A Multi-Game Approach for Effective Co-existence in Unlicensed Spectrum between LTE-U System and Wi-Fi Access Point

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***Abstract*—Cellular networks are facing the challenge of meeting aggressive data demand with limited licensed spectrum and LTE over the unlicensed band (LTE-U) has emerged as an effective way to defeat this hurdle. Using LTE-U along with superior techniques such as carrier aggregation (CA), one can boost the performance of existing cellular networks. Nevertheless, LTE-U can potentially deteriorate the performance of co-existing Wi-Fi systems operating over the unlicensed bands if not well-managed. Furthermore, single operator scenario is considered in most of the existing co-existence works. In this paper, an effective coexistence mechanism between LTE-U and Wi-Fi systems is investigated. The object is to facilitate the cellular networks to use LTE-U with CA to reduce the gap between achieved rate and quality-of-service (QoS) of the user while protecting Wi-Fi users, considering multiple operators in a dense deployment scenario. To resolve this problem, a multi-gaming approach is used. A cooperative Nash bargaining game (NBG) is used for sharing time resource in unlicensed for LTE-U and Wi-Fi systems. Following, a bankruptcy game is used by operators to allocate unlicensed resource among LTE-U users. Simulation results show that the proposed approach is better than the comparing methods regarding per user achieved rate, and fairness. It also shows that the proposed technique defends Wi-Fi user greatly in dense deployment than basic listen-before-talk (LBT) does.**

I. Introduction

The way and amount of information exchange have changed over the past few years due to the technological advancement especially in wireless devices. Study [1] acknowledges that mobile data traffic will reach 49 exabytes per month by 2021 and major part (78%) of that traffic will be rich content (video) in the end of forecast period. Another study [2] of Cisco also anticipates that wireless and mobile traffic will surpass from wired traffic by 2019. Thus, this massive growth of wireless traffic will become a bottleneck for the wireless network.

That is why research communities are investigating different solutions to cope with upcoming traffic demands and challenges of the 5G era. Massive MIMO (Multiple-Input Multiple-Output), carrier aggregation (CA), higher-order modulation schemes, Device-to-Device communication, Co-operative communication are some of these solution approaches including others. But these efforts with limited licensed spectrum are not enough to deal with the upcoming tsunami of wireless traffic. For this reason, mobile companies proposed LTE operations in unlicensed spectrum (LTE-U) and 3rd Generation Partnership Project (3GPP) announced Licensed-Assisted Access (LAA) of LTE in the unlicensed spectrum [3] as part of its release 13. LTE LAA will permit users to accommodate licensed and unlicensed carrier under a single LTE network infrastructure and this can be implemented through CA which was introduced in 3GPP LTE release 10 [4].

Though LTE-U has the possibilities to improve the existing LTE/LTE-A networks without investing heavily, it can cause significant coexisting issues with other technologies like Wi-Fi in the same unlicensed band as it utilizes exclusively the entire assigned spectrum. Thus, LTE-U will affect negatively on the performance of other unlicensed technologies in terms of throughput, latency, and Quality of service (QoS) [5]. Therefore, coexistence is the main challenge of deploying LTE-U in the field if it wants to operate in the same unlicensed spectrum. Moreover, if different cellular network operators (CNOs) use same unlicensed spectrum then the performance of LTE-U deteriorate further. That is why CNOs need to cooperate especially among the small cell base stations (SBSs) to take benefit of unlicensed spectrum.

Most of the co-existence works consider either Listen-Before-Talk (LBT) and resource sharing approach.In the paper [6], the authors propose an LBT based approach that includes distributed coordination function (DCF) protocol and adaptive backoff window size for fair coexistence between LTE-U system and WAPs. But in case of dense deployment scenario, the performance of LBT based mechanism is not good. There are several works ([7], [8], [9]) that deal with the co-existence issue between LTE-U and Wi-Fi system by sharing resources. The authors decide the fraction of time slot based on the average data rate requirement of Wi-Fi user and the number of Wi-Fi users in [7]. They use a learning framework namely echo state networks (ESNs) for optimizing resource allocation in LTE-U system. But their fairness scheme is not affected by the LTE-U networks. In the work [8], the authors use a bargaining game approach to bring fairness between LTE-U

