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Scheduling Mechanisms

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1. Introduction

The WiMAX technology, based on the IEEE 802.16 standards (IEEE, 2004) (IEEE, 2005), is a solution for fixed and mobile broadband wireless access networks, aiming at providing support to a wide variety of multimedia applications, including real-time and non-real-time applications. As a broadband wireless technology, WiMAX has been developed with advantages such as high transmission rate and predefined Quality of Service (QoS) framework, enabling efficient and scalable networks for data, video, and voice. However, the standard does not define the scheduling algorithm which guarantees the QoS required by the multimedia applications. The scheduling is the main component of the MAC layer that helps assure QoS to various applications (Bacioccola, 2010). The radio resources have to be scheduled according to the QoS parameters of the applications. Therefore, the choice of the scheduling algorithm for the WiMAX systems is very important. There are several scheduling algorithms for WiMAX in the literature, however, studies show that an efficient, fair and robust scheduling algorithm for WiMAX systems is still an open research area (So-in et al., 2010) (Dhrona et al., 2009) (Cheng et al., 2010).

The packets that cross the MAC layer are classified and associated with a service class. The IEEE 802.16 standards define five service classes: Unsolicited Grant Service (UGS), extended real-time Polling Service (ertPS), real-time Polling Service (rtPS), non real-time Polling Service (nrtPS) and Best Effort (BE). Each service class has different QoS requirements and must be treated differently by the Base Station. The scheduling algorithm must guarantee the QoS for both multimedia applications (real-time and non-real-time), whereas efficiently utilizing the available bandwidth.

The rest of the chapter is organized as follows. Section 2 presents the features of the WiMAX MAC layer and of the WiMAX scheduling classes. The main components of the MAC layer are presented. Then, the key issues and challenges existing in the development of scheduling mechanisms are shown, making a link between the scheduling algorithm and its implementation. Section 3 provides a comprehensive classification of the scheduling mechanisms. Then, the scheduling mechanisms are compared in accordance with the QoS requirement guarantee. Section 4 describes the scheduling algorithms found in the literature in accordance with the classification of the scheduling mechanisms provided in the Section

3. Then, the performance evaluation of these algorithms is made. Section 5 presents a synthesis table of the main scheduling mechanisms and highlights the main points of each of them. Section 6 does the final consideration of this chapter.

2. WiMAX MAC scheduling and QoS: Issues and challenges

The major purpose of WiMAX MAC scheduling is to increase the utilization of network resource under limited resource situation. In the WiMAX systems, the packet scheduling is implemented in the Subscriber Station (uplink traffic) and in the Base Station (downlink and uplink traffic). The Figure 1 shows the packets scheduling in the Base Station (BS) and in the Subscriber Station (SS) (Ma, 2009).

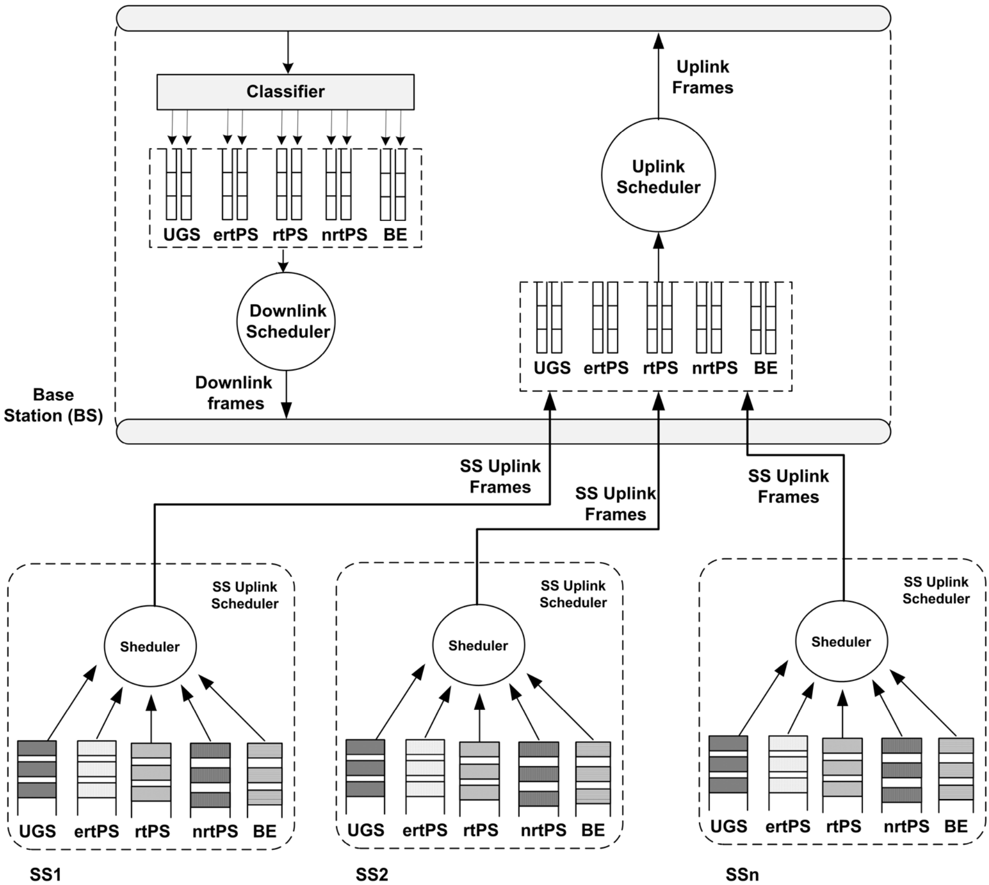

Fig. 1. Packet scheduling in the BS and in the SS (Ma, 2009).

In the downlink scheduling, the BS has complete knowledge of the queue status and the BS is the only one that transmits during the downlink subframe. The data packets are broadcasted to all SSs and an SS only picks-up the packets destined to it. The uplink scheduling is more complex than downlink scheduling. In the uplink scheduling, the input queues are located in the SSs and are hence separated from the BS. So, the BS does not have any information about the arrival time of packets in the SSs queues.

