MCS Aware Connection Admission Control and Uplink Scheduling Algorithm for WiMAX Networks

Summary

Mobile WiMAX standard defines Air Interface for Mobile Broadband Wireless Access (BWA) systems and aimed to provide high data rate with seamless mobility while maintaining the Quality of Service (QoS). However, QoS of real-time applications depends on the link quality, which necessitate the modulation-aware Connection Admission Control (CAC) and scheduling schemes. In this chapter MCS aware CAC scheme and uplink scheduling algorithm are proposed. The proposed CAC scheme aims to improve the system capacity by increasing the number of connections admitted without deteriorating much the QoS performance of already admitted lower priority connections. In the proposed CAC algorithm, a degradation procedure is used, in which the lower priority connections of subscriber stations (SSs) are degraded on the basis of their channel status. Also a channel aware Base Station (BS) Uplink scheduling algorithm is proposed to improve the QoS performances of both real time and non real time services. The performances of proposed algorithms are evaluated through simulation by considering the metrics like throughput, delay and number of connections admitted.
3.1 Introduction

Quality of Service (QoS) guarantee is one of the most important requirements in today’s communication era which is due to the stringent quality requirements of multimedia services. In communication systems QoS is provided through admission control, traffic policing and scheduling. These traffic control mechanisms enable a balance between the utilization of the network resources and the QoS provisioning. This tradeoff between utilization and QoS is of fundamental importance in WiMAX networks [1], which aggregate different types of traffic in a limited resources architecture.

The scheduling mechanism aims at guaranteeing the bandwidth required by the subscriber stations (SS) as well as enabling the efficient wireless link usage. In a WiMAX network, the downlink scheduling requires a single scheduler at the base station (BS), whereas the uplink scheduling needs two components, one of them at the BS and the second one at the SS. The BS scheduler allocates bandwidth for the SSs and the SS scheduler determines which packets will be sent in the received transmission opportunities. The CAC mechanism restricts the number of connections admitted into the network in order to reduce the network congestion and call dropping. Awareness of channel status in scheduling and CAC improves the system performance, as there is a possibility of deterioration of QoS of connections as the channel quality varies [2]. Hence in this chapter, modulation and coding scheme (MCS) aware BS scheduling and CAC schemes are proposed to improve the network utilization and QoS. The rest of this chapter is organized as follows. Section 3.2 outlines the related work in the literature. Section 3.3 and 3.4 describe the CAC and scheduling algorithms in WiMAX network respectively. In Sections 3.5 and 3.6 proposed CAC and scheduling algorithms are presented respectively. Section 3.7 discusses the simulation results followed by conclusion in Section 3.8.

3.2 Related Work

As the CAC and scheduling are the major issues in providing QoS for WiMAX network, many researchers have proposed the algorithms for CAC and scheduling. Authors of [3-4] have proposed adaptive hierarchical polling approach with cost-based CAC and Markov decision process based CAC respectively for increasing utilization of access channel, network reward and reducing polling delay. Authors of [5-6] proposed
CAC algorithms which provide the highest priority for UGS flows and maximizes the bandwidth utilization, in [5] bandwidth borrowing and degradation method is employed and in [6] handoff connections are given higher priority. Jinchang Lu et.al [7] have proposed a cross-layer elastic CAC and holistic opportunistic scheduling for point-to-multipoint (PMP) networks. In order to avoid the QoS degradation authors of [8] have proposed a statistical CAC mechanism which considers the traffic variability and overflow. Authors of [9-11] have proposed CAC algorithms which are based on bandwidth estimation of connections, in which [11] considers the shadow cluster concept to estimate the resources. Authors of [12] have proposed a CAC that improves the QoS of BE traffic by avoiding a strict bandwidth assignment of rtPS and nrtPS traffics. Authors of [13-14] proposed bandwidth degradation scheme for CAC, in which [13] employs Interference Ratio (IR) as the criteria of degradation and [14] uses the concept of adaptive bandwidth degradation. In [15-16] token-bucket based uplink packet scheduling (UPS) combined with CAC schemes are proposed. Scheduling and CAC schemes are proposed in [17-18], among which [17] is concerned with real-time video applications and [18] considers bandwidth polling overhead incurred by services being requested and fairness in resource allocation. Y. Ge et.al [19] proposed a CAC Scheme for adaptive multimedia services. Authors of [20-22] have proposed CAC scheme and bandwidth allocation for mobile WiMAX networks. Authors of [23-25] have proposed CAC scheme along with packet scheduling algorithm. In [23] dual partition of the bandwidth for call admission control and priority earliest deadline for packet scheduling is proposed. CAC scheme of [26] admits new traffics based on condition of the link bandwidth. Paper [27] presents CAC with dual partition (DP), in which total link bandwidth is divided into two partitions, one partition is dedicated to all traffics which have variable bit rate (VBR) and the second portion is dedicated to constant bit rate (CBR) traffics. In [28] the total link bandwidth is divided into three partitions which corresponds to CBR, VBR and handover (HO) services. The fuzzy logic CAC scheme is implemented in the HO portion to keep dropping probability as low as possible based on the available bandwidth.

