Comparing the Performances of LTE-U/Wi-Fi Coexistence Models

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Abstract

In 5G, a new technology has been proposed to enable the operation of LTE in the unlicensed spectrum known as LTE-Unlicensed (LTE-U). In LTE-U, the pertaining licensed spectrum of LTE augments the unlicensed spectrum to meet the demands of cellular users, and to boost the spectrum efficiency. LTE-U is supposed to be the more spectrum efficient as compared to the Wi-Fi system due to its centralized MAC. This paper gives a performance analysis to compare the spectrum efficiency of both the coexisting LTE-U and Wi-Fi networks. Network models for both Wi-Fi and LTE-U are presented and simulations are performed in order to analyze the results.

I. INTRODUCTION

In 2020, mobile cellular traffic is supposed to boost 10 folds to 2010 traffic. To manage such massive amount of traffic, 5G has introduced various technologies including heterogeneous networks (HetNets), wireless network virtualization [1], LTE-unlicensed (LTE-U), the device to device communication (D2D), non-orthogonal multiple access (NOMA) [2] and fog computing [3]. Among these 5G technologies, LTE-U tries to address the problem of spectrum scarcity by augmenting the current licensed spectrum of LTE with the unlicensed bandwidth. For that purpose, LTE-U is required to coexist with the pertaining unlicensed technologies like Wi-Fi.

The centralized MAC of LTE mobile network is spectrally more efficient as compared to the distributed MAC of WiFi network. This is because the central base-station in the LTE cellular network is working as a coordinator to schedule and allocate the resources to the end users. On the other hand, Wi-Fi system uses the contention based scheduling where the network users adapt the career sensing multiple access-collision avoidance (CSMA-CA) to access the channel in a distributed manner.

To get the benefit from the centralized MAC of LTE, and to improve the spectrum efficiency, the operation of LTE networks is allowed in the unlicensed band by introducing the new technology LTE-U. LTE-U is proposed where both the mobile networks and Wi-Fi system coexist together in the same unlicensed spectrum for better spectrum efficiency. However, enabling LTE-U in the unlicensed spectrum can cause severe performance degradations in the Wi-Fi system. To address this issue, many techniques for the fair coexistence of Wi-Fi and LTE-U have been proposed [4].

In order to minimize the effects of LTE-U on the Wi-Fi networks, LTE-U is proposed to operate on low power small-cell base-stations (SBS) for downlink communication. The uplink cellular communication and the control signaling is performed using the licensed spectrum.

The resource allocation problem in LTE-U and Wi-Fi is solved by either using the frame scheduling method or the channel assessment method. In the frame scheduling method, the available unlicensed spectrum is divided among Wi-Fi and LTE-U using a time frame distribution [5]. In the channel assessment method, the cleanest channel having no Wi-Fi transmission in-progress is selected and allocated to LTE-U [6], [7].

In order to develop a fair coexistence scheme LTE-U and Wi-Fi environment, the effects of such coexistence on the performance of both of the coexisting networks is needed to be analyzed. In this paper, we present the performance evaluation of the coexisting Wi-Fi and LTE-U networks. For that purpose, LTE-U and Wi-Fi rate formulation is described. The unlicensed spectrum is shared among the Wi-Fi and LTE-U network using the so-called duty-cycle allocation. Furthermore, the effect of duty-cycle on the performances of each network is presented in the numerical results.

The remaining of the paper is organized as follows. Section

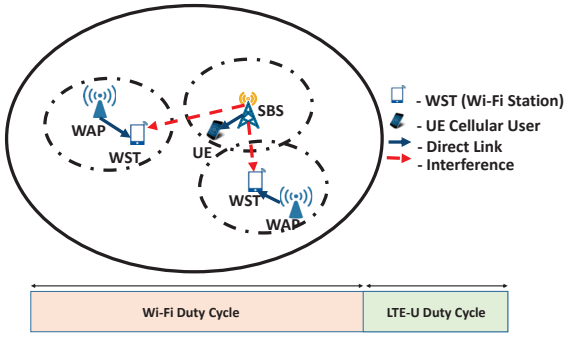

Fig. 1. System model of LTE-U and Wi-Fi Coexistence

II discusses the system model followed by LTE-U Model and Wi-Fi Model in Section III and Section IV. Section V gives the simulation results and Section VI concluded the paper.

