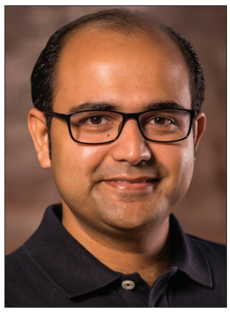
EMERGING APPLICATIONS, SERVICES, AND ENGINEERING FOR CELLULAR COGNITIVE SYSTEMS: PART II



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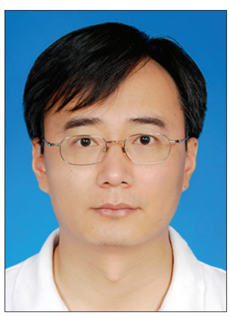

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We are back this month with a sequel to our May 2015 Feature Topic on Emerging Applications, Services, and Engineering for Cognitive Cellular Systems (EASE for CCS). In this followup, we have eight more articles that present emerging applications integrated with CCS through novel frameworks. These emerging applications include energy harvesting, network virtualization, machine learning approaches, backward-compatible cognition in LTE, self-organization capabilities, integration of vehicular networking over unlicensed spectrum, 2.4/5 GHz hybrid architecture, and integration of D2D communications.

Cognition and self-organization in future networks are now widely considered as striking solutions to develop a sustainable cellular infrastructure. The first article, by Zaidi *et al.*, presents a novel framework to evaluate the performance of a cognitive metro-cellular network powered by harvesting a green energy resource, such as sunlight. The authors introduce useful formulations and a methodology, along with a case study, to show how we can assess the potential of self-sustained operation of cellular networks while keeping the “energy outage probability” at a minimum. The framework can be extended and exploited to study the potential of other green energy sources for the operation of cognitive metro-cellular networks.

The second article, by El-Sawy *et al.*, presents a vision of a more flexible and adaptive cognitive network architecture for 5G cellular networks. In this envisioned architecture, the network functionalities are virtually instantiated in the cloud while keeping in mind the application requiring the functionality, as well as the corresponding constraints and physical targets for those applications. The authors present a case study to highlight the potential benefits of their proposal. The framework proposed to evaluate the potential benefits of this architecture can be further employed in future literature and research on network function virtualization and software-defined networking-based architectures for the next generation of cognitive cellular networks.

The third article, by Gao *et al*,. introduces a multi-parameter cognitive architecture, consisting of parameter structuralization, cognition, and prediction. While previous studies ignore the potential relationships between different parameters, their structuralization can lead to cognition accuracy and reduced complexity. Parameter cognition can have sufficient or insufficient prior knowledge, and learning techniques are considered for the latter to intelligently establish a cognition knowledge base. Representative examples of how signal processing and machine learning techniques can be used to cognize multiple parameters are provided. Finally, following multiple parameters cognition, the internal structure and underlying pattern of parameters can be used to predict their evolution. The proposed architecture represents a step forward to the ultimate goal of "full cognition" envisioned by Mitola, and thus toward future wireless communication systems.

Long Term Evolution cognitive radio (LTE-CR) over unlicensed spectrum, such as the industrial, scientific, and medical (ISM) band and television white space, has been studied in Third Generation Partnership Project (3GPP) standardization recently, in which network access is important in determining users' experiences. The fourth article, by Ling *et al.*, overviews network access schemes in existing CR networks first, and then proposes a system information block and cognitive pilot-channel-based backward-compatible scheme to facilitate the application of CR in LTE networks. This has potential to provide fast network access and put no stringent requirements on terminals. Moreover, due to the uncertainty of cognitive spectrum, which compromises the quality of service of users and the offloading efficiency of the network, the scheme is also load-aware. The article is expected to be of high reference value to the research and design of practical LTE-CR networks.

Small cells and their density in networks will be the trend of future wireless systems. Yuhua *et al.* investigate self-organizing optimization for cognitive small cells (CSC), which will play an important role in future cognitive cellular systems (CCS). The authors overview fundamental challenges and requirements for self-organizing optimization in CCS. A framework of game-theoretic solutions for self-organizing optimization in is established, and then featured game-theoretic models are proposed. A two-step scheme of game-theoretic solutions for self-organizing optimization is proposed. Some existing game models are introduced, and future research directions are presented. The authors discuss the usefulness of applying game theory for system analysis and optimization of cognitive small cell wireless networks.

The sixth article, by Shahid *et al.*, explores the possibility of using LTE device-to-device (D2D) communications for vehicular networks. Since a cellular network requires infrastructure-based communication, this incurs large delay that is unacceptable for vehicular applications. D2D offers an interesting solution to this problem by allowing vehicles to directly communicate without the need of an eNB. The article starts with a motivation to use LTE in vehicular networks followed by a review of D2D cellular communication and vehicle-to-vehicle (V2V) communication. Finally, the article proposes a cognitive algorithm to utilize LTE spectrum for V2V applications. Specifically, the algorithm uses path loss sensing to calculate the transmit power employed by vehicles, and allocates resources to vehicles according to the interference. Simulation results show a reduction in end-to-end delay and interference. The topic of the article is interesting and useful for future vehicular research. D2D communications could play a vital role in bringing vehicular communications into the mainstream.

