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A New Scheduling Scheme for QoS in WiMAX Networks

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Abstract-The IEEE 802.11 standard may have some weaknesses, such as the short transmission distances and the small transmission rates. Therefore, the IEEE 802.16 (WiMAX) was proposed to solve the previous disadvantages. Generally, there are three essential components to handle the QoS in the 802.16 standard: admission control, scheduling and buffer management. However, literature shows the limitation of the works done on QoS in the distributed mesh mode in WiMAX. Thus, this paper aims to propose a new scheduling scheme running in the distributed mesh mode to achieve QoS in the 802.16 network. We used the Weight Fair Queue (WFQ) scheme as the scheduling scheme. Our proposed scheduling scheme provides more bandwidth by having higher throughput and lower packet delay rate. Furthermore, it insures the fairness for the lower priority classes, such as the nrtPS and the BE service classes.

Keywords- *WiMAX, Scheduling Scheme, QoS, WFQ, NS-2*

I. INTRODUCTION

The number of people using the wireless networks to login the Internet has increased because it is more suitable and it supplies the mobility. This leads to large operation of the wireless networks, such as WiFi or the IEEE 802.11 standard [2]. Nevertheless, the 802.11 standard may have some weaknesses, such as the short transmission distances and the small transmission rates. Therefore, the IEEE 802.16 standard or the Worldwide Interoperability for Microwave Access (WiMAX) is proposed to solve the previous disadvantages [9]. The broadband wireless access (BWA) is supplied by the 802.16 standard [14]. Furthermore, some high-quality features, such as the high speed access to the Internet, sustaining QoS, the low cost, the broad coverage range and the fast deployment are supplied for the organizing and the sustaining networks by the 802.16 standard. It can reach 75 Mbps as the data rate and it can achieve up to 50 Km as the extreme distance [23][25].

Generally, there are three essential components to handle the QoS in the 802.16 standard: (1) admission control; (2) scheduling; and (3) buffer management. The admission control is used to conclude whether the new connection request can be approved or not. This is based on the remaining complimentary bandwidth. Furthermore, the number of flows admitting into the network can be restricted by the admission control. Thus, several services overflow and the starvation may be controlled [8][15]. The scheduling is used to decide the priority to assure the QoS requirements. In other words, it is adopted to decide the first packet to supply in the particular queue to assure the QoS requirements. The buffer management is used to organize the buffer size and to choose the deleted packets. In other words, the buffer size can be restricted by the buffer management which is used to determine the dropped packet [24].

The purpose of this paper is to design a new scheduling scheme running in the distributed mesh mode to achieve QoS in the 802.16 network. We will use the Weight Fair Queue (WFQ) scheme as the scheduling scheme. Our proposed scheduling scheme will provide more bandwidth by having higher throughput and lower packet delay rate. Furthermore, it will insure the fairness for the lower priority classes, such as the nrtPS and the BE service classes.

The remainder of this paper is organized as follows: section 2 outlines background and several related works of scheduling schemes for WiMAX networks and it describes the frame structure of the mesh mode. Section 3 describes our proposed scheme and section 4 presents the simulation results and the performance analysis. Finally, section 5 gives some brief summary and the future work.

II. BACKGROUND & RELATED WORK

A. Background

There are two fixed stations in the basic architecture of WiMAX: base station (BS) and SS. The BS is the essential tools set and it can offer connectively management and the control of some SSs located in different distances. However, the building prepared with the conservative wireless or wired LAN can be signified by the SS. The internetworking access to the buildings can be offered by the WiMAX throughout external antennas [18].

There are two different operation modes identified in the IEEE 802.16 standard: PMP and mesh mode. In the PMP mode, multiple SSs can be associated by the controlling BS to different public networks. On the other hand, in the mesh mode, a direct communications between the SSs can be maintained without using the BS (figure 1) [20-21][29].

There are four different service classes maintained in the IEEE 802.16 standard.

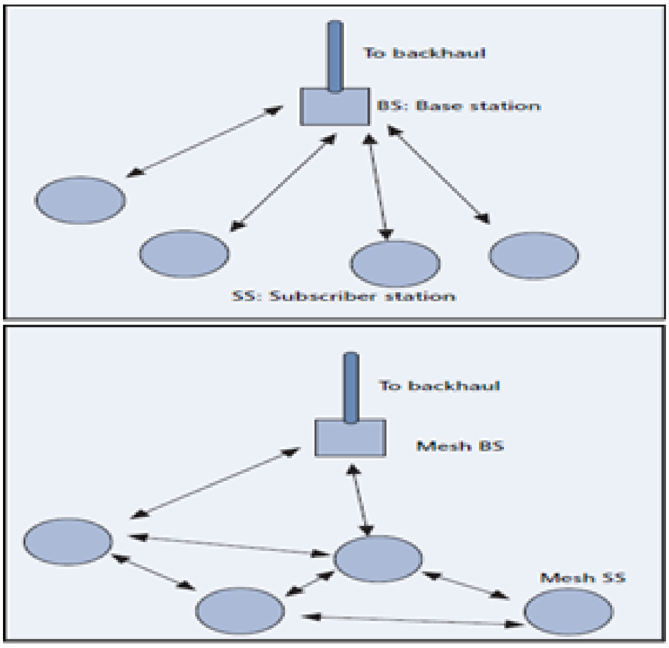

Figure 1. PMP Mode & Mesh Mode

1) Unsolicited Grant Service (UGS)

The UGS service class is proposed to maintain the real – time data streams contained the data packets with the fixed – size concerned at the periodic intervals, such as Voice over IP (VoIP) with no silence suppression and T1/E1. The Maximum Sustained Traffic Rate, the Tolerated Jitter, the Maximum Latency and the Request / Transmission Policy are the compulsory QoS service flow factors for the UGS scheduling service. The Minimum Reserved Traffic Rate factor is equal to the Maximum Sustained Traffic Rate factor when it is present [3].

