Guest Editorial
4G Wireless Systems

RESEARCH working toward the specification of fourth-generation (4G) as well as "beyond third-generation" (B3G) wireless cellular systems is underway with the WRC Conference in 2007, the likely starting point for formal standardization. A key feature of 4G and B3G systems is likely to be the availability of significantly higher data rates than for third-generation (3G) systems. It has been suggested that data rates up to 100 Mb/s for high mobility and 1 Gb/s for low mobility should be target values. These data rates suggest higher spectral efficiencies and lower cost per bit will be key requirements for such future systems. It has been proposed that 4G should only have a cost per bit of 1/10 of that of 3G. Additional important expected features are likely to be increased flexibility of mobile terminals and networks, multimedia services, and high-speed data connections. Future convergence of digital audio and digital video broadcasting systems will clearly be another feature. Extensive use of multiple transmit and receive antennas for achieving radio links with increased reliability and spectral efficiency will probably also be a feature of such future systems. While a large number of papers on multi-input–multi-output (MIMO) systems have been published, much less attention has been paid to multiple-access schemes that would be able to efficiently share potentially high capacity of these systems among different users in an asynchronous channel.

A number of activities are already taking place to upgrade existing 3G systems as evidenced in, for example, HSDPA, Super 3G, Integration with MediaFLO and DMB, Eureka 147 DAB and HIBOC DAB systems, as well as wireless LAN's 802.11 systems, WIMAX and WiBro.

The papers in this issue are focused on state-of-the-art research on 4G wireless systems in radio access networks (RAN) up to layer 3, i.e., physical (PHY), medium access control (MAC), and radio resource control (RRC) layers. In our call for papers, we solicited papers covering a wide variety of issues including but not limited to the following topics: systems and architecture, interworking of networks, radio transmission technologies, wireless application protocols, multiple-access schemes, code-division multiple-access/time-division multiple-access/orthogonal frequency-division multiplexing access (CDMA/TDMA/OFDMA), software defined radio, multiple antennas and MIMO techniques, wireless multimedia audio and video, mobility management, resource allocation issues, bandwidth on demand issues, variable rate modulation and coding schemes, turbo codes and low-density parity-check (LDPC) codes, iterative decoding schemes, multiuser detection schemes, channel modeling and measurements, and convergence of 3G/WLAN/WPAN/DxB systems.

We received around 140 papers for this issue and only the following 25 papers were selected for publication in this 4G Wireless Systems Issue.

In the first paper, "Improved Transmit Null Steering for MIMO-OFDM Downlinks With Distributed Base Station Antenna Arrays," Dawod *et al.* propose a null steering downlink MIMO-OFDM system that reduces both the interuser correlation and the near–far problem resulting in an enhancement in system performance.

In the next paper, "Performance Analysis of Dynamic OFDMA Systems With Inband Signaling," Gross *et al.* introduce two forms of representing the signaling information for dynamic OFDMA systems and discuss how these affect system performance.

In the next paper, "Adaptive MAP Receiver via the EM Algorithm and Message Passings for MIMO-OFDM Mobile Communications," Kashima *et al.* study two new types of maximum *a posteriori* probability (MAP) receivers for MIMO-OFDM mobile communications with a channel coding such as LDPC, which employs the expectation maximization (EM) algorithm so as to improve performance of approximated MAP detection.

In the next paper, "Progressive Linear Precoder Optimization for MIMO Packet Retransmissions," Sun *et al.* investigate the optimal linear automatic repeat request (ARQ) precoder design for packet retransmissions in MIMO systems, which combines the appropriate power loading and the optimal pairing of channel matrix singular values in the current retransmission with previous transmissions.

In the next paper, "A Concatenated Multitone Multiple-Antenna Air-Interface for the Asynchronous Multiple-Access Channel," Tonello presents a transmission technology approach for application in the asynchronous multiple-access wireless channel (uplink) based on the concatenation of an inner filtered multitone (FMT) modulator with transmission over multiple antennas, and an outer space–time cyclically prefixed discrete multitone modulator.

The next paper, "Fast Linearized Energy Allocation for Multimedia Loading on Multicarrier Systems," by Enright and Kuo presents efficient near-optimal energy allocation methods for multicarrier systems with M-QAM and nonuniform noise. It is shown that these algorithms perform well for a wide range of multimedia and nonmultimedia sources.

