Unlicensed Carrier Selection and User Offloading in Dense LTE-U Networks

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***Abstract*—Due to the scarcity of licensed spectrum, Long-Term Evolution (LTE) operation in unlicensed spectrum is a promising solution to provide high data rate and to reduce the load on licensed spectrum. In Release 13, 3GPP introduced LTE in Unlicensed (LTE-U) as Licensed Assisted Access (LAA). In LTE-U, Carrier Aggregation (CA) feature aggregates licensed and unlicensed spectrum to get higher bandwidth. Use of unlicensed spectrum by Wi-Fi and LTE-U networks results in more interference because of lack of coordination and thereby makes it challenging for LTE-U operators to select best component carrier from available unlicensed carriers in case of dense deployments. In this paper, for efficient LTE-U operation, we propose dynamic Unlicensed Component Carrier Selection (UCCS) algorithm which minimizes interference from other networks (Wi-Fi and LTE-U). The algorithm considers fairness factor to achieve better performance for each User Equipment (UE). Further, the user offloading algorithm offloads those UE(s) to licensed carrier that are getting lesser throughput due to interference from adjacent cells operating on the same unlicensed carrier. The simulation results show that the proposed algorithm outperforms *Random* and *Least Received Power* channel selection schemes.**

I. Introduction

In Long-Term Evolution (LTE), frequency reuse of one is used to improve the capacity of cellular networks. Due to high penetration of smartphones and tablets there is an ever increasing demand for spectrum to offer high data rates. Licensing cost of spectrum is too high because of the scarcity of radio spectrum. To reduce capital expenditure (CAPEX) and fullfill user demand, one solution could be LTE operation in unlicensed spectrum. In Release 13, 3GPP introduced Licensed Assisted Access (LAA) [1] for LTE in Unlicensed spectrum (LTE-U) [2] whereby using Carrier Aggregation (CA), LTE-U/LAA small cell base station (eNodeB) operates in both licensed and unlicensed spectrum. The primary challenge in unlicensed spectrum is fair sharing of spectrum among different operators and Radio Access Technologies (RATs). More devices in unlicensed spectrum result in more interference and if they are from different operators or/and different RATs then it is either very difficult or impossible to coordinate among them. In such uncoordinated networks Component Carrier (CC) selection becomes crucial. In this paper, the terms channel and CC are used interchangeably.

In the case of LTE in unlicensed, eNodeB considers a channel is free if received signal strength on the channel is lesser than the energy detection threshold [1] otherwise the channel is considered to be busy. In LTE-U, eNodeB has to listen to the unlicensed channel before performing any of the LTE operations. If the channel is busy, then eNodeB tries to find other free unlicensed channel for data transmissions. If eNodeB could not find any free unlicensed channel, then it shares the unlicensed channel with other networks such as Wi-Fi and other LTE-U eNodeBs. LAA eNodeB shares the channel by following Listen Before Talk (LBT) schemes [1], [3] and LTE-U eNodeB shares the channel by following discontinuous transmission pattern (duty cycle) using Carrier-Sensing Adaptive Transmission (CSAT) like schemes [2], [4]. In the unlicensed spectrum, free channel according to an eNodeB may not be free for all UEs under that eNodeB. Even if the received signal strength at eNodeB is less than the energy detection threshold, it could still create some interference to the users depending on their positions in the cell. If more number of free channels are available, then instead of selecting any random free channel, the wise decision on channel selection can improve the performance of the network. One can consider how many users are getting affected and at what level (amount of interference) they are getting affected while making channel selection decision in unlicensed spectrum. For example, in Fig. 1, assume that we have two unlicensed channels as Ch #2 and Ch #3 which are assigned to eNodeB-2 and eNodeB-3, respectively and eNodeB-1 wants to select a channel. The eNodeB-1 scans the channels and finds that both of these channels are free. Then it can select any one of them. But, in this case, it is better to select Ch #2 over Ch #3 as eNodeB-1 & eNodeB-2 have less overlapping regions, and most importantly less number of users are getting interference from the neighboring cell compared to eNodeB-1 & eNodeB-3.

