Novel IEEE 802.16 Mesh Node Architecture to Achieve QoS in Coordinated Distributed Mode

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Abstract—**the IEEE 802.16 defines two basic operational modes: point-to-multipoint (PMP) and mesh. The mesh mode provides two scheduling algorithms for assigning time slots to each network node: centralized and distributed. The aim of this paper is to address the Quality of Services (QoS) problem in coordinated distributed scheduling in mesh mode by proposing a new architecture for QoS-aware IEEE 802.16 mesh node. The paper explains the new mechanism proposed in mapping the QoS parameter from the upper layer to the IEEE 802.16 Medium Access Control layer (MAC) and introduces a new technique in assigning the data minislots to satisfy the requirements for different traffic types. Another aspect that the paper discusses is how to achieve fairness while distributing the data minislots. Several simulations are performed using OPNET Modeler 16.0 to evaluate the proposed architecture and the important system parameters which affect the network performance.**

Keywords-component; **WiMAX; Traffic Classification; Mesh; Distributed; QoS**

I. Introduction

The IEEE 802.16 standard, also commonly known as WiMAX, is a standard-based technology that enables the delivery of last mile wireless broadband access with lower deployment and maintenance costs as an alternative to cable and DSL.

A WiMAX network can operate under two modes, (PMP) mode where all the Subscriber Stations (SSs) directly connect to the Base Station (BS) through a single-hop wireless link and mesh mode in which a SS can communicate with either the BS or other SSs through multi-hop routes [1].

The mesh mode is more robust to link/node failures as for each subscriber station there are a large number of multihop paths to reach the base station and other SSs. In the mesh mode a special MAC is defined in the IEEE 802.16, which provides two different types of scheduling mechanisms, centralized and distributed scheduling. In centralized scheduling, an end-to-end QoS is provided where all requests are forwarded to the BS, which is responsible for the resource management (bandwidth reservation etc.) in a network. On the other hand the distributed scheduling does not provide end-to-end QoS to flows which is scheduled between subscriber stations in coordinated or uncoordinated fashion [2].

As the future wireless networks promise to support a variety of traffic types, they should satisfy the requirements for high-data-rate delay-sensitive applications, low-data-rate applications, Real-time applications and Non-real-time applications. For such traffic types, various quality-of-service (QoS) classes should be defined. The IEEE 802.16 PMP mode provides different levels of QoS to meet these kinds of transmission services. Five connection based QoS classes have been specified; including Unsolicited grant service (UGS), real-time polling service (rtPS), non-real time polling service (nrtPS), best effort (BE) and extended real time polling service (ertPS). On the other hand the current mesh mode specifications do not allow the realization of such scheduling services. Thus, through this paper a new QoS architecture and mechanism is designed within the framework of the mesh mode to support sophisticated scheduling services. Moreover, interworking of the QoS mechanisms with higher layers (IP layer) is addressed [3].

The rest of the paper is organized as follows: in Section II the 802.16 mesh mode is discussed focusing on frame structure and addressing. Section III introduces the proposed classification and mapping technique, it also explains the proposed mesh node architecture and its working mechanism. Section IV discuss the simulation model and analyze the performance of the proposed framework. Finally Section V concludes the results obtained.

II. IEEE 802.16 Mesh mode

A. IEEE 802.16 Mesh Frame

In the mesh mode unidirectional links can be established between any of the WiMAX nodes, and the information is transmitted on a hop-by-hop basis. Each link is uniquely identified in the network with both the node ID and the link ID. The link ID identifies the link among the set of outgoing links of a node, and the node ID identifies the node from which the link originates. The system access follows a frame-based approach which is shown in Figure 1 where each channel is divided in time into a series of frames. The number of frames in a series is defined during the network creation process. A frame is further divided into two subframes: control subframe and data subframe. The control subframes are used for carrying the information necessary to control the system access, bandwidth allocations, connection establishments, and connection maintenance. The data subframes are used for carrying upper layers' packets. The control subframe is divided into a number of transmission opportunities. The data subframe is similarly divided into a number of minislots. There are two types of control subframes depending on their function.

