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IMPROVING QOS AND FAIRNESS OF PACKET SCHEDULING IN WIMAX NETWORKS

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Abstract:

WiMAX (defined in IEEE 802.16) is a broadband wireless technology suitable for metropolitan area that has better efficiency and more scalability than wired networks. The WiMAX can be used for various applications such as Internet and multimedia (video streaming). Each of these applications has diverse quality of service (QoS) requirements to be satisfied. Scheduling problem in WiMAX networks is a vital challenging. To satisfy various necessities, a proper scheduling algorithm must be designed for WiMAX. Qualities of service and fairness criteria are known as the most important efficiency and evaluation factors. Therefore, we need an algorithm that meets both fairness and QoS. This paper provides two contributions. First, dynamic frame division is proposed for uplink and downlink channel in order to provide dynamic bandwidth allocation for uplink and downlink traffic, where **fairness is divided between uplink and downlink channels. This division is based on the** requested bandwidth for each class **on each link** and **their coefficients.** Simulation results show that when one of the links (either uplink or downlink traffic) requirements is less than half of the available bandwidth and another link demand is more than half of the bandwidth, the frame utilization of the proposed dynamic division is better than static bandwidth allocation [1]. Meanwhile, the dynamic bandwidth allocation approach always has better loss and delay performances than the static bandwidth allocation. Second, the QoS and fairness (QAF) scheduling algorithm is proposed, which is based on the EDF + WFQ + FIFO algorithm. **In this way**, bandwidth is allocated to each subscriber station (**SS) based on** its **traffic priorities and** the **weights of its traffic classes.** The QAF improves loss, delay, and fairness compared with the EDF algorithm.

Keywords: WiMAX, Scheduling, quality of service, Fairness.

1. INTRODUCTION

WiMAX (Worldwide interoperability for Microwave Access) is one of the most emerging technologies based on IEEE 802.16 standard for Broadband Wireless Access (BWA) in metropolitan areas. IEEE 802.16 defines physical and MAC layers for WiMAX [2, 3]. Different modulations can be used in the PHY layer are as: Single Carrier (SC), OFDM (Orthogonal Frequency Division Multiplexing) and OFDMA (Orthogonal Frequency Division Multiple Access)[4]. In OFDM, sub-channels are very close to each other and they are orthogonal to avoid interference. In OFDMA, certain sub-carriers are assigned to different users [5, 6]. IEEE 802.16 has dedicated 10-66 GHz band for LOS (Line of Sight) communications and 2-11 GHz band for NLOS (Non Line of Sight) communication [1]. The standard defines two basic operational modes: point-to-multipoint (PMP) and Mesh. In the mesh mode, a subscriber station (SS) can communicate with other stations and with the base station (BS), but in the PMP subscriber stations can only communicate with each other through the BS[1, 7].

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In IEEE 802.16, MAC layer is composed of the following sublayers: Convergence sublayer (CS), Common Part Sublayer (CPS) and Security Sublayer. Bandwidth allocation is one of the services in CPS. Scheduling is the most important component in MAC layer of WiMAX networks[8]. Bandwidth can be divided into either static or dynamic between uplink and downlink channels[9]. Moreover, uplink channel scheduling is more crucial than downlink channel scheduling[10]. Various applications have different QoS requirements. Therefore, scheduling algorithms must be able to ensure QoS requirements such as throughput, fairness, and delay and packet loss. Packet scheduling algorithms could be used for both BS and SS. A scheduling algorithm in an SS divides bandwidth to its connections. If BS grants the bandwidth to the connections of different SSes, then implementing a scheduler in the SS is not required. This is called Grant Per Connections (GPC)[11]. When, instead of allocating bandwidth to the connections, bandwidth is allocated to the SSes, then a scheduling algorithm is required at the SS, called Grant per Subscriber Station (GPSS)[11]. The IEEE 802.16d has defined four classes of services as follows: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), non-real time Polling Service (nrtPS), and Best Effort (BE) QoS classes. The UGS class is used for constant bit-rate (CBR) applications, e.g., Voice over IP (VoIP). Variable bit-rate (VBR) flows (such as video streams) are supported in the rtPS class. The nrtPS class is used for non-real-time flows, e.g. applications that are time-insensitive. The BE class is used for supporting the best effort traffic such as HTTP. In addition, Extended real-time Polling Service (ertPS) has been defined in IEEE 802.16e for VoIP applications [12 , 21].

Bandwidth allocation is a challenging issue in WiMAX networks. These networks are scalable and their bandwidth demands are ever increasing. Hence, maximum number of subscribers should be supported and their QoS requirements must be met. In addition, allocating bandwidth to subscribers must be in a way to decrease packet loss rate and delay, and increase fairness and throughput. Moreover in presented scheduling algorithms in literature, bandwidth allocation is static in which half of bandwidth is allocated for upstream traffic and the other half for downstream traffic. However, this static bandwidth allocation could not be appropriate in practice. Finally, fairness has not been considered in the proposed scheduling algorithms. These problems motivate us to design a new scheduling algorithm to address these requirements.

Our objective in this paper is to consider dynamic bandwidth allocation and show that dynamic bandwidth allocation is better than static one. A packet scheduling algorithm, called QAF that considers both QoS and fairness metrics is presented that can provide better performance results than other scheduling algorithms for subscribers in terms of delay, loss and fairness. Our contribution is to develop a new fair scheduling algorithm in WiMAX networks that satisfies QoS requirements of subscribers in terms of delay, loss and fairness.

The remainder of this paper is organized as follows. In Section 2, scheduling algorithms proposed for WiMAX networks are reviewed. Section 3 presents our proposed algorithms. In Section 4, performance evaluation results are presented. Concluding remarks are given in Section 5.

