Chapter 3

AN ADAPTIVE POWER EFFICIENT PACKET SCHEDULING ALGORITHM FOR WIMAX NETWORKS

3.1 SCHEDULING IN WiMAX

With a tremendous increase in data services and real time applications over wireless networks, IEEE 802.16 has been designed to support QoS for both continuous and bursty traffic. In downlink and uplink directions, packets traversing the MAC layer interface are associated with a service flow. A unique set of QoS parameters such as delay, bandwidth etc is associated with each MAC level service flow. In order to better support QoS in uplink direction, standard specifies uplink scheduling services for heterogeneous classes of traffic and bandwidth request-grant mechanisms. Each uplink flow is allocated bandwidth for transmission depending on the amount of bandwidth requested and its scheduling service type. However IEEE 802.16 standard does not suggest packet scheduling mechanisms for downlink and uplink flows so as to provide required QoS to various applications. Scheduling details are left as responsibility of implementers.

Therefore, scheduling mechanisms are required for both downlink and uplink flows. In the downlink direction, scheduling is relatively easy simple because BS knows the exact status of its queue and their QoS requirements; hence, existing scheduling mechanisms will suffice. However, uplink scheduling is more complex as it needs to be in accordance with uplink QoS provisions provided by IEE 802.16. A single scheduling mechanism for the entire system will not work since uplink scheduling involves both SS and BS. They need to coordinate with each other for uplink bandwidth allocation. While downlink scheduling requires only one scheduler
at BS, uplink scheduling requires two components, one at the SS and one at the SS. The component at BS allocates bandwidth to SSs and the one at SS schedules uplink packets in the granted slot. Hence, an efficient QoS scheduling architecture for the complete system is required to maintain QoS and fairness for different types of uplink and downlink flows.

An adaptive power efficient packet scheduling algorithm that provides a minimum fair allocation of the channel bandwidth for each packet flow and additionally minimizes the power consumption is proposed in this thesis. Based on the channel state and the various traffic class priorities, the packets are transferred in the slots assigned, in the adaptive scheduling algorithm. Whenever the threshold value is crossed by the buffer size of the traffic queues with higher priority and terrible channel state, then in order to avoid starvation, the sleep duty cycle of the low priority traffic is adjusted to increase the priority of these flows.

3.2 SCHEDULING ISSUES IN WiMAX

Scheduling is a method of assigning time slots to SSs in each frame such that global fairness can be maintained and collision is not caused to the nearby SSs during transmission [10].

Centralized and distributed scheduling techniques are taken up by the WiMAX mesh mode for the allocation of the network resources and network access management. In centralized scheduling, the requests of all the SS that are associated with the BS are considered and extended as a mesh tree with local resource assignment. Whereas in the case of distributed scheduling, the neighbor along with its direct neighbors which form the extended neighborhood are used for handling the requests and grants in the network. For the centralized and the distributed scheduling techniques, the control messages for signaling are supplied by the standard. However
the standard makes it unavailable for the vendors. For utilizing the control and the management messages in the formation of the mesh, the characterization of these messages is done by the standard but the routing metrics to be used is not depicted [26].

In order to attain good transmission performance, various scheduling algorithms such as adaptive uplink and downlink bandwidth adjustment algorithms are proposed. Because of the structure of the frame and bandwidth requesting/granting process in the IEEE 802.16-based network, there is no much enhancement in the delay in packet queuing and radio link utilization [4].

In IEEE 802.16e, the limitations related to power consumption are inspected by various works and in order to enhance the energy efficiency, sleep intervals are suggested by means of preferred algorithms. However in IEEE 802.16e networks, all the works consider only the non real-time connections. Although the sleep mode is applied in the network, since mobile stations handle several real time connections, the proper timing of the sleep mode operations is not available; as a result the amount of power consumed cannot be reduced [17].

To handle the constraints related to delay and delay jitter in the transmission of voice and video signals so as to satisfy the QoS requirement, the major limitation faced is the efficient assignment of the resource among the customers along with the requirement to increase the goodput and decrease the amount of power utilized, maintaining a practical complexity in the algorithm with sufficient scalability in the system [27].

