A Comprehensive survey of Downlink Scheduling Algorithms in WiMAX

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Abstract: ***WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunication technology that offers an internet access through the transmission of wireless data as Wi Fi or other broadband providing techniques, but with higher speed and an alternative to wired broadband like cable, modem and DSL and support real time and non-real time services with high QOS (Quality of Service). The high QOS loads a big challenge on resources allocation to accommodate large number of users demanding several services with different QOS competing for limited capacity in the network. The high QOS is supported by scheduling mechanism. The standard leaves the details of scheduling different services with their QOS as an open issue for researchers and manufacturers to implement. Therefore number of algorithms downlink and uplink has been proposed. This paper provides a comprehensive survey of downlink scheduling algorithms, their aspects, methodology strength and limitations.***

Keywords: WiMAX, IEEE802.16, QOS, Downlink scheduling.

1. Introduction

WiMAX (Worldwide Interoperability for Microwave Access), an IEEE802.16 based standard [1], offers an internet access by transmitting wireless data or services at high speed via number of transmission methods. The WiMAX based networks consists of a base stations (BS) that allocates resources to the number of users called subscriber stations (SS) to fulfill their demands for different services with their QOS (Quality of Service). WiMAX provides broadband wireless access (BWA) to the users that enables variety of application for real-time (audio, video) and non-real-time (video streaming etc.) data services, which varies in their QOS requirement such as throughput, delay and jitter. In order to support various QOS requirements, five scheduling services, UGS, real time polling service (rtPS), extended real time polling service (ertPS) , non-real time polling service (nrtPS) and best effort (BE) were defined. Each scheduling class has different QOS requirements (maximum sustained traffic rate, minimum reserved traffic rate, maximum latency etc.) and is treated separately by its BS. The need for QOS increases when number of users demanding services, compete for limited capacity on the transmission media or in a network. To resolve this, scheduling procedures are required to determine the priority of users to use the limited resource and managing the bandwidth allocation among the users in a best manner [2]. So different scheduling algorithms, uplink (SS to BS) and downlink (BS to SS) are designed to describe the scheduling procedures.

The paper studies downlink scheduling (scheduling in a WiMAX BS), for this different downlink scheduling algorithms are discussed. The rest of the paper is organized as follows: section II presents the WiMAX standard concepts followed by different scheduling concepts, in section III existing scheduling mechanisms are discussed, section IV discusses the existing downlink scheduling algorithms, their aspects, methodology, advantages and limitations are presented in section V, the conclusion along with future scope are discussed in section VI.

2. WiMAX Standard Concepts

Worldwide Interoperability for Microwave Access, WiMAX has become the alternative of fourth generation 4G mobile broadband networks due to its availability of providing technological advances to mobile broadband services demand of their users. IEEE802.16 WiMAX operates in two modes: point to multipoint (PMP) and mesh mode. In PMP SS transmits and receive resources through BS. In mesh mode, the communication is directly between the two or more SS independently. The standard does not mention any transmission scheduling for BS in PMP mode [3]. The focus of the paper is on PMP systems. The standard includes the physical layer and medium access (MAC) layer.

A. Physical and MAC layers

The physical layer of WiMAX operates at both 10.66 GHz and 2-11 GHz [2] with high data rates that depend on bandwidth and modulation technique. The radio interface of 802.16 adopts OFDM (Orthogonal Frequency Division Multiplexing), a multicarrier modulation achieved by TDD (Time Division Duplex) and FDD (Frequency Division Duplex), in which high frequency streams are divided into small sub streams, each modulated on a separate carrier and allows the resource allocation on frame by frame basis [3].

Now the bandwidth is a scarce resource, so scheduling procedures are required to decide what time slot should be allocated for each SS for proper utilization of network resource. For this, MAC layer defines five scheduling services mentioned in introduction [4]. MAC classifies the data services on real time and non-real time basis and supports the QOS attached to these services by associating each service with following service flow (scheduling classes/services) in table 1.