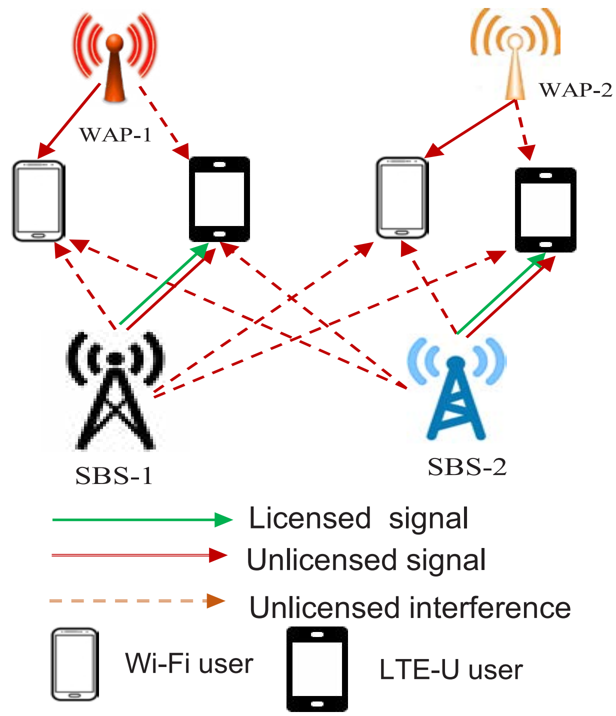

Fig. 1: System Model

and Wi-Fi system by splitting the time resource in unlicensed spectrum. However, they represent no closed-form solution for this optimal sharing process. Paper [9] use ruin theory based surplus model for protecting Wi-Fi system from LTE-U system. But they consider only one SBS for their model. Therefore, most of the co-existence models have not considered inter-operator's influences over the LTE-U network and optimal time sharing in this resource sharing mechanism. In this paper, we propose an effective co-existence mechanism considering multiple operators with time sharing approach. The main contributions of this paper are as follows:

- We formulate an optimization problem to minimize the sum of absolute difference between achieved rate and QoS requirement of each user for every SBS
- We decompose the problem into two sub-problems and solve them by using Nash bargaining game and Bankruptcy game respectively
- We derive a closed-form solution for optimal sharing time with Wi-Fi system and provide an algorithm for unlicensed resource allocation depending on bankruptcy game
- Justification of the proposed approach with simulation.

The rest of the paper is organized as follows. In Section II, we discuss about the system model and problem formulation. The solution approach for the problem is discussed in Section III. Performance evaluation have been represented in Section IV. Finally, the paper is concluded in Section V.

II. System Model and Problem Formulation

CNOs are deploying more and more SBSs to facilitate growing wireless services to the users. This ultra-dense nature

TABLE I: Notation

Symbol	Meaning
$\mathcal{S}$	Set of SBSs with S elements
$\mathcal{W}$	Set of non-overlapping WAPs with W elements
$\mathcal{U}_i$	Set of users associated with SBS i
$\mathcal{U}_w$	Set of U_w active users associated with WAP w
$\mathcal{C}_i^l$	Set of licensed subchannels of SBS i
$\mathcal{C}^u$	Set of unlicensed sub-carriers
$\mathcal{C}_i^u$	Set of unlicensed sub-carriers of SBS i
B_l	Bandwidth of each licensed subchannel
B_u	Bandwidth of each unlicensed sub-carrier
P_i^l	Transmission power of SBS i for each user in licensed spectrum
P_i^u	Transmission power of SBS i for each user in unlicensed sub-carrier
$\boldsymbol{\alpha}_i$	Resource allocation vector for SBS i in licensed spectrum
$\boldsymbol{\beta}_i$	Resource allocation vector for SBS i in unlicensed sub-carrier
$h_{i,j}$	Channel gain between AP i and receiver j
$I_{\mathcal{S}\setminus\{i\}}$	Interference from $\mathcal{S}\setminus\{i\}$ SBSs to any LTE-U user of SBS i in any unlicensed sub-carrier
$I_{\mathcal{W}}$	Interference from $\mathcal{W}$ to any unlicensed subchannel
$r_{i,j}^{l,k}$	Achieved rate of user j associated with SBS i in licensed subchannel k
$r_{i,j}^{u,k'}$	Achieved rate of user j associated with SBS i in unlicensed sub-carrier k'
$R_{w,v}^{max}$	Average rate of user v associated with WAP w when WAP is accessing the channel
$R_{w,v}^{min}$	Average rate of user v associated with WAP w when SBSs act like WAPs
$QoS_{i,j}$	QoS requirement of user j associated with SBS i
τ	Fraction of time that SBSs share with WAPs

of SBSs from different operators are compelled to conflict with each other and also with local WAPs if they want to operate in the same unlicensed spectrum. We are studying a scenario with multi-operators' SBSs and WAPs as shown in Figure 1. This dense deployment scenario consists of a set of dual-mode (which can act both in the licensed and unlicensed spectrum) LTE-A SBSs operated by different CNOs and a set of non-overlapping WAPs. Both SBSs and WAPs operate in the same unlicensed band and they are involved in the downlink operations. For reliable transmission of control signals from the SBS to the user, each SBS has licensed subchannel to serve its user. SBSs work in the supplemental downlink (SDL) mode with CA technology. Details of the symbols used in this paper are shown in the Table I.

