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ADAPTIVE MODIFIED LOW LATENCY QUEUING ALGORITHM FOR REAL TIME TRAFFIC IN WiMAX NETWORKS

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Abstract

Providing service guarantees for real time applications like voice and video are key concerns in WiMAX (IEEE802.16) networks. Proper resource management with the help of an appropriate packet scheduling algorithm achieves the required service guarantee. Scheduling algorithm determines the order of packet delivery among many packets which are waiting to be serviced from the queue. This paper enhances the Modified Low Latency Queuing (MLLQ) algorithm to improve the Quality of Service (QoS) and to ensure service guarantee for real time applications. We propose an Adaptive MLLQ (AMLLQ) algorithm as an extension of the work done in the MLLQ. The MLLQ algorithm introduced an additional Strict Priority Queue (SPQ) in the LLQ to improve the QoS for video applications. The AMLLQ algorithm determines the order of scheduling between the two SPQs dynamically by considering the queue size. The SPQ which exceeds the queue threshold will be processed preferentially than the other SPQ. Simulation results show that the AMLLQ outperforms the MLLQ with respect to throughput and delay for the real time applications.

Keywords: Low Latency Queuing, Real time applications, QoS, Scheduling algorithms, WiMAX.

1. Introduction

The demand for high quality real time applications using broadband technique had increased tremendously in recent years. The IEEE802.16 is a new standard named as WiMAX (Worldwide Interoperability for Microware Access) which is used for the wireless access in broadband mode [1]. It aims at providing high quality real time applications in various fields to increase the level of QoS. Setting up the WiMAX is made easier even in countryside because of its moderate installation cost

Abbreviations

AMLLQ	Adaptive Modified Low Latency Queuing
BS	Base Station
DL	Downlink
DSCP	Differentiated Services Code Point
FTP	File Transfer Protocol
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IPv4	Internet Protocol version 4
LLQ	Low Latency Queuing
MAC	Media Access Control
MLLQ	Modified Low Latency Queuing
PMP	Point-to-Multi Point
QoS	Quality of Service
SS	Subscriber Station
UL	Uplink
VoIP	Voice over Internet Protocol
WiMAX	Worldwide Interoperability for Microware Access

and large coverage area. The WiMAX seems to be the ideal technology for real time applications due to its larger bandwidth and extraordinary QoS support [2].

The WiMAX network comprises of a Base Station (BS) in addition to multiple Subscriber Stations (SSs). It works in two ways namely Point-to-Multi Point (PMP) as well as Mesh mode. The SS can send as well as receive communications through BS in PMP mode. But in case of mesh mode, the SS can communicate directly with other SSs. In PMP mode, transmission takes place in two directions: Downlink (DL) direction (from BS to SS) and Uplink (UL) direction (from SS to BS). Hence, the BS has the responsibility to schedule the packets both in DL and UL effectively to avoid buffer overflows and to ensure QoS for delay sensitive real time applications [2]. The WiMAX MAC layer has mechanisms to guarantee QoS for the DL as well as UL traffics. In the MAC layer, packets are classified and allied with a service class. The set of QoS factors such as delay, throughput and jitter are described by the various service classes. Currently, the standard supports five service classes:

a. Unsolicited Grant Service (UGS) - VOIP

b. Extended real-time Polling Service (ertPS) - VOIP with silence suppression

c. Real-time Polling Service (rtPS) - Streaming Audio or Video

d. Non real-time Polling Service (nrtPS) - FTP

e. Best Effort service (BE)-HTTP

Applications in the service classes should be processed differently by the BS to ensure QoS for real time applications [3]. Design of an appropriate packet scheduling algorithm [4] can ensure differentiated services, fairness support and throughput increase among the various service classes as shown in Fig. 1.

But, the IEEE 802.16 standards do not describe an appropriate packet scheduling algorithm to ensure the QoS for the delay sensitive real time applications. Though many new releases such as IEEE 802.16m [5] and IEEE 802.16-2009 [6] for the WiMAX standards were published, they did not specify any standard for scheduling algorithms. Design of a scheduling algorithm in WiMAX network is especially a challenging task due to the reason that the wireless communication channel is constantly changing in nature. Current readings illustrate that design of an efficient as well as a robust packet scheduler for the WiMAX network is still an active research area [7]. Table 1 [8, 9] shows the behaviour of the real time traffics without QoS. Solution to this issue is the need of the hour because the scheduler must satisfy the QoS requirements of the applications and it should allot the resources fairly and efficiently [2].