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2. RELATED WORK

Recently, many packet scheduling algorithms have been proposed for broadband wireless networks. In most of the scheduling algorithms, bandwidth allocation for uplink and downlink channels is static. Scheduling algorithms are classified into four categories: homogenous algorithms, hybrid algorithms, opportunistic algorithms, and balanced fairness and throughput algorithms. In [23], scheduling algorithms are categorized into 5 categories:

1. Traditional schedulers
2. Hybrid schedulers
3. Cross Layer approaches
4. Dynamic schedulers
5. Soft Computing based

Homogeneous algorithms[13] provide QoS, flow separation, and fairness similar to wired networks. Weighted Round Robin(WRR) and Deficit Round Robin (DRR) algorithms[14] are used in WiMAX networks, where WRR is used for uplink channel scheduling and DRR is used for downlink channel scheduling. The WRR supports QoS requirements for multi-class traffic. For WRR, in [1], weights are assigned to SSes based on:

$$W_i = MRTR_i \Big/ \sum_{j}^{n} MRTR_j \quad ,$$

Where weight W_i is given to SS_i, n is the number of SSes, and $MRTR_j$ is the minimum reserved traffic rate by SS_j.

Earliest Deadline First(EDF)[1] is another homogeneous algorithm originally used for real-time applications. In this method, bandwidth is dedicated to those packets that their deadlines are finished earliest. First, EDF gives deadline to each packet based on packet delay. The EDF is used for the rtPS class because this class is delay sensitive. The Weighted Fair Queuing (WFQ)[15] is another homogeneous algorithm that assigns end of time to each packet. When we have multiple SSes, a weight is assigned to each SS. The handling of SSes is based on their weights. If link data rate is R, weight of SS_i is w_i, and there are N SSes, then the contribution of each SS on the link will be:

$$\frac{R \times w_i}{w_1 + w_2 + \ldots + w_N}$$

Calculation of finish time is based on packet size and the weight of relevant SS[16].

A hybrid scheduling algorithm consists of two or more legacy algorithms in which each algorithm is used for an appropriate service class. The EDF + WFQ + FIFO[1] is a hybrid algorithm, where bandwidth is first allocated to all rtPS packets using EDF. Then, if bandwidth is still available, the remaining bandwidth is assigned to the nrtPS packets using WFQ. At the end, the SSes of the BE class can be scheduled by the first in first out (FIFO) mechanism[13].

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Another method for hybrid algorithms is EDF + WFQ in which the SSes of rtPS class are scheduled by EDF and both nrtPS and BE are scheduled using WFQ[17]. Another hybrid algorithm is WRR + RR, where WRR is used for both rtPS and nrtPS services. Then, the remaining bandwidth is distributed among the BE packets based on the round robin (RR) mechanism. In this method, like the EDF+WFQ+FIFO and EDF + WFQ algorithms, low priority packets in SSes may encounter starvation. Opportunistic algorithms first extract the variability in WiMAX channel conditions. By these algorithms, the SSes with better channel quality have high priority. Then, bandwidth is allocated to SSes according to the decreasing order of their priorities. The cross layer scheduling algorithm [1] and queuing theoretic algorithm[18] are in this category. The queuing theoretic method assigns priority to SSes based on their utilization[18]. An SS with the lowest utilization has the highest priority. In this algorithm, low priority queues may face starvation because bandwidth cannot be allocated to these queues when high priority queues are not empty. In [19], a new cross layer scheduling has been proposed for supporting QoS requirements in single carrier WiMAX PMP networks. A cross layar packet scheduling has been designed for LTE networks too [22]. The fourth category is called balanced fairness and throughput category, e.g., proportional fairness[20]. In this way, bandwidth is allocated to ensure maximum throughput, and fairness between subscribers can be observed. Fairness index can be defined by either the Min-Max method[1] or the Jain’s method[12]. Requests that cannot be satisfied in Min-Max should be minimum. Therefore, sum of bandwidth utilization of SSes should be maximum.

We can use allocated bandwidth to demanded bandwidth for an SS (X) as a parameter in order to compute the Jain’s fairness index among all SSes by

$$X_i = \frac{BW_{allocated}\ \mathrm{to\,SS_i}}{BW_{demand}\ \mathrm{to\,SS_i}}$$

Where $BW_{Allocated}$ is the amount of bandwidth (in bits) that BS has granted to SS_i and BW_{demand} (in bits) is the amount of bandwidth that SS_i has requested. Then, we have

$$\text{Jain's fairness index} = \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n \times \sum_{i=1}^{n} X_i^{\,2}} \ ,$$

Where n is the number of SSes. This index is between zero and one. If this value is closer to 1.0, then fairness is better[1]. In [21], a dynamic strategy has been proposed for packet scheduling in IEEE 802.16e OFDMA system. In [24] scheduling of IEEE 802.16 real time polling and unsolicited grant service for protecting transmission and sub-transmission systems with multi-terminals has been studied. The findings indicate that WiMAX is a suitable network for delay-sensitive protection applications. According to researches carried out in scheduling algorithms for uplink channel, hybrid algorithms can provide better performance than other algorithms[1].