2.1 The uplink medium access

The BS is responsible for the whole medium control access for the different SSs. The uplink medium access is based on request/grant mechanisms. Firstly, the BS makes the bandwidth allocation so that the SSs can send their bandwidth request messages before the transmitting of data over the medium. This process is called polling. The standard defines two main request/grant mechanisms: unicast polling and contention-based polling. The unicast polling is the mechanism by which the BS allocates bandwidth to each SS to send its BW-REQ messages. The BS performs the polling periodically. After this, the SSs can send its BW-REQ messages as a stand-alone message in response to a poll from the BS or it can be piggy-backed in data packets. The contention-based polling allows the SSs to send their bandwidth requests to the BS without being polled. The SSs send BW-REQ messages during the contention period. If multiple request messages are transmitted at the same time, collisions may occur. There are other mechanisms that the SSs can use to request uplink bandwidth such as multicast polling, Channel Quality Indicator Channel (CQICH) (Lakkakorpi & Sayenko, 2009) etc. Depending on the QoS and traffic parameters associated with a service, one or more of these mechanisms may be used by the SSs. A comparison of these mechanisms is presented in (Chuck, 2010).

The choice of the bandwidth request and grant mechanisms has an impact directly on the scheduling delay parameter. The scheduling delay parameter corresponds to the time interval between when the bandwidth is requested and when it is allocated. The scheduling algorithms try to minimize this interval time in order to meet the time constraints of delay-sensitive applications. Moreover, because the standard gives a choice among several bandwidth request mechanisms, it is important for each scheduling mechanism solution to define its own bandwidth request strategy.

2.2 The WiMAX scheduling classes

The packets that cross the MAC layer are classified in connections. At the MAC, each connection belongs to a single service class and is associated with a set of QoS parameters that quantify its characteristics. The standard defines five QoS classes (Li et al., 2007):

- The Unsolicited Grant Service (UGS) receives unsolicited bandwidth to avoid excessive delay and has higher transmission priority among the other services. This service supports constant bit rate (CBR) or fixed throughput connections such E1/T1 lines and voice over IP (VoIP). The BS uplink scheduler offers fixed size uplink (UL) bandwidth (BW) grants on a real-time periodic basis. The QoS specifications are: Maximum sustained rate, Maximum latency tolerance, Jitter tolerance.
- The extended real-time Polling Service (ertPS) also receives unsolicited bandwidth to avoid excessive delay. However, the ertPS service can send bandwidth request messages to change the allocated resource. This service is designed to support real-time multimedia applications that generate, periodically, variable size data packets such as VoIP services with silence suppression. The BS uplink scheduler offers real-time uplink

bandwidth request opportunities on a periodic basis, similar to UGS, but the allocations are made in a dynamic form, not fixed. The QoS specifications are: Maximum sustained rate, Minimum reserved rate, Maximum latency tolerance, Jitter tolerance, Traffic priority.

- The real-time Polling Service (rtPS) uses unicast polling mechanism and receives from BS periodical grants in order to send its BW-REQ messages. This service is designed to support variable-rate services (VBR) such as MPEG video conferencing and video streaming. The BS uplink scheduler offers periodic uplink bandwidth request opportunities. The QoS specifications are: Maximum sustained rate, Minimum reserved rate, Maximum latency tolerance, Jitter tolerance and Traffic priority.
- The non-real time Polling Service (nrtPS) can use contention request opportunities or unicast request polling. However, the nrtPS connections are polled on a regular basis to assure a minimum bandwidth. So, the BS uplink scheduler provides timely uplink bandwidth request opportunities (in order of a second or less) (IEEE, 2005). This service is designed to support applications that do not have delay requirements. The QoS specifications are: Maximum sustained rate, Minimum reserved rate and Traffic priority.
- The Best Effort (BE) service can use unicast or contention request opportunities. However, the BS uplink scheduler does not specifically offer any uplink bandwidth opportunity. This service does not have any QoS requirements.

The Table 1 shows a comparison of WiMAX service classes. Adapted from (So-in et al., 2010).

Service Class	Pros	Cons
UGS	No overhead. Meets guaranteed latency for real-time service	Bandwidth may not be utilized fully since allocations are granted regardless of current need.
ertPS	Optimal latency and data overhead efficiency	Needs to use the polling mechanism (to meet the delay guarantee) and a mechanism to let the BS know when the traffic starts during the silent period.
rtPS	Optimal data transport efficiency	Requires the overhead of bandwidth request and the polling latency (to meet the delay guarantee)
nrtPS	Provides efficient service for non-real-time traffics with minimum reserved rate	N/A
BE	Provides efficient service for BE traffic	No service guarantee; some connections may starve for a long period of time.

Table 1. Comparison of WiMAX Service classes (So-in et al., 2010).

The scheduling algorithm must guarantee the QoS for both multimedia applications (real-time and non-real-time), while efficiently utilizing the available bandwidth. However, the scheduling algorithm for the service classes is not defined by the IEEE 802.16 standards.

2.3 The scheduling and the link adaptation

The design of scheduling algorithms in WiMAX networks is highly challenging because the wireless communication channel is constantly varying (Pantelidou & Ephremides, 2009). The key issue to meet the QoS requirements in the WiMAX system is to allocate the resources among the users in a fair and efficient way, especially for video and voice transmission. However, the amount of allocated resources depends on the Modulation and Coding Schemes (MCSs) used in the physical layer. The aim of the MCSs is to maximize the data rate by adjusting transmission modes to channel variations. The WiMAX supports a variety of MCSs and allows for the scheme to change on a burst-by-burst basis per link, depending on channel conditions. The Figure 2 shows the processing units at MAC and PHY (Liu et al., 2006).

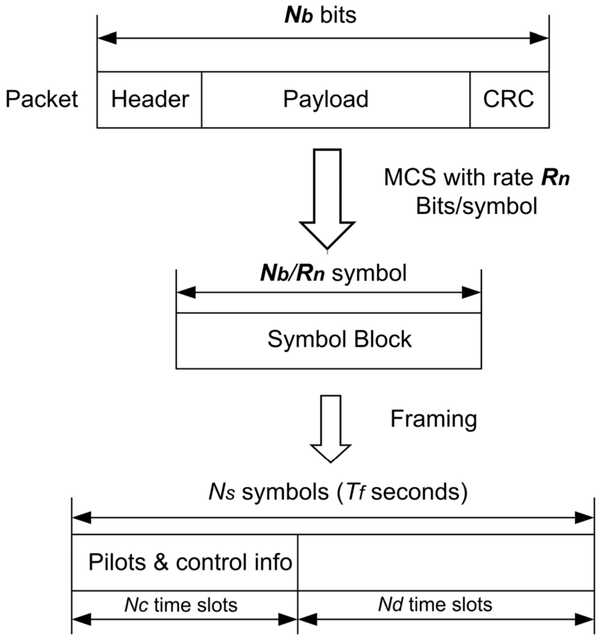

Fig. 2. Processing units at MAC and PHY (Liu et al., 2006).

