Comprehensive Spectrum Management for Heterogeneous Networks in LTE-U

Taras Maksymyuk, Maryan Kyryk, and Minho Jo

Abstract

Recent interesting activities in spectrum analysis have introduced an additional band, the 5 GHz unlicensed spectrum, which has been primarily used for Wi-Fi. There are many challenges related to the coexistence of two different networks, a Wi-Fi network and an LTE network, sharing unlicensed bands but causing interference with each other. In this article, to solve the coexistence challenges, we propose a new protocol for carrier sensing and interference avoidance for heterogeneous networks: carrier sense LTE unlicensed access (CASLUA). The key idea of this protocol is that it listens to the channel by using a Wi-Fi air interface, but actually transmits data via an LTE air interface. This is achieved by using a proposed dual frame aggregation scheme where two frames (an L-frame and a U-frame) are allocated to licensed and unlicensed bands, respectively. Two implementations of CASLUA are carried out, one based on standalone operation (S-CASLUA)and the other operating with assistance from a software-defined network controller (SDN-CASLUA). SDN assistance lies in the monitoring of multiple network parameters, which are then used to make a decision on effective spectrum allocation with awareness of interference and capacity demands. Simulation results show that the CASLUA protocol helps to avoid interference and increases the average throughput by up to 40 percent for both Wi-Fi and LTE users in LTE-Unlicensed.

Taras Maksymyuk is with the Lviv Polytechnic National University and Korea University.

Maryan Kyryk Is with the Lviv Polytechnic National University.

Minho Jo is with Korea University and is the corresponding author.

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Introduction

Necessity of LTE-U for 5G and Above

The dramatic increase in mobile network traffic has resulted in a spectrum scarcity problem. In addition, increases in network capacity require additional spectrum resources. Recently, leading telecom carriers have started to explore new possibilities for utilizing the unlicensed 5 GHz band for LTE-based cellular transmission. The unlicensed 5 GHz band has so far been occupied by Wi-Fi. Recent activities by cellular networks to utilize the unlicensed band are referred to as the LTE — Unlicensed (LTE-U) standard [1]. Use of unlicensed bands can benefit from an additional 400 MHz band, which opens up new prospects for fifth generation (5G) and above deployment. Recent joint band–based 5G tests conducted by SK Telecom and Nokia showed that a capacity of 19.1 Gb/s can be achieved by using 256-quadrature amplitude modulation (QAM) and 8 × 8 multiple-input multiple-output (MIMO) in the 400 MHz bandwidth of the centimeter spectrum.

Challenging Issues for the Coexistence of LTE and Wi-Fi

Even though LTE-U is an appealing standard for 5G and above in the future, there are still many challenges to its implementation. Specifically, Wi-Fi users in both private and public places use the 5 GHz band. Deployment of LTE-U in these areas may cause severe interference, decreasing network performance. Recent studies have shown that throughput of Wi-Fi usually decreases, whereas LTE-U increases, when both are sharing an unlicensed band. Telecom carriers are still able to exchange their own Wi-Fi transceivers with LTE-U transceivers to increase the quality of service for LTE users. In this case, they will lose profit from Wi-Fi users. Moreover, mobile devices need to be capable of operating on LTE-U networks, which will require a few years for users to update their devices. In addition, other Wi-Fi networks will still interfere with LTE-U users. Therefore, the challenging issue is how to enable win-win coexistence of Wi-Fi and LTE in the unlicensed 5 GHz band. Another question is how several providers will share this unlicensed spectrum among themselves. An additional complexity is that Wi-Fi uses random access based on carrier sense multiple access with collision avoidance (CSMA/CA), which differs from deterministic access in an LTE-U network. Wi-Fi does not allow interference avoidance with cellular users because Wi-Fi selects transmission time randomly, whereas LTE transmission time is strictly determined. Under Wi-Fi, users operate in 20 MHz channels, but LTE provides spectrum allocation by resource blocks in 180 kHz bands. Thus, even a single Wi-Fi user will interfere with multiple LTE-U users. Many approaches have been proposed for coexistence of Wi-Fi and LTE, such as advanced filtering techniques in receivers, idle frames transmission, and listen before talk (LBT) protocol. However, there is still the challenge of utilizing the unlicensed band for multi-tier heterogeneous networks, where Wi-Fi coexists with LTE-based macrocells, small cells, and even device-to-device (D2D) channels [2]. One feature of heterogeneous networks is multi-variance of channel scheduling. Introducing LTE-U adds more complexity, because macrocells, small cells, and D2D channels may also share the unlicensed band. Therefore, new solutions are required to improve radio resources management in multi-tier heterogeneous networks underlying LTE-U. The main function of radio resources management is to maximize network capacity in limited spectral resources. In this article, we propose a new approach to radio resources management based on comprehensive network monitoring and software-defined scheduling to solve the upcoming problem. This proposed approach assumes that a software-defined network (SDN) controller contains the relevant information on load and spectrum allocation of each cell, the received signal strength of each user on downlink and each base station on uplink, geo-information on cell locations, user trajectories, user velocities, and cell sizes.