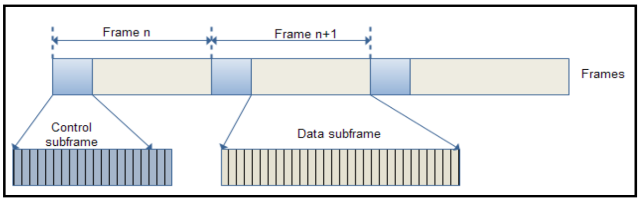


Figure 1. Mesh Frame Structure

The first type of control subframe is the scheduling subframe in which nodes transmit scheduling messages. The second type of control subframe is the network configuration subframe in which nodes broadcast network configuration packets containing topology information, network provisioning information, and network management messages [4].

The scheduling policy for accessing data slots in coordinated distributed fashion is not specified in the IEEE 802.16 standard. The standard only defines the Mesh-Distributed-Scheduling (MSH-DSCH) message shown in Figure 2, and specifies the scheduling to avoid collision between messages of different nodes. The MSH-DSCH contains the scheduling information organized in Information Elements (IE): Request IE, Availability IE, Grant IE and Scheduling IE.

The scheduling procedure follows a three-way handshake to reserve the minislots. First, a node sends an MSH-DSCH message to one of its 1-hop neighbors requesting a set of data slots. In the message, the node also includes the set of data slots that it has available for reservation. The 1-hop neighbor grants the request by replying with another MSH-DSCH message that specifies a set of data slots that satisfies the availability of data slots at both nodes. Finally, the first node confirms the reservation of such set of data slots by echoing the grant in another MSH-DSCH message [5].

B. *MESH Connection Identifier*

The IEEE 802.16 mesh standard uses a combination of a 16-bit mesh node identifier (node ID) and a 16-bit connection identifier (CID) to identify the source and destination of every transmission. The CID in mesh mode is a combination of an 8-bit link ID and an 8-bit QoS description for the connection. The link ID shall be used for mesh addressing in the local neighborhood, each node will assign a link ID to the link it has established with its neighbor during the link establishment process, the CID will be transmitted as a part of the generic MAC header.

The 8-bit QoS in the CID contains three definable fields: Reliability, Priority/Class, and Drop Precedence (Figure 3). Reliability refers to retransmit or not (0 indicates no retransmit while 1 indicates retransmit). Priority/Class refers to the priority of the packet. Drop Precedence refers to the probability of dropping the packet when congestion occurs [3].

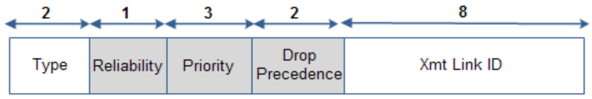


Figure 2. QoS bits in the Mesh CID

According to the standard all the communications are in the context of a link, which is established between two nodes. One link shall be used for all the data transmission between two nodes. The quality of service over the link is provisioned on a message-by-message basis. No service or QoS parameters are associated with a link, but each unicast message has service parameters in its header [6].

III. QoS MANAGEMENT

A. *Traffic Classifcation and Mapping Techniques*

In order to achieve QoS in WiMAX mesh networks the traffic coming from the higher layer must be classified and mapped according to its type. The IP layer which represents the higher layer traffic uses the Type of Service (ToS) field to classify the traffic. According to the model deployed in the network, the ToS field either represents the QoS in terms of precedence, delay, throughput and the reliability or according to Differentiated Services Code Point (DSCP). According to this representation the proposed technique will classify the traffic to one of four classes: Constant Bit Rate-Real Time (CBR-RT), Variable Bit Rate-Real Time (VBR-RT), None Real Time (NRT) and Best Effort (BE).

After classifying the traffic it is mapped to the QoS fields of the CID. As the CID is the most suitable way to treat and forward traffic on the WiMAX network. Table 1 shows the mapping between the ToS Precedence bits and the CID bits, also the mapping between the class selector bits and the CID bits when the classification is done according to the DSCP is shown.

