Editorial

Multi-Channel and Multi-Agent Signal Processing

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Multi-channel and array signal processing is a well-established field with fundamental applications in wireless communications, radar/sonar, remote sensing, medical imaging, and more [1]. Its focus is on signals from multiple sensors or channels, often involving a pair of entities (transmitter and receiver, possibly in asymmetric configuration, e.g., [2]). Many modern application contexts are, however, networked, that is, interconnection of different devices or agents is today a common setup in many different contexts; this can be exploited to solve problems in a cooperative, possibly distributed way, since cooperation improves the performance and may solve problems that are unsolvable in a non-cooperative setting [3]. Moreover, the distributed (in-network) processing paradigm enables the design of privacy-preserving and robust schemes, while taking advantage of the aggregate processing power of many devices, instead of a single node where all data need to be sent for centralized processing. In doing so, the drawbacks of the latter, more conventional approach, i.e., a single point of failure with very high computational, bandwidth, and energy demands, can be overcome.

Although research is very active on both multi-channel (single-link) and multi-agent (networked, i.e., multi-link) signal processing, the potential of combining both fields is still underexploited. A positive example is instead the recent trend in antenna array, i.e., multiple-input multiple-output (MIMO) solutions for 5G and beyond cellular networks, in particular using device-to-device (D2D) communications [4]. Important applications in this respect are user localization, intelligent sensing of the environment, coordinated control of autonomous systems, cooperative extended horizon in vehicular networks, smart factory, etc. At the same time, it is of the utmost importance to identify solutions to improve the throughput and reduce interference from multiple radio access, which in certain systems can be massive. Indeed, the latter issue is becoming a bottleneck given the exponential growth of connected devices (smartphones, wearables, smart objects, etc.) as the internet of things (IoT) paradigm spreads out [5].

This Special Issue was aimed at promoting cross-fertilization between multi-channel/array processing techniques and multi-agent methodologies in order to provide advanced solutions for emerging application contexts. A total of ten papers have been accepted for publication, covering an interesting range of theoretical and practical issues arising in multi-channel, multi-agent contexts. They can be grouped into three, partially overlapping classes: a first one covering multi-channel techniques, in particular regarding MIMO contexts, aimed at improving the performance through the additional degrees of freedom available in the multi-channel setup; a second one focusing on spectrum-sensing techniques for enhanced communications in multi-agent scenarios; and a third one specifically addressing the issue of location-awareness and tracking, which is essential for the practical implementation of multi-agent applications [6]. Particular emphasis is given to multi-channel solutions and radar.

1. Reduced-Complexity Approaches for Performance Improvement in MIMO Systems

A first group of three papers concerns MIMO systems, in particular addressing the problem of improving the performance through the additional degrees of freedom while reducing the complexity of massive systems, by acting on different aspects.

The paper, "Enhanced Precoder for Multi User Multiple-Input Multiple-Output Downlink Systems", by W.-S. Lee, J.-H. Ro, Y.-H. You, D. Hwang, and H.-K. Song [7] addresses the problem of the increasing demand for data rate (high throughput) in modern wireless communication systems, considering MIMO systems. In particular, to overcome the difficulty of implementing massive number of antennas at base stations, an adaptive precoder is proposed which provides high throughput and bit error rate (BER) performances in multi-user MIMO downlink systems with a practical antenna array (up to 16 elements).

A second contribution towards the simplification of massive MIMO systems is provided in the paper, "Energy-Efficient Hybrid Beamforming with Variable and Constant Phase Shifters", by G. M. Gadiel and K. Lee [8]. The authors propose a novel partially connected hybrid beamforming (PC-HBF) architecture, which employs variable phase shifters (VPSs) and constant phase shifters (CPSs) for analog beamforming to harness the potential of these two types of phase shifters. Since exact sum rate optimization is intractable, especially in massive MIMO systems, a reduced-complexity, near-optimal greedy algorithm is proposed. Results show that by optimally combining VPSs and CPSs, the proposed architecture achieves performance close to that of the VPS-based PC-HBF architecture, with higher energy efficiency than the CPS-based fully connected HBF scheme.

A third paper, "Adaptive Threshold-Aided K-Best Sphere Decoding for Large MIMO Systems", by U. Ummatov and K. Lee [9], proposes an adaptive threshold-aided K-best sphere decoding (AKSD) algorithm for large MIMO systems. A suitable strategy is proposed to reduce the complexity in visiting the nodes of the decoding tree, compared to the conventional K-best sphere decoding (KSD). Results show that the proposed AKSD provides nearly the same BER performance as the conventional KSD scheme while achieving a significant reduction in the average number of visited nodes, especially at high signal-to-noise ratios (SNRs).

2. Spectrum Sensing for Enhanced Communications in Multi-Agent Systems

A second group of papers focuses on spectrum-sensing techniques for enhanced communications in scenarios with multiple users or agents.

