IEEE 802.16 Packet Scheduling with Traffic Prioritization and Cross-Layer Optimization

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Abstract. WiMAX is emerging as a broadband wireless access technology to satisfy end user expectations, containing a new set of advantages in terms of throughput, coverage and QoS support at the MAC level which allows convergence of several different types of applications and services. For that reason, the allocation of resources or scheduling becomes of greater importance. This paper focuses on a cross-layer scheduling optimization solution for IEEE 802.16. The relevant features of the proposed packet scheduling optimization scheme consist: of prioritization of users within the same traffic class, allowing for example to an operator, differentiated treatment among users, for instance distinguishing between premium or gold users and silver users; and also cross layer optimization which implies radio resource optimization and a more effective scheduler decision. Simulation scenarios are presented to demonstrate how the scheduling solution allocates resources through particular WiMAX MAC layer implementation in the NS-2 simulator. Results show that the new mechanism implementation results in an improvement to the simple Round Robin fashion present in the original simulation model, being able to increase differentiation between different classes and decrease packets delay, due to its cross-layer processing and traffic prioritization.

Keywords: QoS, WiMAX, Scheduling, NS-2, WiMAX Forum.

1 Introduction

Applications such as video and audio streaming, online gaming, video conferencing, Voice over IP (VoIP) and File Transfer Protocol (FTP), demand a wide range of QoS requirements such as bandwidth and delay. Existing wireless technologies that can satisfy the requirements of heterogeneous traffic are very costly to deploy in rural areas and "last mile" access. Worldwide Interoperability for Microwave Access (WiMAX) provides an affordable alternative for wireless broadband access supporting a multiplicity of applications. The IEEE 802.16 standard provides specification for the Medium Access Control (MAC) and Physical (PHY) layers for WiMAX. A critical part of the MAC layer specification is the scheduler, which resolves contention for bandwidth and determines the transmission order of users: it is imperative for

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a scheduler to satisfy QoS requirements of the users, maximizing system utilization and ensuring fairness among the users.

IEEE 802.16 [1][2] is a broadband wireless technology that already contains intrinsic QoS support, with the usage of Connection Identifiers (CID) to identify service flows with specific characteristics, the downlink and uplink classification and scheduling mechanisms. Nevertheless these mechanisms are not present in the standard [1][2] and were left for proprietary implementation by vendors.

In this paper, the QoS support for WiMAX is addressed, to provide service differentiation over WiMAX networks. It is proposed and evaluated a scheduling solution that uses prioritization and dynamic cross layer information for scheduling decisions in WiMAX networks. The base IEEE802.16 simulation model was implemented by a consortium under the WiMAX Forum [3][4][5] Application Working Group, specially involved in the realization of a WiMAX simulation model based in ns-2. At the moment, the model is only distributed to members and is under development. In order to validate the proposed scheduling solution, a set of QoS oriented scenarios have been simulated and the obtained results show that the implemented scheduler is able to efficiently differentiate between the traffic classes defined in the WiMAX model and achieve gains in throughput and delay, when compared to the base model.

The remainder of this paper is organized as follows. Section 2 provides an overview on WiMAX and section 3 describes the base simulation model proposed by WiMAX Forum. Section 4 details on the proposed scheduling scheme and section 5 discusses the simulated scenario and the obtained results, comparing the proposed algorithm in terms of QoS performance with the base WiMAX Forum simulation model. Finally, section 6 concludes this paper.

2 Overview of IEEE 802.16 Quality of Service

The physical channel defined in the IEEE 802.16 standard [1][2] operates either in PTP (point-to-point) or PTM (poin-to-multipoint) fashion, using a framed format. Each frame is divided in two subframes: the downlink subframe is used by the BS (Base Station) to send data and control information to the SSs (Subscriber Stations), and the uplink subframe is shared by all SSs for data transmission. In TDD (Time Division Duplexing) mode, uplink and downlink transmissions occur at different times since both subframes share the same frequency. Each TDD frame has a downlink subframe followed by an uplink subframe.