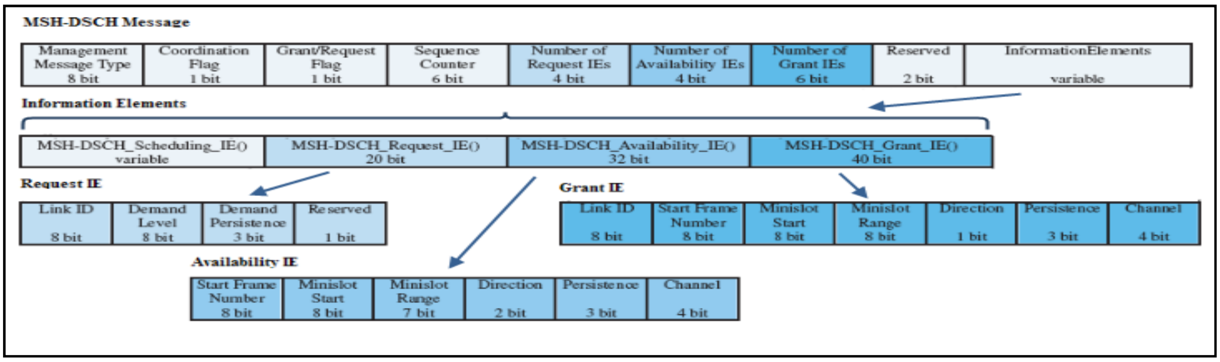


Figure 3. MSH-DSCH Message

TABLE 1. HIGHER LAYER MAPPING

ToS	DSCP	Traffic classes	MSH CID		
Precedence	Class selector		Priority	Drop Precedence	Reliability
000 001	000	BE	000 001	11 11	0 0
010 011	001- 010	NRT	010 011	10 10	0 1
100 101	011- 100	VBR-RT	101 101	01 01	0 0
110 111	101	CBR-RT	111 111	00 00	0 0

The CID Drop precedence and reliability bits will be set to the values that satisfy the type of traffic. According to these techniques the classified upper layer traffic can be mapped to the mesh CID QoS bits to have the suitable class of service treatment on the WiMAX network and retain the QoS interworking between the different layers.

B. Proposed Node Archetecture

Treating the upper layer data according to its type and requirements enhances the QoS in the mesh network. But in order to achieve this goal new modules need to be added to the node to perform the functions of classification, mapping, queuing and data scheduling. Figure 4 shows the suggested structure for the subscriber node. The architecture relies on using the following modules; packet classifier, data scheduler module, resource allocation module, database and a set of queues.

The packet classifier located in the service-specific convergence sublayer receives the upper layer data packet and classifies it to one of the four classes of service using one of the techniques explained above according to the model deployed in the network.

Next the classified data is transferred to the link management module which is composed of the data scheduler module and a set of queues and accordingly has more than one function. First it inserts the classified data into the corresponding queue; the link management module prioritizes the queues giving the CBR-RT queue the highest priority followed by the other types of the traffic VBR-RT, NRT and BE in order.

Next the data scheduler module manages the required resources through the process of minislot assignment which takes place through a three way handshake operation between the transmitting and receiving nodes on the link established in between. The three way handshake takes place through requests, grants and grant confirmation. Requests differ according to the type of traffic. The data schedule module scans the queues and determines the amount of the traffic present and its type and accordingly passes this request information to the resource allocation module to create the request element using the database information.

The Resource Allocation module is responsible for creating the request element (link ID, demand level, demand persistence) to be transmitted on the DSCH message. The number of request field (4-bits field) in the DSCH message is used to determine the number of requests needed in order that each type of traffic has its own request element. In this way different values for demand persistence can be used related to the traffic class to satisfy the traffic requirement (i.e each traffic type has its own request element with its own value of demand persistence) which helps the receiving node to distinguish between the requests of the different traffic types.

