

QoE Based Coexistence Mechanism for LTE in Unlicensed Bands

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Abstract

Recently, LTE in unlicensed bands (LTE-U) has become more interested topic because it can support LTE mobile users to work in unlicensed band. In this band, unlicensed band, LTE-U works with different wireless technologies (i.e WiFi, Bluetooth, ZigBee, ...). This coexistence causes several issues due to the different channel access mechanisms between LTE technology and that technologies. Thus, we propose a coexistence mechanism based on Quality of Experience (QoE) instead of the traditional QoS metric. QoE measures the reaction of the user and his experience to a certain application. Simulation results show that the proposed technique enables both WiFi and LTE-U users to operate efficiently and fairly.

1. Introduction

WHILE the Long Term Evolution (LTE) provides lower latency and high data rates to mobile communication system, it still cannot be able to handle the high increasing in mobile data usage because the licensed bands are limited and scare. To overcome the spectrum scarcity problem, LTE in unlicensed spectrum (LTE-U) is proposed. Small Cells (SCs) are suitable to operate in unlicensed bands because the limitations in maximum power in unlicensed bands.

The main challenge in in LTE-U is the operating with different technologies that have different channel access mechanisms. Due to the differences in MAC protocol, it is difficult for LTE-U to operate in unlicensed bands with WiFi without coexistence mechanism.

In literature, there are several coexistence mechanisms proposed [1]. The authors in [2] propose a coexistence mechanism based on machine learning that allows LTE base station to select their optimum resources given some information related to the user's and network's states. Authors in [3] propose a coexistence mechanism based on ON/OFF duty cycle. ON/OFF duty cycle mechanism allows LTE-U to transmit during the ON periods only and keeps it silent during the OFF periods. Therefore, WiFi can get an opportunity to transmit during the OFF periods.

In this paper, a coexistence mechanism for LTE-U in unlicensed bands, based on Quality of Experience (QoE) of a particular user, is presented. QoE measures the reaction of the user and his experience to a certain application (i.e. Web Browsing, File Download, Video Streaming, ...). The main contribution of this paper is to set the length of ON/OFF periods, in the duty cycle mechanism, according to the Mean Opinion Score (MOS) which is a metric to measure the user's satisfaction for a certain application.

The remaining part of this paper is organized as follows:

Section II presents the data rate calculation of LTE and WiFi networks and introduces an overview on the QoE. System model and the formulation of the optimization problem are presented in section II. Section IV presents the simulation results. Finally, conclusion and the future work are presented in section V.

2. Preliminaries

2.1 LTE Data Rate Calculation

Let R_{ij} be the data rate of user i connected with small base station j . Thus, the total data rate of LTE-U [4]:

$$R_{lte} = B \log_2 \left(1 + \frac{P_j h_{ij}}{\sigma^2} \right) \quad (1)$$

where B is the unlicensed bandwidth, P_j is the transmit power of small base station j , h_{ij} is the channel gain, and σ^2 denotes the Gaussian power noise.

2.2 WiFi Data Rate Calculation

We assume that there is a WiFi network in the saturation state. Thus, the saturation throughput of N WiFi users using the same band is given by [5]:

$$R_{wifi} = \frac{P_{tr} P_s E[S]}{(1 - P_{tr}) T_\sigma + P_{tr} P_s T_s + P_{tr} (1 - P_s) T_c} \quad (2)$$

where P_{tr} denotes the probability that in a time slot there is at least one transmission and can be expressed as $P_{tr} = 1 - (1 - \tau)^N$, where τ denotes the transmission probability of each user. P_s denotes the probability of successful transmission and we can write it as $P_s = N\tau(1 - \tau)^{N-1}$. The probability that there is no user use the channel, all users in the detection stage of backoff stage, is given by $(1 - \tau)^N$. T_s denotes the time that the channel is busy due to the successful transmissions, T_c denotes the time that the channel

is busy due to a collision, T_σ denotes the duration of empty slot, and $E[S]$ is the average size of the packet.