In "Iterative Algebraic Soft-Decision List Decoding of Reed–Solomon Codes" by El-Khamy and McLiece, new decoding algorithms for Reed–Solomon codes are presented which offer both complexity and performance advantages over existing algorithms. This is achieved by combining algebraic

Digital Object Identifier 10.1109/JSAC.2005.862383

soft decision decoding and belief propagation based on adaptive parity-check matrices.

In the next paper, "Algorithm and Implementation of the K-Best Sphere Decoding for MIMO Detection," by Guo and Nilsson, algorithms with near maximum-likelihood (ML) performance for MIMO detection which are also suitable for very large scale integration (VLSI) implementations are presented. The proposed hard output K-Best Schnorr–Euchner (KSE) decoder and the soft output Modified KSE decoder are implemented for 4×4 16 QAM MIMO detection in CMOS technology.

In "Iterative Detection and Decoding With an Improved V-BLAST for MIMO-OFDM Systems," by Lee *et al.*, an improved receiver for the vertical Bell Labs Layered Space–Time (V-BLAST) system is presented, where the decision errors are taken into account. Furthermore, an iterative detection and decoding (IDD) scheme for coded layered space–time architectures in MIMO-OFDM systems is proposed. Significant performance gains over conventional V-BLAST are demonstrated.

In the next paper, "Polarized MIMO Channels in 3-D: Models, Measurements, and Mutual Information" by Shafi *et al.*, a MIMO channel model for cross-polarized systems is proposed for different environments where a composite channel impulse model is used that takes into account both azimuth and elevation spectrum. Closed-form expressions for the spatial correlation are derived. Models that describe the dependence of cross-polarization discrimination on distance, azimuth and elevation and delay are presented.

In the paper, "On the Optimality of Multiantenna Broadcast Scheduling Using Zero-Forcing Beamforming," Yoo and Goldsmith investigate transmit strategies for MIMO broadcast channels with multiple antennas at the base station and a large number of multiantenna users. It is shown that a zero-forcing beamforming (ZFBF) strategy can achieve the same asymptotic sum capacity as that of dirty paper coding (DPC), as the number of users goes to infinity. In proving this asymptotic result, a low-complexity semi-orthogonal user selection (SUS) algorithm is proposed for determining which users should be active under ZFBF. Numerical results are provided to confirm the optimality of ZFBF and to compare the performance of ZFBF and its extension to fair scheduling schemes with that of various MIMO BC strategies.

In the paper, "Performance Analysis of Multirate MC-CDMA in Rayleigh-Fading Channels With Delay Power Spectrum Exceeding the Guard Interval," Kunnari and Iinatti present a generic performance analysis for the multicode and variable spreading factor (VSF) multirate schemes for MC-CDMA in a frequency-selective Rayleigh-fading channel. The results show that the multicode scheme offers better error rate performance than the VSF scheme. Moreover, the multicode scheme enables similar performance for the different rates, opposite to the VSF scheme. It was also shown that besides the more advanced and complex optimum combining (OC) and minimum mean-square error (MMSE) per user combining (MMSEUC), also the simpler MMSE per carrier combining (MMSECC) gives good performance in the downlink. In the uplink, however, only the OC and MMSEUC were shown to give reasonable performance.

In the paper, "A Framework Design for the Next-Generation Radio Access System," Moon *et al.* propose a framework for air interface of packet-based next-generation radio access schemes that can incorporate various advanced transmission technologies such as link adaptation, opportunistic packet scheduling, channel coding, and multiple-antenna techniques. Through investigations on interoperability among these techniques by proposing a so-called cause and effect analysis, they design a differentiated-segments-based OFDM system, called DiffSeg, to accommodate heterogeneous operating conditions in a seamless manner. Simulation results show that the DiffSeg system can provide near-optimum performance with flexible configuration in a wide range of radio environments.

In the paper, "Performance Enhancement of Adaptive Orthogonal Modulation in Wireless CDMA Systems," Muqattash *et al.* present joint power/rate optimization in the context of orthogonal modulation (OM) and investigate the additional performance gains achieved through adaptation of the OM order. It is shown that such adaptation can significantly increase network throughput, while simultaneously reducing the per-bit energy consumption relative to fixed-order modulation systems. The optimization is carried out with two different objective functions: minimizing the maximum service time and maximizing the sum of user rates. Numerical results indicate that relative to an optimal joint rate/power control fixed-order modulation scheme, the proposed adaptive OM scheme achieves significant throughput and energy gains.