The seventh article, by Chandra *et al.*, proposes the CogCell concept, which is a 2.4/5 GHz assisted 60 GHz picocellular network architecture, in which 60 GHz is used for high-speed data communication while 2.4/5 GHz WiFi is employed for control signaling. In CogCell, several 60 GHz picocells are managed by a single WiFi cell, thus facilitating easy and robust network and mobility management. In the absence of a 60 GHz connection, 2.4 GHz can be used as a fallback data communication option. By leveraging the sensing and processing capabilities of smart devices (e.g., motion sensors available in tablets and smartphones), cognitive and adaptive beam tracking can reduce the need for frequent re-beamforming at 60 GHz, and thus lead to more efficient spectrum utilization by effective switching between 2.4/5 GHz and 60 GHz bands for control and data communications. The proposed concept is supported by simulation results showing that with the help of rotation-vector sensor data, frequent re-beamforming for the 60 GHz directional links can be significantly reduced resulting in fewer requests to WiFi APs, thus demonstrating the efficient interplay between and 2.4/5 GHz WiFi and 60 GHz of the CogCell concept.

The eighth article, by Sakr *et al.*, highlights key challenges in resource allocation for in-band D2D enabled cellular networks and provides a comprehensive overview of the existing research advancements related to centralized and distributed resource allocation techniques. Since centralized solutions generally incur high computation and signaling overhead, distributed or semi-distributed solutions that exploit cognition at the D2D terminals are considered promising. Therefore, the authors propose a semi-distributed cognitive spectrum access (CSA) solution in which cognition at D2D terminals allows interference-aware decision making and limited control at the base stations to assist the D2D users in selecting the spectrum band with the least interference. The performance advantages of the proposed CSA scheme are analyzed quantitatively in terms of the channel access probability and spectral efficiency of cellular and D2D links. Finally, a number of directions for future research of CSA in D2D-enabled cellular networks are outlined.

In conclusion, EASE for CCS are now widely considered as frameworks to facilitate the heterogeneous demands of users in heterogeneous-type environments — particularly in the 5G network paradigm, where networks are anticipated to incorporate the provision of high-quality services to users with extremely low delays over limited spectral resources. The biggest challenge is to design new unified cross-layer network architectures for successful integration of the EASE frameworks by exploiting aggregation of highly distributed chunks of spectra (from unseen spectra to visible light spectra), network functions virtualization, spectrum harvesting, and orchestration of licensed and unlicensed spectral resources for ubiquitous connectivity.

Based on the high-quality contributions, we are sure that this two-part Feature Topic has been beneficial for further research, development, and technology advancement in future 5G CCS. Before closing this second part, we would like to thank all submitting authors for considering this Feature Topic as a potential venue for their research work, reviewers for their high-quality evaluation, and the editorial/publishing team of *IEEE Communications Magazine* for their collaboration.

BIOGRAPHIES

MUHAMMAD ZEESHAN SHAKIR (muhammad.shakir@qatar.tamu.edu) has been an assistant research scientist at Texas A&M University at Qatar, Doha, since July 2012. He received his Ph.D. in electronic and electrical engineering from the University of Strathclyde, Glasgow, United Kingdom, in 2010. From January 2006 to September 2009, he was the joint recipient of an industrial research fund and a prestigious overseas research scholarship from the University of Strathclyde. His research interests include design and deployment of diverse wireless communication systems, including hyper-dense heterogeneous small cell networks. He has published more than 75 technical journal and conference papers, and has contributed to six books, all in reputable venues. He is co-author of two research monographs. Most of his research has been sponsored by Qatar National Research Fund and national industrial partners. He has served as a lead Guest Editor for *IEEE Communications Magazine* and *IEEE Wireless Communications*. He has served as co-chair of several special sessions/workshops and symposia at flagship conferences, such as IEEE ICC and GlobalSIP.

OCTAVIA A. DOBRE is an associate professor with Memorial University, Canada. In 2000 she was the recipient of a Royal Society scholarship in the United Kingdom, and in 2001 she held a Fulbright Fellowship in the United States. Her research interests include cognitive radio systems, spectrum sensing techniques, transceiver optimization algorithms, and dynamic spectrum access. She has published over 130 journal and conference papers in these areas. She is a Senior Editor for *IEEE Communications Letters*, and has served as Editor and Guest Editor for other prestigious IEEE journals. She has been the Co-Chair of technical symposia at flagship conferences, such as IEEE ICC and IEEE GLOBECOM.

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ZHONGSHAN ZHANG received his Ph.D. degree in electrical engineering in 2004 from Beijing University of Posts and Telecommunications. From February 2006 to March 2009, he was at the University of Alberta, Canada, as a postdoctoral fellow. He has also worked at DoCoMo Beijing Laboratories, Alcatel-Lucent Shanghai-Bell, and NEC China Laboratories as a researcher. He is currently a professor at the University of Science and Technology Beijing. His main research interests include self-organized networking, cognitive radio, and cooperative communications.

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HIROSHI HARADA joined the Communications Research Laboratory in 1995, part of Japan's Ministry of Posts and Communications (currently National Institute of Information and Communication Technology, NICT). Since 1995, he has researched software defined radio, cognitive radio, dynamic spectrum access network, and broadband wireless access systems on the microwave and millimeter-wave band. Currently he is director of the Smart Wireless Laboratory at NICT and has been a visiting professor of the University of Electro-Communications, Tokyo, Japan, since 2005.