# Performance of WiMAX Packet Schedulers for Multi-Class Traffic

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***Abstract*—With the increasing demand for multimedia services on wireless networks, it is important to optimise air interface parameters to maximise throughput and QoS. In this paper, we examine the effect of WiMAX burst mapping and Round Robin - based packet schedulers on multimedia traffic and network capacity. In this work, we have simulated the IEEE802.16e air interface to examine the downlink channel performance in terms of subframe usage and subframe wastage. The paper presents simulation analysis of the IEEE802.16e downlink service flows for multimedia traffic using an OPNET model. Comparing the characteristics of the service flow parameters, the packet schedulers and the subframe resource allocation methods, we define a new scheduling algorithm based in the service flows QoS configured parameters and the WiMAX OFDMA subframe structure. The proposed new MDRR packet-scheduling algorithm for multimedia traffic shows improvements in the allocation procedures reducing the wastage from 40% down to 20%, improving subframe usage from 60% to 80% leading to serve 10 more users in the network.**

## I. Introduction

With the increasing demand for multimedia services on wireless networks, it is becoming important to develop appropriate packet scheduling algorithms and channel management techniques to support required QoS (Quality of Service) for different class of traffic. WiMAX is one of the emerging wireless networking standards, which will support a range of applications for fixed and mobile users. A WiMAX network can offer differentiated services by using its packet schedulers' and the admission controller. Besides, in this network, to support large number of multimedia terminals it is also necessary to develop some form of dynamic resource allocation technique to minimise the wastage of downlink channels, because the WiMAX downlink, carries a variety of control information along with user data traffic. A proportion of downlink channel capacity could be wasted if the connection parameters are not properly selected. In order to increase the capacity of a WiMAX network and to improve QoS of connections, it is necessary to study the relationship of WiMAX channel utilisation and connection QoS values for different packet scheduling and connection mapping parameters [1].

In this paper, we investigate the performance of various packet schedulers for a WiMAX Point-to-Multipoint (PMP) Network. We focus on the Round Robin (RR) based algorithms namely, Modified Deficit Round Robin (MDRR) and Weighted Round Robin (WRR) for a multi-class service environment. Using these packet scheduling algorithms we examine the effect on service flows parameters, specifically on the bandwidth allocation ones such as Maximum Sustainable and Minimum Reserved Traffic Rate for various classes of traffic. This study was conducted as an initial step to develop advanced packet scheduling and resource allocation algorithms to increase the network capacity by reducing the channel wastage. Performance of packet schedulers were studied by varying different parameters of packet schedulers for a range of applications, which include the Voice over IP (VoIP), FTP and background traffic sources. The outline of the rest of the paper is as follows. Section II introduces the WiMAX service QoS concepts and different packet scheduling concepts. Section III describes the OPNET simulation model and model parameters used to study the WiMAX network. Section IV presents some initial simulation results. Conclusions are made in section V.

## II. WiMAX Standard Concepts

The IEEE802.16e WiMAX standard supports different level of QoS in order to cater for various user application requirements. The agreed QoS levels are maintained by optimising service flows and QoS Scheduling parameters, and using the Static/Dynamic service establishment procedures. The WiMAX standard defines the MAC and the Physical Layer functionalities that can be combined to support QoS requirements for different classes of traffic. Figure 1 shows the MAC scheduler and packet classifier architecture used in a WiMAX network. On the downlink, packets are first classified at the base station (BS) and then filed in different queues. These queues are served by different packet schedulers which pulls out packets from the head of the queue. The service rates of these queues are controlled by the packet scheduling algorithms which are selected based on QoS of different class of connections [2].

