D2D Communications under LTE-U System: QoS and Co-existence Issues are Incorporated

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Abstract—Daily-life oriented applications and multimedia entertainments through smart devices are creating immense stress to the current cellular foundation. To overwhelm from this loopholes, both academia and industry are trying their best by incorporating different technologies with existing ones using licensed spectrum. On the other side, Device-to-Device (D2D) communications are also being used to improve the spectrum efficiency and user experience by reutilizing licensed cellular spectrum. But with insufficient licensed spectrum, it is impossible to meet the demand of users in the current scenario. So, peoples are thinking to utilize unlicensed spectrum with licensed one to alleviate this scarcity issue and provide guaranteed Quality of Service (QoS) to the users. In this paper, we want to extend D2D communication and LTE-A network into the unlicensed spectrum. But this initiative will harm the performance of other technologies which are already working in the same unlicensed band. Moreover, if multiple mobile network operators (MNOs) use the same unlicensed band then they will diminish the benefits of each other. So this paper wants to maximize the sum-rate of LTE users and D2D pairs by allocating licensed and unlicensed subchannels considering their QoS requirements while protecting minimum requirements of WiFi Access Points (WAPs). Then we solve this problem with the help of Nash bargaining game (NBG) between Small Cell Base Stations (SBSs) and WAPs by the cooperative approach. Simulation results show the effectiveness and efficiency of the proposed approach.

Index Terms—Coexistence, NBG, QoS, LTE-U, Wi-Fi.

I. INTRODUCTION

Mobile network operators (MNOs) and service providers are availing great business amenities due to the thriving infiltration of wirelessly connected devices and incarnation of daily-life oriented data-famished applications and multimedia entertainments. During the last 10 years, mobile data traffic has flourished 4000x and it will rise nearly 8-folds between 2015 and 2020 among which video traffic will be three-fourth parts [1]. So this exponential growth of mobile traffic is already creating huge stress to MNOs for maintaining Quality of Service (QoS) of the current users and the situation will deteriorate severely in the upcoming days if MNOs want to handle this traffic cyclone with the current infrastructures. To combat with this challenge, MNOs can increase the capacity of Radio Access Network (RAN) by employing additional licensed spectrum which is both scarce and expensive. On the other side, this exaggerated traffic does not guarantee

superfluous revenue for the MNOs because of immense competition among themselves. So, both industry and academia are exploring up-to-dated techniques to encounter this hazard in the cellular network. Following this, new technologies like Long Term Evolution-Advanced (LTE-A), massive multiple-input-multiple-output (MIMO), device-to-device (D2D) [2] and cooperative communication [3] are coming onward with limited licensed spectrum. MNOs are trying to meet this gargantuan demand of users by reusing it's licensed spectrum with the help of low-cost and low power small cell base stations (SBSs).

But this steps are inadequate to provide emerging services through the current cellular infrastructure using limited licensed spectrum in the proceeding days. So, MNOs are trying to offload part of their traffic in unlicensed band to reduce some burden by employing WiFi Access Points (WAPs). According to [1], cellular networks offload more than 50% of its' traffic on to Wi-Fi. But such initiative leads to major challenges due to the inferior performance of WiFi technology, coordination among different infrastructures, pricing and even revenue loss due to less traffic in mobile networks. Some of these deficiencies can be brought down by pervading the blessings of LTE-A in the unlicensed spectrum known as LTE-U. It can boost the capacity and performance of the network better than Wi-Fi does [4] as it manage it's physical resources in a centralized manner. On the other hand, D2D communication underlaying cellular network is an effective approach to boost spectrum efficiency and user experience in close proximity and increase overall LTE system performance [5]. But the transmission range of unlicensed bands are comparatively small than licensed spectrum due to its' low power regulation and higher frequencies. Consequently, utilization of already deployed SBSs with co-located licensed and unlicensed carriers are more congruent for LTE-U. This can be technically assured via the use of Carrier Aggregation (CA) technology which was standardized in LTE Releases 10-12. LTE-U is already inaugurated (part of the LTE Release 13) to allow consumers for accommodating licensed and unlicensed carrier under a single LTE network infrastructure [6]. As LTE-U and D2D communication offer many exciting benefits in their respective