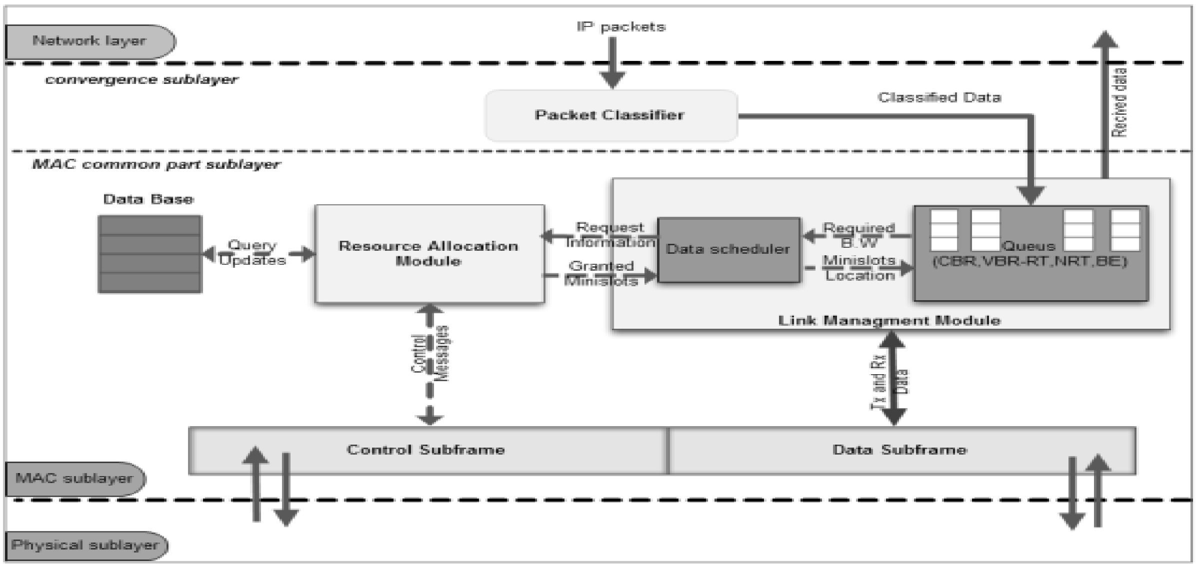


Figure 4. Proposed Node architecture

So for the CBR-RT and VBR-RT traffic (which are real time traffic) that couldn't afford any delay, will have a persistence value of 7 (good until cancel) in order to save the time encountered by the three way handshake and the election time to reserve the transmission opportunity needed each time for transmitting DSCH messages. Persistence less than 7 is used for NRTs and BE traffic as both of these types are not delay sensitive traffic, so it's better to reserve minislots at distinct frames to save more bandwidth on the link. So a value of Persistence 6 is used for NRTs traffic and a value of persistence 3 is used for BE traffic.

One of the QoS problems in IEEE 802.16 is that the resource request message doesn't carry any information about the type of transmitted traffic so the receiving node treats the requests of all types of traffic by the same way regardless of its QoS parameters. In [2] an end-to-end QoS distributed scheduling framework was introduced, the framework is based on creating a new information element to carry the QoS parameter in the DSCH message and send this element to the end of the path. In our proposed technique, the receiving node uses the reserved bit and persistence field in the request element to differentiate the requested traffic class as shown in Table II. Knowing the requested traffic type gives a chance for the granter to prioritize the request message. In the receiving node, the resource allocation module receives the control message (request IE), update the database and create grant confirmation element. The granted minislot in the grant IE is passed to the data scheduler module of the transmitting node which runs a scheduling algorithm to serve all the traffic present in the queues.

TABLE 2. CLASSIFICATION USING PERSISTENCE AND RESERVED BIT

Demand	Reserved bit	Traffic class
111	1	CBR-RT
111	0	VBR_RT
110	0	NRT
011	0	BE

Suggested algorithm to serve the queues is the class-based Deficit Weighted Round Robin (DWRR) [7]. This algorithm is one of the most efficient algorithms to deal with real time traffic as it give this traffic the highest priority and reserve to it a constant ratio of the granted bandwidth to guarantee that it meets the requirements of the delay and packet loss parameters. The DWRR solves the matter of wasting minislots which may occur due to the persistence 7 in case of variable bit rate traffic, so if the Queue of any traffic class is empty it is deleted from the active list and has its bandwidth assigned for the other queues if it has traffic to transmit. The DWRR is efficient in case of variable packet size as it depends on the idea of deficit counter. Using this algorithm the data scheduler module handles the granted minislots and serves the entire traffic queue in fair manner. Also the proposal allows for the QoS handling throughout the WiMAX mesh network through the usage of the CID field in the data subframes. As each node checks to see if it is the final destination of the traffic or not, If not it will retransmit the traffic based on its QoS parameter carried on the CID fields.

