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

Theodoros A. Tsiftsis, *Senior Member, IEEE*, Guoru Ding, *Senior Member, IEEE*, Yulong Zou, *Senior Member, IEEE*, George K. Karagiannidis, *Fellow, IEEE*, Zhu Han, *Fellow, IEEE*, and Lajos Hanzo, *Fellow, IEEE*

WELCOME to the third one in the sequel of three IEEE JSAC special issues on Spectrum Sharing and Aggregation for Future Wireless Networks. In recognition of the fact that a substantial number of submissions have been received in response to the call for papers, the decision has been made to publish three issues on the cutting-edge advances in spectrum sharing and aggregation. The first two issues were published in October 2016 with 20 papers and November 2016 with 19 papers, respectively. This is the third issue with 17 papers, covering a feast of hot research topics as follows.

The first paper, entitled "*The value of side-information in secondary spectrum markets*," considers a model where a primary user is assumed to have the ability to estimate its competitor's channel state information (C-CSI), albeit naturally, this is only achievable at a particular cost. The authors formulate a game between the associated pair of primary users. In the scenario considered each primary user decides whether to acquire C-CSI or not, because again, this would only be achievable at a given cost and then selects its price based on the above decision. It might be interesting to extend these ideas to a multiplicity of users, to a variety of channel estimation qualities, whilst taking into account the typically increased transmit power requirements of non-coherently or blindly detected users.

The second treatise, namely "*Full-duplex-based rate/mode adaptation strategies for Wi-Fi/LTE-U coexistence: A POMDP approach*," proposes joint mode/rate adaptation strategies for Wi-Fi/LTE-U coexistence by exploiting the recent advances in self-interference suppression. The interference generated by the LTE-U transmissions is then modelled by a hidden Markov process and the transmission rates/modes are jointly determined by using a partially observable Markov decision process (POMDP) based framework. However, at the current state-of-the-art flawless full-duplex operation is not achievable, hence this forward-looking paper may lead to further studies bearing in mind realistic full-duplex scenarios.

The third contribution addresses the issues of "*Energy-efficient bandwidth aggregation for delay-constrained video over heterogeneous wireless networks*" in the context of an energy- and video-quality-aware bandwidth aggregation scheme designed for the demanding application scenario of wireless video transmission. Explicitly, video-telephony should be lip-synchronized, which imposes strict delay limits. The authors develop an analytical framework to model the associated video-quality versus energy dissipation tradeoff in the context of heterogeneous wireless networks and propose an efficient bandwidth aggregation framework that integrates energy-conscious rate adaptation, delay-constrained unequal video protection and video-quality-aware packet distribution. This sophisticated optimization problem reflects the emerging research-trend of multi-component optimization invoked for striking an application-scenario-dependent trade-off amongst multiple potentially conflicting design objectives. In this context it is worth emphasizing that the particular choice of the optimization objective function has a more grave impact on the performance of the system than the specific choice of the optimization tools employed.

The fourth contribution, which is entitled "*Overlay spectrum sharing using improper Gaussian signaling*," aims for achieving performance improvements in typical interference limited networks. The noise is usually imposed by the Brownian motion of the electrons in the receiver is typically modelled as a circularly symmetric complex-valued Gaussian variable. By contrast, the interference is often non-circular, which is also termed as being an improper Gaussian process. The authors consider both idealized full as well as realistic partial channel knowledge based scenarios and derive the feasibility conditions of relying on overlay cognitive radio systems. The conditions under which improper Gaussian signalling schemes become superior to their proper Gaussian counterparts are

T. A. Tsiftsis is with the School of Engineering, Nazarbayev University, Astana 010000, Kazakhstan, and also with the Technological Educational Institute of Central Greece, 35100 Lamia, Greece (e-mail: theodoros.tsiftsis@nu.edu.kz; tsiftsis@teiste.gr).

G. Ding is with the College of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China, and also with the National Mobile Communications Research Laboratory, Southeast University, Nanjing 210018, China (e-mail: dr.guoru.ding@ieee.org).

Y. Zou is with the School of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China (e-mail: yulong.zou@njupt.edu.cn).

G. K. Karagiannidis is with the Electrical and Computer Engineering Department, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece (e-mail: geokarag@auth.gr).

Z. Han is with the Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77005 USA (e-mail: zhan2@uh.edu).

L. Hanzo is with the School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, U.K. (e-mail: lh@ecs.soton.ac.uk).

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characterized with the aid of closed-form expressions. It may also be worth further investigating the system considered in the presence of a single dominant interferer.

