ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2016.0186

ICTACT JOURNAL ON COMMUNICATION TECHNOLOGY, MARCH 2016, VOLUME: 07, ISSUE: 01

AN EFFICIENT QoS-CONSTRAINED RESOURCE ALLOCATION STRATEGY FOR MULTI-CARRIER MOBILE COMMUNICATION SYSTEMS

Srinivas Karedla[1] and Ch. Santhi Rani[2]
[1]*Department of Electronics and Communication Engineering, Acharya Nagarjuna University, India*
E-mail: srinivas_karedl@yahoo.com
[2]*Department of Electronics and Communication Engineering, Daita Madhusudana Sastry Sri Venkateswara Hindu College of Engineering, India*
E-mail: santhirani.ece@gmail.com

Abstract

Resource allocation strategies in Mobile Communication Systems (4G/5G) are proposed to enhance the data transmission and to meet the required QoS of the users by reducing the interference (inter/intra cell). The aim of this paper is to propose an efficient QoS-Constrained resource allocation strategy called QoS-Constrained Modified Load Matrix (QoS-MLM) for Multi -Carrier Mobile Communication systems under 4G LTE scenario to reduce interference and to improve aggregate throughput, packet delay. Simulation results show that by using QoS-MLM the aggregate throughput and packet delay has improved significantly when compared to benchmark schedulers.

Keywords:

Quality of Service (QoS), Resource Allocation, Cellular Radio, Interference, Aggregate Throughput, Long Term Evolution (LTE)

1. INTRODUCTION

As the resources (Power and Bandwidth) are limited to a communication system, it is required to develop an efficient resource allocation strategies to distribute resources between various user equipment's (UE's) by the system to ensure all the users promised data rates and assured Quality of Service (QoS). Resource distribution/allocation find its importance to provide high data rates (500 Mbps in the uplink and 1000 Mbps in the downlink) [1]. Various resource allocation strategies are developed for 4G (LTE) mobile communication systems both in uplink and downlink which are given in references [3-7]. To enhance the throughput of the system a scheduler is proposed in [3] by increasing the correlation between subcarriers of OFDMA. A scheduler for best use in non-real time traffic called as Proportional fair (PF) scheduling is proposed in [4] for which objective function is ratio of data rate corresponding to CQI of a user to maximum data rate supported. An allocation strategy best used for real time traffic which schedules the users based on their traffic flow in real time is developed in [5] which is an improvement of PF called Exponential-PF (EXP-PF). Resource allocation strategies particularly for LTE uplink are discussed in [6]. To decrease the transmission latency from UEs to a serving cell an uplink scheduling based on a Load balancing algorithm is proposed in [7]. Uplink scheduling strategies based upon channel state information is proposed in [8]. For Multi-Class services LTE uplink scheduling algorithms are proposed in [9]. A scheduling strategy based on delay experienced by the various users in the network is proposed in [10]. The comparison analysis of different uplink scheduling strategies are analyzed in [11]. In [12] a resource allocation strategy based on constraining the Quality of Service (QoS) of the users is proposed so as to increase the aggregate throughput decrease the transmission delay and increase the RB utilization. Resource allocation strategies can be implemented in two ways i.e., a) Centralized and b) Decentralized. In LTE if the resource allocation to all the UEs is done by the co-ordination between all of the eNodeBs through X2 interface it is called as the centralized or else if resource allocation to all the UEs is done by their serving eNodeB then it is called decentralized. Capacity of uplink in a mobile communication systems is constrained by the total received power at the eNodeB because of constraining the transmit power of UEs. In decentralized type of allocation the eNodeB allocates resources in a significance basis so that the predictable Interference over thermal is under a given threshold level. In decentralized allocation strategies the allocation of resources to users are considered with in an eNodeB by neglecting the effect of inter-cell interference which is considered better in a centralized type of scheduling. A significant proportion of IoT at eNodeB is arising from interference from the adjacent eNodeBs which the eNodeB has no knowledge which reduces the system capacity predominantly under hefty traffic conditions. In mobile communication systems the Inter-Cell Interference (ICI) can be reduced using inter cell interference coordination methods (ICIC methods) which enhance the channel conditions across the interference affected users and spectral efficiency is improved [15] and thus attaining spectral efficiency. For reducing ICI Fractional Frequency reuse method can be applied in which available frequency spectrum is split into two parts one cell center frequency and cell edge frequency. The cell edge frequency is assigned such that it is non-overlapping with other cells, in turn reduces interference at edges. Using selective distribution of total power in which cell center users use less power and cell edge users use more power. The eNodeBs exchange RNTP (Relative Narrowband Transmit Power) messages over X2 interface to indicate the time and frequency for which the power will be transmitted higher for the cell edge users.

Interference and Overload Indication [13]

In this method, High Interference Indicator (HII), a bitmap, shows setting up of cell edge UEs. This message is shared between adjoining cells. The cells be able to harmonize their scheduling assessments and evade interference for cell edge UEs.

Additionally, an Overload Indicator (OI) indicates when cell edge UEs experience high interference. The receiving eNodeB is then able to adjust power and reduce interference.

The methods listed above may reduce ICI but for an extremely loaded network the ICI is a predominant parameter. In this paper, firstly we address the ICI problem by proposing a resource allocation strategy called Modified Load Matrix which is a variant of Load Matrix strategy proposed for single carrier systems [14] then by using the concept of constraining the QoS of users so as to increase the aggregate throughput and RB utilization as proposed in [15] an efficient QoS-constrained Modified Load Matrix Resource allocation strategy (QoS MLM) is proposed.

4G LTE employs multi-carrier based mobile communication systems in which multiple access technologies used for uplink and downlink are single carrier–frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access(OFDMA) respectively. For these type of systems by setting the Interference over thermal (IoT) below a network defined threshold the ICI is reduced better when compared to the other mitigation techniques proposed in the past. Also before scheduling if users are sorted according to their QoS we can increase system throughput and RB utilization. The section 2 discusses about the system model and IoT, section 3 gives in detail about the analysis of resource allocation problem mathematically, section 4 discuss in detail about the Modified Load Matrix strategy, in section 5 the QoS-MLM strategy is proposed. In section 6 the procedure of simulating the QoS-MLM is discussed under 4G LTE compliant scenario and section 7 gives some insight for future study.

2. SYSTEM MODEL AND INTERFERENCE OVER THERMAL NOISE

2.1 SYSTEM MODEL

In this paper a multi-cellular Multi carrier mobile communication system in compliance with 4G LTE standards is considered in which the multiple access strategy for uplink and down link are single carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access (OFDMA) respectively [2]. Considering *N* eNodeBs in the system each with *U* active users. Practically in a multi-carrier system several sub carriers are grouped into a sub channel which constitutes a basic unit for resource utilization. Each user in a cell is assigned with different sub channels to avoid intra cell interference.