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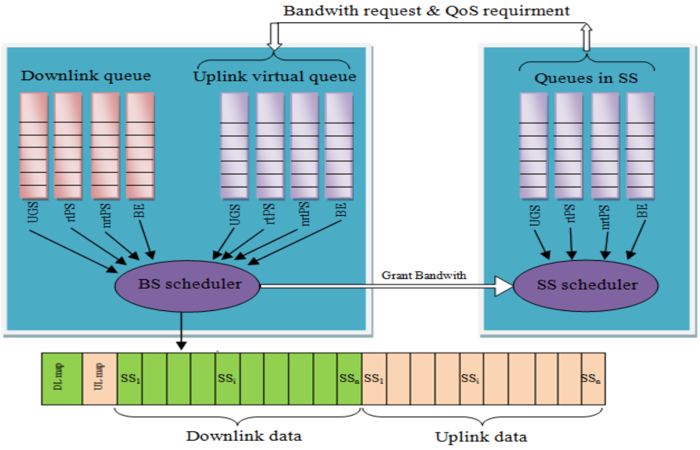
3. THE DYNAMIC FRAME DIVISION FOR UPLINK AND DOWNLINK CHANNELS (DFDUD) AND QAF ALGORITHMS

In this paper, we investigate the PMP mode in WiMAX networks and only consider the scheduling in base station as shown in Fig. 1. In addition, we assume that SSes are stationary not mobile.

Fig. 1. WiMAX networks in the PMP mode

In our modeling, distance between SSes and the base station are equal. We assume that each SS has four classes of services. Each SS sends requests of all classes with QoS requirements to BS and BS schedules the downlink and uplink data in each frame (see Fig. 2). Slots belonging to each SS for uplink and downlink channel are determined in order in uplink map (UL map) and downlink map (DL map). Bandwidth allocation is considered based on GPSS.

Fig. 2. Bandwidth allocation to subscribers by base station



Here, dynamic frame division between uplink and downlink channels is reviewed firstly. Then, QAF for bandwidth allocation in uplink channel is proposed to improve the scheduling in this channel.

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3.1 DFDUD

Under the static bandwidth allocation evaluated in this paper, a frame is equally divided into two parts: one part is allocated for uplink traffic and the other part is allocated for downlink traffic. We use dynamic bandwidth allocation for uplink and downlink channels in which a frame is dynamically broken into two unequal portions. Each SS sends the amount of its service class's requests and QoS requirements to BS.

All these requests make uplink channel needs. Downlink channel requests are also determined in BS. Define UGS_{UL}, $rtPS_{UL}$, $nrtPS_{UL}$, and BE_{UL} to be total demand (in bits) of UGS, rtPS, nrtPS, and BE classes from all SSes for uplink channel, respectively. Similarly, UGS_{DL}, $rtPS_{DL}$, $nrtPS_{DL}$, and BE_{DL} are total demands (in bits) of UGS, rtPS, nrtPS, and BE classes to all SSes in downlink channel. Define S_{UL} and S_{DL} to be the whole traffic of uplink and downlink demands (in bits) from all SSes for a frame, respectively; as

$$S_{UL} = UGS_{UL} + rtPS_{UL} + nrtPS_{UL} + BE_{UL}\ .$$

$$S_{DL} = UGS_{DL} + rtPS_{DL} + nrtPS_{DL} + BE_{DL}\ .$$

Define Parameter F to be the total number of slots within a frame, F_{UL} to be the number of slots in a frame that should be granted to the uplink traffic, and F_{DL} to be the number of slots that should be granted to downlink traffic. If the traffic of uplink (downlink) is too greater than the traffic of downlink (uplink), then up to 80% of the total bandwidth is given to the uplink (downlink) channel. Namely, in each case, at least 20% of the total bandwidth remains for each link, i.e.

$$\text{If } (S_{UL}>4\ S_{DL}) \text{ then } F_{UL} = F\times 80\%\ \&\ F_{DL} = F - F_{UL}$$

$$\text{If } (S_{DL}>4\ S_{UL}) \text{ then } F_{DL} = F\times 80\%\ \&\ F_{UL} = F - F_{DL}$$

The BS checks whether all the requests with high priority can be fulfilled or not. If total of UGS_{UL} and UGS_{DL} traffic is larger than a frame, then the frame is just divided based on these two values. In Fig.3, $UGS_{UL,DL}$ is the whole UGS traffic from all SSes for both uplink and downlink, and C is the capacity of a frame in bits per frame.

Otherwise, the weight of each link is acquired based on the amount of requests and coefficients of all service classes. Service classes are given different coefficients according to their priorities; UGS has the highest coefficient and BE has the lowest coefficient.

Define parameters α, β, γ, and μ to be the coefficients used for the importance of traffic classes; α is used for UGS, β for rtPS, γ for nrtPS and μ for BE, where $\alpha+\beta+\gamma+\mu=1$. Clearly, if a specific class has higher priority than other classes, we can change these values of coefficients accordingly.

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Flowchart of DFDUD is shown in Fig. 3. Using the aforementioned parameters, the BS separately calculates the UL and DL coefficients for both downlink and uplink links for a frame as (see Fig.3):

$$UL = \alpha\times UGS_{UL} + \beta\times rtPS_{UL} + \gamma\times nrtPS_{UL} + \mu\times BE_{UL}$$