The MCS is determined in accordance with the Signal-to-Noise Ratio (SNR) and depends on two values:

- The minimum entry threshold: represents the minimum SNR required to start using more efficient MCS.

- The mandatory exit threshold: represents the minimum SNR required to start using a more robust MCS.

The Table 2 shows the values of the receiver SNR assumptions which are proposed in Table 266 of IEEE 802.16e amendment of the standard (Aymen & Loutfi, 2008).

Modulation	Codification rate	SNR(dB)
BPSK	1/2	3.0
QPSK	1/2	6.0
	3/4	8.5
16QAM	1/2	11.5
	3/4	15.0
64QAM	2/3	19.0
	3/4	21.0

Table 2. Values of the SNR (Aymen & Loutfi, 2008).

The link adaptation mechanism allows the making of an adaptive modification of the burst profiles, adapting the traffic to a new radio condition. However, a new issue emerges: how to make an efficient scheduling of the SSs, located in different points away from the BS, sending data to different burst profiles, in accordance with the MCSs used for data transmission. This issue is important because the scheduler must guarantee the application's QoS requirements and allocate the resources in a fair and efficient way.

2.3.1 The WiMAX system capacity

The WiMAX system capacity determines the amount of data that can be delivered to and from the users (Dietze, 2009). There are several ways of quantifying the capacity of a wireless system. The traditional way of quantifying capacity is by calculating the data rate per unit bandwidth that can be delivered in a system. The OFDM symbol is a basic parameter used to calculate the data rate. The expression (1) is used to calculate the data rate (Nuaymi, 2007):

$$Data\,Rate = \left(\frac{Number\ of\ uncoded\ bits\ per\ OFDM\ symbol}{OFDM\ symbol\ time} \right) \tag{1}$$

$$Data\,Rate = \frac{Nsc \times d \times c}{\left[NFFT / (BW \times n) \right] \times (1+G)} \tag{2}$$

Where:

- Nsc: is the number of subcarriers used for useful data transmission. In OFDM PHY, 192 subcarriers are used for useful data transmission whereas the total number of subcarriers is equal to 256.
- d: represents the number of bits per symbol of modulation. This number depends on the MCS used.
- c: represents the code rate of the Forward Error Correction (FEC).

- NFTT : represents the total number of subcarriers. For the OFDM PHY, the total number of subcarriers is equal to 256.
- *BW*: represents the channel bandwidth;
- *n*: represents the sampling factor;
- *G*: represents the ratio of the guard time to the useful symbol time.

Given the values of BW = 7MHz, n = 8/7, d = 4 (16QAM modulation), c = 3/4 and G = 1/16, the data rate is computed as following (Nuaymi, 2007):

$$Data\,Rate = \frac{192 \times 4 \times (3/4)}{\left[NFFT/(BW \times n)\right] \times (1+G)} \tag{3}$$

$$Data\,Rate = \frac{192 \times 4 \times (3/4)}{\left[256/(7MHz \times (8/7))\right] \times (1+1/16)} = 16.94\,Mb/s \tag{4}$$

The Table 3 shows the data rates for different MCSs and G values (Nuaymi, 2007).

G Ratio	BPSK 1/2	QPSK 1/2	QPSK 3/4	16-QAM 1/2	16-QAM 3/4	64-QAM 2/3	64-QAM 3/4
1/32	2.92	5.82	8.73	11.64	17.45	23.27	26.18
1/16	2.82	5.65	8.47	11.29	16.94	22.59	25.41
1/8	2.67	5.33	8.00	10.67	16.00	21.33	24.00
1/4	2.40	4.80	7.20	9.60	14.40	19.20	21.60

Table 3. Data rates for different MCSs and G values (Nuaymi, 2007).

As it can be seen in the Table 3, the highest order modulations offer a larger throughput. However, in a practical use, not all users receive adequate signal levels to reliably decode all modulations. Users that are close to the BS are assigned with the highest order modulation, while users that are far from BS use lower order modulations for communications to ensure that the data are received and decoded correctly. This implies that the BS needs to allocate more resources for these users aiming at maintaining the same throughput as the users that use the highest order modulation. This issue must be taken into account in the scheduling development, in order to maximize the resources in a function of the number of users at the access networks and the modulation types used.

3. The WiMAX scheduling mechanisms

The scheduling mechanism plays an important role in the provisioning of QoS for the different types of multimedia applications. The WiMAX resources have to be scheduled according to the QoS requirements of the applications. Therefore, the application performance depends directly on the scheduling mechanism used. In the last few years, the scheduling mechanism research has been intensively investigated. However, recent studies show that an efficient, fair and robust scheduler for WiMAX is still an open research area, and the choice of a scheduling algorithm for WiMAX networks is still an open question. Since the scheduling is a very active field, we cannot describe all the algorithms proposed for WiMAX. However, we present a study of some proposals for WiMAX.

3.1 The WiMAX scheduling mechanisms classification

There are several proposals about WiMAX scheduling mechanisms. In a general way, these proposals can be classified in: Point-to-Multipoint (PMP) scheduling mechanisms and Mesh scheduling mechanisms. Moreover, some scheduling works are focused on downlink scheduling, others on uplink scheduling, and others on both scheduling (downlink and uplink). The Figure 3 shows the general classification of WiMAX scheduling mechanisms.

Taking into account the classification shown in the Figure 3, the scheduling mechanisms are classified in three categories (Dhrona et al., 2009):

- Homogeneous.
- Hybrid.
- Opportunistic algorithms.

The three categories of scheduling mechanisms have the same aims which are to satisfy the QoS requirements of the applications. What differs one category from the other are the characteristics of the scheduling algorithms employed in the scheduling mechanism and the number of algorithms used to ensure QoS for the service classes.

