A Fair Co-existence Mechanism for LTE-U and Wi-Fi Network

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Abstract

The exponential growth of mobile data traffic is affecting negatively in cellular industry. The situation is becoming unbearable with existing restricted licensed spectrum. On the other hand, the bandwidth of the unlicensed spectrum is not yet saturated. Therefore, we want to use unlicensed spectrum to satisfy licensed users after protecting systems that are already using them. In this paper, we propose a fair co-existence mechanism between LTE-U system and Wi-Fi system. For providing fairness between two systems, we use Nash Bargaining Game concept in this paper. Effectiveness of the proposed method is represented through simulation results.

1. Introduction

Cellular network is experiencing huge pressure due to mobile data growth in the recent past. In the last ten years, mobile data traffic has emerged 4000X and it seems to be reached nearly 8-folds between 2015 and 2020 [1]. To reduce the burden from cellular network, different emerging technologies like long-term evolution (LTE), LTE-Advanced has evolved. However, cellular network operators (CNOs) are suffering from capacity improvement due to the bottleneck of licensed spectrum resources. That is why, mobile data offloading is becoming exoteric and more than 50% of mobile traffic was offloaded to the Wi-Fi in 2015 [1]. This initiative dispels some burden from cellular network but it faces major challenges due to the outcome of Wi-Fi technology. Besides, it can create revenue loss for diverting traffic from cellular network.

To cope with the current challenge, researchers are interested to extend LTE in the unlicensed spectrum known as LTE-U. It has been seen as a promising supplementary solution in the upcoming days because of the availability of huge unlicensed spectrum. 3GPP has already introduced Licensed Assisted Access (LAA) in case of downlink by engaging carrier aggregation of licensed and unlicensed spectrum in part of their release 13 [2]. Currently, many major telecommunication companies like Huawei, Qualcomm, Nokia etc. are deeply involved in LTE-U research.

Although LTE-U system delivers some exhilarating benefits over Wi-Fi network, it will initiate new complexities for already established Wi-Fi system. If LTE-U uses same unlicensed spectrum with Wi-Fi system, then Wi-Fi system can starve due to different access mechanism of spectrum. In the study [3], the authors performed comprehensive simulation in office environment to evaluate the performance of LTE-U and Wi-Fi and found that it affects the performance of Wi-Fi very severely. Currently, LTE-U can operate in supplemental downlink, time division LTE with CA and standalone LTE-U mode [4]. There are some potential co-existence proposals between LTE-U and Wi-Fi. Qualcomm has proposed Dynamic Channel Selection (DCS), Carrier-Sensing Adaptive Transmission (CSAT) and Opportunistic SDL for fair co-existence between LTE-U and Wi-Fi [5]. A time domain resource splitting approach based on almost blank subframe (ABS) for sharing unlicensed resource between LTE and Wi-Fi system was proposed in [6]. The authors of [7] proposed a Listen Before Talk (LBT) based mechanism with DCF protocol and adaptive backoff window size for fair co-existence.

In this paper, we propose a fair co-existence mechanism between LTE-U and Wi-Fi system based on bargaining game.

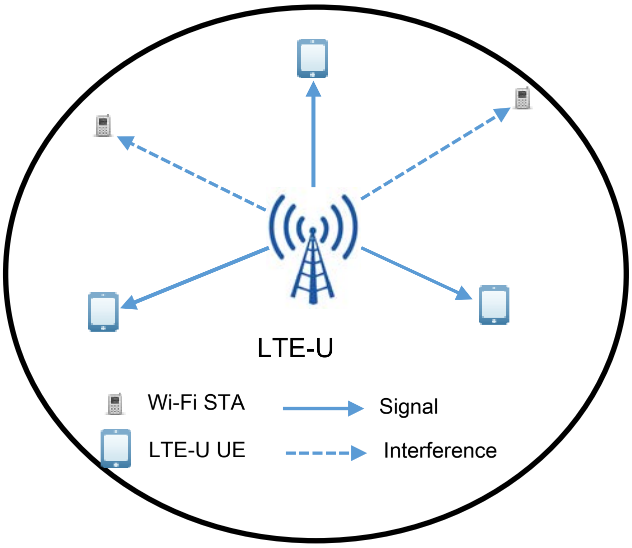

Figure 1 System Model

2. System Model and Problem Formulation

We consider the deployment scenario as shown in Fig. 1, where W Wi-Fi STAs, an LTE-U SBS and its U associate LTE-U user equipment (UE) operating in a channel of the 5GHz unlicensed band. LTE-U network will divide the channel bandwidth into N sub-carriers of width B, for supporting orthogonal frequency-division multiple access (OFDMA)-based downlink transmission. All Wi-Fi STAs work based on the IEEE 802.11n protocol with RTS/CTS mechanism.

As LTE-U system degrades the performance of Wi-Fi system in the same unlicensed band severely, it will share the time with Wi-Fi system for fair co-existence. We assume LTE-U SBS will share $\tau \in \{0,1\}$ with Wi-Fi system. As SBS employs OFDMA technique to allocate unlicensed resources among its users, there is no intra-user interference. When SBS allocates unlicensed subcarrier(s) to user j, the instantaneous throughput of the user:

$$R_j = B\sum_{k=1}^{N} x_{j,k} \log_2\left(1+\frac{P_k\,|\,h_{j,k}\,|^2}{N_0 B}\right) \tag{1}$$

Here, $x_{j,k}$ is the subcarrier allocation result, and $x_{j,k}=1$ when subcarrier k is allocated to the user j, $x_{j,k}=0$ otherwise. P_k is power allocated to subcarrier k, $h_{j,k}$ is the channel gain between LTE-U SBS and UE j on channel k and N_0 is the noise spectral density. So, the throughput of UE j is given as follows:

$$S_j = (1-\tau)R_j \tag{2}$$

In the Wi-Fi network, only one Wi-Fi STA will transmit at any instant of time over the whole channel. We assume that all STAs have equal time occupation on average. So average throughput of each Wi-Fi STA w can be denoted as follows:

$$S_w = \frac{\tau}{W} R_{wap} \tag{3}$$

where R_{wap} is the overall downlink saturation throughput of the WAP.