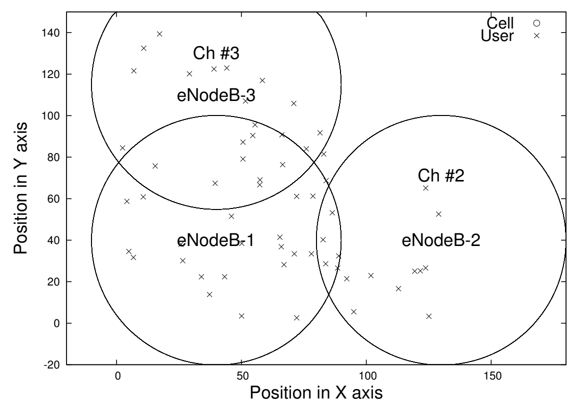

Fig. 1: An example of LTE-U network with three overlapping eNodeBs.

For solving channel selection problem in 802.11 Wireless Local Area Networks (WLANs) many co-ordinated and uncoordinated techniques such as Least Congested Channel Search (LCCS) [5], weighted coloring based approach (H_{minmax}/H_{sum}) [6], and client driven CFAssign-RaC centralized algorithm [7] are proposed. In [8], many such techniques are surveyed for 802.11 WLANs. Most of the techniques in WLANs use beacons of Wi-Fi Access Points (APs) to make decisions. Hence, such techniques cannot be used directly in LTE-U. LTE uses frequency reuse of one in licensed spectrum for increasing capacity, but now as it is unlicensed spectrum where the channel condition and availability vary dynamically, we need Wi-Fi like dynamic channel (CC) selection scheme for efficient operation of LTE in unlicensed spectrum.

Most of the existing solutions of Wi-Fi can be adapted for LTE-U channel selection by modifying LTE-U behavior to support Wi-Fi like beacons. In this case, LTE-U and Wi-Fi devices should listen to each other's beacons. But this approach leads to significant changes in LTE-U. Hence, we address unlicensed CC selection for LTE-U eNodeBs without modifying it to minimize inter-cell interference and improve the overall network performance. In our work, we propose an uncoordinated and dynamic Unlicensed CC Selection (UCCS) algorithm which estimates the quality of each free channel based on User Equipment (UE) feedback and selects the best channel. The fairness factor of the algorithm helps to achieve better throughput for each user being served using unlicensed CC. Further, the affected users due to unlicensed CC selection are offloaded to the licensed CC for better performance.

The rest of the paper is organized as follows. In Section II, the system model is described. The proposed work is described in Section III. In Section IV, simulation results are provided and analyzed. Finally, conclusions and future works are given in Section V.

II. System Model

In our system model, we considered dense deployment of wireless networks with LTE-U/LAA eNodeBs from different operators. We assumed that users are stationary (or slowly moving) and each user is connected to one eNodeB for wireless communication. The LTE-U eNodeB utilizes both licensed and unlicensed CC with CA (shown in Fig. 2 as L_{CC} and U_{CC}). Licensed CC is used to transfer both data plane and control plane information whereas unlicensed CC is used to carry only data plane information. Hence, to serve users on unlicensed CC the scheduling information is transferred through licensed CC. As more data demand is in downlink, we assumed that unlicensed CC is used only for downlink transmission.