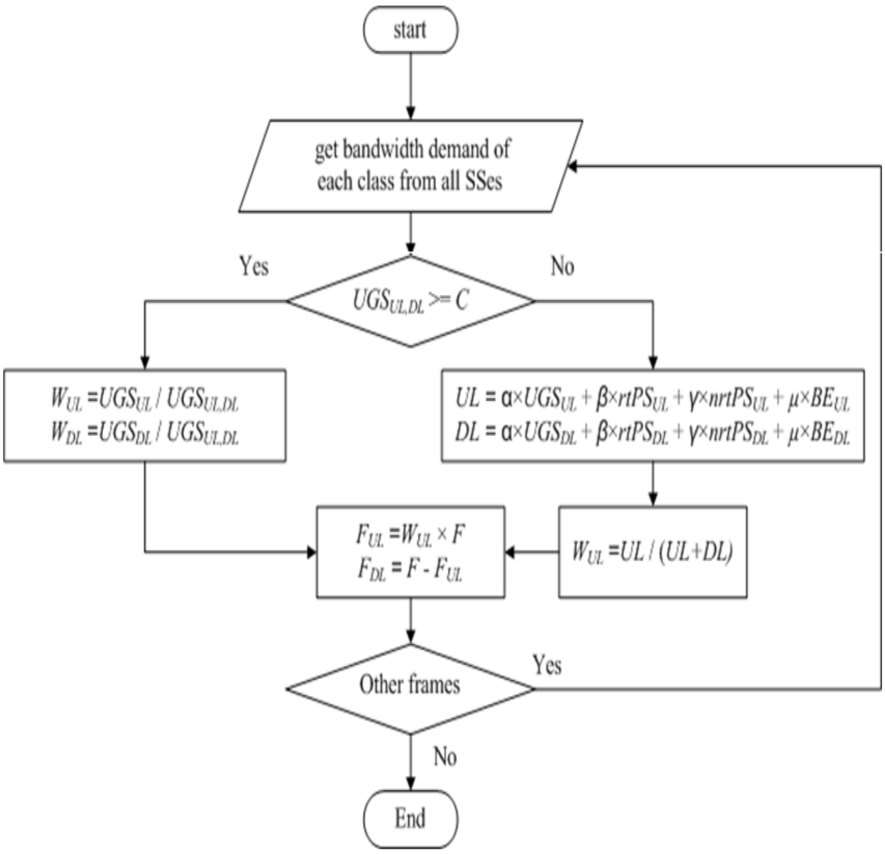
$$DL = \alpha\times UGS_{DL} + \beta\times rtPS_{DL} + \gamma\times nrtPS_{DL} + \mu\times BE_{DL}$$

After that, weight of each link is calculated. Parameters W_{UL} and W_{DL} are the weights of uplink and downlink traffic. Finally, frame division is carried out based on uplink and downlink link weights as

$$F_{UL} = W_{UL} \times F$$

$$F_{DL} = F - F_{UL}$$

Fig. 3. Dynamic Frame Division for Uplink and Downlink Channels(DFDUD) Flowchart



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3.2 QoS and Fairness scheduling algorithm (QAF)

Here, we develop a hybrid algorithm that can improve QoS requirements such as delay and fairness. In this method, our proposed DFDUD and the GPSS mode [7, 12] are combined. We use the EDF algorithm for scheduling of the rtPS class, WFQ for scheduling of the nrtPS class, and FIFO for scheduling of the BE class.

$$C_{UL} = \sum_{i=1}^{i=F_{UL}} P_i \times Slotsize$$

Parameter C_{UL} is the capacity of the uplink part of a frame (in bits) that it is calculated by multiplying F_{UL} in size of a slot. Figure 4 shows the flowchart of QAF. First, all SSes send their bandwidth demands (in bits) and QoS requirements for uplink channel to BS. Then, if the capacity of uplink link in a frame is less than UGS_{UL}, then we sort SSes based on the amount of their UGS requests in increasing order and then schedule them, where UGS_{ULi} specifies the UGS demand of uplink channel from SS_i.

Otherwise, we consider requests of other classes. To calculate the remaining bandwidth R_1 (in order to meet the bandwidth requests of other classes), UGS_{UL} should be subtracted from C_{UL}. Again, R_1 is compared with all requests of rtPS, nrtPS and BE classes from all SSes. If R_1 is less than the whole requests of rtPS, nrtPS and BE classes, then the bandwidth is allocated to rtPS classes based on Minimum Reserved Traffic Rate (MRTR)[1] and bandwidth is distributed among SSes based on their weights. Otherwise, all classes can be easily satisfied.

Define α_1 to be the coefficient for rtPS class, β_1 to be the coefficient for nrtPS class, and μ_1 to be the coefficient for BE class. To calculate the weight of SS i (i.e.,W_i), we use the following priority function:

$$W_i = \alpha_1 \times rtPS_i / (S_{UL} \times deadline_i) + \beta_1 \times nrtPS_i / (S_{UL} \times D_i) + \mu_1 \times BE_i / S_{UL},$$

Where $rtPS_i$, $nrtPS_i$, BE_i are requests of SS_i for rtPS, nrtPS and BE services. Parameter $deadline_i$ denotes the time that the packet at the head of the rtPS queue of SS_i should be sent (otherwise, it will be lost), which is equal to the remaining time until transmission time divided by the maximum delay (where the maximum delay for each class is specified in Table 2). Parameter D_i shows the delay of the packet at the head of the rtPS queue of SS_i which is equal to delay of this packet divided by the maximum delay.

After sorting SSes by their weights, for meeting the rtPS demand of SS_i (i.e., $rtPS_{ULi}$), we reduce MRTR requirement (i.e., $rtPS_{MRTRi}$) from the available bandwidth. If all of rtPS requests are fulfilled, the nrtPS class traffic should be scheduled. Otherwise, the frame is only scheduled for UGS and rtPS services. To schedule the nrtPS and BE services, the remaining bandwidth R_2 is computed by subtracting the allocated bandwidth to rtPS traffic of all SSes