The fifth paper, namely "*Throughput and fairness analysis of Wi-Fi and LTE-U in unlicensed band*" relies on the popular stochastic geometry theory to develop a framework for multi-radio access technology (multi-RAT) based heterogeneous networks, which consist of an LTE-U tier and a Wi-Fi tier. The authors derive the coverage probability as well as the spatial distribution of the throughput of the Wi-Fi and LTE-U networks considered. They also carry out the associated asymptotic performance analysis, when the density of both the Wi-Fi and LTE-U nodes tends to infinity. This paper might inspire researchers to extend these ideas to mm-wave as well as to optical wireless aided heterogeneous networks.

The sixth treatise, which is entitled as "*Auction-based coopetition between LTE unlicensed and Wi-Fi*," proposes a spectrum sharing framework for the 'coopetition' (i.e., cooperation and competition) between LTE and Wi-Fi in the unlicensed band, where the LTE network may opt for operating in one of the following two modes: in the competition mode, where it randomly accesses an unlicensed channel and interferes with the Wi-Fi access point using the same channel; by contrast, in the cooperation mode, where it delivers traffic for the Wi-Fi users in exchange for the exclusive access to the corresponding channel. It is plausible that in case of aggressive competition a large fraction of the sessions are prone to outages and even to being dropped. Cooperation may be encouraged by the reward of increased communications quality, which is however expected to result in reduced number of sessions being supported.

The seventh study, "*Co-primary spectrum sharing for inter-operator device-to-device communication*" considers a spectrum sharing scenario, where a number of operators construct a spectrum pool dedicated to the support of inter-operator D2D communication. The operators are assumed to negotiate in the form of a non-cooperative game about how much spectrum each operator contributes to the joint spectrum pool. However, operators, who contribute little to the common bandwidth-pool, whilst exploiting a larger fraction of it than their fair share might become marginalized and left out from future alliances.

The eighth paper, which is entitled as "*Efficient 3D resource management for spectrum aggregation in cellular networks*," introduces the power domain for spectrum aggregation from the perspective of the MAC layer. More explicitly, it extends the resource block concept to a new resource management unit termed as resource cube (RC), which has three dimensions: time, frequency, and power. Furthermore, the authors propose a 3D radio resource management scheme for exploiting the aggregated 3D RCs.

The ninth contribution advocates "*Small-Macro cell cooperation for HetNet uplink transmission: Spectral efficiency and reliability analyses*" and investigates the benefits of cooperation between the macro-cells and a small cell in terms of improving the spectral efficiency and reliability of the uplink transmission in a heterogeneous network (HetNet). The authors propose a transmission scheme based on superposition block-coding at each user equipment, while using both coherent decode-and-forward relaying and sliding window based decoding at the small-cell BS. By contrast, quantize-and-forward based relaying is proposed for the macro-cell BS. The optimal quantization scheme to be used at the macro-cell BS that maximizes the overall spectral efficiency is also determined.

The tenth treatise, namely "*Spectrum sharing for drone networks*," studies spectrum sharing of drone-assisted small cell (DSC) networks modeled by a 3D Poisson point process. These networks exhibit numerous potential benefits, such as the provision of temporary radio coverage for large-scale public events, concerts, sporting events etc. Naturally, they require further research, since they also pose many open challenges, including their reliable navigation and control in the face of strong winds, their powering with the aid of laser-charging, just to name a few. This work also investigates an underlay spectrum sharing regime between the 3D DSC networks and the traditional cellular networks modeled by 2D Poisson point processes. Both analytical and numerical coverage probability and achievable throughput results are presented.

The eleventh contribution reports on advances in "*Heterogeneous networks in shared spectrum access communications*" where a macro-cellular network (MCN) is supported by efficient offloading services offered by a small cell network (SCN) in the vicinity. In exchange, the SCN is rewarded with licenses to share the spectrum that was originally owned by the MCN. Furthermore, the authors employ a network model known as a Binomial point process (BPP) to carry out the analysis of the system. It is anticipated that the pros and cons of the binomial versus Poisson point processes might be investigated in the future.

The twelfth paper is entitled "*Sparse frequency domain spectrum sensing and sharing based on cyclic prefix auto-correlation*," which proposes an attractive detection scheme for orthogonal frequency-division multiplexing based primary users communicating in spectrum sharing aided systems. Novel analytic expressions are derived for the corresponding detection threshold, for the probability of false alarm and for the probability of successful detection. The analytical results are also confirmed by extensive computer simulations.