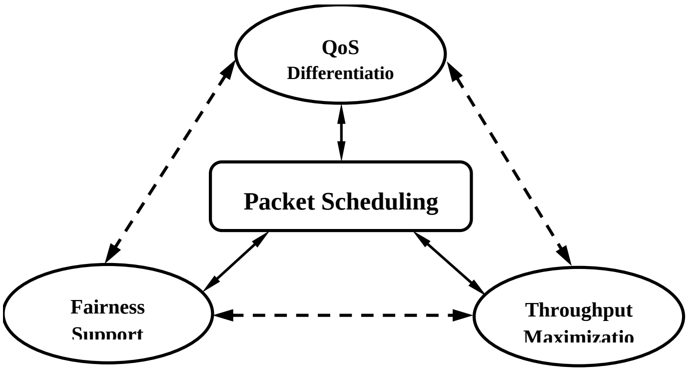

Fig. 1. Impact of packet scheduling.

Table 1. Real time applications behaviour without QoS 8, 9].

Application Type	Behaviour without QoS
Voice	• Very difficult to understand • Voice breaks up, sounds jerky • Interacting is difficult due to delay • Calls are disconnected • Picture display quality is very poor
Video	• Jerky movements • No synchronization between audio and video • Movement slows down

The remaining part of this paper is structured as follows: Section 2 gives the overview of the various scheduling algorithms in WiMAX networks. Section 3 discusses the related works done in this field. Section 4 narrates the proposed scheduling algorithm. Section 5 illustrates the simulation settings and also discusses the outcomes obtained through simulation. Lastly, section 6 presents conclusion and future work.

2. Scheduling Algorithms in WiMAX

In this section some of the classic scheduling algorithms are discussed along with their advantages and disadvantages.

2.1. First-In-First-Out(FIFO) algorithm

The traditional packet scheduling algorithm is FIFO which places all packets into one common queue and processes them as they arrived without changing the order. The FIFO is easy to implement but it cannot differentiate among the different types of traffics. If a bursty traffic comes in, the whole buffer space will be used for the same traffic. It may cause delays in real time sensitive traffic and also, other flows may not be serviced until the buffer is empty [8].

2.2. Priority queuing (PQ) algorithm

Priority Queue is having a scheme to support differentiated services. It can be achieved with the help of four different levels of priority queues. The incoming packets are categorized based on 8-bit DSCP (Differentiated Services Code Point) value which exists in the IPv4 packet header [10] as shown in Fig. 2 and placed into the appropriate priority queue. Packets from the high priority queue will be sent first before the packets from the lower priority queue [9]. When compared to other algorithms, it requires less computational load. But, the PQ suffers starvation problem when the amount of high priority traffic is excessive and complete resource malnourishment for the lower-priority traffic.

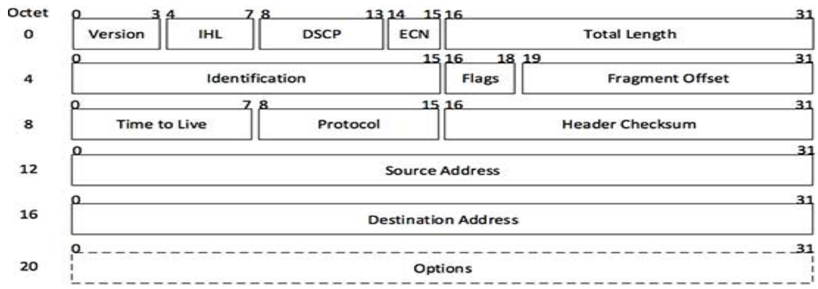

Fig. 2. IPv4 packet format.

2.3. Weighted fair queuing (WFQ) algorithm

WFQ helps flows with diverse bandwidth requirements through a Generalized Processor Sharing (GPS) policy [9]. The queues are assigned with different weights which are proportional to the amount of bandwidth allocated for that queue in the output port. In addition to this, all the packets are attached with a completion time when it is being placed into its corresponding flow queues. The packet which has the shortest finish time will be processed preferentially than other packets by the scheduler. Each service class is guaranteed with the minimum amount of output port bandwidth independent of the other service classes. The major weakness of this algorithm is lack of traffic differentiation based on user-defined classes and also it cannot provide bandwidth assurances to a real time traffic flow.

2.4. Deficit round robin (DRR) algorithm

DRR algorithm is different from the traditional Round Robin (RR) algorithm [8]. It splits the different data flows into many sub queues and processes them from the respective queues in an iterative manner. Each queue is assigned with two values one is the maximum number of bits allotted to transmit and the number of deficit bits from the previous round. The queue which is not completely serviced in the current round will be recompensed in the next round. Each flow must wait for n-1 other flows to be processed until it gets the next chance. But, the DRR has poor delay due to the reason that the flow transmits its complete quantum only once in each round.