In the paper, "Fairly Adjusted Multimode Dynamic Guard Bandwidth Admission Control Over CDMA Systems," Yu *et al.* present the Fairly Adjusted Multimode Dynamic Guard Bandwidth (FAM-DGB) call admission control scheme for direct-sequence code-division multiple-access (DS-CDMA) systems with predictive adaptation control to adapt interference-based guard loading-limits under nonstationary call arrival condition; and reactive adaptation control to counteract arrival rate estimation errors. When the predictive adaptation control is not able to maintain long-term call dropping targets due to estimation errors, this will trigger reactive adaptation control that includes temporary blocking or preemption of one or more lower priority classes subject to fairness constraints to ensure fair degradation during estimation error recovery. Analytical and simulation results show that proposed scheme is able to provide performance guarantees in terms of dropping probabilities under nonstationary traffic arrival and imperfect arrival rate estimation.

The paper, "Throughput-Range Tradeoff of Wireless Mesh Backhaul Networks," by Mukherjee and Viswanatham deals with the tradeoff in throughput range for wireless mesh backhaul networks. Mesh networking where information is routed from source to destination over multiple wireless links, has potential advantages over traditional single-hop networking especially for backhaul communication. The paper develops a linear programming framework for determining optimum routing and scheduling of flows that maximizes throughput in a wireless mesh network accounting for the effect of interference and variable rate transmission. The authors then apply this framework to examine the throughput and range capabilities for providing wireless backhaul to a hexagonal grid of base

stations, for both single-hop and multihop transmissions for various network scenarios. Numerical results show a significant benefit for mesh networking under unbalanced loading.

The next paper, "Multichannel Random Access in OFDMA Wireless Networks," by Choi *et al.* deals with random access with fast retrials in OFDMA systems, which develops a fast retrial scheme that is based on slotted Aloha and exploits the structure of OFDMA. A salient feature of the scheme is that when collisions occur, retrials occur randomly in time they occur randomly in frequency, i.e., the scheme randomly selects the subchannels for retrial. The paper confirms through analysis and simulation that their fast retrial algorithm has the advantage of high throughput and low access delay, and that the full-sharing policy for random access channels shows higher throughput as well as low collision.

The next paper, "Cross-Layer Design in HSDPA System to Reduce the TCP Effect," by Assaad and Zeghlache deals with the interaction between the transport control protocol (TCP) layer and the radio interface in the high-speed downlink packet access (HSDPA) wireless system. In the paper, the interaction between TCP, hybrid automatic repeat request (HARQ), and scheduling techniques (especially, proportional fair scheduling) is explored with analytical models to evaluate HSDPA cell capacity, user bit rate, and interaction with TCP layer. It is shown that even if the bit rate per flow decreases strongly with the congestion frequency in the wired network, the overall capacity achieved by HSDPA is not as affected by the TCP layer. Using this result, a method to reduce the effect of TCP on wireless network without losing much cell capacity is proposed. This method has the advantage of modifying the scheduling algorithm only and of not requiring any change to the TCP protocol.

The paper, "Dynamic Spectrum Access in Open Spectrum Wireless Networks," by Xing *et al.* deals with the interesting dynamic spectrum access in open spectrum wireless networks. This issue is a key area of research by many regulators as they wrestle with many demands on limited spectrum. The paper considers continuous-time Markov models for dynamic spectrum access in open spectrum wireless networks. The paper derives analytical results based on the Markov models. It then proposes a random access protocol that is shown to achieve airtime fairness. A distributed version of this protocol that uses only local information is also proposed based on anthropological model. These protocols are then extended to spectrum agile radios and extensive simulation results are presented to compare the performances of fixed versus agile radios. This area is one we are likely to see more of in the literature.

The next paper, "Mobility Management in Heterogeneous Wireless Networks," by Assouma *et al.* deals with mobility management issues in heterogeneous wireless networks. In particular, it focuses on the key challenges in global mobility management of intersystem location management which consists of keeping track of mobile users who roam into foreign networks. The paper introduces a scheme which improves location management efficiency in terms of total signaling costs and intersystem paging delay. More specifically, cost reduction reaches about 50% when comparing the proposed architecture with conventional architectures.