3.3 Connection Admission Control in WiMAX

Admission Control is a validation process where a check is performed before a connection is established to see if current resources are sufficient for the requested
connection. The CAC algorithm determines whether or not a given connection is admitted based upon network resources and the network’s ability to maintain QoS support for the already established connections. If the admission control admits too few connections, it results in wastage of system resources. On the other hand, if CAC admits too many connections, all the connections contend for resources and scheduler will not be able to provide QoS. Therefore, judicious decision making mechanisms for allocating bandwidth to different classes of service are needed.

In IEEE 802.16, before an SS initiates a new connection or changing or deleting an already admitted connection, it must make a request to the BS. A new connection can be created, changed or deleted through the issue of dynamic service addition (DSA), dynamic service change (DSC) and dynamic service deletion (DSD) messages. The task of admission control is to accept or reject the arriving requests for a connection in order to maximize the bandwidth utilization, by accepting as many connections as possible, while keeping the QoS level of all connections at the level specified in their traffic profile. In other words it ensures that QoS of already admitted connections will not be affected by the decision made. Although it is a simple procedure, it has great influence on QoS of the admitted connections.

The connection admission control only guarantees the bandwidth resources for an admitted connection, the actual allocation of bandwidth resources for that admitted connection will be made by the BS uplink scheduler based on the availability of bandwidth.

### 3.4 Scheduling in WiMAX

In cellular networks, the wireless bandwidth is shared among the mobile users according to the service requests. As the service request deals not only with the bandwidth but also with delay and other QoS parameters, the network conducts scheduling to decide the bandwidth to allocate and the type of the bandwidth allocation. The scheduling algorithm essentially arranges such that the network resources can be shared fairly among the users in consideration of the requested QoS.

A single cell in WiMAX consists of a Base Station (BS) and multiple Subscriber Stations (SSs). Three modes of network operations are defined in WiMAX standard; they are point to multipoint mode (PMP), mesh mode and relay mode. The work in this chapter considers PMP mode of network operation. In PMP mode, the BS schedules the
traffic flow for SSs and SSs do not communicate directly. The communication between BS and SS are bidirectional i.e., a downlink channel (from BS to SS) and an uplink channel (from SS to BS). The downlink channel is in broadcast mode. The uplink channel is shared by various SS’s through Time Division Multiple access (TDMA) manner. The standard supports two type of duplex mode, Time Division Duplex (TDD) and Frequency Division Duplex (FDD). The TDD frame consists of downlink and uplink subframes, the duration and the number of subframe slots are determined by the BS scheduler. The downlink subframe has downlink map (DL map) contains information about the duration of subframes and which time slot belongs to a particular SS as the downlink channel and uplink map (UL map) consists of information element (IE) which includes transmission opportunities.

In PMP mode, centralized scheduling is used, in which the BS schedules both uplink and downlink traffics. The scheduling architecture in WiMAX is as shown in figure 3.1. The scheduling in WiMAX is divided into downlink scheduling and uplink scheduling. The downlink scheduling is solely managed by BS, while the uplink scheduling is managed by both BS and SS. The SS requests for uplink bandwidth on a per connection basis and the uplink scheduler at BS grants an aggregated amount of bandwidth by considering all the bandwidth requests. The uplink scheduler at SS shares the bandwidth among the different connections whilst maintaining QoS and fairness [29].

The uplink scheduler of BS is responsible for sharing the bandwidth resources among the connected SSs. In WiMAX, scheduling will be made on the basis of scheduling classes (service types) defined. WiMAX defines five scheduling classes, unsolicited grant service (UGS), extended real time polling service (ertPS), real time polling service (rtPS), non real time polling service (nrtPS) and best effort (BE) services. The 802.16e standard defines uplink scheduling only for UGS services and for all other services scheduling is kept as an open issue. For non-UGS connections, bandwidth request/grant mechanisms are defined and based on the requested bandwidth the BS uplink scheduler decides the bandwidth allocation. For UGS connections, the BS uplink scheduler grants the maximum sustained bandwidth unsolicitedly. For non-UGS connections, the BS allocates requested bandwidth, if the requested bandwidth is less than the bandwidth guaranteed for that connection during admission, otherwise it allocates guaranteed bandwidth.
3.5 Proposed MCS Aware Connection Admission Control Mechanism

In this chapter MCS aware connection admission control algorithm and BS uplink scheduling algorithms are proposed to improve the system capacity in terms of number of connections admitted along with enhancement in QoS.

In WiMAX standard adaptive modulation and coding (AMC) technique is used to enhance the system performance in varying channel condition. To aid the AMC process the SS feedbacks the channel State Information (CSI) to the BS through Channel Quality Indicator (CQI) channel. The channel State Information (CSI) contains receive signal strength (RSS) and Carrier to Interference and Noise Ratio (CINR) values. After receiving the CSI, the BS decides the appropriate modulation and coding scheme for that SS, i.e., based on RSS and CINR values it select one of the modulation schemes among 64-QAM, 16QAM and QPSK modulation. Then the BS broadcasts downlink channel descriptor (DCD) and uplink channel descriptor (UCD) with forward error
correction (FEC) to notify the MCS to be followed by SS [30]. The SS uses this MCS to transmit its data burst. This work makes an attempt to utilize channel information to design the proposed CAC and scheduling algorithms.