2.5. Class based weighted fair queuing (CBWFQ) algorithm

CBWFQ enhances the mechanism of the WFQ to support the traffic classes which are defined by the user [11]. The traffic classes are created based on the match criteria which includes access control lists, input interfaces and protocols. A separate queue is created for each class, and packets which fulfil the particular class match criteria comprise the traffic for the corresponding queue. The weights assigned to the queues are used to guarantee that it is getting a fair service. The major benefit of this algorithm is the exact amount of bandwidth to be allotted for each traffic class can be declared initially. But, it lacks a mechanism to provide strict priority for real-time applications to alleviate latency.

2.6. Low latency queuing (LLQ) algorithm

In order to overcome these problems, Cisco Systems has introduced Low Latency Queuing (LLQ) [12] algorithm which combines a single strict priority queue (SPQ) with CBWFQ. High priority traffics could be placed in the SPQ. It permits the delay sensitive voice and video traffics to be scheduled first before the packets in other queues. A major advantage in the LLQ is the SPQ will not suffer the low priority queues. It is controlled by the bandwidth policer either by a percentage of the bandwidth or the bandwidth.

In recent years, advancements in the field of Telesurgery, Video Conferencing and E-Learning applications had increased the demand for high quality video services. In LLQ, it is possible to include various types of real time traffic into the single SPQ. But, there are some drawbacks as mentioned below,

- When a bursty video packet comes, the voice traffic also may not be delivered successfully. The reason is that the behaviour of the voice traffic is controllable whereas the video traffic is uncontrollable.
- To avoid jitter, voice traffic requires a non-variable delay which is the most important requirement for voice applications. But the video traffic could introduce dissimilarity in delay, thereby spoiling the steadiness of the delay which is required for successful voice traffic transmission.
- There is no distinctive consideration for video applications which is also requiring more throughputs and less delay.

2.7. Modified low latency queuing (MLLQ) algorithm

In order to overcome the above mentioned problems in LLQ, an additional SPQ is introduced along with the existing SPQ in the MLLQ algorithm [13]. The existing SPQ which is primarily dedicated for delay sensitive voice traffic in the LLQ algorithm is re-named as Primary Strict Priority Queue (PSPQ) and a new queue is added which is named as Secondary Strict Priority Queue (SSPQ). This SSPQ will be exclusively used for video traffic along with the policer. All other classes of traffic are processed using CBWFQ algorithm. Simulation results prove that the MLLQ algorithm improved throughput and delay for voice and video applications than the LLQ algorithm.

3. Related Work

Settembre et al. proposed an adaptive packet scheduling algorithm [14] in which the bandwidth is allocated adaptively by considering the queue status and bandwidth requirements of the application. The scheduler follows three different packet scheduling strategies for different service categories. Strict priority is given for UGS service classes, WRR for rtPS and nrtPS and RR is used for BE service classes. Combination of WFQ as well as Earliest Deadline First (EDF) is used for the uplink traffic as discussed in [15]. To control the delay bound for the real time applications, EDF scheduling is used. WFQ is followed to guarantee minimum bandwidth for the non-real time traffics.

A dynamic queue-aware algorithm by Niyato and Hossain [16] is projected for uplink bandwidth provision as well as rate control mechanisms. Based on the variants in traffic load, channel state and queue size, the amount of bandwidth allocated for polling services at SS gets modified dynamically. But at the same time it maintains the QoS measurements such as delay and drop rate at desired level. But, still this approach lacks in differentiation between real-time as well as non real-time applications and fails to achieve QoS features such as latency in scheduling.

The main objective of cross layer technique in scheduling is to enhance the communication between different layers of network architecture. For multiple connections with different QoS requests, a priority-based scheduler is presented at the MAC layer where each link pays AMC (Adaptive Modulation and Coding) technique at the physical (PHY) layer [17, 18]. The channel quality, QoS gratification and service urgency are considered by the priority function (PRF) to assign and update the priority dynamically across the layers. For UGS, the essential amount of time-slots ‘t’ is fixed and all non-UGS connections were allocated slots with precedence as rtps > nrtPS > BE. Though the proposed technique is simple and easy to implement, it may lead to starvation for low priority flows.