The 802.16 MAC protocol is connection-oriented. In this sense, an SS must register to the BS before it can start to send or receive data. During the registration process, an SS can negotiate the initial QoS requirements with the BS. These requirements can be changed later and new connections may be established.

Service flows (SF) in the WiMAX standard are used for establishing connections from SS to BS and vice-versa. Each SF is characterized by the set of QoS parameters that determine the QoS needed by the connection; for example, they can specify the maximum tolerated delay, required bandwidth, the way in which the SS can request the bandwidth, and the behavior of the scheduler.

The QoS requirements may be either per connection based or per SS based. For the purpose of supporting QoS at the MAC level, the BS must allocate slots using a specific algorithm based on the QoS requirements, bandwidth request sizes, or network parameters.

The basic approach for providing the QoS guarantees in the WiMAX network considers that the BS performs the scheduling for both the uplink and downlink directions; an algorithm at the BS has to then translate the QoS requirements of SSs into the appropriate number of slots. When the BS makes a scheduling decision, it informs all SSs about it by using the *UpLink* and *DownLink* management messages (UL-MAP and DL-MAP) in the beginning of each frame. These special messages define explicitly slots that are allocated to each SS in both the uplink and downlink directions. The algorithm to allocate the slots, the scheduling policy, is not defined in the WiMAX standards and is left open for proprietary implementations.

To support a wide variety of multimedia applications, the IEEE 802.16 standard defines five different scheduling classes, or traffic classes, each with different QoS requirements. Each connection between the SS and the BS is associated to one service flow. The Unsolicited Grant Service (UGS) receives fixed size data grants periodically. The real-time Polling Service (rtPS) receives unicast polls to allow the SSs to specify the size of the desired grant. QoS guarantees are given as bounded delay and assurance of minimum bandwidth. The extended real-time Polling Service (ertPS) uses a grant mechanism similar to the one for UGS connections. Moreover, periodic allocated grants can be used to send bandwidth requests to inform the required grant size. For the non-real-time Polling Service (nrtPS), the BS provides timely unicast request opportunities; besides that, the SS is also allowed to use contention request opportunities. Minimum bandwidth guarantees are also provided to nrtPS connections. The Best Effort service (BE) requests bandwidth through contention request opportunities as well as unicast request opportunities.

3 WMF 802.16 Model

This section briefly describes the ns-2 WiMAX forum release 2.1 of the 802.16 module, specifically addressing QoS and scheduling capabilities. The merge of the efforts to produce a scheduling model in ns-2 was taken from the independent development efforts supported by the *Application Working Group* (AWG) of the WiMAX Forum [7] and NIST [9]. This collaboration resulted in a release software module for OFDMA PHY [3][4][5]. The teams at *Rensselaer Polytechnic Institute* (RPI) and *Washington University in St. Louis* (WUSTL) are the primary development teams, among others, supported by the AWG. The authors of this paper are also involved in this group.

The model currently implemented is based on the IEEE 802.16 standard (802.16-2004) and the mobility extension 80216e-2005. A set of features are inherited and present in both models, such as WirelessMAN-OFDM with configurable modulation and TDD at the physical level; it also encompasses the standard management messages to execute network entry without authentication. At the MAC level, fragmentation and concatenation are supported as well. Nevertheless, this model features a series of new capabilities to the existing ones, not only with the introduction of an

OFMA physical layer, but also with the implementation of QoS and SFs, as the most important ones. A description of available features that were included in the WMF model are listed below [3]:

- OFDMA physical layer;
- Selectable fast fading models: ITU PED A, PED B, VEHIC A;
- Service Flow and QoS scheduling;
- ARQ (without ARQ blocks).

3.1 Packet Classification

In terms of packet classification, this model implements an approach using the destination MAC address located in the packet and the packet type to determine the proper CID. The data traffic transmission takes place through a general Data connection.