Taking into consideration of the traffic class as separately or not is the major problem related to inter class scheduling. The next major problem is defining the requirement of the resource to each class; related to weights [27].
Fair Scheduling, Distributed Fair Scheduling, MaxMin Fair Scheduling, Channel State Dependent Round Robin (CSD-RR), Feasible Earliest Due Date (FEDD) and Energy Efficient Scheduling are among the several efficient scheduling algorithm, but in WiMAX its application is limited because of some few characteristics of the technology. For instance, the Request/Grant mechanism, Orthogonal Frequency Division Multiple Access (OFDMA) vs. Carrier Sense Multiple Access/ Collision Avoidance (CSMA-CA) for Wireless LANs are the explicit characteristics of the WiMAX networks [27].

The various kinds of traffic services in WiMAX system are

1. UGS (Unsolicited Grant Service),
2. rtPS (Real Time Polling Service),
3. ertPS (Extended Real Time Polling Service),
4. nrtPS (Non-Real Time Polling Service), and
5. BE (Best Effort)

1. UGS:

A preset periodic assignment of bandwidth is performed by this class of traffic service. No request is required after the setting up of the connection. For application involving the constant bit rate (CBR) real-time traffic like E1/T1 circuit emulation, this service is suitable. The increased sustained rate (MST), increased latency and tolerated jitter (the maximum delay variation) are the major QoS characteristics of this service class [27].

2. rtPS:

For real time traffic with variable bit rate such as MPEG compressed video, this class is suitable. In rtPS, the needed bandwidth keeps changing with time and hence periodic polling of every MS has to be performed by the BS in order to perform
the required allocations. In rtPS, the QoS characteristics are comparable with that of the UGS except for the least reserved traffic rate and utmost sustained traffic rate, which has to be specifically described. Whenever these two characteristics are present in the UGS and ertPS class, they will be similar [27].

3. ertPS:

Using silent suppression to sustain the VoIP is performed by ertPS class. Hence at silent periods, there is no traffic transmission. Since the assignment of the maximum sustained rate in active mode is done by the BS and at the silent periods, there is no traffic transmission, the ertPS service becomes comparable with the UGS service class. In order to find out whether the silent period is still on process or has ended, the BS needs to keep polling the MS at the silent period. The QoS characteristics of ertPS and UGS are similar [27].

4. nrtPS:

For non-real-time traffic with variable bit rate and no delay assurance this class is suitable. This class provides assurance only related to the minimum rate. An example for nrtPS class employment is in File Transfer Protocol (FTP) traffic [27].

5. BE:

Major part of the data traffic belongs to this service class. Both delay and throughput are not assured by this class. In case of extra bandwidth from other service classes, it will be assigned to the MS. Practically; in this class also implementations are specified with reduced traffic rate and utmost sustained traffic rate [27].

The traffic flow can be divided into three types:

1. Class 1 (UGS, rtPS and ertPS)

2. Class 2 (nrtPS)

3. Class 3 (BE)
For the three traffic classes, every node \( n_i \) sustains three queues, \( q_{i1}, q_{i2}, \) and \( q_{i3} \). In the control frame of the 802.16e, every node within the communication range shares its information related to queuing with all the other available nodes in the communication range. The channel is regularly inspected by the Channel Condition Estimator (CCE) and the channel state error (SNIR) is determined. The priority based scheduling of the resources is done in the absence of error in the channel, in a proficient way. In case of channel error,

In the presence of Class1 packet in the node, the transmission is preceded

Else, the transfer is halted and the already assigned slots are now assigned to the neighboring nodes.

Estimating the sleep period length and listen period length within the radio resource and the QoS constraints; is necessary in order to reduce the power consumed by any of the mobile station (MS) with several real-time connections.

The QoS parameters of a mobile station \( j \) consisting \( N \) real-time connections, for connection \( i \) is depicted as \( Q_j = \{ \text{PS}_i, \text{AT}_i, D_i \} \), where

\( D_i \) represents the delay constraint between two successive packets with the connection \( i \).