way, a natural way to further improve system performance is the combination of these two. However this efforts could cause terrible performance corrosion of Wi-Fi transmissions who are already operating in the same unlicensed band. Thus co-existence is the main challenge of LTE-U and D2D combination and we need to design such a mechanism that each others' benefits are preserved in the unlicensed band. There are several proposals to coexist fairly of LTE-U and WAP, but very few of them have considered inter-operators interaction and in the eye of bargaining game. Moreover, there is almost no proposals except [7] which brought D2D communication under LTE-U system as per our knowledge. In this paper, we superintend the underlaid D2D communications to LTE-U network considering the QoS requirement of the LTE-U users while preserving minimum data rate for WAPs. The main differences with their work are: (i) Single BS vs Multiple SBSs of different operators (ii) Uplink vs Downlink (iii) They have not considered the QoS requirement of users and D2D pairs (iv) Minimum requirements of WAPs. D2D pairs can work as underlay in both licensed and unlicensed spectrum under direct supervision of LTE-U SBSs. As LTE-U and WiFi are diminishing each others performance and within themselves, this interactions can be modeled as a game theory framework namely bargaining game to improve their performance. In this paper, we have tried to maximize LTE-U sum-rate considering the QoS requirement of the users and D2D pairs and co-existence issue with WAPs by using bargaining game. Here, we formulate the problem as an optimization one and then solve it using bargaining game.

II. Literature review

There are some works to evaluate the performance of LTE-U in presence of other WAPs. In [8], authors represent the analytical result of LTE-U and WLAN by employing a simple fractional unlicensed bandwidth sharing technique. By simulating, they show that WLAN performance is severely degraded by LTE transmission if there is no restriction on LTE-U. They also show that this performance of WLAN system can be preserved by controlling activity carefully in LTE system. The authors in [9] show that the WiFi users' performance is reduced about 70% to 100% with the presence of LTE system without inter-system coordination. So LTE-U affects the WiFi users' performance drastically and as a newcomer in the unlicensed band, LTE-U should have some mechanism to coexist fairly with already deployed WAPs.

There are some potential proposal to mitigate interference between LTE-U and WiFi to coexist fairly in the fields. Qualcomm has proposed Dynamic Channel Selection (DCS), Carrier-Sensing Adaptive Transmission (CSAT) and Opportunistic SDL (OSDL) for fair coexistence in their white paper [10]. For sharing unlicensed spectrum between LTE networks and WiFi systems, a time-domain resource splitting approach based on almost blank subframe (ABS) was proposed in [11]. By muting some LTE sub-frame, it gives opportunity to WiFi users for using it to increase their throughput. In [12], the authors brought fairness between WiFi and femtocell

networks by splitting unlicensed spectrum depending on the QoS requirements of the users. Authors of [13] proposed a spectrum sharing scheme between LTE-U and WiFi networks based on cognitive coexistence. They jointly determined DCS, CA and fractional spectrum access of LTE-U network to maximize the performance while satisfying the WiFi users. But they don't consider the heterogeneity cost of this two.

An Listen Before Talk (LBT) based mechanism with DCF protocol and adaptive backoff window size has been proposed for fair coexistence between LTE-U system and WAP in the work [15]. But LBT based mechanism is just like adding another WAP in the system and so performance gain is not satisfactory. The authors in [14] have created a win-win situation for both LTE-U and WiFi network by migrating some of WiFi users to the LTE-U system. But they have not mentioned how the unlicensed users of WiFi would integrate in licensed LTE system. A time sharing approach of co-existence between SBSs and WAPs is represented in [16] with the help of Nash bargaining game.

On the other hand, 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 for transmitting data from one another. D2D communication increases the spectral utilization consuming less power [17]. D2D communication can be occurred between pairs in the unlicensed spectrum also with the assist of LTE BS. In [7], the authors have explored the process of underlaid D2D communication into unlicensed spectrum by utilizing LTE-U network. They have solved the resource allocation problem of LTE-U users and D2D pairs with the help of many-to-many matching game considering one BS and introducing interfering range for WiFi users. But in reality, other SBSs are the main sources of interference if all of them want to extend their service in unlicensed spectrum. They have not considered the QoS requirement of the LTE-U users and any minimum rate required for fair coexistence with WAPs.

