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# Introduction to the Special Section From the GLOBECOM 2018 Cognitive Radio and Networks Symposium

Faouzi Bader, *Senior, IEEE*, and Octavia A. Dobre, *Senior, IEEE*

**W**E ARE delighted to introduce the readers to this section of the IEEE TRANSACTIONS ON COGNITIVE COMMUNICATIONS AND NETWORKING (TCCN), which is devoted to selected papers from the IEEE GLOBECOM'2018 Cognitive Radio and Networks Symposium.

The IEEE GLOBECOM'2018 conference was held in Abu Dhabi, UAE, during December 9-13, 2018. The Cognitive Radio and Networks (CRN) Symposium received 81 sub-missions, out of which 33 were accepted by the conference. Prof. Michele Zorzi, Editor-in-Chief of TCCN (2015-2018), invited the co-chairs of the symposium to run a special issue. The symposium co-chairs (and guest editors of this special section) invited a subset of the authors of the CRN GLOBECOM Symposium to submit extended versions of their papers for consideration for this special section. The invitations were based on the review scores from GLOBECOM. The invited papers, submitted to this special section were expanded with respect to their original GLOBECOM CRN Symposium versions and each went through another rigorous review process by (at least) three independent expert reviewers. Eventually, we selected four papers, which are briefly introduced below.

In the "Cognitive Network Management and Control with Significantly Reduced State Sensing" paper, the authors consider a Network Management and Control (NMC) system where sensing and routing decisions are made with cognitive understanding of network states and short term behavior of exogenous offered traffic. A realistic example of adaptive monitoring is studied based on significant sampling techniques. This technique balances the need for updated state information against the updating cost and provides an algorithm that yields near optimum performance with significantly reduced burden of sampling, transport, and computation.

To illustrate the efficacy of the proposed cognitive management approach, the authors use the example that primarily focuses on challenges involved with "shortest path"

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routing in dynamic networks. In this context, an NMC system has to monitor the state of queues throughout the network to decide which path(s) should be used to connect different origin-destination (OD) pairs. In practice, various shortest path algorithms (Bellman-Ford, Dijkstra, etc.) are used to identify the optimal shortest path. Shortest path routing algorithms assign a length/weight to each link of the network; this length is usually a proxy for traffic congestion on the link, but can also incorporate other factors. Depending on the specific implementation, the length may depend on the number of packets waiting in the queue, loading of the output line, or the average packet delay on the link during a pre-specified amount of time. Neighboring nodes exchange their estimated shortest distances to all other nodes periodically and new information will be disseminated throughout the network after a few rounds of exchanges.

It is shown in this paper that the presented adaptive monitoring system can reduce the NMC overhead by a factor of 100 in one example. The spirit of cognitive NMC is to collect network states only when they can improve the network performance.

In the paper entitled "On the Outage of Underlay CR-NOMA Networks with Detect-and-Forward Relaying," the authors study an underlay CR-non-orthogonal multiple access (NOMA) relaying network, where a secondary source communicates with MNOMA secondary destination users (SDUs) by means of a decode-and-forward secondary relay under imperfect channel state information (CSI) conditions. The authors, derive generalized outage probability (OP) expressions included form for MNOMA-enabled SDUs. Moreover, the authors evaluate the OP of the CR-NOMA and conventional CR orthogonal MA (OMA) schemes to show the superiority of the former. Furthermore, the authors study a downlink CR-NOMA network with a detect-and-forward relaying and multiple SDUs and they consider interference temperature constraint (ITC) at the primary receiver. The main contributions of this paper are summarized as: i) The system with the imposed ITC is more realistic, and hence more practical insights into the system behavior can be extracted. Moreover, the introduction of the ITC makes the analytical derivations more complicated since an additional random variable should be also considered. Taking this into account, the authors first derive closed-form expressions for the OP, and then, the average throughput for messages dedicated to MNOMA SDUs is obtained, ii) the authors

optimize the power allocation (PA) factors of NOMA users based on the channel quality between the relay and NOMA secondary users in order to guarantee the user fairness among NOMA users in terms of the OP. Moreover, it is shown that the OP performance of the proposed CR-NOMA network is superior compared to the conventional CR-OMA, and iii) in the proposed system, it is assumed that primary transmitters cause interference to the secondary users (SUs). In addition, the authors assume imperfect CSI as perfect CSI is highly idealistic because the estimation of the real-time wireless channel is mostly imperfect. Considering the aforementioned assumptions, the authors study the impact of the imperfect CSI and primary interference on the OP of the NOMA SDUs. From presented numerical results, it was deduced that the fairness for NOMA users' performance can be guaranteed by a proper evaluation of PA factors. Moreover, comparison results of the OP for CR-NOMA and CR-OMA showed that the NOMA system performs better than OMA with and without implementing the ITC.