A. Data Rate of LTE-U User

The achieved rate of user $j \in \mathcal{U}_i$ associated with SBS $i \in \mathcal{S}$ in the licensed spectrum is as follows:

$$R_{i,j}^l(\boldsymbol{\alpha}_i) = \sum_{k \in \mathcal{SC}_i^l} r_{i,j}^{l,k}. \tag{1}$$

where

$$r_{i,j}^{l,k} = B_l \log_2\left(1 + \frac{\alpha_{i,j}^k P_i^l h_{i,j}}{\sigma^2}\right) \tag{2}$$

Here, $\alpha_{i,j}^k = 1$ when SBS $i \in \mathcal{S}$ allocates the sub-carrier $k \in \mathcal{SC}_i^l$ to user j and $\alpha_{i,j}^k = 0$, otherwise. The descriptions of other symbols are shown in Table I.

If $R^l_{i,j} > QoS_{i,j}$, the user requires not using of the unlicensed spectrum. Otherwise, SBS will allocate unlicensed sub-carrier to user j. In that situation, the obtained rate by LTE-U user $j \in \mathcal{U}_i$ over the unlicensed spectrum is as follows:

$$R^u_{i,j}(\boldsymbol{\beta}) = \sum_{k^{'} \in \mathcal{SC}^u_i} r^{u,k^{'}}_{i,j}. \quad (3)$$

where

$$r^{u,k^{'}}_{i,j} = B_u \log_2 \left(1 + \frac{\beta^{k^{'}}_{i,j} P^u_i h_{i,j}}{I_{\mathcal{S}\setminus i} + I_{\mathcal{W}} + \sigma^2}\right). \quad (4)$$

Here, $\beta^{k^{'}}_{i,j} = 1$ when SBS $i \in \mathcal{S}$ passes out the unlicensed sub-carrier $k^{'} \in \mathcal{SC}^u$ to the user $j \in \mathcal{U}_i$ and $\beta^{k^{'}}_{i,j} = 0$, otherwise. The meaning of other symbols are represented in Table I.

But, Wi-Fi presence has very insignificant influences over LTE-U performance in the dense deployment scenario [10]. Thus, we can overlook $I_{\mathcal{W}}$ from (4) and the value of $I_{\mathcal{S}\setminus i}$ can be shown as follows:

$$I_{\mathcal{S}\setminus i} = \sum_{s \in \mathcal{S}, s \neq i} \sum_{n \in \mathcal{U}_s} \beta^{k^{'}}_{s,n} P^u_s h_{s,j}. \quad (5)$$

However, in a dense deployment, $I_{\mathcal{S}\setminus i}$ is very very greater than the received power of the user j and $r^{u,k^{'}}_{i,j}$ 0. That means, SBSs need to share the unlicensed resource in such a manner where the user of one SBS will not be affected by other SBSs. This can be ensured by forming coalition [11] namely grand coalition and distribute unlicensed resources in orthogonal fashion among the SBSs. In this approach, every SBS can avoid $I_{\mathcal{S}\setminus i}$. Assume, the unlicensed resources are distributed as $\mathcal{C}^u = \mathcal{C}^u_1 \cup \mathcal{C}^u_2 \cup ... \cup \mathcal{C}^u_S$ where $\mathcal{C}^u_i = \{1, 2, ..., K^u_i\}$ and $\mathcal{C}^u_i \cap \mathcal{C}^u_j = \emptyset$, $\forall i, j \in \mathcal{S}$ among the SBSs and this is done proportionally depending on their QoS requirements. So, (4) looks like as follows:

$$r^{u,k^{'}}_{i,j} = B_u \log_2 \left(1 + \frac{\beta^{k^{'}}_{i,j} P^u_i h_{i,j}}{\sigma^2}\right). \quad (6)$$

Thus, user $j \in \mathcal{U}_i$ achieves a rate as follows:

$$R_{i,j} = R^u_{i,j}(\boldsymbol{\alpha}_i) + R^u_{i,j}(\boldsymbol{\beta}_i). \quad (7)$$

Subsequently, SBS $i \in \mathcal{S}$ has a set of users $\mathcal{U}^{'}_i \subseteq \mathcal{U}_i$ who needs support from the unlicensed spectrum.

B. Data Rate of Wi-Fi user

When Wi-Fi system only utilize unlicensed channel, the maximum average throughput of each user $v \in \mathcal{U}_w$ is as follows:

$$R^{max}_{w,v} = \frac{R_w}{U_w}. \quad (8)$$

where R_w is the overall downlink capacity of WAP $w \in \mathcal{W}$ and U_w is the total number of its associated users. Now, we assume each SBS just like a WAP, then average throughput [12] of the user looks like as follows:

$$R^{min}_{w,v} = \frac{P_{tr} P_s E[P](S+1)^{-1} U^{-1}_w}{(1 - P_{tr})T_\sigma + P_{tr} P_s T_s + P_{tr}(1 - P_s)T_c}. \quad (9)$$

The details of these parameters are in [12]. Thus, SBSs should give enough opportunity for WAP so that it can guarantee an average rate between $R^{min}_{w,v}$ and $R^{max}_{w,v}$ to its users.