However, one of the most important enhancements in terms of QoS in the WMF model is the implementation of SFs. This module has the basic infrastructure for requesting and establishing SF with given QoS, although the actual establishment of connections and SF that are based on application requirements is not implemented. Each connection can be associated with a SF and corresponding QoS parameters. The list of flows is configurable in each SS. These provisioned flows are stored as static connections. They are established every time the SS attaches to a new BS. While the structure supports the definition of QoS flows, it is the scheduler that makes use of that information. Furthermore, no admission control mechanisms are provided. The model accepts all the flow requests from the mobile stations, hence congestion and packet loss might occur.

Some parameters used to configure the list of flows that must be setup after network entry are the following [5]:

- Direction - Downlink (DL) and Uplink (UL);
- Data Rate (bytes/s);
- Scheduling Type (BE/rtPS/nrtPS/UGS);
- Data size (bytes).

3.2 Scheduler Mechanism

This section describes the scheduler operation in the WiMAX Forum release of ns-2 module, including both scheduling mechanisms in the BS or SS.

The model presents two schedulers: one for the BS and one for the SS. The BS scheduler is responsible for filling up the downlink subframe. The SS scheduler is responsible for dividing the bandwidth allocated to it amongst its various connections. An interface is defined between the scheduler and the remaining code. The interface defines a set of input parameters and expects the map structure as an output.

The downlink interface returns the DL Map; the uplink interface returns the UL Map. To the downlink/uplink scheduler, a list of downlink/uplink connections is sent.

The DL scheduler is a round robin priority scheduler that allocates bandwidth to a connection when it has data to be sent. It performs round robins through various connections in the following order: UGS, rtPS, nrtPS, and BE. Prior to allocating bandwidth for data connections, it allocates bandwidth to basic, primary and secondary connections. These features and scheduling rules are similar in both models. The bandwidth allocation is performed in multiple of slots. Bandwidth in the uplink direction is allocated per SS. This means that, if a SS has multiple connections, the bandwidth allocated to it is represented by a single UL Map, that is, in a frame in which the allocated bandwidth is the aggregate bandwidth for all its connections. In the WMF model, for all other connections apart from UGS, the scheduler checks the bandwidth request (BWR) packet received from the SSs. For rtPS connections, the BS increments the allocated bandwidth by the amount of bandwidth required to send another BWR packet.

The UL scheduler needs to split this bandwidth amongst all its connections, as it serves the various connections in the same round robin fashion used in DL, and only proceeds to the next class if there is more bandwidth left in the uplink direction. For UGS, a fixed amount of bandwidth is allocated depending on the rate at which bandwidth has been reserved for the connection. Currently, an SS can have only one connection in the DL and UL direction: the scheduler checks which connection it is related to, and transmits data from that connection. For all connections, apart from UGS, a BWR packet is created and queued for transmission.

4 Priority-Based and Cross-Layer WiMAX Scheduler

In this section, a proposal for the WiMAX scheduler that is capable of allocating slots based on the QoS Service class, traffic priority or the WiMAX network and transmission parameters is described. To test the proposed solution, the QoS model for the IEEE 802.16d/e MAC layer in the NS-2 simulator developed by the WiMAX forum and detailed in the preceding section, was taken as base. In section 5, simulation scenarios and traffic are presented to demonstrate how the scheduling solution allocates resources in various cases. Simulation results will reveal an optimized scheduling solution that ensures the QoS differentiation of the different WiMAX service classes and sharing of the free resources in a fairly manner, taking into account the instant transmission conditions.

4.1 Description

The proposed algorithm depicted in Figure 1 represents an enhancement to the previous WiMAX Forum algorithm. This algorithm, called **Enhanced Round Robin** (eRR), by using the same approach as the simple round robin solution, introduces more elements in the decision making process of packet allocation in each frame . These elements are either used to distinguish traffic and applications, and to give transmission preference to terminals with best radio conditions and its connections. The dynamic decisions are based on the actual transmission channel conditions.