Another cross-layer architecture presented by Mai et al. [19, 20] shows that the involvement of Layer 3 (L3) and Layer 2 (L2) is essential for better QoS service and which could also support in the scheduling process. They embraced the mapping between L3 as well as L2 QoS where 802.16 MAC service classes are mapped to integrated and differentiated services. A new flow will be admitted only when the capacity of the outstanding link is greater than the requirements of the flow. The proposed work in [21, 22] shows a cross layer mechanism that enables the BS and SS to communicate with application layer as part of optimization process. It creates a lot of difficulty at BS though the technique profits in terms of QoS and capacity of system.

Mohamed and David applied priority queue scheduling algorithm in IEEE 802.16 in [23]. The real time as well as non-real time applications could use priority queuing algorithm which considers the application’s demand only to determine the priority of the service. Deficit Fair Priority Queue (DFPQ) is a QoS providing mechanism developed by Jianfeng et al. [24] which comprise buffer management and admission control in addition to scheduling architecture. The UL and DL bandwidth are adjusted dynamically to improve the overall performance. Robust

QoS control mechanism developed by Xiaofeng et al. [25] ensures the desired parameter settings for service classes in both UL and DL connections to improve the QoS. A scheduling algorithm based on round robin technique is proposed by Hahne, and Gallager [26] to process both uplink and downlink connections in BS. A cross layer architecture developed by Qingwen and Xin [27] improved the QoS by considering the channel quality to determine the priority of the connection.

4. Proposed Work

The aim of this work is to enhance the performance of the MLLQ [13] algorithm. The MLLQ consists of two SPQs namely Primary SPQ and Secondary SPQ which is dedicated for voice and video applications respectively. The existing algorithm schedules the voice packets from PSPQ and then the video packets from SSPQ. It always empties the PSPQ first and then SSPQ after those other class packets are serviced through CBWFQ scheduler. Due to this scheduling order, packet drop may be high for video traffic in the MLLQ algorithm. More packet drop will lead to poor QoS and chance of congestion also will be high in the network. Meanwhile the video applications also have stringent QoS requirements similar to the voice applications as mentioned in Table 2 [28]. Hence, it is important that an appropriate strategy should be developed in order to improvise the existing MLLQ algorithm's performance.

Table 2. QoS requirements for real time applications [28].

Traffic	Bandwidth	Delay	Jitter	Loss
Voice	Low	Low	Low	Low
Interactive Video (2 Way)	High	Low	Low	Low
Streaming Video (1 Way)	High	High	High	Low

As an enhancement, an adaptive scheduling strategy is followed between the SPQs by the Adaptive Queue Aware Priority Scheduler (AQAPS) as shown in Fig. 3.

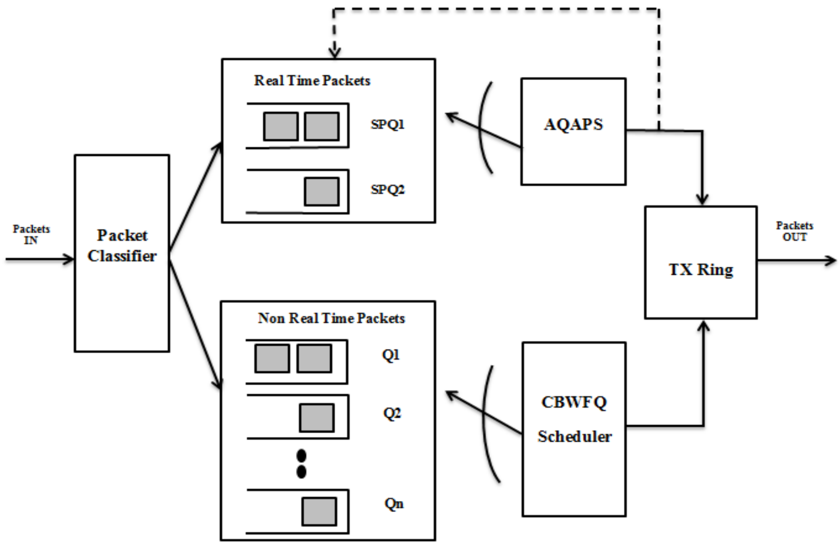

Fig. 3. Adaptive MLLQ (AMLLQ).

The AQAPS determines the scheduling priority between the SPQs dynamically by considering the size of the SPQ. The size of each SPQ is set to 64 [28]. If the queue size is more the waiting time for the packets in the queue will be more and if the queue size is very less then there will be more packet drops. The minimum and maximum queue threshold values are set to 32 and 48 respectively. The high priority status is given to the SPQ which exceeds the maximum queue threshold value. The AQAPS calculates the size of the SPQs after processing every single packet to determine the scheduling priority between the SPQs. Now, the AQAPS processes the packet from the SPQ which has got the highest priority, until both SPQs are empty as shown in the algorithm.