The major contributions of this article are as follows:

1. A resource management scheme for heterogeneous networks (HetNets) underlying LTE-U is proposed.
2. An approach for comprehensive network monitoring is developed based on SDN.
3. Intelligent spectrum allocation in the unlicensed band is proposed by developing a carrier sense LTE unlicensed access protocol, taking into account multiple criteria, such as interference, cell load, and capacity.
4. Deployment strategies for LTE-U in heterogeneous networks are described and their performance assessed.

This article is organized as follows. First, we cover prior work on HetNets in unlicensed spectrum and SDNs. We then describe the proposed carrier sense LTE unlicensed access protocol based on comprehensive network monitoring. Next, we present a few deployment strategies for LTE-U. Finally, we conclude this article.

Parameter	Standard	
	Wi-Fi [12]	LTE [13]
Peak downlink spectral efficiency	7.5 b/s/Hz	16.3 b/s/Hz, 30 b/s/Hz (LTE-Advanced)
Peak uplink spectral efficiency		4.3 bps/Hz, 15 b/s/Hz (LTE-Advanced)
Bandwidth	20 MHz (for all) /40 MHz (for 802.11n only)	1.4/3/5/10/15/20 MHz, 5 × 20 MHz aggregation (LTE-A only)
Modulation	BPSK, QPSK, 16/64-QAM	QPSK, 16/64-QAM
Multiplexing	CSMA	OFDMA
Duplexing	TDD	TDD/FDD
Spectrum	2.4 GHz, 5 GHz	700 MHz, 1800 MHz, 2.3 GHz, 2.6 GHz, 5 GHz (LTE-U only)

Table 1. Comparison of Wi-Fi and LTE air interfaces.

Software-Defined Control Plane for Multi-Tier Heterogeneous Network

Unlicensed Spectrum Access for Heterogeneous Networks

Heterogeneous networks are widely accepted as an effective technology for increasing the capacity of mobile networks through densification of the infrastructure. Denser deployment of transceivers provides higher spectrum reuse. Higher spectrum reuse gives wider frequency bands by reusing more spectrum of neighboring small cells. This results in much higher throughput for each user and increases the sum capacity of a mobile network. Densification of transceivers can be made by decreasing cell size (i.e., generating more cells), offering additional benefits in deployment costs. Because small cells require much less transmission power and are installed in a dense urban environment, building a large tower for each transceiver is not economically justified. A multi-tier HetNet provides significant advantages over conventional single-tier cellular networks in terms of effectiveness of resource allocation and overall network capacity. Nevertheless, the capacity of a HetNet is still bound by significant interference influence between co-channel small cells. Interference degrades network performance and requires advanced approaches to enable denser small cell network deployment. A combination of licensed and unlicensed bands in a HetNet is an attractive solution to attenuate interference by using unlicensed Wi-Fi channels in interference-overloaded areas. However, Wi-Fi channels provide much lower performance compared to LTE channels, which has a negative impact on total network capacity. Developing LTE-U helps to improve network performance by utilizing the unlicensed band for LTE users. However, it brings additional complexity to spectrum management, because there are still many Wi-Fi transceivers in densely populated cities. LTE-U networks selfishly invade the territory of Wi-Fi networks, causing significant interference with Wi-Fi. Meanwhile, a Wi-Fi network will also influence an LTE-U network. Recent research has proposed some approaches to enable harmonious coexistence between Wi-Fi and LTE in the unlicensed spectrum.

Recent simulation results on Wi-Fi and LTE-U coexistence have shown that Wi-Fi networks have little impact on LTE-U networks, whereas LTE-U badly decreases the performance of Wi-Fi [3]. This diversity in performance comes from different medium access control (MAC) protocols. LTE-U uses synchronized allocation of physical channels, different from CSMA in Wi-Fi. Since Wi-Fi performs channel sensing before transmission, data will not be transmitted if LTE transmission is detected. Different from the irregular transmission of Wi-Fi, LTE transmits frames continuously, which makes a Wi-Fi transceiver stay in listen mode (carrier sensing) most of the time. Interference becomes even worse when both networks operate on non-line-of-sight (NLOS) channels. Further insights were given by study of different spectrum bands. Results have shown that LTE-U transmission in 3–5 MHz band significantly decreases the performance of a Wi-Fi network, whereas in 1.4 MHz band with center frequency located on the guard band of Wi-Fi channels, LTE-U has little impact on Wi-Fi [4].