In [8],[9],[10],[11] many idea for routing on the Wimax mesh network are introduced. Routing is out of the scope of this paper. So we assume the received node is a final destination for the traffic.

IV. SIMULATION MODEL

The simulation of the suggested proposal is carried out using OPNET Modeler 16.0; the simulation is based on the WiMAX-RBDS-Sim framework [12]. Each node supports up to ten radio channels. The node model consists of 1 radio transmitter and 1 radio receiver that form the physical layer. The MAC layer is composed of 1 main processor that is responsible for the generation and exchange of control packets that carry MSH-NCFG and MSH-DSCH messages in order to perform the link-establishment and distributed-scheduling. The MAC layer also contains 10 processors and 10 queue-processors (one for each channel) that are responsible for processing and queuing the inbound and outbound packets. The upper layer is composed of a processor module that is responsible for generating the data packets to and receiving the data packets from the MAC layer. An 802.16 mesh network with distributed scheduling can be modeled by using several nodes and placing them within a spatial area such that they are capable of establishing links between them.

The simulation is run for a duration of 90 seconds, 60 seconds from which are set as an initialization period. During such initialization period no data packet generation takes place, only MSH-NCFG and MSH-DSCH messages are exchanged between the mesh nodes. The most important simulation attributes are shown in Table 3.

TABLE 3. SIMULATION ATTRIBUTES

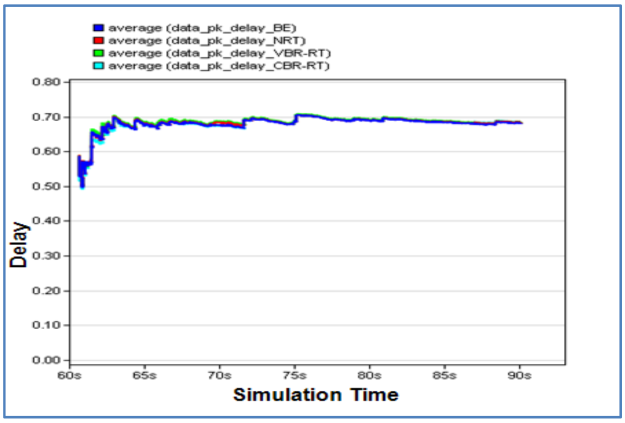
Simulation attribute	Value
Simulation time	90 seconds
Initialization period	60 Seconds
Number of minislots per data subframe	256
Frame length in time	10 m sec
Physical Channel width	10 MHz
Burst profile	BPSK 1/2

The WiMAX-RBDS-Sim framework concentrates only on the transmission of data packets after calculating its schedules. It doesn't take in concern any effect of classifying and prioritizing the traffic according to its type. So the above model is modified in order to reflect the effect of the classification of the traffic on the way it is served by the node and the network. The effect will be examined through three cases that each study two performance metrics for each traffic type, the end-to-end delay and the serving ratio. The end-to-end delay calculates the time each packet takes while being transmitted from the source until processed by the destination, the calculation considers the processing time taken in each node layer, the queuing delay, the transmission delay and the propagation delay to the destination which is one hop distance from the source. The serving ratio represents the ratio of the data packets leaving the MAC layer queue relative to the data packets that entered the

MAC layer queue. The serving ratio serves to show the amount of the granted minislots for each traffic type.

A. *Case one:*

In case one the upper layer generates traffic for the four data types previously specified (CBR-RT, VBR-RT, NRT and BE) with the same rate. And since the MAC layer process module inserts all the traffic in a common queue. A situation arises that results in that all traffic types will be served in the same manner; that is; they have the same serving ratio which means that the granted minislots will be equally distributed among all traffic types. Also all the data packets will encounter the same end-to-end delay as shown in Fig.5.