2) Real-time Polling Service (rtPS)

The rtPS service class is proposed to maintain the real – time data streams contained the data packets with the variable – size concerned at the periodic intervals, such as the Moving Picture Experts Group Video (MPEG). The Maximum Sustained Traffic Rate, the Minimum Reserved Traffic Rate, the Maximum Latency and the Request / Transmission Policy are the compulsory QoS service flow factors for the rtPS scheduling service [5].

3) Non real-time Polling Service (nrtPS)

The nrtPS service class is proposed to maintain the delay - tolerant data streams contained the data packets with the variable – size when the minimum data rate is involved, such as the File Transfer Protocol (FTP). The Maximum Sustained Traffic Rate, the Minimum Reserved Traffic Rate, the Traffic Priority and the Request / Transmission Policy are the compulsory QoS service flow factors for the nrtPS scheduling service [7].

4) Best Effort (BE)

The BE service class is proposed to maintain the data streams when there is no minimum service level involved, such as the HTTP. Hence, it can be held on the space – variable basic. The Maximum Sustained Traffic Rate, the Traffic Priority and the Request / Transmission Policy are the compulsory QoS service flow factors for the BE scheduling service [4].

B. Frame Structure

The PMP mode network architecture is like the cellular networks. However, the mesh mode network architecture is like the ad-hoc networks where every SS can be the source node and the router at the same time [16].

Figure 2 shows the mesh mode frame structure. The control and the data sub-frames are the main components of the mesh mode frame. The design and the preservation of selecting between the diverse SSs is a principal functionality of the control sub-frame. The coordinate scheduling for the SSs data transmit is the other principal functionality of the control sub-frame. The broadcast MAC protocol data unit (MAC-PDUs) from diverse users is the main components of the data sub-frame. Furthermore, the common MAC header, the mesh sub header and the possible data are the main components of the MAC PDU.

There is a sixteen transmission opportunities in each control sub-frame. The control subframe length is set as the MSH-CTRL-LEN X7 Orthogonal Frequency Division Multiplexing (OFDM) symbols. There is four bits in the MSH-CTRL-LEN parameters and their values are sorted between 0 and 15. These values can be presented in the structure network descriptor. The network control and the schedule control are the two diverse control sub-frames categories. The network control sub-frame can be worked occasionally through the specified period in the structure network descriptor. However, the schedule control sub-frames can be worked in the whole frames with no the network control sub-frames.

New nodes are used the network control sub-frame to attain synchronization and connect the mesh network. The network entry element that transmits the mesh network entry (MSH-NENT) message information is the initial transmission opportunity. The network configuration elements that transmit the mesh network configuration (MSH-NCFG) message information are the remaining (MSH-CTRL-LEN -1) transmission opportunities. The seven OFDM symbols can compute every transmission opportunity length. Therefore, the transferring opportunities lengths that transmit the MSH_NCFG message are equivalent to MSH-CTRL-LEN -1 multiple of seven OFDM symbols. The schedule control subframe can be used in the centralized scheduling and the distributed scheduling schemes to split the SSs in the general radio resource. The transmission bursts of the PHY layer can be supplied by the data subframe. The bursts of PHY layer with a long preamble, which is about two OFDM symbols can be begun to supply for the synchronization, and then they are subsequent by some MAC PDUs directly [6][13-14][17].