The basic connection admission control algorithm implemented in QualNet simulator works as follow. When a new connection request arrives, the CAC considers the QoS requirement of that connection as an admission criterion and checks the availability of the bandwidth resources. If sufficient bandwidth is available to satisfy the QoS requirement of that connection, then that connection will be admitted, otherwise will be rejected. The basic algorithm considers maximum sustained rate (MSR) of a connection as an admission criterion for UGS or ertPS and average rate of a connection as an admission criterion for rtPS or nrtPS. The BE connections are not considered in the admission process, i.e., the BE connections are admitted directly since they do not require QoS guarantee.

In basic algorithm, if the available bandwidth is greater than the admission criterion bandwidth, then that connection will be admitted by guaranteeing admission criterion bandwidth, otherwise that connection will be rejected. The CAC updates the available bandwidth after admitting a connection as per the equation 3.1.

\[ BW_{available_{CAC}} = BW_{available_{CAC}} - BW_{guaranteed} \quad (3.1) \]

The basic algorithm admits the rtPS connections by guaranteeing average rate even though the network is less congested or number of connections is less. This makes the utilization of bandwidth less efficient and leads to the wastage of resources. Also if low priority connections are already admitted and if there is no enough bandwidth to admit the high priority UGS/ertPS connection request then the basic algorithm rejects that connection.

The proposed CAC algorithm tries to improve the utilization of bandwidth efficiently by providing higher bandwidth than the admission criterion bandwidth to the rtPS connection when the network is less congested. Also an attempt has been made to improve the admission of higher priority connections when there is no sufficient bandwidth available to admit, by degrading the lower priority connections on the basis of modulation scheme without affecting their QoS performance much.

When a new connection request belonging to UGS/ertPS service type seeks for admission, the proposed algorithm considers MSR as an admission criterion. If the
connection request belongs to rtPS service type, the proposed algorithm considers 80% of its MSR as an admission criterion and checks the availability of bandwidth, if the available bandwidth is less than the 80% of its MSR, the proposed algorithm considers average rate as an admission criterion for that rtPS connection. If the connection request is for nrtPS, the proposed algorithm considers average rate as an admission criterion and checks the availability of bandwidth, if the available bandwidth is less than the average rate, the criteria for admission will be changed to minimum reserved rate (MRR).

After deciding the admission criteria, the BS checks for the availability of bandwidth. If the available bandwidth is greater than the admission criterion bandwidth, that connection will be admitted by guaranteeing admission criterion bandwidth. The CAC updates the available bandwidth after admitting a connection as per the equation 3.1. If the connection request is for a real time service (UGS/ertPS/rtPS) and available bandwidth is less than the admission criterion bandwidth, then the proposed algorithm tries to admit that connection by degrading the lower priority connections. The additional bandwidth required \( BW_{AR} \) to admit the higher priority connection request is calculated using the equation 3.2.

\[
BW_{AR} = BW_{admission\ criterion} - BW_{available_{CAC}} \quad (3.2)
\]

In order to avail the additional bandwidth required \( BW_{AR} \) to admit the real time services, initially nrtPS connections are considered for degradation on the basis of modulation scheme used by the SSs, i.e., connections of SSs with higher order modulation are considered first and then connections of SSs with lower order modulation schemes. One of the nrtPS connections of SSs which use 64QAM modulation scheme is selected for degradation from the list of connected SSs. Since 64QAM provides the higher data rate and is capable to suffice the QoS requirements of nrtPS connection even with the minimum reserved rate (MRR) bandwidth guarantee.

The maximum possible bandwidth \( BW_{degrade_{(max)}} \) that can be degraded from the nrtPS connection considered is calculated using the equation 3.3,

\[
BW_{degrade_{(max)}} = BW_{guaranteed_{nrtPS}} - BW_{MRR_{(nrtPS)}} \quad (3.3)
\]
Then the $BW_{degrade_{(max)}}$ is compared with $BW_{AR}$, if $BW_{degrade_{(max)}}$ is greater than $BW_{AR}$, then bandwidth of nrtPS connection is degraded as per the equation 3.4, $BW_{available}$ and $BW_{AR}$ are updated as per the equation 3.5 and 3.6 respectively.

$$BW_{guaranteed_{(nrtPS)}} = BW_{guaranteed_{(nrtPS)}} - BW_{AR}$$ (3.4)

$$BW_{available_{CAC}} = BW_{available_{CAC}} + BW_{AR}$$ (3.5)

$$BW_{AR} = 0$$ (3.6)

If $BW_{degrade_{(max)}}$ is less than $BW_{AR}$, then bandwidth of nrtPS connection considered for degradation will be degraded to MRR, $BW_{available_{CAC}}$ and $BW_{AR}$ are updated as per the equation 3.7 and 3.8 respectively.

$$BW_{available_{CAC}} = BW_{available_{CAC}} + BW_{degrade_{(max)}}$$ (3.7)

$$BW_{AR} = BW_{AR} - BW_{degrade_{(max)}}$$ (3.8)

Further to avail the additional bandwidth required ($BW_{AR}$) to admit the real time services, other nrtPS connections of SSs which uses 64QAM modulation scheme are considered for degradation one by one and still the available bandwidth is not sufficient ($BW_{AR} \neq 0$) to admit the real time connection request, then nrtPS connections of SSs which uses 16QAM and QPSK modulation scheme are considered based on the order of modulation one by one.