Algorithm: AMLLQ

WHILE *TX Ring has free space* **Do**
  IF *SPQ1 is not empty && SPQ1 is greater than queue threshold* **THEN**
    Voice packets from SPQ1 are placed into TX Ring
  ELSE IF *SPQ2 is not empty && SPQ2 is greater than queue threshold* **THEN**
    Video packets from SPQ2 are placed into TX Ring
  ELSE
    Packets from other queues are placed into TX Ring
  ENDIF
ENDWHILE

The working principle for the AMLLQ algorithm is as shown below:

a. Packet classifier will classify the incoming packets based on the DSCP value. In case of IPv6 packet, 8 bit Traffic Class value will be referred.
b. Voice and Video packets will be placed into the SPQ1 and SPQ2 respectively. Initially SPQ1 is given with high priority than SPQ2.
c. Other type of packets will be placed into the respective queues based on CBWFQ algorithm.
d. The AQAPS calculates the priority of the SPQs by comparing the queue size with the maximum queue threshold value.
e. The SPQ which exceeds the threshold value gets high priority and will be serviced first by the AQAPS.
f. If both queues have not reached the maximum queue threshold value, voice packets from SPQ1 will be processed first.
g. When the TX Ring (Hardware Queue which is located in physical layer of the device and it places the packets in an outgoing interface) has free space, the AQAPS schedules the packets from the high priority SPQ among the two SPQs.
h. The priority will be recalculated after processing every single packet to determine the scheduling priority between the SPQs.
i. This process will be repeated until both SPQs are empty.
j. When both SPQs are empty, packets from other queues will be processed based on CBWFQ algorithm.

k. At the time of congestion (noticed through Explicit Congestion Notification (ECN) as shown in Fig. 2), both SPQs will be monitored by the Voice and Video policer to avoid starvation for the low priority applications.

l. The Voice and Video packets will be dropped by the policer when the allocated bandwidth for the SPQs goes beyond its maximum threshold limit at the time of congestion.

5. Simulation Settings

The performance of the AMLLQ algorithm is assessed through simulations which are conducted using OPNET Modeler (Version 14.5) [29]. The WiMAX network is designed in PMP mode. The WiMAX network consists of four BSs and twenty mobile SSs in a 10 X 10 km area with five SSs in each cell as shown in Fig. 4.

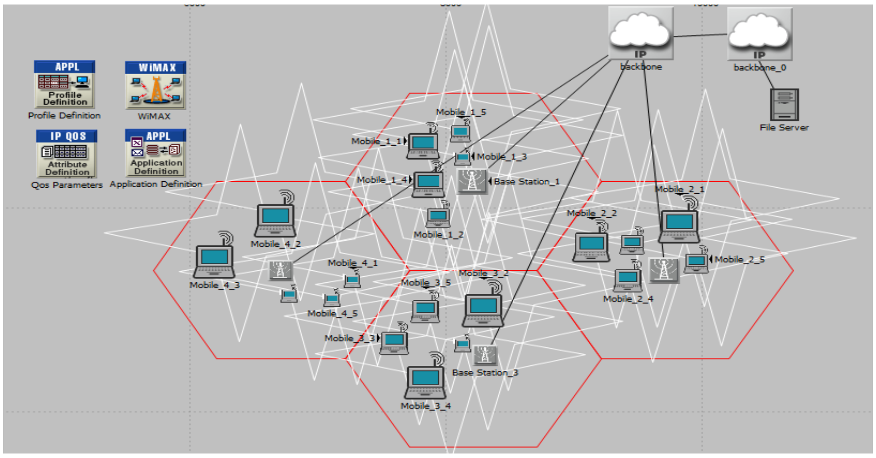

Fig. 4. WiMAX network model.

Input traffic models for Voice and Video applications are created by using application and profile configuration as shown in Fig. 5. The voice and video traffics are identified by the DSCP values EF and AF41 respectively. The required service priority for the created applications are provided through MAC service class parameters [30] as shown in Table 3. These parameters are configured at all the BSs and SSs through WiMAX classifier definitions as shown in Fig. 6.

All the SS nodes are configured with the created input traffic profiles along with WiMAX classifier definitions. It allows mapping between higher layer traffic to the service class in WiMAX. Every mapping consists of a match criteria as well as corresponding service class as shown in Fig. 6. Two simulation scenarios have been designed to analyse the performance of the proposed algorithm.

Table 3. MAC service class parameters.