C. Problem Formulation

For fair coexistence between LTE-U and Wi-Fi systems, SBSs need to share an appropriate portion of the time slot with WAPs. We assume that SBSs share $\tau \in [0, 1]$ with WAPs and the achievable rate of Wi-Fi user $v \in \mathcal{U}_w$ and LTE-U user $j \in \mathcal{U}_i$ are as follows:

$$\begin{aligned} R_{w,v} &= R^{max}_w \cdot \tau, \\ R_{i,j} &= R^l_{i,j}(\boldsymbol{\alpha}_i) + R^u_{i,j}(\tau, \boldsymbol{\beta}_i) = R^l_{i,j}(\boldsymbol{\alpha}_i) + (1-\tau) \cdot R^u_{i,j}(\boldsymbol{\beta}_i). \end{aligned} \quad (10)$$

With the fixed $\boldsymbol{\alpha}_i$, every SBS $i \in \mathcal{S}$ now wants to satisfy as many as its users possible after sharing τ in unlicensed spectrum. For that, we design an optimization problem for each SBS as follows:

$$\begin{aligned} \min_{\tau, \boldsymbol{\beta}_i} \quad & \sum_{j \in \mathcal{U}_i} \left| R_{i,j} - QoS_{i,j} \right|, \forall i \in \mathcal{S} \\ \text{s.t.} \quad & C_1 : \sum_{j \in \mathcal{U}^{'}_i} \beta^{k^{'}}_{i,j} \leq 1, \forall k^{'} \in \mathcal{C}^u_i \\ & C_2 : \sum_{j \in \mathcal{U}^{'}_i} \sum_{k^{'} \in \mathcal{SC}^u_i} \beta^{k^{'}}_{i,j} \leq |\mathcal{C}^u_i| \\ & C_3 : \beta^{k^{'}}_{i,j} \in \{0, 1\}, \forall k^{'} \in \mathcal{C}^u_i, \forall j \in \mathcal{U}^{'}_i \\ & C_4 : R^{min}_{w,v} \leq R^{\tau}_{w,v} \leq R^{max}_{w,v}, \forall v \in \mathcal{U}_w \\ & C_5 : 0 \leq \tau \leq 1. \end{aligned} \quad (11)$$

(11) is a Mixed Integer Non-Linear Programming (MINLP) problem, which is NP-hard due to it's combinatorial property and impossible to solve in real time.

III. Decomposition of the Problem for Solving with Nash Bargaining and Bankruptcy Game

For solving the problem (11), we decompose the problem first into two sub-problems and then solve them with appropriate techniques. The two sub-problems are shown as follows:

$$\begin{aligned} \min_{\tau} \quad & \sum_{j \in \mathcal{U}_i} \left| R_{i,j} - QoS_{i,j} \right|, \forall i \in \mathcal{S} \\ \text{s.t.} \quad & C_4, \text{and } C_5. \end{aligned} \quad (12)$$

and,

$$\begin{aligned} \min_{\boldsymbol{\beta}_i} \quad & \sum_{j \in \mathcal{U}_i} \left| R_{i,j} - QoS_{i,j} \right|, \forall i \in \mathcal{S} \\ \text{s.t.} \quad & C_1, C_2, \text{and } C_3. \end{aligned} \quad (13)$$

Sub-problems (12) and (13) have same goal with different constraints and they are interconnected through the parameters τ and $\boldsymbol{\beta}_i$. The first sub-problem (12) is solved using Nash bargaining game (NBG) keeping fixed $\boldsymbol{\beta}_i$ and the second one (13) is solved by utilizing Bankruptcy game after replacing the solution τ of (12).

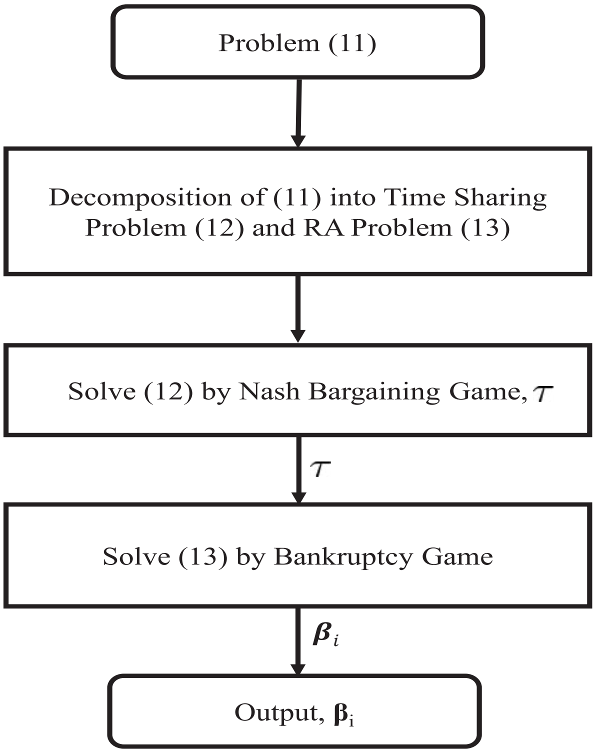

Fig. 2: Solution Approach of the Problem (11)