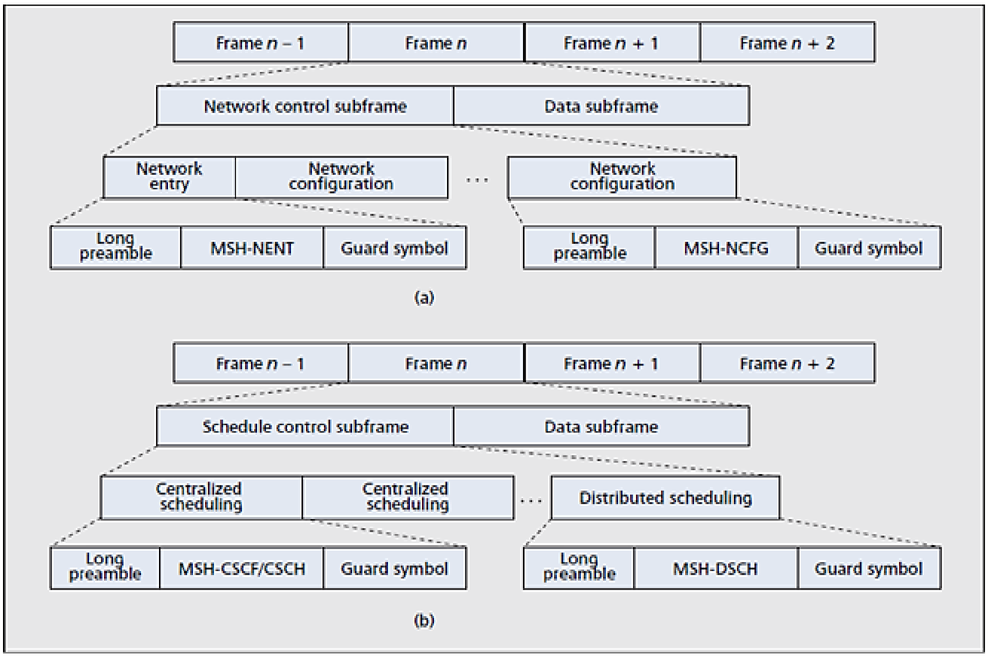

Figure 2. Frame Structure in IEEE 802.16 Mesh Mode: a) Frame n has a Network Control Sub-frame; b) Frame n has a Schedule Control Sub-frame.

C. Centralized Scheduling

The centralized scheduling may have similar network connections and topology as the distributed scheduling. However, the SSs scheduled transmissions have to be identified by the BS in the centralized scheduling. The BS in this scheduling is similar to the BS in the PMP mode excluded that it is not important for the whole of the SSs to be associated directly to the BS.

The control sub-frame transmission opportunities and the data sub frame mini-slots can be divided in the mesh mode. The SS can be calculated for the control channel access. The control sub-frame connection result may not have any cause on the transmitted data that happens throughout the data sub-frame of the similar frame. Thus, the control sub-frame contention method has to be involved to develop several performance metrics.

The BS can work the cluster head in the centralized scheduling scheme to decide how the channel can be divided by the SSs in diverse time slots. The scheduling scheme process is not complex because the control and the data packets are transferred throughout the BS. Thus, the centralized scheduling scheme may not be appropriate for the special traffic [10].

D. Centralized Scheduling Issues

The centralized scheduling and distributed scheduling are identified for mesh mode to avoid conflict when the transmission opportunities (TxOpp) are used. The network is divided into a tree based clusters in the centralized scheduling mode. There is BS node in every cluster acquired responsibility to assign the network resources to the served SS node. The centralized scheduling mode has some disadvantages while it may supply a free collision transferring for the data and the control packets.

Firstly, the utilized routes numbers may not be essentially decreased because the tree based topology which may not use the whole probable routes in the network is used by the centralized scheduling mode. Furthermore, the route between two nodes on the tree may not be the shortest route when the tree based topology is used compared with the mesh based topology. Furthermore, the root node may become as the performance bottleneck because the packets may require transmit throughout it to achieve the receiver node.

Secondly, there is some complexity to capably develop the spatial reuse property of the wireless connection in the centralized scheduling mode. Just the BS node can inform the SS node of its bandwidth allocation. The message may not have any fields used to permit the BS node to indicate the initiate and the finish minislot offsets for the allocation. The conventional approach is acquired by every SS node to transmit the data schedule in the centralized scheduling mode to avoid interference. Therefore, there is just one active SS node in each cluster at a time although the allocation minislots is a free collision [27].

E. Distributed Scheduling

However, there are two advantages presented by the distributed scheduling mode. Firstly, the mesh topology is used by the distributed scheduling mode in order to avoid the performance bottlenecks by permitting the whole probable routing paths to be used. Furthermore, the wireless connections spatial reuse may be developed in the distributed scheduling mode to enhance the capacity of the network. Secondly, the bandwidth may be more capably used because the data schedules can be created on the on – demand basis by the distributed scheduling mode [27].

Each node in the distributed scheduling scheme can be contended for the access of the channel by using the pseudo random election method depending on the two hop neighbors scheduling information. The data sub-frames may be assigned depending on the nodes request grant confirm three-way handshaking. Thus, the distributed scheduling scheme may be supplementary supple and capable on the data transmission and the connection setup [10].

Controlling the distributed channel access may not be simple because the transmission time of each node is calculated with no worldwide information while the enhanced suppleness and scalability can be shown by the mesh mode. The control and the data channels are divided and the control channel access is calculated by each node in the IEEE 802.16 mesh mode standard. The recent transmit data channel may not be involved by the control channel communications. Thus, the delay performance and the system throughput cannot be calculated in the mesh mode with no the scheduler behaviors know in the control channel methodically [12].

The coordinated distributed mode and the uncoordinated distributed mode are the two different operational modes for the IEEE 802.16 mesh network standard. There are several differences between the coordinated and the uncoordinated distributed scheduling. For example, the MSH-DSCH messages may be scheduled in the control sub-frame when there is no any collision mode in the coordinated distributed scheduling. However, the MSH-DSCH massages may have a collision in the uncoordinated distributed scheduling. The main different between them is whether the scheduling message been coordinated or uncoordinated in contending for the divided radio channel. In the coordinated distributed scheduling mode, the data schedules transmitting over the transmission opportunities with no collision are established by the control messages. However, only several control messages may be transferred on the transmission opportunities unused from the coordinated distributed scheduling mode or on not allocated minislots in the uncoordinated distributed scheduling mode. As a result, the coordinated distributed scheduling mode may offer better QoS supports than the uncoordinated distributed scheduling mode [27].