Name of the Service Class	Type of Scheduling	Sustained Traffic Rate (Max.)	Reserved Traffic Rate (Min.)
Gold	UGS	1.5 Mbps	1 Mbps
Silver	rtPS	1 Mbps	0.5 Mbps
Bronze	Best Effort	384 Kbps	384 Kbps

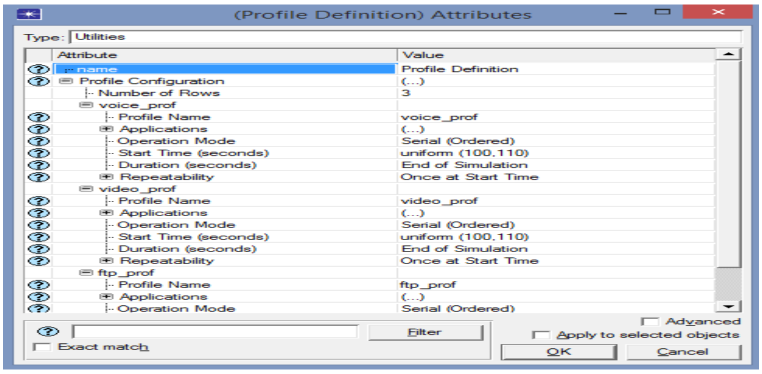

Fig. 5. Profile configuration.

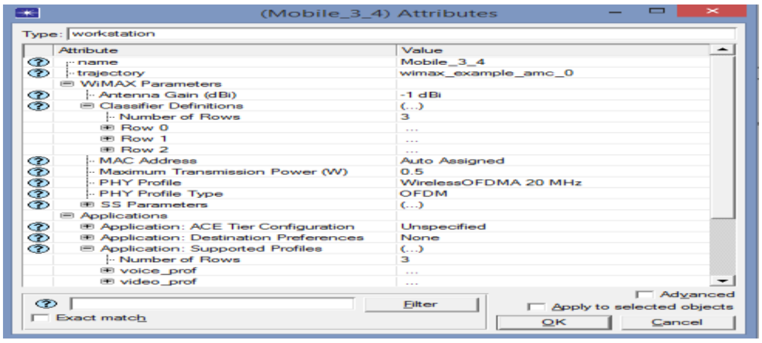

Fig. 6. Mobile subscriber station configuration.

6. Results Analysis

The performance of the AMLLQ algorithm is analysed by comparing with the MLLQ algorithm in terms of traffic sent and received, delay, jitter and overall network throughput for the real time voice and video applications. Graphical results for each factor are discussed elaborately in the subsequent sections. In addition to this, statistical results obtained through simulations are also shown in Table 4.

Table 4. Statistical results for MLLQ and AMLLQ.

	MLLQ	AMLLQ
Video Traffic Sent (bytes/sec)	1,832,775	1,972,484
Video Traffic Received (bytes/sec)	74,160	85,997
Video Traffic Delay Variation	0.005501	0.0044037
Voice Traffic Sent (bytes/sec)	150,941	156,560
Voice Traffic Received (bytes/sec)	4,437	4,457
Voice Jitter	0.00000086	-0.00002002
WiMAX Throughput (bits/sec)	6,603,666	7,448,256
WiMAX Delay (sec)	0.08355	0.07913

6.1. Video traffic sent

Figure 7 shows the performance comparison between the MLLQ and AMLLQ algorithm in terms of video traffic sent. From the graphical results, it is observed that the AMLLQ algorithm has improved the amount of video traffic sent than the MLLQ.

Increase in the video traffic sent is very important in determining the performance of our proposed work. The AQAPS in the proposed algorithm has processed the video applications preferentially by considering the size of the SPQ2.

6.2. Video traffic received

Graphical results in Fig. 8 highlight the performance between the MLLQ and AMLLQ algorithm. It is observed that the AMLLQ algorithm has improved the amount of video traffic received. The increase in the value of the video traffic received shows that the video packets are being received continuously at the receiver side with good quality.

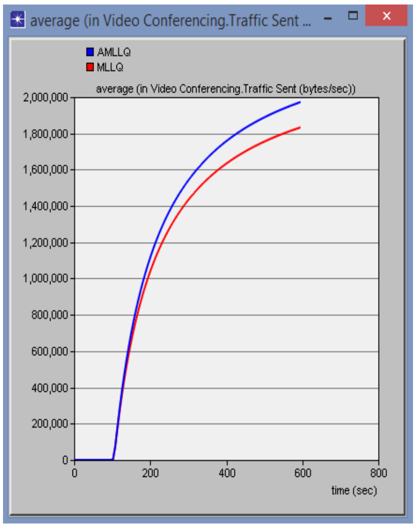

Fig. 7. Video traffic sent (bytes/s).