In this work, for each eNodeB, we assume k number of free channels in unlicensed spectrum denoted as set $C = \{c_1, c_2, c_3, \ldots, c_k\}$, where k is greater than one. The objective is to select one free channel from unlicensed spectrum which has less inter-cell interference and improve overall throughput of users in unlicensed spectrum. Users are served in downlink either by licensed CC or unlicensed CC or both. Let us assume

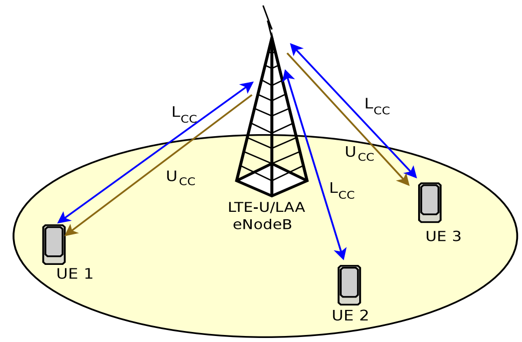

Fig. 2: An example of LTE eNodeB in unlicensed with CA.

that each eNodeB is serving N_u number of UEs in unlicensed spectrum denoted by set $U = \{u_1, u_2, u_3, \ldots, u_{N_u}\}$. In LTE, each UE feedback the Channel Quality Indicator (CQI) index to the serving eNodeB. The proposed UCCS algorithm uses wideband CQI reporting for channel selection and also to estimate the current channel condition which helps to trigger the UCCS algorithm. As the proposed UCCS algorithm needs each user's CQI per channel, initially each eNodeB operates on each channel for some time t. The average CQI of UE over t is considered as CQI of UE by the algorithm. Due to UCCS algorithm channel selection, the users whose CQI gets affected because of more interference from neighboring cells can be offloaded to freely available licensed spectrum. But there is a possibility that after some instance the licensed spectrum can be fully utilized or occupied by LTE users due to increase in licensed traffic load. In those scenarios, we assumed that the existing scheduling algorithm would efficiently offload the user from licensed to unlicensed or vice versa based on available resources.

III. Proposed Work

We propose a dynamic UCCS algorithm which makes use of CQI feedback given by UEs. The proposed solution is uncoordinated and distributed because, in practical deployment scenarios, it is very difficult to assume there is some coordination between different operators as well as between different RATs. The dynamic behavior of algorithm considers uncertainty in channel conditions of unlicensed spectrum. At each eNodeB, the UCCS algorithm selects an unlicensed CC, then the user offloading method offloads the users from unlicensed CC to licensed CC which are getting more interference because of selected channel. If the average CQI of the current channel is lower than certain threshold, then the triggering method calls UCCS algorithm again. Each algorithm is explained further below in detail.

A. Unlicensed CC Selection (UCCS) Algorithm

The UCCS algorithm (*i.e.,* Algorithm 1 notations are as shown in Table I) runs at each LTE-U eNodeB and selects a CC from the set of available unlicensed carriers in such a way that the selected CC maximizes cell throughput and tries to maintain fairness by achieving good throughput for each UE being served by the eNodeB.

TABLE I: Glossary

Notation	Definition
N_u	Number of users in unlicensed spectrum
k	Number of free channels in unlicensed spectrum
CCS	Selected unlicensed channel
$CQI_{i,j}$	CQI of user j over channel i
$CQI_{avgFinal}$	Average CQI of CC selected by UCCS
λ	Threshold on CQI for triggering UCCS algorithm
UE_ID	User identification number
$LR_{Available}$	Available resource blocks in licensed spectrum
$MCUE_j$	Maximum CQI of user j over all unlicensed CC
α	Decision making parameter

Algorithm 1 UCCS Algorithm

Inputs: k, N_u, $CQI_{i,j}$
Outputs: CCS (Selected CC), $MCUE_j$, $CQI_{avgFinal}$