If LTE-U and WiFi use different unlicensed channel then there is no obstacle to coexist. But as the number of non-overlapping unlicensed channels are limited, there must be situation when LTE-U and WiFi need to use the same unlicensed channel which makes the coexistence problem interesting and challenging.

III. System Model and Problem Formulation

We consider an environment shown as in Figure 1 consisting of a set of S dual-mode LTE-A SBSs, S={1,2,..,S} operated by S different operators and a set W={1,2,..,W} of W WAPs. Each SBS $i \in S$ can serve downlink operation of N_i LTE-U users, denoted by $U_i = \{1, 2, ..., N_i\}$ and M_i D2D pairs, denoted by $D_i = \{1, 2, ..., M_i\}$. Each SBS $i \in S$ owns K_i orthogonal licensed subchannel of uniform bandwidth B_l, denoted by SC_i to support it's users and D2D pairs. Both SBSs, WAPs and it's associated users are distributed randomly in the area of interest. As only one user can be served by WAP at a time, we assume that there are W WiFi users distributed
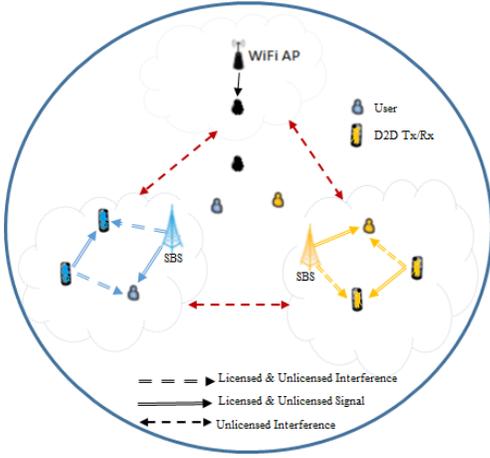
Fig. 1. System Model

randomly in the same area. Both SBSs and WAPs operate in the same unlicensed band. As unlicensed channel is much wider than one licensed subchannel and LTE system works centrally, each SBS divides this unlicensed spectrum into K^u unlicensed subchannels with bandwidth B_u represented by SC^u. For reliable transmission of control signals from SBS to user/D2D pair, SBS allocates at least one licensed subchannel to it's active LTE-U user and D2D pair. We assume that one subchannel can be allocated to a maximum of one LTE-U user and one D2D pair for maintaining the QoS. SBSs work in SDL mode with CA technology.

A. Data Rate of LTE-U User and D2D Pair

As SBS employs OFDMA technique to allocate the resources, there is no intra-operator interference among it's users in licensed and unlicensed spectrum. In licensed spectrum, an user perceives interference from D2D pair to whom SBS allocates the same subchannel. When SBS $i \in S$ allocates licensed subchannel $k \in SC_i$ to LTE-U user $j \in U_i$, the achieved rate of that user is shown as follows:

$$R_{i,j}^{l,k} = B_l log_2(1 + \frac{x_{i,j}^k P_i^c |g_{i,j}^k|^2}{\sum_{m \in D_i} y_{i,m}^k P_i^d |g_{m_t,j}^k|^2 + \sigma^2}) \quad (1)$$

where $\boldsymbol{x}$ and $\boldsymbol{y}$ are the allocation matrix for LTE-U users and D2D pairs and $x_{i,j}^k = 1$ when SBS i allocate licensed subchannel k to user j and $y_{i,m}^k = 1$ when SBS i allocate licensed subchannel k to D2D pair m, otherwise those values are zero. P_i^c is the transmission power for cellular user from SBS i and P_i^d is the transmission power of transmitter of D2D pair m. $g_{i,j}^k$ and $g_{m_t,j}^k$ represent the channel gain from SBS i and D2D transmitter m_t to LTE-U user j in subchannel k considering free space propagation path-loss model with Rayleigh fading. Here $|g_{i,j}|^2 = G d_{i,j}^{-\alpha} |g_0|^2$ with G indicates constant power gain factor introduced by amplifier and antenna, $d_{i,j}$ is the distance between i and j, α is the path-loss exponent and $g_0 \sim \mathcal{CN}(0,1)$ is a complex Gaussian variable representing Rayleigh fading.