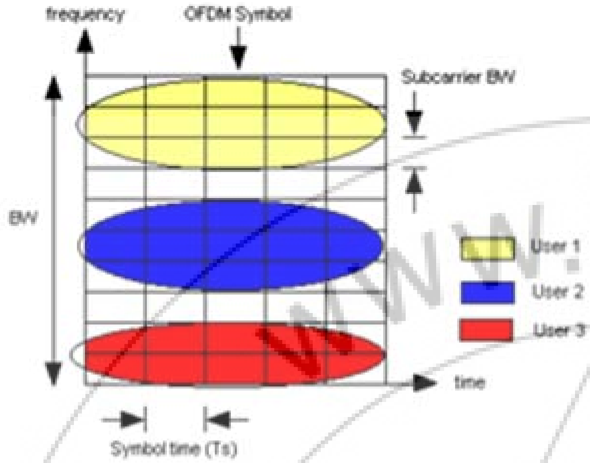

Figure 1: OFDM

Table 1: Scheduling Services

Services	Specification	Application	QOS Specification
Unsolicited Grant Services UGS	Designed to support Real time applications that generates fixed size data packets at periodic intervals.	VOIP	Maximum sustained rate Maximum latency toleranc Jitter tolerance
Real time Polling Service RtPS	Designed to support real time applications that generates variable size data packets	Audio and video streaming	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Traffic priority
Extended real time Polling Service ErtPS	Combines the advantages of UGS and rtPS	Voice with silence suppression	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Jitter tolerance Traffic priority
Non Real time Polling Service NrtPS	Designed to support non real time applications that generates variable size data	File transfer protocol	Minimum reserved rate Maximum sustained rate Traffic priority
Best Effort BE	Designed to support data streams for which no minimum service level is required	Data transfer, web browsing etc	Maximum sustained rate Traffic priority

A Service flow (SF) is a unidirectional traffic connection that offers a particular QOS level as described by the service class (UGS, rtPS, ertPS, nrtPS and BE). A unique Connection Identifier (CID) describes the SF in a network [5].

B. Downlink Scheduling

In PMP mode, BS has to schedule packets (resource) in uplink (UL) and downlink (DL) to obtain efficient transmission quality. The BS traffic is expected to be very high during DL compared to UL [6] and it needs to relay packets as soon as possible to avoid overflows and ensuring QOS requirements. Hence, an efficient downlink scheduling scheme for BS is essential. In downlink scheduling, the BS has complete information of all downlink queues (no. of packets and packet size, QOS parameter, amount of BW required). The BS distributes the entire BW among all the downlink users.

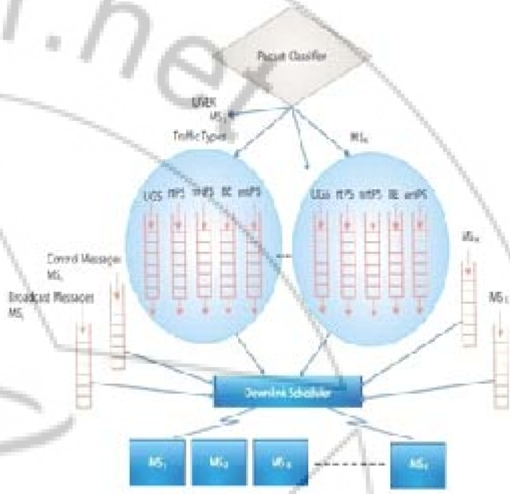

Figure 2: Downlink Scheduling

3. Scheduling Mechanisms

Scheduling mechanism refers to the ways on which the schedulers (algorithms which performs scheduling) are made. The literature reveals that the schedulers can be classified into following categories in table 2, [7].

1. Channel Unaware Scheduling Algorithms
   1.1 Homogeneous
   1.2 Heterogeneous
2. Channel Aware Scheduling Algorithms
   2.1 Opportunistic/Cross Layer
   2.2 Queue Aware
   2.3 Queue Unaware

4. Schedulers

A scheduling mechanism needs to consider the allocations logically and physically. Logically, the scheduler should calculate the number of slots based on QOS service classes. Physically, the scheduler needs to select which sub channels and time intervals are suitable for each user. The goal is to minimize power consumption, to minimize bit error rate and to maximize the total throughput. So, several downlink scheduling algorithms have been proposed in literature, some of them are discussed below.