To address the complexity of resource planning in HetNets, some advanced solutions have

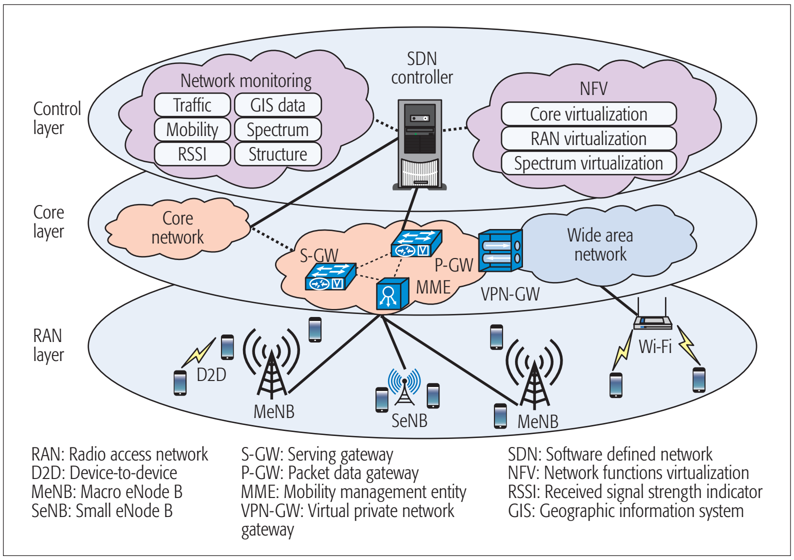

FIGURE 1. Simplified architecture of heterogeneous mobile networking based on SDN and NFV.

been developed so far. Stochastic and deterministic geometry solutions have been developed for resource planning in a three-tier HetNet [5,6]. The advantage of a stochastic approach lies in good reflection of network topology and feasibility of random spectrum distribution among multiple small cells. On the other hand, the probabilistic calculation of network parameters does not allow estimation of interference among multiple small cells in unlicensed spectrum. The deterministic cell planning and spectrum distribution based on fractal geometry provide precise calculations of the interference between different cells in single-tier or multi-tier HetNets by deriving all equations based on fractal scaling. However, this approach is more complicated for existing network topology and is more useful for planning new network topology.

For fair distribution of resources according to capacity demands, each cell should receive information on network conditions. Cooperation among transceivers is complicated and may be implemented only for small areas due to delay in data transmission between neighboring cells and in time spent on making the decision [7]. A centralized control plane can estimate network conditions by collecting data from the entire network [8]. Therefore, a centralized control plane to provide resource allocation in HetNets is a good solution for improving network performance when using unlicensed spectrum.

CENTRALIZED RESOURCE MANAGEMENT AND NETWORK CONTROL BASED ON SDN

Software-defined networking is a new concept to decouple the data layer and the control layer. The control layer provides logically centralized network monitoring and management. The data layer and network infrastructure are abstracted by using network functions virtualization (NFV) [9]. In a heterogeneous mobile network, NFV is used to abstract the radio access network, the core network, and spectral resources as virtual entities in a cloud-based control system [10]. The advantage of NVF is to improve network performance by precise spectrum management, handover control, and quality maintenance. SDN enables radio access network (RAN) sharing by several network providers via intelligent spectrum slicing and logical isolation of wireless resources in both licensed and unlicensed spectrum. That provides new opportunities for utilizing unlicensed spectrum [11]. However, this approach requires a new network architecture, which can provide simultaneous monitoring of multiple network parameters and quick decision making for network management.

Summarizing all the prior work above on software-defined mobile networking, we propose simplified architecture for a software-defined heterogeneous mobile network (Fig. 1). The network is divided into three layers: the RAN layer, the core layer, and the control layer. All layers are logically separated according to their functional responsibilities.

The RAN layer provides all functions related to channel scheduling, data encoding, signal processing, modulation, and air transmission to mobile users. This layer is logically the same as the Evolved Universal Terrestrial RAN (E-UTRAN). In heterogeneous networks, this layer combines all macro and small cells, as well as Wi-Fi access points and D2D links.

The core layer provides functionality of the evolved packet core (EPC). The core layer consists of service and packet gateways (S-GW and P-GW), mobility management entities, and edge routers to communicate with external networks. This layer aggregates all traffic from the RAN layer and transfers it to the global network, and vice versa. This layer is also responsible for handover, service delivery, interaction with other networks or with different cell sites, network management functions such as authentication, authorization and accounting (AAA), and user access control by a home subscriber server (HSS).

The control layer is responsible for network monitoring, load balancing over all cells, spectrum sharing, spectrum reallocation, infrastructure reconfiguration, and other management parameters. Network monitoring is carried out by using a client/server system where all base stations, Wi-Fi access points, and mobile devices send their status data to a remote database. A controller similar for all devices selects the periods of data transmission. The amount of data monitoring is very small, so it will not degrade RAN performance. All data are in text form, and each device sends a payload of less than 1 kB. RAN and core layers may neglect such minimal traffic monitoring, but it creates a large database on current network conditions and previous statistics in the control layer. This information is helpful when making decisions on network reconfiguration according to current network conditions. Moreover, the available statistics, collected through an unlimited period, help to predict traffic behavior and prevent cell overload. To simplify load balancing and spectrum allocation on the control plane, spectrum and RAN are virtualized by using NFV.

