and J. Thompson develops an iterative algorithm jointly exploiting the channel's low rank and beamspace sparsity to provide accurate hybrid beamforming in mmWave wideband massive MIMO systems. The paper by H. Yan and D. Cabric proposes to use a quasi-omni pseudorandom sounding beam for initial access and develops a compressive sensing algorithm to jointly achieve initial cell discovery, synchronization, and fine resolution beam training.

Finally, the topic of system analysis in angle domain is touched upon by the issue. The paper by X. Hu, C. Zhong, X. Chen, W. Xu, and Z. Zhang investigates the performance of angle domain mmWave MIMO non-orthogonal multiple access (NOMA) systems in the presence of angular estimation error. The paper by C. L. Miller, P. J. Smith, P. A. Dmochowski, H. Tataria, and M. Matthaiou, presents a mathematical framework to analyze the performance of zero forcing (ZF) and minimum mean-squared error (MMSE) combining from angular domain with in *ray-based* models. The paper by R. Mendrzik, F. Meyer, G. Bauch, and M. Z. Win establishes a model that describes the statistical dependency between channel state information and the position, orientation, and clock offset of a user equipment along with the locations of features in the propagation environment.

All above suggest an exciting direction of leveraging advanced array processing techniques to aid massive MIMO communications, leading to a second wave of cross-pollination between array signal processing and wireless communications. As a result, this special issue received more high-quality papers than were possible to accept. We would like to thank all the authors for their submissions and the reviewers for their great efforts to provide reviews in time. Finally, we hope that the wide range of papers in this special issue could spurs the future development of array signal processing enhanced wireless communications.

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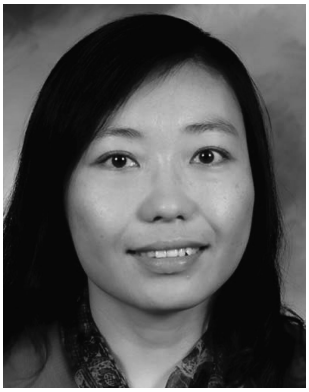

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