II. System Model

The system model consists of a cellular network consisting of an SBS J having a set of associated cellular users represented by $\mathcal{U} = \{1, 2, 3, \ldots, U\}$. This cellular network is coexisting with a Wi-Fi network consisting of a set of Wi-Fi access points (WAPs) denoted by $\mathcal{A} = \{1, 2, 3, \ldots, A\}$ and each WAP is associated with a set of Wi-Fi stations (WSTs) denoted by $\mathcal{W}_A = \{1, 2, 3, \ldots, W\}$. Both of the networks are using the same unlicensed spectrum consisting of a set of channels $\mathcal{C} = \{1, 2, 3, \ldots, C\}$ where each channel $c \in \mathcal{C}$ has a bandwidth of 5 MHz.

It can be seen from the Fig. 1 that the communication of the cellular network is causing interference with the pertaining Wi-Fi system in the form of increased collisions and delays. Each channel $c \in \mathcal{C}$ is shared among the Wi-Fi and LTE-U networks using the duty-cycle method. A frame of time duration T is divided among both of the networks by allocating the proportion $1 - \tau_c$ of the time frame to LTE-U and the proportion τ_c of the time frame to the Wi-Fi network.

III. LTE-U Model

We have considered a single SBS cellular network, therefore cellular users are not facing any interference on the unlicensed band from the neighboring tier. Therefore, the signal to interference and noise ratio (SINR) for a cellular user is given as:

$$\gamma_{uJ} = \frac{P_{uJ} g_{uJ}}{\sigma^2}, \tag{1}$$

where P_{uJ} is denoting the downlink power from the SBS J to the cellular user $u \in \mathcal{U}$, $g_u J$ is the pathloss gain and σ^2 is the noise temperature. Based on the given SINR, the sum-rate for all cellular users during the LTE-U duty-cycle $1 - \tau_c$ is given as:

$$\sum_{c \in \mathcal{C}} \sum_{u \in \mathcal{U}} B(1 - \tau_c) \log(1 + \gamma_{uJ}), \tag{2}$$

where B is representing the bandwidth of the unlicensed channel.

IV. Wi-Fi Model

In the Wi-Fi network, every network user $w \in \mathcal{WU} = \mathcal{AUW}_{\mathcal{A}}$, including the WAPs and WSTs try to access the channel after sensing it free to use. Collisions can happen when more than one network user tries to access the channel. Therefore, the throughput of the Wi-Fi network depends on the successful transmission time T_s, time wasted on collisions T_c and the idle time when there is no transmission T_i. Let $E[P]$ denote the expected payload size, then the throughput of Wi-Fi user can be represented as:

$$R_w = \frac{E[P]}{T_s + T_c + T_i}. \tag{3}$$

The sum-rate of Wi-Fi user is dependent on Wi-Fi duty-cycle τ_c and is given as:

$$\sum_{c \in \mathcal{C}} \sum_{w \in \mathcal{WU}} \tau_c R_w. \tag{4}$$

Clearly, it can be seen that more Wi-Fi rate can be achieved if the duration of the Wi-Fi duty-cycle τ_c is increased.

The duty-cycle τ_c is controlling the allocation of the unlicensed spectrum among Wi-Fi and LTE-U. It can be seen that the more allocation of τ_c to a network reduces the performance of the other network and vice versa.

The overall sum-rate of the coexisting networks can be found as follows:

$$R = \sum_{c \in \mathcal{C}} \sum_{u \in \mathcal{U}} B(1 - \tau_c) \log(1 + \gamma_{uJ}) + \sum_{c \in \mathcal{C}} \sum_{w \in \mathcal{WU}} \tau_c R_w \tag{5}$$

V. Numerical Results

This section presents the simulation results. For that purpose, the simulation environment of LTE-U and Wi-Fi coexistence is built using Python language. We considered 1 SBS and 3 WAPs where the SBS has 10 associated cellular users, and each WAP has 5 associated WSTs. We have considered 3 orthogonal channels from the unlicensed band. Full duty-cycle duration is 100 ms. A full buffer traffic model is considered where all nodes in the network have packets in the queue to transmit.