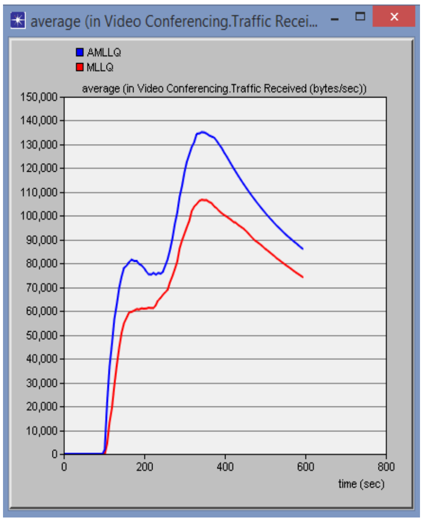

Fig. 8. Video traffic received (bytes/s).

6.1. Video traffic delay variation

Packet delay variation is the difference in the time between the arriving packets and it should be very low for the timely delivery of delay sensitive real time applications like Voice and Video. The graphical results in Fig. 9, shows the delay variation for the video traffic is very low in AMLLQ than the MLLQ algorithm.

6.2. Voice traffic sent

The two graphical outcomes shown in Fig. 10 prove that the AQAPS has also increased the amount of voice traffic sent. Increase in the amount of voice traffic sent helps in providing a good quality voice and henceforth QoS also will be improved.

6.3. Voice traffic received

By looking at the graphical results shown in Fig. 11, the average voice traffic received is little bit high than the MLLQ algorithm. The increase in the value of the voice traffic received shows that the voice packets are being received continuously at the receiver side with good quality.

6.4. Voice jitter

The voice jitter which is similar to delay variation defined as dissimilarity in the delay of the received packets. Improper queuing mechanisms can introduce more jitter. The simulation outcomes presented in Fig. 12 show that the jitter is slightly lower in the AMLLQ algorithm. The decrease in the value of jitter increases the voice quality and the amount of traffic to be received.

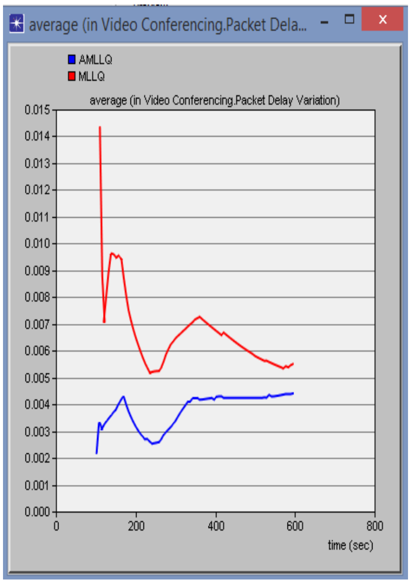

Fig. 9. Video traffic delay variation.

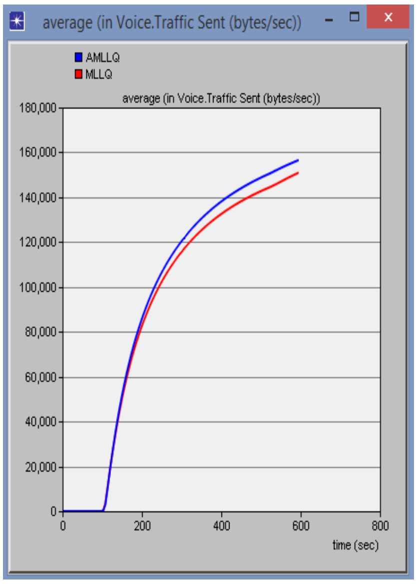

Fig. 10. Voice traffic sent (bytes/s).

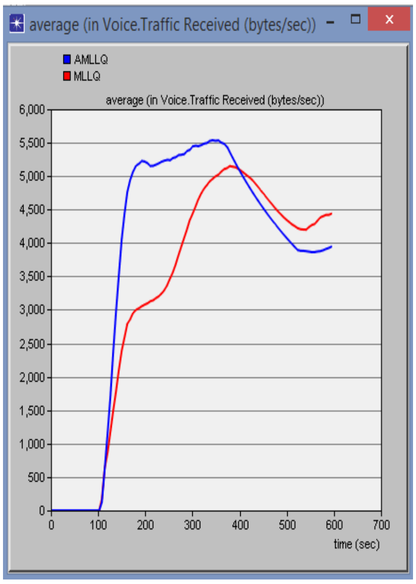

Fig. 11. Voice traffic received (bytes/s).