The coordinated distributed scheduling scheme is explained here. The important function can be done throughout the scheduling process by the MSH-DSCH message in the distributed scheduling. The availability IE, the scheduling IE, the request IE and the grants IE fields can be transmitted by the MSH-DSCH message. The number of initial frame, the initial minislot in the frame and the obtainable minislots numbers can be specified for the granter to allocate by the availabilities IE. Furthermore, the transmission time of the next MSH-DSCHmessage (NextXmt-Time) and the (XmtHoldofExponent) of the node and the set of neighbor nodes is illustrated by the scheduling IE fields. Furthermore, the node resource command is specified by the request IE field. The number of the granted initial frame, the granted initial minislot in the frame and the range of the granted minislots are transmitted by the grants IE field.

The coordinated distributed scheduling MSH-DSCH message is worked in the control sub-frame. The (NextXmtTime) of the MSH-DSCH can be decided for the period of the recent transmission time (XmtTime) by the distributed election scheduling. The next eligibility interval can be decided by the (NextXmtMx) and (XmtHoldoffExponent) parameters in the MSH-NCFG message

$$2^{XmtHoldoffExponent} \times NextXmtMx < NextXmtTime \times$$
$$2^{XmtHoldoffExponent} \times (NextXmtMx + 1)$$

Obviously, the eligibility interval length is equivalent to 2XmtHoldoffExponent. The node can transfer in any slot for the period of this interval. The hold off time (XmtHoldoffTime = 2XmtHoldoffExponent +4) is remained by the node before any new transferring and after the eligibility interval. After the hold off time (XmtHoldoffTime), the temporary transmission opportunity (TempXmtTime) equivalent to the first transmission slot is selected by the node. Next, the set of the whole eligible nodes (Seligible) opposing for the slot (TempXmtTime) is decided by the node. The (Seligible) may contain the whole nodes in the comprehensive neighborhood assuring any of the subsequent properties.

The (TempXmtTime) is contained in the (NextXmtTime), for example node B in figure 3.

The (NextXmtTime) is unidentified, for example node D in figure 3.

The (EarliestSubsequentXmtTime) has not worked later than the (TempXmtTime) where the (EarliestSubsequentXmtTime) is equivalent to the rundown of the (NextXmtTime) and the (XmtHoldoffTime), for example node C in figure 3.

$$EarliestSubsequentXmtTime = NextXmtTime + XmtHoldoffTime$$

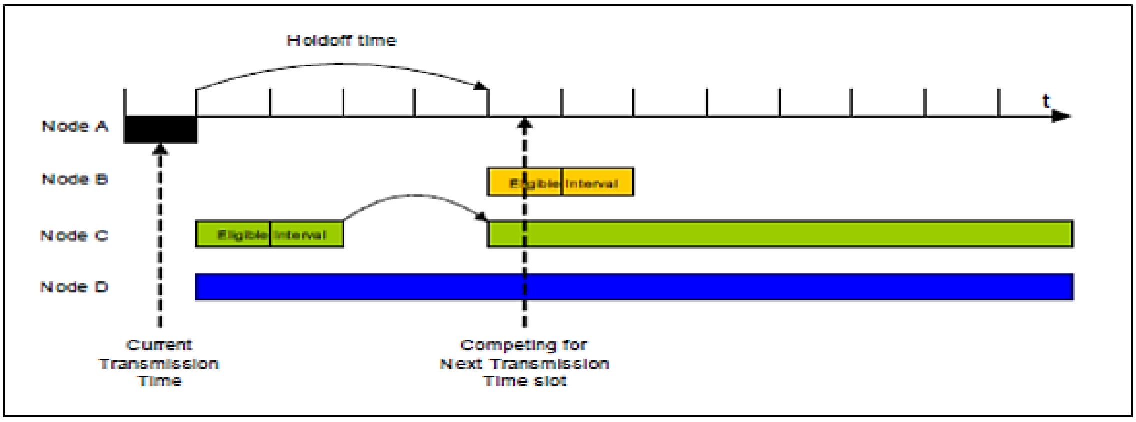

Figure 3. The IEEE 802.16 schedule control sub-frame contention.

Every node pseudo – random MIX rate is computed by the pseudo – random mixing method after the Seligible set is constructed for the particular node. When the largest MIX rate is created by the specific node, the node will win the competition and next transmission time (NextXmtTime) will be equal to the (TempXmtTime). After that, the node is transmitted to the neighbor nodes in the MSH-NCFG message. On the other hand, the node will lose the competition for the slot and the (TempXmtTime) will be set as the next transmission slot. Furthermore, the node will do the same process again until it is won.

The three-way handshake is utilized by the coordinated and the uncoordinated distributed scheduling. First of all, the MSH-DSCH: Request which is completed together with the MSH-DSCH: Availabilities to specify the possible slots for responds and real schedule. Secondly, the MSH-DSCH: Grant is drive as a reply to specify the division of the recommended availabilities which may fit the request when it is achievable. The node neighbors which may not be occupied in the schedule have to suppose that the transmission obtains the place as granted. Thirdly, the MSH-DSCH: Grant is drive by the inventive requester that held the copy of the grant from supplementary party to maintain the schedule to supplementary party. The node neighbors which may not be occupied in the schedule have to suppose that the transmission obtains the place as granted.