A. Non Channel Aware Homogeneous Algorithms

i. WRR (Weighted Round Robin)

Table 2: Scheduling Mechanism

Mechanism	Description
Homogeneous	Schemes that have considered the usage of one type of algorithm to all the traffic class of WiMAX
Heterogeneous / Hybrid	Schemes that combine more than one algorithms for different traffic class
Opportunistic	Cross layer approach algorithms, use of two layers (physical and MAC)
Channel Aware	Channel state information (CSI) is considered in making scheduling decisions
Non- Channel Aware	Channel state information is not considered
Queue Aware	Queue state information (for example queue length) is considered in making bandwidth allocation decisions
Non- Queue Aware	Queue state information not considered

According to WRR, packets are categorized into different service classes and then assigned to a queue that can be assigned various percentage of bandwidth and served based on Round Robin order. WRR is proposed for meeting the throughput guarantee by that the weight can be dynamically adjusted. WRR has been adapted for WiMAX scheduling in [8], [9], [10] as the downlink scheduler at BS in order to schedule the downlink traffic.

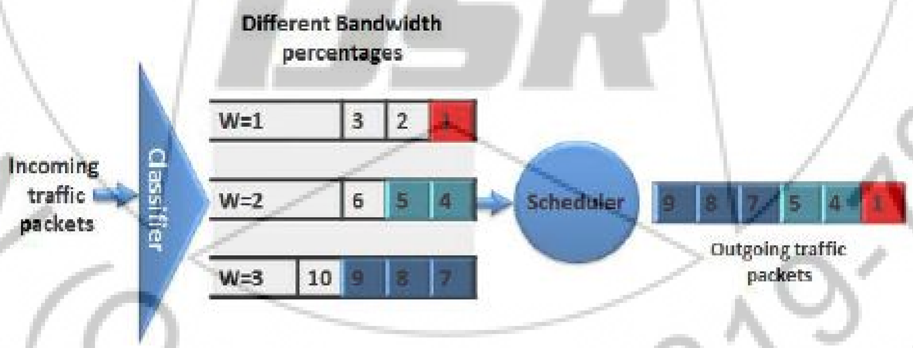

Figure 3: WRR as in [8]

ii. DRR (Deficit Round Robin)

This algorithm is a variation of RR (Round Robin). A fixed quantum of service is assigned to each SS flow. When an SS is not able to send a packet due to less available bandwidth, the remainder quantum is stored in a deficit counter. The value of deficit counter is added to the quantum in the following round. When the length of the packet waiting to be sent is less than the deficit counter, the head of the queue is de-queued and the value of deficit counter is decremented.

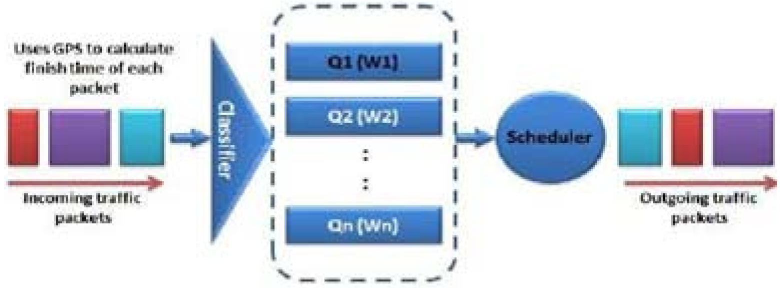

Figure 4: DRR as in [11]

DRR [11] can be used for variable length packets. DRR and WRR algorithms have been considered to be applied in WiMAX and have been evaluated in [12] the focus was to provide a connection with the minimum guaranteed rate.

iii. EDF (Earliest Deadline First)

EDF has been used in [13] to guarantee the delay requirements, and has been used for bandwidth allocation within rtPS connections in [14] by which packets with earliest deadline are scheduled first. The simulation result in [15] showed that EDF scheme is given more priority to streams with more crucial deadline requirements (for example, in real time traffic), while downgrades the quality of non-real time traffic.

iv. WFQ (Weighted Fair Queue)

The WFQ scheduler assigns different weights to SS according to the bandwidth requirements by using the theoretical approach of generalized processor sharing (GPS) that estimates and assigns finish time to each packet. So, the packets are selected in increasing order of their finish times. The WFQ was evaluated in [16]. The algorithm results were in superior performance as compare 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. The authors in [15] concluded that WFQ is suitable when fairness has to be strictly exercised among the various service flows.

