Licensed and Unlicensed Spectrum for Future 5G/B5G Wireless Networks


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The incredible increase in connected appliances and downloaded applications has pushed mobile operators to the limits of their licensed spectrum bands. This has triggered the idea of evolving the current radio access network to use the underutilized unlicensed spectrum to extend spectrum resources beyond current usage charts. This mode of cellular access has raised a lot of questions about use cases, enabling technologies, and fairness to other native unlicensed users, such as WiFi. Nevertheless, unlicensed access is being accepted as one of the most significant solutions to improve the resource availability and system scalability in future fifth gneration (5G)/beyond 5G (B5G) networks. The local contiguous access of spectrum using the ultra-dense deployment of small cells enables the utilization of every single Hertz of the spectrum including the unlicensed band. The milestones for such technology have been verified with the emergence of licensed-assisted access (LAA) and LTE-WiFi aggregation (LWA) technologies. The interoperability between licensed and unlicensed spectrums allows transferring higher data volumes with the additional airtime obtained from the unlicensed spectrum. However, this interoperability needs to be investigated from two perspectives: the radio access network (RAN) segment and backbone management. The aggregation of two wireless interfaces at the RAN side is still shaping up for efficient and fair spectrum sharing. The Third Generation Partnership Project (3GPP) and WiFi Alliance are the main leading bodies debating such technologies. Supporting interoperability from the backbone segment to enable multi-connectivity and packet forwarding between dynamic clusters has gained more attention within the IEEE 5G Initiative and the creation of the IEEE 1932.1 Standard WG. Therefore, the IEEE 5G Initiative is looking at the opportunity to have a deep technical analysis. Through new CFPs, *IEEE Network* can be a forum for such discussions. Since 5G development is moving from the conceptual stage to alpha-level testbeds, the IEEE 5G Initiative and Guest Editors intend to have three Special Issues on this topic, leading to a better understanding of this challenge to 5G networks.

The employment of unlicensed band by operators leverages radio access technologies and requires innovative solutions to intergrade multiple interfaces in a single access point. For LAA, the access point may employ two or more interfaces where both transmit the same frame size over different bands. The unlicensed interface, in this case, can be only a supplementary downlink (SDL) that supports the data plane for higher throughputs at the user side. This unlicensed interface is only another LTE technology with the listen-before-talk (LBT) mechanism to maintain fair sharing of spectrum with WiFi. However, the longer frame of LTE required for inter-operator technology synchronization may raise many questions about how fair this is to other unlicensed users such as WiFi. In large networks and beyond the single access point model, LAA networks will employ ultra-dense small cells (Scells) that are chained to the LAA primary cell (Pcell). From an operator perspective, the initial proposals assume those Scells to operate as multiple SDLs for the Pcell while sharing the unlicensed band in coexistence with WiFi. However, those Scells could be used to deliver both control and user planes, which requires transmitting and receiving over the unlicensed band. This will impact WiFi units as control signaling requires allocated time slots that conflict with fair share usage of the unlicensed band. There might be other scenarios to manage multiple connectivities using new protocols for identifying Scell and user locations in addition to service assessment to decide if multiple connectivity is even required. At this point, there is a need to evaluate such innovative technology to determine the performance of various deployment scenarios and ensure seamless integration.

Summaries of Accepted Papers

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within the IEEE 5G Initiative and the creation of the IEEE 1932.1 Standard WG. Therefore, the IEEE 5G Initiative is looking at the opportunity to have a deep technical analysis through this Special Issue of *IEEE Network*, which can be a forum for such discussions.

This Special Issue of *IEEE Network* includes different aspects of licensed and unlicensed spectrum technologies. This issue intends to bring together all mobile stakeholders, academia, and industry to identify and promote technical challenges and recent results related to 5G/B5G licensed and unlicensed spectrum. This theme was reflected in the very large number of papers: 57 papers were submitted, out of which we have selected the top 15 research articles.

In the first article, "Multi-Scale Dynamic Allocation of Licensed and Unlicensed Spectrum in Software-Defined HetNets" by Zhenyu Zhou *et al.*, the authors propose a multi-scale dynamic spectrum allocation (DSA) framework for software-defined heterogeneous networks (HetNets), in which both licensed and unlicensed spectra are used on a flexible and on-demand basis.

In the second article, "Unleash Narrowband Technologies for Industrial Internet of Things Services" by Saba Al-Rubaye *et al.*, the authors propose a new framework architecture to enable technical decision makers with an overview of narrowband Industrial Internet of Things (NB-IIoT). Moreover, the authors highlight the key aspects of narrowband technology by focusing on the challenges, standardization, and requirements to facilitate the IIoT connectivity in the smart grid paradigm.