Further if the bandwidth available is not sufficient ($BW_{AR} \neq 0$) to admit the requested real time connection and the connection request belongs to UGS or ertPS, to avail the additional bandwidth required ($BW_{AR}$), the rtPS connections are considered for degradation. The guaranteed bandwidth of rtPS connections is degraded till average rate following the same procedure as followed for nrtPS connection degradation. If the available BW after degrading nrtPS and rtPS connections is not sufficient to admit the higher priority connection request that connection request will be rejected. The flow charts of proposed CAC mechanism are shown in figures 3.2 and 3.3.
Figure 3.2 Flow chart of proposed CAC Mechanism
In this chapter along with CAC algorithm a channel aware BS Uplink scheduling algorithm is also proposed to improve the QoS performances of both real time and non real time services. The proposed scheduling algorithm tries to improve the performance of real time services by making an effort to allocate the requested bandwidth when requested bandwidth is more than the guaranteed bandwidth. Also the proposed algorithm attempts to improve the performance of non real time services by allocating the requested bandwidth to the BE services in a Round-robin way by considering the modulation schemes used by the SSs.

In the basic scheduling algorithm, the bandwidth is allocated to the admitted connections on the basis of service type priority of the connections. That is, bandwidth is allocated to all the UGS connections first, then to ertPS connections, later to the requested rtPS, nrtPS and BE connections. Weighted fair queue (WFQ) scheduling algorithm is used to schedule the connections of same service type. For UGS connections the BS allocates the maximum sustained bandwidth and for non-UGS connections BS allocates the bandwidth based on the requested bandwidth. If the
requested bandwidth by a connection is less than the guaranteed bandwidth of that connection, then BS allocates requested bandwidth for that connection, otherwise that connection will be allocated with the guaranteed bandwidth. The available bandwidth is updated after allocating the bandwidth to each connection as per the equation 3.9.

\[ BW_{\text{available}} = BW_{\text{available}} - BW_{\text{allocated}} \]  

(3.9)

In proposed algorithm, same procedure as that of basic algorithm is followed for allocating the bandwidth to the requested connections of all service types, except when requested bandwidth is greater than guaranteed bandwidth for ertPS and rtPS connections.

When requested bandwidth of ertPS/rtPS connections is greater than guaranteed bandwidth, the proposed algorithm degrades the nrtPS connections for which bandwidth guaranteed is more than the bandwidth requested by those nrtPS connections. To allocate the requested bandwidth of ertPS/rtPS connections, additional bandwidth required \((BW_{AR})\) is calculated using the equation 3.10.

\[ BW_{AR} = BW_{\text{requested}} - BW_{\text{guaranteed}} \]  

(3.10)

In order to avail this additional bandwidth required \((BW_{AR})\), one of the nrtPS connections of SSs which use 64QAM modulation scheme is considered from the list of connected SSs for degradation first. If the requested bandwidth by that nrtPS connection is less than the guaranteed bandwidth for that connection, then the bandwidth is taken out in that frame. The additional bandwidth obtained \(BW_{\text{additional}}\) and the additional bandwidth required \((BW_{AR})\) are updated as per the equation 3.11 and 3.12 respectively.

\[ BW_{\text{additional}} = BW_{\text{guaranteed (nrtPS)}} - BW_{\text{requested (nrtPS)}} \]  

(3.11)

\[ BW_{AR} = BW_{AR} - BW_{\text{additional}} \]  

(3.12)

Further if the additional bandwidth required \((BW_{AR})\) is greater than zero, then to avail \(BW_{AR}\), other nrtPS connections of SSs which uses 64QAM modulation scheme are considered for degradation and further if \(BW_{AR}\) is greater than zero, then nrtPS connections of SSs which uses 16QAM and QPSK modulation scheme are considered based on the order of modulation one by one. After degrading all the nrtPS connections, if \(BW_{AR}\) is greater than zero, no further degradations will be carried out. The additional bandwidth \((BW_{\text{additional}})\) obtained by the degradation process is allotted to the
considered ertPS/rtPS connection along with the guaranteed bandwidth. Meanwhile, after each degradation process if the additional bandwidth required \((BW_{AR})\) is less than or equal to zero, then ertPS/rtPS connection is allotted with the requested bandwidth.