Initialization: $\alpha_{max} \leftarrow 0$, $MCUE_j \leftarrow 0$;
for $i = 1$ to k **do**
    $CQI_{sum} \leftarrow 0$;
    for $j = 1$ to N_u **do**
        $CQI_{sum} \leftarrow CQI_{sum} + CQI_{i,j}$;
        /*Find max CQI of each UE over all channels*/
        if $CQI_{i,j} > MCUE_j$ **then**
            $MCUE_j \leftarrow CQI_{i,j}$;
        end if
    end for
    $CQI_{avg} \leftarrow \frac{CQI_{sum}}{N_u}$; /* Calculate Average (Avg) CQI */
    /* Calculate Fairness factor */
    $f_i \leftarrow \sqrt{\frac{(CQI_{i,1}-CQI_{avg})^2+(CQI_{i,2}-CQI_{avg})^2+\cdots+(CQI_{i,N_u}-CQI_{avg})^2}{N_u}}$;
    $\alpha_i \leftarrow 2 * CQI_{avg} - f_i$; /* Calculate α parameter */
    if $\alpha_{max} < \alpha_i$ **then**
        $\alpha_{max} \leftarrow \alpha_i$;
        $CCS \leftarrow i$; /* Store channel number of max α */
        $CQI_{avgFinal} \leftarrow CQI_{avg}$; /*Store Avg CQI of max α */
    end if
end for

The UCCS algorithm calculates CQI_{avg} of all N_u UEs for each free channel. The decision making parameter α for channel i is

$$\alpha_i = 2 * CQI_{avg} - f_i \tag{1}$$

where, f_i is fairness factor for channel i which is the standard deviation of CQIs. The algorithm follows greedy approach as it calculates α of each free channel using Eqn (1) and selects the channel with maximum α. We are assuming that a channel is best when it gives more cell throughput and better per UE throughput when compared the other channels. Here, more weightage is given to cell throughput when compared to throughput fairness. The time complexity of the proposed UCCS algorithm is O(kN_u). The proposed algorithm is more suitable in dense deployment scenarios as the value of k is small due to channel scarcity.

The UCCS algorithm also maintains the record of maximum CQI of each UE in MCUE array and stores the CQI_{avg} of selected channel as $CQI_{avgFinal}$. The MCUE array is used in Algorithm 2 for deciding user offloading from unlicensed to licensed spectrum and the $CQI_{avgFinal}$ is used in Algorithm 3 for triggering decision.

B. User Offloading

In this section, user offloading means offloading users from unlicensed to licensed spectrum. One simple way of user offloading can be offloading the user who has least CQI, but that user may be cell edge UE (hence least CQI), offloading such cell edge UEs may not improve their performance after offloading also. So, the better way is to offload users who are affected the most because of unlicensed CC selection. Such offloading increases the probability of improvement in the user and cell performances. Unlicensed CC given by UCCS algorithm for an eNodeB may not be best for all of its UE(s). There can be some UE(s) which are getting more interference from neighboring cell(s) after selecting the best CC because of the use of same CC by neighboring cell(s). Such affected UE(s) can perform better if we move them to the licensed CC. Hence, we propose the user offloading algorithm (*i.e.,* Algorithm 2) that identifies users which are getting affected because of interference from neighboring cells in unlicensed spectrum and offloads them from unlicensed CC to the licensed CC. For this, we used $MCUE_j$ and $CQI_{CCS,j}$ parameters given by Algorithm 1.

Algorithm 2 User Offloading

Input 1: $MCUE_j$: Maximum CQI of user j
Input 2: $CQI_{CCS,j}$: CQI of user j over selected channel CCS
Input 3: $LR_{Available}$: Available resources in licensed spectrum
Output: User Offloading from unlicensed to licensed CC.

Initialization:
/*HashMap HM with UE_ID as key & CQI difference as value */
HashMap ⟨key, value⟩ HM $=\phi$;
for $j = 1$ to N_u **do**
    if $MCUE_j > CQI_{CCS,j}$ **then**
        $\delta \leftarrow MCUE_j - CQI_{CCS,j}$;
        /* Insert UE_ID & its CQI difference in HashMap */
        HM.put(j, δ);
    end if
end for
/*offload affected UE to licensed carrier */
while $LR_{Available}$ *AND* HashMap not empty **do**
    $Offload_{user} \leftarrow$ Max(HM); /*offload max δ UE */
    Calculate Δ_{LR} of $Offload_{user}$ using Eqn (2);
    if $LR_{Available} > \Delta_{LR}$ **then**
        Allocate Δ_{LR} to $Offload_{user}$ in licensed spectrum;
        $LR_{Available} \leftarrow LR_{Available}$ - Δ_{LR}; /*update $LR_{Available}$ */
    else
        $LR_{Available} \leftarrow 0$;
    end if
end while