In the third article, "Intelligent Remote Monitoring of Parking Spaces Using Licensed and Unlicensed Wireless Technologies" by Rahat Iqbal *et al.*, the authors discuss how an end user can interact with the system and manage it with a user interface. The user interface provides a range of dashboard facilities that provide various statistics about car park utilization and optimization facilities. The authors' proposed solution comprises a range of sensors including high-resolution cameras, which are distributed throughout a car park. The cameras are connected using different types of wireless communication. The data is processed in real time by the sensors and sent to a cloud server, where it is analyzed, stored, and presented to the end user.

In the fourth article, "Machine-Learning-Based Cognitive Spectrum Assignment for 5G URLLC Applications" by Qian Huang *et al.*, the authors introduce machine learning (ML) and fountain codes into millimeter-wave (mmWave) hybrid access and proposes an adaptive channel assignment method. The proactively predictive power of ML can reduce the transmission delay, and the rateless characteristic of fountain codes can ensure transmission reliability without retransmission.

In the fifth article, "Deep Learning for Secure Mobile Edge Computing in Cyber-Physical Transportation Systems" by Yuanfang Chen *et al.*, the authors propose a deep-learning-based model to learn the attack features. It uses unsupervised learning to achieve the active learning process. Extensive experiments are carried out with 10 different datasets. The results illustrate that the deep-learning-based model gets an average gain of 6 percent accuracy compared to four state-of-the-art machine learning algorithms.

In the sixth article, "Spectrum Analysis of Filtering Technologies in Management Networks and Wireless Systems" by Fumin Zhu *et al.*, the authors introduce several popular technologies developed for analysis of a dynamic state-space model, including Kalman and particle filtering, Markov chain Monte Carlo (MCMC) algorithms, as well as the sequential Bayesian learning method. Their applications in fields of interest are also discussed. Filtering technologies have a great superiority in solving the problems arising from management and communications, making them deserving of further exploration.

In the seventh article, "Integrating Licensed and Unlicensed Spectrum in Internet of Vehicles with Mobile Edge Computing" by Celimuge Wu *et al.*, the authors propose a joint aggregation, caching, and decentralization scheme to efficiently combine route aggregation, data caching, and decentralized computing approaches to compensate for the limited wireless resources. Asynchronous multihop broadcast and asynchronous multihop unicast schemes are introduced to improve the routing performance in multihop broadcast and multihop unicast communications, respectively.

In the eighth article,"Dynamic Spectrum Management via Machine Learning: State of the Art, Taxonomy, Challenges, and Open Research Issues" by Fuhui Zhou *et al.*, the authors survey the state-of-the-art research results along this direction. The authors devise a taxonomy to categorize the literature based on the operation modes, learning paradigms, enabling functions, and design objectives. Moreover, the key challenges are outlined to facilitate the application of machine learning for DSM. Finally, they present several open issues as a future research direction.

In the ninth article, "Coordination Multipoint Enabled Small Cells for Coalition Game-Based Radio Resource Management" by Panagiotis Georgakopoulos *et al.*, the authors propose the adaptation of game theory, which will optimize the formation of cooperating base station clusters. The system level simulations performed indicate that there is a significant increase in the throughput of users located at the edge of cells, without compromising the quality of service experienced by the rest of the users, thus rendering it a suitable candidate for the emerging next-generation networks

In the 10th article, "6G Wireless Communications: Vision and Potential Techniques" by Ping Yang *et al.*, the authors sketch the potential requirements and present an overview of the latest research on the promising technique evolution to 6G, which have recently attracted considerable attention. Moreover, the authors outline a number of key technical challenges as well as the potential solutions associated with 6G, including physical-layer transmission techniques, network designs, security approaches, and testbed developments.

In the 11th article, "Resource Allocation with Automated QoE Assessment in 5G/B5G Wireless Systems" by Basel Dudin *et al.*, the authors propose a resource allocation architecture with automated QoE assessment. The architecture builds on recent advances in affective computing and sensing and accounts for allocation considerations in a mixed (licensed/unlicensed) context.

In the 12th article, "A Base Station Agnostic Network Slicing Framework for 5G" by G. Tseliou *et al.*, the authors investigate a base station agnostic framework for network slicing (NetSliC), a new virtualization layer that creates slices taking into account a set of specific constraints per base station (BS). The proposed mechanism is able to effectively deal with these new network architectures by abstracting the complexity of BSs and slicing the network to guarantee the traffic requirements

In the 13th article, "Terahertz-Enabled Wireless System for Beyond-5G UltraFast Networks: A Brief Survey" by K.M.S Huq *et al.*, the authors provide a brief survey of THz frequency enabled wireless systems, focusing on applications utilizing THz bands and hinting at future research directions in this rapidly developing area from the perspective of an ultra-fast B5G mobile heterogeneous network (MHN). This survey identifies and promotes attractive scenarios, use cases, real-life applications, and research challenges that would shape the B5G THz-enabled wireless systems research in the coming years.