2.2 INTERFERENCE OVER THERMAL NOISE (IOT)

Using SC-FDMA which is FFT-Pre-coded version of OFDMA reduces the Peak Average Power Ratio (PAPR) compared with OFDMA. SC-FDMA transmits information symbols in serial way although maintaining the orthogonally among inter-cell users. Therefore, there is no intra-cell interference since the available spectrum is reused in neighboring cells especially when two or more edge users in neighboring cell use the same spectrum. Therefore inter-cell interference degrades the system output.

The transmission time interval in 4G LTE constitutes of 12 sub carriers which are grouped to form a primary resource block (PRB). LTE deploys localized FDMA for subcarrier mapping in which consecutive PRB's are assigned to same users. As required by L-FDMA each user is given some consecutive PRB's. In power allocation strategies to achieve a specific SINR level for a user the target IoT and inter-Cell interference level are generally considered. When a cell IoT value exceeds the specified target value then it informs all the UEs to raise their transmit powers to cope up with the situation but it will cause interference to the neighboring cells and the situation becomes worse as the neighboring cells also raise their power levels. Hence the adjacent cell users also boot up their transmit power which will make the situation worse.

To obtain desired IoT all eNodeBs are required to exchange their current IoT levels through X2 interface and the average IoT should be calculated and the eNodeB s should schedule their users that IoT level should not be going over IoT target and the Inter-cell interference is controlled.

2.2.1 Calculation of IoT Level at eNodeB:

For a certain eNodeB *j* IoT at a given Transmission time instant (TTI) '*w*' is calculated using,

$$IoT_{j,w} = (a + b + N')/N'. \tag{1}$$

In Eq.(1) '*a*' is the overall received power at eNodeB *j* due to the active users in the given eNodeB *j* and '*b*' is the total received power owing users in all eNodeBs excluding eNodeB *j*.

$$a = \sum_{k=1}^{K}\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right) \tag{2}$$

$$b = \sum_{k=1, k \notin eNB_j}^{K}\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right) \tag{3}$$

where, $p_{k,sc}$ is subcarrier power, $G_{k,sc}$ be the sub carrier channel gain.

The average value of IoT can be calculated over '*W*' TTIs at each eNodeB as,

$$IoT_{j,avg} = \frac{\sum_{w}^{W} IoT_{j,w}}{W} \tag{4}$$

where, *W* is the size of moving average window.

The change between the $IoT_{j,avg}$ and IoT_{target} is calculated and IoT correction indicator in dB is updated for definite TTIs as below.

Once the IoT correction meter is higher than zero, the eNodeB will send it to its adjacent interfering cells to specify the interference status via X2 interface. Put up on the IoT correction indicator (∅), each cell will estimate the accumulated IoT level of each neighboring interfered cell intermittently.

$$IoT_{accumulated,w} = IoT_{j,w} + \varnothing \tag{5}$$

To see the interference necessity of neighboring interfered cells, the principle of the power modification is to control the extreme transmit power of each UE so as to make the interference influence to each neighboring interfered cell lower than the resultant accumulated IoT level. Although an interfered cell perhaps suffers strong interference from multiple UEs coming from adjacent interfering cells, its IoT level will be increasingly congregated to the pre-defined IoT target. The reason lies in that for each repetition each interfering UE could adjust its transmit power to see the IoT condition of the neighboring interfered cell conferring to IoT correction indicator from all the adjacent cells.

The influence of Inter-cell interference problem is emphasized using the definite simulation scenario i.e. all the cells have same traffic spreading and interference situation. In each cell 5 users with full buffer are waiting for transmission. We have chosen this scenario to express the effect of Inter-cell interference in worst case scenario

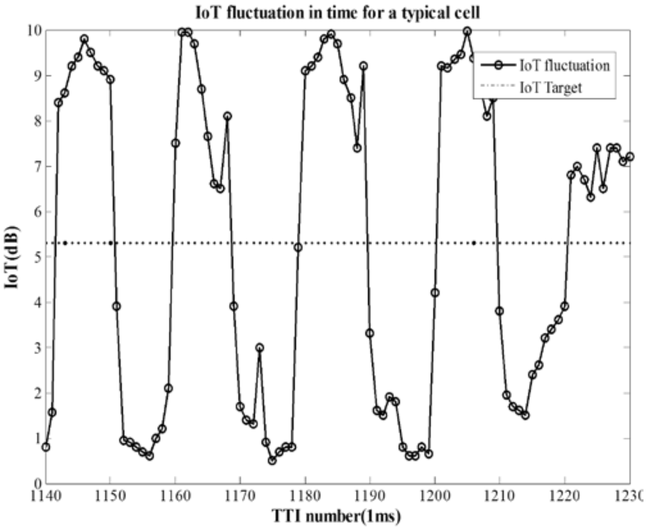

Fig.1. IoT fluctuation in a multi cell scenario

The Fig.1 shows the IoT fluctuation of a normal cell for a period of 10s and the TTI is considered as 1ms, at TTI 1150 the IoT level is way below the IoT target so the scheduler assigns resource to more users unaware that all other eNodeBs do the same thing. Owing this in the next scheduling interval the IoT increases way above the IoT target, then the scheduler cuts all the resources to the users. This continues and the IoT takes a pulse shape. As stated, the worst case scenario with respective to Inter-cell interference i.e. more fluctuations of IoT level over the IoT target results in more Inter-cell interference. Therefore using efficient resource allocation strategy, IoT level will be close to the IoT target at scheduling instants to decrease the Inter-cell interference.

3. RESOURCE ALLOCATION PROBLEM

The aim of allocating resources in wireless communication to the numerous users at a time in a faithful manner leads to complex quantization problems. The effects of interference, power usage at the base station and user equipment (UE) caused due to allocating radio bearers and eNodeB should be investigated in the time varying frequency selective fading channels. Employing an efficient resource allocation strategy these effects can be reduced. These effects are combinatorial in nature and computationally prohibitive.

Firstly we consider the resource allocation problem in single cell case and then multi-cell case.