Higher value of $MCUE_j$ than $CQI_{CCS,j}$ indicates that the user is affected because of the newly selected unlicensed CC. The difference between $MCUE_j$ and $CQI_{CCS,j}$ gives how much the user is affected. Hence, we are maintaining the list of such affected users with their CQI difference in a HashMap. The affected users are offloaded to the licensed CC one by one starting with highest affected user first. Max(HM) is a function which returns the key of maximum value (*i.e.,* it returns `UE_ID` of highly affected user) and deletes the entry from the HashMap. The traditional scheduler for resource allocation on licensed CC contains the information such as the number of active users, Quality of Service (QoS) to be guaranteed, etc. Depending upon this information, the scheduler can provide freely available Resource Blocks (RBs) in licensed spectrum in each TTI. Let $LR_{Available}$ is currently available number of RBs in licensed spectrum and Δ_{LR} is the number of RBs required in licensed spectrum for the offloaded user. The Δ_{LR} for i^{th} user can be calculated as,

$$\Delta_{LR} = \frac{D_{min} * SB_{duration}}{C_0 * MCS_i * \beta} \quad (2)$$

Where, D_{min} is minimum data rate required for the user, $SB_{duration}$ is the subframe duration (*i.e.,* 1ms), C_o is 126 which is the product of 12 sub-carriers, 7 symbols, 2 slot times, and 0.75 for transmission of actual data (assuming 0.25 as control channel transmission overhead), MCS_i is Modulation Coding Scheme of the i^{th} user which is a function of SINR, β is MIMO value (*i.e.,* 1 for SISO).

After offloading a user, the $LR_{Available}$ is reduced by Δ_{LR} till either the number of RBs available in licensed spectrum reaches to zero or all the affected users are offloaded. Such interference aware user offloading from unlicensed to licensed CC ensures better performance to affected users and improves overall system performance.

C. Triggering Decision

The UCCS algorithm can be run periodically or one can use triggering algorithm (*i.e.,* Algorithm 3) to run UCCS algorithm dynamically. For triggering $CQI_{avgFinal}$ and $CQI_{avgCurrent}$ are used, where $CQI_{avgFinal}$ is average CQI of selected channel at the last time when UCCS algorithm ran and $CQI_{avgCurrent}$ is the current average CQI of the same channel. If the difference between these two values is above threshold λ, it means the channel is not good anymore and need to select an appropriate channel by running UCCS algorithm again. It first shifts offloaded users back to unlicensed CC and then triggers the UCCS algorithm for selecting new best channel.

If the value of λ is small, then even for slight degradation in the channel quality the algorithm will get triggered. This results in instability of overall network and more computation overhead at each eNodeB. Hence, the value of λ need to be chosen wisely, and it should depend on the current network condition. For this, in the beginning the value of λ is set to λ_{min} and then based on network condition λ varies, and the updated value is given as input for next triggering decision. The TH_{time} is time after which if the UCCS algorithm runs