In this model, the WiFi uses the Distributed Coordination Function (DCF) mechanism and RTS/CTS access mechanism. Therefore, T_c and T_s can be written as [5]:

$$T_s = RTS/C + CTS/C + (H + E[P])/C + ACK/C + 3SIFS + DIFS + 4\delta \quad (3)$$

$$T_c = RTS/C + DIFS + \delta \quad (4)$$

where H is the packet header, δ denotes the propagation delay, C denotes the channel bit rate, ACK denotes the time of the acknowledgment, $DIFS$ denotes the distributed inter-frame space, RTS and CTS are the request and clear to send respectively.

2.3 Quality of Experience (QoE)

In this paper, the QoE metric is used to measure the user's satisfaction level for the application. The MOS is a metric to capture the user's satisfaction [6]. Let's consider the users consuming a certain service and there are a number of QoS parameters for each service denoted by x . Thus, there exists a mapping function (Q) from QoS parameters to QoE value MOS:

$$Q : x \rightarrow MOS = Q(x) \in [L, H] \quad (5)$$

where x_i is the QoS parameter of user i and MOS_i is the corresponding QoE value. H and L denote the upper and lower bounds respectively (i.e $H = 5$ and $L = 1$).

In this paper, all users are considered to use the web browsing service. In web browsing, users give high importance to the loading speed of the page. In [6], authors present a function that fits the MOS of their web browsing experimental results.

$$MOS = 5 - \frac{578}{1 + (11.77 + 22.61/d)^2} \quad (6)$$

where FS denotes the web page size, R is the user data rate, RTT is the time consumed during the traveling of an IP packet from the server to the user and back, and d denotes the service response time given by:

$$d \simeq 3RTT + \frac{FS}{R} \quad (7)$$

3. System Model

We consider the scenario that there is one LTE-U small base station and one WiFi Access point (AP) working in the same unlicensed band as shown in Fig. 1. We consider that there are M LTE-U UEs and N WiFi users distributed in the coverage area of LTE-U small base station and WiFi AP. All WiFi users and LTE-U UEs are connected to WiFi AP and LTE-U small base station respectively.

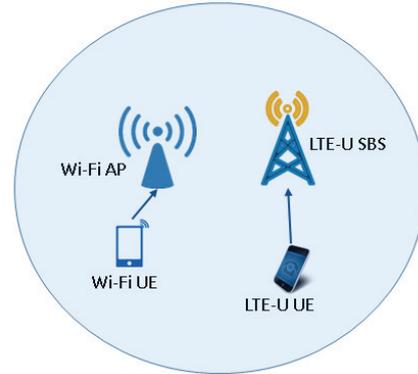


Figure 1: System Model

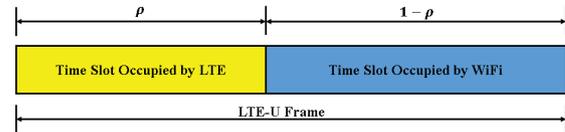


Figure 2: Time Slot Distribution between LTE and WiFi

In this paper, the duty cycle mechanism is considered. In this mechanism, the LTE-U On/OFF periods is set based on the number of WiFi and LTE-U users. During the ON periods, LTE-U small base station transmits packets to LTE-U users and WiFi broadcasts CTS with Network Allocation Vector (NAV). Based on the NAV, the WiFi estimates the length of ON period. Therefore, WiFi transmits only during the OFF periods and keeps silent during the ON periods Fig. 2.

Based on this system model, the LTE-U and WiFi data rate equations are modified and given by:

$$R_{lte} = \rho B \log_2 \left(1 + \frac{P_j h_{ij}}{\sigma^2} \right) \quad (8)$$

$$R(N) = (1 - \rho) \frac{P_{tr} P_s E[S]}{(1 - P_{tr}) T_\sigma + P_{tr} P_s T_s + P_{tr} (1 - P_s) T_c} \quad (9)$$

where ρ is the fraction of time allocated to LTE small base station and $(1 - \rho)$ is the fraction of time allocated to WiFi AP.