In the 14th article, "QoS-Aware Buffer-Aided Relaying Implant WBAN for Healthcare IoT: Opportunities and Challenges" by Guofa Cai *et al.*, the authors propose a framework in which hierarchical modulations are considered to fulfill the different QoS requirements of different sensor data from an implant medical

device. They further conceive some new transmission strategies for the buffer-aided signal-relay and multi-relay implant WBANs. Simulation results show that the proposed cooperative WBAN provides better performance than the conventional cooperative counterparts

In the 15th article, "Ultra-Reliable Communications for Industrial Internet of Things: Design Considerations and Channel Modeling" by Jingya Yang *et al.*, the authors presented the 5G system architecture in smart factories enabling process automation for warehouses and pay close attention to the ultra-reliable use cases. The key technologies, including diversity, short packet transmission, and fast receiver processing, are discussed for 3GPP future-standardized URLLC.

In the 16th and final article, "Hybrid Communication Path Orchestration for 5G Heterogeneous Ultra-Dense Networks: Opportunities and Challenges" by Xinchang Zhang *et al.*, the authors propose a communication path orchestration architecture for heterogeneous ultra-dense networks. In this architecture, data can be transported from one interior communication node (i.e., a base station or user device) to another interior node along a hybrid device communication path (HDCP). HDCPs can be used for communications between two user devices and to migrate traffic between backhaul links

Biographies

Shahid Mumtaz [SM] (smumtaz@av.it.pt) has more than 10 years of wireless industry/academic experience and is currently working as a principal research scientist at Instituto de Telecomunicações Portugal. He received his Master's and Ph.D. degrees in electrical and electronic engineering from Blekinge Institute of Technology, Sweden, and the University of Aveiro, Portugal. From 2005 to 2006 he worked for Ericsson and Huawei at Research Labs in Sweden. He has published 3 books as well as more than 150 publications in very high-ranked IEEE transactions, journals, books, book chapters, and international conferences. He is a Senior Member of IET. In January 2015 he was nominated Chair for the new IEEE standardization on P1932.1: Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Networks.

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Haris Gačanin [SM] (haris.gacanin@nokia-bell-labs.com) received his Dipl.-Ing. degree in electrical engineering from the University of Sarajevo in 2000. In 2005 and 2008, respectively, he received M.Sc. and Ph.D. degrees from Tohoku University, Japan. He was with Tohoku University from 2008 until 2010, first as a Japan Society for Promotion of Science postdoctoral fellow and later as an assistant professor. Since 2010, he has been with Alcatel-Lucent (now Nokia), where he leads a research department at Nokia Bell Labs. His professional interest is related to the application of artificial intelligence to enable autonomous networking and design of mobile and wireless systems. He has 200+ scientific publications (journals, conferences, and patent applications) and invited/tutorial talks. He is a Senior Member of the Institute of Electronics, Information, and Communication Engineering (IEICE).

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Rulei Ting (rt@ieee.org) has been with AT&T and Bell Labs, New Jersey, for 20+ years, with responsibilities from Distinguished Member of Technical Staff to the senior technical director. He contributed to FT2000, which became an outstanding technology and industry success, delivering multi-billion dollars in revenue. He pioneered AT&T's business development in the AP region and has served as a senior director of telecommunication equipment startups. He was awarded the AT&T Bell Labs President Award; the IEEE Millennium Award; the IEEE Region1 Award; and the President's Volunteer Service Gold Award of the United States. Over the past 15 years, he has volunteered as a ComSoc Chapter Chair, IEEE NJ Coast ExCom and Treasurer, and, in 2003, his Chapter received ComSoc's Chapter Achievement Award.

Di Zhang (di_zhang@zzu.edu.cn) received his Ph.D. degree with honors from Waseda University, Tokyo, Japan (2013–2017) and his M.S. degree with honors from Central China Normal University, Wuhan (2010–2013). Currently, he is an assistant professor at Zhengzhou University, China, He is also a senior researcher with the Information System Laboratory, Department of Electrical and Computer Engineering, Seoul National University, Korea. He visited the National Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University (2015–2017), and the Advanced Communication Technology Laboratory, National Chung Hsing University (2012). He has engaged in two international projects in wireless communications and networking co-funded by EU FP-7, Horizon 2020, and the Japanese Monbushou and NICT. He has served as a TPC member of several IEEE conferences, such as IEEE ICC, WCNC, VTC, CCNC, and Healthcom. His research interests include 5G, the Internet of Things, vehicle communications, green communications, and signal processing.