In the paper titled "A Fast Blind Scheme with Full Rendezvous Diversity for Heterogeneous Cognitive Radio Networks", the authors propose a fast blind rendezvous scheme named modified enhanced heterogeneous radio rendezvous (MEHRR) scheme for the secondary users (SUs) in distributed heterogeneous Cognitive radio networks (CRNs). Compared with the authors' previously published paper, they consider in this work rendezvous diversity when designing the MEHRR scheme. The SUs can achieve full rendezvous diversity (i.e., rendezvous on all commonly available channels) by the MEHRR scheme, that can increase the success probability of rendezvous while reducing the impact of blocking primary users (PUs) for a long time. The upper bounds on the time to rendezvous (TTR) with full rendezvous diversity are derived by theoretical analysis for the MEHRR scheme. Besides, they also theoretically analyze the channel loading, and the optimal allocation of multiple radios that can achieve the shortest maximum TTR (MTTR) with full rendezvous diversity for the SUs using the MEHRR scheme.

The authors have demonstrated in this work, that the EHRR scheme can further shorten the MTTR compared with the HRR scheme. However, the rendezvous diversity and channel loading are not well considered by the EHRR scheme. Besides, the optimal allocation of radios, i.e., the allocation of jump radios and stay radios for the SU, that can minimize the MTTR is neither well analyzed. Hence, to guarantee rendezvous for the SUs in heterogeneous CRNs with full rendezvous diversity and minimum channel loading, they propose a fast blind rendezvous scheme named modified EHRR (MEHRR) scheme in this paper.

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The main contributions of this paper can be summarized as: i) The MEHRR scheme including the modified enhanced single radio rendezvous (MESRR) scheme and the enhanced multiple radios rendezvous (EMRR) scheme is proposed. The MESRR scheme and the EMRR scheme are designed to generate channel hopping sequences for the SUs with a single radio and multiple radios, respectively. SUs can achieve rendezvous within upper bounded time by the MEHRR scheme regardless of the number of radios. Besides, full rendezvous diversity and minimum channel loading can be achieved by the MEHRR scheme, ii) The upper bounds on the TTR for the MEHRR scheme are derived by theoretical analysis. Moreover, the channel loading of the channel hopping sequences generated by the MEHRR scheme is also derived by theoretical analysis, which shows that the MEHRR scheme can achieve minimum channel loading, and iii) The optimal allocation of multiple radios for the SUs using the MEHRR scheme that can achieve minimum MTTR with full rendezvous diversity is analyzed.

Presented simulation results verify the theorems derived through theoretical analysis. Moreover, the superiority of the MEHRR scheme compared with other state of the art blind rendezvous schemes for the multiple radios based SUs in terms of MTTR with full rendezvous diversity is also shown. In the paper "Distributed Wideband Sensing-Based Architecture for Unlicensed Massive IoT Communications," the authors propose a sensing-based architecture that identifies spectral and spatial resources at a fine resolution. In particular, the authors first propose a sensing assignment

scheduler, where each base station (BS) is assigned a subset of the spectrum to sense at a high resolution. Then, they propose a distributed sensing algorithm, where BSs locally process and share their sensing reports, so that each BS obtains occupancy information of the wideband spectrum at its location. Once the spatio-spectral resource blocks are identified, they further propose a distributed resource allocation algorithm that maintains high spatial reuse of spectral opportunities while limiting the intra-network and inter-network interference. Numerical simulations are presented to validate the effectiveness of the proposed distributed algorithms, comparing them to centralized and non-cooperative schemes. It is shown that the presented architecture identifies more spatio-spectral resources, with lower misdetection of incumbents. As a result, more IoT devices are connected with limited interference to incumbents. Note that the authors of this work propose a sensing-based architecture for unlicensed massive IoT, where BSs, e.g., small cells, are equipped with spectrum scanners to: i) identify a large number of narrow band channels in a wideband spectrum, as many massive IoT applications have low-rate requirements, and ii) aggressively reuse the unlicensed channels over space to accommodate a high density of IoT devices. The former objective requires sensing at a fine spectral resolution, and the latter requires capturing the incumbents' footprints at a fine spatial resolution. The main contributions of this work are twofold. First, the authors aim to limit the sensing burden at each BS, as sensing a wideband spectrum at a fine spectral resolution requires complex receivers. To this end, the authors formulate an integer program where they optimize sensing assignments across BSs, so each one only senses a subset of the spectrum. The problem is combinatorial with high complexity in dense networks. Thus, they further develop a heuristic low-complexity assignment scheduler and compare its performance to the integer program and its linear relaxation. The second contribution is the development of distributed sensing and resource allocation algorithms. In particular, the authors propose a distributed sensing algorithm, where each BS senses its assigned subset of channels, shares and collects measurements from nearby BSs, and processes the collected data to infer the spectrum occupancy across all channels. Different from the distributed sensing algorithm, each BS may arrive at a different decision as the occupancy of a channel varies over space, achieving high spatial resolution. In addition, they use the combine-then-adapt diffusion algorithm and propose a novel update of the algorithm's weights to quickly diffuse information about the wideband spectrum at each BS. The proposed sensing algorithm is shown to improve the deflection coefficient compared to the non-cooperative energy detection.

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