In the paper, "Joint Frequency-Domain Differential Detection and Equalization for DS-CDMA Signal Transmissions in a Frequency-Selective Fading Channel," Liu and Adachi propose a frequency-domain differential encoding and detection scheme for DS-CDMA mobile radio. Joint frequency-domain differential detection and equalization (FDDDE) based on minimum mean-square error (MMSE) criterion is presented, where a simple decision feedback filter is used to provide a reliable reference signal for MMSE-FDDDE. It is confirmed by both approximate bit-error rate (BER) analysis and computer simulation that MMSE-FDDDE provides good BER performance close to the coherent MMSE-FDE and shows high robustness against the Doppler spread. It outperforms coherent MMSE-FDE for large Doppler spreads. The proposed MMSE-FDDDE can also be applied to multicarrier CDMA (MC-CDMA). Performance comparison between uncoded DS- and MC-CDMA shows that DS-CDMA with MMSE-FDDDE achieves better BER performance than MC-CDMA with MMSE-FDDDE for small spreading factors.

Cooperative diversity has been recently proposed as a way to form virtual antenna arrays that provide dramatic gains in slow-fading wireless environments. However, as most of the proposed solutions require distributed space–time coding algorithms, the careful design is left for future investigation if there is more than one cooperative relay. In the paper, "A Simple Cooperative Diversity Method Based on Network Path Selection," Bletsas *et al.* propose a novel scheme that alleviates these problems and provides diversity gains on the order of the number of relays in the network. The scheme first selects the best relay from a set of M available relays, and then uses this "best" relay for cooperation between the source and the destination. The simplicity of the technique, allows for immediate implementation in existing radio hardware and its adoption could provide for improved flexibility, reliability, and efficiency in future 4G wireless systems.

Multiuser detection (MUD) for CDMA systems usually relies on some *a priori* channel estimates, which are obtained either blindly or by using training sequences and the covariance matrix of the received signal, usually replaced by the sample covariance matrix. However, such prior estimates are often affected by errors that are typically ignored in subsequent detection. In the paper, "Robust Multiuser Detection for Multicarrier CDMA Systems," Wang *et al.* present robust channel estimation and MUD techniques for MC-CDMA by explicitly taking into account such estimation errors. The proposed techniques are obtained by optimizing the worst-case performance over two bounded uncertainty sets pertaining to the two types of estimation errors. At a slightly higher computational complexity, the proposed robust detectors are shown to yield improved performance over the standard detectors that ignore the prior estimation errors.

In the paper, "A Comparison of Reverse Link Access Schemes for Next-Generation Cellular Systems," Das and Viswanathan consider different transmission options on the reverse link of cellular systems for packet data. The different transmission options are classified based on the nature of in-cell and out-of-cell interference power statistics. The categories are: a) no in-cell interference, averaged out-of

cell interference; b) no in-cell interference, bursty out-of-cell interference; and c) averaged in-cell interference, averaged out-of-cell interference. Depending on the reverse link transmission orthogonality, the interference structure falls into one of the above three categories. The throughput performance of the system is analyzed in each of these cases when incremental redundancy is employed to combat uncertainty in the interference power. The authors compare the different options under an in-cell rise-over-thermal (IROT) constraint and provide some insights for reverse link design for next-generation cellular systems. The results show that transmission option a) with optimal choice of the number of simultaneous transmissions within the cell has the best performance over several different scenarios. Time multiplexed transmissions, despite the bursty out-of-cell interference power structure, has throughput comparable to that of a multiple-user orthogonal transmission system for small cells where mobiles have sufficient transmit power to meet the target IROT.

In the final paper, "A Future-Radio-Access Framework," Astély *et al.* discuss the requirements on future radio access and, based on the requirements, propose a framework for such a system. The proposed OFDM-based system supports very low latencies and data rates up to 100 Mb/s with wide area coverage and 1 Gb/s with local area coverage. Spectrum flexibility is identified as one main requirement for future systems and the proposed framework can be deployed in a wide range of spectrum allocations with bandwidths ranging from 2.5 up to 100 MHz. Multihop relaying, useful to extend the range for the high data rates, and multiple-antenna configurations are integral parts of the framework. A packet-centric approach is taken for the dataflow processing, implying that the scheduling mechanism and the retransmission protocol operates on complete packets rather than segments thereof and, thus allowing for cross-layer optimization. Finally, numerical evaluations are provided, illustrating the feasibility of future wideband radio access.

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ACKNOWLEDGMENT

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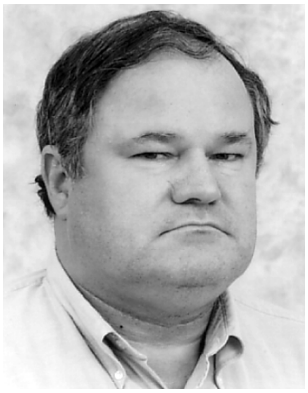

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