\( \text{PS}_i \) represents the average packet size in terms of bytes involved with the connection \( i \).

\( \text{AT}_i \) represents the average inter packet arrival time in terms of milliseconds with the connection \( i \).

**The possibilities of the connections are**

1. Downlink connection from the base station towards the mobile station
2. Uplink connection from the mobile station towards the base station.
3.3 UPLINK SCHEDULER

The three major parts of the uplink (UL) scheduler are

1. Information module
2. Database module and
3. Service assignment

Information module

The functions performed by this module are

1. Based on the MS, the packets are differentiated the information related to the queue size is derived
2. Deciding the arrival time: the time of arrival of the packets in the previous frame is estimated which is known as the time bound. Based on the total time required by packet’s arrival time and packet’s utmost delay requirement, the time bound is determined. Once the steps are performed, then it is transferred to the scheduling data base module.

Scheduling Database Module

In the network for all the MS the information database is served by the scheduling database module.

Service Assignment Module

The uplink sub-frame allocation is estimated by the service assignment module in terms of the number of bits per MS. All the bits will be transformed into time slots i.e., in the information element (IE) of the Up Link Map (UL-MAP) generation, the number of units used. The physical layer in the wireless network estimates the number of bits per time-slot [28].
In the BS, the downlink (DL) scheduler allocates the overall downlink bandwidth between its downlink connections. For scheduling the control messages and the data packets, the Adaptive Proportional Fair (APF) scheduling scheme is used by the BS. As soon as the uplink sub-frame comes to an end, the BS initially broadcasts the DL-MAP and UL-MAP, followed by the RANG-RSP messages; next the REGREP messages are transferred followed by the CONN-RSP messages. Finally, the downlink data packets are sent to MSs. The downlink channel is always maintained as a channel for broadcasting. Precise amount of data is transferred by the Downstream Generator, from every downlink connection on the basis of the output from the downlink scheduler. Transmission of the messages which are produced at the uplink scheduler is carried out by the downlink scheduler [28].
A communication link is depicted by \( l_i = (s_i, r_i) \), in which \( s_i \) and \( r_i \) are the sender and the receiver node. In this model, when there is no interference the Packet Reception Rate (PRR) that is experienced by the link \( l_i \) is represented by \( f(SNR_i) \), in which \( SNR_i \) depicts the signal-to-noise ratio at node \( r_i \). For the signal transmitted by node \( s_i \), \( P_i \) is the power that is received at node \( r_i \) and the power of the background noise is represented by \( N \).

The PRR in the link \( l_i = (s_i, r_i) \), when there are several parallel transmissions in the set of links \( l_1 \ldots l_k \) is represented by \( f(SNR_i) \), in which \( SNR_i \) is the signal-to-
noise-and interference ratio measured at the node $r_i$ when the other nodes $S_j$, $s$ are transmitting.

$$SNIR_j = \frac{P_j}{N + \sum_{j \neq i} P_j}$$

where $P_j$ indicates the power that is received at the node $r_i$ of the signal

### 3.6. ADAPTIVE SLEEP DUTY GENERATION

Whenever there are no packets in the network to be sent or received then the mobile station will change to sleep mode for the purpose of saving power in the mobile WiMAX system. In order to hold the connections in the network that possess various characteristics, three power saving classes are identified by the IEEE 802.16e. On the basis of the requirement, every connection of the mobile station is linked with any of the power saving class, and then the connections that possess similar demand property are categorized into one power-saving class. The base station and the mobile station negotiates the several parameters related to the power-saving class such as time to sleep and listen, the length of a sleep period and a listen period [17].

Based on the sleep mode behaviors of all the related connections, the possible periods up to which a mobile station can sleep can be determined, whenever the mobile station sets up numerous connections of various demand properties. Apparently in a mobile station with several real time connections, incase a suitable schedule for the operations in the sleep mode is not available then the total power consumed by the mobile station cannot be decreased even after the application of the sleep mode.