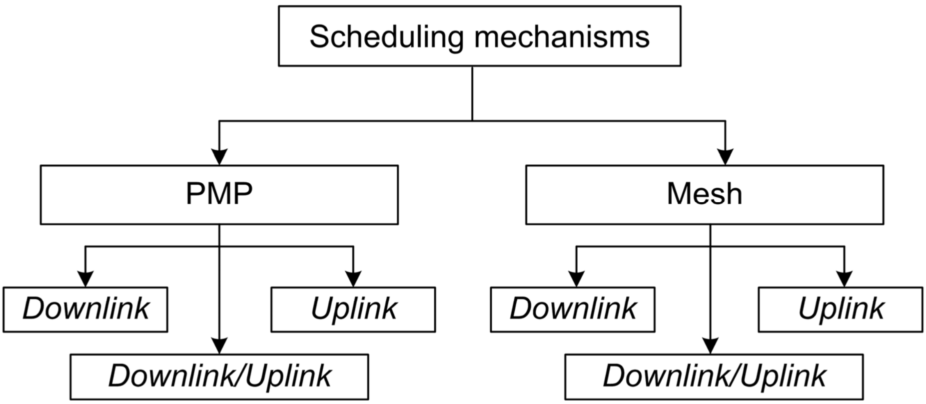

Fig. 3. General classification of WiMAX scheduling mechanisms

The homogeneous category uses scheduling algorithms which were originally proposed for wired networks, but are used in WiMAX to satisfy the QoS. Generally, these algorithms do not address the issue of link channel quality. Some examples of these algorithms are: Round Robin (RR) (Cheng, 2010), Weighted Round Robin (WRR) (Sayenko et al., 2006), Deficit Round Robin (DRR) (Shreedhar &Varghese, 1995), Earliest Deadline First (EDF) (Andrews, 2005), Weighted Fair Queuing (WFQ) (Cicconetti, 2006) etc.

The hybrid category employs multiple legacy schemes in an attempt to satisfy the QoS requirements of the multi-class traffic in WiMAX networks. Some of the algorithms in this category also address the issue of variable channel conditions in WiMAX. Some examples of these algorithms are: EDF+WFQ+FIFO (Karim et al., 2010), EDF+WFQ (Dhrona et al., 2009), adaptive bandwidth allocation (ABA) (Sheu & Huang, 2011) etc.

The opportunistic category refers to algorithms that exploit variations in channel conditions in WiMAX networks. This technique is known as cross-layer algorithms. Some examples of these algorithms are: Temporary Removal Scheduler (TRS) (Ball, 2005), Opportunistic Deficit Round Robin (O-DRR) (Rath, 2006) etc.

The authors in (So-in et al., 2010) classify the scheduling algorithms into two categories:

- Algorithms that use the physical layer.
- Algorithms that do not use the physical layer.

Furthermore, algorithms that do not use the physical layer are divided into two groups:

- Intraclass.
- Interclass.

The authors in (Msadaa et al., 2010) also classify the algorithms into three categories: algorithms based on packet queuing, algorithms based on optimization strategies and cross-layer algorithms. The scheduling strategy based on queuing packet has the same characteristics of the algorithms developed for wired networks. This category is divided into two groups: one layer structure which is shown in the Figure 4 and the multi-layer structure, illustrated in the Figure 5.

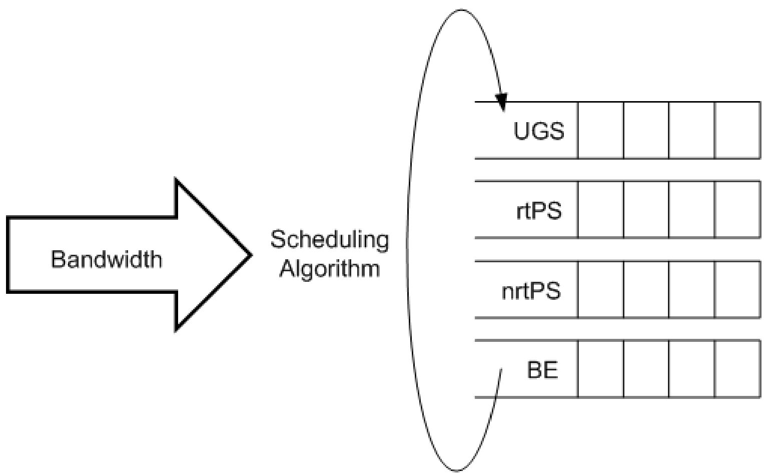

Fig. 4. One layer scheduling structure (Msadaa et al., 2010).

In the one layer scheduling structure, only a single scheduling algorithm is used for all service classes. For example, in (Sayenko et al., 2008), it was proposed that a scheduling solution based on the RR approach. In this case, the authors consider that there is very litte time to do the scheduling decisions, and a simple one-layer scheduling structure is a better solution than a multi-layer scheduling structure.

In the multi-layer scheduling structure, two or more steps are used in the scheduling which defines a multi-layer scheduling. The authors in (Wongthavarawat & Ganz, 2003) were the first to introduce this scheduling structure model. The multi-layer structure, shown in the

Figure 5, combines the strict priority policy among the service classes, and an appropriate queuing discipline for each service class.

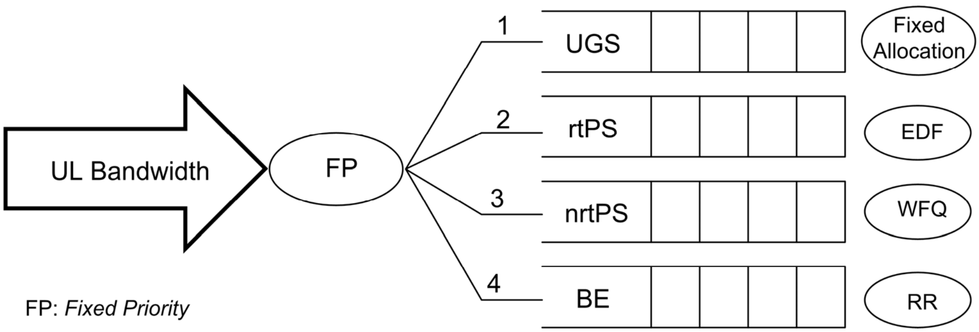

Fig. 5. Multi-layer scheduling structure (Msadaa et al., 2010).