Comprehensive Resource Management For Heterogeneous Networks in Licensed and Unlicensed Bands

Comparison of Wi-Fi and LTE Air Interfaces

The complexity of Wi-Fi and LTE coexistence comes from significant differences in air interfaces and MAC schemes. Wi-Fi operates in 20 MHz channels and uses CSMA/CA. Specifically, each transmitter senses current activity on the wireless channel before packet transmission. If a channel is busy, the transmitter waits for a random time before the next channel sensing to let the current user finish the current active transmission on the channel. In CSMA/CA, if a channel is available, the transmitter sends the data packets. CSMA/CA allows multiple users to access the media using a limited number of spectrum channels. The drawback to this approach is that increasing the quantity of devices degrades network performance. This happens because sensing time increases while data transmission time decreases.

Compared to Wi-Fi, LTE can transmit data using different spectrum bands from 1.4 MHz to 20 MHz. MAC layer LTE uses orthogonal frequency-division multiple access (OFDMA). In OFDMA, the available bandwidth is split into multiple subcarriers that satisfy the orthogonality condition. Each subcarrier has a bandwidth of 15 kHz. Subcarriers are arranged in resource blocks. Each resource block consists of 12 subcarriers, resulting in 180 kHz bands, which can be allocated for users' data transmissions. In the time domain, a resource block consists of six or seven symbols, with a duration of 66.7 μs, separated by guard intervals. Thus, a resource block is transmitted in a time slot of 0.5 ms. Two consecutive time slots constitute a 1 ms subframe. An LTE frame consists of 10 subframes. An LTE frame can be shared by 10 users in the same bandwidth. Of course, increasing the number of users decreases the throughput for each user. However, compared to CSMA/CA, OFDMA helps to distribute resources between all users according to their demand. Therefore, total network capacity is not affected significantly, but still decreases due to more signaling data. A detailed comparison of the Wi-Fi and LTE air interfaces is shown in Table 1.

Carrier Sense LTE Unlicensed Access Protocol

Utilization of unlicensed bands for LTE transmission leads to a significant decrease in user quality of experience due to the interference problem. We expect that using an unlicensed band with the carrier aggregation approach used in LTE will provide better performance compared to conventional utilization of the unlicensed spectrum. Therefore, we developed an approach that aggregates throughput in licensed and unlicensed bands simultaneously. Data requiring a low error rate, such as signaling data and voice data, are still transmitted over the licensed spectrum band, whereas the unlicensed band is used to boost throughput for data-hungry applications, which allows some packet loss. We propose an approach of dual-subframe allocation. In the proposed approach, one subframe is transmitted over a licensed band (the L-subframe) while the other frame is transmitted over an unlicensed band (the U-subframe). Subframe allocation is carried out with assistance from an SDN controller in order to avoid interference with Wi-Fi networks. We assume that Wi-Fi networks do not interfere with LTE-U due to channel sensing before transmission under the CSMA protocol. Our approach is to exploit Wi-Fi's MAC protocol advantage for LTE channels in the unlicensed band. Therefore, we propose a new MAC protocol, called carrier sense LTE unlicensed access (CASLUA). CASLUA can be implemented in both a standalone and SDN-assisted way (S-CASLUA and SDN-CASLUA, respectively). Figure 2 shows the proposed MAC protocol diagram and algorithm for S-CASLUA.

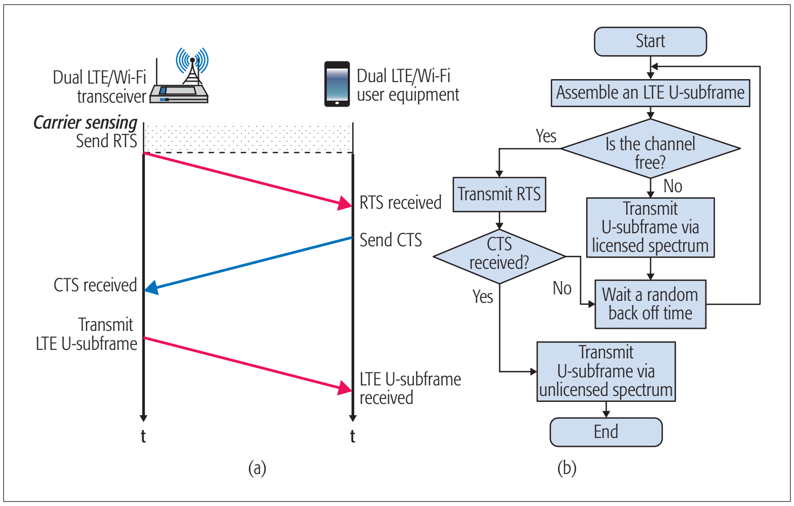

Figure 2. The proposed a) MAC protocol diagram; b) transmission algorithm for S-CASLUA.

