EURASIP Journal on Wireless Communications and Networking
a SpringerOpen Journal

EDITORIAL **Open Access**

Advanced technologies for LTE advanced

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With the explosive growth in mobile data traffic fueled by smartphones and mobile applications, transition from the 3rd generation (3G) toward 4th generation (4G) cellular networks is progressing at an unprecedented pace. Since the first release (release 8) of the 3rd generation partnership project (3GPP) long-term evolution (LTE) standard in December 2008, LTE has become the de facto standard on the way toward 4G cellular networks. Accordingly, LTE networks have seen rapid growth since 2009 when only two networks were initially launched. The number quickly expanded over the next few years, currently reaching 89 networks across 45 countries [1]. From the users' side, the number of global LTE subscribers is likely to surge more than five-fold to reach some 50 million in 2012 from 9 million in 2011, and is expected to exceed 560 million in 2016 [2].

3GPP has been working on further evolution of the LTE, which is referred to as LTE Advanced (release 10 and beyond), to develop a true 4G standard. The LTE Advanced is targeted to fulfill or even surpass all the requirements of international mobile telecommunications-Advanced (IMT-Advanced) [3] which is an official definition of 4G made by international telecommunication union (ITU) in 2008. These requirements include peak data rates, peak spectral efficiency, cell spectral efficiency, and scalable bandwidth. There are a lot of technical challenges for successful standardization of the LTE Advanced that meets the ITU requirements and supports backward compatibility with the LTE. The key features of the LTE Advanced differentiated from the LTE include support for wider bandwidth, improved uplink performance, better energy efficiency, advanced multiantenna technology, advanced interference management, and self-organizing network. Accordingly, from the perspective of physical (PHY) and medium access control (MAC) layers, multihop relay, multicell multi-input multi-output (MIMO), carrier aggregation, and intelligent interference management are challenging areas to be explored. Network aspects to be considered are heterogeneous networks (HetNets), femtocell optimization, and self organizing networks. The aim of this special issue is putting together recent original achievements and developments of enabling technologies for PHY, MAC, and network layers of the LTE Advanced. After extensive reviews, we have selected twelve articles in the relevant areas.

This special issue opens with a comprehensive review article, "*Overview of Enabling Technologies for LTE Advanced*" by Thien-Toan Tran, Yoan Shin, and Oh-Soon Shin. The article provides a detailed view of physical layer features as well as network architecture that qualify the LTE Advanced as a true 4G technology meeting the ITU's strict definition. Specifically, such features as carrier aggregation, advanced MIMO, wireless relays, enhanced intercell interference coordination (eICIC), and coordinated multipoint (CoMP) transmission/reception are covered at the right level of detail, which makes this article a good starting point to understand 4G technology.

The article "*Low-Complexity Multiuser MIMO Downlink System based on a Small-Sized CQI Quantizer*" by Jiho Song, Jong-Ho Lee, Seong-Cheol Kim, and Younglok Kim presents a multiuser multiple-input multiple-output (MU-MIMO) system with random beamforming. The authors develop a user selection algorithm suitable for random beamforming, and propose an efficient quantizer for channel quality indicator (CQI) to reduce feedback overhead. The small-sized CQI quantizer is designed based on a closed-form expression for the expected SINR of the selected users. Numerical results are provided to confirm that the random beamforming with the proposed CQI quantizer provides higher throughput and better fairness among users than conventional schemes under small amount of feedback.

The article "*Determinant-Based MIMO Scheduling with Reduced Pilot Overhead*" by Kyeongjun Ko and Jungwoo Lee proposes a user scheduling scheme with reduced complexity in MU-MIMO cellular systems. In a MU-MIMO cellular system where there are many candidate users, it is critical to select a user group which maximizes the overall throughput of the system. However, the optimal scheduling strategy based on exhaustive user

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selection is computationally prohibitive when the total number of users is large. In this article, the authors propose a determinant-based user selection algorithm which reduces the search complexity without much performance degradation. A key contribution of this article is to use a matrix determinant as a measure of orthogonality as well as channel quality in user selection. In order to reduce the pilot overhead, the authors also propose a new pilot scheme with only one set of pilot, which is another key contribution of this article.