F. Related Work

Scheduling which is one of the most significant problems can crash the system performance in the mesh mode. It is a fixed length time slots sequence when every probable communication is allocated the time slot in such a way that the communication allocated to the identical time slot do not crash. Commonly, the broadcast and the link are the two types of scheduling. The entities scheduling are the nodes themselves in the broadcast scheduling. The node transmission is proposed for all neighbors and it must be expected collision free by the whole of its neighbors. However, the links involving nodes are scheduled in the link scheduling. The node transmission is proposed for the exacting neighbor and it is involved that the receiver does not have any collision [11].

Most of previous researches were in the PMP mode and there are no much works done in the mesh mode. Ali et al. (2009) proposed several scheduling schemes. They classified their works in three categories: (1) homogeneous algorithms; (2) hybrid algorithms; and (3) opportunistic algorithms. They introduced several scheduling scheme, such as Round Robin (RR), Weight Fair Queue (WFQ) and Earliest Deadline First (EDF) [1].

Tsai and Wang (2007) introduced the Short Widest Efficient Bandwidth (SWEB) as the routing metric scheme. The SWEB metric considers three parameters: (1) Link Packet Error Rate; (2) Link Capacity; and (3) Hop Count. It may provide balanced performance in the aspects of packet delay and throughput. However, it only obtains into account the node traffic activity inside the two hop neighborhood without considering the other nodes activities along the path [26].

Lenzini et al. (2004) use the Deficit Round Robin (DRR) scheduling scheme as the packet scheduling algorithm. In this scheme, the bandwidth is shared by different flows depended on the priority value for each flow. It may take all DRR round time to distinguish the scheduling fairness. As a result, the packet delay is increased by using this scheme [19].

Zhu et al. (2011) proposed a scheme to achieve QoS differentiation in the WiMAX mesh mode. They introduced the distributed scheduling concept and improved a new formula for theoretical evaluation in random topologies. The node may be transmitted in any slot throughout the eligibility interval and it has to be contended with the other nodes in the distributed scheduling. This contention could be irrespective of the service type and priority. Therefore, the scheme to prioritize traffic and allow the QoS differentiation is proposed in order to solve this drawback [28].

III. PROPOSED SCHEME

The admission control, packet scheduling and bandwidth manger are three main components of our proposed scheme. The WFQ scheduling scheme is used as the packet scheduling while the DRR scheme is used as the bandwidth manager in order to distribute the bandwidth between the nodes. These three components will be explained in the following three subsections.

Equation (1) uses to calculate the minimum and maximum end-to-end bandwidth for each active node.

$$B_n = \begin{cases} \frac{B}{N} \ when \ \sum S_n < N \\ max\left(\frac{B}{N}, \sum_r B_n^r\right) \ when \ \sum S_n \approx N \end{cases} \quad (1)$$

Where:

B= the maximum bandwidth support by mesh network

N= the number of the active nodes.

Sn= the bandwidth satisfaction index of the n node.

B_n^r= the bandwidth requires by the n node.

A. *Admission Control*

The admission control is one of the most significant components of the mesh networks to achieve the QoS level requirements. It is executed in the hop-by-hop bases. Therefore, the certain nodes along the path may accept the flow while the node close to the destination may reject it. The request node may not be able to request establishing other flow during the certain time period.

The active nodes have data to transmit and the inactive nodes do not have any data to transmit and they are not considered in the scheduling process until being active. In the mesh networks, the transmission time have to be shared equally between the whole of the active nodes. When the inactive nodes become active, they have to wait for a particular time period to be able to integrate in the bandwidth distribution structure. Furthermore, the other active nodes may share the non-used bandwidth of the node having lower activities equally.

B. *Packet Scheduling*

Firstly, the bandwidth manager allocates the node mini-slots and then the packet scheduling will be happened. Although each node may allow scheduling any packet form any flow in the buffer, this process has to be more efficient and insure the fairness. The WFQ scheme is used as the packet scheduling scheme. There are three routines: findNextIndex, en-queue and de-queue, to implement the WFQ scheme. The data structures are one First-in-First-out (FIFO) queue for each session. The findNextIndex function may perform a binary research in the sorted array. The virtual finish time (F) for the first packet in every queue is sorted in the queue header. When the packet is de-queued, accordingly F is updated. Each time the packet is de-queued, the time is increased.

The packet is selected and outputted at the time among the active sessions in the WFQ scheme. When each packet arrives, it is given a virtual start time S(i,j) and a virtual finish time F(i,j). Equation (2) uses to calculate the S(i,j) and F(i,j) of the i packet in the j session.