S-CASLUA: In S-CASLUA, each transmitter senses the channel via a Wi-Fi transceiver using CSMA. We also complement our CASLUA protocol with request to send/clear to send (RTS/CTS) handshake mechanism to reduce interference caused by the problem of hidden LTE or Wi-Fi nodes. RTS/CTS handshake is an optional mechanism for 802.11 protocol and thus is fully supported by existing hardware. In Fig. 2, if an unlicensed channel is detected as free, the transmitter sends an RTS to the target receiver. After receiving the CTS, the transmitting device allocates a U-subframe under LTE to this channel. Otherwise, the device waits a random amount of time before the next channel sensing. Meanwhile, the U-subframe is temporarily allocated to the licensed band until S-CASLUA detects a free unlicensed channel. Note that CASLUA does not interrupt legacy LTE transmission in licensed spectrum, but used to boost LTE data rate by leveraging both licensed and unlicensed spectrum. This ensures reliable performance for both Wi-Fi and LTE users. When there are many users in the system, LTE performance will be reliable due to a stable anchor in licensed band, and Wi-Fi users will not suffer from severe interference from LTE users. Another important benefit of the S-CASLUA protocol is that it is compatible with the legacy CSMA protocol and can be implemented for both uplink and downlink channels. All functionalities of the MAC layer are inherited from conventional Wi-Fi and LTE protocols. An important feature is that LTE-Advanced (LTE-A) and LTE-U transmissions are carried out simultaneously. In licensed spectrum LTE-A operates in ordinary mode, whereas in unlicensed spectrum CASLUA uses Wi-Fi for spectrum sensing and random channel access and LTE-U for data transmission. Users are scheduled for data transmission over unlicensed spectrum as long as CASLUA detects no activity by Wi-Fi users in this spectrum.

SDN-CASLUA: SDN-CASLUA is an advanced approach that requires assistance from the control plane of the HetNet, combined with comprehensive network monitoring. In this protocol, all devices send their sensing data to the remote database. The database gathers the data on spectrum sensing, cell loads, cell throughput, cell locations, user localization, and many other data and network parameters. The controller collects these data, makes the decision about channel allocation on licensed and unlicensed bands, and transmits these data to the corresponding devices. Each device then has information on L-subframe and U-subframe allocation. The benefit of such an approach is that the controller assigns all channels by interference awareness and capacity demand. Users that share the same licensed band are properly separated by distance, whereas users that share the unlicensed band are multiplexed in time. Another advantage is that SDN-CASLUA does not require all devices to support both Wi-Fi and LTE radio. The reason is that all Wi-Fi-enabled devices have already sent data on channel occupation in the unlicensed spectrum. Then the controller allocates U-subframes to unoccupied channels in unlicensed spectrum for the devices that are close to these Wi-Fi devices. Such a feature is very similar to cooperative spectrum sensing in cognitive radio networks [14]. Figure 3 shows the principle of comprehensive monitoring for SDN-CASLUA and dual-frame structures for LTE transmission.

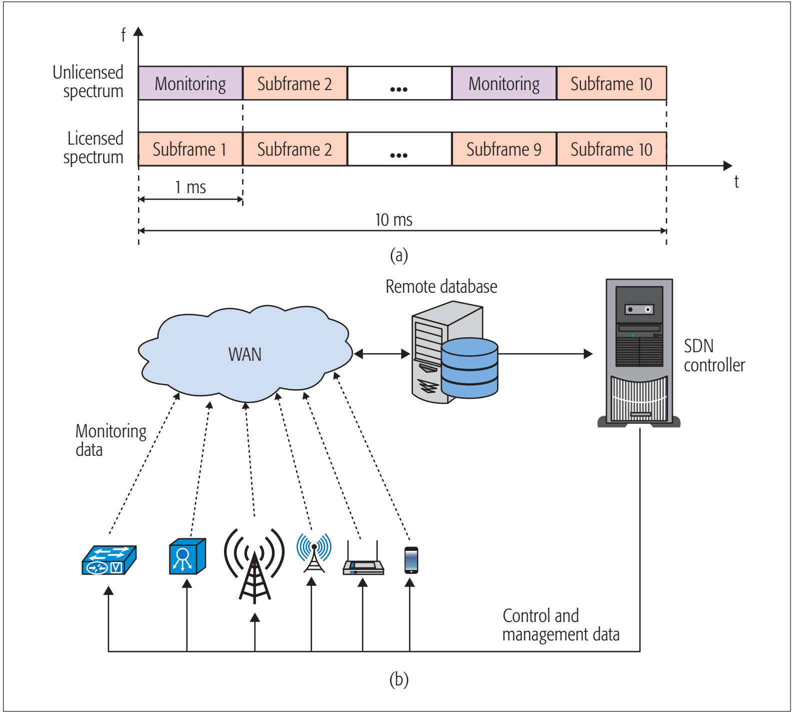

Figure 3. a) Dual-frame structure and b) simplified architecture of SDN-CASLUA.