Algorithm 3 Triggering Decision

Input 1: $CQI_{avgFinal}$, $CQI_{avgCurrent}$
Input 2: λ, L_{time}, TH_{time}, I_{time}, λ_{min}, λ_{max}
Output 1: Triggering decision for UCCS algorithm
Output 2: Updated λ, L_{time}, I_{time}

if $CQI_{avgFinal} - CQI_{avgCurrent} > \lambda$ **then**
  Shift offloaded users back to unlicensed for selecting new channel;
  $C_{time} \leftarrow$ System.Time();
  /* algorithm running after TH_{time}, set λ to λ_{min} */
  if C_{time} - $L_{time} \geq TH_{time}$ **then**
    $\lambda \leftarrow \lambda_{min}$; $I_{time} \leftarrow C_{time}$;
    /* ran multiple times in TH_{time} increase λ value */
  else
    $\lambda \leftarrow$ Min $(\lambda + 1, \lambda_{max})$;
  end if
  /* After every TH_{time} change λ value */
  if C_{time} - $I_{time} \geq TH_{time}$ **then**
    λ=Max $(\lambda_{min}, \frac{\lambda}{2})$; $I_{time} \leftarrow C_{time}$;
  end if
  $L_{time} \leftarrow C_{time}$;
  /* Call The channel selection algorithm */
  Call UCCS Algorithm () ;
end if

then no need to change λ value and it can be reset to λ_{min} only. But if the algorithm runs before TH_{time} then increase λ value to avoid frequent running of UCCS. Hence the proposed triggering algorithm not only triggers the UCCS algorithm but also helps to calculate λ value for next triggering decision, based on the current network condition. In general, we can say that the lower value of TH_{time} gives better throughput with more computation overhead compared to higher value. The triggering algorithm uses C_{time} which is current time of the system, and L_{time} which is the time when triggering algorithm ran last time. I_{time} stores a time to keep track of periodic check of TH_{time}. Initially, L_{time} and I_{time} are set to zero then the algorithm updates it's values, and these are inputs to triggering algorithm for next run. Min(a,b) and Max(a,b) functions return minimum and maximum values between a and b, respectively.

IV. Performance Evaluation

The system model is simulated in MATLAB with the simulation parameters given in Table II.

A. Simulation parameters and setup

For simulation, we considered a small cell network topology with 20 LTE-U eNodeBs having 20 active users served in unlicensed carrier per cell as shown in Fig. 3. In each cell, users are deployed randomly with minimum 10 m away from eNodeB and are connected to the same eNodeB throughout the simulation. The neighbouring cells are overlapping with each other. We considered three number of free channels in unlicensed spectrum and for each eNodeB all the three

TABLE II: Simulation Parameters

Parameter	Value
Number of Cell	20
Number of UEs per Cell	20
UE Deployment	Random
Transmit Power	20 dBm
Traffic	Downlink (Full Buffer)
Number of Free Channels	3
Bandwidth	20 MHz
Pathloss Model	$37 + 30Log_{10}(d[meter])$
User Mobility	1 m/s
TH_{time}	100 ms
λ_{min}, λ_{max}	1,15
λ	λ_{min}

channels are free. Initially, we assigned random channels to eNodeBs and then ran the UCCS algorithm to select the best channel one by one for each eNodeB. In simulation, the time for running algorithm and time to switch the channel are not considered. The performance study of licensed spectrum is beyond the scope of this work hence, results are shown for unlicensed spectrum only. The proposed algorithm is compared with two other algorithms listed below.

1) **Random Channel Selection:** In *random channel selection*, eNodeB selects any free channel from the set of available free channels.
2) **Least Received Power Channel Selection:** In *least received power* channel selection, eNodeB selects a channel which has the least received power at eNodeB.

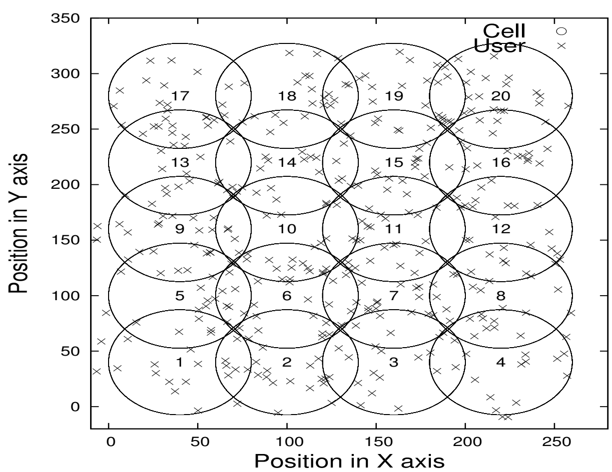

Fig. 3: Positions of 20 eNodeBs with 400 UEs in small cell network.