The article "*Kalman Interpolation Filter for Channel Estimation of LTE Downlink in High-Mobility Environments*" by Xuewu Dai, Wuxiong Zhang, Jing Xu, John M Mitchell, and Yang Yang considers an estimation of fast-fading LTE downlink channels in high-speed applications of LTE Advanced. In order to adequately track the fast time-varying channel response, an adaptive channel estimation and interpolation algorithm is essential. In this article, the multi-path fast-fading channel is modeled as a tapped-delay, discrete, finite impulse response filter, and the time-correlation of the channel taps is modeled as an auto regressive (AR) process. Using this AR time-correlation, the authors develop an extended Kalman filter to jointly estimate the complex-valued channel frequency response and the AR parameters from the transmission of known pilot symbols. Furthermore, the channel estimates based on the known pilot symbols are interpolated to estimate the unknown data symbols by using the estimated time-correlation. This article integrates both channel estimation based on pilot symbols and interpolation of data symbol into the proposed Kalman interpolation filter.

The article "*Low Complexity PAPR Reduction Methods for Carrier-Aggregated MIMO OFDMA and SC-FDMA Systems*" by Pochun Yen and Hlaing Minn provides a solution to the problem of increased peak-to-average power ratio (PAPR) due to carrier aggregation. The authors propose several low-complexity and zero-overhead PAPR reduction methods for carrier aggregated systems based on orthogonal frequency division multiple access (OFDMA) or single-carrier frequency division multiple access (SC-FDMA), when MIMO is incorporated. In conjunction with phase-rotation based PAPR reduction methods, a reliable phase rotation detector is also developed to maintain the receiver performance. The proposed methods are shown to provide substantial PAPR reduction with low complexity and no signaling overhead.

The article "*A Resource Block Organization Strategy for Scheduling in Carrier Aggregated Systems*" by Guillermo Galaviz, David H Covarrubias, Angel G Andrade, and Salvador Villarreal tackles resource scheduling problem in carrier aggregated systems. When each available resource block (RB) is handled individually, assigning multiple RBs to each user may increase the scheduling delay, affecting the quality of service. The article proposes an efficient scheduling strategy based on a priori organization of available RBs so as to reduce RB assignment delay for carrier aggregated systems. Two different RB organization algorithms are presented and compared. Numerical results show that using the proposed strategy it is possible to reduce the delay required to assign RBs to users without affecting the downlink user capacity as compared to block-by-block scheduling strategies proposed in literature.

The article "*Resource Management Issues for Multi-Carrier Relay-Enhanced Systems*" by Jacek Gora and Simone Redana discusses relaying that has been considered in 3GPP as a key feature for enhancing capacity and coverage in LTE Advanced. Although tens of papers discussed the performance of relay solutions, this paper proves that there is still much to say about this topic. Indeed, the authors reviewed the problem of resource allocation in multi-carrier LTE Advanced systems with a focus on the wireless backhaul as the capacity bottleneck. By comparing the different possible solutions for implementing the wireless backhaul, be they based on time partitioning, frequency partitioning or a hybrid combination of them, this article offers a precious background for engineers that are interested in relaying in multi-carrier systems.

The article "*Optimizing Distance, Transmit Power, and Allocation Time for Reliable Multi-hop Relay System*" by Pham T Hiep, Fumie Ono, and Ryuji Kohno addresses optimization problems of multi-hop relay systems to ensure end-to-end channel capacity. First, it tackles individual optimization problems for transmit power, distance between transceivers, and allocation time. Then, it solves the joint optimization problem of these parameters by Markov Chain Monte Carlo method. The performance of multi-hop relay systems with decode-and-forward method is examined for each optimization.

The article "*Cooperative Relaying in OFDMA Networks Based on the Joint Use of Hierarchical Modulation and Link Adaptation*" by Anis Jdidi and Tijani Chahed considers an OFDMA network with cooperative relays. For cooperative relaying, the base station broadcasts a signal which the relay overhears and forwards to the destination. The destination combines the two copies of the received signal from the base station and from the relay to reconstruct the original one. The authors make use of hierarchical modulation to send additional information to the relay without the need for extra resource. Moreover, the link adaptation is adopted to take advantage of the typically good radio conditions between the base station and relay. They model such a system at the user level including a realistic arrival and departure setting, and quantify the gains in terms of throughput and blocking probability.