A. Nash Bargaining game-Based Solution of Problem (12)

For fulfilling the objective of (12), SBS wants of the major portion of τ that will suppress the performance of Wi-Fi users. We want to obtain a win-win maneuvering for both LTE-U users and Wi-Fi users. As τ is fixed, it is unlikely to give opportunities for both the systems concurrently for fulfilling their objectives. Consequently, we need an effective allocation of time τ to match both sides' benefits.

So, with fixed $\boldsymbol{\beta}_i, \forall i \in \mathcal{S}$ reformulate (12) as follows:

$$\begin{aligned} \max_{\tau} \quad & \{R_S, R_w\} \\ \text{s.t.} \quad & R_{w,v}^{min} \le R_{w,v}(\tau) \le R_{w,v}^{max}, \forall v \in \mathcal{U}_w \\ & \tau_0 \le \tau \le 1. \end{aligned} \quad (14)$$

where $R_S = \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{U}_i} R_{i,j}$, $R_w = |\mathcal{U}_w| \cdot R_{w,v}$, and τ_0 is the fraction of time slot that is necessary for maintaining $R_{w,v}^{min}, \forall v \in \mathcal{U}_w$ when SBSs absconding from using unlicensed spectrum. Now (14) is a multi-objective problem and can be solved by using Nash Bargaining Solution (NBS) [13] where $\mathcal{P} = \{w, \mathcal{S}\}$ are the players. NBS can provide us a unique solution concept [13] that satisfies the following:

$$\mathbf{s}^*(\tau) = \phi(\mathbf{S}, \mathbf{d}) \in \underset{\mathbf{s} \in \mathbf{S}}{\operatorname{argmax}} \prod_{p \in \mathcal{P}} U_p. \quad (15)$$

Here, $\mathbf{S}$ is the set of payoff allocations for the players when they share the time slot in unlicensed spectrum, $\mathbf{d}$ is the disagreement point for the players, and U_i is the utility for player $p \in \mathcal{P}$. The utilities of players are $U_w = |\mathcal{U}_w|(R_{w,v}^{\tau} - R_{w,v}^{min}) = |\mathcal{U}_w|(\tau \cdot R_{w,v}^{max} - R_{w,v}^{min})$ and $U_{\mathcal{S}} = R_S - R_S^l = (1-\tau) \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{U}_i} R_{i,j}^u(\boldsymbol{\beta}_i)$ respectively where $R_S^l = \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{U}_i} R_{i,j}^l(\boldsymbol{\alpha}_i)$. Another similar representation of (15) can be formulated using logarithm as follows:

$$\mathbf{s}^*(\tau) = \underset{\mathbf{s} \in \mathbf{S}}{\operatorname{argmax}} \sum_{p\mathcal{P}} \ln(U_p). \quad (16)$$

Now we require such a τ that will maximize the value of $\mathbf{s}^*(\tau)$ in (16). The value of this optimal sharing time τ^* is shown in Theorem 1.

TABLE II: Value of Simulation Parameters

Symbol	Value	Symbol	Value
S	5	$\lvert\mathcal{U}_i\rvert, \forall i$	50
B_l	180 kHz	$\lvert\mathcal{C}_i^l\rvert, \forall i$	50
B_u	15 kHz	$\lvert\mathcal{C}^u\rvert$	1200
$P_i^l, \forall i$	19 dBm	$P_i^u, \forall i$	17dBm
σ^2	-174 dBm	$U_w, \forall w$	5

Theorem 1. *The optimal time slot allocation for a given set of SBSs and WAPs is*

$$\tau^* = \begin{cases} \frac{1}{2} + \frac{R_{w,v}^{min}}{2 \cdot R_{w,v}^{max}}, & \textit{if } |S| \ge 1 \\ 1, & Otherwise \end{cases}$$

Proof. Setting the first-order derivative of (16) with respect to τ and set zero, we get as follow:

$$\frac{d\mathbf{s}^*(\tau)}{d\tau} = \frac{d}{d\tau}\{\ln(U_w) + \ln(U_S)\} = 0. \quad (17)$$

Now substituting the value of U_w and $U_{\mathcal{S}}$ into (16), we have:

$$\frac{R_{w,v}^{max}}{\tau \cdot R_{w,v}^{max} - R_{w,v}^{min}} + \frac{-1}{1-\tau} = 0 \quad (18)$$

which implies that

$$\tau^* = \frac{1}{2} + \frac{R_{w,v}^{min}}{2 \cdot R_{w,v}^{max}}. \quad (19)$$

