GUEST EDITORIAL

NEXT GENERATION COGNITIVE CELLULAR NETWORKS: SPECTRUM SHARING AND TRADING





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In the past few years, fundamental research has demonstrated great potentials of cognitive radio (CR) in increasing the spectrum agility and system capacity of wireless communications systems. With the ability to detect and adapt to the surrounding environment, CR has become one of the widely recognized features for future wireless communication systems. Specifically, CR has been recommended as a key technology to solve the spectrum scarcity problem in the next generation cellar networks. For example, the IEEE 802.16h standard was recently published for the license-exempt operation of WiMAX networks by defining a set of CR capabilities. On the other hand, a lot of efforts are being made to introduce CR features into 3GPP LTE-Advanced.

Evidently, integrating CR technologies into future generation cellular networks is becoming more and more important and will attract significant attention from both academia and industry. However, despite the large amount of research work conducted in recent years, there are still many open problems in developing and deploying large-scale CR-enabled cellular networks, from strategic design to technical implementation. To promote the investigation of CR technologies for next generation cellular networks, we have planned this Feature Topic to help both the industry and academia research communities to better understand the recent progress and potential research directions.

The response to our Call for Papers on this special issue was overwhelming, with a large number of articles submitted from around the globe. During the review process, each article was assigned to and reviewed by at least three experts in the relevant areas, with a rigorous two-round review process. Thanks to the courtesy of the Editor-in-Chief of *IEEE Wireless Communications*, Dr. Hsaio-Hwa Chen, we were able to accept 12 excellent articles covering various aspects of next generation cognitive cellular networks.

In "Expand LTE Network Spectrum with Cognitive Radios: From Research to Implementation," the authors study how to improve the performance of cellular networks by incorporating CR technology. Specifically, they consider a CR-enabled Long Term Evolution (LTE) system, based on which the authors survey the literature on enabling technologies, standards, and regulations. They also develop a prototype that demonstrates the feasibility of utilizing TV white space in cellular network.

To utilize CR technology for cellular networks, spectrum sharing is a key concern of many mobile network operators. In "Simple Rules for Mobile Network Operators' Strategic Choices in Future CognitiveSpectrum Sharing Networks," the authors discuss this issue. They first review the existing spectrum sharing framework from the perspective of regulatory, technology, and business models. They then present a dynamic spectrum sharing framework, so-called Simple Rules, for mobile network operators, including incumbents and challengers. Their study may help network operators adopt CR technology in future cellular network.

In "On the Scalability of Cognitive Radio: Assessing the Commercial Viability of Secondary Spectrum Access," the authors present an inspiring report on the commercial applicability of the CR system. Based on their research project, which was funded by European Union FP7, the authors evaluate several application scenarios and argue that some applications, in particular, wide area mobile broadband access, are not feasible from both the business and technique perspectives. On the other hand, indoor and short-range communication scenarios are more attractive because of the lower cost of CR systems and simpler spectrum management.

To exploit CR technology in future cognitive cellular networks, a number of challenges have to be addressed, including the scalability of the system, the complexity of architecture, the heterogeneous of system, and the dynamics of spectrum, etc. Aiming at addressing these issues, the authors of "Self-Organization Paradigms and Optimization Approaches for Cognitive Radio Technologies: A Survey" suggest that self-organizing shall be taken into consideration in the design of CR systems. Particularly, they present a nice survey on the self-organization aspects of various elements in CR systems.

In "Cognitive Femtocell Networks: An Opportunistic Spectrum Access for Future Indoor Wireless Coverage," the authors investigate how to integrate CR technology into femtocell architecture. In their study, they first identify three interference mitigation schemes, and then propose a joint opportunistic interference avoidance scheme based on interweave CR. Numerical results show that the proposed scheme can achieve considerable gain for indoor applications.