More specifically, not only the traffic is mapped using fixed priorities to different service classes but also different priorities are possible inside the same traffic class, making possible to distinguish with more granularity the kind of traffic to prioritize in terms of transmission. Also, apart from the static traffic prioritization, the scheduler performs cross layer information processing: it first prioritizes connections from terminals which present the highest received power signal strength, commonly called

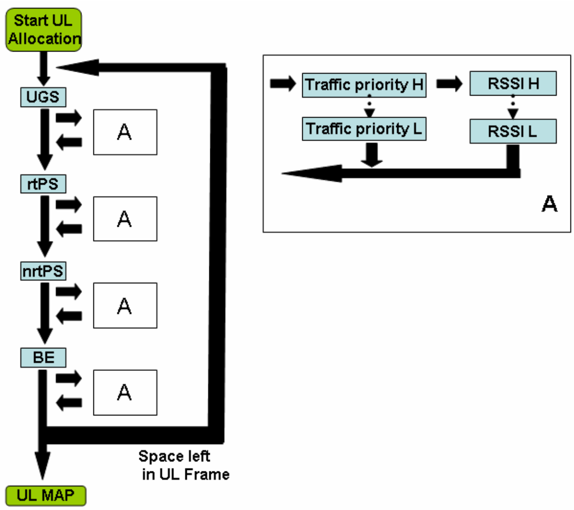

Fig. 1. Enhanced Round Robin Algorithm

RSSI (Received Signal Strength Indication), applying these rules in the case the connections are from the same traffic class and possess equal priority inside the respective class. According to this last rule, terminals with equal service class connections and traffic priority will be served in a certain order that privileges the ones that have better radio conditions, or are closer to the transmitting antenna. In practice, the algorithm initially performs the same round robin procedure as explained in the previous models, i.e. serving first connections in the following order: UGS, rtPS, nrtPS and BE. From the list of existing connections inside the same class, a priority is also established and used to allocate the corresponding packets in the given frame that is to be allocated at the present time. Assuming that more than one connection from the same class has equal traffic priority, the connections will be served taking into account the RSSI value for the given node, from the highest RSSI to the lowest, thus achieving some degree of radio resource optimization as well as guaranteeing that connections with better radio conditions are served minimizing also transmission errors.

This algorithm was implemented using the WMF IEEE802.16 Release 2.1 simulation model. The intended optimization considered only the uplink scheduler implemented in the model and modifications were mainly performed on the uplink frame allocation function *uplink_stage()* present in the *bsscheduler.cc*; the SF class was easily extensible to support the static traffic priority assignment using the configurable SF in the *tcl* simulation scripts. Apart from that, a structure is created each time an allocation is performed in which all the existing connections that are passed to the scheduler are stored with the instant value for their respective terminal's RSSI calculation. Finally, the information is processed in order to give the scheduler allocation decision based on the information that is present at the time.

5 Performance Evaluation

This section presents the results and performance comparison in order to evaluate the proposed model, in terms of efficiency, considering both throughput, delay and differentiation metrics. For this purpose, simulation scenarios were implemented to test QoS using a Point-to-multipoint (PMP) network topology,in which the number of SS's is increased We take WMF model as a basis for comparison with the new scheduler.

5.1 Simulation Parameters/Scenarios

The network topology considers differentiated traffic traversing the uplink direction from different hosts. A PMP wireless scenario is considered (Figure 2), in which single hosts are connected to SSs, with each host's traffic representing one connection flow per SS in the uplink direction. In order to test the different network topologies, assuring differentiation between the different service classes, we defined and implemented new traffic sources. As an example, BE traffic generator contains a variable packet size and interval to emulate FTP/web traffic, and an UGS traffic generator contains a constant transmission rate. rtPS traffic presents a variable packet size and interval, consistent with real time video transmission. Table 1. presents the different values adopted for these traffic generators.