The data rate D2D pair $m \in D_i$ gets over licensed subchannel $k \in SC_i$ is represented as follows:

$$R_{i,m}^{l,k} = B_l log_2(1 + \frac{y_{i,m}^k P_i^d |g_{m_t,m_r}^k|^2}{\sum_{j \in U_i} x_{i,j}^k P_i^c |g_{i,m_r}^k|^2 + \sigma^2}) \quad (2)$$

where g_{m_t,m_r}^k and g_{i,m_r}^k are the channel gains between D2D pair m and SBS i to receiver of D2D pair m_r respectively in the licensed subchannel k.

In the unlicensed subchannel LTE-U user and D2D pair not only receive mutual interference from each other, but also from users and D2D pairs of other MNOs and WAPs who are also working in the same unlicensed band. The achieved rate of user $j \in U_i$ and D2D pair $m \in D_i$ in the unlicensed subchannel $k' \in SC^u$ are shown as follows:

$$R_{i,j}^{u,k'} = B_u log_2(1 + \frac{x_{i,j}^{k'} P_i^c |g_{i,j}^{k'}|^2}{I_{S \setminus i}^c + I_S^d + I_W + \sigma^2}) \quad (3)$$

$$R_{i,m}^{u,k'} = B_u log_2(1 + \frac{y_{i,m}^{k'} P_i^d |g_{m_t,m_r}^{k'}|^2}{I_S^c + I_{S \setminus i}^d + I_W + \sigma^2}) \quad (4)$$

where $g_{i,j}^{k'}$ is the channel gain between SBS i and user j in the unlicensed subchannel k', $I_{S \setminus i}^c = \sum_{s=1,s \neq i}^S \sum_{n \in U_s} x_{s,n}^{k'} P_s^c |g_{s,j}^{k'}|^2$ is the interference caused by LTE-U users from other MNOs in the same subchannel, $I_S^d = \sum_{s \in S} \sum_{m \in D_s} y_{s,m}^{k'} P_s^d |g_{m_t,j}^{k'}|^2$ is the interference evolved from D2D pairs from all MNOs working in the same sub-band. $g_{m_t,m_r}^{k'}$ is the channel gain between the transmitter and receiver of D2D pair m in the unlicensed subchannel k', $I_S^c = \sum_{s \in S} \sum_{n \in U_s} x_{s,n}^{k'} P_s^c |g_{s,m_r}^{k'}|^2$ is the interference generated by LTE-U users from all MNOs in the same subchannel, $I_{S \setminus i}^d = \sum_{s \in S, s \neq i} \sum_{m' \in D_s} y_{s,m'}^{k'} P_s^d |g_{m_t',m_r}^{k'}|^2$ is the interference introduced by D2D pairs from other MNOs working in the same sub-band. I_W is the interference produced from WAPs.

But the study [9] shows that WiFi presence affects negligibly to the LTE-U system performance. So we can ignore the interference generated by WAPs to LTE-U system from (3) and (4). Moreover in a dense deployment, $I_{S \setminus i}^c + I_S^d >> P_i^u |g_{i,j}^{k'}|^2$ and $I_S^c + I_{S \setminus i}^d >> P_i^d |g_{m_t,m_r}^{k'}|^2$, so $R_{i,j}^{u,k}$ and $R_{i,m}^{u,k'}$ will be negligible and will provide insignificant benefit to the LTE-U users and D2D pairs. So, to take the advantage from this unlicensed band, SBSs can form a coalition and allocate the unlicensed resources in orthogonal fashion like licensed spectrum. By doing so, they can avoid interference $I_{S \setminus i}^c$ and $I_{S \setminus i}^d$ generated from other SBSs in the conflicting area. Assume, SBSs divide the unlicensed subchannels as $SC^u = SC_1^u \cup SC_2^u \cup ... \cup SC_S^u$ where $SC_i^u \cap SC_j^u = \emptyset$, $\forall i, j \in S$. Thus, the data rate of LTE-U user $j \in U_i$ and D2D pair $m \in D_i$ are expressed as follows:

$$R_{i,j}^{u,k'} = B_u log_2(1 + \frac{x_{i,j}^{k'} P_i^c |g_{i,j}^{k'}|^2}{\sum_{m \in D_i} y_{i,m}^{k'} P_i^d |g_{m_t,j}^{k'}|^2 + \sigma^2}) \quad (5)$$

$$R_{i,m}^{u,k'} = B_u log_2(1 + \frac{y_{i,m}^{k'} P_i^d |g_{m_t,m_r}^{k'}|^2}{\sum_{n \in U_i} x_{i,n}^{k'} P_i^c |g_{i,m_r}^{k'}|^2 + \sigma^2}) \quad (6)$$

