Introduction to the Issue on Hybrid Analog Digital Signal Processing for Hardware-Efficient Large Scale Antenna Arrays (Part I)

5G and beyond systems necessitate the exploitation of high-gain MIMO beamforming by using large antenna arrays at both the base stations and the mobile units of the network to deliver the high data rates promised. The high cost and power consumption of radio frequency (RF) components such as power amplifiers (PAs) high-resolution analog-to-digital converters (ADCs) makes dedicating a separate RF chain for each antenna prohibitive, and conventional, fully digital baseband (BB) processing becomes infeasible. Beyond the deployment of large arrays, hardware efficient transceivers are also sought for small cell deployments as well as in emerging applications through the internet of things (IoT) involving massive connectivity. All these applications still rely on transceivers capable of beamforming, using cheap, low-power, and physically small devices. Hybrid analog-digital (HAD) processing provides a key solution for the deployment of such systems, allowing a reduced number of RF chains and low-specification RF components. The principle behind HAD is that the transceiver processing is divided into the analog and digital domain, allowing for the high-dimensional processing to be implemented through elementary analog components, and facilitating a low-dimensional digital processing which necessitates only a few RF chains.

This special issue has been motivated by the recent increasing interest in: a) the practical challenges the deployment of large scale antenna systems (LSAS); b) the rising interest in the millimeter wave (mmWave) spectrum for 5G deployment which necessitates high-gain beamforming with low cost; c) the recent advances on analog-digital signal processing; and d) the ever-increasing interest in energy efficient communications. LSAS have been under development since 2010, and important potential gains have been established theoretically. However, it is only recently that the practical challenges of deploying LSAS have been the focus of the relevant research. These include but are not limited to: hardware and RF-chain complexity and cost reduction, mixed base-band and RF signal processing with low complexity, channel state information (CSI) acquisition and pilot contamination, physical space constraints and antenna array topology optimization. Traditional MIMO approaches to the above do not apply and innovative solutions are required.

Open problems include the study of fundamental limits of communication by HAD architectures, the development of signal processing techniques robust to low-specification RF components and hardware imperfections, reduced RF chain implementations through parasitic arrays and load modulated MIMO, adaptive transmission / reception techniques for parasitic, reflect, phased, load modulated and other hybrid massive antenna array structures, Hybrid RF antenna arrays for K, V, W and mmWave frequency bands, including wideband designs, channel modelling for HAD large scale antenna systems, studies and optimization of antenna topologies for massive MIMO deployment with HAD transmission, efficient channel state information (CSI) acquisition techniques for HAD transmission, beamspace MIMO transmission, distributed multi-cell HAD transmission, as well as broader applications of HAD signal processing, including security, energy harvesting, IoT among others.

Accordingly, the aim of this Special Issue (SI) has been to gather the relevant contributions focusing on the practical challenges of hybrid analog-digital transmission as outlined above. We received a total of 59 submissions of particularly high quality, spanning a broad range of topics. After a strict review process, we decided to accept 23 papers, which will be published in two issues. The first issue contains 12 papers, covering a wide selection of topics as follows.

The first paper from Wang et. al. studies HAD precoding and combining with finite-resolution phase shifters as analog beamformers to reduce the hardware cost and power consumption. The authors propose an iterative algorithm aiming at conditionally maximizing the spectral efficiency. They further investigate the design of hybrid beamformers with one-bit resolution phase shifters, and present a novel binary analog precoder and combiner optimization algorithm.

In the second paper by Vazquez et. al. the authors propose analog beamforming methods for spectrum sharing in satellite communications at 18 GHz and 28 GHz bands. They evaluate two different optimization techniques, in terms of complexity and performance, to design the weights of the phase shifters to perform analog beamforming. The design criterion aims to mitigate the interference when fixed satellite services and backhaul fixed services share the spectrum.

Yu et. al. investigate the design of switch networks to provide dynamic connections from phase shifters to antennas for the implementation of the analog beamforming. They propose a hybrid precoding, based on fixed phase shifter implementation that only requires a small number of phase shifters with quantized and fixed phases. The design is addressed using an alternating minimization algorithm with closed-form solutions in each iteration to determine the hybrid precoder and the states of switches. To further reduce the number of switches, they also explore a group-connected mapping strategy.

