A Quality of Service (QoS) Constrained Resource allocation Strategy for MC-DS-CDMA Systems

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Abstract

Quality of service (QoS) resource allocation strategies helps in enhancing the performance of a resource allocation strategy. Generally, in QoS constrained resource allocation strategies in uplink [4], a three stage approach is implemented for allocation of resources. In the first stage user equipment’s (UEs) are differentiated using a time domain scheduler based on QoS requirements, in the second stage they are prioritized using a frequency domain scheduler based on their SINR requirements and channel quality and third stage allocation of required resource blocks using a resource allocation strategy. In this paper, a QoS constrained resource allocation strategy based on modified load matrix (QoS-MLM) is proposed for multi-cell MC-DS-CDMA mobile communication system in compliance with LTE scenario. Simulation results show that the aggregate throughput, packet delay benchmark schedulers.

Keywords: Quality of Service (QoS), aggregate throughput, packet delay, resource allocation.

I. INTRODUCTION

Resource allocation plays an important role to improve the performance of the mobile communication system from generation to generation (i.e., from 2G to 5G) by assuring all the users the promised Quality of Service. Interference (inter-cell and intra-cell) is an inherent drawback in mobile communication systems which is to be decreased to improve the performance of the system. Generally, in a downlink scenario intra-cell interference is predominant than inter-cell interference and a variety of downlink resource allocation strategies are proposed in the past to decrease the effect of intra-cell interference for single carrier systems. In a mobile communication, the uplink cell capacity in an interference limited system is restricted by the total received power at
the cell as the transmit power of user equipment’s (UEs) is limited, also in a multi-cell scenario, the base station has no knowledge of the interference of the powers from the neighboring base stations which leads to inter-cell interference. Inter-cell interference is predominant in uplink and which severely degrades the performance of the system in highly loaded conditions and has to be decreased. In [3], the effect of inter-cell interference in single carrier systems is controlled by keeping rise over thermal noise (RoT) below a threshold value, and proposed a resource allocation strategy called Load Matrix. It is noted that from [5] that a parameter called interference over thermal noise (IoT) defined for multi-carrier systems which helps in controlling the interference (intra-cell and inter-cell. By constraining the QoS of active users, the performance of allocation strategy and schedulers are enhanced [4].

In LTE[7], MC-DS-CDMA in uplink gives better PAPR performance than SC-FDMA, which motivates to evaluate the performance of allocation strategy in MC-DS-CDMA mobile communication systems. In this paper the performance of QoSMLM strategy is evaluated in MC-DS-CDMA mobile communication system also in a multi-cell scenario. In section II, system model and the evaluation of IoT in a multi-cell scenario is presented. In section III, multi-cell resource allocation problem and the type of methods used to solve this problem is presented. In section IV the QoSMLM and its application to MCRAP is presented. In section V the performance of QoSMLM in MC-DS-CDMA systems in terms of aggregate throughput and packet delay is analyzed. In section VI, conclusion and few directions into the future study is presented.

II. SYSTEM MODEL AND IOT

Two schemes of realizing the multi-carrier spread spectrum are (i) MC-CDMA which is referred to as CDMA-OFDM and (ii) MC-DS-CDMA. In these two schemes by using separate user specific spreading codes, all the users are able to share all the spectrum at the same duration and differentiation of user’s data is done in code domain. In this work, a cellular communication system with \(N\) cells and \(M\) users in every cell is considered and the multiple access technology for uplink and downlink is MC-DS-CDMA. MC-DS-CDMA is a modulation process in which the DS-CDMA information is transmitted over multi-carriers. The every data symbol of the user is transmitted over a different sub-channels of very narrow band widths simultaneously in MC-CDMA. Every chip of the user-defined spreading code is multiplied by defined narrow band sub-channels. The use of MC-DS-CDMA helps in achieving less peak to average power ratio in uplink than MC-CDMA. In this work, a MC-DS-CDMA cellular communication system in a multi-cell scenario is considered, let \(M\) denote the number of cells or base stations or eNodeB in the network each consisting of \(N\) active users and \(K\) be the number of sub-carriers used in the MC-DS-CDMA. The IoT of a cell \(i\) at a given TTI ‘\(w\)’ denoted as \(IoT_{i,w}\) is calculated as follows
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\[ IoT_{i,w} = \frac{r + s + N'}{N'} \]  \quad (1)