$$(A_{rtPS} = \sum_i rtPS_{ULi}) \text{ from } R_1 \text{ as}$$

$$R_2 = R_1 - A_{rtPS}$$

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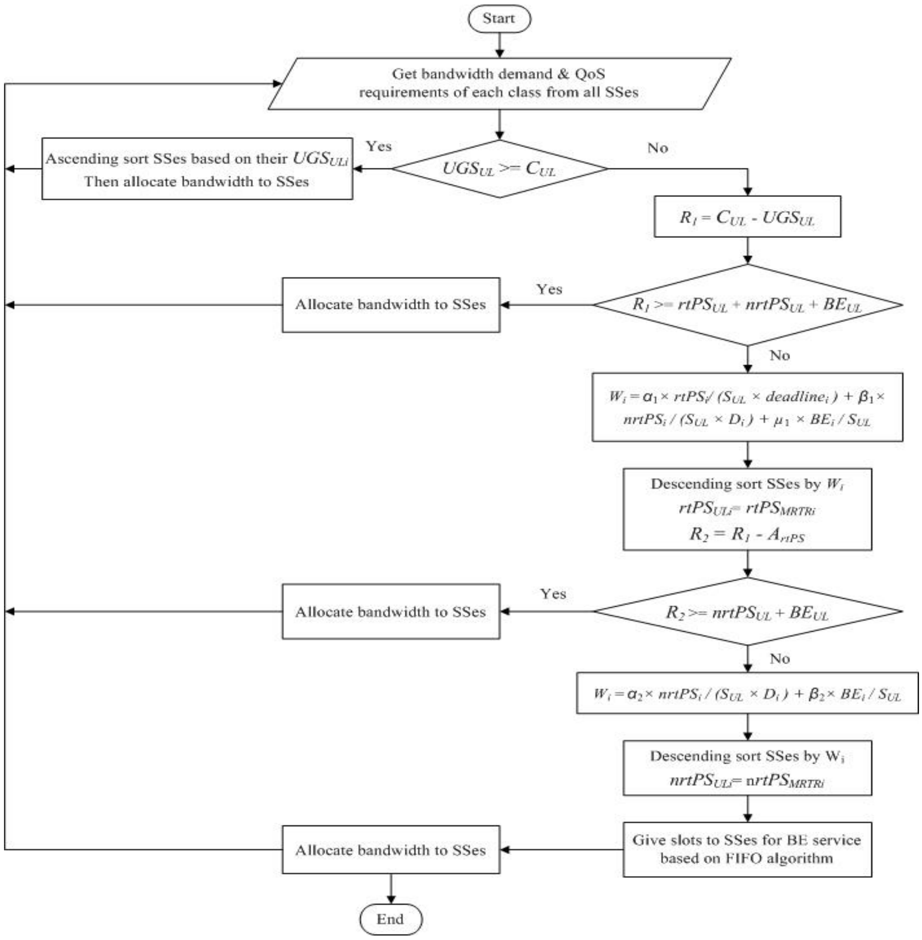
Fig. 4. Flowchart of QAF algorithm



If the requirements of nrtPS and BE classes are less than the remaining slots, then all of them can be scheduled. Otherwise, the weights of SSes are updated. Descending sort of SSes according to their weights is performed in which the weight of SS_i is computed as following:

$$W_i = \alpha_2 \times nrtPS_i / (S_{UL} \times D_i) + \beta_2 \times BE_i / S_{UL}$$

Here, the summation of coefficients α_2 and β_2 is 1.0. This time, using MRTR, bandwidth is assigned to the nrtPS class as

$$nrtPS_{ULi} = nrtPS_{MRTRi}$$

Where $nrtPS_{ULi}$ is the amount of bandwidth that should be remained for nrtPS of SS_i, and $nrtPS_{MRTRi}$ is the need of MRTR from nrtPS of SS_i. Finally, the remaining slots are distributed among SSes using the FIFO algorithm for BE classes.

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4. PERFORMANCE EVALUATION

To evaluate the performance of the proposed algorithms, we have developed a simulation in C++. With 10 runs and 95% confidence intervals (C.I.), we have drawn diagrams in the following. The shown points in a diagram are average points and the worst C.I. is within at most 5% of the shown points. In other words, if y is average for a point in a diagram, the C.I. for that point is at most between 0.95y and 1.05y.

Table 1: System parameters

Parameters	Values
Channel bandwidth	2.5 MHz
Number of base station	1
Number of SS	1 to 10
Channel modulation	16 QAM
Coding	¾
Station mobility	No
Antenna	Omni-directional
Error and noise	No
Fragmentation	No
Frame duration	ms
Data rate	16.82 Mb/s

4.1 System model

We explain the simulation parameters as system parameters and traffic parameters. System parameters are shown in Table 1. Packets inter-arrival times, packet sizes and coefficients for each class are summarized in Table 2 as traffic parameters. In our simulation, each frame has 73 slots and one slot is equal to 576 bits. In the other words, each frame is 5256 bytes. Duration of each frame is 2.5 milliseconds. Hence, maximum data rate is 2,102,400 bytes per second.

Table 2: Traffic parameters

Class type	Used for	Distribution	Values
UGS for each SS	Data rate	Constant	400 Kbps
rtPS	Packet size	Geometric	Mean = 800 bits
rtPS	Inter-arrival time	Normal	Mean = 2 ms Std.dev = 0.2 ms
nrtPS	Packet size	Exponential	Mean = 600 bits
nrtPS	Inter-arrival time	Normal	Mean = 2.5 ms Std.dev = 0.2 ms
BE	Packet size	Exponential	Mean = 600 bits
BE	Inter-arrival time	Normal	Mean = 2.5 ms Std.dev = 0.2 ms
UGS	α coefficient (for DFDUD)	-	0.5
rtPS	β coefficient (for DFDUD)	-	0.3
nrtPS	γ coefficient (for DFDUD)	-	0.15
BE	μ coefficient (for DFDUD)	-	0.05
rtPS	α_1 (for QAF)	-	0.5
nrtPS	β_1 (for QAF)	-	0.3
BE	μ_1 (for QAF)	-	0.2

