Deploying LTE in Unlicensed Spectrum Considering Quality of Experience (QoE)

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Abstract

The exponential growth of mobile traffic is an opportunity on one side and bottleneck in another side. LTE in unlicensed spectrum can be a good choice for the mobile operators to grab this opportunity owing limited licensed spectrum. This cause co-existence issue and resource allocation issue to the LTE system. Moreover, most of the authors consider QoS requirements of the users for allocating resources, which cannot guarantee user's satisfaction. Thus, we propose a co-existence mechanism between LTE-U and Wi-Fi system considering the quality of experience (QoE) of the users. For solving two issues, we use Nash bargaining and bankruptcy game respectively. Simulation results show the effectiveness of the proposed method over other methods.

1. Introduction

With the increasing explosion of cellular traffic, many researchers are suggesting to utilize free unlicensed spectrum with LTE networks to serve and meet the growing demands of users. 3GPP already announced Licensed-Assisted Access (LAA) of unlicensed spectrum in LTE for the downlink in part of their release 13 [1] with the help of carrier aggregation (CA). Though this approach can possibly solve the spectrum scarcity issue of cellular networks, it will create a humongous trouble for the existence of already deployed technologies in the unlicensed spectrum like Wi-Fi. Thus, LTE in unlicensed (LTE-U) will create two issues: co-existence and resource allocation.

For solving the co-existence issue of LTE-U deployment, different authors mainly focused on either listen-before-talk (LBT) approach or resource sharing approach. An LBT based approach of co-existence between LTE-U and Wi-Fi systems is proposed in the paper [2]. They use adaptive back-off window size for their work, but the performance of LBT based approach is not comparable with LTE system. Thus resource sharing approaches ([3], [4], [5]) are becoming predominant in this co-existence issue. The authors in [3] use bargaining game between LTE-U SBSs and Wi-Fi system for finding the appropriate portion of sharing time. In the paper [4], the authors find a fraction of time slot based upon the minimum requirements of the Wi-Fi user. They have not considered LTE-U system in that co-existence mechanism. A ruin theory based co-existence model is proposed in the work [5]. It has no clear direction on how time resource will be shared between the two systems.

For allocating unlicensed resources, most of the works consider quality-of-service (QoS) requirements of the users. But, QoS takes care of network operator's perspective, not the users' perceived quality of experience (QoE) and a system which is QoS fair, can be QoE unfair [6]. As per our knowledge, there is no work that deals with deploying LTE-U considering QoE of users. Thus, in this paper, we propose a QoE-enabled co-existence mechanism for deploying LTE network in unlicensed spectra.

2. System Model and Problem Formulation

We have one small cell base station (SBS) and a set of non-overlapping Wi-Fi access points (WAP) working in downlink scenario as shown in Fig. 1. SBS has a set of users U_s under its coverage area and each WAP has a set of connected users U_w. SBS has a set of licensed subchannels $\mathcal{L}$={1,2,⋯,L} for supporting its user. Both SBS and WAPs use same unlicensed spectrum in 5GHz band. Each SBS can support a set of services *S*={1,2,⋯.,S} by using a set of modulation and coding scheme (MCS) *M*={1,2,⋯,M}.

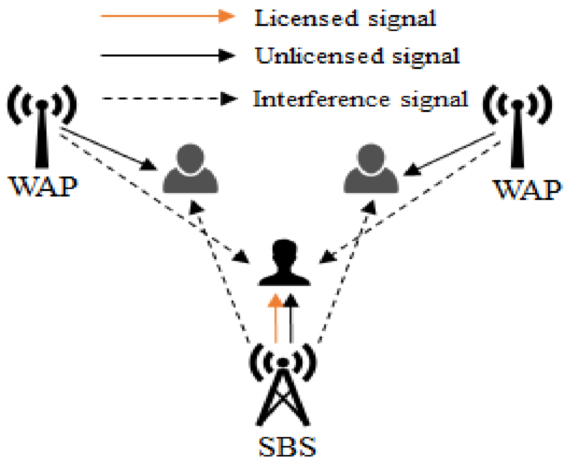

Figure 1: Illustration of system model

A. Application Model

QoE is application specific and we use mean opinion score (MOS) as the QoE metric to measure user's satisfaction. In the following section, we are going to represent the mapping between the transmission characteristics and MOS of different applications.

