Guest Editorial
Multiuser Detection for Advanced Communication Systems and Networks

POTENTIAL for improved performance through joint detection of multiuser signals, coupled with associated challenges in achieving this potential at affordable receiver complexity, has motivated significant amount of research to be carried out in the area of multiuser detection (MUD) in the past two decades. Much of the early research in this important area has been centered around systems employing code division multiple access (CDMA) promising capacity improvement in terms of the number of simultaneous users supported in the system. The optimum MUD complexity, which is exponential in the number of users, has inspired a considerable effort toward the development of low-complexity, suboptimal alternatives capable of resolving the detrimental effects of multiple-access interference. Interference cancellation strategies have received particular attention, due to their competitive performance at low complexity and simple modular structure. Their performances, however, are still far from the optimum maximum-likelihood (ML) performance. Iterative methods based on soft-decision cancellation have been shown to achieve near-ML performance. Since most practical communication systems use coding, iterative multiuser decoding of coded CDMA signals has received considerable research attention, and so has the topic of joint multiuser channel estimation and decoding.

More recent approaches to low-complexity MUD involve application of techniques from, e.g., belief propagation, Bayesian inference, neural networks, Markov-Chain Monte-Carlo methods, and probabilistic data association, just to name a few. This trend is reflected in several of the papers in this special issue. Several detectors based on the above techniques have been shown to achieve an average per-bit complexity that is linear in the number of users, while achieving near-optimal performance in a large system setting. We see an emerging trend in MUD research: achieving near-optimal performance in linear complexity and the establishment of the fundamental connections between the various approaches which achieve this complexity.

Another interesting feature of current multiuser detection research is its immediate relevance/applicability to low-complexity multiple-input multiple-output (MIMO) detection. Multiuser systems and MIMO systems are both described by a vector-matrix channel model with the same structural format. In case of a multiuser system the channel matrix is defined by the normalized cross-correlations between the signature sequences of the active users, whereas the channel matrix in a MIMO system is defined by the spatial signatures between the receive and transmit antennas. Thus, it is no surprise that this special issue has several papers that propose and investigate detection methods for CDMA and MIMO systems without and with transmit pre-processing. Another new multiuser research avenue is in the arena of cooperative communications — also evidenced by papers in the special issue.

We received a total of fifty-two submissions in response to our Call for Papers for this special issue. We thank all the authors for their enthusiastic response. In the review process, we were ably helped by several expert reviewers who proved to be instrumental in completing the review process in a timely manner. We thank all these reviewers for their valuable time and their high quality reviews. In the end, thirteen papers were selected for inclusion. These thirteen papers can be collected in three thematic groups: MUD in

- i *CDMA* (4 papers);
- ii *MIMO and Multicarrier CDMA/OFDM* (6 papers);
- iii *Cooperative Communications* (3 papers).

In the following, we introduce these papers briefly pointing to some highlights of the contributions made in them.

In the paper "Multiuser Detection of Sparsely Spread CDMA," Guo and Wang study sparsely spread CDMA and low-complexity multiuser detection based on belief propagation (BP). They show that BP-based detection is asymptotically optimal for sparse CDMA as long as the load of the system is not too large, where the asymptotic equivalence of BP and a posterior detection is established in the (strongest) sense of the posterior probability for arbitrary input distributions. Numerical results are shown to support the finding that BP is near-optimal for sparse CDMA systems of moderate size.

In the paper "A Divergence Minimization Approach to Joint Multiuser Decoding for Coded CDMA," Hu et al. propose a formal optimization framework, based on divergence minimization (DM), for the systematic design of low-complexity iterative receivers that perform iterative joint channel estimation, noise covariance estimation, multiuser interference cancellation using soft code symbols, and single user APP decoding. The DM receiver represents a generalization of several other receivers in the literature, including known receivers based on EM/SAGE algorithms and variational free energy minimization.

In the paper "Achieving Single-User Performance in a FEC-coded DS-CDMA system for Frequency Selective and Flat Fading Channels," Wong and McLane present a reduced-complexity soft-input soft-output trellis/tree multiuser equaliz-

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er for a coded CDMA system under frequency selective Rayleigh fading. Equalization of large trellises is shown to be possible using the proposed algorithm while achieving near-optimal performance.

In "Joint Receiver and Transmitter Optimization for Energy-Efficient CDMA Communications," Buzzi and Poor employ tools from game theory and large system analysis to investigate the cross-layer issue of joint multiuser detection and resource allocation for energy efficiency in wireless CDMA networks. A non-cooperative game for utility maximization with respect to linear multiuser receiver, transmit power and spreading code assignment is formulated and analyzed. Using large system analysis, a distributed power control algorithm that needs little prior information is proposed. The proposed non-cooperative game is shown to outperform competing alternatives while exhibiting only small performance loss compared to the socially optimum solution.