Where

\( r \) - The total received power at eNodeB \( i \) due to the active users in the given eNodeB \( i \)

\( y \) - the total received power of users in all eNodeB excluding eNodeB.

\[ r = \sum_{j=1}^{M} \left( \sum_{sc} p_{j,sc} \cdot G_{j,sc} \right) \]  \quad (2)

\[ s = \sum_{j=1, k \in eNB_i}^{M} \left( \sum_{sc} p_{j,sc} \cdot G_{j,sc} \right) \]  \quad (3)

\( p_{k,sc} \) - subcarrier power

\( G_{k,sc} \) - The subcarrier channel gain.

\( N' \) - Thermal noise power.

The term \( s \) is referred to as an inter-cell interference to the given eNodeB \( i \) in the uplink. The effect of inter-cell interference is observed using a definite simulation scenario. In each cell 5 users with full buffer are waiting for transmission. The IoT characteristic under this scenario is as shown in the figure 1.

III. QoS CONSTRAINED MLM (QoSMLM)

The QoS constrained resource allocation strategies are used to enhance the performance of a resource allocation strategy. AQoS constrained resource allocation strategy is a three step procedure, in first step, the active users are categorized into various QoS classes using a time domain scheduler (specifically considering the packet delay budget and packet error loss rate). Second step constitutes of prioritizing the time domain scheduled users of step 1 according to an allocation strategy, in this paper a resource allocation strategy called modified load matrix (MLM) is considered.
In third step, the assignment of resource blocks as stated by the MLM strategy to the active users is done. The operation of time domain scheduler consists of two steps which can be described as follows

Step 1-A (TD): In this step, types of resources are classified according to the QoS class identifier (QCI) as stated by 3GPP into Guaranteed bit rate (GBR) and Non-guaranteed bit rate (Non-GBR). Further, GBR and Non-GBR resource types are ranked into nine QCI ranks according to their required packet budget and packet loss rates. As the active users packets arrive, they are categorized according to Table I and they are assigned to different service queues, resources are allocated firstly to GBR users and then to Non-GBR users.

Step 1-B(TD: Scheduling of GBR service by constraining their QoS).

In scheduling the GBR packets the scheduler looks for the packet delay budget. GBR service bearing packets are assigned highest priority to acquire RB’s since they should not get overdue. The expression to compute the number of RBs to be owed to an user or user equipment (UE)\(k\) at time of instant \(t\), \(N_{RB-GBR}(k,t)\) for GBR service is

\[
N_{RB-GBR}(k,t) = \left\lfloor \frac{Q_i(k) + n_{q_i}(k,t) \times S}{d \times N_{RE} \times mc_{level}(k,t)} \right\rfloor;
\]

\[k = 1,2 \ldots K\] (10)

\(K\) is the no of active users,

\(Q_i(K)\): the number of packets of UE \(k\) in \(q_i\),which are not effectivelysent in the previous scheduling instant ,

\(q_i\): type \(i\) of queues corresponding to the nine QCI ranks, \(1 \leq i \leq 9\),

**Figure 1:** IoT variation in a multi-cell scenario
S: span of packet (bits)

d: packet delay budget ,

N_{RE}: number of resource elements (RE) of a RB , m_{c_{level}}(k,t): the number of bits, using a definite rank of modulation, that can be sent by a resource element of UE k at time instant t.