Further in the proposed algorithm, the BE connections are served in a round robin manner based on the modulation schemes used. In the first frame, one of the BE connections of SSs which uses 64QAM modulation scheme is considered based on the WFQ algorithm for bandwidth allocation. If the available bandwidth \((BW_{available})\) is greater than the requested bandwidth of the considered connection, then requested bandwidth is allotted to that connection, otherwise available bandwidth is allotted. If the bandwidth is available after allocation to considered BE connection, then other BE connections of SSs which uses 64QAM modulation scheme are considered for bandwidth allocation one by one in the similar procedure. If the bandwidth is still available, then BE connections of SSs which uses 16QAM and QPSK modulation schemes are considered for bandwidth allocation in the similar procedure till available bandwidth exhaust.

In the second frame, similar procedure is followed to allocate bandwidth to the BE connections. But the BE connections of SSs considered for bandwidth allocation is in the order 16QAM, QPSK and 64QAM. In the third frame, similar procedure is followed to allocate the bandwidth by considering the BE connections of SSs in the order of QPSK, 64QAM and 16QAM modulation schemes. Further, in the subsequent frames the similar procedure is followed to allocate the bandwidth and BE connections of SSs are considered by rotating the modulation schemes following the Round Robin procedure as explained. In this way all the BE connections are served by giving equal priority. The figures 3.4 and 3.5 show the flow charts of proposed scheduling algorithm.
Allocate BW to connections in the order i) 64QAM SS ii) 16QAM SS iii) QPSK SS

Allocate BW to connections in the order i) 16QAM SS ii) QPSK SS iii) 64QAM SS

Allocate BW to connections in the order i) QPSK SS ii) 64QAM SS iii) 16QAM SS

Figure 3.4 Flow chart of proposed scheduling algorithm
Figure 3.5 Flow chart of proposed Scheduling algorithm for (a) allocate BW (b) degrade nrtPS BW
3.7 Simulation and Results

The performance of proposed channel aware CAC and BS scheduling algorithm is evaluated through simulation studies using QualNet 5.0.2 simulator [31]. The performance of proposed algorithm is compared with the basic algorithm present in simulator. A single WiMAX cell is considered in the simulation area of 2Km X 2Km working at a frequency 2.4 GHz. The path loss model selected is two-ray with constant shadowing model of shadowing mean 4dB. The simulation parameters settings used are mentioned in table 3.1. The traffic generated for various service types along with QOS parameters (minimum reserved rate and maximum sustain rate) considered are given in table 3.2.

<table>
<thead>
<tr>
<th>Table 3.1 Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
</tr>
<tr>
<td>Channel bandwidth</td>
</tr>
<tr>
<td>FFT size</td>
</tr>
<tr>
<td>Antenna model</td>
</tr>
<tr>
<td>BS antenna gain</td>
</tr>
<tr>
<td>SS antenna gain</td>
</tr>
<tr>
<td>BS antenna height</td>
</tr>
<tr>
<td>SS antenna height</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3.2 Traffic Considered for simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Type</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>UGS</td>
</tr>
<tr>
<td>ertPS</td>
</tr>
<tr>
<td>rtPS</td>
</tr>
<tr>
<td>nrtPS</td>
</tr>
<tr>
<td>BE</td>
</tr>
</tbody>
</table>

3.7.1 Scenario 1

This scenario is designed to study the performance of implemented work for different channel conditions (64QAM, 16QAM and QPSK region). In this scenario, six SSs are placed in each region, hence total number of SSs considered is eighteen. The SSs have to transmit five traffics each mapped to UGS, ertPS, rtPS, nrtPS and BE
respectively. Hence the total number of connections can be 90, among which each service type has 18 connections. The snapshot of scenario is shown in figure 3.6. The simulation studies have been carried out by considering the generation of these traffics in four different schemes for both basic and proposed algorithms. The performances of basic and proposed algorithms are compared by considering the metrics like number of connections admitted, throughput and delay.

![Figure 3.6 Snapshot of scenario 1](image)

**Simulation Scheme 1**

Simulation study has been carried out by considering the generation of traffic on the priority basis from highest priority to least priority, i.e., from UGS to BE. The simulator has been programmed to generate considered traffics at various simulation times as given in the table 3.3.

<table>
<thead>
<tr>
<th>Simulation time (second)</th>
<th>Service type</th>
<th>Number of connections generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UGS</td>
<td>18</td>
</tr>
<tr>
<td>30</td>
<td>ertPS</td>
<td>18</td>
</tr>
<tr>
<td>60</td>
<td>rtPS</td>
<td>18</td>
</tr>
<tr>
<td>90</td>
<td>nrtPS</td>
<td>18</td>
</tr>
<tr>
<td>120</td>
<td>BE</td>
<td>18</td>
</tr>
</tbody>
</table>
Simulation Scheme 2

In this scheme, the simulation study has been repeated by generating all the 90 traffics (UGS, ertPS, rtPS, nrtPS and BE connections of 18 each) simultaneously at the beginning of simulation.