In the fourth paper, Ribeiro et. al. address an important tradeoff of digital and analog phase shifting networks for mmWave bands with a focus on low complexity and low power operation. Low resolution and hybrid analog-digital phase shifting systems were found to offer significant performance with higher energy and spectral efficiency.

The work by Guo et al. considers single-sided lens antenna arrays for mmWave transmission that are based on a joint design of beam selection and precoding for multi-user MIMO systems. Aiming at sum rate maximization under power constraints, the authors derive a joint selection / precoding algorithm that relies on a penalty dual decomposition-based algorithm. The proposed hybrid analog-digital technique exhibits fast convergence and near-optimal sum-rate performance, thus outperforming competing fully digital precoding schemes.

In the paper titled "Hybrid Beamforming Based on Implicit Channel State Information for Millimeter Wave Links", Chiang et. al. address the problem of optimizing the hybrid breamforming structure from a practical perspective. Their paper proposes the idea of using the channel norm as a proxy for optimizing the hybrid beamforming architecture for the frequency-selective channel, while circumventing the need for channel estimation.

Y. Long et. al. propose a data-driven method of analog beam selection, by describing the beam selection problem as a multiclass-classification problem. They exploit the support vector machine (SVM) algorithm to obtain a statistical classification model, which maximizes the sum rate. For real-time transmissions, with the derived classification model they can select, with low complexity, the optimal analog beam of each user. The presented results show that, as long as the training data is sufficient, the proposed data-driven method achieves a near-optimal sum-rate performance with a limited complexity.

In the paper by J. P. Gonzalez-Coma et. al., channel estimation and hybrid beamforming for frequency-selective mmWave systems is investigated. The algorithms are based on compressive sensing methods and rely on the sparse nature of the mmWave channels and the channel reciprocity. The channel is estimated in uplink and it outperforms its downlink counterpart. To perform hybrid precoding, two methods have been considered. The first method is based on factorization of the digital beamforming matrix into RF and baseband beamformers. The second solution is an iterative method based on alternating minimization.

S. Perera et al. propose a hybrid multi-beam antenna array for wideband communications in the mmWave regime. The array relies on a multi-beam network that comprises two levels of beamforming (analog and digital) and which implements a factorization of a Vandermonde matrix to generate true time delay beams with no squint. Specific CMOS-based circuits are proposed for the implementation of the derived low-complexity algorithms and the overall hybrid analog-digital system is designed and simulated in Cadence for the generation of 8 beams at 28GHz.

In the paper by M. R. Castellanos et. al., the focus is on HAD for multi-user transmissions, based on cell-specific codebook of beamforming vectors. Their work develops an advanced directional precoding structure for simultaneous transmissions at the cost of an additional marginal feedback overhead. Numerical studies show that the proposed scheme results in a significant sum rate performance improvement over naive schemes even with a coarse initial beam alignment codebook.

In the final paper of this issue, Hong et. al. propose a novel programmable weight phased array (PWPA) architecture for providing physical layer security in mmWave systems. In this structure, the phased array consists of phase shifters and amplifiers to change the amplitude of the beamforming weights. The proposed method generates artificial noise in unwanted directions and increases the secrecy rate. In addition, the symbol error rate and secrecy capacity of their algorithms is robust to eavesdroppers gain and transmission distance.

The above contributions represent high quality solutions for hybrid analog-digital transmission schemes, aimed at deployment in the mmWave frequencies. Stay tuned for the second part of this Special Issue, for further studies on hybrid transmission in generic frequency non-specific implementations.

Our guest editorial team would like to thank the Authors of all published and unpublished papers who contributed their works towards this Special Issue. Our sincere gratitude also goes to our expert Reviewers for their timely and thorough reviews that have significantly improved the quality of the Special Issue.

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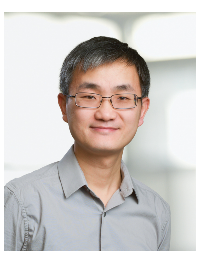

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