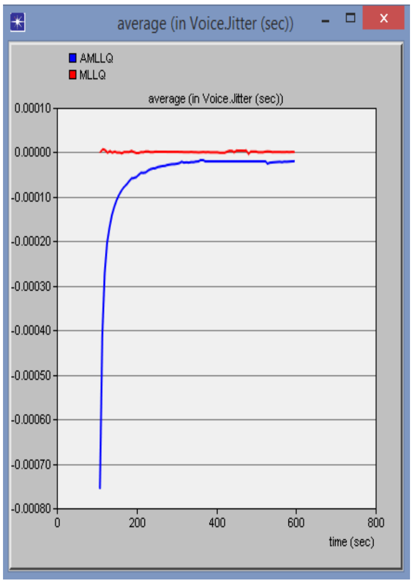

Fig. 12. Voice jitter (s).

6.5. WiMAX throughput

Throughput is the most significant value to determine the performance of our AMLLQ algorithm. It is very difficult to get equal throughput in any network. The objective of our proposed work is to increase the overall network throughput for real time applications.

Throughput=Number of bits sent/Time taken (bps)

As per the statistical results shown in Table 4, throughput obtained for MLLQ is 11006.11 bps and for AMLLQ is 12413.76 bps. Figure 13 shows the graphical results for WiMAX network throughput obtained with AMLLQ and MLLQ algorithm. Better result is observed in the AMLLQ algorithm when compared to MLLQ.

6.6. WiMAX delay

The graphical results in Fig. 14 show the WiMAX delay between the AMLLQ and the MLLQ. The AQAPS handles the two SPQs appropriately based on the size hence the delay got reduced.

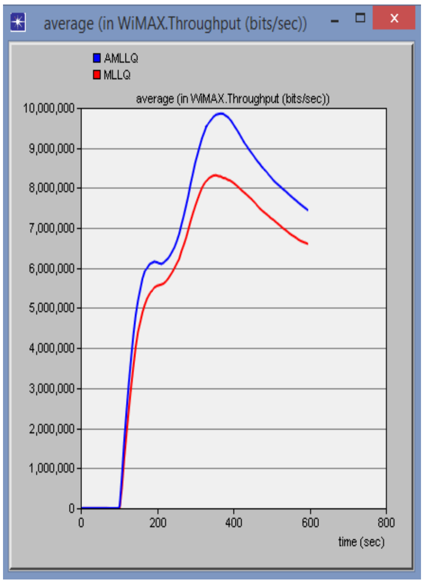

Fig. 13. WiMAX throughput (bits/s).

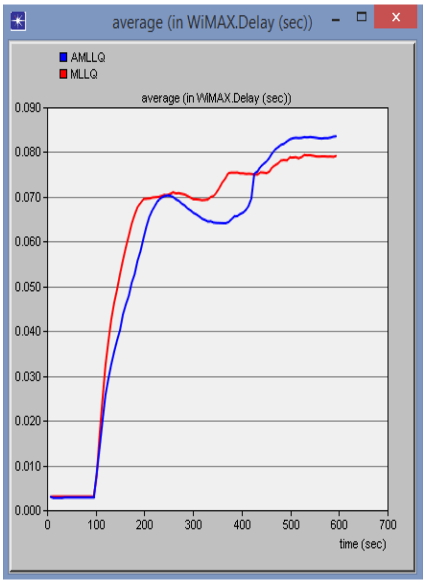

Fig. 14. WiMAX delay (s).

7. Conclusions and Future Work

In this paper, we proposed an Adaptive MLLQ (AMLLQ) algorithm as an extension of the MLLQ algorithm. The AMLLQ algorithm considers the size of the SPQs to determine the scheduling priority between the two SPQs. A new component called Adaptive Queue Aware Priority Scheduler (AQAPS) is introduced to determine the priority of the SPQs dynamically. The SPQ priority is calculated by comparing the queue size with the maximum queue threshold value. The SPQ which exceeds the maximum threshold value will get the high priority and to be serviced preferentially than the other SPQ. The order of selection of the SPQ will get changed based on the queue size which is recalculated after processing every single packet by the AQAPS. The simulation and statistical results show that the AMLLQ outperforms the MLLQ with respect to traffic sent and received, delay, jitter and overall network throughput for the real time voice and video applications in WiMAX network. As a future work, it has been planned to implement the AMLLQ algorithm in real time with the help of physical test bed.

Acknowledgement

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