Due to the requirement of the periodic power save scheme to maintain a sleep and listen period which is fixed for every station, it will have to remain awake for some frames in the listen period even though none of the packets are present. Hence a
non periodic scheme needs to be employed. In this scheme, the sleep and the listen period lengths are not fixed and hence it can determine the sleep and the wake up cycle on the basis of frames. When a connection on a MS is set up or released, the BS will immediately trigger this scheme for the purpose of resource re-scheduling in the frames for all the MS.

For the purpose of determining the traffic class, every connection in the MS are verified and arranged in the order of its priority. The arrangement of the connections in every class is based on its request dead-lines.

Once the scheduling priorities of all the connections in the scheduler is fixed, then the packets related to connection i with the first priority and belonging to the node j are scheduled. The requested bandwidth for the connection i belonging to the node j in the kth OFDM frame is represented by RBW_{ij}(k). The overall accessible bandwidth in an OFDM frame with period T_{f} to node j is given by TBW_{j}.

In order to schedule RBW_{ij}(k), it is necessary to satisfy both the constraints; bandwidth and delay

\[
\text{If } RBW_{ij}(k) < TBW_{j} - ABW_{j}(m), \quad m \geq k \tag{2}
\]

\[
\text{If } (m - k + 1) T_{f} \leq DC_{i} \tag{3}
\]

ABW_{j}(m) represents the bandwidth which is already assigned to the node j to get connected to the m^{th} frame and DC_{i} represents the delay constraint between any two successive packets for the connection i in terms of milliseconds.

For RBW_{ij} the possible scheduling frame set is denoted by F\{RBW_{ij}\}.

In order to allocate priority and choose a frame F_{i} \in F\{RBW_{ij}\}, the steps to be carried out are as follows:

1. In case the resources related to the in-used frames F_{i} are accessible to hold RBW_{ij}, then the first priority in the system is given to F_{i}. 
2. In case of two in-used frames F_i and F_j, the first priority is determined based on the min(F_i, F_j).

3. In case all the in used frames F_i, i=1,2,...,n remain unused in the system then the first priority is assigned to the un-used frame which appears at the last i.e., F_n. This is due to the fact that, whenever the latter frame is chosen in the network, maximum opportunities will be provided to it, inorder to serve remaining packets in the other OFDM frames.

Once these three steps are carried out then scheduling of the RBW_{ij} is done to the frame chosen.

3.7 ADAPTIVE POWER EFFICIENT PACKET SCHEDULING ALGORITHM

1. Get the traffic request from the node MSS_i.

2. Estimate the channel error (SNIR) for MSS_i by (1).

3. If SNIR < SNIR_{thr}, where SNIR_{thr} is the threshold value for SNIR, then

   3.1 MSS belongs to Group1

   Else

   3.2 MSS belongs to Group2.

   End if.

4. If MSS belongs to Group1,

   4.1 Check the traffic class.

   4.2 Assign priorities as per the traffic class.

   4.3 Allocate the required bandwidth and slots for MSS by.

   4.4 Generate sleep duty cycles for the nodes satisfying (2) and (3).

   End if.

5. If MSS belongs to Group2,
5.1 Check the traffic class \( j \), \( j = 1 \) to 3.

5.1 Add the traffic \( TR_k \) into the corresponding queue \( q_{ij} \)

5.2 If \( j = 1 \) and If \( Q_{size_{ij}} > Q_{thr} \), where \( Q_{size_{ij}} \) is the queue length of \( q_{ij} \) and \( Q_{thr} \) is the maximum queue length, then

5.2.1 Increase the sleep duration for any traffic \( TR_{ji} \), \( j = 2 \) or 3 of Group1 node.

5.2.2 Allocate the slot of \( TR_{ji} \) to the excess traffic flow \( TR_k \)

Else

Repeat from Step.2

End if.

End if.