Simulation Scheme 3

In this scheme the simulation study has been repeated by considering the random generation of traffic. Connections from each service types of one each are generated at every interval of 5 seconds. Initially at the beginning of simulation, 5 connections of one service type each are generated, at 5th second another 5 connections of one service type each are generated, at 10th second another 5 connections of one service type each are generated and so on till all the 90 connections are generated.

Simulation Scheme 4

In this scheme the simulation study has been repeated by considering the generation of traffic in reverse order compared to simulation scheme 1, i.e., the connections are generated from low priority (BE) to high priority (UGS). The traffics generated at various simulation times are given in table 3.4.

<table>
<thead>
<tr>
<th>Simulation time (second)</th>
<th>Service type</th>
<th>Number of connections generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BE</td>
<td>18</td>
</tr>
<tr>
<td>30</td>
<td>nrtPS</td>
<td>18</td>
</tr>
<tr>
<td>60</td>
<td>rtPS</td>
<td>18</td>
</tr>
<tr>
<td>90</td>
<td>ertPS</td>
<td>18</td>
</tr>
<tr>
<td>120</td>
<td>UGS</td>
<td>18</td>
</tr>
</tbody>
</table>

The table 3.5 and Figure 3.7(a-d) depicts the number of connections of different service types admitted by basic and proposed algorithms for all the four simulation schemes. It is observed from the table 3.5 and figure 3.7(a) that the number of connections admitted by basic and proposed algorithms is same for simulation scheme 1, since in this simulation scheme, as the higher priority connections are seeking for admission prior to the low priority connections, there is no chance for degradation of
low priority admitted connections. Hence in this simulation scheme the basic algorithm and proposed algorithm works in a similar way.

Table 3.5 Number of Connections Admitted

<table>
<thead>
<tr>
<th>Service Types</th>
<th>Number of Connections admitted</th>
<th>Simulation Scheme 1</th>
<th>Simulation Scheme 2</th>
<th>Simulation Scheme 3</th>
<th>Simulation Scheme 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
<td>Proposed</td>
<td>Basic</td>
<td>Proposed</td>
<td>Basic</td>
</tr>
<tr>
<td>UGS</td>
<td>18</td>
<td>18</td>
<td>13</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>ertPS</td>
<td>18</td>
<td>18</td>
<td>14</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>rtPS</td>
<td>18</td>
<td>18</td>
<td>13</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>nrtPS</td>
<td>17</td>
<td>17</td>
<td>13</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>BE</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 3.7 Number of connections admitted for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4
It is observed from table 3.5 and figure 3.7(b-d) that in all other simulation schemes (simulation scheme 2–4), the number of connections admitted in proposed algorithm is better compared to the basic algorithm. The table 3.5 and figure 3.7(d) depict that for simulation scheme 4 the UGS and ertPS connections are not admitted in basic algorithm, whereas the proposed algorithm successfully admits 14 UGS and 15 ertPS connections. The proposed algorithm performs better for simulation scheme 4 since in this scheme the chance to degrade the low priority connections is more than for any other schemes.

![Graphs showing throughput performance](image)

Figure 3.8 Throughput performance of UGS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.

Figures 3.8(a-d) give the throughput performance of UGS connections with respect to simulation time for the simulation scheme 1-4 respectively. It is observed from the figures 3.8(a-d) that the throughput performance of UGS connections for
proposed algorithm is better compared to basic algorithm in all the schemes except in simulation scheme 1 for which throughput performance is same for both basic and proposed algorithms. It is observed from figure 3.8(d) for simulation scheme 4 that throughput is zero till 120\(^{th}\) second for both basic and proposed algorithm, as the UGS connections are started at 120\(^{th}\) second. After 120\(^{th}\) second the throughput of UGS connections for proposed algorithm increases but the throughput of basic algorithm remains zero. As in this simulation scheme the nrtPS and rtPS connections of higher datarate are started before UGS, in basic algorithm almost all of the resources of admission control are utilized for admitting the nrtPS and rtPS connections, so the higher priority UGS connections are not admitted. Whereas in proposed algorithm, UGS connections are admitted since the BS degrades the lower priority connections in order to admit higher priority connections.

![Graphs showing throughput performance](image)

Figure 3.9 Throughput performance of erTPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4
Figures 3.9(a-d) give the throughput performance of ertPS connections with respect to simulation time. It is observed from the figures 3.9(a-d) that the throughput performance of ertPS connections for proposed algorithm is better compared to basic algorithm in all the schemes except in Simulation scheme 1 for which both proposed and basic algorithm performance is same. It is observed form figure 3.9(d) for Simulation scheme 4 that throughput is zero till 90th second for both basic and proposed algorithm, as the ertPS connections are started at 90th second. After 90th second the throughput of ertPS connections of proposed algorithm increases but the throughput of basic algorithm remains zero, since in basic algorithm sufficient bandwidth may not be available to admit ertPS connections. Whereas the proposed algorithm degrades the lower priority connections to admit higher priority ertPS connections.

Figure 3.10 Throughput performance of rtPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4
Figure 3.11 Throughput performance of nrtPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.