### TABLE I
QCI based Resource type classification

<table>
<thead>
<tr>
<th>QCI</th>
<th>Resource type</th>
<th>priority</th>
<th>Packet delay Budget(in ms)</th>
<th>Packet error loss rate</th>
<th>Example Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GBR</td>
<td>2</td>
<td>100</td>
<td>10^{-2}</td>
<td>Conversational voice</td>
</tr>
<tr>
<td>2</td>
<td>GBR</td>
<td>4</td>
<td>150</td>
<td>10^{-3}</td>
<td>Conversational video</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3</td>
<td>50</td>
<td>10^{-3}</td>
<td>Real time gaming</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>5</td>
<td>300</td>
<td>10^{-6}</td>
<td>Non-Conversational video</td>
</tr>
<tr>
<td>5</td>
<td>NON-GBR</td>
<td>1</td>
<td>100</td>
<td>10^{-3}</td>
<td>IMS signaling</td>
</tr>
<tr>
<td>6</td>
<td>NON-GBR</td>
<td>6</td>
<td>300</td>
<td>10^{-6}</td>
<td>Video TCP-based</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>7</td>
<td>100</td>
<td>10^{-6}</td>
<td>Voice, video ,interactive gaming</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>8</td>
<td>300</td>
<td>10^{-3}</td>
<td>Voice TCP-based</td>
</tr>
</tbody>
</table>

Step 1-C (TD): QoS-Constrained Non-GBR Bearer Service Scheduling

For Non-GBR service packets it is only required thing is had the packets reached destination successfully or not. Hence, for Non-GBR packets it is not required to consider packet delay budget. To ensure definite number of RBs to UEs in this paper a method is used called as maximum bit rate(MBR). The expression which calculates the number of RBs to be allocated for Non-GBR packets for a UE k at an instant t is

\[ N_{RB-\text{nonGBR}}(k,t) = \left[ \frac{R_{imax}(k)}{1000 \times N_{RE} \times m_{c_{level}}(k,t)} \right], \]

\[ k = 1,2 ... K \]

(11)
Where

\( R_{\text{max}}(k) \) is the max. reserve data rate (bps) for UE \( k \).

Given a Non-GBR user \( k \) the set of possible \( N_{\text{RB-nonGBR}}(k, t) \) is possible based on \( mc_{\text{level}}(k, t) \) which indicates the set of possible data rates \( \{r_k\} \)

Step-2: Prioritizing using MLM

MLM is a resource allocation strategy which controls the interference (inter-cell and intra-cell) in multi-carrier based mobile communication systems in a multi-cell scenario and in compliance with LTE standards, by allocating the resources (power and data rate) to the users so as to maximize the aggregate throughput and keep the parameter called IoT in intact.

In this paper, before using MLM strategy, arrived packets are time domain scheduled according to the QCI i.e., we are constraining the QoS to prioritize the users initially as explained in step 1. After step 1 we use MLM strategy to prioritize them based upon channel condition and SINR. The MLM strategy can be described as follows

Given a Mobile Communication System of \( K \) users and \( N \) eNodeB's the constraints to be satisfied are

Power constraint: Every user \( k \) in the system, transmit power should assure

\[ p_k \leq P_{k,\text{max}} \forall k \]  \hspace{1cm} (12)

\( k^{th} \) user sub-carrier power is given by

\[ p_{k,sc} = \frac{P_k}{12(\bar{k})} \]  \hspace{1cm} (13)

where \( \bar{k} \) is chosen from the set \( \bar{k} \in \{\bar{k}_1, \bar{k}_2, \ldots, \bar{k}_K\} \) to assign successive set of PRB’S.

IoT constraint: The interference over thermal noise (IoT) in each eNodeB \( j \) should be below the threshold i.e., \( \text{IoT}_{\text{target}} \). IoT constraint can be expressed as follows

\[ \text{IoT}_{j,w} = \frac{\sum_{k=1}^{K} (\sum_{sc} p_{k,sc} * G_{k,sc}) + N'}{N'} \]  \hspace{1cm} (14)

\[ \text{IoT}_j \leq \text{IoT}_{\text{target}} \]  \hspace{1cm} (15)

Generally, the \( \text{IoT}_{\text{target}} \) is fixed and set by the service provider to maintain uplink interference level below a level and is between 3 to 10 dB. In this work it is set to 5.3 dB for simulation.

\( \text{SINR} \) constraint: For the rate proposed \( r_k \) to every active user \( k \) by Step-1 using based
on the resource type the minimum essential SNIR known as SNIR_{target,k} where SNIR_{target,k} is the signal to interference plus noise ratio essential at eNodeB. If rate r_{i} is allocated to user k to attain a given frame error rate. SNIR constraint can be given as follows

\[ \text{SNIR}_{k} \geq \text{SNIR}_{\text{target},k} \]  \hspace{1cm} (16)

The MLM is a database consisting of all active users load factors. MLM can be employed using either centralized or decentralized manner. The centralized scheduling is employed in this paper.