3.8 SIMULATION RESULTS

3.8.1 Simulation Model And Parameters

To simulate the proposed scheme, network simulator (NS2) is used. The proposed scheme has been implemented over IEEE 802.16 MAC protocol. In the simulation, clients (SS) and the base station (BS) are deployed in a 1000 meter \( \times \) 1000 meter region for 50 seconds simulation time. All nodes have the same transmission range of 250 meters. In the simulation, the video traffic (VBR) and CBR traffic are used.
The simulation settings and parameters are summarized in Table 3.1:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area Size</td>
<td>1000 X 1000</td>
</tr>
<tr>
<td>Mac</td>
<td>802.16</td>
</tr>
<tr>
<td>Clients</td>
<td>2, 4, 6, 8 and 10</td>
</tr>
<tr>
<td>Radio Range</td>
<td>250m</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>50 sec</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>DSDV</td>
</tr>
<tr>
<td>Traffic Source</td>
<td>CBR, VBR</td>
</tr>
<tr>
<td>Video Trace</td>
<td>JurassicH263-256k</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>OFDM</td>
</tr>
<tr>
<td>Packet Size</td>
<td>1500 bytes</td>
</tr>
<tr>
<td>Frame Duration</td>
<td>0.005</td>
</tr>
<tr>
<td>Rate</td>
<td>1Mb</td>
</tr>
<tr>
<td>Error Rate</td>
<td>0.01, 0.02, …, 0.05</td>
</tr>
</tbody>
</table>

3.8.2 Performance Metrics

In this work the proposed APEPS scheme with the Periodic Base Scheduling (PBS) (17). The performance is compared with the following metrics:

**Channel Utilization:**

It is the ratio of bandwidth received into total available bandwidth for a traffic flow.

**Throughput:**

It is the number of packets received successfully.

**Average End-to-End Delay:**

The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

**Average Energy:**

It is the average energy consumption of all nodes in sending, receiving and forward operations.
3.8.3 RESULTS

A. Effect of Varying MSS

In the first experiment, the number of MSS is varied as 2, 4, 6, 8 and 10 and we measure the channel utilization, throughput, energy and end-to-end delay.

Figure 3.3: MSS Vs Utilization

Figure 3.3 shows the channel utilization obtained, when the number of MSS is varied. It shows that APEPS has better utilization than the PBS scheme.

Figure 3.4: MSS Vs Delay (CBR)

Figure 3.5: MSS Vs Delay (VBR)
Figure 3.4 and Figure 3.5 shows the delay of CBR and VBR traffic occurred, when MSS is varied. It shows that the delay of APEPS is significantly less than the PBS scheme for the both the traffics.

![Figure 3.6: MSS Vs Throughput](image)

Figure 3.6 shows the throughput obtained with our APEPS scheme compared with PBS scheme. It shows that the throughput of APEPS is more than the PBS, as MSS increases.

![Figure 3.7: MSS Vs Energy](image)

The energy consumption of both the schemes is presented in Figure. 3.7 From the figure, we can observe that the energy consumption is less in APEPS when compared to the PBS scheme.

**B. Effect of Varying Channel Error Rates**

In the second experiment, the channel error rate is varied The results were given for class1 and class2 traffics.
Figure 3.8: Error Rate Vs Utilization (CBR)

Figure 3.9: Error Rate Vs Utilization (VBR)

Normally, when the channel error rate is increased, the channel utilization of all the flows will tend to decrease. As it can be seen from the figures 3.8 and 3.9, the utilization of all the flows slightly decreases, when the error rate is increased. As per the proposed algorithm, the class1 flow is admitted and other types of flows are blocked when there is a channel error. So the utilization for class1 is more, when compared with class2 flows.

Figure 3.8 and Figure 3.9 gives the channel utilization for CBR and VBR traffics obtained for various error rates. It shows that APEPS has better channel utilization than the PBS scheme.
Figure 3.10: Error Rate Vs Delay (CBR)

Figure 3.11: Error Rate Vs Delay (VBR)

Figure 3.10 and Figure 3.11 shows the delay for the CBR and VBR traffics occurred for various error rates. It shows that the delay of APEPS is significantly less than the PBS scheme.