In the paper, "Dynamic Carrier-Sense Threshold Selection for Improving Spatial Reuse in Dense Wireless LANs", by J. So and J. Lee [9], the problem of increasing the system spectral efficiency in wireless LANs is addressed by acting on carrier-sense threshold, since, frequently, transmissions are unnecessarily blocked by carrier sensing. Using high carrier-sense threshold and allowing nodes to transmit aggressively may increase the system throughput, but this approach can lead to unfair channel sharing and cause starvation for the edge nodes. The authors propose a new medium access control (MAC) protocol based on a dual-threshold, which can achieve higher system throughput compared to using a single carrier-sense threshold, without penalizing edge nodes.

Spectrum sensing to find Television White Spaces (TVWS) to be exploited by cognitive radio systems is investigated in the paper, "An Accurate Probabilistic Model for TVWS Identification", by D. Corral-De-Witt, S. Ahmed, F. Awin, J. L. Rojo-Álvarez, and K. Tepe [10], as a means to improve spectrum efficiency. Considering false alarm and detection probabilities jointly, a probabilistic model is proposed which can identify TVWS with improved accuracy. For demonstration purposes, a low-cost mobile prototype was designed and used for experiments in the UHF-TV spectrum. Analysis of the collected data showed that the proposed model improves the TVWS detection compared to other models, reducing the complexity while maintaining the accuracy.

3. Detection, Localization, and Tracking in Multi-Agent Systems

The third and last group of papers specifically addresses location-awareness and tracking, which is essential for the implementation of multi-agent applications, by exploiting multi-channel techniques.

The review paper, "Distributed Localization with Complemented RSS and AOA Measurements: Theory and Methods", by S. Tomic, M. Beko, L. M. Camarinha-Matos, and

L. Bica Oliveira [11], presents a survey (from a signal processing perspective) of existing distributed solutions for multi-agent localization (IoT devices such as sensors, machines, and vehicles) in 5G systems, which may not rely on GNSS due to energy and/or cost limitations or because of lack of coverage. The paper focuses in particular on (distributed) hybrid solutions based on received signal strength (RSS) and angle of arrival (AOA), which offer very promising performances in the considered scenarios.

When the localization of a mobile agent is concerned, suitable tracking techniques are also needed. This problem becomes more complex in multi-agent systems, for instance in terms of formation tracking. In the paper, "A Dropout Compensation ILC Method for Formation Tracking of Heterogeneous Multi-Agent Systems with Loss of Multiple Communication Packets", by Y. Wu, J. Zhang, Y. Ge, Z. Sheng, and Y. Fang [12], the formation tracking problem for heterogeneous multi-agent systems with loss of multiple communication packets is addressed. A dropout compensation iterative learning control method is presented to construct effective distributed iterative learning protocols, and convergence conditions are theoretically established.

Another tracking-related problem concerns the correct association of detections and measurements in multi-agent/multi-target scenarios. In the paper, "Labeled Multi-Bernoulli Filter Joint Detection and Tracking of Radar Targets", by Rang Liu, Hongqi Fan, and Huaitie Xiao [13], a labeled multi-Bernoulli (LMB) filter is presented to jointly detect and track radar targets. In fact, new or close tracks often violate the conventional assumption that measurements of different targets do not overlap, leading to a bias in the cardinality estimate. To address this problem, a one-to-one association method between measurements and tracks is proposed, and an approximate method for calculating the point spread function of radar is developed to improve the computational efficiency. Results demonstrate the effectiveness of the proposed algorithm in low SNR scenarios with closely spaced targets.

The last two papers of the Special Issue consider more specific aspects and applications of multi-agent radar systems. In "Radar Application: Stacking Multiple Classifiers for Human Walking Detection Using Micro-Doppler Signals", by J. Kwon and N. Kwak [14], radar sensors are considered for the problem of human walking recognition based on micro-Doppler signals. Several types of background noise typically found in operational contexts (line of sight, fan, snow, and rain) are considered, and a deep neural network approach for signal classification is devised, based on experimental data. Then, stacking methods are proposed to combine base classifiers of different structures in a single (ensemble) classifier with improved performance. Test results report an accuracy of more than 95%.

Finally, in "Reinforcement Learning-Based Anti-Jamming in Networked UAV Radar Systems", by Q. Wu, H. Wang, X. Li, B. Zhang, and J. Peng [15], the problem of quantifying and optimizing the anti-jamming performance of networked UAV radar systems is addressed. The latter may exploit inter-UAV cooperation for enhancing information acquisition capabilities, meanwhile its inter-UAV communications may be interfered with by external jammers. A modified Q-Learning method is proposed based on double greedy algorithm to optimize the anti-jamming performance, through joint programming in the frequency-motion-antenna domain.

Conflicts of Interest: The author declares no conflict of interest.

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