S(i,j) = max(F(i-1,j), V(a(i,j))) (2)

F(i,j) = S(i,j) + L(i,j) / r(j)

Where:

a(i,j) = the packet arrival time

L(i,j) = the packet length

V(t) = the virtual time function representing the virtual time process in the simulated GPS model

Figure 4 and 5 show the algorithm for the en-queue and de-queue functions respectively.

```
en-queue (i, j)
if not active (j)
       activate (j)
       active_r += r(j)
if queue (j) is empty
       S(i,j) = F(i,j) =  max(F(i-1,j), V(a(i,j))) + L(i,j) / weight
else
       F(i,j) += L(i,j) / weight
put (i, queue(i))
```

Figure 4. en-queue Function Algorithm

```
de-queue()
i = min (active queues S(i,j))
packet = get (queue(i))
t += L(i,j) / r(j)
if active (i)
       S(i,j) += nextL(i,j) / r(j)
For ever
       J = min (active queues F(i,j))
       tmp_t = prev_t + S(i,j) – V(t)) * active_r /r(j)
       if tmp_t > t
         V(t) += (t – prev_t) * r(j) / active_r
         Prev_t = t
      Return packet
      Prev_t = tmp_t
      V(t) = F(i,j)
      Deactivate (j)
      Active_r -= r(j)
```

Figure 5. de-queue Function Algorithm

C. *Bandwidth Manager*

The bandwidth manager is used to allocate the transmission time for every node depended on the priority weight. The certain node weight is dependent on how many it uses to communicate to the BS by other nodes. The DRR is used and the node weights are computed depended on the pre-set bandwidth values setting by the network administrator in our proposed scheme. The DRR, which is the weighted RR algorithm provided the priority of the certain nodes, is useful algorithm for allocating the bandwidth for the complex mesh networks.

IV. SIMULATION MODULE & RESULTS

The Network Simulator 2 (NS2) version 2.31 is used in our proposed algorithm [22]. As the official NS2 release does not have any implementation for the IEEE 802.16 standard, the WiMAX patch exists for the NS2 developed. Table I describes the configurations used to conduct the NS2 simulation. There are three flow types used in our simulation: (1) the Constant bit-rate (CBR) flow; (2) Variable bit-rate (VBR) flow; and (3) the Best Effort (BE) flow. The Video on Demand (VoD) is used as the VBR flow and the File Transfer Protocol (FTP) is used as the BE flow. In addition, both CBR and VBR flows are considered non-greedy flows while the BE flow are considered greedy flows. When the flow may not have any constant data rate demand, it is considered greedy

TABLE I. SIMULATION CONFIGURATION

Simulation Time	10 sec
Number of Channels	1
OFDM Symbol Duration	20 us
OFDM Symbols in a Frame	500
Physical Prorogation	20 us
Frequency	10 MHz
MSH-DSCH Control Slots in a Frame	4
Number of MSH-DSCH messages between two Consecutive MSH-NCFG messages	16
Number of Priority Levels	3
Priority Levels Values	0 (BE) = 40000 Bits 1 (VBR) = 125000 Bits 2 (CBR) = 250000 Bits

Table II describes the flows configuration. Both CBR and VBR flows have higher QoS expectations. Therefore, their packet delay has to be low as possible. However, the BE flow does not have any strict QoS requirements as it is considered as greedy flows.

TABLE II. FLOWS CONFIGURATION

CBR	Packet Size	1 KB
	Rate	2 MB
VBR	Rate	1 MB
BE	TCP max Congestion Window Size	64
	TCP max Segment Size	1024

There are four scenarios simulated in order to determine the efficiency of our proposed scheme (WFQ) as shown in figures 6, 10, 13 and 19. We compare the results with the scheme used the Round Robin (RR) as the packet scheduling scheme.

A. Packet Delay

Scenario 1 is used to test the proposed scheme in the congested network had more than one subscriber node. Figure 7 shows that the CBR flows packet delay are reduced by using our proposed scheme. However, the VBR and the BE flows may have the same packet delay as shown in figures 8 and 9 respectively.