If there is no SBS that affects WAPs then $R_{w,v}^{min}$ and $R_{w,v}^{max}$ will be the same. Therefore, we get $\tau^* = 1$ from (19). ∎

B. Solution of Problem (13) by using Bankruptcy Game

The problem (13) is still NP-hard. Therefore, we want to solve the problem by using bankruptcy game [14]. Standard bankruptcy game consists of a set of agents $\mathcal{A}$, amount of money M and a claim vector $\boldsymbol{d}$ with $\sum_{a \in \mathcal{A}} d_a \ge M$. If $\boldsymbol{x}^*$ represents a solution vector then it must satisfy the followings:

$$\begin{aligned} & 0 \le x_a \le d_a, \forall a \in \mathcal{A} \\ & \sum_{a \in \mathcal{A}} x_a = M \end{aligned} \quad (20)$$

In our case, we have a set of unsatisfied users $\mathcal{U}_i^{'}$, amount of unlicensed sub-carriers $|\mathcal{C}_i^u|$ and requirement of unlicensed sub-carriers to fulfill their QoS are the claims. Bankruptcy game is responsible to allocate unlicensed sub-carriers to the unsatisfied users considering the solution τ^* of previous subsection. Algorithm 1 represents a bankruptcy game-based resource allocation for the users.

Algorithm 1 Bankruptcy Game-Based Unlicensed Resource Allocation of SBS i

Input: $\mathcal{U}_i^{'}$, $\mathcal{C}_i^u$, $\mathbf{QoS}_i$,$\mathbf{R}_i^l$
Output: $\boldsymbol{\beta}_i$
for each $j \in \mathcal{U}_i^{'}$ **do**
  Find QoS gap of j by $QG_{i,j} = QoS_{i,j} - R_{i,j}^l$
  Calculate $r_{i,j}^u$ as from (6)
  Calculate claim of j by $d_{i,j} = \lceil QG_{i,j}/(1-\tau) \cdot r_{i,j}^u \rceil$
end for
for each $j \in \mathcal{U}_i^{'}$ **do**
  Calculate $x_{i,j} = \frac{d_{i,j}}{\sum_{j \in \mathcal{U}_i^{'}} d_{i,j}} . |\mathcal{C}_i^u|$
  if $x_{i,j} > d_{i,j}$ **then**
    Set $x_{i,j} = d_{i,j}$
  end if
end for
Set $j = 1$ and $k = 1$
while $j \leq |\mathcal{U}_i^{'}|$ **do**
  while $x_{i,j} > 0$ **do**
    Set $\beta_{i,k} = j$
    Set $x_{i,j} = x_{i,j} - 1$
    Set $k = k + 1$
  end while
  Set $j = j + 1$
end while

IV. Performance Evaluation

In this segment, we assess the performance of the LTE-U system in terms of per user average achieved rate, $\sum_{i \in \mathcal{S}, j \in \mathcal{U}_i} |R_{i,j} - QoS_{i,j}|$ and Jain's fairness index [15] and per user normalized throughput for Wi-Fi system. The important parameters are exhibited in Table II. All SBSs, WAPs, and users are spread randomly in the working range of radius 150m. Wi-Fi networks follow the IEEE 802.11n protocol in the 5GHz band with the RTS/CTS mechanism, and the Wi-Fi parameters used here are similar to those of [12]. SBSs also work in the same unlicensed band as with WAPs besides the licensed spectrum. We utilize QoS specifications of multimedia applications as indicated in [16]. In this evaluation section, we have compared the performance of LTE-U(Proposed) with LTE-A, LTE-U with no coalition namely LTE-U(NC) and LTE-U with the randomly chosen users indicated as LTE-U(Random). We use the path loss (PL) models $15.3+37.5log_{10}(d)$ and $15.3+50log_{10}(d)$ for licensed and unlicensed spectrum respectively and $10^{-PL/10}$ as the common channel gain. We presented the results of 1000 runs of the programs to represent the figures.

In Fig. 3, we demonstrate the comparison of the per-user achieved rate of LTE-U(Proposed) with the comparing schemes and shows that the rate of the proposed method is better than all other rivaling methods. The same figure also shows that LTE-A and LTE-U(NC) produce an average per-user achieved rate of $540 \sim 550Kbps$ in most of the times. On the contrast, these ranges are $590 \sim 510Kbps$ for LTE-U(Random) and LTE-U(Proposed) in most of the cases and the