We need to maximize the sum of MOS of all LTE-U and WiFi users and keep the performance of WiFi users at accepted level. Thus, we formulate an optimization problem to maximize the sum of MOS of all LTE users while guaranteeing fair spectrum access for WiFi as follows:

$$\begin{aligned} \max & \left(\sum_{i=1}^M MOS_{lte} + \sum_{i=1}^N MOS_{wifi} \right) \\ \text{s.t.} & 0 \leq \rho \leq 1 \\ & MOS_{wifi} \geq thres \end{aligned} \quad (10)$$

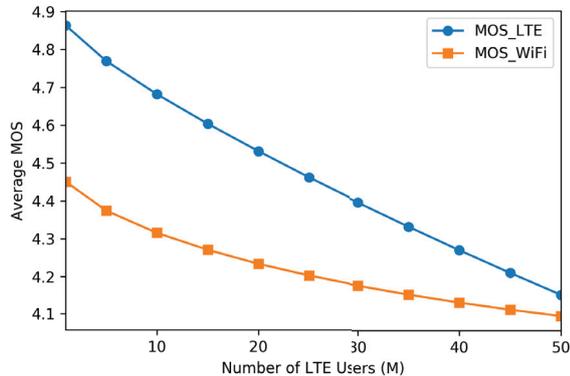


Figure 3: Comparison of MOS with varying number of LTE-U users (M), N=5

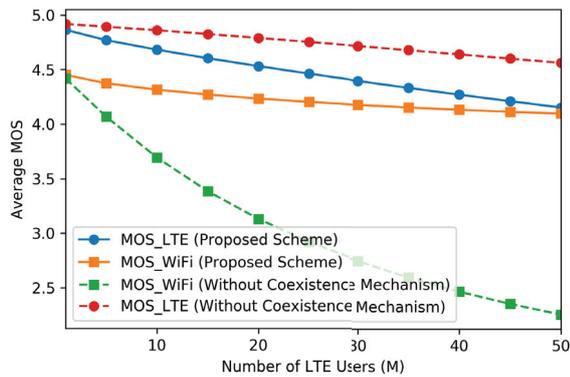


Figure 4: Average MOS in case of there is no coexistence mechanism and in case of the proposed mechanism

where the second constraint is to maintain the performance of WiFi users at accepted level.

4. Performance Evaluation

We evaluate the proposed scheme using python. The WiFi and LTE-U parameters, that we use it in the simulation, follow the 802.11a6 [7] and FCC requirements [8]. RTT , FS , and $Thres$ are set to 100 ms, 1000 KB, 2.5 respectively.

Fig. 3 shows the average MOS of LTE-U and WiFi users with number of LTE-U users. As shown in this figure, the average of MOS of LTE-U users and WiFi users converge from each other and approximately have the same MOS. This means that the resources are fairly distributed between LTE-U users and WiFi users.

Fig. 4 shows the MOS in case of the proposed scheme and in case of there is no coexistence mechanism between LTE-U and WiFi networks. As shown in Fig. 4, if there is no coexistence mechanism, the LTE-U network causes a negative impact on WiFi network and the LTE-U users have high

MOS value and WiFi users have lower MOS value. This is due to the differences between channel access procedures used by each network. In the contrary, the resources in the proposed mechanism case are allocated fairly between the LTE-U and WiFi networks and all users, both LTE-U and WiFi users, have approximately the same value of MOS.

5. Conclusions

In this paper, the unlicensed band is allocated to LTE-U and WiFi networks based on the QoE which gives the user experience and reaction to a certain application. Simulation results show that the proposed scheme gives a fair resource allocation between the LTE-U and WiFi networks. As a future work, users with different applications (i.e video, voip, file download, ..) will be considered.

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