The thirteenth treatise is related to the subject of "P^2*-SAS: Privacy-preserving centralized dynamic spectrum access system*" which relies on sophisticated secure multi-party computation, where none of the incumbent users' or secondary users' data is exposed to any snooping party, including the central server itself. Indeed, spectrum sharing is prone to information security breaches, hence the authors formally prove the privacy-preserving nature of their scheme and characterize its scalability based on experiments relying on real-world data.

The fourteenth paper, which is entitled as "*Multipath streaming: Fundamental limits and efficient algorithms*," investigates streaming over multiple links, where a file is split into small chunks that may be transmitted over different links according to some policy and they are received after some random delay. The authors determine the lower bounds of the 'starvation probability' and then propose simple

practical schemes for approaching these limits. Their numerical experiments demonstrate the accuracy of the proposed bounds.

The fifteenth study is dedicated to the "*Cost-reliability tradeoff in licensed and unlicensed spectra interoperable networks with guaranteed user data rate requirements*." The authors design a framework for 5G licensed and unlicensed spectrum based interoperable networks relying on a cloud radio access network and the emerging decoupled control/data based network architecture. They investigate the network-level reliability versus cost tradeoff from two different aspects. Firstly, they study the fundamental tradeoff between the achievable reliability and the associated cost by minimizing the cost of a given reliability level. Secondly, they define a quality of experience based utility, which is invoked for the sake of characterizing the reliability versus cost relationship by highlighting the inherent tradeoff between them.

The penultimate paper entitled "*A filter-bank transceiver architecture for massive non-contiguous carrier aggregation*" focuses on the digital baseband processing part of the transceiver and proposes a filter-bank based architecture that supports inter-band carrier aggregation at a modest complexity price compared to that of a transceiver operating on a single component carrier having the same aggregate bandwidth. The construction of this new architecture is cast as a filter design problem subject to some basic constraints imposed on the transmitted waveform, on the channel statistics and on the receiver scheme.

The final paper, namely "*Clustering-based spectrum sharing strategy for cognitive radio networks*" considers multiuser orthogonal frequency division multiplexing-based cognitive networks, where the objective is to maximize the sum-rate of the system under a specific total transmit power budget for the system, whilst satisfying the transmission rate requirements of the end users. The authors propose a two-stage algorithm for solving the associated mixed integer programming optimization problem. Finally, simulation results validate the efficiency of the proposed algorithm.

Once again, we hope that through the selection of the articles in our sequel of our three special issues, namely the October 2016 issue, the November 2016 issue and the current issue, we can stimulate further in-depth discussions and new contributions to the related areas.

Recent Trends in the Evolution of Spectrum Sharing: Based on the papers in this issue some clustering of the contributions may be observed, as detailed below

1) The specific spectrum sharing techniques investigated, including cognitive radios, multi-operator solutions, device-to-device support by spectrum sharing, auctions, compressive spectrum sensing, aggregation of multiple subcarriers, information-privacy issues, etc.
2) The particular system contexts considered, as exemplified by LTE and WiFi, representing large and small cells, respectively.
3) The novel multi-component optimization tools invoked for improving the techniques mentioned under 1) as well as Poisson versus binary point processes both in 2D and drone-assisted 3D contexts.
4) Applications, such as video streaming, multi-route streaming, decoupled control and data links, drone-aided networking and its radical research aspects.

To elaborate a little further on the above-mentioned four aspects:

1) The specific spectrum sharing techniques, such as cognitive radio techniques as well as decoupling the data and control information, indeed have the potential to exhibit substantial service-quality benefits, but they also impose further open research challenges.
2) Again, several contributions investigated the all-important LTE/WiFi coexistence, with a special emphasis on the achievable throughput and fairness aspects. Their auction-based 'coopetition' relying both on cooperation and competition was also analysed.
   To expound further, the system contexts investigated LTE and WiFi which tend to have different propagation scenarios and bitrates, whilst supporting diverse services. Indeed, this is one of the reasons why their spectrum sharing tends to be beneficial.
3) Since the base station of a large terrestrial-cell typically has a higher coverage area than that of a small base station, large cells have to handle higher tele-traffic, despite their potentially more tenuous link quality. By contrast, the small cells tend to benefit from benign line-of-sight propagation scenarios and they can be invoked for providing a backhaul for the adjacent large cells.
4) Device-to-device communications aspects continue to attract research attention also in this issue in the context of a spectrum-pool sharing based on inter-operator bandwidth-contributions.
5) Compressed spectrum sensing and full-duplex relaying have also attracted special attention.
6) Cutting-edge application scenarios, such as video streaming relying on multi-level H.265 video coding would also call for more research, where the video-enhancement layers may be transmitted over the somewhat intermittent CR-aided specrum-slivers. Even more ambitiously, stereoscopic or holographic video streams could be transmitted in the associated cameraphone networks.
7) Somewhat unexpectedly, the choice of optimization tools invoked for improving the techniques mentioned under 1) remained limited in this issue, even though the demanding optimization problems considered call for powerful multi-component optimization procedures. We might speculate that this was perhaps the consequence of having a recent JSAC special issue on the application of game-theoretic optimization approaches.
8) Similarly, further communication theory research is needed on the subject of fundamental limits. *Hence this paucity of powerful multi-component optimization tools and the lack of network-theoretic analysis may indeed require further research by You - valued colleague.*