B. Data Rate of WiFi

The achieved rate of a single WiFi user:

$$R_w = \frac{R_W}{W} \quad (7)$$

where R_W is the saturation capacity according to the study [18]. Now if we consider that each SBS in the conflicting region acts as like a WAP then the achieved rate for a single WiFi user is shown in the equation (9).

$$R_w^{min} = \frac{P_{tr'} P_{s'} E[P](W+S)^{-1}}{(1-P_{tr'})T_\sigma + P_{tr'} P_{s'} T_s + P_{tr'}(1-P_{s'})T_c} \quad (8)$$

where $P_{tr'} = 1 - (1-\tau)^{W+S}$, $P_{s'} = \frac{(W+S)\tau(1-\tau)^{W+S-1}}{P_{tr'}}$ and all other parameters are just like used in equation (7). So when SBSs want to use unlicensed band, they must have to maintain at least R_w^{min} rate to a WAP for the shake of co-existence.

C. Problem Formulation

R_w is achievable when WiFi network only accesses the unlicensed channel. For fair coexistence of WAPs and SBSs in the same unlicensed band, it is necessary to share the time slot in such a way that WAPs can maintain a minimum data rate and SBSs can guarantee the QoS of its users and provide some data rate for D2D pairs. Let, SBSs share $t \in [0,1]$ time slot with WAPs. The achievable rate for a WAP, LTE-U user and D2D pair are shown as follows respectively.

$$R_w^t = R_w * t \quad (9)$$

$$R_{i,j}^t = \sum_{k \in SC_i} x_{i,j}^k R_{i,j}^{l,k} + (1-t) * \sum_{k' \in SC_i^u} x_{i,j}^{k'} R_{i,j}^{u,k'} \quad (10)$$

$$R_{i,m}^t = \sum_{k \in SC_i} y_{i,j}^k R_{i,m}^{l,k} + (1-t) * \sum_{k' \in SC_i^u} y_{i,j}^{k'} R_{i,m}^{u,k'} \quad (11)$$

Now our goal is to develop an efficient spectrum allocation scheme that can allot both licensed and unlicensed subchannel $\{x_{i,j}^k, y_{i,m}^k\}$ to maximize the sum rate of LTE-U users and D2D pairs in their fraction of time.

$$\max_{\mathbf{x},\mathbf{y},t} \sum_{i \in S} \left(\sum_{j \in U_i} R_{i,j}^t + \sum_{m \in D_i} R_{i,m}^t \right)$$

$$\text{s.t.} \quad C_1 : \sum_{j \in U_i} x_{i,j}^k \leq 1, \sum_{m \in D_i} y_{i,m}^k \leq 1, \forall k \in SC_i, \forall i \in S$$

$$C_2 : \sum_{j \in U_i} x_{i,j}^{k'} \leq 1, \sum_{m \in D_i} y_{i,m}^{k'} \leq 1, \forall k' \in SC_i^u, \forall i \in S$$

$$C_3 : \sum_{k \in SC_i} x_{i,j}^k \geq 1, \sum_{k \in SC_i} y_{i,m}^k \geq 1, \forall j \in U_i, \forall m \in D_i$$

$$C_4 : x_{i,j}^k, y_{i,m}^k \in \{0,1\}, \forall k, \forall j \in U_i, \forall m \in D_i, \forall i \in S$$

$$C_5 : R_{i,j}^t \geq QoS_{i,j}, R_{i,m}^t \geq QoS_{i,m}, \exists j, m, \forall i \in S$$

$$C_6 : R_w^t \geq R_w^{min}, \forall w \in W, t \in [0,1]$$
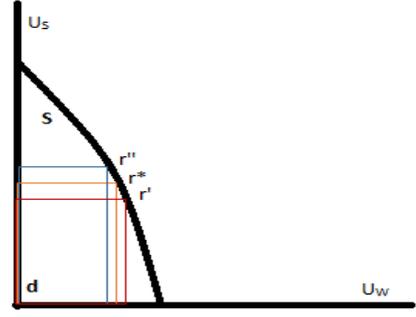$$(12)$$

Fig. 2. NBS in two players' game

The optimization problem (12) is a MINLP problem, which is NP-hard due to it's combinatorial property and impossible to solve in real time if there are many users/pairs in the region. So, we use bargaining game with heuristic approach to solve this problem in real time.