### *A. Service Classes and Service Flows*

A Service Flow (SF) is an unidirectional traffic connection that offers a particular QoS level as described by the service class [1]. A user can have many SFs, each one is described as a connection. A unique Connection Identifier (CID) describes the SF in a network. Number of connections can be restricted based in the available capacity and QoS requirements. The

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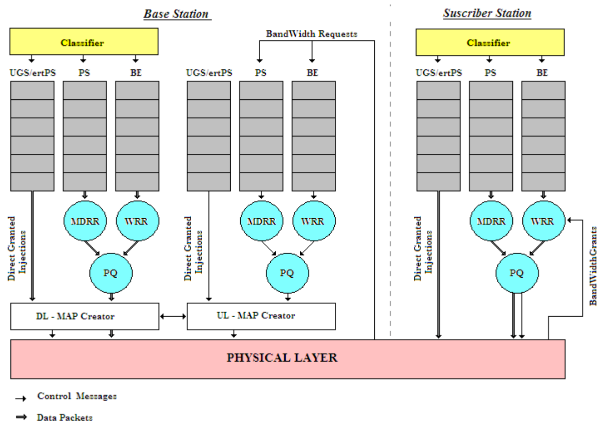


Fig. 1. WiMAX packet schedulers and classifier arrangement at a BS.

Admission Controller limits the number of connections in a network by examining each SFs requested QoS parameters and then comparing its requirements with the available capacity. All SFs are described using a number of parameters which includes service class, scheduler type used, the Maximum Sustained and the Minimum Reserved Traffic Rate. Depending on the Scheduler type, the scheduler will use one of the last two parameters for the bandwidth request in the allocation and scheduling processes.

Briefly, the SF model is described in this paragraph. Each user application stamps a Type of Service (ToS) mark on the packet that is forwarded to the MAC layer. The MAC layer classifies the packet into a Service Class. After the classification of a packet at the BS, it is conducted into a SF. Then, packets are enqueued in a scheduler buffer, according to the SF and scheduling requirements of class and then the queue is serviced as shown in Figure 1. A WiMAX BS has three buffers, the first one used for the unsolicited connections (UGS and ertPS traffic), the second one supports polling connections (rtPS and nrtPS traffic) and the last one used for the Best Effort traffic.

### *B. The Schedulers*

Currently in the literature, many packet scheduling scheme exists. They can be classified in two groups [4]; channel-Unaware algorithms and channel-Aware algorithms. Channel-Unaware schedulers use traffic and QoS parameters found in the MAC layer and assume error-free channels to schedule packet transmissions. Most of them deal with the fairness of the scheduling process, but do not take account of the quality of the wireless channel. First-In First-Out (FiFo), Multi-tap scheduling [5], Round Robin (RR) [6], Deficit Round Robin (DRR) [6] [7], General Processor Sharing (GPS) [9], Weighted Fair Queueing (WFQ) and the Deadline First family (EDF, LWDF and DTPQ) are examples of channel unaware scheduling algorithms. These algorithms are able to work as an intra-class mode scheduler. Frequently used inter-class schedulers are Weighted Round Robin (WRR) and Priority Queueing (PQ) [4].

Channel-Aware scheduling algorithms use traffic and channels information as input parameters in the scheduling process. There are four key objectives to pursuit; fairness, QoS guarantee, system throughput maximization and transmission power minimization. A set of RR based algorithms could be found in the literature: Wireless Deficit Round Robin (WDRR), Uniformly-Fair Deficit Round Robin (UF-DRR) [8], Deficit Round Robin with Fragmentation (DRRF) [9] and Customised Deficit Round Robin (CDRR) [10]. As well as the utility ones like the studied by Nascimiento that is mainly based on the Dynamic Resource Allocation (DRA) technique proposed in the IEEE802.16e standard [11]. Below briefly the Modified Deficit Round Robin (MDRR) and the Weighted Round Robin algorithms are described which are used in our simulation model.

*1) Round Robin Algorithms:* For multimedia traffic, it is assumed that each user has a FIFO queue and the queue will be served in a sequential fashion. The RR scheduler may not be able to offer fairness packets of different lengths in different queues. In order to solve that problem, the WRR algorithm is introduced which assigns a weight to each queue that represents a portion of the available bandwidth for that specific queue. Hence, the number of packets served is proportional to the weight value assigned to a queue. Nonetheless, it still has an unfair behaviour because the value of the weight is proportional with the size of the queue instead of QoS requirements of the queue [6].