The performance of proposed UCCS algorithm is compared with the above two algorithms of channel selection for static and mobility scenarios.

B. Performance in Static Scenario

In this scenario, the position of users are assumed to be static. The Signal to Interference and Noise Ratio (SINR) are observed for all the users in each cell. Fig. 4 shows the CDF of average SINR for all users in the network. To understand the performance of each cell for all the mentioned channel

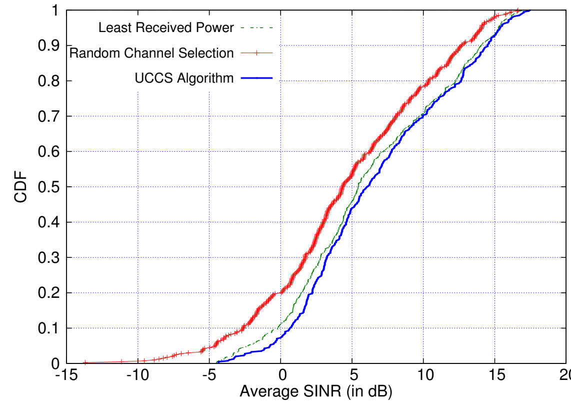

Fig. 4: CDF of Average SINR of all users in the network.

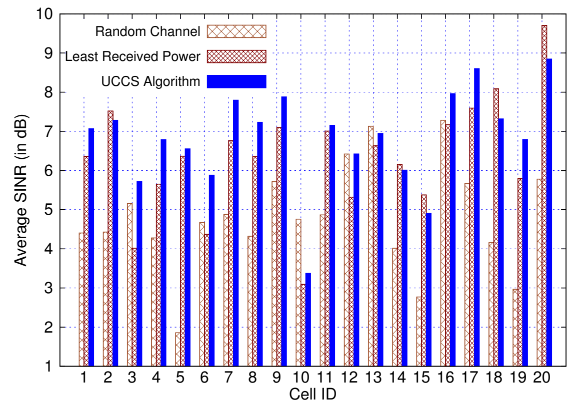

Fig. 5: Variation in average SINR across cells in the network.

selection techniques, we plotted bar graph of average SINR of each cell in Fig. 5.

The basic idea in LTE-U is to select a free CC but if it is not available, then LTE-U nodes share the CC. If we assume there are more than one free channel, then one can select any random free channel from the set of available channels. The *random selection* of free channel may select a channel which is used by one or more adjacent cells which results in a lot of interference and poor performance. Improvement to this is to select a channel which has *least received power* at eNodeB. This also may not guarantee good performance in dense networks as least interference at eNodeB does not guarantee overall minimum interference for the cell. Hence, the proposed algorithm is considering interference at each user, and eNodeB collects this information in the form of CQI reports from each user. Without modifying LTE standard, the CQI reporting feature of LTE is used in LTE-U to make a wise decision about channel selection.

C. Performance in Mobile Scenario

To check the performance of our proposed algorithm in mobility scenario, we added mobility to users. In this scenario, half of the users of each cell are moving with the speed of approximately 1 m/s using random walk 2D model. The setup assured mobility of users are within the range of the eNodeB and users are connected to the same eNodeB throughout

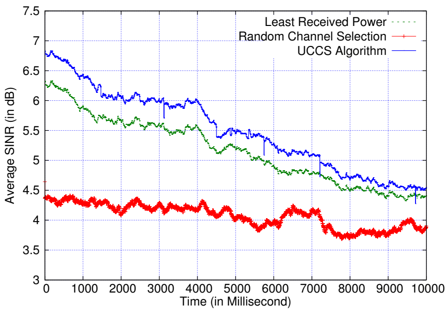

Fig. 6: Average SINR of all users in the network over 10 sec with mobility.