IV. SOLUTION WITH BARGAINING GAME

Bargaining game is a typical cooperative game that is fair in case of resource allocation. A two players bargaining game is shown in Fig. 2, where $P = \{W, S\}$ are the set of players. Then the ordered pair (**S,d**) is called a $|P|$-player bargaining game [19] where **S** represents the set of feasible payoff allocations and **d** indicates the set of disagreement payoff. Here, the utility functions are $U_W = \sum_{w \in W} R_w^t$ and $U_S = \sum_{i \in \mathbf{S}}(\sum_{j \in U_i}(R_{i,j}^t - \sum_{k \in SC_i} x_{i,j}^k R_{i,j}^{l,k}) + \sum_{m \in D_i}(R_{i,m}^t - \sum_{k \in SC_i} y_{i,j}^k R_{i,m}^{l,k}))$ respectively for the players.

A. Nash Bargaining Solution

NBS gives a unique and fair Pareto optimal point that satisfies the following axioms of Definition 2.

Definition 1(Bargaining Set): The set $\mathbf{B} = \{(r_1, r_2) \in \mathbf{S} | r_1 \geq R_w^{min}\}$ which satisfies the first three axioms of Definition 2.

Definition 2(NBS): r is said to be a NBS in **S** for **d** i.e. $r = \phi(\mathbf{S}, \mathbf{d})$ if it follows the axioms of individual rationality, feasibility, pareto optimality, independence of irrelevant alternatives, independence of linear transformations and symmetry [19] where $\phi : (\mathbf{S}, \mathbf{d}) \to \mathcal{R}^{|P|}$.

Theorem 1: There exists a unique solution concept $\phi(\mathbf{S}, \mathbf{d})$ that satisfies all six axioms of Definition 2 and it follows [19]

$$r^* = \phi(\mathbf{S}, \mathbf{d}) \in argmax_{\mathbf{r} \in \mathbf{B}} \prod_{i=1}^{|P|}(r_i - d_i) \quad (13)$$

Without sacrificing generality, another equivalent expression of (13) can be formulated using logarithm as follows:

$$r^* = argmax_{\mathbf{r} \in \mathbf{B}} \sum_{i=1}^{|P|} \ln(r_i - d_i) \quad (14)$$

Theorem 2: The point in bargaining set **B** which satisfies just the minimum rate (R_w^{min}) requirement of WAPs is the solution of Nash bargaining game.

Proof: Let at $T = t$, the minimum rate of WAPs can be

Symbol	Value	Comments
W	5	No. of WiFi APs
S	5	No. of LTE-U SBSs
B_l	180 kHz	Licensed subchannel bandwidth
SC	50	Number of Licensed subchannel/SBS
B_u	180 kHz	Unlicensed subchannel bandwidth
SC_u	100	Number of unlicensed subchannel
N	10 to 25	Number of LTE-U users/SBS
D	10 to 25	Number of D2D pairs/SBS
P^s	13 dBm	SBS's transmit power/subchannel
P^d	3 dBm	D2D's transmit power
σ^2	5 dB	Noise figure
α	3	Decay factor of the path loss
G	-31.5 dB	Power gain factor

achieved. So according to the Theorem 2, NBS will be the point when LTE-U system shares t time slot with WAPs and that should be r^* in Figure 2. From (14), we get as follow at this point:

$$U_{r^*} = \sum_{i=1}^{|P|} \ln(r_i - d_i) \qquad (15)$$

and that will be maximum. By contradiction we want to prove that there is no other point in the bargaining set that will give us better value than U_{r^*}.