*2) Deficit Round Robin:* The DRR algorithm is proposed by Shreedhar includes a deficit counter. The counter is initialised by a value called *quantum* that reflects the shared bandwidth reserved to this flow. The DRR scheduler visit each queue, adds the *quantum* value to the deficit counter and compares its value with the size of the first packet in the queue. If the size of the packet is smaller than deficit counter, the packet would be transmitted and the size of the transmission queue would be deducted from the deficit counter. If not, the packet will be held for subsequent rounds until the deficit counter exceed the size of the packet [12]. This behaviour leads in to two scenarios: first, if the arriving packet is smaller than the *quantum*, the transmitted data will be smaller than the allocated bandwidth, leading to an under-utilised channel. On the other hand, if the packet size is much bigger than the *quantum*, the packet will be hold in the queue until enough bandwidth is granted increasing the queueing delay. A proper size of the *quantum* should be selected to achieve the connection QoS requirements and an optimal channel usage.

In WiMAX, this *quantum* parameter should be proportional to QoS parameters, i.e. Maximum Sustained and the Minimum Reserved Traffic Rate values. Lailas described the value of the $quantum = Q_i$ as shown in equation 1. The $r_{min}$ represents the lowest reserved rate and $r_i$ the reserved rate for the SF $i$[10]. Moreover, the values of reserved rates should not exceed the channel capacity as shown in equation 2.

$$Q_i = \left(\frac{r_i}{r_{min}}\right) * MaxSizePacketInTheRound \quad (1)$$

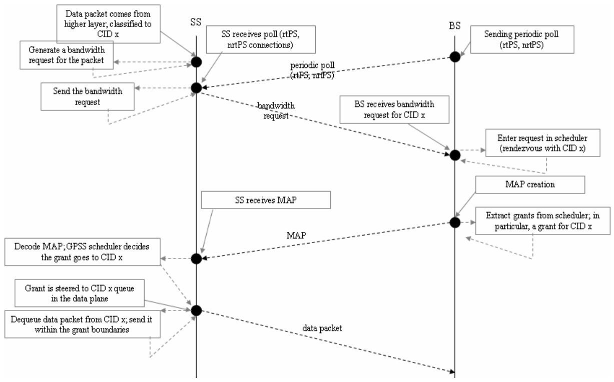


Fig. 2. Example of UL SS-BS data exchange for MAP creation based in [1]

$$\sum_{i=0}^{n} r_i \leq AvailableChannelCapacity \tag{2}$$

*3) Modified Deficit Round Robin:* Modified Deficit Round Robin (MDRR) is a variation of the DRR algorithm. The main difference is that MDRR adds a low-latency queue, which is useful for real time connections (rtPS). It could work in two modes: *Alternate Mode*; when the queue is alternated between the no-low-latency queues and *Strict Priority Mode*; where no other queue is served until the low-latency queue is fully served. Another important modification of the MDRR is the definition of a Maximum Transmission Unit (MTU), which is the maximum packet size that could be dequeued. For MDRR the *quantum* value can be calculated using equation 3, where $w_i$ is the weight of the actual queue defined by equation 4. Equation 5 shows that $Q_i$ should be greater than zero in order to give the opportunity to send at least one packet in the first round. Finally, if the queue is empty, the deficit counter will be reset to zero avoiding a waste of symbols in the MAP creation [6].

$$Q_i = MTU + 512 * w_i \tag{3}$$

$$w_i = \left(\frac{MRTR}{TotalCapacity}\right) * 100 \tag{4}$$

$$MTU \leq Q_i \leq 51.200 + MTU \tag{5}$$

### C. MAP: The Subframe Allocation procedures

Transmission procedure of data packets in a WiMAX network depends on the direction of transmission. For UL connections, when a packet arrives from the higher layer in the SS, it is classified and a Bandwidth request (BW-Req) is generated. The BS sends periodic polls to the SSs. All SSs replies to their polls with their BW-Reqs. When the BS receives a BW-Req, it passes the request to the UL scheduler. The scheduler output triggers the creation of an UL-MAP which defines number of symbols and sub carriers are allocated to the connection. Then the BS sends a frame with the UL-MAP for the next frame transmission. The SS receives the UL-MAP, decodes it, dequeues a data packet and sends them in the UL Sub frame granted boundaries. For a DL connection, the BW-req is generated and passed straight away to the DL Scheduler. Similar to the UL procedure, the DL-MAP is created as well as data in the queue are serviced on DL connections. Figure 2 shows an example of the UL data exchange for a MAP creation. The MAP creation technique at the BS divides the UL and DL subframes to accommodate the users' data bursts. The mapping process is implemented in a conservative fashion. It works in a wrapping style, starting with the DL and UL MAPs continuing with the DL data followed by UL grants and ends with the UL requests. The BW request allocation for the UL subframe is sent using the UL-MAP.