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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.

Dr. Tsiftsis was a member of the Editorial Boards of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY and the IEEE COMMUNICATIONS LETTERS. He acts as a reviewer of several international journals. He is currently an Area Editor of the Wireless Communications II of the IEEE TRANSACTIONS ON COMMUNICATIONS.

Guoru Ding (S'10–M'14–SM'16) received the B.S. degree (Hons.) in electrical engineering from Xidian University, Xi'an, China, in 2008, and the Ph.D. degree (Hons.) in communications and information systems from the College of Communications Engineering, Nanjing, China, in 2014. Since 2014, he has been an Assistant Professor with the College of Communications Engineering, and a Research Fellow with the National High Frequency Communications Research Center of China. Since 2015, he has also been a Post-Doctoral Research Associate with the National Mobile Communications Research Laboratory, Southeast University, Nanjing. His research interests include cognitive radio networks, massive MIMO, machine learning, and big data analytics over wireless networks.

Dr. Ding was a Technical Program Committee member of a number of international conferences, including the IEEE Global Communications Conference, the IEEE International Conference on Communications, and the IEEE Vehicular Technology Conference (VTC). He was a recipient of the Best Paper Awards from the EAI MLICOM 2016, the IEEE VTC 2014-Fall, and the IEEE WCSP 2009. He currently serves as a Guest Editor of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS and an Associate Editor of the *KSII Transactions on Internet and Information Systems*. He is a voting member of the IEEE 1900.6 Standard Association Working Group.

Yulong Zou (SM'13) received the B.Eng. degree in information engineering from the Nanjing University of Posts and Telecommunications (NUPT), Nanjing, China, in 2006, the first Ph.D. degree in electrical engineering from the Stevens Institute of Technology, Hoboken, NJ, USA, in 2012, and the second Ph.D. degree in signal and information processing from NUPT, in 2012. He is currently a Full Professor and the Doctoral Supervisor with NUPT.

His research interests span a wide range of topics in wireless communications and signal processing, including the cooperative communications, cognitive radio, wireless security, and energy-efficient communications. He was a recipient the 9th IEEE Communications Society Asia-Pacific Best Young Researcher in 2014. He was a co-recipient of the Best Paper Award at the 80th IEEE Vehicular Technology Conference in 2014. He is currently serving or served as an Editor of the IEEE COMMUNICATIONS SURVEYS & TUTORIALS, the IEEE COMMUNICATIONS LETTERS, *IET Communications*, and the *China Communications*.

George K. Karagiannidis (M'96–SM'03–F'14) was born in Pythagoreio, Greece. He received the University Diploma and the Ph.D. degrees in electrical and computer engineering from the University of Patras in 1987 and 1999, respectively. From 2000 to 2004, he was a Senior Researcher with the Institute for Space Applications and Remote Sensing, National Observatory of Athens, Greece. In 2004, he joined the faculty of Aristotle University of Thessaloniki, Greece, where he is currently a Professor with the Electrical and Computer Engineering Department and the Director of the Digital Telecommunications Systems and Networks Laboratory. He is also an Honorary Professor with South West Jiaotong University, Chengdu, China.

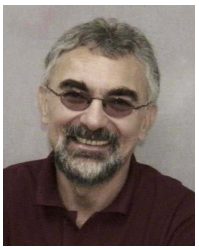
His research interests are in the broad area of digital communications systems with emphasis on wireless communications, optical wireless communications, wireless power transfer and applications, molecular communications, communications and robotics, and wireless security.