3.1 SINGLE CELL CASE

Consider K UEs and N scheduling blocks in single eNodeB, the minimum data rate to be provided to the k^{th} user is R_k Mbits/s. The scheduling block in time domain is defined as set consisting of N_s OFDM symbols and N_{sc} sub carriers in the frequency domain. Due to control signals and other pilots only $N_{sc}^d(s)$ of N_{sc} are used to send the data of the s^{th} OFDM symbol with $s \in \{1,2,3,...N_s\}$ and $N_{sc}^d(s) \le N_s$. Let j is the set which represents different type of Modulation Coding and strategy and $j \in \{1,2,\ldots,J\}$, R_j^c the related code of MCS j, M_j is the constellation of the j^{th} MCS and T_s is the OFDM symbol duration, then the achieved data rate $r^{(j)}$ by a single SB is,

$$r^{(j)} = \frac{R_j^c.\log_2\left(M_j\right)}{T_s N_s}.\sum_{s=1}^{N_s} N_{sc}^d(s). \tag{6}$$

The Channel quality indicator (CQI) of k^{th} user on the N^{th} SB is, $g_k = [g_{k,1}, g_{k,2}, \ldots, g_{k,N}]$ and for all users on all SBs is $G = [g_1, g_2, g_3, \ldots, g_k]$. Further, for selecting the MSC by the n^{th} SB each user k sends its $g_{k,n}$ to the eNodeB and let the highest rate MCS supported by the k^{th} user for the n^{th} SB at CQI value $g_{k,n}$ is indexed by, $q_{k,\max(g_{k,n})} \in \{1,2,....,J\}$.

The Maximum throughput that can be obtained by user k on one sub-frame in eNodeB is,

$$r_k = \sum_{n=1}^{N} \rho_{k,n} \sum_{j=1}^{q_{k,\max(g_{k,n})}} b_{k,j}\, r^{(j)} \tag{7}$$

where,

$$\rho(k,n) = \begin{cases} 1 & \text{if } n^{\text{th}} \text{ SB is allocated to the } k^{\text{th}} \text{ user} \\ 0 & \text{if for all } k'k \text{(one SB is assigned to one and a single user)} \end{cases}$$

$b_{k,j} = 1$ if j^{th} MSC is chosen by user k.

An efficient allocation of radio resources is required for maximization of throughput of all users in single eNodeB subjected to the constraints:

$$\max \sum_{k=1}^{K} r_k \tag{8}$$

Constraint to:

$$r_k \le R_k \forall k \tag{9}$$

$$\rho_{k,n} = 1, \quad \rho_{k,n} = 0 \,\forall k \ne k' \tag{10}$$

$$\sum_{j=1}^{q_{k,\max(g_{k,n})}} b_{k,j} = 1 \tag{11}$$

The Eq.(8) represents the objective function, Eq.(9) represents the constraint that promises the minimal data rate to the user and Eq.(10) ensures that a single user is assigned by one SB. In Eq.(11), MSC is same for all SBs (it is an LTE networks constraint).

The Eq.(8) can be shown to be a NP-hard one and can be compared to the classic Knapsack problem and in literature different algorithms are developed to reach the objective.

3.2 MULTIPLE CELL CASE

Multi-cell case of the problem is considered when an area is covered by N eNodeBs with a total of U users (i.e. $\sum_{j=1}^{N} K_j$) with K_j representing users in eNode j .The expression for Multi-cell resource allocation problem is almost same except the constraint in Eq.(8) should be expressed as follows,

$$r_k \le R_{k,j} \quad \forall k,\, j;\, j \in \{1,2,...,N\} \tag{12}$$

where,

j represents one of the eNodeB in N eNodeBs

$r_{k,j}$ represents the minimal data rate in one subframe for the k^{th} user

$R_{k,j}$ is the maximum possible data rate to the k^{th} user in eNodeB j.

Single cell resource allocation problem is same as multi-cell resource allocation $N = 1$. Since SCRAP is NP-Hard the MCRAP is also NP-hard and both cannot be solved by a polynomial time algorithm and therefore a good resource allocation strategy is required to solve the objective.

4. MODIFIED LOAD MATRIX

Scheduling in uplink of multi carrier based mobile communication system requires to assign radio resources to all the users whilst to meet their QoS requirements. An efficient resource allocation strategy called Modified Load Matrix is proposed which controls inter-cell interference and optimizes the through put by allocating resources to the users.

Given a Mobile Communication System of U users and N eNodeBs, the constraints to be satisfied are,

Constraint 1: For each active user k in the network the transmission power should be ensuring the condition,

$$p_k \leq P_{k,\max} \forall k \tag{13}$$

Power per subcarrier of k^{th} user is calculated as,

$$p_{k,sc} = \frac{p_k}{12(F_k)} \tag{14}$$

Since group of 12 subcarriers form a resource block and F_k number of successive PRBs selected from the set $F \in \{F_1, F_k, \ldots F_K\}$ is assigned to a user in SC-FDMA.

Constraint 2: The inter cell interference parameter is kept intact if the interference over thermal noise (IoT) at a given eNodeB j is below the threshold i.e. IoT_{traget}. Constraint 2 can be expressed as follows,

$$IoT_{j,w} = \frac{\sum_{k=1}^{K}\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right) + N'}{N'} \tag{15}$$

$$IoT_j \leq IoT_{target}. \tag{16}$$

Normally, the target value of IoT is stated by the network operator to keep uplink interference level in control and is between 3 to 10dB. In this work it is set to 5.3dB for simulation.

Constraint 3: For each active user in the network based on channel type, each rate r_k has minimum required SINR called $SINR_{target,k}$ where, $SINR_{target,k}$ is the signal to interference plus noise ratio required at eNodeB if rate r is assigned to user k to achieve a given block error rate or frame error rate. Constraint 3 can be given as follows,

$$SINR_k \geq SINR_{target,k}. \tag{17}$$

The Modified Load Matrix is a data base consisting of all active users Load factors. Modified Load Matrix can be implemented using the centralized and decentralized scheduling. In this paper the centralized scheduling is considered.

The Load factor contributed by active user k in eNodeB j is expressed as,

$$MLM_{k,j} = \frac{\sum_{sc} p_{k,sc} * G_{k,sc}}{N' + \sum_{k=1}^{K}\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right)} \tag{18}$$

where, $\Sigma_{sc} p_{k,sc} * G_{k,sc}$ represents the power received by eNodeB from the active user k.

By using $LM_{k,j}$ values stored in column j of LM database IoT of eNodeB at w TTI can be calculated as,

$$IoT_{j,w} = \frac{1}{1 - \sum_{k=1}^{K} LM_{i,j}}. \tag{19}$$

Also,

$$SINR_{k,j} = \frac{\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right)}{N' IoT_{j,w} - \left(\sum_{sc} p_{k,sc} * G_{k,sc}\right)}. \tag{20}$$

Since the data rate allocated to a user is function of SINR i.e., signal to noise plus interference ratio the power allocated to a user should be varied in accordance with IoT Correction indicator $\varnothing$ and to keep accumulated IoT level below the IoT_{target} and $SINR_{k,j}$ above the $SINR_{target,k}$ respectively.