Figures 3.10(a-d) and Figures 3.11(a-d) give the throughput performance of rtPS and nrtPS connections with respect to simulation time respectively. It is observed from the figure 3.10(a) and 3.11(a) for simulation scheme 1 that rtPS and nrtPS throughput performances are same for both proposed and basic algorithm, since the number of connections admitted are same. Figures 3.10(b-c) and 3.11(b-c) depict that the throughput performances of rtPS and nrtPS connections for proposed algorithm are better compared to basic algorithm for simulation scheme 2-3. It is observed from figure 3.10(d) and 3.11(d) for simulation scheme 4 that the throughput of rtPS and nrtPS connections for proposed algorithm is less than the basic algorithm, because higher priority connections are get admitted by degrading lower priority connections in proposed algorithm.
Figure 3.12 Throughput performance of BE connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.

Figures 3.12(a-d) give the throughput performance of BE connections with respect to simulation time. In simulation scheme 1, for both basic and proposed algorithm throughput of BE connections is observed to be zero (figure 3.12(a)). Since BE connections are not served in Simulation scheme 1 (figure 3.7(a)) as the available bandwidth may be utilized completely to admit higher priority connections. It is observed from the figures 3.12(b-d) that the throughput performance of BE connections for proposed algorithm is marginally better compared to basic algorithm.
Figure 3.13 Delay performance of UGS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.
Figure 3.14 Delay performance of ertPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.

Figures 3.13(a-d) and 3.14(a-d) depict the delay performances of UGS and ertPS connections with respect to simulation time. It is observed from the figures 3.13(a-b) and 3.14(a-b) that delay performance of UGS and ertPS connections for proposed algorithm are marginally more compared to basic algorithm in simulation scheme 1-2. Figures 3.13(c) and 3.14(c) for simulation scheme 3 depict that delay performances of proposed algorithm are better compared to basic algorithm. It is observed from the figures 3.13(d) and 3.14(d) for Simulation scheme 4 that the delay performances of proposed algorithm are within the tolerable values and in basic algorithm UGS/ertPS connections are not admitted.
Figure 3.15 Delay performance of rtPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4.

Figure 3.15(a-d) depicts the delay performances of rtPS connections with respect to simulation time. It is observed from the figures 3.15 (a, b, d) that the delay performances of rtPS connections for proposed algorithm are marginally more compared to basic algorithm in Simulation scheme 1-2 and Simulation scheme 4, but the delays are within the tolerable values. Figure 3.15(c) for simulation scheme 3 depict that the delay performances of proposed algorithm are better compared to basic algorithm.
Figure 3.16 Delay performance of nrtPS connections with respect to simulation time for (a) simulation scheme 1 (b) simulation scheme 2 (c) simulation scheme 3 (d) simulation scheme 4

Figure 3.16(a-d) gives the delay performances of nrtPS connections with respect to simulation time. It is observed from the figures 3.16(a-b) that the delay performance of nrtPS connections for proposed algorithm are marginally more compared to basic algorithm in Simulation scheme 1-2, but the delays are within the tolerable values. Figures 3.16(c-d) for simulation scheme 3-4 depict that the delay performances of proposed algorithm are better compared to basic algorithm.

### 3.7.2 Scenario 2

In this scenario, design of scenario 1 is retained and the performance of basic and proposed algorithm are studied by considering number of connections admitted, throughput and delay as performance metrics for varying number of connections.

Initially 15 connections are considered for study among which 5 connections are considered in each channel conditions (i.e., 5 connections each at 64QAM, 16QAM and QPSK region). Five connections of each region are mapped to UGS, ertPS, rtPS, nrtPS...
and BE service types. The simulation study has been carried out by generating all the traffics simultaneously at the beginning of simulation.

The simulation studies are repeated by increasing the number of connections up to 90 connections insteps of 15. Among each 15 connections, 5 connections are considered in each channel conditions and connections at each channel conditions are mapped to UGS, ertPS, rtPS, nrtPS and BE service types.

Table 3.6 Number of connections admitted for varying number of connections

<table>
<thead>
<tr>
<th>Total number of Connections generated</th>
<th>Total Number of Connections admitted</th>
<th>Total Number of Connections admitted in each service type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
<td>Proposed</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>45</td>
<td>36</td>
<td>42</td>
</tr>
<tr>
<td>60</td>
<td>43</td>
<td>57</td>
</tr>
<tr>
<td>75</td>
<td>64</td>
<td>70</td>
</tr>
<tr>
<td>90</td>
<td>70</td>
<td>83</td>
</tr>
</tbody>
</table>

Figure 3.17 Number of connections admitted for varying number of connections
Tables 3.6 and figure 3.17 give the number of connections admitted for varying number of connections. It can be observed from tables 3.6 and figure 3.17 that for less number of connections (upto 30 connections) the number of connections admitted in both proposed and basic algorithm are same, since for less number of connections the bandwidth requirement may be less than the available bandwidth, hence degradation is not necessary. As the number of connections increases, the proposed algorithm outperforms basic algorithm. From table 3.6 and figure 3.17 it is evident that the number of connections admitted in each service type is more for proposed algorithm compared to basic algorithm. It is also noted that the BE connections served is almost same in both proposed and basic algorithm, as the BE connections do not go through admission control.