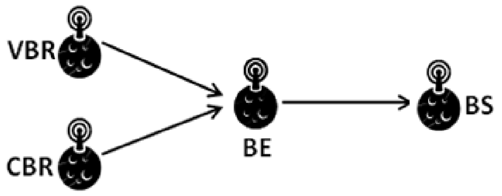

Figure 6. Scenario 1 Topology and Flows

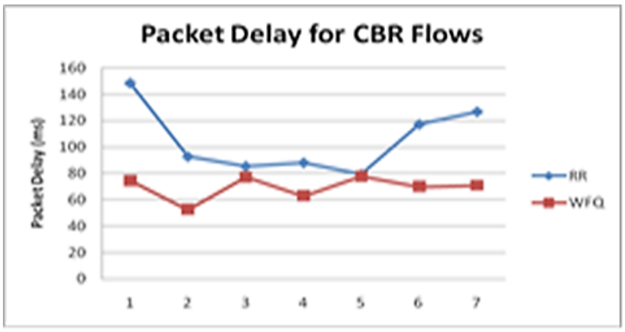

Figure 7. Packet Delay for CBR Flows in Scenario 1

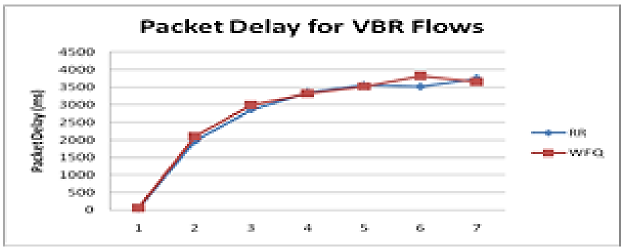

Figure 8. Packet Delay for VBR Flows in Scenario 1

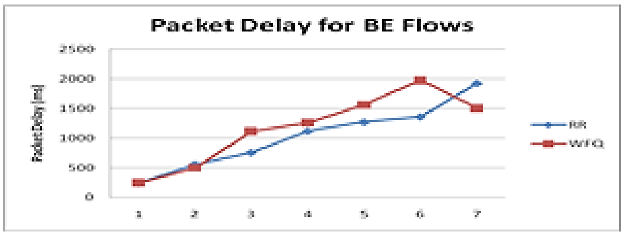

Figure 9. Packet Delay for BE Flows in Scenario 1

Moreover, figure 11 and 14 show that our proposed scheme has higher QoS compared to RR scheme because the packet delay for the higher priority class (rtPS) is decreased in scenarios 2 and 3. Furthermore, figure 12 and 15 show that our proposed scheme has almost the same results as the RR scheme for the lower priority class (BE).

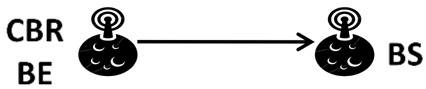

Figure 10. Scenario 2 Topology and Flows

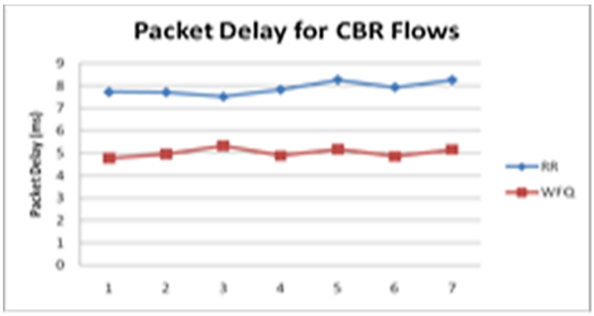

Figure 11. Packet Delay for CBR Flows in Scenario 2

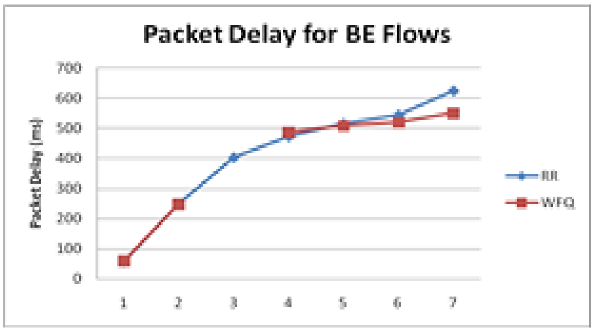

Figure 12. Packet Delay for BE Flows in Scenario 2

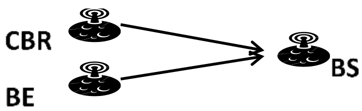

Figure 13. Scenario 3 Topology and Flows

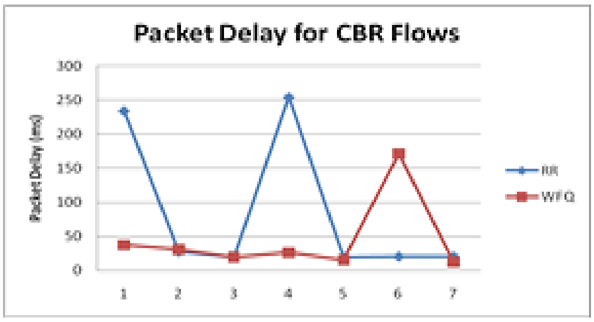

Figure 14. Packet Delay for CBR Flows in Scenario 3

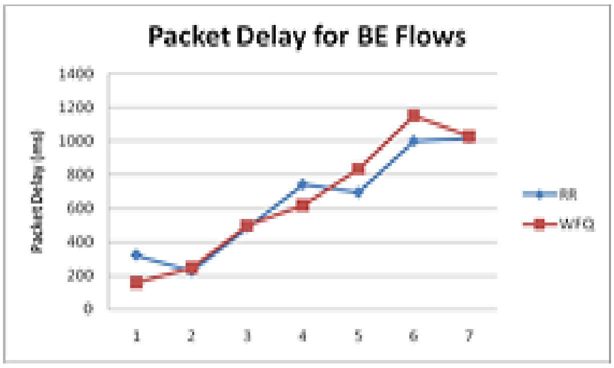

Figure 15. Packet Delay for BE Flows in Scenario 3

B. Throughput

Figure 16 and 20 show that our proposed scheme almost has the same throughput as the RR scheme while it has lower packet delay. However, figure 17, 18, 21 and 22 show that it has higher throughput for the lower priority class. As a reuslt, it insures the fairness for the lower priority classes, such as the nrtPS and the BE service classes.

