Opportunistic tri-band carrier aggregation in licensed spectrum for multi-operator 5G hetnet

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ABSTRACT

Increasing capacity of mobile networks is a real challenge due to rapid increasing of traffic demands and spectrum scarcity. Carrier aggregation technology is aimed to increase the user data rate by combining the throughput of few spectrum bands, even if they are not physically collocated. Utilization of unlicensed Wi-Fi 5 GHz band for mobile transmission opens new perspectives for carrier aggregation due to vast amount of spectrum range, which can be available for aggregation to supplement data rates for end users. There are many solutions proposed to enable mobile data transmission in unlicensed band without disturbing interference for the existing Wi-Fi users. The paper presents a new approach for opportunistic carrier aggregation in licensed and unlicensed band for multi-operator 5G network. It allows multiple network operators to utilize unlicensed spectrum opportunistically if it is not currently used by Wi-Fi or other mobile network operators. Performance of the proposed approach has been simulated in case of two competing operators. Simulation results reveal that applying the proposed method ensures achieving satisfactory performance of carrier aggregation for the case of two network operators.

Keywords: 5G, carrier aggregation, Wi-Fi, LTE-Unlicensed, spectrum sharing

1. INTRODUCTION

5G heterogeneous networks (HetNets) are designed to ensure outstanding performance by exploiting many small cells of extremely high area spectral efficiency[1,2]. High frequency reuse of HetNet allows to provide large portions (parts) of spectrum for end users to increase peak data rates. This advantage can be further enhanced by using non-contiguous carrier aggregation (CA) allowing to combine several spectral bands, which belong to different tiers of HetNet coverage[3,4] (i.e. macro cell, small cell). CA has been used for a while by combining Wi-Fi and LTE networks. The latest examples of Giga LTE deployment have achieved throughput of 1.17 Gbps by combining LTE and Wi-Fi throughputs. Recent studies have shown that higher performance may be achieved using Wi-Fi spectrum for LTE transmission due to higher spectral efficiency of LTE network[5-8]. Thus, new topic emerges namely LTE in unlicensed spectrum[9] (LTE-U).

Utilization of unlicensed spectrum gives a mobile network provider many advantages. However, it is unlikely that unlicensed spectrum will be considered as a primary band for LTE transmission in the near future because of the interference between LTE and Wi-Fi femtocells[10]. Additional problem appears when several network operators are using the same unlicensed bands. In such a case a harmful interference occurs resulting in significant degradation of network performance. There are several methods aimed to cope with the challenge of inter-operator interference in the unlicensed spectrum, such as approaches to coordinate spectrum usage by several network operators based on Nash equilibrium game have been proposed[11,12]. There are also some punishment policies, which may be used for a selfish operator such as restrictions for access to the unlicensed spectrum during some time after the "abuse".

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Alternative solution is to use centralized control plane with software defined networking[13]. Nevertheless, it is still probable that operators will try to behave selfishly and to trick their competitors in some way. To avoid the situation described, a new opportunistic tri-band carrier aggregation has been proposed for use in both licensed and unlicensed bands. The novelty of approach proposed is logical division of unlicensed spectrum band between mobile operators using primary and secondary access.

This paper is organized as follows. Section II describes the proposed opportunistic tri-band carrier aggregation approach. Section III covers the simulation and performance analysis of the proposed approach. Section IV concludes the paper.

2. LTE NETWORK ENHANCEMENT FOR UTILIZATION OF THE UNLICENSED SPECTRUM BAND

As more users demand high quality wireless network access, more attention is paid to 5 GHz unlicensed bands, from 5.150 to 5.925 GHz which are used by Wi-Fi networks. These wide spectrum resource can be utilized by LTE mobile network operators in addition to licensed bands, to enhance their service. So far, the 5 GHz unlicensed bands have been mainly used only for Wi-Fi. Currently, there are two methods for using the unlicensed band by LTE, namely LTE-U and LAA (Licensed-Assisted Access). Since LTE-U is just a simple approach, which does not implement the LBT (Listen-Before-Talk), it is only suitable for the countries without LBT regulation, i.e. US, South Korea or China. As for other big markets such as Europe or Japan, LBT is strictly required. Therefore, 3GPP (3rd Generation Partnership Project) is currently working on the Release-13, which aims to design a global framework for LTE in unlicensed spectrum, currently known as LAA. In addition to LBT regulations, LAA also supports other regulations such as occupied bandwidth, power spectral density, etc. The main goal of LAA is to achieve good coexistence with the present Wi-Fi networks. Therefore, the impact of additional LAA small cell will be the same as impact of additional Wi-Fi access point[14]. In order to support these features additional techniques and mechanisms are necessary such as transmission power control, cell range expansion and adaptive resources allocation in unlicensed spectrum[15-17].

