Guest Editorial Spectrum Sharing and Aggregation for Future Wireless Networks, Part I

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I. Introduction

WELCOME to the IEEE JSAC special issue on Spectrum Sharing and Aggregation for Future Wireless Networks. The conception of this special issue is motivated by the following observations: the ever-increasing penetration of both the mobile Internet and of the Internet-of-things is gradually clogging up the most valuable spectral bands available in the sub-2 GHz frequency range for future wireless networks. Hence there is an urgent need for improved spectrum exploitation to satisfy this demand. It is expected that the wireless tele-traffic will continue to grow quite dramatically in the ensuing years, hence further widening the spectrum-supply versus demand gap. In order to mitigate this gap, spectrum sharing and aggregation have been well recognized as promising approaches, which led to rapid advances by harnessing a large cross-section of the research community. Nonetheless, there are numerous unsolved technical challenges. This special issue aims for reporting on some of these cutting-edge advances in spectrum sharing and aggregation, whilst opening new avenues of research in this area.

The response of the research community to the call for papers has been overwhelming. We received a total of 174 submissions. After a strict and highly selective review process, the decision has been made to publish three issues on the cutting-edge advances in spectrum sharing and aggregation. This first issue has 20 papers, covering a wide selection of topics as follows.

The first paper, entitled "*A full-space spectrum-sharing strategy for massive MIMO cognitive radio systems*," introduces a new spatial spectrum-sharing strategy designed for large-scale multiple-input multiple-output (MIMO) cognitive radio (CR) systems. In contrast to the conventional MIMO CR systems, it is argued that CR terminals can also be readily distinguished with the aid of their angle of arrival information, provided that the angular resolution of the CR base stations is sufficiently high.

The second paper, namely "*Licensed-assisted access for LTE in unlicensed spectrum: A MAC protocol design*," proposes a listen-before-talk based MAC protocol for a LTE-based license-assisted access (LAA) system, operating in the unlicensed WiFi band. By quantifying both the WiFi throughput and the packet delay in the coexisting system, this paper quantifies the constraints in terms of the LAA-LTE transmission time to be satisfied for the sake of maintaining a high WiFi service quality. The feasible region of the LAA-LTE transmission time is determined, and the LAA-LTE protocol is optimized either for maximizing the LAA-LTE or the overall throughput that may be maintained by the LAA-LTE and WiFi systems.

The third paper advocates "*Optimizing unlicensed spectrum sharing for LTE-U and WiFi network coexistence*" and investigates efficient spectrum sharing techniques designed for coexisting WiFi and LTE-U services via a joint optimization of the user association and resource allocation techniques employed. More explicitly, the authors formulate a network utility maximization problem based on the classic Nash bargaining solution and analyze the performance of the proposed algorithm under various fading channel models.

The fourth paper is entitled "*Towards multi-radio vehicular data piping for dynamic DSRC/TVWS spectrum sharing*" and proposes a geolocation database assisted adaptive vehicular data piping framework for the joint utilization of Dedicated Short Range Communications (DSRC) and TV White Space (TVWS) spectrum. To elaborate, the authors formulate the adaptive vehicular data piping problem for dynamic DSRC/TVWS spectrum sharing as a coalitional formation

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game and propose a technique that reaches the optimal and Nash-stable vehicular data pipe selection partition, despite operating in a distributed way.

The fifth paper advocates "*Training-free indoor white space exploration*," invokes sensing of the indoor white spaces and studies their characteristics. Based on the analysis of real-world spectrum measurements, the authors propose a training-free indoor white space exploration mechanism based on Bayesian compressive sensing, as well as a sophisticated spectrum-hole detector deployment technique. Furthermore, the authors conceived an algorithm for determining the most appropriate number of spectrum detectors to be employed.

The sixth paper, namely "*Coexistence of power-controlled cellular networks with rotating radar*," studies the ramifications of spectral coexistence between rotating radar and power-controlled cellular networks in the radar bands. The authors propose a spatio-temporal analysis technique relying on adaptive base station power control for adjacent spectrum sharing between a pair of systems. Moreover, a new model of the interference emanating from power-controlled cellular base stations is developed.