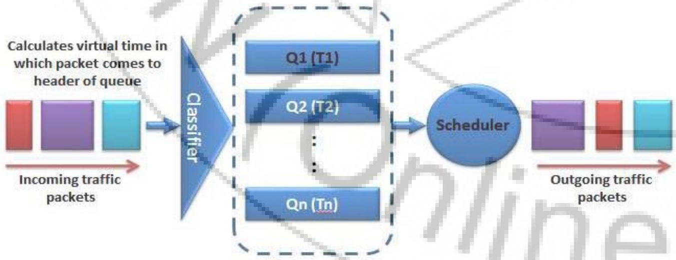

Figure 5: WFQ as in [16]

B. Non Channel Aware Heterogeneous Scheduling Algorithms

EDF + WFQ

It was proposed in [16] a hybrid algorithm that uses the EDF for SS of ertPS and rtPS classes and WFQ for SS of nrtPS and BE. This algorithm is limited by the allocation of bandwidth among the traffic classes.

SP + APF + PF

In [17], the authors proposed a QOS priority and fairness scheduling scheme for downlink traffic which guarantees the delay requirement of UGS, ertPS and rtPS service classes. The proposed mechanism is a two-level scheduling scheme that intends to maximize the BE traffic throughput. Firstly, a strict priority (SP) between service classes is adapted in the first level as UGS > ertPS > rtPS > NrtPS > BE. Secondly, a fixed size data is granted periodically for UGS service class, an adaptive Proportional Fairness (APF) scheduling is applied for both rtPS and ertPS service classes and a Proportional Fairness (PF) scheduling is used for nrtPS and BE service classes.

DFPQ (Deficit Fair Priority Queue)

The priority order may starve some connection of lower classes. In [18], a Deficit Fair Priority queue (DFPQ) is introduced in order to reduce the problem of lower priority class starvation. A DFPQ is deployed in the first layer with counter to serve different types of service flows in both uplink and downlink. The counter is deceases according to the size of the packets. The scheduler moves to the next class when the counter returns to zero. Three different scheduling algorithms are used for each traffic class. WFQ for nrtPS and RR for BE. A DFPQ is better than strict priority scheduling in order to achieve the fairness among classes.

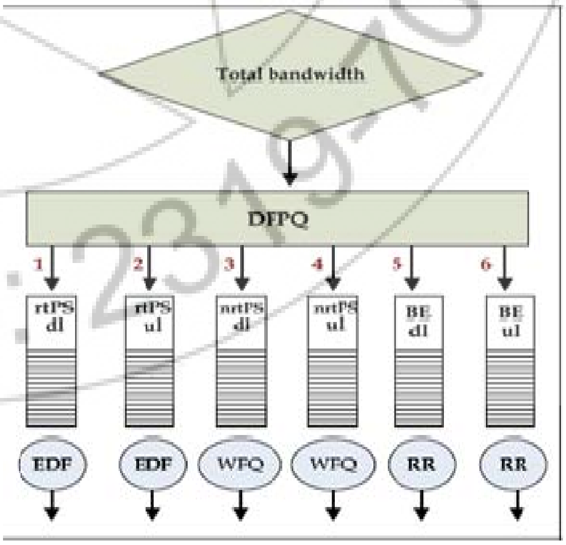

Figure 6: DFPQ as in [18]

C. Channel Aware Scheduling Algorithm

It has been proved that the scheduling algorithm that considered the channel state information (CSI) performs better than the algorithm that does not consider the CSI [19].

i. TRS: Temporary Removal Scheduler

The TRS scheduler makes the scheduling list in accordance with the SSs that have Signal Interference Ratio (SIR) greater than a preset threshold [20]. When the radio conditions are poor then the scheduler suspends the packet call from the scheduling list for an adjustable time period. The scheduling list contains all the SSs that can be served at the next frame. When the expires, the suspended packet is checked again and if the radio conditions are still poor the packet is suspended for another time period. This process is repeated times, where is equal to consecutive suspend procedure. The TRS scheduler can be combined with Round Robin (RR) and maximum Signal to Interference Ratio schedulers. When TRS is combined with RR the whole radio resources are divided by the numbers of subscribers in the list and the entire subscriber will get resources equitably.