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nrtPS	α_2 (for QAF)	-	0.7
BE	β_2 (for QAF)	-	0.3
Simulation time	-	-	10 s
Number of slots	Per frame	-	73
Slot size	-	-	576 bits
rtPS, nrtPS	MRTR	-	Half of requested
UGS	Max delay	-	10 ms
rtPS	Max delay	-	10 ms
nrtPS	Max delay	-	20 ms
BE	Max delay	-	30 ms

4.2 Simulation Results

To demonstrate the performance of the proposed algorithms, we focus on utilization, delay, fairness and loss criteria. These criteria are calculated as follows:

$$Frame\ Utilization = \frac{Unused}{Frame\ Size} \times 100$$

Frame utilization is used for performance evaluation of bandwidth in which Unused is the number of slots that are not used and Frame Size is total size of a frame. Parameter Delay is defined as

$$Delay = \frac{\sum_{i=1}^{m} WT_i}{m}$$

Where WT_i is waiting time of packet i and m is the number of successfully transmitted packets. Parameter Loss is defined by the ratio of all lost packets over total number of packets sent to the network. For fairness measurement, the Jain's fairness [1] is utilized as previously described.

4.2.1 Performance of the DFDUD algorithm

Frame utilization, delay and loss parameters are evaluated for static bandwidth allocation (defined in Section 3.1) against dynamic bandwidth allocation (i.e., the DFDUD algorithm). When there are four SSes or more, all of the bandwidth almost may be needed. With this number of SSes, it can be seen that under dynamic bandwidth allocation, frame utilization is better than static bandwidth allocation (see Fig. 5). In this case, packet loss cannot happen in dynamic bandwidth allocation as demonstrated in Fig. 5.

We evaluate the static and dynamic bandwidth allocation algorithms according to delay of rtPS, nrtPS and BE classes. Fig. 6 shows that delay in dynamic allocation (i.e., the DFDUD algorithm) is less than the static bandwidth allocation. This is because if the uplink channel has more rtPS traffic than the downlink channel, then more bandwidth will be assigned to the uplink channel and most of packets will be fast sent, and delay of rtPS will reduce as a result. Also, with such reasoning we can see in Fig. 7 and Fig. 8 that delays of nrtPS and BE in the dynamic division are less than the static division. Therefore, packet loss decreases when we use dynamic allocation too (see Fig. 9). In static division, packet loss occurs with four SSes.

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Whereas in dynamic division, packet loss starts at five SSes since more bandwidth is given to the link that needs more bandwidth. Note that in this case, the uplink channel needs more bandwidth than the downlink channel, and therefore, the dynamic division assigns more bandwidth to the uplink channel.

Fig. 5. Frame utilization in static and dynamic division

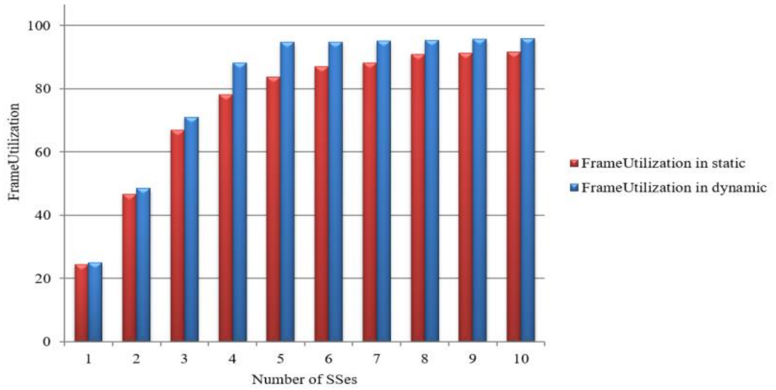

Fig. 6. Delay of rtPS class for static and dynamic division

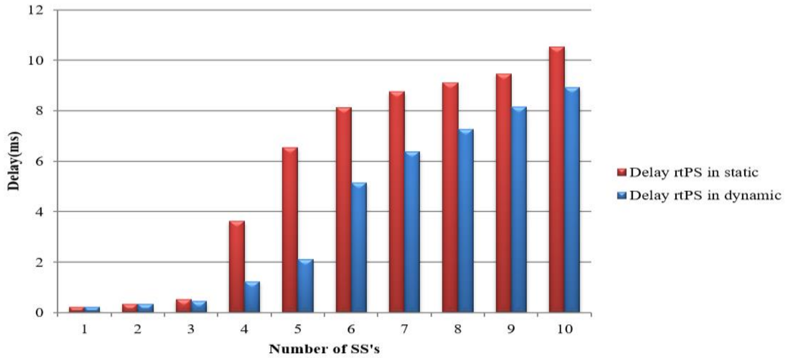

Fig. 7. Delay of nrtPS class for static and dynamic division

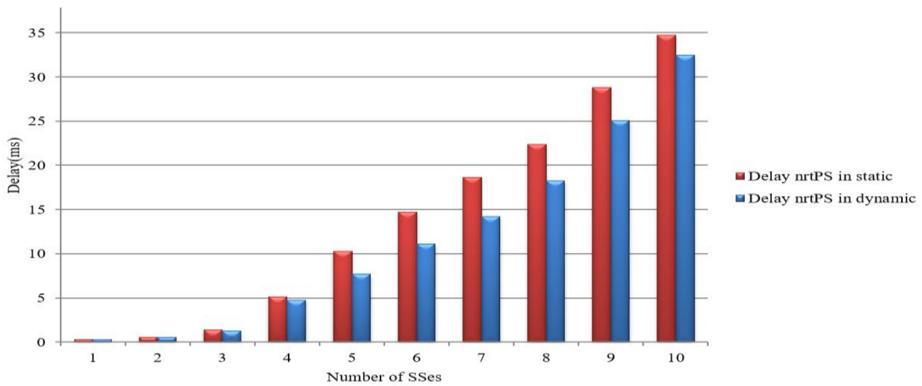

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Fig. 8. Delay of BE class for static and dynamic division

