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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: CLOUD AND BIG DATA-BASED NEXT-GENERATION COGNITIVE RADIO NETWORKS

In cognitive radio networks (CRN), secondary users (SUs) are required to detect the presence of the licensed users, known as primary users (PUs), and to find spectrum holes for opportunistic spectrum access without causing harmful interference to PUs. However, due to complicated data processing, non-real-time information exchange and limited memory, SUs often suffer from imperfect sensing and unreliable spectrum access. Cloud computing can solve this problem by allowing the data to be stored and processed in a shared environment. Furthermore, the information from a massive number of SUs allows for more comprehensive information exchanges to assist the resource allocation and interference management at the cloud center while relieving the stringent capacity demands in fronthaul links. Moreover, spectrum resources should be made available to more users, especially when the spectrum is underutilized but occupies a large band. Hence, cloud-based CRN can generate massive sensing samples that will benefit the applications of big data algorithms. The approaches to spectrum sensing and spectrum management can be greatly improved with decision-making capabilities of spectral big data.

To integrate cloud and big data in CRN and to support high quality transmission, a lot of problems need to be addressed, such as cloud-based CRN, cloud-based spectrum management, and big data-based spectrum sensing. This Special Section in IEEE ACCESS has brought together leading researchers and developers from both industry and academia to discuss and present their views on all aspects of cloud and big data-based CRN.

IEEE journals are considered as the flagship in the engineering field. IEEE ACCESS is a new multidisciplinary, applications-oriented, all-electronic archival journal continuously presenting the results of original research or development across all of the IEEE's fields of interest. Because of its open access nature, this Special Section is freely accessible to readers all over the world. After a rigorous peer-review process, twenty-two high-quality articles have been accepted from leading groups around the world to form this Special Section.

In the article "Secrecy outage analysis on underlay cognitive radio system with full-duplex secondary user," Zhang *et al.* investigated the secrecy outage performance of the primary-user system in underlay cognitive radio networks in the presence of the eavesdropping and interfering of full-duplex secondary users. By considering that the information delivery in PU system may be overheard by secondary users, secrecy outage performance has been studied, and the approximated closed-form analytical expression for secrecy outage probability and the lower boundary of the asymptotic secrecy outage probability have been derived. The authors found that increasing the transmit power at primary-user can improve the secrecy performance, and the interference constraint at primary-user also exhibits a positive effect on the secrecy performance. The authors presented results demonstrating the validity of the proposed analytical model.

In the article "Spectrum optimization for cognitive satellite communications with cournot game model," Wang *et al.* proposed a spectrum allocation scheme by investigating the action strategy of terrestrial cognitive terminals in a distributed competition. The resource allocation scheme catering for cases of incomplete user information is developed as an extension of the basic scheme by formulating the problem as a Cournot game model. The main contribution of this article is to address the spectrum optimization problem in realistic circumstances where cognitive satellite users do not have complete information of the whole channel status and other users. Numerical results are provided to justify the proposed method's performances and illustrate the impacts of corresponding parameters on terrestrial cognitive users' benefits.

In the article "Multi-objective resource allocation in a NOMA cognitive radio network with a practical non-linear energy harvesting model," Wang *et al.* studied a non-orthogonal multiple access cognitive radio network with simultaneous wireless information and power transfer under a practical non-linear energy harvesting model, to improve energy efficiency and spectral efficiency. A multi-objective resource optimization problem was formulated for maximizing the harvesting power of each energy harvesting receiver. The authors have proposed a weighted Tchebycheff method to solve the formulated problem. They demonstrated that the performance achieved under the non-linear energy harvesting

model is better than that obtained under the linear energy harvesting model.