Even though LTE-U does not require listen before talk in some regions, as mentioned before, the coexistence issues for Wi-Fi/LTE-U should be carefully considered. Despite keeping the same MAC standard as 3GPP Release 11, LTE-U performs channel scanning in unlicensed bands. After identification of clear channel LTE-U occupies the bandwidth completely for supplementary downlink transmission (SDL). If there are no available channels, the channel is shared with Wi-Fi by using CSAT[18] (Carrier-Sensing Adaptive Transmission). Moreover, in such a case, SDL is used only if there is a high data demand by the users. SDL carrier normally should be switched of while data demand is low, to avoid frequent collisions and reduce interference to the Wi-Fi access point in the vicinity. Channel scanning will be resumed when data demand increases again.

3. OPPORTUNISTIC TRI-BAND CARRIER AGGREGATION

The paper presents an approach for unlicensed spectrum sharing by several mobile network operators based on straightforward spectrum division. The spectrum is divided into separate bands and each operator is assigned with exclusive pseudo-license for a part of unlicensed spectrum. Each operator is a primary user of his band of unlicensed spectrum, but can opportunistically access bands of the other operators as a secondary user. The principle of opportunistic carrier aggregation is depicted in Fig.1. Mobile network operator can boost capacity by aggregation of several spectrum bands. Spectrum aggregation can be divided into two cases: primary spectrum access and secondary spectrum access. In a primary access case, network operator can aggregate all the available licensed spectrum with a part of unlicensed spectrum that is assigned to this operator. It is worth noting that access to unlicensed spectrum should be performed by using LBT (Listen Before Talk) mechanism to ensure fairness to Wi-Fi users.

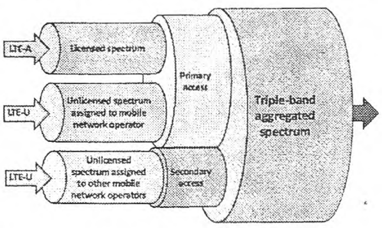

Figure 1. Principle of opportunistic tri-band carrier aggregation in downlink channel.

In a secondary access case, principles of cognitive radio[19-21] are applied. First, mobile network operator must scan the availability of unlicensed bands, which belong to other mobile network operators. If some of these bands are available, network operator is allowed to aggregate that part of unlicensed spectrum. Otherwise, network operator can aggregate only primary access spectrum. The spectrum sharing strategy for opportunistic carrier aggregation is shown in Fig.2.

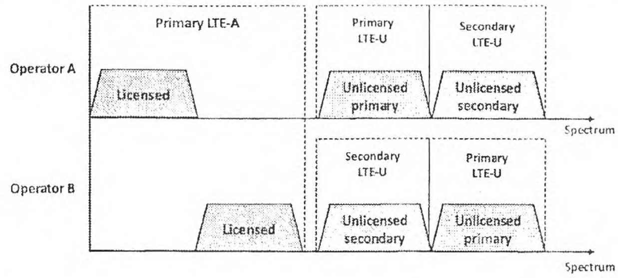

Figure 2. Principle of opportunistic tri-band carrier aggregation in downlink channel.

Opportunistic spectrum aggregation provides more effective usage of unlicensed spectrum and simultaneously satisfies the reliability of service provision to the end users. Comparing with conventional random access to unlicensed spectrum the approach proposed reduces the number of unsuccessful transmission attempts by using reliable anchor connection to the license band and primary access to the half of unlicensed spectrum (in case of two mobile network operators). The flow-chart of our proposed algorithm is shown in Fig.3. The workflow of the proposed algorithms can be summarized in a few steps:

Step 1. Sense the availability of secondary unlicensed spectrum. Network operator should check for both LTE and Wi-Fi transmission, because they have higher priority to use this band. If there is an available spectrum (i.e. neither competitive LTE networks nor Wi-Fi networks utilize this part of unlicensed band), network operator aggregates it for upcoming data transmission and then proceeds to the step 2. If there are not any available bands in secondary unlicensed spectrum, proceed to Step 2.

Spectrum availability is checked starting from those with higher congestion probability. This is important, because even in case when all unlicensed spectrum is occupied, operator will still have the opportunity to provide service via licensed spectrum.

Step 2. Check the availability of primary unlicensed spectrum. While checking the primary unlicensed spectrum, network operator has a higher priority to access among all LTE operators. However, there is still a need to check for active Wi-Fi transmissions, in order to avoid interference, because Wi-Fi has a higher priority to use this band. Therefore, if there is an available spectrum in primary unlicensed band, it is aggregated for upcoming transmissions. Otherwise, this band is ignored and algorithm proceeds to Step 3.