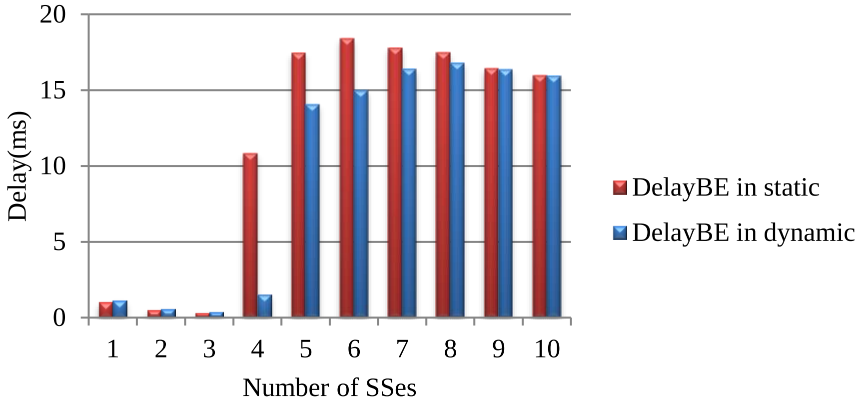
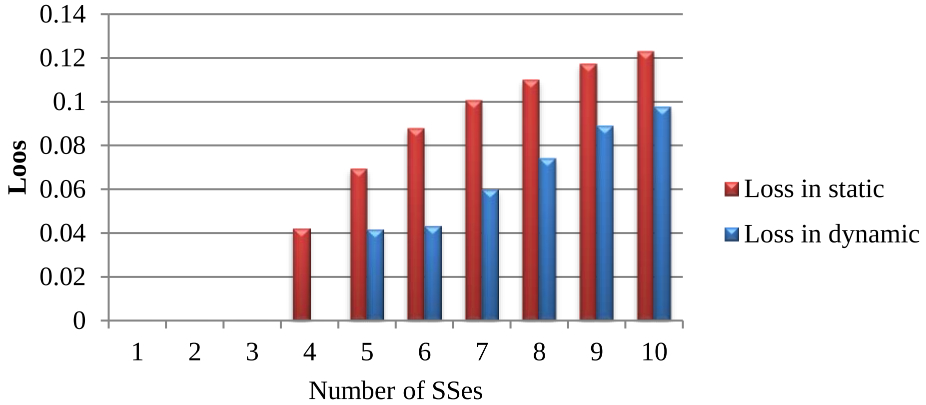


Fig. 9. Packet loss in dynamic and static methods



4.2.2 Performance of the QAF algorithm

In this method, as previously mentioned, combination of EDF, WFQ and FIFO has been used. We consider dynamic frame division in the QAF algorithm. The QAF method is compared with EDF and WRR [1] algorithms based on delay, loss and fairness performances. Under WRR, rtPS class delay goes up rapidly at 4 SSes (see Fig. 10) whereas this happens at 6 SSes under EDF and 9 SSes under QAF. Fig. 11 shows that QAF has better performance in term of delay of nrtPS class as well. Using the EDF algorithm when we have 6 SSes or more, average delay will not be more than 17 ms in Fig. 11. This is because when delay of a packet is more than 20 ms, the packet is lost. For BE class, delay in other methods is more than the QAF algorithm (see Fig. 12).

According to Fig.13, with increasing the number of SSes, the fairness index in WRR reduces. We can see in Fig. 13 that reduction of fairness in EDF is smaller than WRR. While fairness in QAF does not decrease much and there is an oscillation in its diagram. Fig. 14 shows that

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packet loss in QAF happens at 7 SSes, but with WRR and EDF, packet loss occurs at 4 and 5 SSes, respectively. Therefore, QAF can decrease traffic loss better than EDF and WRR.