In the article "MAC based energy efficiency in cooperative cognitive radio network in the presence of malicious users," Dai *et al.* proposed and evaluated the message authentication code (MAC) based energy-efficient cooperative spectrum sensing scheme. This is a low-overhead symmetric cryptographic mechanism that reduces the effects of the malicious users on energy efficiency. The energy efficiency optimization problem is formulated, where the design variables are the number of cooperative sensor nodes and the number of the additional security bits are design variables. The relation between energy efficiency and the two variables are theoretically analyzed under two types of spectrum sensing data falsification (SSDF) attacks, respectively. The research results are of great significance in cloud and big data-based next-generation cognitive radio networks.

In the article "Spectrum allocation with asymmetric monopoly model for multibeam-based cognitive satellite networks," Li *et al.* proposed a spectrum allocation method for cognitive satellite networks to improve spectrum efficiency by addressing the situation that scarce spectrum resource is under-utilized while the overall demands of cognitive satellite users are not satisfied. Due to the scarcity of spectrum resource, satellite systems have to eliminate some of the cognitive users' transmission information types in order to fulfill the spectrum demands of priority users. After declining one or several kinds of modulation modes, cognitive users can update their spectrum lists. Through rounds of eliminating operations, the satellite systems can identify the final Bayesian equilibrium as an optimal spectrum allocation strategy. Also, the proof for the existence of Bayesian equilibrium has been provided.

In the article "Practical implementation of multi-user transform domain communication system for control channels in cloud-based cognitive radio networks," Hu *et al.* investigated a transmission scheme for control channel (CC) in cloud-based CRNs, which is over several noncontiguous spectral holes. Transform domain communication system (TDCS)-based transmission scheme with spectrally-constrained sequence design was presented for CC. The authors presented a practical testbed design for TDCS-based CC with multiple National Instruments PXIe devices and six universal software defined radio reconfigurable input/output devices.

In the article "Turbo receiver channel estimation for GFDM-based cognitive radio networks," Na *et al.* proposed and evaluated a threshold control strategy for iterative channel estimation in Generalized Frequency Division Multiplexing (GFDM) based cognitive radio networks. As a non-orthogonal multi-carrier technology, GFDM has the advantages of low Peak to Average Power Ratio (PAPR), high flexibility, and high spectrum efficiency which make GFDM one of the best candidate waveforms for the next generation cognitive radio networks. In order to make full use of the feedback information in Turbo decoder and improve the performance of channel estimation, the authors redesigned the Turbo receiver to utilize the feedback information for channel estimation. The authors designed a threshold control strategy to cope with the noise enhancement in the process of iterative channel estimation. The performance of the proposed channel estimation method is verified by simulations. This article provides a new candidate of non-orthogonal multi-carrier transmission scheme to the next generation of cognitive radio networks and designs an iterative channel estimation method to improve transmission quality.

The article "Packet multicast in cognitive radio ad hoc networks: A method based on random network coding," by Chen *et al.* studied packet multicast technology in cognitive radio ad hoc networks using a random network coding-based approach. The authors presented a four-element tuple model for the multichannel single-hop wireless multicast problem, which is the key problem of packet multicast applications in cognitive radio ad hoc networks. In addition, the authors also proposed the framework of the multicast algorithm based on the network coding technology, and provided several multicast algorithms based on the framework which made full use of the broadcast nature of wireless channel to reduce the number of packets transmitted. In the article, the authors fully considered access authority of the transport nodes and packet transmission quality to different channels in cognitive radio networks for the purpose of maximizing the earnings of the trailing nodes and improving the efficiency of packet multicast and broadcast. The authors presented results demonstrating that the network coding scheme can effectively reduce the transmitted packets, which can promote technological development and improve transmission efficiency for the big data-based cognitive radio networks.

In the article "A multichannel cognitive radio system design and its performance optimization," Liu *et al.* proposed a cognitive radio (CR) system based on transform domain communication system to access the non-continuous spectrum. The proposed CR system senses spectrum status by energy detection and marks the spectrum availability as a spectrum marker vector. A basis carrier generated from the spectrum marker vector may concentrate the power on the idle subchannels. The bit error rate of the CR system is analyzed both in the cases of spectrum inconsistency and multiple access. The transmission data is modulated on the basis carrier using binary modulation and cyclic code shift keying modulation. A system optimization unit is designed to improve the system throughput by jointly optimizing sensing threshold and transmission power of each subchannel. The authors presented simulation results to show the outstanding performance of the proposed CR, which can achieve larger throughput compared with the traditional scheme.