Step 3. If there are not any aggregated bands in unlicensed spectrum, network operator should allocate the necessary bandwidth in licensed spectrum to provide users with "best effort" service. If there are aggregated bands in unlicensed spectrum, then network operator should complement it with necessary amount of licensed spectrum, but not less than a reliable "anchor" band to provide reliable connection for important data (e.g. signaling data or delay sensitive data). Then algorithm proceeds to Step 4.

Note that it is very important to allocate enough part of licensed spectrum, because unlicensed spectrum may not be reliable due to high probability of interference. Primary unlicensed spectrum is more reliable than secondary unlicensed spectrum, because network operator should coordinate its transmission only with Wi-Fi networks. Secondary unlicensed connections are less reliable due to lower priority to access comparing with other LTE networks and Wi-Fi networks.

Step 4. Network operator aggregates all bands gained from previous steps and performs data transmission via triple-band aggregated channel. If there are multiple users in the target area of coverage, aggregated bandwidth is fairly distributed among them, according to their demands.

Note that, even after successful carrier aggregation from unlicensed spectrum, operator should release unlicensed bands in the next subframe after CASLUA protocol detects higher priority request to this spectrum.

Finally, after successful transmission session, algorithm is returned to Step 1.

The user throughput CUE, achieved by opportunistic carrier aggregation can be calculated as following:

$$C_{UE} = l\log_2\left(1+SINR_l\right)+p\log_2\left(1+SINR_p\right)+s\log_2\left(1+SINR_s\right) \quad (1)$$

where l – bandwidth allocated for user in licensed spectrum, p – bandwidth channels allocated for user in primary unlicensed spectrum, s – bandwidth allocated for user in secondary unlicensed spectrum, $SINR_l$, $SINR_p$, $SINR_s$ – signal to interference plus noise ratio for each of allocated bands.

The mobile network operator throughput C_{MNO} is than calculated as:

$$C_{MNO} = \sum_i l_i\log_2\left(1+SINR_i\right)+\sum_j p_j\log_2\left(1+SINR_j\right)+\sum_k s_k\log_2\left(1+SINR_k\right) \quad (2)$$

where l_i – bands allocated for operator in licensed spectrum, p_j – bands allocated for operator in primary unlicensed spectrum, s_k – bands allocated for operator in secondary unlicensed spectrum, $SINR_i$, $SINR_j$, $SINRk$ – signal to interference plus noise ratio for each of allocated bands.

The total throughput C_{total} for two mobile network operators, which are sharing unlicensed spectrum, is calculated as following:

$$C_{total} = \sum_{i1} l_{i1}\log_2\left(1+SINR_{i1}\right)+\sum_{i2} l_{i2}\log_2\left(1+SINR_{i2}\right)+\sum_j p_j\log_2\left(1+SINR_j\right)+$$
$$\sum_k s_k\log_2\left(1+SINR_k\right); \quad \text{if } i\neq k, \quad \sum_j p_j\log_2\left(1+SINR_j\right)+\sum_k s_k\log_2\left(1+SINR_k\right)=const$$

where l_{i1} – bands allocated for first operator in licensed spectrum, l_{i2} – bands allocated for second operator in licensed spectrum.

The total throughput that is aggregated by two operators is limited by mutual exclusion of the unlicensed spectrum bands. For example, if first operator uses 7 channels out of 10 in the primary unlicensed spectrum, the second operator can access only 3 remaining channels in this part of unlicensed band.

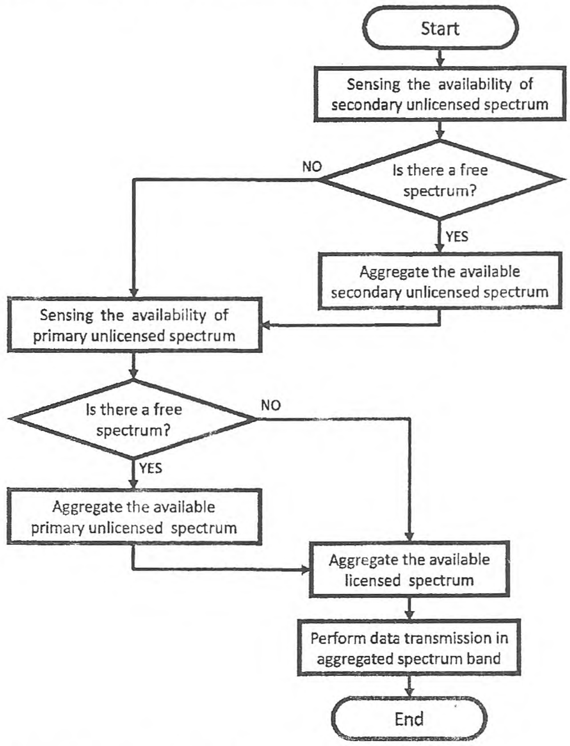

Figure 3. Block diagram of opportunistic carrier aggregation algorithm.