The article "*Uplink Interference Protection and Scheduling for Energy Efficient OFDMA Networks*" by Harald

Burchardt, Zubin Bharucha, Gunther Auer, and Harald Haas deals with an uplink interference protection issue in OFDMA systems. One of key challenges for future OFDMA-based networks is inter-cell interference coordination. With full frequency reuse and small inter-site distances, coping with co-channel interference (CCI) in such networks has become increasingly important. In this article, an uplink interference protection (ULIP) technique to combat CCI is introduced and investigated. The level of uplink interference originating from neighboring cells (affecting co-channel mobile stations (MSs) in the cell of interest) can be effectively controlled by reducing the transmit power of the interfering MSs. This is done based on the target signal-to-noise-plus-interference ratio (SINR) and tolerable interference of the vulnerable link. Bands are prioritized in order to differentiate those (vulnerable/victim) MSs that are to be protected from interference and those (aggressor/interfering MSs) that are required to sacrifice transmission power to facilitate the protection. Furthermore, MSs are scheduled such that those users with poorer transmission conditions receive the highest interference protection, thus balancing the areal SINR distribution and creating a fairer allocation of the available resources. In addition to interference protection, the individual power reductions also serve to decrease the total system uplink power, resulting in a greener system.

The article "*A Decentralized Spectrum Allocation and Partitioning Scheme for a Two-Tier Macro-Femtocell Network with Downlink Beamforming*" by Sunheui Ryoo, Changhee Joo, and Saewoong Bahk deals with interference issue due to femtocells. Femtocells are expected to be massively deployed in mobile networks, especially with the possibilities offered by the HetNets architecture of LTE Advanced. However, interference is the major issue in this context and interference mitigation and avoidance solutions are essential for taking advantage of the possibilities offered by femtocell deployments. This article discusses spectrum partitioning and allocation scheme in downlink beamforming systems as an efficient way to reduce interference. The obtained results show that the proposed solution is a promising one, even in decentralized systems. However, there are still further investigations to perform in this context, especially by taking into account the dynamics introduced by user's mobility and flow arrivals and departures.

The article "*Implementing Opportunistic Spectrum Access in LTE-Advanced*" by Vicente Osa, Carlos Herranz, Jose F Monserrat, and Xavier Gelabert discusses practical issues when implementing opportunistic spectrum access (OSA) in LTE Advanced. Indeed, although theoretical aspects of cognitive radio have been extensively studied in the literature, very few practically implementable solutions have been proposed. This paper fills this gap for LTE Advanced systems and proposes the usage of a geo-located data base that retrieves and maintains information about the spatial usage of spectrum in order to allow access for secondary users. Using a realistic simulator, this paper shows that this kind of databases (already used for secondary systems operating within TV white spaces) is an efficient solution for LTE Advanced spectrum. The editors believe, however, that the road is still long for convincing operators about the opportunity of allowing OSA in their LTE Advanced spectrum, through experimental testbeds and field trials.

We hope that the articles published in this special issue will serve as good references for readers' research work and promote further research in the emerging field of LTE Advanced. We would like to take this opportunity to thank all the authors who have submitted their papers to this special issue and express our gratitude to all the reviewers who provided valuable feedback to the authors. Their timely reviews and valuable comments helped us select the papers as well as improve the quality of this special issue. Our special thanks are also addressed to the devoted staff of JWCN, Bernardino McCartney, for his excellent support through the entire editing process, and to the Editor-in-Chief of the journal, Prof. Luc Vandendorpe, for his valuable comments during the process of defining of the special issue.

Competing interests
The authors declare that they have no competing interests.

Acknowledgements
The study of O-S Shin and Y Shin was supported in part by the Human Resources Development program (No. 20114010203110) of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy, and in part by the Korea Communications Commission (KCC), Korea, under the R&D program supervised by the Korea Communications Agency (KCA) (KCA-2012-12-911-01-107).

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Received: 20 November 2012 Accepted: 20 November 2012
Published: 8 February 2013

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doi:10.1186/1687-1499-2013-25
Cite this article as: Shin *et al.*: Advanced technologies for LTE advanced. *EURASIP Journal on Wireless Communications and Networking* 2013 **2013**:25.