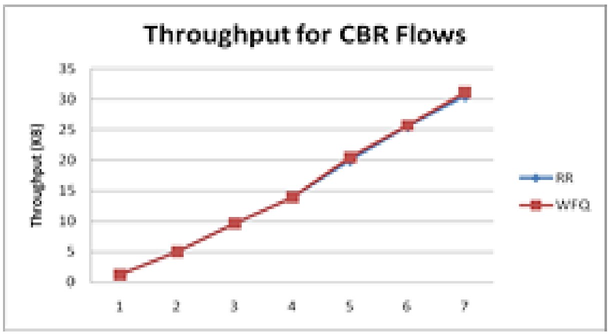

Figure 16. Throughput for CBR Flows in Scenario 1

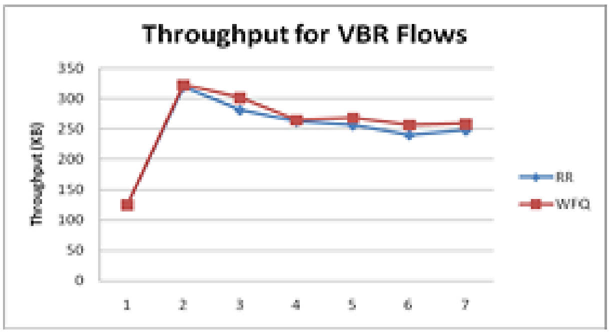

Figure 17. Throughput for VBR Flows in Scenario 1

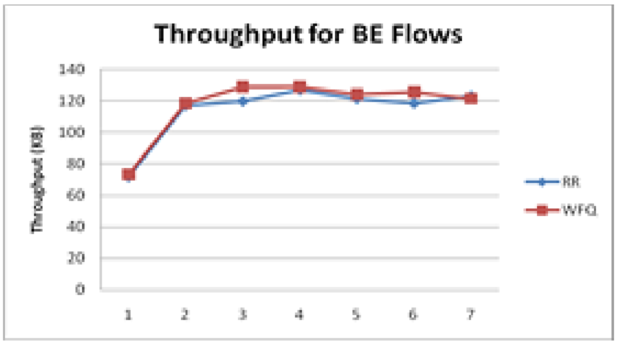

Figure 18. Throughput for BE Flows in Scenario 1

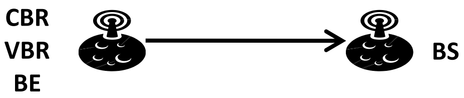

Figure 19. Scenario 4 Topology and Flows

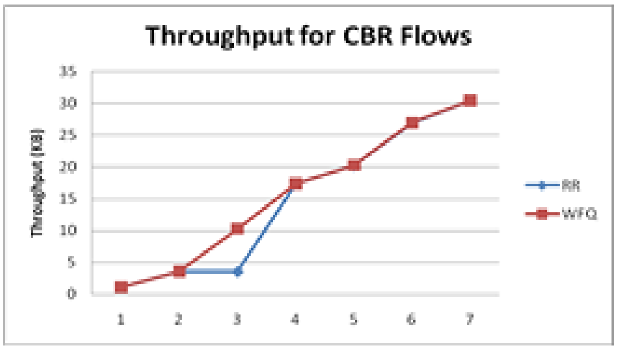

Figure 20. Throughput for CBR Flows in Scenario 4

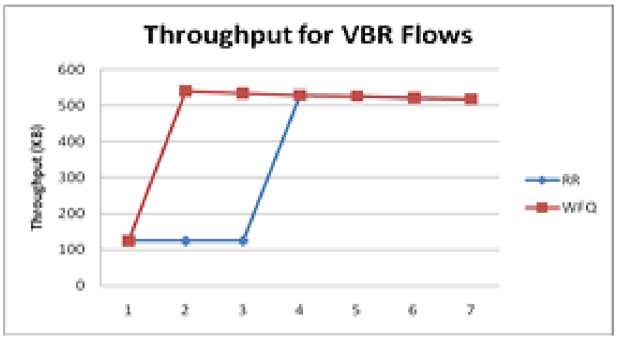

Figure 21. Throughput for VBR Flows in Scenario 4

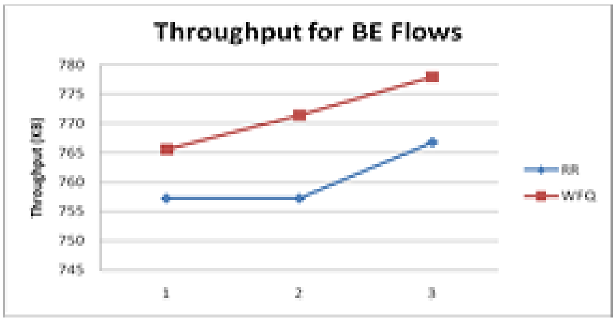

Figure 22. Throughput for BE Flows in Scenario 2

V. CONCLUSION & FUTURE WORK

The IEEE 802.11 standard may have some weaknesses, such as the short transmission distances and the small transmission rates. Therefore, the IEEE 802.16 (WiMAX) was proposed to solve the previous disadvantages. Generally, there are three essential components to handle the QoS in the 802.16 standard: admission control, scheduling and buffer management. However, literature shows the limitation of the works done on QoS in the distributed mesh mode in WiMAX.

Thus, we proposed a new scheduling scheme running in the distributed mesh mode to achieve QoS in the 802.16 network. We used the WFQ scheme as the scheduling scheme. Our proposed scheduling scheme provides more bandwidth by having higher throughput and lower packet delay rate. Furthermore, it insures the fairness for the lower priority classes, such as the nrtPS and the BE service classes.

Combining our proposed scheduling scheme with scheduling scheme, such as Earliest Deadline First (EDF) is a good idea for the future work in order to choose which scheduling scheme is suitable for each flow types. Furthermore, designing a new admission control may be required as future work.

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