Consider a sufficiently small time span $\triangle$ at which WAPs can get δ data rate and LTE-U users and D2D pairs can produce σ data rate. Here $\sigma > \delta$ as LTE-U system can manage the resource a better way than WAPs do. Now from Fig. 2,

$$r^{'} = (r_1^{'}, r_2^{'}) = (U_W(t+\triangle), U_S(1-t-\triangle)) = (r_1^* + \delta, r_2^* - \sigma) \qquad (16)$$

Here r_1^* and r_2^* are the components of r^* at $T = t$ and hence

$$U_{r'} = \ln(r_1^* + \delta - d_1) + \ln(r_2^* - \sigma - d_2) \qquad (17)$$

As $\sigma > \delta$, so the incrimination in the first term of equation (17) is less than the shrinkage in the second term. Now comparing from (15) and (17), we can say that $U_{r'} < U_{r^*}$. Moreover, from Fig. 2,

$$r^{''} = (r_1^{''}, r_2^{''}) = (U_W(t-\triangle), U_S(1-t+\triangle)) = (r_1^* - \delta, r_2^* + \sigma) \qquad (18)$$

But as r_1^* is the minimum rate required for WAPs and hence $r_1^* - \delta$ is surely less than R_w^{min}. So, this point $r^{''}$ is out of the bargaining set **B** and cannot be a solution of the game.

Finally we can say that U_{r^*} gives us the maximum value in **B** and thus r^* is the solution of the game.

B. Algorithm using NBS

As WAPs use DCF, there is no cooperation among themselves. But SBSs can notice the activities of such WAPs by utilizing CSAT like mechanism. So, by exchanging the information among SBSs, they can form a coalition, can run the following Algorithm 1 and take best benefits from unlicensed spectrum.

V. PERFORMANCE EVALUATION

Here, we evaluate the performance of proposed mechanism using MATLAB simulation. SBSs are distributed randomly in the conflicting area of radius 150m. WiFi network performs

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Algorithm 1 Cooperated Unlicensed Spectrum Utilization among SBSs of different MNOs

1: Initialization: Set of WiFi APs W and set of SBSs S
2: Each $i \in S$ distributes licensed spectrum among it's users and D2D pairs based upon constraints C_1, C_3, C_5
3: Each $i \in S$ determines minimum QoS capacity gap of it's users and D2D pairs by $QG_i = \sum_{j \in U_i} max(QoS_{j,i} - R_{j,i}^l, 0) + \sum_{m \in D_i} max(QoS_{m,i} - R_{m,i}^l, 0)$
4: Each $i \in S$ senses the active WAPs in the conflicting area
5: Every member of S exchanges that information to form a grand coalition and one SBS acts as an arbitrator
6: Arbitrator determines the bargaining set **B** depending upon the received information from all SBSs
7: Finds $r^* \in argmax_{\mathbf{r} \in \mathbf{B}} \prod_{\forall k \in P} r_k$ considering $\mathbf{d} = (0,0)$
8: Finds $t \in [0,1]$ from r^* during which SBSs will not operate in unlicensed band satisfying constraint C_6
9: Arbitrator finds $N_i^u = \frac{QG_i}{\sum_{j \in S} QG_j} C_u, \forall i \in S$ denoted by set $SC_i^u = \{1, 2, ..., N_i^u\}$ to allocate unlicensed resources to the SBSs and inform them with frequency to use it in $1 - t$ time slot
10: Each SBS $i \in S$ allocates SC_i^u among it's users and D2D pairs based upon their minimum QoS capacity gap to use with licensed spectrum using CA to reduce this gap or to meet the requirement with satisfying constraints C_2, C_5.
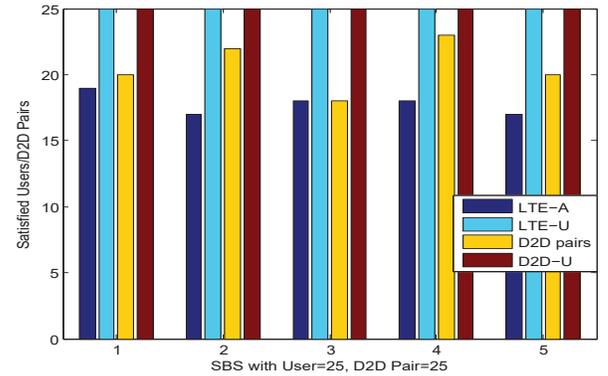