The MAP algorithm divides the subframe allocation task in five steps. First, it calculates the size of the title in the subframe. The title size is one subchannel wide by one or two symbols long for Full Usage of Sub Channels (FUSC) and Partial Usage of Sub Channels (PUSC), respectively. Second, it tries to allocate all the granted data that resides in buffers, if succeeds then it assigns a value to the MAP and put the data in a temporal buffer. Third, it tries to allocate all the Polling Services (PS) queues in terms of BW-Req, if it succeeds then it assigns a value to the MAP and concatenate data in the temporal buffer. Fourth, if there is some space left it tries to allocate the BW-Req of the BE buffers and assigns their position to the UL or DL respective MAPs. Last of all, it creates the DL-MAP and the UL-MAP; put them in the DL subframe and then fills the rest of the DL subframe with the DL data bursts [13][14].

It is important to show that as more user requests are served, the UL and DL MAP size increases leading to decrease of the DL Sub frame usable capacity. Kitroser mentioned that for a simple algorithm and normal traffic scenarios, the consumption of bandwidth by the MAPs could be more that 50%. The description and analysis of other mapping algorithms like Persistent Allocation or Semi-Fixed Allocation [14][15] is out of scope of this study.

## III. The Model

In this work we used a single cell OPNET based WiMAX model to analyse the performance of the WiMAX network. We developed the model to study interactions between SF QoS parameters and packet scheduler parameters and to analyse WiMAX network performance for multimedia traffic. The table I shows the values of WiMAX MAC and Physical layer parameters used in the simulation. We used multimedia traffic generators comprising of VoIP, file transfer and internet browsing which are mapped on rtPS, nrtPS and best effort services respectively. Table II shows the traffic generator characteristics.

### A. Network Configuration

The principal objective of this simulation is to analyse the performance the packet schedulers for different classes of traffic. Accordingly, it is important to select appropriate

TABLE I
NETWORK PARAMETERS

| *Parameter* | *Values* |
|---|---|
| Physical Layer | OFDMA - TDD |
| System Bandwidth [MHz] | 20 |
| No. of Subchannels | UL: 70, DL: 80 |
| No. of Data Subcarriers | UL: 1120, DL: 1440 |
| UL/DL boundary | 50%/50% |
| Channel capacity [bps] | UL: 5'299.200, DL: 6'336.000<br>Total: 11'635.000 |
| Frame Duration [msec] | 5 |
| Symbol Duration [usec] | 100.8 |
| Slot Size [Symbols] | 48 |
| BW Req for Allocation [Kbps] | 200, 150, 100, 75, 65, 50 and 20 |
| ARQ and HARQ | Disable |
| Type of Mapping | PUSC and FUSC |
| Voice Codec | G.711 and G.729 |

TABLE II
TRAFFIC INFORMATION

| *Application* | *Parameter* | *Value* |
|---|---|---|
| Voice | Traffic Rate<br>Silence/Talk ratio<br>Interarrival Time | 64Kbps(G.711) - 8Kbps(G.729)<br>60%*<br>5msec |
| FTP | File Size<br>Interarrival time<br>Get/Push ratio | 25KB*<br>5sec*<br>50% |
| WEB | Web Page Size<br>Interarrival time | 18.75KB*<br>30sec* |

∗Exponential Distribution

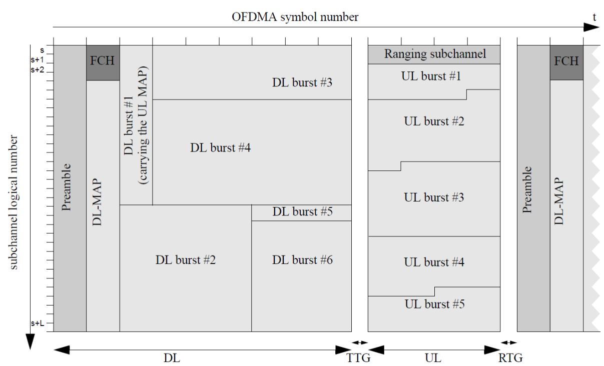


Fig. 3. OFDMA Frame Construction in WiMAX. Based in [1]

WiMAX parameters and the network configuration. We simulated a TDD (Time Division Duplex) based OFDMA link with 2048 sub carriers in the 5GHz band. The UL/DL boundary is set to 50% of the number of symbols for each link set to (23 symbols). Figure 3 shows the frame structure of the OFDMA link used in the simulation model. This physical frame configuration leads to a certain UL and DL capacities as shown in table I.