The allowed transmission power to decrease inter-cellular interference is calculated as follows,

$$p_k = \frac{N' IoT_{target} SINR_{target,k} \left(12 * F_k\right)}{\sum_{sc} G_{k,sc}\left[1 + SINR_{target,k}\right]}. \tag{21}$$

The above assigned is acceptable if it satisfies the three constraints specified above. Initially it should satisfy the Constraint 1, by observation Constraint 3 has already got satisfied because the $SINR_{k,j}$ is considered as $SINR_{target,k}$. Now the Constraint 2 which takes into account the effect of inter-cell interference caused by allocating this power to the user. Constraint 2 verifies whether the inter-cell interference caused by the user k in the neighboring cells does not raise the IoT level above the IoT target.

For this the $MLM_{k,j}$ has to be updated for all the elements of row k. The Load Factor imposed by user k on eNodeB is given as,

$$MLM_{k,j} = \frac{\sum_{sc} p_{k,sc} * G_{k,sc}}{N' + \sum_{k=1}^{K}\left(\sum_{sc} p_{k,sc} * G_{k,sc}\right)} \tag{22}$$

where, $p_{k,sc} = \frac{p_k}{12(F_k)}$.

Using Eq.(22) the IoT can be expected and now check if Constraint 2 fulfils or not. If yes the data rate is acceptable and will be assigned else the same process will be repeated for remaining possible data rates. If none of the data rate is satisfied the above constraints it will be scheduled for next instant of transmission and is given the highest priority.

After assigning the data rates to all the users in the first round Modified Load Matrix elements are updated a new IoT is evaluated in each cell using Eq.(19). This is because Eq.(20) and Eq.(22) are valid only if IoT is closer to IoT target . It is not possible to achieve IoT_{target} since this is a NP-hard problem and requires more rounds. Precisely, on each instant of scheduling, p_k is iteratively adjusted in Eq.(19) and then Eq.(20) by substituting IoT_{target} with updated IoT from MLM in Eq.(18) after each round of rate allocation. By this the probability of interference outage lowers and increasing the resource utilization with possible highest IoT (less than target) in each cell.

For assigning priority to the users in the next scheduling instant for those who are not scheduled for transmission in the previous instant, the priority function as proposed in [15] is used to the multi carrier mobile communication system also and the priority function takes into consideration of sub channel gains in giving the priority. As it is obvious that a user with good channel condition can result in better throughput but in a multi-cell case may have severe impact on throughput of other cells. Hence a global priority function is stated as follows,

$$priority_k = \frac{\sum_{sc} G_{k,sc,j}}{\sum_{n=1}^{N} \sum_{sc} G_{k,sc,n}} \quad \forall k \in \{1,...K\} \tag{23}$$

where, the $G_{k,sc,j}$ be the subcarrier channel gain from user k to the eNodeB of cell j.

Modified Load Matrix approach for Multicarrier communication system tries to increase the system capacity by inter and intra cell interference management. Table.1 summarizes the MLM algorithm for rate assignment in a multi cell scenario. The step 1 of MLM allocation process initializes all the MLM elements to zero and users in every cell are prioritized using Eq.(21). The resources to users in each cell are increased up to a point to avoid inter-cell interference .The approach consists of a no of assignment rounds same as the no of users. MLM serves the highest priority user in each cell in every round of assignment, updates MLM elements and checks whether the IoT level in each cell is less than IoT_{target}, if yes, it means the rates assigned are valid and do lead to interference in other cells. If no, the user is scheduled for the other next instant.

Table.1. Modified Load Matrix

```
Scheduling Procedure
Initialize MLM[i,j] to zero
for cell j=1:N
    for user[i] in cell[j]
        set priority[i,j] as in (23);
    end
  sort all users in cell[j] according to priority[i,j]
end
for assignment round=1:Number of users per cell
     for cell j=1:N
       for the highest priority user[i] in cell[j] if MLM[i,j]=0
         for data rate of user k $r_k$ =Max possible: Min possible
           get $p_k$ using (21);
(constraint 3 is already satisfied)
Next data rate cnst3 is not satisfied)
Check IoT[j] with "intra-cell margin";
Next rate if constraint 2 is not satisfied;
Check for all other IoT[;]with "inter-cell margin"
Next rate if constraint 2 is not satisfied
Update MLM[i,j];
end;
end;
remove user[i] from sorted users of cell[j]
end; end;
```

MLM approach uses margin concept i.e. while checking the IoT level of each cell in every round of assignment it checks for a margin around the IoT_{target} instead of a fixed IoT_{target} value. Two variables called inter-cell margin and intra-cell margin are used for taking better decision during the check process. The intra-cell margin is the region around IoT_{target} in which user loading in serving cell should not cross. The inter-cell margin which limits variations of overall IoT is caused by a user from other cells.

5. QOS CONSTRAINED MODIFIED LOAD MATRIX (QOS-MLM)

QoS-MLM scheduling is a three step allocation approach as depicted in the Fig.2. The first step employs a time domain scheduler used to classify the active user services into various QoS Classes. Specifically delay constrained services are noted. The second step employs MLM scheduling to prioritize the incoming packets of the users according to their channel gain as discussed in section 4. The third step constitutes of assigning RB's (available) as per stated by the strategy using the appropriate modulation downgrade under the two constraints of SC-FDMA.

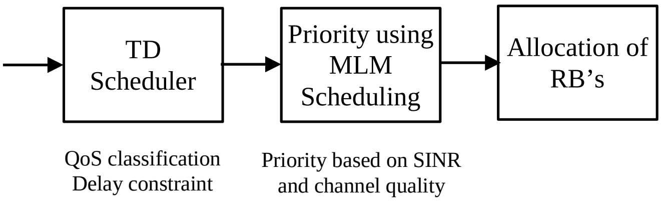

Fig.2. Flow of QoS-MLM scheduling in uplink

5.1 STEP 1-1(TD): CLASSIFICATION OF RESOURCE TYPE BASED ON QCI

In our method, resource types classification based on QCI by 3GPP as given in Table.2. Based on QCI resource types are classified into GBR and non-GBR type. They are subdivided into 9 QCI (QoS Class Identifier) ranks with diverse packet delay budget and packet error loss rate. When the packets of each UE service arrive, they are classified according to Table.1 and assigned to different service queues. The RBs are allocated to UEs of type GBR followed by UEs with non-GBR bearer service.

