D2D with LTE-U under unlicensed spectrum considering coexistence issue with WAP

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Abstract

Mobile traffic is increasing exponentially during last decade which is causing intolerable pressure to the current mobile cellular industry. The first straight forward solution of this problem is to engage more licensed spectrum with the current structure. But this resource is scare and not easily available in the recent days. So, in this paper we try to utilize unlicensed spectrum under same LTE-A network after maintaining some guaranteed rate for WAP who are also working in the same unlicensed band. We also use this spectrum for D2D communication after mitigating QoS requirement of the users. For this, we use Kalai-Smorodinsky bargaining concept to find a solution. Simulation result shows the effectiveness and efficiency of the proposed approach.

1. Introduction

Current cellular network infrastructure is facing terrific challenges with extra ordinary data demand from the users due to the introduction of many rich content applications specially with smart devices. Mobile data traffic has shown tremendous growth in the past decade and study [1] finds that it will reach upto 1000X in the next five years. Another study [2] forecasts that online video will be the origin of 60% mobile traffic in the year 2020. So, to tackle with this traffic “hurricane” in mobile network, both academia and wireless communication industry are exploring different techniques like LTE/LTE-A, Massive MIMO, D2D communication in the licensed spectrum.

But this moves are not appropriate to deal with such traffic “cyclone” in cellular communication network with the limited licensed spectrum. So, several cellular network operators (CNOs) in many countries are engaging wireless access points (WAPs) to offload part of their load to take advantage of unlicensed spectrum. But this action is not so fruitful due to contemptible performance of WiFi technology and cost involvement with the process. This incapability can be brought down by taking LTE-A into unlicensed spectrum, LTE-U. LTE forum has allowed (part of the LTE Release 13) LTE-U to accumulate licensed and unlicensed spectrum under a unified LTE network infrastructure [3].

In spite of providing exciting benefits by LTE-U, it will introduce new complexities for WAPs who are already working in the same unlicensed spectrum. Presently, there are three proposed mode of operating of LTE-U: supplemental downlink, time division LTE with CA and standalone LTE-U [4]. There are some proposals for sharing unlicensed spectrum among LTE networks and WiFi system [5], [6]. On the other side, a D2D link is established between UEs using licensed cellular spectrum without direct involvement of cellular base station and can play a vital role in cooperative communication. It generally uses unutilized and under-utilized licensed spectrum to transmitting data from one another. D2D communication increases the spectral utilization consuming less power [7]. To know more about D2D communication, we can follow the research paper [8].

In this paper, we propose a mechanism to maximize the achieved rate of LTE-U and D2D when they are working in the same unlicensed spectrum with WiFi network. Here we consider the coexistence issue with WAP and maintain QoS of the LTE-U users. We solve the problem with the help of Kalai-Smorodinsky bargaining solution concept.

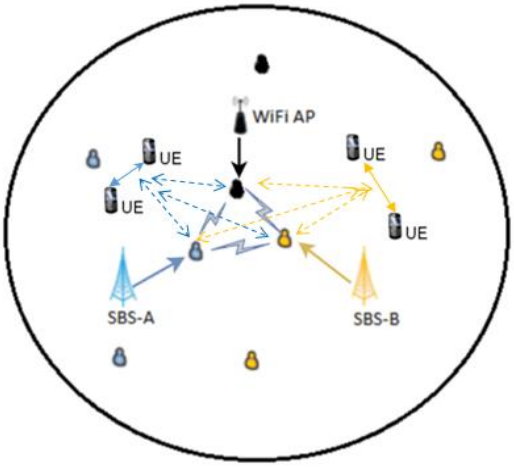

Figure 1 System Model

2. System Model and Problem Formulation

CNOs are deploying more and more SBSs to offer growing services to its users as it is the efficient solution to do so till today. This dense deployment of SBSs from different CNOs are constrained to conflict with each other and with local WAPs if they operate in the same unlicensed spectrum. In our model, we have N dual-mode LTE-A SBSs run by N different CNOs. There is one WAP with M users. SBS i can serve U^i licensed users and D^i D2D pairs by employing its licensed spectrum B_l^i and unlicensed spectrum B_u. WAP also operates in the same unlicensed spectrum and all SBSs work in SDL mode.

As SBS employs OFDMA technique to apportion licensed resources among its users, there is no intra-operator interference. When a user j of SBS i uses licensed spectrum, the achieved rate using Shannon's capacity law is as follows:

$$R_{j,l}^i = b_{j,l}^i \log_2(1+\frac{b_{j,l}^i P^i h_{ij}}{\sigma^2}) \quad (1)$$

Now if $R_{j,l}^i \geq QoS_j^i$ then it needs not use the unlicensed spectrum. Otherwise it needs to use unlicensed spectrum to fulfill the QoS requirement of user j. In that case it's achieved rate by the above process:

$$R_{j,u}^i = b_{j,u}^i \log_2(1+\frac{b_{j,u}^i P^i h_{ij}}{I_{CNO}+I_D+I_{WAP}+\sigma^2}) \quad (2)$$

But study [9] shows LTE-U is affected negligibly by the presence of WiFi and to take the advantage of the unlicensed band, SBSs can form a coalition and allocate the resources in orthogonal fashion among themselves and then split them among its users and D2D pairs. In that case there will be no I_{CNO}, I_D, I_{WAP} and the achieved that user j can get by using both licensed and unlicensed spectrum:

$$R_j^i = b_{j,l}^i \log_2(1+\frac{b_{j,l}^i P^i h_{ij}}{\sigma^2}) + b_{j,u}^i \log_2(1+\frac{b_{j,u}^i P^i h_{ij}}{\sigma^2}) \quad (3)$$