Web browsing [7]: $\eta_b = 5 - \frac{578}{1 + (11.77 + \frac{22.61}{d})^2}$ (1)

File downloading [8]: $\eta_d = a\log_{10}[br(1-p_e)]$ (2)

Video Streaming [9]: $\eta_s = \frac{a_1 + a_2 f_r + a_3 \log_2 r}{1 + a_4 p_e + a_5 p_e^2}$ (3)

where d, r, p_e, f_r are the service response time, sender bit rate, packet error probability, frame rate respectively and a, b, a_1~a_5 are the coefficients.

B. Network Model

LTE uses orthogonal frequency division multiple access (OFDMA) technique to allocate physical resources to its users. It also employs same MCS over multiple resource units in a time for a user. Thus, SBS will provide at least one resource block (RB) to all of its current users. It will provide unlicensed resources to those users who are unsatisfied with current QoE. For managing unlicensed resource, let us assume that SBS divides it a set of sub-carriers *K*={1,2,⋯,K}. Then, SBS can offer the following rate for a user $j \in U_s$.

$$r_j = \sum_{l\in L}\alpha_j^l \sum_{m\in M}\gamma_j^m r_m + \sum_{k\in K}\beta_j^k \sum_{m\in M}\gamma_j^m r_m^u \quad (4)$$

Where $r_m = \frac{n_{sc} r_c^m \log_2 C_m}{t_s}$ and $r_m^u = \frac{r_m}{n_{sc}}$ with n_{sc}, r_c^m, C_m and t_s representing number of sub-carriers in a RB, code rate of MCS m, constellation size of MCS m and OFDM symbol duration respectively.

C. Problem Formulation

We assume that one user can use one application at a time and every user owns one licensed sub-channel. For co-existing with WAP, SBS needs to share $\xi \in [0,1]$ time in unlicensed spectrum. Rest of the time SBS can utilize for its unsatisfied users. Now, our goal is to maximize the sum of MOS and the problem statement is shown as follows:

$$\text{Max} \sum_{j\in U}\sum_{s\in S}\lambda_j^s \eta_s^j \quad (5)$$

s.t. $C1: \alpha_j^l, \beta_j^k, \gamma_j^m, \lambda_j^s \in \{0,1\}, \forall j,l,k,m,s$

$C2: \sum_{j=1}^{U}\alpha_j^l \le 1, \sum_{j=1}^{U}\beta_j^k \le 1, \forall l,k$

$C3: \sum_{l=1}^{L}\alpha_j^l = 1, \sum_{k=1}^{K}\beta_j^k \ge 1, \forall j$

$C4: \sum_{j=1}^{U}\sum_{k=1}^{K}\beta_j^k \le K$

$C5: \sum_{m=1}^{M}\gamma_j^m = 1, \sum_{s=1}^{S}\lambda_j^s = 1, \forall j$

$C6: \xi_0 \le \xi \le 1$

Here, constraint C1~C5 is for LTE-U system and C6 is for the co-existence with Wi-Fi system and ζ_0 is the minimum amount of time that is necessary for ensuring minimum rate to Wi-Fi users when SBS acts just like another WAP which affects the performance of all the Wi-Fi users. This is a mixed integer non-linear programming (MINLP) problem and NP-hard to solve.