Let active user k in eNodeB j contributes a load factor which is given as

\[ \text{MLM}_{k,j} = \frac{\sum_{sc} p_{k,sc} \cdot G_{k,sc}}{N' + \sum_{k=1}^{K} \left( \sum_{sc} p_{k,sc} \cdot G_{k,sc} \right)} \]  \hspace{1cm} (17)

\( \sum_{sc} p_{k,sc} \cdot G_{k,sc} \) denotes the power received by eNodeB j by k\textsuperscript{th} active UE taking MLM\(_{k,j}\), elements of column j of MLM database the IoT of eNodeB j at w TTI can be evaluated by the following expression

\[ \text{IoT}_{j,w} = \frac{1}{1 - \sum_{k=1}^{K} \text{LM}_{k,j}} \]  \hspace{1cm} (18)

Also

\[ \text{SNIR}_{k,j} = \frac{\left( \sum_{sc} p_{k,sc} \cdot G_{k,sc} \right)}{N' \cdot \text{IoT}_{j,w} - \left( \sum_{sc} p_{k,sc} \cdot G_{k,sc} \right)} \]  \hspace{1cm} (19)

Now, to reduce inter-cellular interference, permissible transmission power is evaluated as follows

\[ p_{k} = \frac{N' \cdot \text{IoT}_{\text{target}} \cdot \text{SNIR}_{\text{target},k} (12 + \bar{c}_{k})}{\sum_{sc} G_{k,sc} \left[ 1 + \text{SNIR}_{\text{target},k} \right]} \]  \hspace{1cm} (20)

(20) is permissible if it satisfies the power, IoT and SNIR constraints. Firstly, power constraint should satisfy, by observation SNIR constraint is satisfied already because the SNIR\(_{k,j}\) is considered as SNIR\(_{\text{target},k}\).

The effect of inter-cell interference is defined by IoT constraint that caused by
assigning $p_k$ power to the user. IoT constraint checks that whether the inter-cell interference from user $k$ in the adjacent eNodeB’s do not make the IoT level in that eNodeB exceed above the IoT target.

The elements of $MLM_{k,j}$ has to be updated for every row $k$. Every active user $k$ on eNodeB $j$ is expressed as follows

$$MLM_{k,j} = \frac{\sum_{sc} p_{k,sc} * G_{k,sc}}{N' + \sum_{k=1}^{K} (\sum_{sc} p_{k,sc} * G_{k,sc})}$$ (21)

In (21) $p_{k,sc}$ is $p_{k,sc} = \frac{p_k}{12(\pi_2)}$.

By (21) IoT is predictable next check if IoT constraint justifies or not. The data rate $r_k$ is acceptable if yes and will be allotted, if not the same procedure will be performed for other data rates possible according to step 1. The user is given highest priority if none of the data rates given by step 1 satisfies the power, IoT, and SINR constraints.

After first round of allocating the data rates to all the users, elements of MLM database are updated and IoT is estimated in each cell $j$ using (18). This is because (19) and (21) are valid only if IoT is near IoT target. As MCRAP is NP-hard task which needs various assignment rounds for IoT to come closer to IoT target. In each instant of scheduling $p_k$ is set iteratively in (18) and then (19) by replacing IoT target with updated IoT of MLM in (17) subsequently in each assignment round of rate distribution, which makes lowers the interference outage probability and whilst increasing the resource utilization with certain highest IoT (<IoT target) in each cell/eNodeB.

MLM allocation strategy concept assigns priority to the users waiting for transmission in the next scheduling instant by considering the channel condition and also SINR, the priority function. It is clear that a better channel condition user/UE can yield more aggregate throughput but do not have a better impact on throughput of other eNodeB’s in a multi-eNodeB case. MLM proposes a global priority function which is given as follows

$$\text{priority}_k = \frac{\sum_{sc} G_{k,sc,j}}{\sum_{n=1}^{N} \sum_{sc} G_{k,sc,n}} \forall k \in \{1, K\}$$ (22)

Note that $G_{k,sc,j}$ denotes gain of subcarrier of user/UE $k$ to the eNodeB $j$.