In the article "Green-RPL: an energy-efficient protocol for cognitive radio enabled AMI network in smart grid," by Yang *et al.* the energy efficiency is enhanced for the cognitive radio enabled AMI network, in order to reduce the energy consumption of smart grid. A new RPL-based routing protocol termed as Green-RPL is proposed, where the

energy efficiency over virtual distance (EEVD) is considered as the key factor of routing. During a single hop, multiple neighbor nodes are selected to structure a forwarder set. The EEVD of each forwarder is estimated and adopted as the basis of forwarding priority. Therefore, the candidate with higher energy efficiency has a larger chance for forwarding, such that the energy-efficient route can be selected. Furthermore, it fulfills the QoS requirements of communications in smart grids, and considers protection to PUs as well. Additionally, micro-frame scheme is adopted to transmit ACK information, such that the cooperation overhead is reduced. Performance evaluation shows that Green-RPL can improve the energy efficiency of the CR-AMI networks significantly, without resulting in obvious damage to other performances. Therefore, Green-RPL provides a potential solution for communications in smart grids.

In the article ''Symbol rates estimation of time-frequency overlapped MPSK signals for underlay cognitive radio network,'' Liu *et al.* proposed symbol rate estimation of interference temperature measurement in underlay cognitive radio network (CRN). This is underpinned by teager energy operator (TEO) magnitude spectrum to extract the position information. Nonlinear filter is employed to improve the spectral resolution of the TEO magnitude spectrum. The authors also analyzed the modified Cramer-Rao Bound (MCRB) of the symbol rate estimation for time-frequency overlapped signals. The authors presented results demonstrating the estimation performance of the proposed symbol rate estimation of time-frequency overlapped MPSK signals, thereby illustrating the feasibility of symbol rate estimation based on the TEO in low signal to noise ratio (SNR) regions.

In the article "A services routing based caching scheme for cloud assisted CRNs," Huang *et al.* propose a service routing-based caching scheme (SRCS) for CRNs with the coexistence of cloud computing and edge computing, to efficiently process the sensing data from various sensing sources. In such a system, the cloud and edge computing platforms have different characteristics in terms of computing capacity and distance to data sources. To fully harness the computing resources, at the edge layer, data is first converted to service flow, thus achieving the network architecture centered on service computing. Then, a service routing is proposed based on service similarity, where similar services can be transmitted through the same path, and service data are fused on the path to minimize transmission load. Moreover, SRCS caches services in content routers (CRs) and the requested service can be served by the CRs in the future, thus reducing the service latency. The authors also provide the theoretical analysis and experiment results to evaluate the performance of the proposed scheme.

In the article ''Digital signal modulation classification with data augmentation using generative adversarial nets in cognitive radio networks,'' Tang *et al.* proposed a smart approach of Auxiliary Classifier Generative Adversarial Networks (ACGAN) for Automated Modulation Classification (AMC) in Cognitive Radio Networks. In their previous work, the authors had proposed Convolution Neural Network (CNN) for AMC; however, the authors believed they could improve it. In the past year, Generative Adversarial Networks (GAN) have been widely used for data augmentation. Therefore, in this article, according to the problem of insufficient data and overfitting, ACGAN is used to generate more simulation data to supplement the signal data set. In the meantime, in order to alleviate common issues in the traditional GAN training, such as discriminator overfitting, generator disconverge and mode collapse, several training tricks have been proposed, which are very helpful for the application. Finally, CNN and AlexNet model have been used as classifiers. Compared with the result of the original dataset, the new method can increase 0.1∼6% in the classification accuracy. AMC plays a very important part in Cognitive Radio Networks. Deep Learning is also a powerful tool for the pattern recognition problem.