In "A Low-Complexity Detector for Large MIMO Systems and Multicarrier CDMA Systems," Vishnu Vardhan et al. present a low-complexity likelihood ascent search detector based on Hopfield neural networks, which exhibits near-optimum performance in large MIMO and multicarrier CDMA systems. In large MIMO systems involving tens/hundreds of antennas, with an outer turbo code, the proposed detector is shown to perform to within 7 dB of the theoretical MIMO capacity. It is argued that the practical feasibility of low-complexity, near-optimal performance achieving detectors can potentially trigger wide interest in the practical implementation of large MIMO systems, with a motivation to realize the potential for achieving high spectral efficiencies of the order of tens/hundreds of bps/Hz.

In "Asymptotic Analysis of General Multiuser Detectors in MIMO DS-CDMA Channels," Takeuchi et al. employ the replica method to analyze decoupling structures of a MIMO DS-CDMA channel with a general multiuser detector front end, in order to compare space-time spreading (STS) and time spreading (TS) schemes in terms of performance and complexity. The STS scheme is shown to outperform the TS scheme in fast fading if spatial correlations exist, at a lesser complexity than the TS scheme.

In "Convergence of Markov-Chain Monte-Carlo Approaches to Multiuser and MIMO Detection," Henriksen et al. investigate the convergence of Markov-Chain Monte-Carlo (MCMC) methods, which offer an attractive approach to design approximate, near-optimal multiuser and MIMO detectors. The paper extends the theoretical understanding on MCMC methods by rigorously establishing both convergence and convergence rate results for a wide class of Metropolis-Hastings methods.

In "A Bayesian Multiuser Detection Algorithm for MIMO-OFDM Systems Affected by Multipath Fading, Carrier Frequency Offset and Phase Noise," Merli et al. present a Bayesian algorithm for multiuser detection in the uplink of a MIMO-OFDM system employing stacked space-time block codes (STBC). The proposed approach, which relies on MCMC methods, accomplishes joint estimation of the carrier frequency offset, phase noise, channel impulse response and data of each active user. The proposed approach is shown to achieve good performance for various STBCs without and with an outer turbo code.

In "Interference Suppression Receivers for the Cellular Downlink Channel," Prasad and Wang propose two low-complexity interference suppression receivers, based on group MMSE and decision feedback techniques, to combat out-of-cell interference in MIMO downlink channels in next-generation cellular networks, and present their bit error performances.

In "Vector Precoding for Wireless MIMO Systems and its Replica Analysis," Müller et al. study a nonlinear vector MIMO precoding scheme which minimizes the transmit energy by relaxing the transmitted symbols to a larger alphabet for precoding, which preserves the minimum signaling distance. Analytical formulas for evaluating the minimum transmit energy in nonlinear precoding with random MIMO channels in the large-system limit is obtained. It is shown that vector precoding can significantly reduce the transmit power in MIMO systems.

In "Reduced-Complexity Belief Propagation for System-Wide MUD in the Uplink of Cellular Networks," Bavarian and Cavers study a BP based approach for system-wide multiuser detection in which the base stations of a cellular system cooperate to detect the data of all mobile stations. A reduced complexity BP algorithm is proposed and its performance is evaluated in a multi-cell system model that includes path loss, shadowing and power control.

In "Relay-Assisted Decorrelating Multiuser Detector (RAD-MUD) for Cooperative CDMA Networks," Huang et al. investigate a relay-assisted multiuser detection approach to alleviate the loss in cooperative diversity benefits due to multiuser interference in cooperative CDMA networks. A relay-assisted decorrelating MUD (RAD-MUD) is proposed to separate interfering signals at the destination with the help of precoding at the relays along with pre-whitening at the destination. In the proposed approach, there is no power expansion at the transmitters or noise amplification at the receiver. Cooperative transmission strategies including transmit beamforming, selective relaying, and distributed space-time coding are considered on top of RAD-MUD.

Finally, in "Complex Field Network Coding for Multiuser Cooperative Communications," Giannakis and Wang introduce a complex field network coding (CFNC) approach with attractive rate and diversity features useful for wireless cooperative networks involving multiple sources and relays. The throughput-diversity benefits of CFNC-based networks are possible when multiuser ML detection is employed regardless of the SNR and the constellations used.

These papers capture some of the recent trends and developments in multiuser detection. We believe they will be of strong value to the research community in this and allied areas.

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