The seventh paper is focussed on "*Cooperative infrastructure and spectrum sharing in heterogeneous mobile networks*" and addresses the problem of radio access network infrastructure and spectrum sharing in heterogeneous mobile networks. Its specific focus is on the scenario in which multiple mobile network operators plan to deploy small cell base stations in a geographical area in order to upgrade their existing network infrastructure. To address this problem, the authors propose a pair of cooperative game models operating eith with or without transferable utility: for a given network and economic scenario, these models output a cost-partitioning policy that guarantees coalition (sharing agreement) stability.

The eighth paper is entitled "*Small-scale spectrum aggregation and sharing*." It deals with a scenario, where a set of narrow and disjoint frequency bands closely located to each other along the frequency axis can be utilized simultaneously. The authors first discuss how such a scheme can be applied to various multi-carrier systems and then propose an interference model that takes into account the limitations of both the transmitter's and the receiver's frequency selectivity. Finally, they present the results of their hardware experiments to validate the theoretical interference models assumed.

The ninth paper deals with "*Spectrum sharing for coexistence of fixed satellite services and frequency hopping tactical data link*" and verifies whether spectrum sharing facilitates the coexistence of Fixed Satellite Services (FSS) and Frequency Hopping Tactical Data Links (FH-TDL). The authors first propose FH-TDL relying on a particular spectrum use rule and on a new frequency-hopping method for reducing the collision probability and then analyze the mutual interference between FH-TDL and FSS.

The tenth paper, namely "*Hypergraph based wireless distributed storage optimization for cellular D2D underlays*," investigates the overall transmission cost minimization problem based on a beneficial content encoding strategy conceived for error-resilient high-integrity device-to device (D2D) based distributed storage, while guaranteeing the users' target quality of service. In addition to the optimization of the coding process, the cost minimization problem also considers the distribution of content files, the selection of content helpers for each content requester, and the spectrum reuse for establishing D2D links in between.

The eleventh paper, "*Spectrum investment under uncertainty: A behavioral economics perspective*," studies a virtual wireless operator's spectrum investment problem under realistic spectrum sensing uncertainty. In oredr to strike a compelling tradeoff between the expected profit and the associated risk, this paper analyzes the operator's optimal decision problem using the classic prospect theory borrowed from the field of behavioral economics.

The twelfth paper considers "*A strategy-proof auction mechanism for adaptive-width channel allocation in wireless networks*" and presents a combinatorial auction mechanism conceived for the problem of channel allocation in multi-hop wireless networks. The mechanism guarantees the strategy-proof nature of the channel auction, whilst exploiting the wireless channels' spatial reusability, and achieves a high channel occupancy. Their numerical results show that the mechanism prevents buyers from manipulating the auction, hence achieving a high performance.

The thirteenth paper is entitled "*VERACITY: Overlapping coalition formation based double auction for heterogeneous demand and spectrum reusability*," which proposes an overlapping coalition formation based double auction scheme for jointly considering all the multiple demands of the buyers, as well as the heterogeneous spectrum and fiscal efficiency. According to this scheme, the auctioneer groups the set of conflict-free buyers into the same coalition and allows a buyer to join multiple coalitions based on their heterogeneous demands. Dynamic overlapping coalition formation is implemented by the auctioneer, which is then used for finding a near-optimal coalition structure in terms of maximizing the attainable social welfare.

The fourteenth paper, "*On the secure spectral-energy efficiency tradeoff in random cognitive radio networks*," develops a framework for studying the spectrum-efficiency (SE) and energy-efficiency (EE) in the context of secure transmissions in underlay-based random CR networks. This paper evaluates the secure SE and EE in the secondary network, based on the analysis of both the connection outage probability and the secrecy outage probability. Finally, the authors formulate the joint secure SE and EE optimization problem and an iterative algorithm is proposed.

The fifteenth paper has the eloquent title of "*You can jam but you can't hide: Defending against jamming attacks for geo-location database driven spectrum sharing.*" It presents the novel query based jamming attack in the context of geo-location database-aided spectrum sharing and proposes a jammer-inference based jamming defense mechanism. This paper also implements the proposed scheme on the widely-used Universal Software Radio Peripheral (USRP) to validate the theoretical results.