Table.2. QCI based resource type classification

QCI	Resource type	Priority	Packet delay Budget (in ms)	Packet Error Loss Rate	Example Services
1	GBR	2	100	10^{-2}	Conversational voice
2		4	150	10^{-3}	Conversational video
3		3	50	10^{-3}	Real time gaming
4		5	300	10^{-6}	Non-Conversational video
5	NON-GBR	1	100	10^{-3}	IMS signaling
6		6	300	10^{-6}	Video TCP-based
7		7	100	10^{-6}	Voice, video, interactive gaming
8		8	300	10^{-3}	Voice TCP-based
9		9	300	10^{-6}	

5.2 STEP 1-2(TD): QoS CONSTRAINED SCHEDULING OF GBR SERVICE

For GBR packet scheduling, the scheduler should see the packet delay budget. The packets bearing GBR service should not get overdue, hence these packets are assigned highest priority to acquire RB's. Formula we proposed to calculate the number of RBs to be allocated to UE *u* at time *t*, $N_{RB\text{-}GBR}(u,t)$ for GBR service is,

$$N_{RB-GBR}(u,t)=\left\lceil \frac{Q_i(u)+n_{q_i}(u,t)\times L}{d\times N_{RE}\times mc_{level}(u,t)}\right\rceil \quad u=1,2,...,U \tag{24}$$

In Eq.(24) U: the number of active users, $Q_i(u)$: the number of packets of UE u queuing in q_i, which are not successfully delivered in the previous time unit, q_i: type i of queues corresponding to the nine QCI ranks, $1 \leqq i \leqq 9$, $n_{q_i}(u,t)$: the number of packets of UE u queuing in q_i at time t, L: the length of packet data (bits), d: packet delay budget, N_{RE}: the number of resource elements (RE) of a RB, $mc_{level}(u,t)$: the number of data bits (bits), using a certain rank of modulation, that can be transmitted by a resource element of UE u at time t.

5.3 STEP 1-3 (TD): QoS-CONSTRAINED NON-GBR BEARER SERVICE SCHEDULING

Non-GBR packets mainly considers whether the destination can be reached successfully. So, it is not important to consider delay budget for these packets. Low service priority are assigned to them, and no fixed RBs are available in the near future. For fixed RB allocation of Non-GBR service, our method uses maximum bit rate (MBR) to ensure each UE may get a definite number of RBs to avoid UE from starvation. The formula to allocate the number of RBs to UE *u* at time *t*, $N_{RB\text{-}nonGBR}(u,t)$ for Non-GBR service. Where $R_{i\max}(u)$ is the maximum reserved rate (bps) for UE *u*.

$$N_{RB-nonGBR}(u,t)=\left\lceil \frac{R_{i\max}(u)}{1000\times N_{RE}\times mc_{level}(u,t)}\right\rceil \quad u=1,2,...,U \tag{25}$$

5.4 STEP 2: ALLOCATING RBS USING MLM

In the real scenario the number of accessible RBs is limited. For connection admission control, the scheduler has to find whether the accessible RBs i.e. the data rate is sufficient and whether it satisfies the Constraints 1, 2 and 3 of MLM .The total number of system RBs can be found in the mapping table of channel bandwidth and number of RBs specified by 3GPP (Table.3). The number of current available RBs can be calculated by the expression,

$$RB_{available}(t)=RB_{total}(t)-\sum_{u=1}^{U}N_{RB}(u,t). \tag{26}$$

Let $RB_{total}(t)$ be the total of requested RBs of UE *u* at time *t*, $RB_{available}(t)$ be the number of available RBs. When there is new request of connection, the system simply checks whether $RB_{available}(t)$ is greater than satisfies all the constraints of MLM. If yes, the connection request is admitted. Otherwise, the request is rejected.

Table.3. Mapping between channel bandwidth and number of RB in frequency band of LTE

Channel BW in MHz	1.4	3	5	10	15	20
#RBs in frequency band	6	15	25	50	75	100

5.5 STEP 3: ADAPTIVE ADJACENT RBS DISTRIBUTION

As SC-FDMA is required to allocate adjacent RBs and the allocated RBs have to use the same modulation technique. These two limits apply modulation downgrade to the same rank in order to concatenate adjacent RBs. Though, uninhibited modulation downgrade may cause overall system performance degradation. This is since every RB is capable to transmit less data volume using lesser rank of modulation technique. Therefore, control the modulation downgrade to a definite degree is necessary. The previous formulae are improved to the following ones.

For GBR:

$$N_{RB-GBR}(u,t)=\left\lceil \frac{Q_i(u)+n_{q_i}(u,t)\times L}{d\times N_{RE}\times mc_{level-i}(u,t)}\right\rceil \quad u=1,2,...,U \tag{27}$$

For Non-GBR:

$$N_{RB-nonGBR}(u,t)=\left\lceil \frac{R_{i\max}(u)}{1000\times N_{RE}\times mc_{level-i}(u,t)}\right\rceil \tag{28}$$

Notice that $mc_{level}(u,t)$ is changed to $mc_{level-i}(u,t)$ to indicate the control of modulation downgrade.

6. SIMULATION RESULTS

Initially the proposed Modified Load Matrix is implemented in Multi-carrier Mobile Communication system using MATLAB communication and signal processing tool box in compliance with 4G LTE standards. The results are compared with the commonly used uplink schedulers such as Round Robin (RR), proposed minimum area difference (MAD) and First maximum expansion (FME) as proposed in [11]. The List of simulation parameters are tabulated in Table.4. The pdf of IoT is observed in a simulation scenario with [0%, 1%, 2%] inter-cell margin effect and is plotted in Fig.3. The 0% inter-margin can be considered as no hysteresis case. It can be observed from Fig.3 that the IoT with 5.3dB is occurring mostly in different cases hence it is fixed as the threshold for performance evaluation. The pdf of IoT is observed in a simulation scenario with [0%, 1%, 2%] intra-cell margin effect and is plotted in Fig.4. The PDF of IoT of the best three combinations of Inter and intra cell margin effect is shown in Fig.5. The objective in this paper is to show the impact of inter-cell interference on the system performance using various scheduling algorithms. It is known that comparing upper-bound limit is a better indication of scheduling algorithm efficiency. The CDF curves of IoT as shown in Fig.6, Fig.7 and Fig.8 shows that upper-bound limit is defined as 'step function' means that using MLM there is a maximum possibility of maintaining IoT near the IoT_{target} and the possibility of IoT raising above IoT_{target} is very less. The Interference outage (IoT raising above IoT_{target}) affects the parameters like throughput and packet delay of the system. The aggregate throughput with different number of active users using different benchmark schedulers (RR, MAD, FME) is plotted in Fig.9. It is observed that, there is a significant increase in throughput when using MLM .The packet delay performance of different schedulers is shown in Fig.10. It can be observed in Fig.10 that 92% of the packets experiencing a delay less than 42 TTI'S using MLM when compared to others experiencing delay approximately close to 200 TTI'S when using the other scheduling algorithms. Finally under the same scenario QoS constrained MLM scheduler is evaluated. The plot of PDF of IoT found by using the QoS-MLM considering the best three combinations of inter-cell, intra-cell combinations can be observed from Fig.11. It is observed hat the probability of IoT reaching IoT_{target} is significantly more using QoS-MLM scheduler which indicates the better control of interference than MLM scheduling. Likewise the performance comparison without QoS-MLM and with QoS-MLM scheduling in terms of throughput, packet delay for various conditions of traffic i.e., in terms of [voice]:[gaming]:[buffered] is plotted in Fig.12, Fig.13, Fig.14 and Fig.15. From Fig.11, Fig.12, Fig.13, Fig.14 and Fig.15, it is observed that there is a significant increase in performance when compared to a QoS constrained resource scheduler proposed in [12].