To exploit the potential of CR in a cellular network, a key challenge is how to handle the coexistence and self-coexistence issues. To address this challenge, the authors of "Self-Coexistence in Cellular Cognitive Radio Networks Based on the IEEE 802.22 Standard" consider the self-coexistence issue as a channel assignment problem. In particular, assuming IEEE 802.22

as the standard, the authors propose two channel assignment schemes in cognitive cellular network with cooperative and non-cooperative cells, respectively. They also conduct extensive numerical study to investigate the pros and cons of difference schemes in terms of throughput, complexity, and fairness to users.

Certainly, to implement cost-effective CR systems, there are a lot of technical challenges to be addressed. In "Design and Implementation of Spatial Interweave LTE-TDD Cognitive Radio Communication on an Experimental Platform," the authors develop an experimental system. In particular, they use LTE as the physical layer standard, and design and implement a spatial interweave CR, with which the spectrum reuse can be improved because a secondary user can perform null-beamforming in the primary user's direction. In their experimental system, they also design calibration protocol to restore channel reciprocity.

In "Overlay Cognitive Radio OFDM System for 4G Cellular Networks," the authors investigate how to integrate an overlay CR system into 4G cellular networks so as to utilize the available TV white space. Specifically, they consider a two-layer OFDM architecture, in which the first layer is dedicated to the digital TV system, and the second one is used to access the cellular network. Based on such a layered model, they develop an overlay CR system using time domain hierarchical transmission or frequency domain hierarchical modulation. The authors demonstrate that with the proposed system, the receiver performance can be substantially enhanced by adaptively cancelling layer 1 interference.

Spectrum sensing is apparently an important component for any CR system. To fully exploit possible spectrum opportunities, future CR system may be required to sense a wide range of spectrum bands, from a few hundred megahertz to a few gigahertz. To tackle this challenge, many new technologies have been proposed recently. In "Wideband Spectrum Sensing for Cognitive Radio Networks," the authors present a survey of state-of-the-art wideband spectrum sensing. Specifically, they focus on sub-Nyquist techniques, including compressive sensing and multichannel sub-Nyquist sampling. The authors discuss the pros and cons of different algorithms, and also present important topics for future investigation in wideband spectrum sensing.

In "Deploying Cognitive Cellular Networks under Dynamic Resource Management," the authors discuss in general how to manage spectrum resources in CR-enabled cellular systems that provide cellular coverage by both macrocells and small cells. They first survey challenging issues for such systems, including network coordination, interference management, and so on. They then propose a framework for cognitive routing and adaptive spectrum management to maximize the spectrum utilization and mitigate interference between macrocells and small cell users. To achieve efficient power control, a game-theoretical approach is also introduced.

In "Spectrum Prediction in Cognitive Radio Networks," the authors generalize the requirements for CR systems into four spectrum-related functions: sensing, decision, sharing, and mobility. To improve the performance of these four functions, the authors emphasize that spectrum prediction is one of the key technologies. In this regard, they present the state-of-the-art research work in the literature, including six prediction techniques and how they can enhance the performance of each of the four functions. Some open issues and future research directions are also discussed.

Last but not least, in "Feasibility of Cognitive Machine-to-Machine Communication Using Cellular Bands," the authors discuss a possible application for cognitive cellular networks. Specifically, they study the possibility of utilizing cellular bands instead of well-known spectrum bands for CR, such as TV white space, to enable machine-to-machine communications. In their work, they first propose hierarchical network architecture, in which cluster heads collect information from local devices using CR technologies and then forward the data to the cellular network. They then elaborate on the potential of the proposed architecture and investigate its engineering value and, more important, the business model of such applications.

In closing, we would like to thank all the authors for their excellent contributions. We would also like thank all the reviewers for their dedicated efforts in reviewing the papers, and for their valuable comments and suggestions for improving the quality of the articles. Finally, we appreciate the advice and support of former and current Editors-in-Chief of *IEEE Wireless Communications*, Dr. Yuguang Michael Fang and Dr. Hsiao-Hwa Chen, for their help in the publication process.

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