In the article ''An optimized algorithm for protecting privacy based on coordinates mean value for cognitive radio networks,'' Xing *et al.* proposed a privacy protection algorithm to preserve local sensing information of secondary users in Next-generation cognitive radio networks. The authors evaluated the correlation of various attributes of current privacy protection methods, and presented the coordinates mean value-based privacy preserving method, which showed tradeoffs between the attributes of privacy protection. The main task of the method was to generate an anonymous area for the secondary users' real location and to form a location service area based on the anonymous area. The authors optimized the algorithm by stochastic gradient descent method to obtain the best performance given different k-values. The algorithm provides a way to protect privacy in Next-generation cognitive radio networks.

In the article ''Spectrum mapping in large-scale cognitive radio networks with historical spectrum decision results learning,'' Huang *et al.* proposed a spectrum mapping scheme which can exploit spectrum sensing results and show the entire spectrum states of cognitive radio network (CRN). The spectrum mapping scheme is a machine learning framework based on Least Squares Support Vector Machine (LS-SVM) to deal with spectrum heterogeneity problems in large-scale CRN. According to the support vector characteristics of LS-SVM, the authors deduced that the Lagrange multiplier corresponding to the sensing data is negatively correlated with the distance from the unauthorized user to the spectrum state boundary. Based on this inference, a boundary user searching algorithm was proposed to efficiently decrease the time and energy consumption of the spectrum mapping scheme. The proposed spectrum mapping scheme effectively exploited the historical spectrum sensing big data in CRN.

In the article ''TDCS-IDMA system for cognitive radio networks with cloud,'' Hu *et al.* presented a new multiple access communication system, called transform domain communication system IDMA communication system, to deal with spectral nulling problems. In order to support multiple access, the authors proposed two improved schemes based

on BPSK and cyclic code shift keying modulations, whose structure integrated the advantages of both OFDM-IDMA and CRNC, which can make full use of other users' information while satisfying CR constraints. Simulation results demonstrated that the two proposed system architectures can achieve significant improvement on BER performance, multiple access capability, and anti-interference ability with spectral nulling.

In the article "Joint resource allocation for wireless energy harvesting enabled cognitive sensor networks," Lu *et al.* proposed a spectrum sharing protocol in wireless energy harvesting enabled cognitive sensor networks (CSN). In order to gain spectrum to transmit the signal of cognitive sensor transmitter (CST) to its receiver, CST helps forward the signal of the primary transmitter (PT) to primary receiver (PR) in the second transmission slot, which utilizes the power harvested from the received PT's signal with power splitting in the first transmission slot. Moreover, joint power splitting ratio and bandwidth allocation is investigated to maximize the CSN transmission rate subject to the primary transmission rate constraint. Simulation results demonstrate that the performance of both primary and cognitive sensor systems can be effectively improved.

In the article "Cache-aided multiuser cognitive relay networks with outdated channel state information," Lai *et al.* proposed to use the wireless caching technique to alleviate the burden from wireless big data for the multiuser cognitive relay networks, which can help improve the transmission performance and enhance the quality of user experience. To further enhance the network performance, two user selection criteria in choosing the best secondary source are used to maximize the channel gain of the direct link or the transmit power at the selected secondary source, respectively. Moreover, the authors studied the scheduling delay by introducing the impact of outdated channel state information on the user selection. For the considered networks with or without cache, the authors derived the analytical and asymptotic expressions of the outage probability under the two user selection criteria, respectively. From the simulated and analytical performance results, it is concluded that by using caching technique, the wireless big data transmission in cognitive relay networks can be improved substantially.