## IV. RESULTS AND ANALYSIS

One of the main objectives of this paper is to analyse the performance of the WiMAX - OFDMA DL subframe. To analyse the performance of the network first we used the model to establish the capacity of the network. The Maximum Sustained Rate and the Minimum Reserved Traffic Rate (MRTR) are used as a variable in the SF configuration. Nevertheless, these

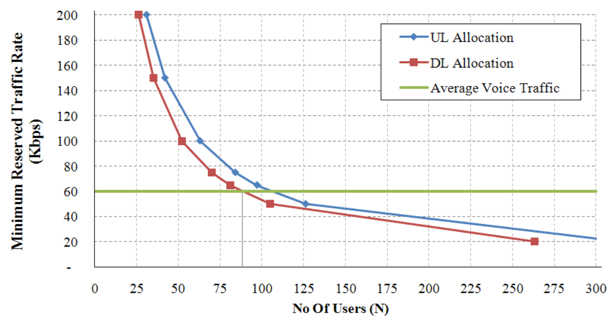


Fig. 4. Number of Users v.s. Allocation Values

values could affect the BW-req size by each of users, and the network capacity. Figure 4, shows the relationship between the maximum number of users in a network for different allocation values of MRTR. It is important to note that the system capacity does not increases or decreases linearly with different MRTR allocations. Figure 4 shows that if MRTR allocation level is equal to the average voice traffic requirements than the system can support about 87 users. The traffic capacity of a network is limited not only by the MRTR allocation but also by overheads and channel wastage due to the mapping process discussed in the next section. Next, we analyse the impact of the scheduling process on the mapping process on the DL Subframe. The DL subframe accommodates the preamble, the DL-MAP, the UL-MAP, the data bursts and the Frame Control Header (FCH). The burst size used is integer numbers of slot sizes. For the voice traffic, equations 6 and 7 show the DL subframe capacity usages for different number of users for the 60% voice activity factor. In equation 7, N represents the number of users.

$$\begin{aligned} DLSubframe &= Preamble + DLMAP + ULMAP \\ &+ DATABurst + FCH \end{aligned} \tag{6}$$

$$\begin{aligned} DLSubframe &= [1 * 1440] + [88 + 36N] * 60\% \\ &+ \lceil (48 + 56N)/SlotSize \rceil * SlotSize * 60\% \\ &+ \lceil 960N/SlotSize \rceil * SlotSize * 60\% + 192 \end{aligned} \tag{7}$$

Figure 5 shows the DL channel utilisation and channel wastage for different number of users using the MDRR scheduling algorithm. Figure 5 shows that the DL link utilisation increases with the number of users but the link utilisation saturate after certain number of users due to channel wastage. Result shows how the capacity wastage increases with the number of users, reaching a maximum value of 40%. There are two important causes for the wastage: i) Over allocation of the subheaders in the BW-req and ii) Use of fractional numbers of slots in the OFDMA subframe for the MAC PDU. The first cause of loss can be minimised if allocation can be adaptively matched with the BW-req. When a data packet arrives to the WiMAX MAC layer and after the packet has been classified, a BW-req is created. This BW-req ask for a capacity equals to