The system capacity is excelled using MLM approach for MC-DS-CDMA communication system by jointly controlling the inter-cell and intra-cell interference. MLM algorithm is summarized in Table II, for data rate assignment in a multi-cell MC-
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DS-CDMA mobile communication system. The highest priority user in each cell is served first in every assignment step and elements of MLM are updated, verifies whether the IoT level in each cell is <IoT_target, if yes, valid rates are assigned to the user that do not cause interference in other cells, else the user is kept in queue waiting for the next scheduling instant.

V. SIMULATION RESULTS

The QoSMLM simulation is carried out in MATLAB with the help of communications and signal processing tool box and in compliance with LTE standards. Table II tabulates the simulation parameters used in the work. Different types of services assumed are VoIP, gaming, and buffered data users and their [VoIP]:[gaming]:[buffered] traffic ratio is assumed in [1]:[2]:[1], [1]:[3]:[1], and [1]:[2]:[2] for simulation and for example the traffic ratio [1]:[2]:[1] indicates in 12 users 3 are VoIP, 6 are gaming users and other 3 are buffered users. QoSMLM performance in terms of throughput and packet delay is evaluated and compared with the benchmark schedulers. The aggregate throughput is evaluated for different ratios of traffic is plotted in figures 2 and 3 QoSMLM with MLM approach and benchmark schedulers, and it is observed that there is significant increase in throughput when compared with benchmark schedulers and also with MLM approach. The packet delay is also evaluated for different ratios of traffic and is plotted in figures 4, 5, and 6 with QoSMLM and compared with the benchmark schedulers and MLM approach, and it is observed that there is significant decrease in packet delay when compared with benchmark schedulers and also with MLM approach.

**TABLE II: SIMULATION PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eNodeBs</td>
<td>5</td>
</tr>
<tr>
<td>Number of users per cell</td>
<td>25</td>
</tr>
<tr>
<td>Channel Band width</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2GHz</td>
</tr>
<tr>
<td>No. of primary resource blocks</td>
<td>25</td>
</tr>
<tr>
<td>No. of subcarriers in RB</td>
<td>12</td>
</tr>
<tr>
<td>Spreading sequence</td>
<td>Walsh-Hadamard</td>
</tr>
<tr>
<td>Spreading Factor</td>
<td>8</td>
</tr>
<tr>
<td>Sub carrier spacing</td>
<td>15kHz</td>
</tr>
<tr>
<td>IoT target</td>
<td>5.3 dB</td>
</tr>
</tbody>
</table>
Figure 2: Aggregate throughput with Traffic Ratio [VoIP]:[Gaming]:[Buffered] as [1]:[2]:[1]

Figure 3: Aggregate throughput with Traffic Ratio [VoIP]:[Gaming]:[Buffered] as [1]:[3]:[1]
Figure 4: Packet delay of a cell with [VoIP]:[Gaming]:[buffered]=1:2:1, traffic ratio of users.

Figure 5: Packet delay of a cell with [VoIP]:[Gaming]:[buffered]=1:3:1, traffic ratio of users.
IV. CONCLUSION

In this paper, a QoS constrained resource allocation strategy called QoSMLM is proposed in a multi-cell scenario for MC-DS-CDMA cellular systems to reduce interference in compliance with LTE standards in which MC_DS_CDMA is used as radio access technology both in uplink and downlink to reduce interference and the performance parameters like aggregate throughput and packet delay are evaluated by considering the different ratios of VoIP, gaming and buffered data service using users with QoSMLM and compared with benchmark schedulers and also with MLM approach. Simulation results show that using QoSMLM strategy for scheduling and allocating resources to users there is a significant improvement in aggregate throughput and packet delay when compared to MLM approach and other benchmark schedulers used for LTE. Performance analysis of QoSMLM for LTE-A mobile communication systems remains as future study.

REFERENCES