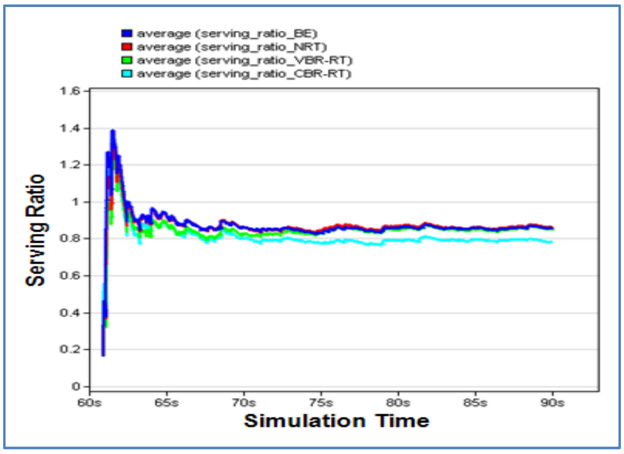
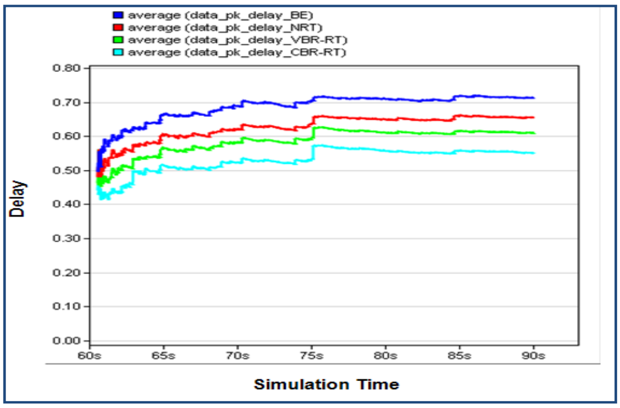


Figure 5. Case one: Packet delay and serving ratio

B. *Case two:*

The modified MAC layer process module will have four queues; one for each type of traffic; such that the packets received from the upper layer is inserted in the corresponding queue according to its classification. The CBR-RT queue which has the highest priority is served in the best way; that is its packets will be processed immediately and is granted the required minislots prior to the other traffic types (VBR-RT, NRT and BE). So as Figure 6 shows the end-to-end delay is minimum for CBR-RT traffic and increases for the other types until it is maximum for BE traffic. Also the figure shows that the serving ratio is best for CBR-RT traffic, worst for BE traffic and moderate for the other two types, where all the CBR-RT is served with the required minislots then the VBR-RT traffic then the NRT traffic and at last the BE traffic.