![Figure 3.18 Throughput performance of UGS connections for varying number of connections](image-url)
Figure 3.19 Throughput performance of ertPS connections for varying number of connections

Figure 3.20 Throughput performance of rtPS connections for varying number of connections
Figures 3.18-3.21 give the throughput performances of UGS, ertPS, rtPS and nrtPS connections with respect to varying number of connections respectively. It is observed from the figures 3.18-3.21 that for less number of connections the throughput performance is same for both proposed and basic algorithm. As the number of connections increases, the throughput performances of proposed algorithm is better compared to basic algorithm, since the number of connections admitted and served are more in proposed algorithm compared to basic algorithm.
Figure 3.22 depicts the throughput performance of BE connections for varying number of connections. It is observed from the figure 3.22 that BE throughput of proposed algorithm is marginally better compared to basic algorithm, may be attributed to proposed round robin BS scheduling algorithm. For 90 connections the throughput of BE for basic algorithm is more because the number of BE connections served is more in basic algorithm.

![Figure 3.23 Average Delay performance for varying number of connections](image)

Figure 3.23 gives the average delay performance of real time services with respect to varying number of connections. It is observed from the figure 3.23 that the delay performances are almost same for proposed and basic algorithm.

### 3.7.3 Scenario 3

This scenario is designed to study the performance of the proposed BS uplink scheduling algorithm for different service types. It is observed from the results of scenario 2 (table 3.6) that all the generated connections get admitted for the number of connections less than 30. Hence in this scenario 20 connections are considered for study. The simulation time considered is 100s.

Initially five connections (one connection from each service type) are considered for simulation and as the simulation progresses the connections of different service types are generated at various simulation times as given in table 3.7. The performance metrics considered for simulation study are throughput and delay. As the proposed
scheduling algorithm works in similar way to basic algorithm for UGS and nrtPS cases, the performances of those connections are not considered.

### Table 3.7 Traffic generated for Scenario 3

<table>
<thead>
<tr>
<th>Simulation time (second)</th>
<th>Service type</th>
<th>Number of connections generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>UGS</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>ertPS</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>rtPS</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>nrtPS</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>BE</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>UGS</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>ertPS</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation time (second)</th>
<th>Service type</th>
<th>Number of connections generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>rtPS</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>nrtPS</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>BE</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>UGS</td>
<td>1</td>
</tr>
<tr>
<td>36</td>
<td>ertPS</td>
<td>1</td>
</tr>
<tr>
<td>39</td>
<td>rtPS</td>
<td>1</td>
</tr>
<tr>
<td>42</td>
<td>nrtPS</td>
<td>1</td>
</tr>
<tr>
<td>45</td>
<td>BE</td>
<td>1</td>
</tr>
</tbody>
</table>

![Graph showing Throughput performance of ertPS Connections](image)

**Figure 3.24.** Throughput performance of ertPS Connections
Figure 3.25 Throughput performance of rtPS Connections

Figures 3.24 and 3.25 show the throughput performance of ertPS and rtPS connections respectively with respect to simulation time. It is observed from the figures 3.24 and 3.25 that throughput increases for both proposed and basic algorithm initially since for every 3 seconds a new connection is get added up. After 50th second the throughput becomes almost constant since no new connections get added after 50th second. Figures 3.24 and 3.25 also depict that throughput performance of proposed algorithm is better compared to basic algorithm since in proposed algorithm the scheduler degrades the bandwidth guaranteed for nrtPS connections if real time services requires more bandwidth.

Figure 3.26 Throughput performance of BE Connections
Figure 3.26 gives the throughput performance of BE connections with respect to simulation time. Figure 3.26 depicts that throughput performance of proposed algorithm is better compared to basic algorithm since in proposed algorithm the scheduler serves the BE services in a round robin manner which gives equal priority to all connections of different MCS regions.

![Figure 3.27 Delay performance of ertPS Connections](image)

![Figure 3.28 Delay performance of rtPS Connections](image)

Figures 3.27 and 3.28 depict the delay performance of ertPS and rtPS connections respectively with respect to simulation time. It is observed form the figures that delay
performance of proposed algorithm is better compared to basic algorithm since the proposed algorithm allocates more bandwidth to ertPS and rtPS connections.

3.8 Conclusion

In this chapter MCS aware CAC scheme and uplink scheduling algorithm is proposed. A connection bandwidth degradation method for lower priority services is proposed to increase the system capacity to admit more number of higher priority connections without affecting the QoS performance of lower priority much. Also a channel aware BS uplink scheduling algorithm is proposed to improve the QoS performances of ertPS, rtPS and BE services. The proposed algorithm is implemented using QualNet simulation tool. It is observed from the simulation results that the proposed algorithms outperform the basic algorithms.

References


Chapter 3  
MCS Aware CAC and Uplink Scheduling Algorithm for WiMAX


[31] http://www.scalablenetworks.com\qualnet\documentation, Documentation of QualNet simulation tool