In the article "Energy efficiency of access control with rate constraints in cognitive radio networks," Zhai *et al.* proposed an access control algorithm to support more users satisfying their communication rate requirements in the next generation cognitive radio networks. This is caused by numerous users sharing the same spectrum resource, leading to severe interference. The spectral radius of the network characteristic matrix is employed as the admission price to access the secondary users. The authors demonstrate better energy efficiency through design of an algorithm such that the network has the near-optimal solution for the system capacity at the same time. The authors presented results demonstrating the decent performance of the proposed hybrid access strategy, thereby illustrating the novel access control for green communications when there are plenty of cognitive users.

In the article "Physical-layer network coding based multi-user cooperative relay transmission with multi-antennas in cognitive wireless networks," Yang *et al.* proposed a new multi-user transmission coding scheme, cooperative quadrature physical-layer network coding, for cognitive wireless networks. Jointly employing physical-layer network coding (PNC) and multi-antenna space-time block coding (STBC) is a promising way to improve the performance and guarantee the Quality of Service (QoS) of cognitive wireless cooperative relay networks. Simulation results in different cases of cognitive wireless networks show that the proposed scheme outperforms the traditional cooperation and cooperative network coding transmission schemes on the performance of anti-noise and throughput. In next generation cognitive radio networks, the demand of systems' reliability and validity is higher and higher. The proposed method in this article can provide a valuable referred scheme to satisfy this demand.

In the article "Joint RRH activation and robust coordinated beamforming for massive MIMO heterogeneous cloud radio access networks," considered heterogeneous cloud radio access networks (H-CRANs) with imperfect channel state information at transmitters, Zhang *et al.* proposed a low-complexity joint remote radio head (RRH) activation and outage constrained coordinated beamforming algorithm to save the total network energy consumption and guarantee the quality of service. By using an extended Bernstein-type inequality to conservatively approximate the RRH user equipment's outage constraints, the original energy minimization problem is reformulated to a semidefinite program. To reduce the complexity of the algorithm, the authors presented a RRH priority sorting scheme and proposed a binary search-based joint RRH activation and robust coordinated beamforming algorithm. Simulation results demonstrate that the proposed algorithm can significantly reduce the H-CRANs power consumption.

We have recommended Yulong Gao as an invited author for the Special Section due to his ongoing efforts with cognitive radio. Cognitive radio is proposed to realize intelligent communication and improve spectral efficiency. In cognitive radio, spectrum sensing plays a key and fundamental role. At present, the focus of spectrum sensing has changed into wideband spectrum sensing from the narrowband scenarios. The invited article, "Sparse-Bayesian-Learning-Based Wideband Spectrum Sensing With Simplified Modulated Wideband Converter" falls into the Special Section's fields of interest. In the invited article, Gao *et al.* proposed a promising and practicable wideband spectrum sensing scheme in terms of a modulated wideband converter (MWC) and sparse Bayesian learning (SBL). Due to the fact that wideband spectrum sensing is an inference problem, it is unnecessary to acquire the specific signal waveform. Correspondingly, the authors employed SBL to directly extract the relevant information from the compressed measurements to estimate

the support set to perform wideband spectrum sensing. The estimated support set is employed as the test statistic to facilitate spectrum sensing and analyze the sensing performance. For practical applications of support sets, different matching criteria are presented according to the requirements imposed by wideband spectrum sensing. In addition, the CTF block and pseudoinversion operation in the conventional MWC are removed to reduce the hard cost and computational complexity. Finally, the authors presented results demonstrating the superiority of the proposed method over the MWC-based orthogonal matching pursuit (MWC-OMP) method.

We are happy with the technical depth and span of this Special Section. Finally, we sincerely thank all the authors and reviewers for the tremendous efforts, and of course the Editor-in-Chief and staff members for their great guidance.

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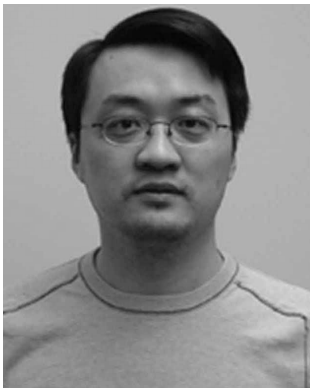

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