Table.4. Simulation parameters

Parameter	Value
Channel bandwidth and Carrier frequency	5MHz and 2GHz
Sub-frame Length	1ms
No. of primary resource blocks (PRBS)	25
UEs traffic ratios (VoIP: gaming: buffered)	1:1:3, 1:2:2, 1:3:1, 2:2:1, 3:1:1
No. of subcarriers in PRB	12
No. of symbols per resource block	7
Sub carrier spacing	15kHz
Path loss model	128.1 + 37.6 log10 d, d: distance from the eNodeB (km)
Modulation and Coding Schemes	QPSK 1/2, 16-QAM 1/2, and 64- QAM ¾
Maximum UE transmission power	23dBm
Minimum UE transmission power	-43dBm
Fading	Rayleigh
IoT target	5.3dB

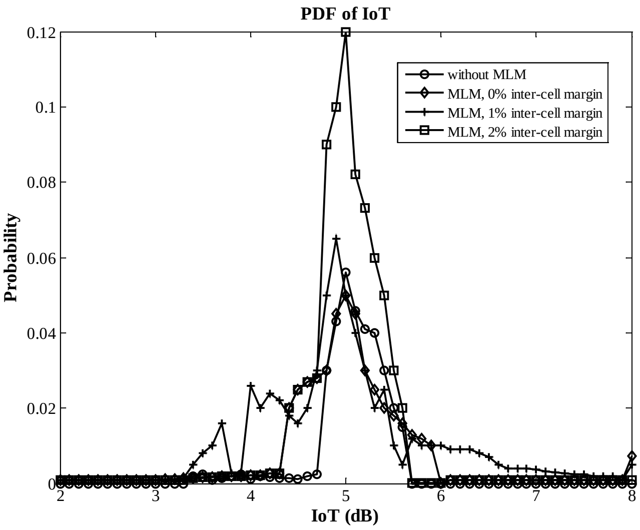

Fig.3. PDF of IoT (inter-cell margin effect)

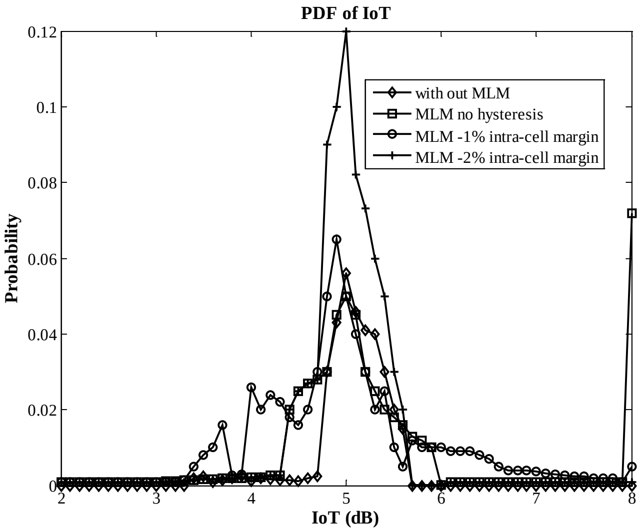

Fig.4. PDF of IoT (intra-cell margin effect)

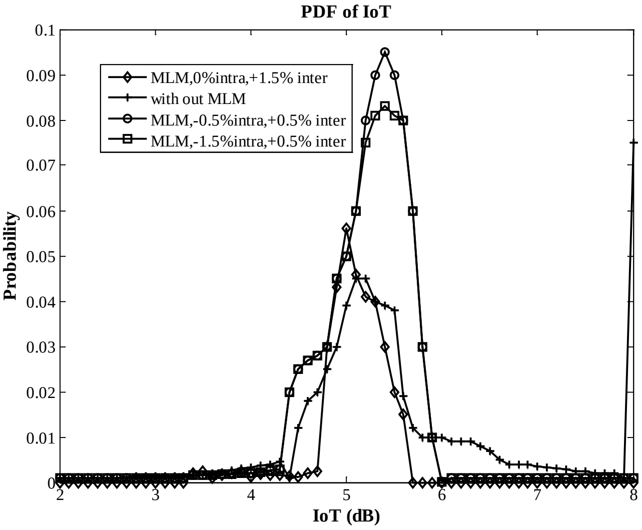

Fig.5. PDF of IoT (best three combinations)

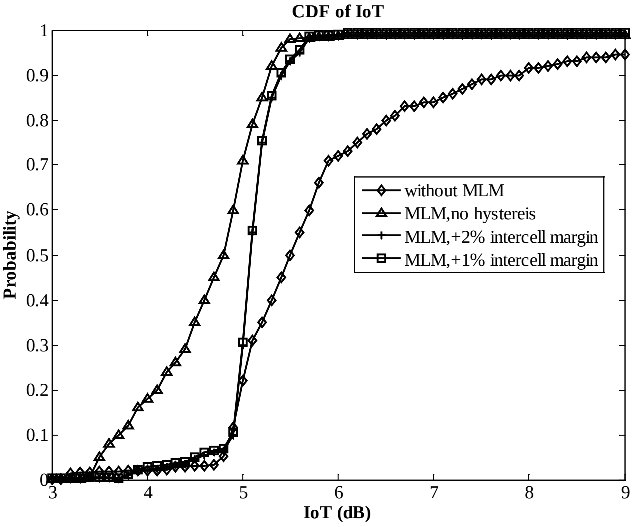

Fig.6. CDF of IoT (inter-cell margin effect)