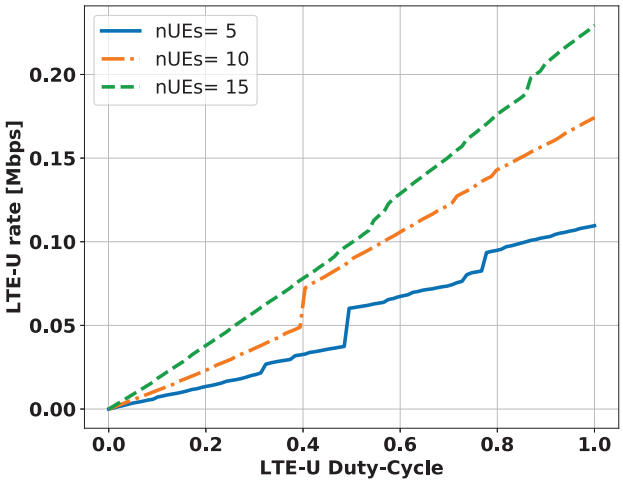

Fig. 2. Plot of LTE-U rate vs. the LTE-U duty-cycle

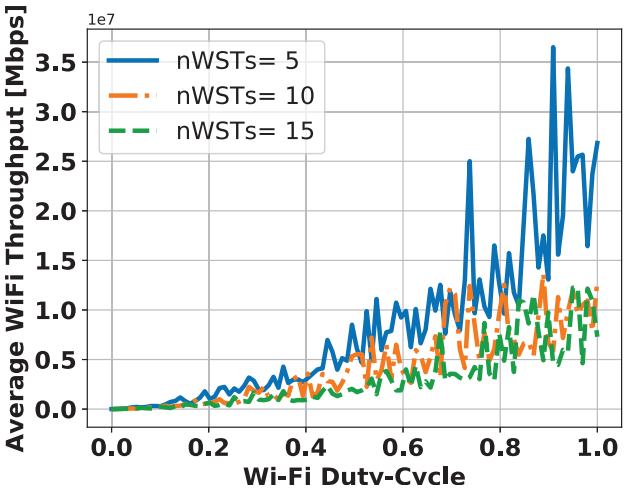

Fig. 3. Plot of WiFi throughput vs. the Wi-Fi duty-cycle

Fig. 2 shows the plot of LTE-U rate against the duty-cycle proportion. It can be seen that the sum-rate of LTE-U is increased with an increase in the duty-cycle of LTE-U. This is due to the fact that LTE-U is given more chance to access the channel by increasing the LTE-U duty-cycle. Moreover, it can be seen that the increase in the number of cellular users, increase the sum-rate of LTE-U. This is due to the fact that LTE-U is spectrally more efficient and the available unlicensed spectrum is enough to satisfy the cellular user's demand.

Fig. 3 shows the plot of Wi-Fi throughput against Wi-Fi duty-cycle. The similar kind of trend can be seen for the Wi-Fi throughput where the overall network throughput is increased by increasing the proportion of Wi-Fi duty-cycle. Further, we can observe that the increased number of WSTs decrease the performance of the Wi-Fi system due to the increased number of collisions. This trend is opposite to the LTE-U. This proves the claim that LTE-U is spectrally more efficient as compared to the Wi-Fi network.

VI. Conclusion

LTE-U is proposed to address the problem of spectrum scarcity in 5G cellular networks. For that purpose, LTE-U is enabled by augmenting the available licensed spectrum with the unlicensed spectrum. This paper demonstrates the analysis for the performance of both Wi-Fi and LTE-U by varying the duty-cycle duration for both networks. Simulation environment is built where Wi-Fi and LTE-U are coexisting together to share the same unlicensed band.

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