Fig. 10. Delay of rtPS class in QAF, EDF and WRR methods

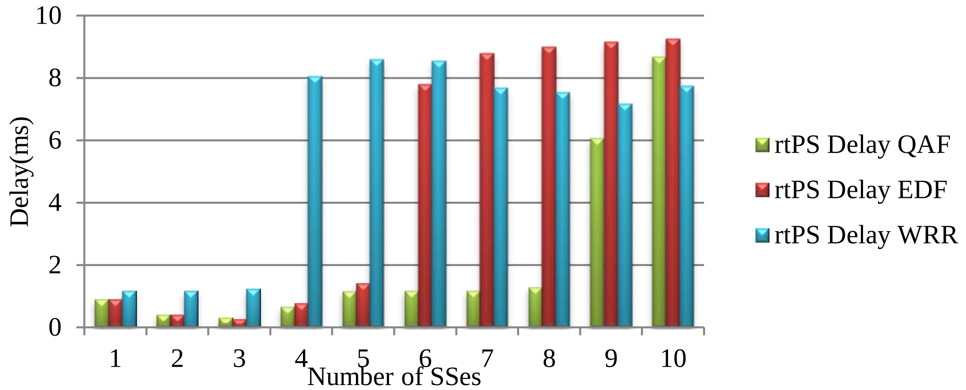

Fig. 11. Delay of nrtPS class in the QAF, EDF and WRR methods

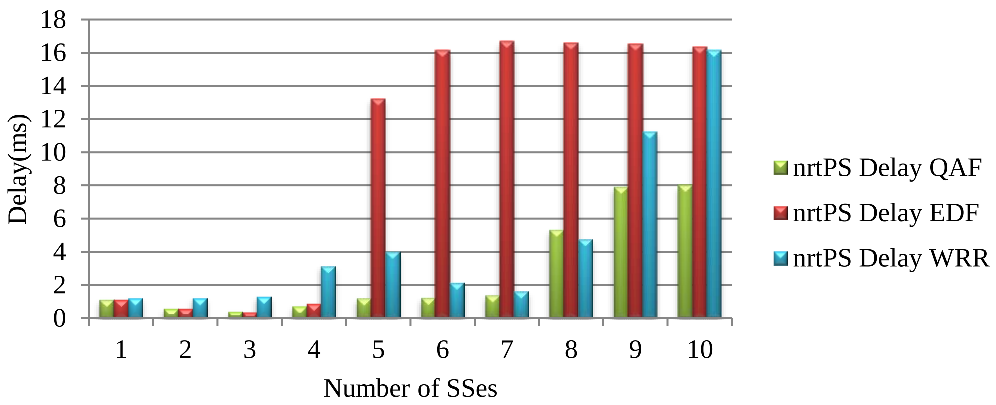

Fig. 12. Delay of BE class in QAF, EDF and WRR methods

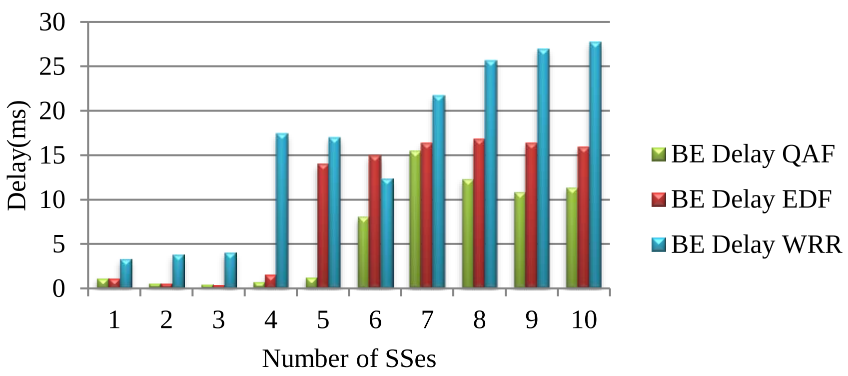

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Fig. 13. Fairness in QAF, EDF and WRR methods

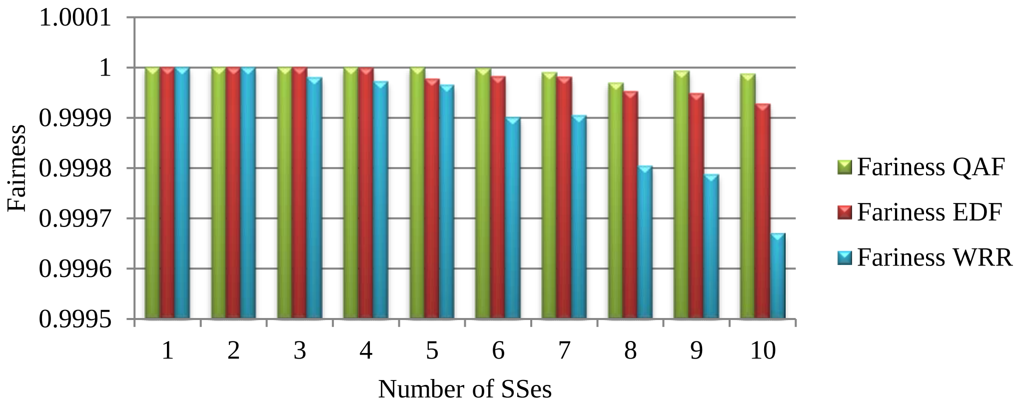
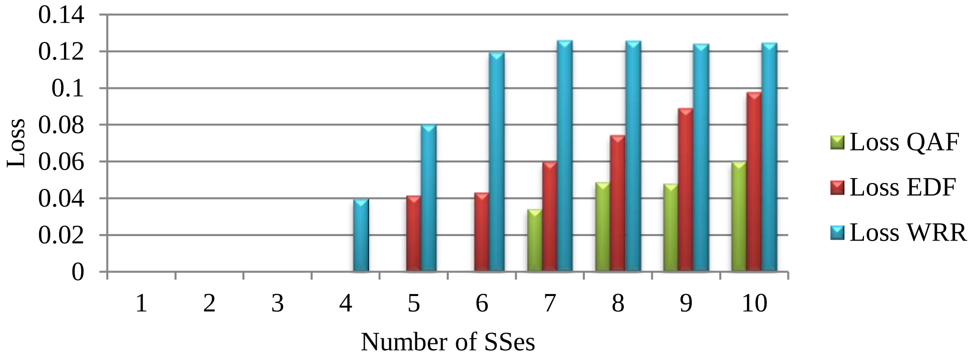


Fig. 14. Loss in QAF, EDF and WRR methods



5. CONCLUSION

In this paper, scheduling in uplink channel of WiMAX networks has been investigated. Two methods have been proposed. First, we have provided a research on static and dynamic frame division for uplink and downlink channels. Using our proposed DFDUD, frame utilization, packet loss and delay can be improved. In addition, the QAF algorithm has been proposed based on the combination of EDF, WFQ and FIFO. In this algorithm, we give priority to each SS based on its QoS requirements. The EDF scheduling is used for rtPS class, WFQ is used for nrtPS class, and FIFO for BE class. Under QAF, we use dynamic frame division for scheduling in WiMax PMP networks. Simulation results show that QAF improves packet loss, delay, and fairness performance parameters compared with other algorithms.

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