The Table 4 summarizes the existing classification in the literature on scheduling mechanisms and exemplifies some scheduling algorithms that have been evaluated for WiMAX networks.

<table>
<tr><td rowspan="2"></td><td colspan="5">Proposes</td><td rowspan="2">Scheduling Algorithms</td></tr>
<tr><td>(Dhrona et al., 2009)</td><td colspan="2">(So-in et al., 2010)</td><td colspan="2">(Msadaa et al., 2010)</td></tr>
<tr><td rowspan="4">Classification</td><td rowspan="2">Heterogeneous</td><td rowspan="4">Channel Anware</td><td rowspan="2">Intra class</td><td rowspan="2">Packet Queuing derived strategies</td><td>One Layer structure</td><td>RR, WRR,DRR</td></tr>
<tr><td>Hierarquical structure</td><td>EDF, WFQ</td></tr>
<tr><td>Hybrid</td><td>Inter class</td><td colspan="2">Optimization based strategies</td><td>EDF +WFQ+FIFO, EDF + WFQ, WRR+RR+PR DFPQ</td></tr>
<tr><td>Opportunistic</td><td colspan="3">Cross-layer approach algorithms</td><td>TRR, O-DRR, mSIR, mmSIR</td></tr>
</table>

Table 4. Classification of scheduling mechanisms.

4. The uplink scheduling algorithms

The uplink scheduling algorithms executed at BS for uplink traffic have to make complex decisions, because it does not have queue information. So, the main focus of this section is on these scheduling algorithms. We made the choice of the main algorithms found in the literature and we distinguished them among the scheduling categories described above.

4.1 The homogeneous scheduling algorithms

Some homogeneous scheduling algorithms are based on the RR scheduler. The RR scheduler is the simplest algorithm that distributes the equal bandwidth to the SSs. However, it does not support the QoS requirements for different traffic classes, such as delay and jitter. In order to improve the RR algorithm for WiMAX systems, some proposes based on RR scheduler were made and they can be found in the literature.

4.1.1 Weighted Round Robin (WRR) scheduling

The WRR scheduling is an extension of RR scheduling. This algorithm has been implemented and evaluated in (Dhrona et al., 2009). The algorithm is executed at the beginning of every frame at the BS. At this moment, the WRR algorithm determines the allocation of bandwidth among the SSs based on their weights. So, the authors assign weight to each SS with respect to its Minimum Reserved Traffic Rate (MRTR) as follows:

$$Wi = MRTRi \Bigg/ \sum_{j=1}^{n} MRTRj \qquad (5)$$

where Wi is the weight of SSi and n the number of SSs.

4.1.1.1 Performance evaluation

The WRR algorithm was evaluated by means of simulation study described in the reference (Dhrona et al., 2009). The main parameters used were: OFDM PHY layer, symbol duration time of 12.5 µs and the channel bandwidth of 20 MHz. The authors have observed that the WRR algorithm does not perform well when the traffic contains variable sized packets. The algorithm will not provide a good performance in the presence of variable size packets.

4.1.2 Deficit Round Robin (DRR) scheduler

This algorithm is a variation of RR. A fixed quantum (Q) of service is assigned to each SS flow (i). When an SS is not able to send a packet, the remainder quantum is stored in a deficit counter (DC_i). The value of the deficit counter is added to the quantum in the following round. When the length of the packet (L_i) waiting to be sent is less than the deficit counter DC_i the head of the queue (Q_i) is dequeued and the value of the (DC_i) is decremented by L_i. The algorithm is flexible enough as it allows provision of quantum of different sizes depending on the QoS requirements of the SSs. However, the DRR algorithm requires accurate knowledge of packet size (L_i), very complex in its implementation.

4.1.3 Earliest Deadline First (EDF)

The EDF was originally proposed for real-time applications in wide area networks (Khan et al., 2010). This algorithm assigns a deadline to each packet and allocates bandwidth to the SS that has the packet with the earliest deadline (Hussain et al., 2009). The deadlines can be assigned to the packets of the SSs based on the SS's maximum delay requirement. Since each SS specifies a value for the maximum latency parameter, the arrival time of a packet is added to the latency to form the tag of the packet. The EDF algorithm is suitable for SSs belonging to the UGS and rtPS scheduling services.

4.1.4 Performance evaluation of DRR and EDF algorithms

The performance of the DRR and EDF algorithm were evaluated in (Karim et al., 2010). However, the authors consider only the downlink resource allocation. The simulation configuration and the parameters follow the performance evaluation parameters specified in Mobile WiMAX systems Evaluation Document and WiMAX Profile. The results showed that the EDF algorithm introduces unfairness when a under loaded. The DRR algorithm is fair and gives a better performance than EDF algorithm.

4.1.5 Weighted Fair Queuing (WFQ) scheduler

The WFQ scheduler assigns finish times to the packets. So, the packets are selected in increasing order according to their finish times. The finish times of the SS packets are calculated based on the size of the packets and the weight assigned to the SS. The WFQ was also evaluated in (Dhrona et al., 2009). The algorithm results in superior performance as compared to the WRR algorithm in the presence of variable size packets. However, the disadvantage of the WFQ algorithm is that it does not consider the start time of a packet.

4.2 Heterogeneous and opportunistic scheduling algorithms

The heterogeneous scheduling algorithm category is used as the combination of legacy scheduling algorithms. An important aspect of heterogeneous algorithms is the allocation of bandwidth among the traffic classes of WiMAX. Some of the algorithms in this category also address the issue of variable channel conditions in WiMAX.

4.2.1 Adaptive Bandwidth Allocation (ABA)

An adaptive bandwidth allocation (ABA) model for multiple traffic classes was proposed in (Sheu & Huang, 2011). In order to promise the quality of real-time traffic and allow more transmission opportunity for other traffic types, the ABA algorithm first serves the UGS connections. Then, polling bandwidth is allocated for rtPS service to meet their delay constraints and for the nrtPS to meet their minimum throughput requirements. For the BE service, the ABA algorithm will prevent it from starvation. The ABA algorithm assigns initial bandwidth, UGS, rtPS, nrtPS and BE, based on the requested bandwidth of UGS, the required minimum bandwidth of rtPS and nrtPS and the queue length of BE service respectively. If remaining bandwidth exists, the ABA then assigns extra bandwidth for the rtPS, nrtPS and BE services.