3. Solution of the Problem

For solving the problem (5), we have to consider two issues namely co-existence issue and resource allocation issue. For solving first issue, we can use Nash Bargaining Game (NBG) [10] that gives one unique and fair solution between contending parties SBS and WAP. Using the solution concept of NBG, we can show that,

$$\xi^* = \frac{1}{2} + \frac{\sigma}{2} \quad (6)$$

Where σ is the ratio of average achieved rate of a Wi-Fi user without and with the presence of SBS in the unlicensed spectrum (like WAP). Thus, SBS can utilize $1-\xi^*$ period for LTE-U users in the same unlicensed spectrum without affecting Wi-Fi users. For solving the second issue, we use bankruptcy game (BG) [11] framework. BG consists of a set of agents (A), amount of money (P) and a claim vector (**c**). If **x*** is a solution of this game then it must have to satisfy the following conditions:

$$c_j \geq x_j \geq 0,\ \sum_{j \in A} x_j = P,\ \sum_{j \in A} c_j \geq P$$

In our scenario, we have a set of unsatisfied users, amount unlicensed sub-carriers with time $1-\xi^*$ and requirements of unlicensed sub-carrier for achieving highest MOS.

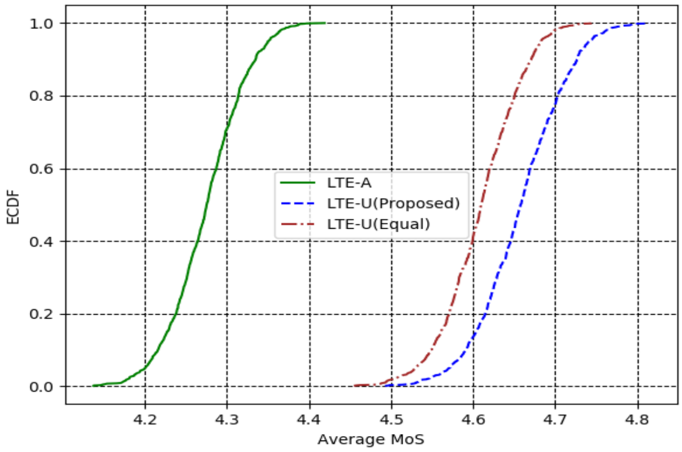

Figure 2 Comparison of average MOS

4. Performance Evaluation

We assess the performance of the proposed method by comparing with LTE-A and LTE-U with equally distributed unlicensed resource (LTE-U(Equal)) by using simulation. SBS has 50 users with 50-licensed RB for browsing, file downloading and video streaming and distributed randomly in the conflicting area of radius 150m. Both networks use 20MHz unlicensed band in 5GHz band. We use 15.3+37.5log10(d) as the path loss model for both licensed and unlicensed spectrum. In the figures, we presented the results of 1000 runs of the program. Figure 2 shows the comparison of average MOS of LTE-U user. It shows that the average MOS of the proposed method is better than that of LTE-A and LTE-U(Equal). Specifically, the proposed method achieves MOS of more than 4.6 in more than 80% of cases where LTE-U (Equal) archives the same in 60% of cases. Moreover, LTE-A achieves less than 4.3 MOS score in 70% of cases. Figure 3 depicts the fairness among the users in different methods and it shows that the Jain's index of the proposed method is better than that of LTE-A and LTE-U(Equal) in most of the cases.

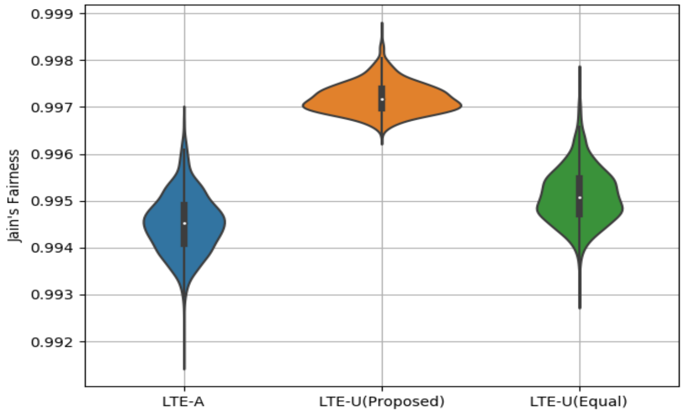

Figure 3 Comparison of Fairness

5. Conclusion

In this paper, we propose a QoE oriented LTE-U mechanism that can co-exist with Wi-Fi system fairly. For solving the problem, we have used NBG and bankruptcy game. The proposed approach gives good MOS and fairness among users than LTE-A and LTE-U(Equal).

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