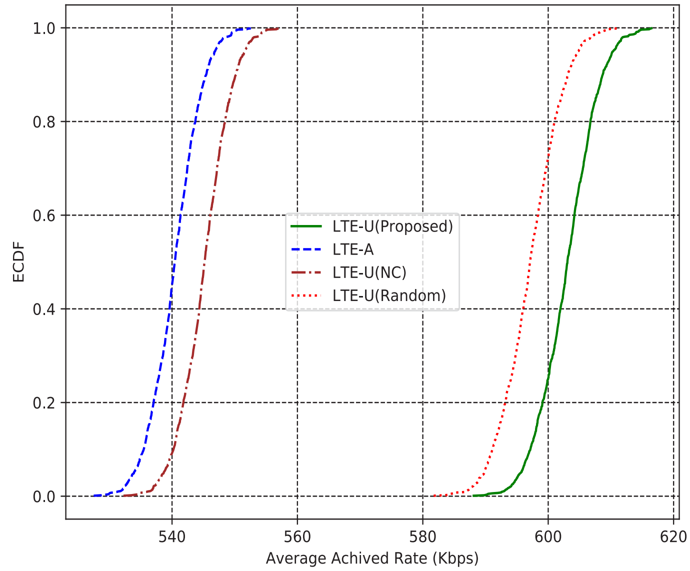

Fig. 3: Comparison of Average Achieved Rate

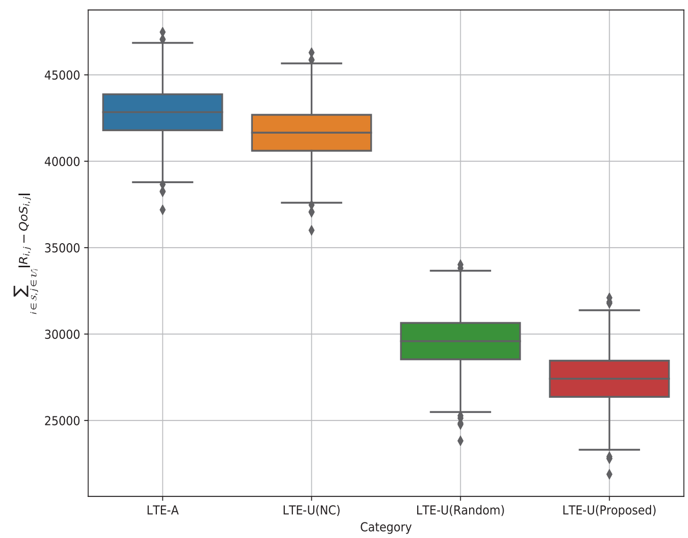

Fig. 4: Comparison of Sum of Objective for all SBSs

proposed method achieves more than $600Kbps$ in almost 80% of times. Moreover, the proposed method achieves $62.60Kbps$, $57.85Kbps$ and $5.86Kbps$ more rate than LTE-A, LTE-U(NC) and LTE-U(Random) respectively on average.

In Fig. 4, we represent the sum of objective value for all the comparing methods. It shows that the proposed method is better than all the other methods. Specifically, the proposed method achieves 56.30%, 51.97% and 7.84% better results than LTE-A, LTE-U(NC) and LTE-U(Random) respectively.

In Fig. 5, we notice the comparison of Jain's fairness scores among different methods. It shows that the proposed method is most fair than other competing methods to the users. Specifically, these scores of LTE-A and LTE-U(NC) reside between $88\% \sim 90\%$ whereas the same indices for LTE-U(Random) and LTE-U(Proposed) happen inside $96\% \sim 98\%$

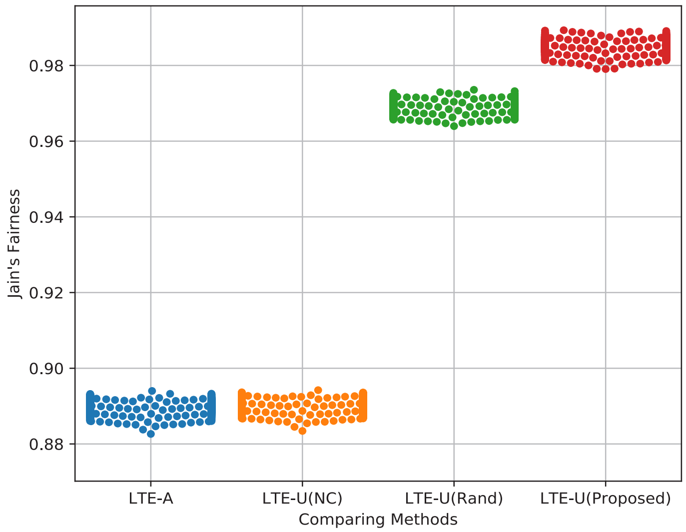

Fig. 5: Comparison of Fairness

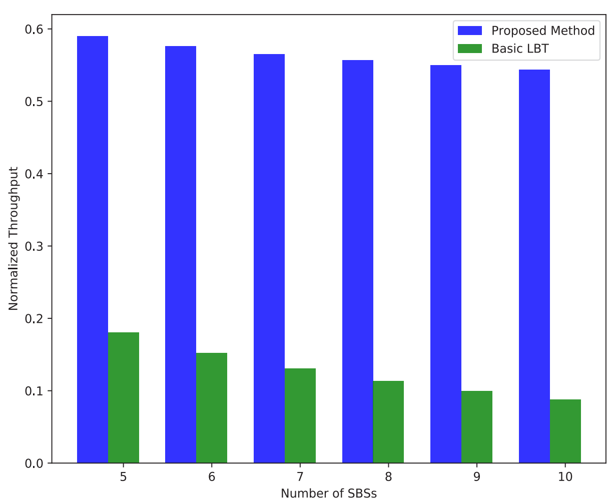

Fig. 6: Comparison of per Wi-Fi User's Normalized Throughput considering variable SBSs

and $98\% \sim 99.5\%$ respectively. The mean value of these scores for the proposed method is 9.52%, 9.47% and 1.60% greater than LTE-A, LTE-U(NC) and LTE-U(Random) respectively.