Fig. 3. Comparison of QoS Satisfied User/D2D pairs in each SBS

based on the IEEE 802.11n protocol in 5GHz band with RTS/CTS mechanism. SBSs also work in the same unlicensed band. Other parameters are shown in Table 1 and WiFi parameters are same as [18]. We use typical QoS requirements of multimedia applications as indicated [20]. Fig. 3 shows the comparison of QoS satisfied users and D2D pairs in case of LTE-A and LTE-U system considering each SBS has both 25 users and D2D pairs. From the figure, we find that a good number of users and D2D pairs are not satisfied with their achieved rate in LTE-A system where almost every users and pairs' QoS can be guaranteed by utilizing unlicensed resources with licensed one in LTE-U system.

Sum rate of all SBSs for LTE-A and LTE-U system keeping 25 D2D pairs per SBS with varying number of LTE-U users is depicted in Fig. 4. From the figure, we observe that LTE-
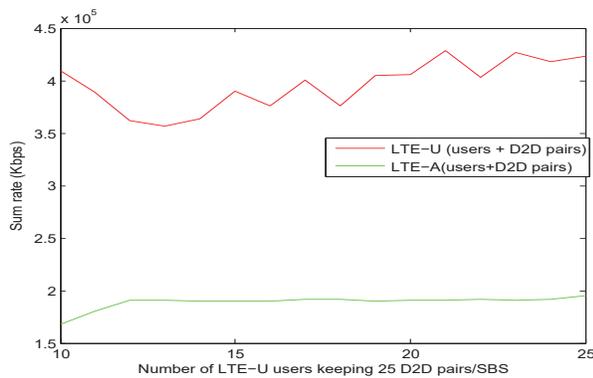
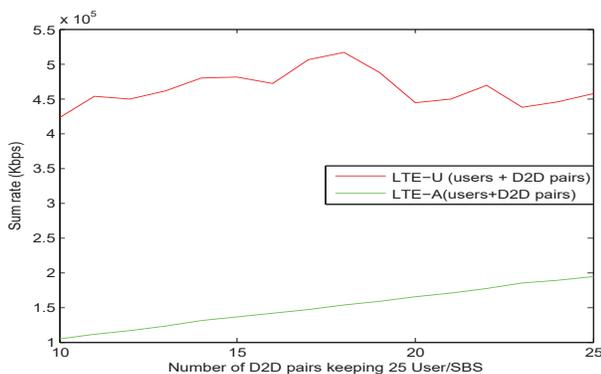Fig. 4. Sum Rate of all SBSs with varying number of users

Fig. 5. Sum Rate of all SBSs with varying number of D2D pairs

U sum rate is almost doubled than LTE-A for all the case of users. In case of LTE-A, the sum rate is almost equal for different number of users as the amount of interference caused by fixed number of D2D pairs are same. But on the hand, the sum rate has increased with the rise of number of users as only a few number of D2D pairs are creating interference in the unlicensed spectrum under every SBS. Fig. 5 represents the sum rate of all the users and D2D pairs based on LTE-A and LTE-U system while keeps fixed number of users in each SBS. LTE-U sum rate is more than double from LTE-A as shown in the figure. But this rate is growing linearly with the increasing number of D2D pairs as D2D pairs are affected less by users as they are in close proximity. On the other hand, this rate is approximately similar as unlicensed resources are distributed based upon the QoS gap in the licensed spectrum.

VI. CONCLUSIONS

In this paper, we have superintended D2D communication with LTE-U system where D2D pairs work as an underlay to the LTE-U network both in licensed and unlicensed spectrum. We have tried to guarantee the QoS requirements of the LTE-U users and D2D pairs by augmenting unlicensed spectrum with licensed one in LTE-A network by utilizing CA technology. We have formulated the problem as an optimization one and solved it by utilizing cooperative approach like NBG which provides a unique solution of the problem. Simulation results show that opportunistic use of unlicensed spectrum in LTE-A network can provide better sum rate for the networks

and can meet QoS requirements of almost all the LTE-U users and D2D pair in a dense deployment than traditional LTE-A system. So, careful design of such mechanism can be beneficial for users and D2D pairs while protecting the performance of WAPs.

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