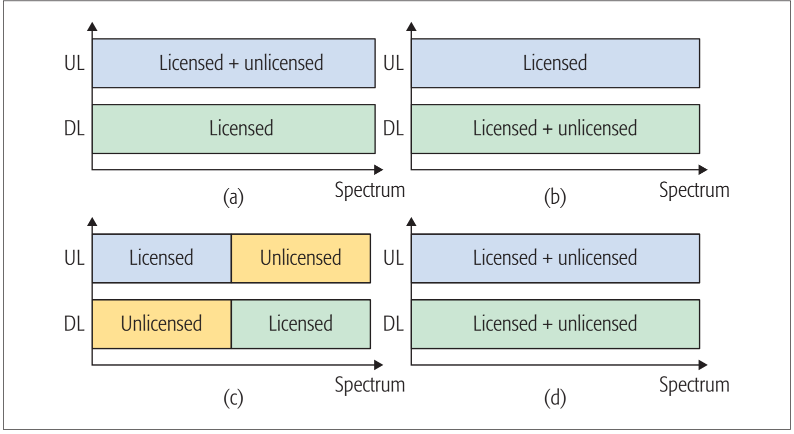

Figure 4. Four spectrum-sharing strategies for uplink and downlink channels.

As shown in Fig. 3a, the dual-frame structure consists of 10 L-subframes for conventional LTE transmission and 10 U-subframes. Odd U-subframes are used for monitoring and making the decision on spectrum allocation according to the received data. Even U-subframes are used for LTE transmission via the unlicensed spectrum band. The protocol diagram and algorithm for SDN-CASLUA are almost the same as S-CASLUA. The difference is that instead of RTS, the transmitter sends data on network conditions, and instead of CTS, the transmitter receives control commands from the SDN controller.

Note that CASLUA can detect both Wi-Fi and LTE active transmissions by using carrier sensing. However, carrier sensing will show good performance in LTE detection only if the power spectral density of the LTE signal is similar to the power spectral density of the Wi-Fi signal. LTE can use much narrower bands compared to Wi-Fi. In addition, the transmission power of LTE small cells and Wi-Fi is nearly the same. Thus, Wi-Fi carrier sensing may not recognize active LTE transmissions. We suggest decreasing the energy detection threshold in spectrum sensing to enable good performance under CASLUA, particularly if several LTE providers share the unlicensed spectrum band. Existing approaches to spectrum sensing in wireless networks can also be implemented to improve device capabilities in LTE detection [15].

Performance Analysis of Different Spectrum Sharing Models in Licensed and Unlicensed Bands

Spectrum Sharing Strategies for Uplink and Downlink Channels in LTE-U Networks

In HetNets, a macrocell can cover a large territory. Thus, many Wi-Fi networks will be in the coverage area of the macrocell. In high density deployment unlicensed band is reused by nearby Wi-Fi access points, which may introduce additional interference. This interference is managed by standard features of 802.11. If a Wi-Fi device detects an interference-active transmission before it starts its own transmission, it will hold off until the interference-active transmission is finished. If interference occurs in the middle of an ongoing 802.11 transmission, which results in