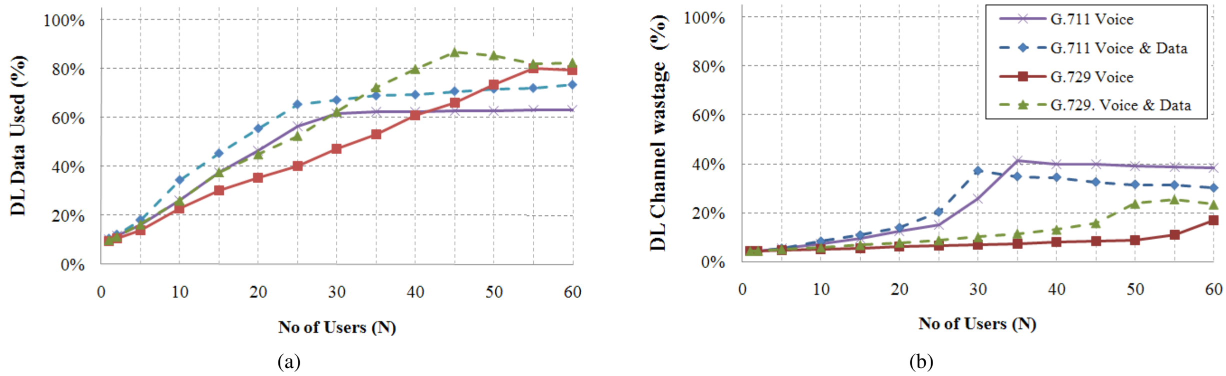


Fig. 5. Download subframe usage using MDRR. a)Data usage (Preamble + MAPs + DataBurst) b) Wastage usage

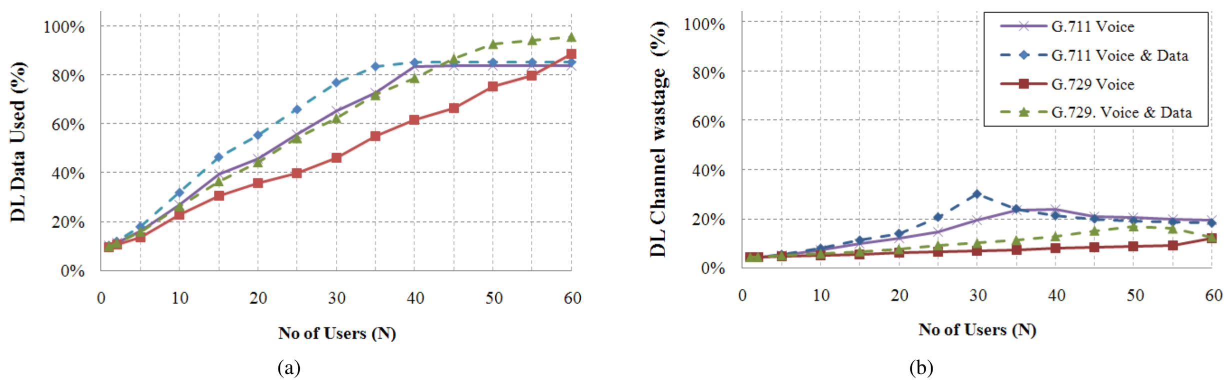


Fig. 6. Download subframe usage using New MDRR. a)Data usage (Preamble + MAPs + DataBurst) b) Wastage usage

the sum of the payload (variable), the MAC Header (48bits), two Packing subheaders (16 bits each), the Grant Manager subheader (16 bits) and the optional CRC size (32 bits). A total of 128 bit of overhead per PDU is added. In our model, initially we only use one classifier for UL and DL connections. The classifier used is unable to identify if the packet (SDU) is going to be packetized with other SDU in a PDU, hence the packing subheaders space could be wasted if it is not used. As a result, there are losses of 48 bits per packet, and if the packet size is small like the voice packets, the wastage by unused subheaders is 6.9% and 11.7% for G.711 and G.729 respectively for our simulations.

The second cause of wastage is due to the mapping process. All PDUs should be allocated in an integer number of slots, 48 bits size in our model. However, the allocation is not made according to the PDU size of the BW request. For example, for a PDU size of 688 bits, 768 bits (16 slots) are allocated. 10.4% is wasted in the G.711 codec, and 15% in the G.729 one, per packet. Other implication on the wastage is the type of Information Element (IE) used in the mapping process. In this model for a DL Subframe, we use a Burst type 2 [1], where a variable number of subchannels and symbols are selected. An aggregation process is used to unite same-CID in a single burst [16].