4.2.1.1 Performance evaluation

The analytical results of the ABA algorithm were obtained by running on the MATLAB software. These results were validated through the simulator developed by the authors written in Visual C/C++. The results showed that the ABA algorithm meet the delay constraints of rtPS and the minimum throughput requirements of nrtPS, while it endeavors to avoid any possible starvation of BE traffic.

4.2.2 EDF, WFQ and FIFO scheduling algorithms

The authors in (Karim et al., 2010) have combined three scheduling algorithms. It is used the strict priority mechanism for overall bandwidth allocation. The EDF scheduling algorithm is used for SSs of ertPS and rtPS classes. The WFQ algorithm is used for SSs of nrtPS class and FIFO is used for SSs of BE class. The bandwidth distribution among the traffic classes is executed at the beginning of every frame whereas the EDF, WFQ and FIFO algorithms are executed at the arrival of every packet. This algorithm was evaluated in (Sayenko et al., 2008). A drawback of this algorithm is that lower priority SSs will essentially starve in the presence of a large number of higher priority SSs due to the strict priority of overall bandwidth allocation.

4.2.3 EDF and WFQ

It was proposed in (Dhrona et al., 2009) a hybrid algorithm that uses the EDF scheduling algorithm for SSs of ertPS and rtPS classes and WFQ algorithm for SSs of nrtPS and BE classes. Although the details of overall bandwidth allocation are not specified, it is not done in a strict priority manner, but a fair manner is used to allocate the bandwidth among the classes. At the arrival of every packet the EDF and WFQ algorithms are executed.

4.2.3.1 Performance Evaluation of (EDF+WFQ+FIFO) and (EDF+WFQ) scheduling algorithms

The performance analysis of the scheduling scheme above described is performed by simulations (Dhrona et al., 2009). The main parameters of the simulation are the following: the air interface is WirelessMAN-OFDM, the channel bandwidth is 20 MHz, the OFDM symbol duration is 12.5 μs.

- EDF+WFQ+FIFO: This solution shows superior performance for SSs of ertPS classes in relation to average throughput, average delay and packet loss when the concentration of real-time traffic is high.
- EDF+WFQ: This algorithm is limited by the allocation of bandwidth among the traffic classes.

4.2.4 EDF and Connection Admission Control (CAC) scheme

A scheduling scheme which combines the CAC mechanism and the EDF algorithm was proposed in (Wu, 2010). This solution aims at the scheduling of rtPS class and uses the EDF algorithm to reduce the average latency. The Figure 6 shows the flowchart about the scheduling scheme.

In the proposed scheduling solution, the BS verifies if the requested service is rtPS class or not, when an SS asks the BS for a connection request. If the connection request is the rtPS, the CAC will judge if the connection can be admitted or not. The connection request will be admitted if the sum of available bandwidth and the collected bandwidth from BE service is greater than the Maximum Sustained Traffic Rate (MSTR) of rtPS class. In this case, the Minimum Reserved Traffic Rate (MRTR) will be taken into account to determine if the request can be admitted. Once admitted the rtPS connection, the BS will schedule the rtPS service class according to the EDF algorithm.

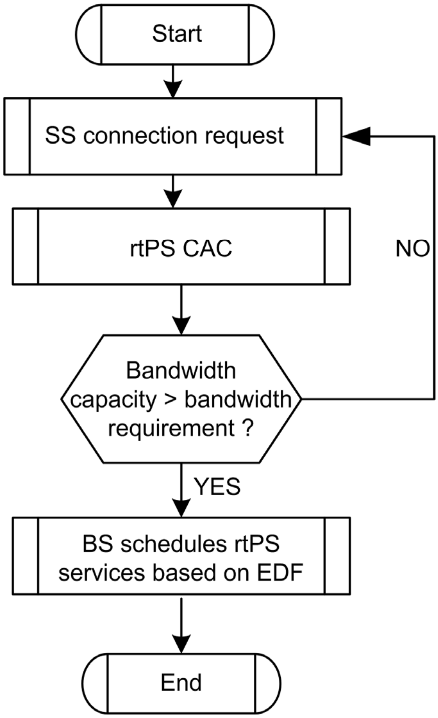

Fig. 6. Flowchart of the scheduling algorithm (Wu, 2010).

4.2.4.1 Performance evaluation

The performance analysis of the scheduling scheme above described is performed by simulations. The main parameters of the simulation are the following: the PHY layer is OFDM, the MCS is 64QAM 3/4, and the frame duration is 5 ms. The compared performance metrics are latency, jitter, throughput and the rate of packet loss. The results showed that the scheduling scheme can reduce the average latency and achieve the QoS.

4.3 Cross layer approach algorithms

4.3.1 Temporary Removal Scheduler (TRS)

The TRS scheduler makes the scheduling list in accordance with the SSs that have Signal Interference Ratio (SIR) greater than a preset threshold (Ball, 2005). When the radio conditions are poor then the scheduler suspends the packet call from the scheduling list for an adjustable time period *Tr*. The scheduling list contains all the SSs that can be served at the next frame. When the *Tr* expires, the suspended packet is checked again, and if the radio conditions are still poor the packet is suspended for another time period *Tr*. This process is repeated *L* times, where *L* is equal to consecutive suspend procedure. The TRS scheduler can be combined with the Round Robin (RR) and maximum Signal to Interface Ratio (mSIR) schedulers. When TRS is combined with RR the whole radio resources are divided by the number of subscribers in the list, and all the subscribers will get resources equitably.

4.3.2 UAF WiMAX scheduler

The UAF_WiMAX scheduler was developed in (Khan et al., 2010). The scheduler serves the SSs with minimum signal to interface ratio, taking into account the already allocated resources to the SSs which have greater signal to interface ratio. When the BS provides periodical unicast request polling to the subscribers, the subscribers respond with their required bandwidth request that is equal to its uplink data connection queue. The UAF_WiMAX scheduler first chains the SSs in the scheduling list that have bandwidth request. The UAF_WiMAX scheduler identifies the SSs packets call-power depending upon the radio conditions.