The sixteenth paper is entitled as "*Joint differentially private gale-shapley mechanisms for location privacy*

protection in mobile traffic offloading systems," which investigates the potential application of spectrum sharing in cellular networks for mobile traffic offloading. A pair of joint differentially private Gale-Shapley mechanisms guaranteeing reliable privacy protection for mobile traffic offloading systems are proposed.

The seventeenth paper, "*Reliable and efficient sub-Nyquist wideband spectrum sensing in cooperative cognitive radio networks*," proposes a sub-Nyquist wideband spectrum sensing scheme, which is capable of blindly locating the occupied channels by exploiting the jointly sparse nature of multiband signals. To elaborate, exploiting the common frequency-domain signal-support shared among multiple secondary users, an efficient cooperative spectrum sensing scheme is developed, in which the energy consumption of wideband signal acquisition, processing, and transmission is reduced, whilst satisfying a stringent detection performance guarantee. The theoretical analysis of the proposed sub-Nyquist wideband sensing algorithm is provided and the results are verified by numerical analysis in the context of real-world TV-white-space signals.

The eighteenth paper, "*On throughput region for primary and secondary networks with node-level cooperation*," studies the node-level cooperation between the primary and secondary networks and quantifies the maximum achievable throughput of both the primary and secondary users. The authors formulate a multi-criterion optimization problem, with the goal of maximizing the throughput of both the primary and secondary users. Furthermore, they transform it into a single criterion optimization problem by invoking the classic weighted Chebyshev norm, and iteratively find a sequence of Pareto-optimal solutions. Moreover, through a case study, the authors show that the throughput region under node-level cooperation is substantially higher than that in the absence of node-level cooperation.

The penultimate paper entitled "*Proactive cross-channel gain estimation for spectrum sharing in cognitive radio*" proposes a proactive scheme for the estimation of the cross-channel gain in the context of a cognitive transmitter (CT) communicating with a primary receiver, which is achieved by exploiting the relaying capability of the CT. The key idea is that the CT proactively acts as a full-duplex amplify-and-forward relay for the sake of assisting the primary transceivers in order to trigger the power adaptation of a primary transmitter.

The closing paper, namely "*Cognitive dynamic system as the brain of complex networks*," advocates a new way of thinking in terms of integrating dynamic spectrum management and a cognitive dynamic system (CDS). The authors discuss the issue of spectrum sharing from a pair of perspectives: i) The need for DSM to improve spectrum utilization; and ii) The vision for CDS as the 'engine' of complex wireless communication networks. The authors project the vision that the hierarchical CDS relying on deep learning is capable of transforming complex wireless networks!

This issue serves as the first one of the three issues on spectrum sharing and aggregation for future wireless networks. We hope that through the selection of the articles in this issue and the following two issues we can stimulate new discussions and new contributions to the related areas.

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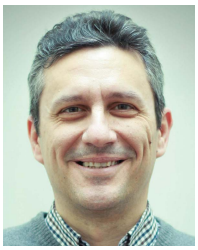

Theodoros A. Tsiftsis (S'02–M'04–SM'10) was born in Lamia, Greece, in 1970. He received the B.Sc. degree in physics from the Aristotle University of Thessaloniki, Greece, in 1993, the M.Sc. degree in digital systems engineering from Heriot-Watt University, Edinburgh, U.K., in 1995, the M.Sc. degree in decision sciences from the Athens University of Economics and Business, Greece, in 2000, and the Ph.D. degree in electrical engineering from the University of Patras, Greece, in 2006. He joined the Department of Electrical Engineering, Technological Educational Institute of Central Greece in 2010. He is currently an Associate Professor of Communication Technologies with the Department of Electrical and Electronic Engineering, School of Engineering, Nazarbayev University, Astana, Kazakhstan. He has authored or co-authored over 100 technical papers in scientific journals and international conferences. His research interests include the broad areas of cooperative communications, communication theory, wireless communications, and optical wireless communication systems.

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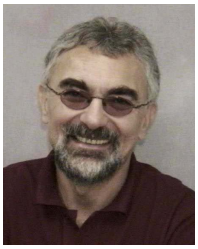

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