In order to reduce the channel wastage as shown in figure 5 we propose a new scheduling scheme that we refer as the NewMDRR. In the proposed scheme we try to pack higher number of small packets in the same WiMAX burst reducing number of overhead bits [17] and then serving them as quickly as possible. Other important discovery found during the analysing of the MDRR scheduler is that the $Q_i$ is same for all traffic under 110Kbps (table I) of MRTR (1% of total traffic), resulting all packets, voice and data receiving the same priority. Equations 3 and 4, show that $w_i$ is a integer relation between the minimum reserved rate and the total system capacity. The MDRR algorithm is used widely in broadband routers where the flow per connection is compared with the total capacity. For a multiclass traffic we proposed modified definitions of $Q_i$ and $w_i$ to work with the NewMDRR algorithm. We assumed that the fairness is directly related with the configured MRTR from the framing point of view. That means taking in account the reserved size of the packet per frame also, make it discrete in terms number of slots used. The modifications of the $Q_i$ and the definition of $l_i$ are presented in equations 8 and 9. The concept of the MAC Header is the same of the MTU used in equation 3.

$$Q_i = \left\lceil \frac{MACHeader + l_i}{SlotSize} \right\rceil * SlotSize \tag{8}$$

$$l_i = \frac{MRTR}{\#FramesPerSec} \tag{9}$$

Performance of the NewMDRR is presented in figure 6. Here, the NewMDRR algorithm significantly reduces the

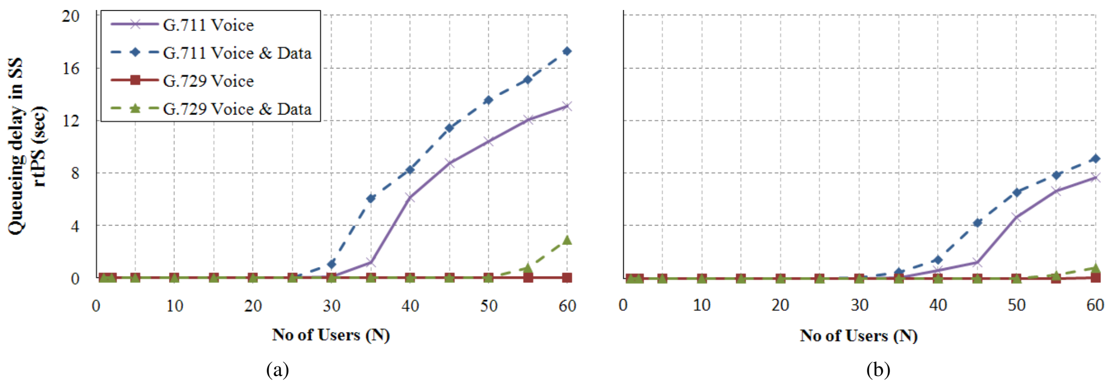


Fig. 7. FrameQueueing Delay in the SS for rtPS connection. a)MDRR b) NewMDRR

channel wastage. This modification allows smaller packets with higher reserved rate being served first leading to faster service rates for services such as VoIP. Simulation results presented in figure 7 show that the queue size and queuing delay per connection is reduced for both codecs used for voice traffic (rtPS). Results also show that the queuing delay for the combined traffic is reduced too. Reduction of queuing delays will lead to improved traffic capacity and QoS values.

## V. Conclusions

A WiMAX network can be configured as a future versatile wireless network to support multiclass traffic for various applications. The QoS characteristics involved in every connection should be a reference for the performance of the resource allocation involved in serving the connections. This paper analysed the effectiveness of a WiMAX network from packet and connection overhead minimisation point of views. The analysis of the configured service flow parameters and the subframe resource allocation methods endorse the creation of a novel round robin based scheduler called NewMDRR. The NewMDRR defines the weight of the served queue based in the Minimum Reserved Traffic Rate and the used slot size in the subframe. This scheduler designed for small packet size and delay sensitive traffic performs better than MDRR and WRR. Accordingly, the simulation results, performed in OPNET simulation model, show the improvements in the in efficiency using the NewMDRR scheduler. The channel wastage due misallocation has been reduced down to the half for both codecs. This reduction leads to an improvement in the data usage from 60% to 80% and 80% to 90% in the G.711 and G.729 codec respectively. As a result, the extra usable space is employed to include more users to the network serving them with similar QoS values as the previous round robin based schedulers.

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