4.3.3 Performance evaluation of the UAF and TRS schedulers

The UAF scheduler was evaluated by means of simulation study, and the results were compared with the TRS scheduling algorithm (Khan et al., 2010). The main parameters used were: OFDM PHY layer, channel bandwidth is 5MHz, the frame duration is 20 ms, and the MCSs used are 64QAM 3/4, 64QAM 2/3, 16QAM 3/4, 16QAM 1/2, QPSK 3/4, QPSK 1/2.The results showed that the UAF_WiMAX scheduler has less mean sojourn time when compared to TRS combined with mSIR scheduler. The UAF scheduler serves the SSs with the minimum signal to interface ration when it already has resources to the SSs having a greater signal to interface ratio.

4.3.4 maximum Signal-to-Interference Ratio (mSIR)

The authors in (Belghith et al., 2010) make a comparison of WiMAX scheduling algorithms and propose an enhancement of the maximum Signal-to-Interference Ratio (mSIR) scheduler, called modified maximum Signal-to-Interference Ratio (mmSIR) scheduler. The mSIR scheduler serves those SSs having the highest Signal-to-Interference Ratio (SIR) at each frame. However, SSs having slightly smaller SIR may not be served and then the average delay to deliver data increases. To solve this problem, the authors proposed a solution where the BS only serves the SSs that do not have unicast request opportunities in the same frame.

4.3.4.1 Performance evaluation

The mSIR scheduler was evaluated by means of simulation study in (Belghith et al., 2010), where three scenarios were used: pessimistic, optimistic and realistic. In the pessimistic scenario, bad radio conditions are considered. All SSs use the most robust MCS (BPSK 1/2). In the optimistic scenario, ideal radio conditions are considered. All the SSs use the most efficient MCS (64QAM 3/4). In the realistic scenario, random radio conditions are considered. Hence, the SSs may have different MCSs (64QAM 3/4, 64QAM 2/3, 16QAM 3/4, 16QAM 1/2, QPSK 3/4, QPSK 1/2). The air interface is OFDM and the channel bandwidth is 7 MHz. The mmSIR scheduler was compared with two schedulers: RR and Prorate. The mmSIR had good spectrum efficiency in all scenarios.

4.3.5 Adaptive scheduler algorithm

An adaptive scheduling packets algorithm for the uplink traffic in WiMAX networks is proposed in (Teixeira & Guardieiro, 2010). The proposed algorithm is designed to be

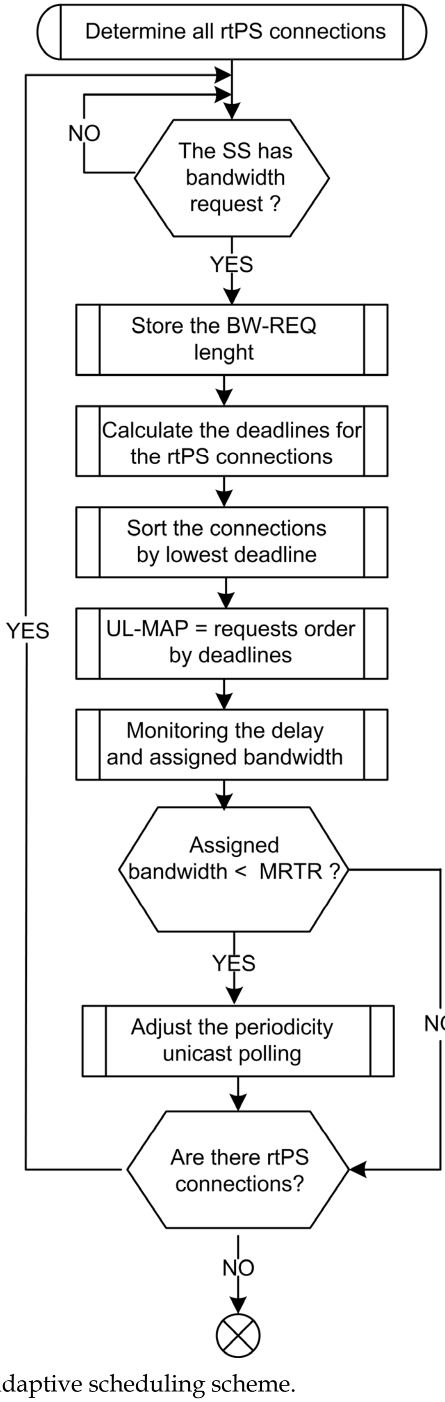

Fig. 7. Flowchart of the adaptive scheduling scheme.

completely dynamic, mainly in networks that use various MCSs. Moreover, a method which interacts with the polling mechanisms of the BS was developed. This method controls the periodicity of sending unicast polling to the real-time and non-real-time service classes, in accordance with the QoS requirements of the applications. The Figure 7 shows a flowchart of the adaptive scheduling scheme.

The scheduler monitors the average delay of the rtPS service and the minimal bandwidth assiged to the rtPS and nrtPS service classes. The limited maximum delay is guaranteed for the rtPS service through the use of a new deadlines based scheme. The deadlines calculation is made by using the following parameters: the information about the MCSs used for the sending packets between the SS and the BS; the information about the bandwidth request messages sent by the SSs; and the queuing delay of each bandwidth request message in the BS queue. Once the deadlines are calculated, they are assigned to the rtPS connections. Thus, the scheduler defines the transmission order of the rtPS connections based on the lowest deadline. Moreover, the scheduler also ensures the minimal bandwidth for rtPS and nrtPS services in accordance with the minimum bandwidth requirement per connection, the amount of bytes received in a current period, and the amount of backlogged requests (in bytes).

4.3.5.1 Performance evaluation

The adaptive scheduling algorithm was evaluated by means of modeling and simulation in environments where various MCSs were used and also in environments where only one type of MCS was used. The main parameters of the simulation are the following: OFDM PHY layer, frame duration is 20 ms, MCSs used are 64QAM 3/4, 64QAM 2/3, 16QAM 3/4, 16QAM 1/2, QPSK 3/4, QPSK 1/2. The performance of the adaptive scheduling algorithm was compared with RR and WRR algorithms in (Teixeira & Guardieiro, 2010), where it showed a better performance.