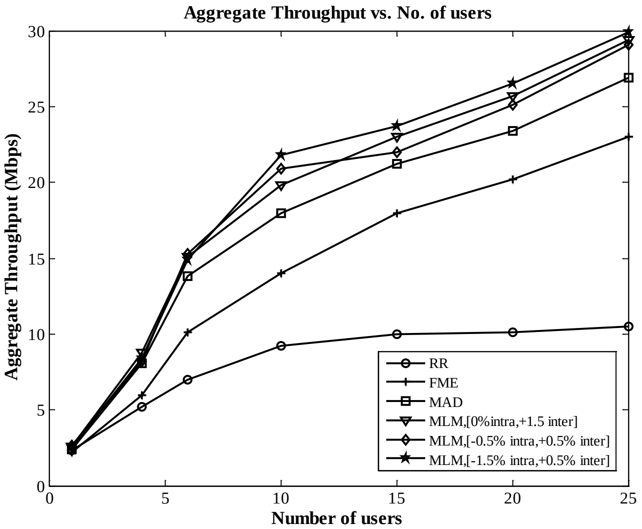

Fig.9. Aggregate Throughput vs. No. of Users

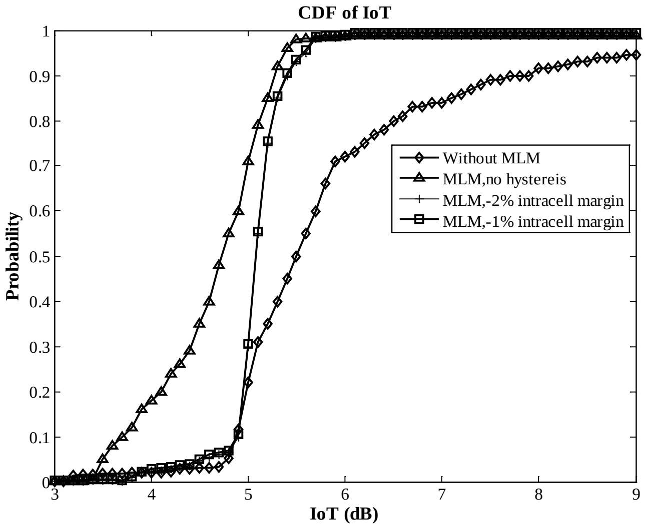

Fig.7. CDF of IoT (intra-cell margin effect)

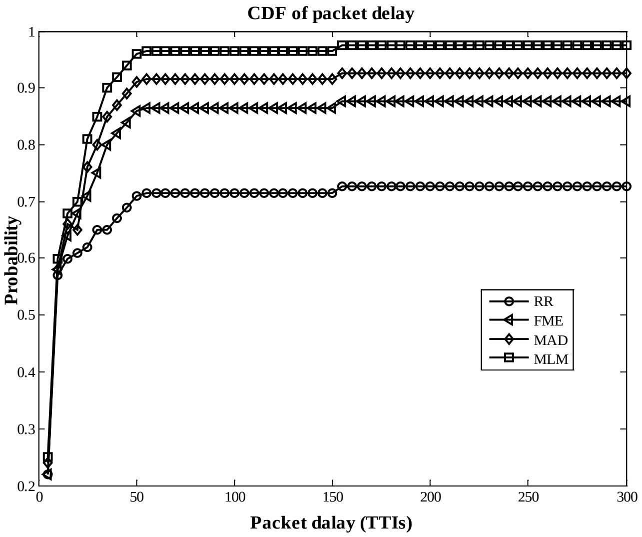

Fig.10. CDF of packet delay

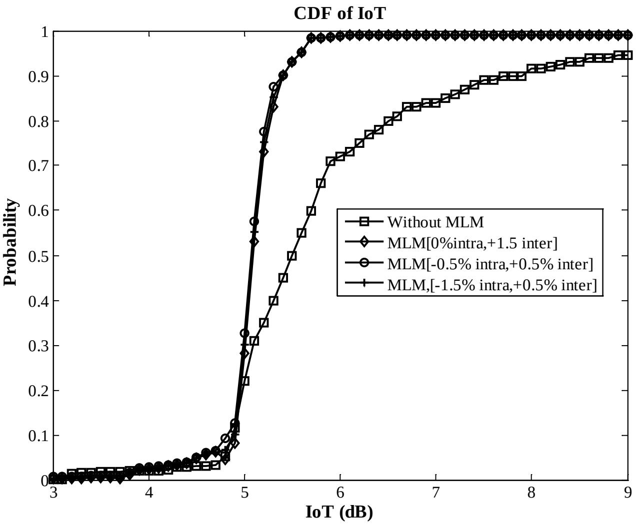

Fig.8. CDF of IoT(best three combinations)

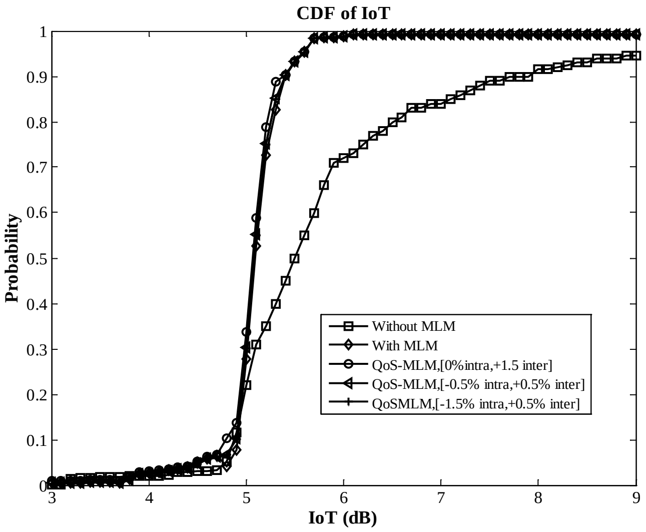

Fig.11. CDF of IoT (best three combinations)

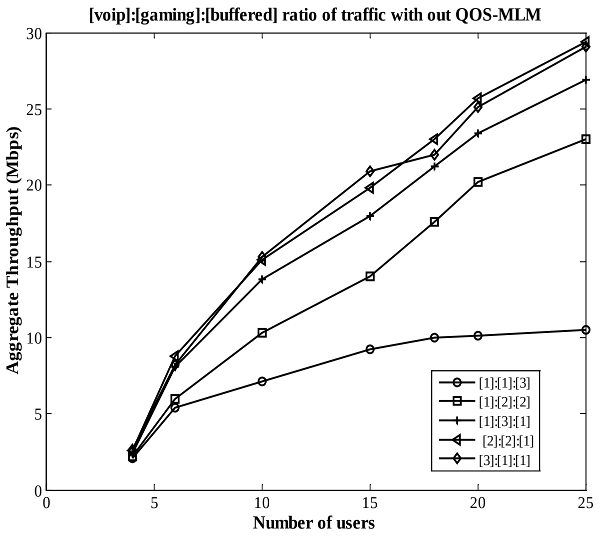

Fig.12. Aggregate Throughput vs. No. of users (without QoS MLM)

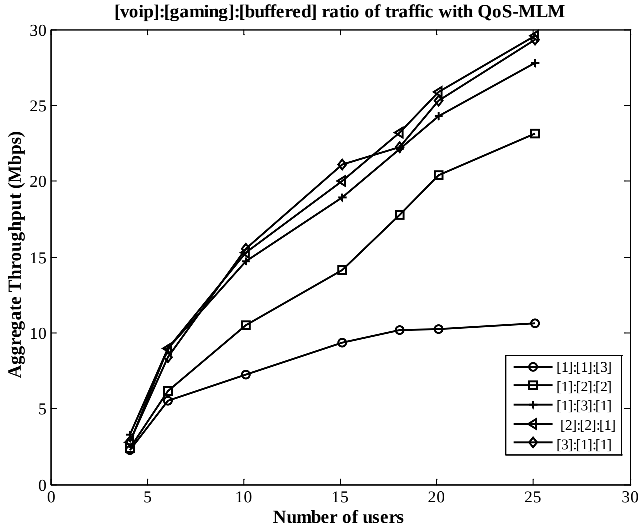

Fig.13. Aggregate Throughput vs No. of users (with QoS MLM)