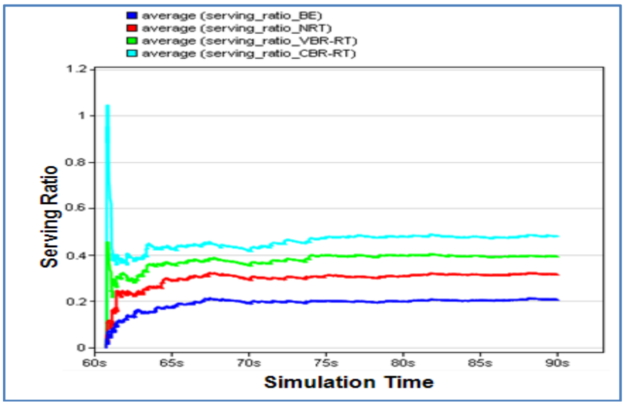


Figure 6. Case Two: Packet delay and serving ratio

C. *Case three:*

The second scenario doesn't take into consideration any fairness in the distribution of the minislots and may result in the starvation of all the bandwidth by the CBR-RT traffic. So in order to achieve this fairness the weighted round robin (WRR) algorithm is applied in the third scenario as the data packets generated by the upper layer are of fixed size. Using the WRR the granted minislots are distributed with fairness among the different types of traffic. The MAC layer process module will cycle the four queues, assigns each queue a ratio from the granted minislots such that in each cycle the CBR-RT queue will be granted a higher ratio from the assigned minislots, next will be the VBR-RT queue then the NRT queue and at last the BE queue. In this way the serving ratio for all traffic types still retain the priority assigned for each traffic type as in case two, that is the CBR-RT still best served then VBR-RT then NRT then BE. The extra benefit achieved is that the ETE delay for BE traffic is minimized as shown in Figure. 7. The figure shows that in case 1 where the BE traffic is treated as other types of traffic will have moderate delay, in case 2 the BE traffic is the last traffic served so the delay is maximum while in Case 3 has the minimum delay due to the cycling operation in all the queues which results in that the BE traffic is served better. The same concept occurs for the CBR-RT traffic as shown in Figure 7.

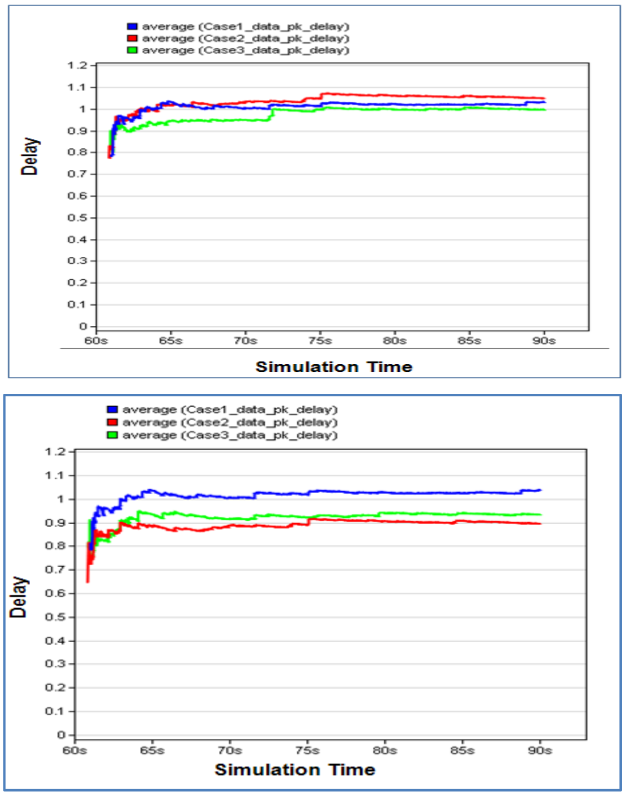


Figure 7. BE and CBR-RT packet delay in the three cases

Also the fairness in the distribution of the minislots is achieved which is shown in Figure 8 through the comparison of the serving ratio in the three scenarios taken for the CBR-RT traffic. In case 1 the serving ratio is the worst as the CBR-RT traffic is treated as other types of traffic with no prioritization, case 2 is the best as CBR-RT is prioritized and case 3 is moderate as fairness is applied.

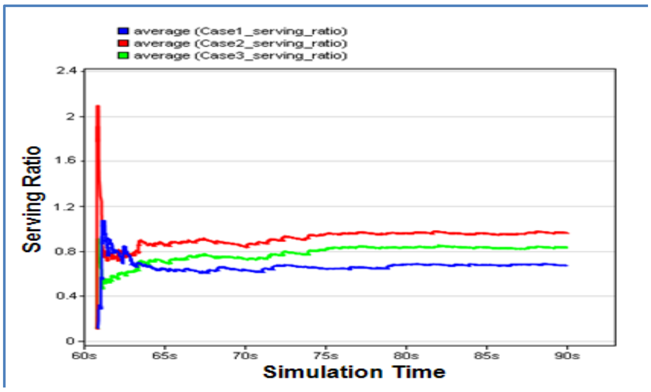


Figure 8. CBR-RT serving ratio in the three cases

V. Conclusion

The simulation carried out proved that the WiMAX mesh node model proposed by this paper; which classifies the upper layer data and treating them according to their requirements; will result in an enhancement in both the packet end-to-end delay and the serving ratio.

Also applying the WRR algorithm results in achieving fairness in the distribution of the granted minislots among the traffic classes.

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