5. A synthesis of scheduling mechanisms

The goals of the scheduling mechanisms are basically to meet QoS guarantees for all service class, to maximize the throughput, to maintain fairness, to have less complexity and to ensure the system scalability. There are several scheduling mechanisms in the literature, however, each one with its own characteristics.

The homogenous and hybrid scheduling mechanisms do not explicitly consider all the required QoS parameters of the traffic classes in WiMAX. The algorithms consider only some of the parameters which are not sufficient since the scheduling classes have multiple QoS parameters such as the rtPS class that requires delay, packet loss and throughput guarantee. The WRR, WFQ and hybrid (EDF+WFQ) algorithms provide a more fair distribution of bandwidth among the SSs. The WFQ and WRR algorithms attempt to satisfy the minimum reserved traffic rate (MRTR) of the SSs by assigning weights to the SSs based on their MRTR. The worst case delay bound guaranteed by the WFQ algorithm can be sufficient for the UGS connections but not for ertPS and rtPS connections.

The algorithms such as EDF and hybrid (EDF+WFQ+FIFO) indicate superior performance for SSs of ertPS and rtPS classes with respect to average throughput, average delay and packet loss when the concentration of real-time traffic is high. However, these algorithms will also result in starvation of SSs of nrtPS and BE classes.

The cross-layer algorithm takes into account some QoS requirements of the multi-class traffic in WiMAX such as the average delay, average throughput and the channel quality. The mSIR scheduler serves those SSs having the highest SIR at each frame. However, SSs having slightly smaller SIR may not be served and then the average delay to deliver data

Scheduling Mechanisms	Possibility of use for WiMAX	DL	UL	Comments	Algorithm parameters
WRR	Yes	Yes	Yes	Not provide good performance in the presence of variable size packets.	Static weights.
DRR	Yes	Yes	No	Requires accurate knowledge of packet size, being very complex in its implementation.	Fixed quantum.
EDF	Yes	Yes	Yes	Allocates bandwidth to the SS that has the packet with the earliest deadline. Needs to know the arrival time of the packets.	Dealines (can be the arrival time – send time of the packets in some cases).
ABA	Yes	Yes		Initially assigns bandwidth for UGS, rtPS, nrtPS and BE serice classes based. If remaining bandwidth exists, the ABA then assigns extra bandwidth for the rtPS, nrtPS and BE services.	UGS bandwidth requirement.
EDF, WFQ, FIFO	Yes	Yes	Yes	SSs with lower priority will starve in the presence of a large number of higher priority SSs due to the strict priority.	Weights for WFQ, Deadlines for EDF.
WFQ, EDF	Yes	Yes	Yes	Limited by the allocation of bandwidth among the traffic classes.	Weights for WFQ, deadlines for EDF.
EDF + CAC	Yes	Yes	Yes	Can reduce the average latency and achieve the QoS.	MRTR, deadline.

Table 5a. Synthesis of some scheduling mechanisms.

Scheduling Mechanisms	Possibility of use for WiMAX	DL	UL	Comments	Algorithm parameters
TRF	Yes	Yes	Yes	The scheduler makes the scheduling list in accordance with the subscribers that have SIR greater than a preset threshold.	Removal time (Tr).
UAF	Yes	Yes	Yes	Serves the SSs with minimum signal to interface ratio, taking into account the already allocated resources to the SSs which have greater signal to interface ratio.	SIR.
mSIR	No	Yes	Yes	SSs having a poor SIR may be scheduled after an excessive delay	SIR.
Adaptive Scheduler	Yes	Yes	Yes	Controls the periodicity of sending unicast polling to the real-time and non-real-time service classes, in accordance with the Quality of Service requirements.	Polling interval, SIR, MCS.

Table 5b. Synthesis of some scheduling mechanisms.

increases. The cross-layer algorithms do not exploit all characteristics of WiMAX system. On the other hand, the optimization scheduler mechanisms take into account the characteristics of WiMAX system, for example, polling mechanism, backoff optimization, overhead optimization and so on. For example, the adaptive scheduler uses a cross-layer approach where it makes the scheduling in accordance with the MCSs and interacts with the polling mechanisms of the BS. Scheduling mechanisms, cross-layer and optimization mechanisms are still an open ongoing research topic. The Tables 5a and 5b show a synthesis of deployment of some important scheduling mechanisms.

6. Conclusion

In this chapter, we present the state of the art of WiMAX scheduling mechanisms. Firstly, we we present the features of the WiMAX MAC layer and of the WiMAX scheduling classes. The main components of MAC layer are also presented. After that, we present the key issues and challenges existing in the development of scheduling mechanisms. A classification of the scheduling mechanisms was also made. So, we present a synthesis table of the scheduling mechanisms performance where we highlight the main points of each of them. All the proposed WiMAX algorithms could not be studied in this chapter, but we have shown some relevant proposals.

The adaptive scheduling algorithm proposed in (Teixeira & Guardieiro, 2010) makes the scheduling in accordance with the MCSs and interacts with the polling mechanisms of the BS. Its evaluation shows a good performance in the realistic and optimistic scenarios. The mSIR and mmSIR scheduling algorithms were evaluated in (Belghith et al., 2010) and show good spectrum efficiency in the realistic scenarios where random radio conditions are considered. The scheduling algorithms such as WRR, WFQ and EDF+WFQ were evaluated in (Dhrona et al., 2009) and show a fair distribution of bandwidth among the SSs. However, the performance evaluation of these algorithms was made considering only the optimistic scenarios.

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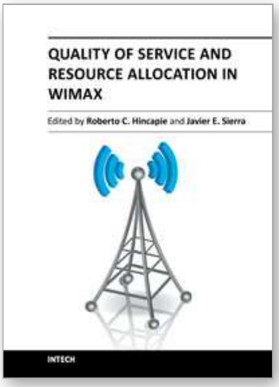

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This book has been prepared to present state of the art on WiMAX Technology. It has been constructed with the support of many researchers around the world, working on resource allocation, quality of service and WiMAX applications. Such many different works on WiMAX, show the great worldwide importance of WiMAX as a wireless broadband access technology. This book is intended for readers interested in resource allocation and quality of service in wireless environments, which is known to be a complex problem. All chapters include both theoretical and technical information, which provides an in depth review of the most recent advances in the field for engineers and researchers, and other readers interested in WiMAX.

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