4. SIMULATIONS AND PERFORMANCE ANALYSIS

To assess the performance of two mobile network operators which share unlicensed band by using opportunistic carrier aggregation, a simple simulation has been performed regarding carrier throughput and total aggregated throughput, achieved by each operator. During the simulation, 100 MHz of licensed spectrum was assumpted. Each mobile network operator has exclusive right to use 50 MHz in licensed band. In addition, 100 MHz of unlicensed spectrum was allocated, which is logically divided into two 50 MHz bands. Each operator uses his 50MHz in unlicensed spectrum via pseudo-license, and uses other 50 MHz in unlicensed band via cognitive radio access[20]. During the simulation it was assumed that licensed access is provided via macro eNodeB with spectral efficiency of 5 bps/Hz. Unlicensed spectrum is more likely to be utilized by small cells rather than macro cells in order to avoid interference. Small cells are deployed according to space-time users localization of users density[14]. In this case, channels conditions for unlicensed channels will be much better comparing with those for licensed channels. Therefore, spectral efficiency of 10 bps/Hz for unlicensed channels was set. It is worth noting that the total throughput that is aggregated by two operators is limited by mutual exclusion of the unlicensed spectrum bands. For example, if first operator uses 7 channels out of 10 in the primary unlicensed spectrum than second operator can access only 3 remaining channels in this part of unlicensed band. The simulation results of aggregated throughput are presented in Fig.4.

As shown in Fig.4, the performance of both operators is very similar. It is achieved by the features of opportunistic spectrum access, which prevents selfish domination of a single operator among the others in unlicensed spectrum and also allows to decrease the interference by using prioritized access to the unlicensed spectrum. From Fig.4.a and Fig.4.b it is observed, that total throughput of two operators in unlicensed band is constant.

5. DISCUSSION AND CONCLUSIONS

Deployment of LTE in unlicensed spectrum is a challenging task not only in terms of viable technical solutions but also in terms of economic issues. Important problem is how to stimulate users to migrate from Wi-Fi to LTE unlicensed. Paying to access the unlicensed band is very unlikely and not really justified. Wi-Fi offers all services for free, but there also need to pay some money for the Internet connection of Wi-Fi transceiver. This prevents users' migration from Wi-Fi to LTE, because nobody wants to pay, if there are reliable and free Wi-Fi hot spots. The solution may be found if providers change their service model from throughput selling to service selling. This will recruit more users to LTE-U and reduce the amount of Wi-Fi users in dense urban environment, resulting in much lower interference among LTE and Wi-Fi in unlicensed spectrum.

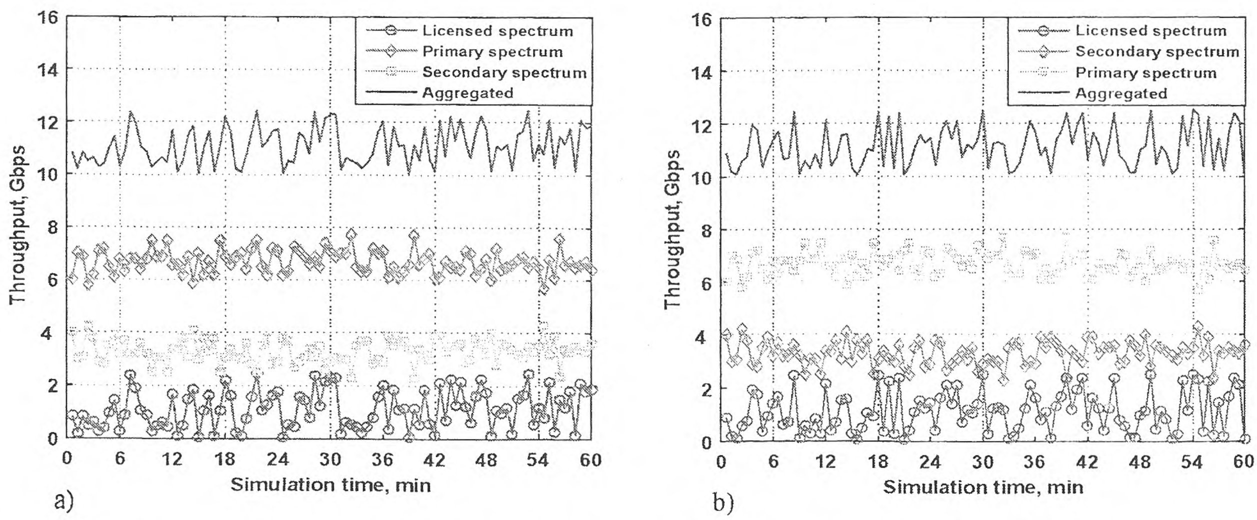

Figure 4. Simulation results of achieved total throughput for a) – mobile network operator A, b) – mobile operator B.

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