He has authored or co-authored over 400 technical papers published in scientific journals and presented at international conferences. He is also the author of the Greek edition of a book on telecommunications systems and the co-author of the book *Advanced Optical Wireless Communications Systems* (Cambridge Publications, 2012). He has been involved as the general chair, the technical program chair, and a member of technical program committees of several IEEE and non-IEEE conferences. He was an Editor of the IEEE TRANSACTIONS ON COMMUNICATIONS and the *EURASIP Journal of Wireless Communications and Networks*, a Senior Editor of the IEEE COMMUNICATIONS LETTERS, and a Guest Editor of the IEEE JOURNAL SELECTED AREAS IN COMMUNICATIONS. From 2012 to 2015, he was the Editor-in Chief of the IEEE COMMUNICATIONS LETTERS.

Dr. Karagiannidis has been selected as a 2015 Thomson Reuters Highly Cited Researcher and he was listed in the Thomson Reuters 2015 World's Most Influential Scientific Minds.

Zhu Han (S'01–M'04–SM'09–F'14) received the B.S. degree in electronic engineering from Tsinghua University in 1997, and the M.S. and Ph.D. degrees in electrical engineering from the University of Maryland, College Park, MD, USA, in 1999 and 2003, respectively. From 2000 to 2002, he was a Research and Development Engineer with JDSU, Germantown, MD, USA. From 2003 to 2006, he was a Research Associate with the University of Maryland. From 2006 to 2008, he was an Assistant Professor with Boise State University, Boise, ID, USA. He is currently an Associate Professor with the Electrical and Computer Engineering Department, University of Houston, Houston, TX, USA. His research interests include wireless resource allocation and management, wireless communications and networking, game theory, wireless multimedia, security, and smart grid communication.

Dr. Han co-authored eight papers that received the IEEE best conference paper awards. He was a recipient of the NSF CAREER Award in 2010. He was also a recipient of the 2011 IEEE Communications Society Fred W. Ellersick Prize, the 2015 EURASIP Best Paper Award for the *Journal on Advances in Signal Processing*, and the 2016 IEEE Leonard G. Abraham Prize in communications systems (Best Paper Award for the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS). He has been an IEEE Distinguished Lecturer since 2015. He was the MAC Symposium Vice Chair of the IEEE Wireless Communications and Networking Conference in 2008. He was the Guest Editor of the Special Issue on Cooperative Networking Challenges and Applications (the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS) Fairness of Radio Resource Management Techniques in Wireless Networks (*EURASIP Journal on Wireless Communications and Networking*), and the Special Issue on Game Theory (*EURASIP Journal on Advances in Signal Processing*). He has been an Associate Editor of the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS since 2010.



Lajos Hanzo (M'91–SM'92–F'04) received the master's degree in electronics in 1976, the Ph.D. degree from the Technical University of Budapest in 1983, and the D.Sc. degree in 2004. From 2009 to 2012, he was a Chaired Professor with Tsinghua University, Beijing, China. Since 1986, he has been with the University of Southampton, U.K. During his 40-year career in telecommunications, he has held various research and academic posts in Hungary, Germany, and the U.K. Since 1986, he has been a member of academic staff with the School of Electronics and Computer Science, University of Southampton, U.K., where he currently holds the Chair in Telecommunications and is also the Head of Southampton Wireless. He has co-authored 20 John Wiley/IEEE Press books, over 10 000 pages on mobile radio communications, and authored 1600 research contributions on the IEEE Xplore. He has also organized and chaired major IEEE conferences, such as WCNC 2006, WCNC 2009, VTC 2011, ICC 2013, and EUSIPCO 2016, and presented tutorial/overview lectures at international conferences. He has presented a number of named lectures and keynotes.

Dr. Hanzo is a fellow of the IEE/IET, the Royal Academy of Engineering, and the EURASIP, a Wolfson Fellow of the Royal Society, and a foreign member of the Hungarian Academy of Science. He has received a number of distinctions, most recently the IEEE Wireless Technical Committee Achievement Award in 2007, the IET Sir Monti Finniston Achievement Award across all disciplines of engineering in 2008, and an honorary doctorate of the Technical University of Budapest in 2010 and the University of Edinburgh in 2015. His most recent paper awards include the WCNC 2007 Hong Kong, the ICC 2009 Dresden, the ICC 2010 Cape Town, the WCNC 2013 Shanghai, and the VTC 2014 Vancouver. From 2009 to 2013, he was the Editor-in-Chief of the IEEE Press. He is an IEEE Distinguished Lecturer of the Vehicular Society. He is also the Governor of the IEEE VTS and ComSoc.