Now the optimization framework is formulated to maximize the throughput of LTE-U UEs and Wi-Fi STAs and shows as follows:

$$\max U(\tau, x_{j,k}) = \sum_{j=1}^{U}\log\left(S_j\right) + \sum_{w=1}^{W}\log\left(S_w\right) \tag{4}$$

s.t. $C1: x_{j,k} \in \{0,1\}, \forall j, \forall k$

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

$$C3: \sum_{j=1}^{U}\sum_{k=1}^{N} x_{j,k} \le N$$

$$C4: \tau_0 \le \tau \le 1$$

3. Solution of the Problem

This optimization problem (4) is difficult to solve in real time. Via some mathematical derivations, we can decouple the problem (4) into two sub-problems.

$$U(\tau, x_{j,k}) = U_1(\tau) + U_2(x_{j,k}) + U_0 \tag{5}$$

Where,

$$U_1(\tau) = M\log(1-\tau) + W\log\tau \text{ ,s.t. C4} \tag{6}$$

$$U_2(x_{j,k}) = \sum_{j=1}^{M}\log R_j \text{ , s.t. C1, C2, C3} \tag{7}$$

$$U_0 = W\left(\log R_{wap} - \log W\right) \tag{8}$$

Solution of sub-problem (6) can give us fairness among LTE-U and Wi-Fi system and we know Nash Bargaining Game can give fairness among different contending parties. NBS can give us a unique solution concept [8] that follows:

$$\tau^* = \max \sum_{i \in P} \log U_i \text{ , s.t. C4} \qquad (9)$$

Theorem 1: Optimal sharing time between LTE-U and Wi-Fi system is $\tau^* = \max(\frac{W}{M+W}, \tau_0)$.

It can be proved by comparing (6) and (9) and taking first derivative of (6) w.r.t. τ and put it equal to zero. Subproblem (7) represents the resource allocation problem in LTE-U system. It can be solved by using matching theory or heuristic method. Here, we use heuristic algorithm for allocating resources. Final term of (5) is a constant and the value is represented in (8).

4. Performance Evaluation

We assess the performance of the proposed method by using MATLAB simulation. There are 5/10 Wi-Fi STAs and varying number of LTE-U users under a serving SBS and distributed randomly in the conflicting area of radius 150m. Both networks use 20MHz unlicensed band in 5GHz band. We use free space path loss model for unlicensed spectrum to find the channel gain. For our simulation, we use typical QoS requirements of multimedia applications as in [9]. Figure 2 shows the average achieved rate of LTE-U UE with varying number of UEs and 5 Wi-Fi STAs. The figure represents that average QoS of the UEs are satisfied in almost all the cases in the proposed LTE-U method while preserving Wi-Fi STAs fairly. Figure 3 depicts the normalized throughput of each Wi-Fi STA with varying number of LTE-U users. It shows that the proposed method can protect far better way than basic LBT method in both the cases where there are 5 and 10 Wi-Fi STAs are in the conflicting region respectively.

5. Conclusion

In this paper, we propose a LTE-U mechanism that can meet the QoS requirement of good number of it UEs while fairly protecting Wi-Fi STAs. For fair allocation of time resource in unlicensed spectrum between two different networks, we use Nash Bargaining Game. Simulation result shows good performance of the proposed method while protecting Wi-Fi STAs in a better way than basic LBT does.

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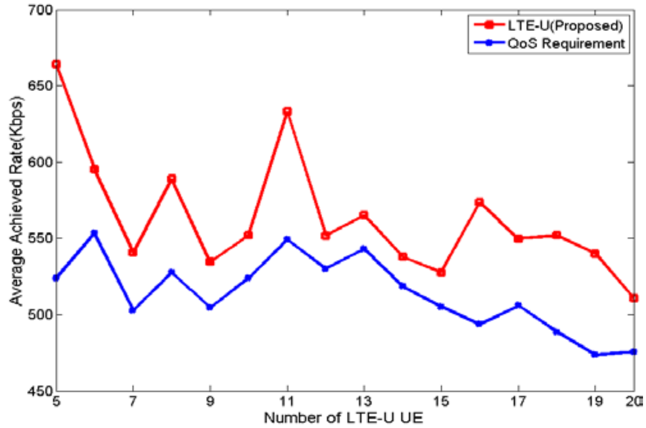

Figure 2 Achieved rate vs QoS requirement

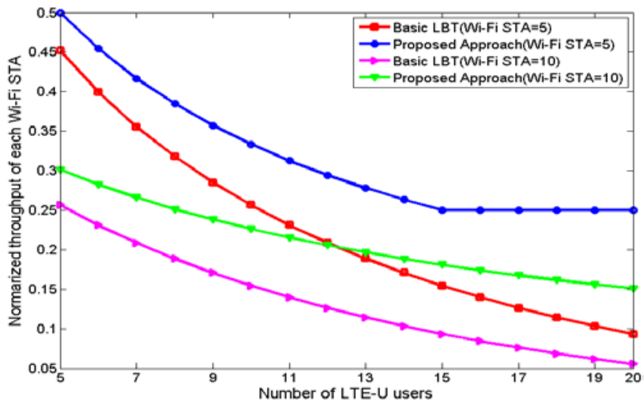

Figure 3 Throughput of Wi-Fi STA

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