SBSs will allocate unlicensed orthogonal resources to the D2D pairs after maintaining QoS of its users. So the achieved rate of a D2D pair:

$$R_d^i = b_{d,u}^i \log_2(1+\frac{b_{d,u}^i P^d h_d^i}{\sigma^2}) \quad (4)$$

As WiFi downlink is contention free, then average throughput for each user could be written as:

$$R_m = \frac{R_{WAP}}{M} \quad (5)$$

Where R_{WAP} is the overall downlink saturation throughput of WAP. R_m is achievable when WiFi network only access the unlicensed channel. But when WAP and SBSs use the same unlicensed spectrum in the same conflicting area, then WAP will get insignificant data rate. So they need to share the time slot between WAP and SBSs to coexist fairly in the conflicting area.

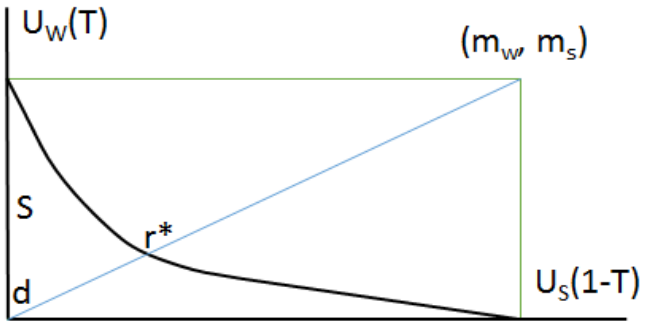

Figure 2 Kalai-Smorodinsky solution of two players

3. Solution of the Problem with Kalai-Smorodinsky

Bargaining game is a typical cooperative game that can distribute resources fairly. Being a newcomer, SBSs have to protect the minimum requirement of the WAP if it wants to take benefit from unlicensed spectrum. The interaction here can be seen as a two player bargaining game as shown in the figure 2. Let S be a set of feasible payoff allocations that the players can achieve if they cooperate using their utility function and d is the set of disagreement

point. Then the ordered pair (S, d) is called a bargain game [10]. Now we want to find the bargaining solution from S by means of Kalai-Smorodinsky bargaining solution (KSBS).

Theorem 1: There exists a unique solution concept F(S,d) over the family F_0 satisfying symmetry, efficiency, independence of the units of measurement and limited monotonicity. That solution r^* is the highest point located in S and on the line connecting d and (m_w,m_s) [10].

It can be seen from figure 2. This r^* gives us the distribution of time slot between WAP and SBSs. SBSs can notice the activity of WAP by utilizing CSAT mechanism. Now with the exchange information among themselves, SBSs can split the unlicensed spectrum and use that resources with the licensed one for fulfilling the QoS of its users and for D2D communication under its influence.

4. Performance Evaluation

Here, we evaluate the performance of the proposed approach by using simulation with MATLAB. There are 5 users under a single WAP and five SBSs of different operators distributed randomly in the conflicting area of radius 100m. Users of SBSs and WAP are randomly distributed in the conflicting area. Each SBS uses 5MHz licensed band to serve maximum 25 number of users. Both networks use 20MHz unlicensed band in 5GHz band and WiFi works based on the IEEE 802.11n protocol with RTS/CTS mechanism. D2D communication occurs in unlicensed band only when QoS requirement of the users are fulfilled by SBSs. We use path loss model $15.3+37.5\log_{10}(d_m)$ and $15.3+50\log_{10}(d_m)$ for licensed and unlicensed spectrum respectively. Figure 3 shows the average achieved rate in case of varying number of users for LTE-A and LTE-U with respect to QoS requirement. From the figure, we find that LTE-A can provide greater average sum-rate than average QoS requirement upto 18 users. LTE-U can provide better average sum-rate or at least same as LTE-A and can grantee QoS for almost all of it's users. It also depicts the average D2D achieved rate.

5. Conclusion

In this paper, the QoS requirements of the users are met by augmenting unlicensed spectrum with licensed one in LTE-A network which also supports D2D communication in the unlicensed spectrum with maintaining some minimum rate of WAP users. We have solved the problem by using KSBS. Simulation result shows promising performance of the proposed method.

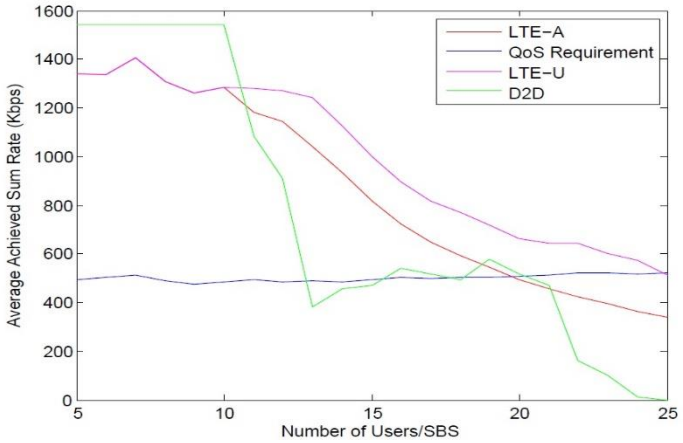

Figure 3 Comparison of achieved rate

Acknowledgement: "This research was supported by the MSIP, Korea, under the G-ITRC support program (IITP-2016-R6812-15-0001) supervised by the IITP." *Dr. CS Hong is the corresponding author.

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