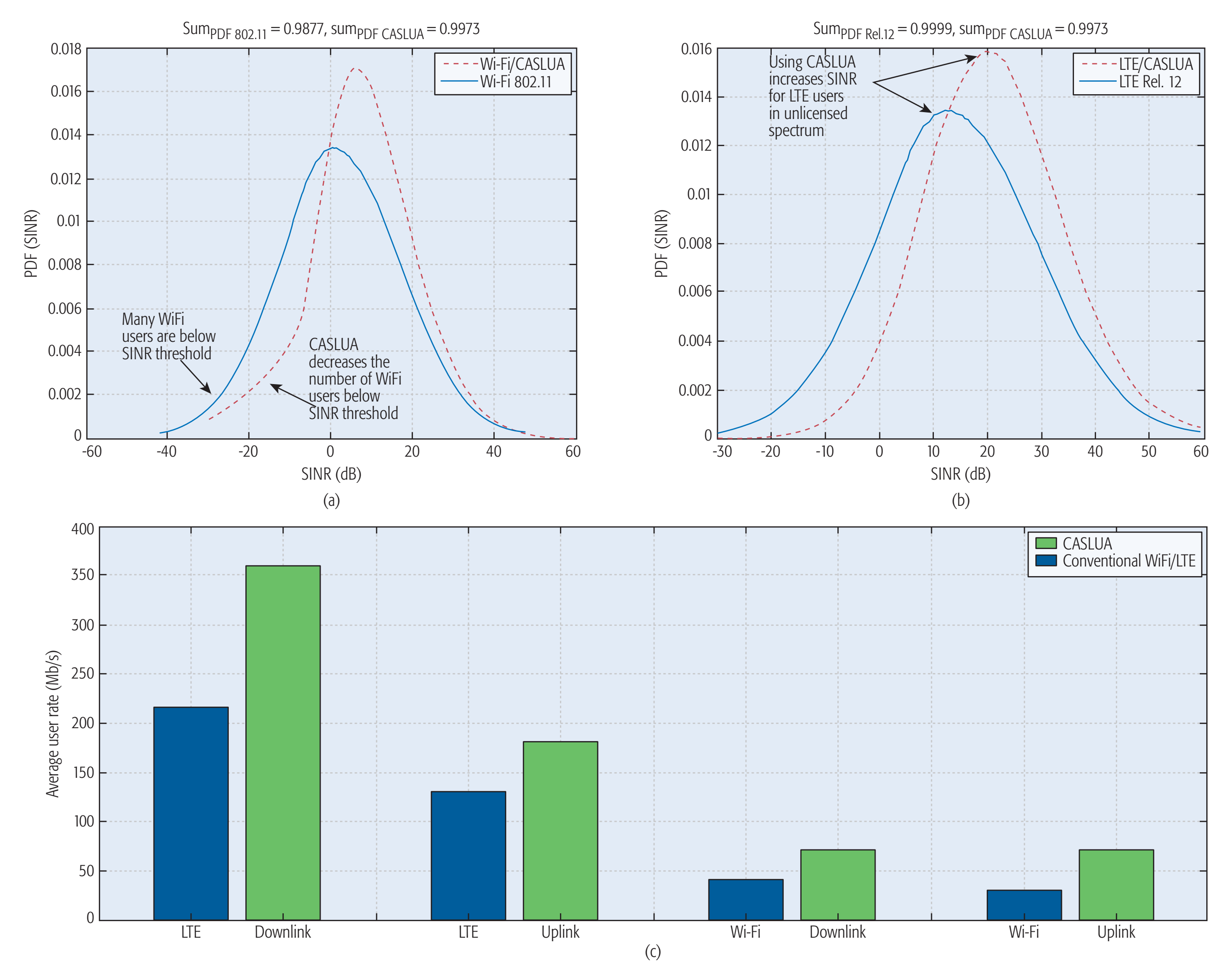

FIGURE 5. a) Signal-to-interference-plus-noise ratio probability density functions for Wi-Fi; b) for LTE users; c) average throughput of Wi-Fi and LTE users on an unlicensed band.

improper packet reception, the transmitter will not receive an acknowledgment packet. In this case, the transmitter will have to resend the packet. However, this resilience to interference results in significant decrease of network throughput and capacity. Thus, an unlicensed band is not feasible for the macrocell because it interferes with all Wi-Fi networks in the area and decreases their performance.

Therefore, we suggest using LTE-U only for small cells in a HetNet. We propose four models for spectrum sharing on both uplink and downlink channels, as well as for both licensed and unlicensed bands. The four spectrum-sharing models are depicted in Fig. 4. The first model, presented in Fig. 4a, uses only licensed bands for downlink channels while using both licensed and unlicensed bands for uplink channels. In this model, LTE and Wi-Fi do not interfere on the downlink channel. On uplink, LTE users may interfere with neighboring Wi-Fi users when using an unlicensed band for transmission. The second model, in Fig. 4b, is the inverse of the first model. Unlicensed and licensed bands are combined on downlink channels to boost throughput for end users, whereas a licensed band is used for the uplink channel. In this case, Wi-Fi and LTE transmitters interfere on downlink. The third model uses both licensed and unlicensed bands for uplink and downlink, as shown in Fig. 4c. However, bands are divided 50/50, that is, 50 percent of the licensed band is used for uplink, and other 50 percent is used for downlink. The unlicensed band is divided in the same way. In this model, uplink and downlink channels do not overlap. This model is suitable for the frequency-division duplexing (FDD) mode of an LTE network. This model also provides lower interference between Wi-Fi and LTE because only 50 percent of the channels overlap with Wi-Fi on uplink and downlink. Nevertheless, the price for lower interference is lower aggregated throughput, compared to the first two models. Aggregated throughput is the sum rate that can be achieved by using licensed and unlicensed bands simultaneously. The best model in terms of peak-aggregated throughput is the fourth model, which combines licensed and unlicensed spectrum for both uplink and downlink channels. For all presented models, CASLUA may be implemented, regardless of uplink or downlink channels.

Results show that our approach outperforms a conventional Wi-Fi/LTE network by up to 40 percent in average user throughput. In future research, we will do more insightful analytics and modelling of the challenges to spectrum sharing by different services in the unlicensed band.

Simulation and Performance Analysis of an LTE-U Network

We simulated network performance by using a 100 MHz licensed band and a 400 MHz band of unlicensed spectrum. For LTE-U, we used spectral efficiency of 30 b/s/Hz on downlink, and 15 b/s/Hz on uplink. For Wi-Fi, we use spectral efficiency of 7.5 b/s/Hz for both uplink and downlink channels. Users were randomly placed using a Poisson point process. We assumed that the licensed band is fairly distributed between 100 users (i.e., each user utilizes a 10 MHz band for the L-subframe). In the unlicensed band, SDN-CASLUA provided all necessary information for the user to perform effective spectrum allocation. Simulation results are shown in Fig. 5.

Results show that in conventional systems, which use Wi-Fi and LTE in unlicensed spectrum, interference significantly limits network performance. Wi-Fi users suffer from neighboring LTE users due to higher transmission power under LTE. Many Wi-Fi users are below the required SINR threshold, as shown in Fig. 5a. This, in turn, decreases the performance of the Wi-Fi network, as observed in Fig. 5c.