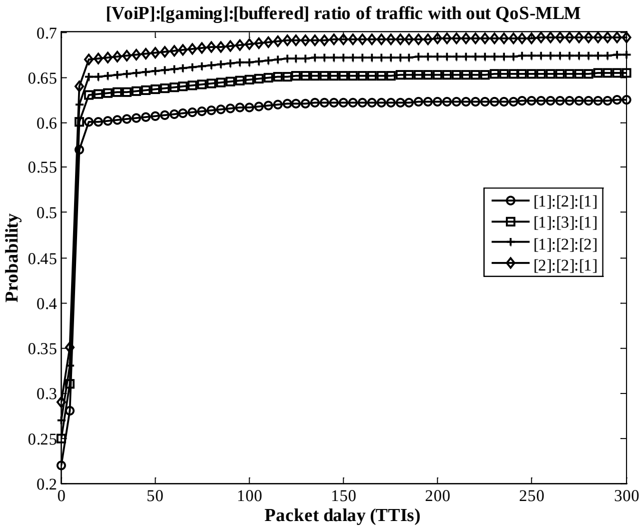

Fig.14. PDF of packet without QoS-MLM for different traffic

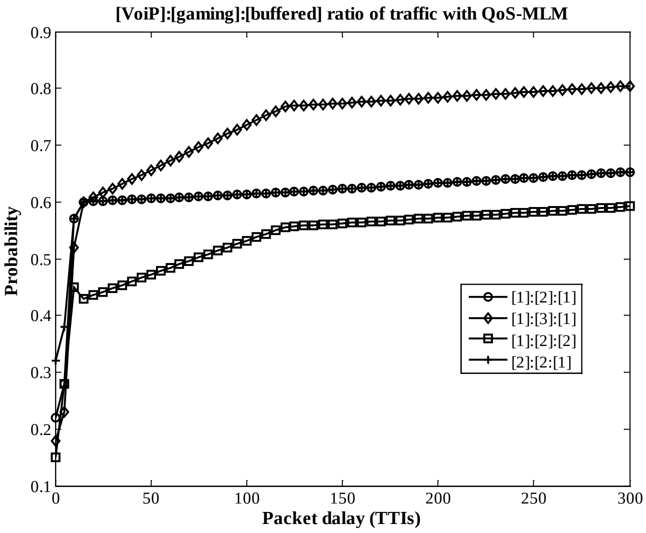

Fig.15. PDF of packet delay with QoS-MLM

7. CONCLUSION

In this paper resource allocation approaches called modified Load matrix approach and QoS constrained Modified Load Matrix is proposed for multi-carrier based mobile communication systems in which SC-FDMA is used as multiple access in uplink to control interference by keeping the parameter called IoT below the specified target value. The simulation is carried under 4G LTE compliance and interference outage performance is compared with different benchmark scheduling algorithms. The performance measures like through put and packet delay is evaluated and compared with the standard schedulers. The proposed approach combined with different subcarrier allocation i.e., Localized FDMA and Interleaved FDMA methods can remain as future study.

REFERENCES

[1] 3GPP TR 36.913, “Requirements for Further Advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced)”, 2009.

[2] 3GPP TR 36.814, “Further Advancements for E-UTRA Physical Layer Aspects”, Version: 9, 2010.

[3] R. Kwan, C. Leung and J. Zhang, “Downlink Resource Scheduling in an LTE System”, *Mobile and Wireless Communications: Physical Layer Development and Implementation*, pp. 189-208, 2010.

[4] R. Kwan, C. Leung and J. Zhang. “Proportional Fair Multiuser Scheduling in LTE”, *IEEE Signal Processing Letters*, Vol. 16, No. 6, pp. 461-464, 2009.

[5] R. Basukala, H.A.M. Ramli and K. Sandrasegaran, “Performance Analysis of EXP/PF and M-LWDF in Downlink 3GPP LTE System”, *Proceedings of IEEE First Asian Himalayas International Conference on Internet*, pp. 1-5, 2009.

[6] F.I. Sokmen and T. Girici, “Uplink Resource Allocation Algorithms for Single-Carrier FDMA Systems”, *Proceedings of European Wireless Conference*, pp. 339-345, 2010.

[7] Haider Safa and Kamal Tohme, "LTE Uplink Scheduling Algorithms: Performance and Challenges", *Proceedings of 19th International Conference on Telecommunications*, pp. 1-6, 2012.

[8] L.A.M. Ruiz de Temin, G. Berardinelli, S. Frattasi and P. Mogensen, "Channel-Aware Scheduling Algorithms for SC-FDMA in LTE Uplink", *Proceedings of IEEE 19th International Symposium in Personal, Indoor and Mobile Radio Communications*, pp. 1-6, 2008.

[9] Oscar Delgado and Bridgite Jaumard, "Scheduling and Resource Allocation for Multiclass Services in LTE Uplink Systems", *Proceedings of IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications*, pp. 355-360, 2010.

[10] Z. Li, C. Yin and G. Yue, "Delay-Bounded Power-Efficient Packet Scheduling for Uplink Systems of LTE", *Proceedings of 5th International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 1-4, 2009.

[11] Khalid Elgazzar, Mohamed Salah, Abd-Elhamid M. Taha and Hossam Hossanein, "Comparing Uplink Schedulers for LTE", *Proceedings of 6th International Wireless Communications and Mobile Computing Conference*, pp. 189-193, 2010.

[12] Hung-Chin Jang and Yun-Jun Lee, "QoS-Constrained Constrained Resource Allocation Scheduling for LTE Network", *Proceedings of IEEE International Symposium on Wireless and Pervasive Computing*, pp. 1-6, 2013.

[13] C. Kosta, B. Hunt, A.U. Quddus and R. Tafazolli, "On Interference Avoidance through Inter-Cell Interference Coordination (ICIC) based on OFDMA Mobile Systems", *IEEE Communications Survey & Tutorials*, Vol. 15, No. 3, pp. 973-995, 2012.

[14] M. Abaii, Y. Liu and R. Tafazolli, "An Efficient Resource Allocation Strategy for Future wireless Cellular Systems", *IEEE Transactions on Wireless Communications*, Vol. 7, No. 8, pp. 2940-2949, 2008.

[15] Yong-Seok Kim, "An Efficient Scheduling Strategy to Enhance the Capacity of VoIP Services in Evolved UTRA uplink", *Journal on Wireless Communications and Networking*, Vol. 2008, No. 28, 2008.