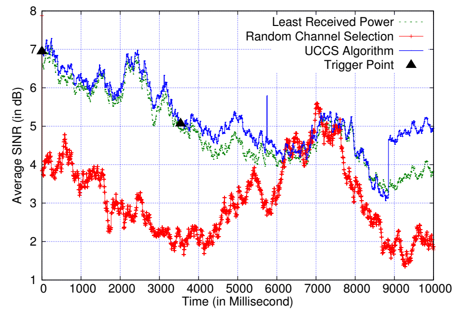

Fig. 7: Average SINR of all users in a cell over 10 sec with mobility.

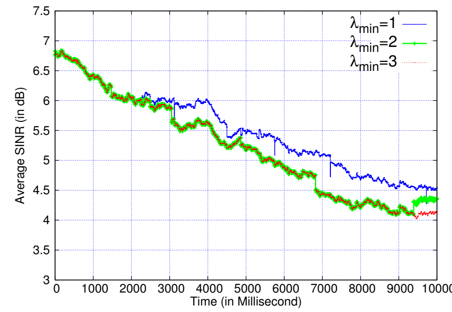

Fig. 8: Average SINR of all users in the network over 10 sec with mobility and varying λ_{min}.

the simulation. The triggering method is used for all the three algorithms (*i.e.,* the algorithm gets triggered if presently operating channel quality degrades by λ). To observe the performance of UCCS algorithm with user mobility, we plotted the average SINR of the network over simulation time as shown in Fig. 6. The average SINR of one of the cell in the network for all the algorithms over simulation time is shown in Fig. 7. For proposed algorithm along with average SINR, two triggering points at t=1 ms and t=3541 ms are also shown in Fig. 7. The triggering point is a point at which UCCS algorithm runs again and selects the current best channel for eNodeB. Initially, the UCCS algorithm runs and selects the best channel, that point is considered as the first triggering point. After that, the algorithm gets triggered second time because the selected channel quality degrades its performance by λ (*i.e.,*1).

From simulation results, we can say that the overall system performance of UCCS algorithm is better than *random channel selection* and *least received power* in both static and mobile scenarios.

TABLE III: Performance of UCCS algorithm with triggering values

Lambda (λ_{min})	Average SINR (in dB) of network	Total number of triggers in network
1	5.5029	51
2	5.2284	39
3	5.2144	38

To check the performance of UCCS algorithm with varying λ_{min}, we ran the simulation with three different λ_{min} values as 1, 2 and 3. The network performance is shown in Fig. 8 over time and the total number of triggers with average SINR of the network over 10 seconds is shown in Table III. In Fig. 8, the network performance for λ_{min} value of 3 is nearly same as 2 but at the end of simulation the performance of λ_{min} value of 2 is slightly better compared to 3. From Fig. 8 and Table III, it is clear that the decreasing λ_{min} mostly results in increasing number of triggers and performance of the system. From the simulation results, we can say that because of mobility the algorithm get triggered multiple times which can be controlled by setting proper value of λ_{min} and TH_{time}. But, in case of mobility, the CQI reporting of mobile users vary frequently hence, in such cases least received power channel selection can be a good solution. Our proposed solution is more suitable in case of indoor scenarios where users are mostly static or slowly moving.

V. Conclusions And Future Work

The proposed dynamic UCCS algorithm selects unlicensed channel that improves overall system performance and gives fairness among users. The simulation results show that the proposed algorithm can be used in dense deployment of LTE-U eNodeBs to improve the overall network performance. The performance can be further improved by using proposed user offloading algorithm. The centralized approach with coordination between different operators and RATs for CC selection can outperform the distributed and uncoordinated approach. Hence as a part of future work, we plan to develop the centralized and coordinated approach for CC selection in LTE-U.

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