LTE users are not significantly affected by a Wi-Fi network because the majority of LTE users are above the SINR threshold, as seen from Fig. 5b. Nevertheless, interference between different LTE networks may negatively affect their own performance. Implementation of the proposed CASLUA protocol allows a heterogeneous mobile network under LTE-U to avoid interference in the unlicensed spectrum and improve network performance. Probability density functions in Figs. 5a and 5b show that CASLUA implementation helps to increase signal-to-interference-plus-noise ratio (SINR) values by 10 dB for most users. This definitely provides an advantage in throughput because throughput depends on channel conditions and SINR. Figure 5c shows the comparison of average user throughput for Wi-Fi and LTE users on both uplink and downlink channels. Results show that CASLUA obviously increases the average data rates for users by up to 40 percent.

Conclusion

Using the unlicensed spectrum for legacy mobile transmissions is beneficial for many reasons. An additional 400 MHz band from the unlicensed spectrum provides an opportunity to increase the capacity of congested cells. In combination with a heterogeneous network architecture and cognitive radio approaches, unlicensed access is a viable solution for 5G and above network deployment because using more spectrum resources can increase the average data rate for end users. In this article, we study preliminary work on unlicensed spectrum usage for mobile networks, and describe the upcoming challenges. We propose a new multiple access protocol called carrier sense LTE unlicensed access (CASLUA). Our protocol can be implemented either as a standalone application or as part of a software-defined mobile network. We propose an approach to comprehensive monitoring of network parameters with centralized coordination/decision making to improve network management functions, such as load balancing, spectrum allocation, interference mitigation, and network reconfiguration. We discuss pros and cons with respect to four possible models for joint utilization of licensed and unlicensed spectrum on both uplink and downlink channels. We discuss a simulation of network performance by using our developed CASLUA algorithm. Results show that our approach outperforms a conventional Wi-Fi/LTE network by up to 40 percent in average user throughput. In future research, we will do more insightful analytics and modeling of the challenges to spectrum sharing by different services in the unlicensed band, and we will develop our ideas on centralized resource allocation by using software-defined networking.

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Biographies

Taras Maksymyuk [M'14] (taras.maksymyuk.ua@ieee.org) is now an assistant professor in the Telecommunications Department, Lviv Polytechnic National University, Ukraine, and an invited research professor in the Department of Computer and Information Science, Korea University, Sejong Metropolitan City, South Korea.

He received his Ph.D degree in telecommunication systems and networksin 2015, his M.S. degree in information communication networks in 2011, and his B.A. degree in telecommunications in 2010, all from the same university. He was recognized as the Best Young Scientist of Lviv Polytechnic National University in 2015. He is currently an Editor of *KSII Transactions on Internet and Information Systems* (SCI and SCOPUS indexed). He is currently a member of the IEEE Communications Society and IEEE Software Defined Networks Community. His research interests include cognitive radio net-

works, LTE in unlicensed spectrum, mobile cloud computing, massive MIMO in 5G, machine-to-machine communication and heterogeneous network in 5G, software defined radio access networks, and the Internet of Things.

MARYAN KYRYK (mkyryk@gmail.com) is now an associate professor in the Telecommunication Department, Lviv Polytechnic National University. He received hisPh.D. degree in telecommunication systems and networks from Odessa National Academy of Telecommunications, Ukraine, in 2009, and his M.S. in information communication networks from Lviv Polytechnic National University in 1999. He has experience in network administration and management. He worked as a software engineer in the Lviv Polytechnic IT Center. Currently he is a CEO of a telecommunication company that provides IPTV services on the metropolitan scale. His current research interests include distributed networks, cloud computing, quality of experience in IPTV, network resource management, and software defined networks.

MINHO JO [M'07] (minhojo@korea.ac.kr) is now a professor with the Department of Computer and Information Science, Korea University, Sejong Metropolitan City, South Korea. He received his B.A. degree from the Department of Industrial Engineering, Chosun University, South Korea, in 1984, and his Ph.D. degree from the Department of Industrial and Systems Engineering, Lehigh University, in 1994. He is one of the founders of Samsung Electronics LCD Division. He is the Founder and Editor-in-Chief of *KSII Transactions on Internet and Information Systems* (SCI and SCOPUS indexed). He was awarded the Headong Outstanding Scholar Prize 2011. He is currently an Editor of *IEEE Wireless Communications*, and an Associate Editor of the *IEEE Internet of Things Journal*, *Security and Communication Networks*, and *Wireless Communications and Mobile Computing*. He is now the Vice President of the Korean Society for Internet Information, and was the Vice President of the Korea Information Processing Society. His current research interests include LTE-unlicensed, cognitive radio, IoT, deep learning AI in IoT, HetNets in 5G, green (energy-efficient) wireless communications, mobile cloud computing, network functions virtualization, 5G wireless communications, optimization and probability in networks, network security, and massive MIMO.