In Fig. 6, we present the comparison of normalized throughput per Wi-Fi user in the cases of the proposed method and basic Listen-Before-Talk (LBT) with the diverging number of SBSs. It depicts that the proposed method defenses Wi-Fi user better than basic LBT does in all cases, although the throughputs are decreasing with the increasing number of SBSs. This reduction in throughput is due to the escalating competition with increased SBSs. More precisely, the proposed method can ensure 77.41% more throughput per Wi-Fi user than basic LBT on average. Besides, this protection reflects more in denser deployment.

V. Conclusions

In this paper, we have proposed an efficient co-existence mechanism in the unlicensed spectrum for multi-operators' scenario in the time sharing domain. We have solved this co-existence issue and found a closed-form solution by using NBG and unlicensed resource allocation issue by utilizing bankruptcy game. Simulation results show that the proposed approach can provide better per user achieved rate, fairness than LTE-A, LTE-U(NC) and LTE-U(Random) methods. Moreover, this approach protects Wi-Fi users fur better way than basic LBT does.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (NRF-2016R1D1A1B01015320). *Dr. CS Hong is the corresponding author.

References

[1] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016 - 2021," *White Paper*, 2017.
[2] Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2014 - 2019," *White Paper*, 2015.
[3] D. Flore, "Evolution of LTE in Release 13," 2015, available at: http://www.3gpp.org/news-events/3gpp-news/1628-rel13
[4] 3GPP, "Evolved Universal Terrestrial Radio Access (E-UTRA); Carrier Aggregation; Base Station (BS) Radio Transmission and Reception (Rel 10)," *3GPP TR 36.808 V10.1.0*, July 2013.
[5] Huawei, "U-LTE: Unlicensed Spectrum Utilization of LTE," *White Paper*, 2014.
[6] R. Yin, G. Yu, A. Maaref, and G. Y. Li, "LBT based adaptive channel access for LTE-U system," *IEEE Transactions on Wireless Communications*, vol. 15, no. 10, pp. 6585-6597, October 2016.
[7] M. Chen, W. Saad, and C. Yin, "Echo state networks for self-organizing resource allocation in LTE-U with uplinkdownlink decoupling," *IEEE Trans. Wireless Communication*, vol. 16, no. 1, pp. 3-16, January 2017.
[8] A. K. Bairagi, N. H. Tran and C. S. Hong, "LTE-U sum-rate maximization considering QoS and co-existence issue," in *2017 IEEE International Conference on Big Data and Smart Computing (BigComp 2017)*, pp. 352-357, February 2017.
[9] A. Manzoor, N. H. Tran and C. S. Hong, "Ruin Theory Based Modeling of Fair Spectrum Management in LTE-U," in *2017 19th Asia-Pacific Network Operations and Management Symposium (APNOMS 2017)*, pp. 181-186, September 2017.
[10] A. M. Cavalcante, E. Almeida, R. D. Vieira, S. Choudhury, E. Tuomaala, K. Doppler, F. Chaves, R. C. D. Paiva, and F. Abinader, "Performance evaluation of LTE and WI-FI coexistence in unlicensed bands," in *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, pp. 1-6, June 2013.
[11] W. Saad, Z. Han, M. Debbah, A. Hjorungnes, and T. Basar, "Coalitional game theory for communication networks," *IEEE Signal Processing Magazine*, vol. 26, no. 5, pp. 77-97, September 2009.
[12] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 3, pp. 535-547, March 2000.
[13] M. Maschler, E. Solan and S. Zamir, "Game Theory," *Cambridge University Press*, ch. 15, pp. 622-658, 2013.
[14] B. ONeill, "A problem of rights arbitration from the Talmud," Mathematical Social Sciences, vol. 2, no. 4, pp. 345-371, June 1982.
[15] R. Jain, D.M. Chiu, and W.R. Hawe, "A quantitative measure of fairness and discrimination for resource allocation in shared computer system," *Eastern Research Laboratory, Digital Equipment Corporation*, vol. 38, September 1984.
[16] T. Q. S. Quek, G. de la Roche, I. Gven, and M. Kountouris, "Small Cell Networks: Deployment, PHY Techniques and Resource Management," *Cambridge University Press*, June 2013.