ii. A Queue and channel Aware Downlink Scheduler

[21] designs a queue and channel aware downlink scheduler (priority based) algorithm for WiMAX, where all of the QOS metrics, such as channel, queue, non-urgent and urgent data status are translated to priority metric by a black-box formula in the study, but is not fair to all users, as there is no channel quality information (CQI) reporting metrics.

iii. Cross layer downlink scheduler

[22] works on a cross layer scheduler that assigns priority for each flow based on its service and channel status, then the flow with highest priority is scheduled, it only give precedence to good channel flow and thus bad channel flow suffers. In [22], the author proposed cross layer downlink scheduler at the MAC layer with the physical (PHY) layer, by which each downlink connection utilize Adaptive Modulation and Coding scheme at the PHY layer based on the estimated channel condition of a SS. A connection is assigned priority based on its channel quality and service priority where the scheduler schedules the connection with the highest priority each time.

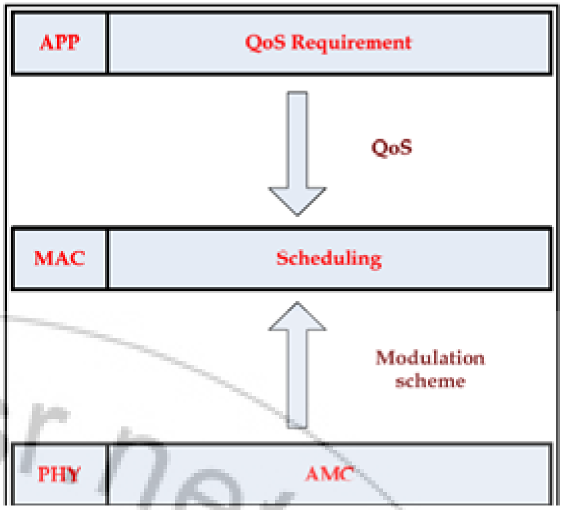

Figure 7: Cross Layer

iv. Modified Largest Weighted Delay First (MLWDF)

[23] Has been proposed to support specific QOS parameters such as provide packet delay and minimum throughput guarantee for various users sharing a wireless channel. This has been achieved by maintaining the data packet delays below a specific threshold. MLWDF scheduler has utilized both current channel state conditions and the state of the queue (queue length) in making the scheduling decision.

D. Weight and priority Calculations

As discussed in above section of algorithms, the main aim of scheduler is to decide the priority of users to decide the order of servicing them. This order is commonly calculated by weight and priority procedures. Following are some of the factors that can be used in the weight and priority based schemes.

Weight factors: (1) queue length and packet delay, (2) the number of slots, (3) size of bandwidth request, (4) average data rate, or (5) minimum reserved rate.

Priority factors: (1) priority service order (UGS > ertPS > rtPS > nrtPS > BE) from higher priority to lower priority service order respectively, (2) packets delay (highest priority assigned to packets with largest delay), (3) the queue length (more bandwidth to connections with longer queue length), (4) based on SS channel quality.

5. State-of-Art-of Schedulers

Table 3: State-of-Art-of Schedulers

Scheduling Algorithm	Properties	Limitations
WRR	Suitable for non-real time applications	Does not perform well in variable packet size
EDF	Focusing on efficiency	Unfit for non-real time applications
WFQ	More fairness added	Does not consider the start time of a packet
DFPQ	Provide more fairness to system	Complex implementation
TRS	Good throughput	SS with lower SIR than preset threshold suffers
Cross layer	Good throughput, high frame utilization	Can be implemented only at BS
MLWDF	Minimum delay, good throughput	Complex implemented

6. Conclusion

In this paper we presented the downlink scheduling. Starting from its basic concepts to the scheduling mechanism and the existing downlink algorithms, their aspects methodology, advantages and limitations are discussed. In order to give comparative study between the discussed algorithms, we draw one summary table showing the strength and limitations of the algorithms, discussed in the paper. All the proposed WiMAX algorithms could not be studied in the paper, but we presented the algorithms belonging to present scheduling mechanisms.

Scheduling is a main component of the WiMAX that assures QOS to various service classes. None of the previously proposed schemes have considered all the connection QOS requirements in their algorithms. Thus, research of optimal and robust schedulers for WiMAX systems is still an open research problem.

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