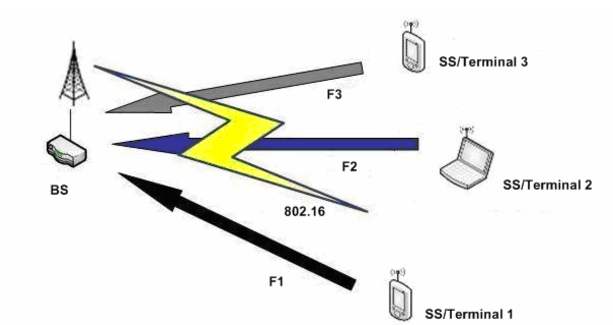

Fig. 2. PMP scenario

Table 1. Traffic generator parameters

Packet Type	Bitrate (Kb/s)	Packet Size (bytes)
BE	200	512 to 1024
UGS	200	300
rtPS	200	200 980

5.2 Simulation Results

In this scenario we have defined the relevant PHY layer simulation parameters. The most important used parameters are summarized in Table 2.

Table 2. Simulation parameters

Frequency	3.493 GHz
Bandwidth	20MHz
Frame duration	5 ms
Downlink ratio	0.3
Modulation	16 QAM
Cyclic prefix	0.25
Queue lenght	100 packets

Comparison results of both schedulers comprise throughput, delay, and traffic differentiation from an increasing number of SSs from 3 to 12 and one terminal attached to each SS, with only one of the respective traffic sources for UGS, rtPS or BE.

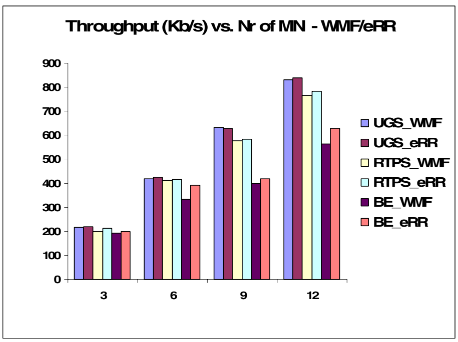

Fig. 3. Throughput WMF/eRR results

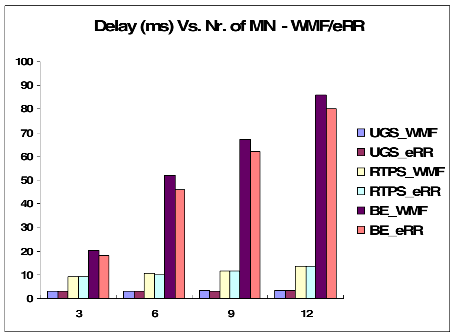

Fig. 4. Delay WMF/eRR results

Figure 3 shows the results with an increasing of terminals up to 12. It is visible the slight gain difference that can be achieved in throughput using the enhanced Round Robin solution as well as the observed earlier service class differentiation. In this particular case, the traffic priority was assumed to be equal among the same classes, being the decision parameters here in evidence only the service class and RSSI of respective terminal.

In relation to delay, as can be seen in Figure 4, there is also a slight decrease when using the proposed scheduling solution, meaning that in every case the scheduler either equals or outperforms slightly the existent Round Robin in the WMF model, expectable also since it is based on the same principle.

Figure 5 and Figure 6 illustrate the obtained differentiation inside the same service class and among different ones, using only traffic prioritization, RSSI based decision is not effective since all connections are of different classes and priorities. Results are presented for separate connections for rtPS and BE in terms of throughput and delay for the enhanced RR solution. The scenario consisted of terminals with connections with the rtPS and BE classes respectively, and different traffic priorities inside each

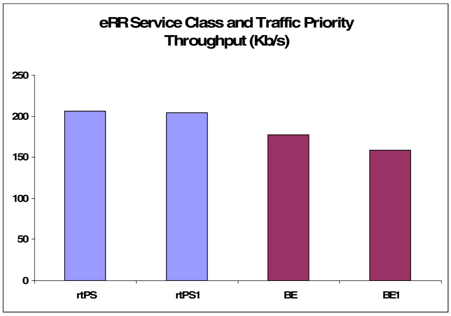

Fig. 5. Throughput values for distinct service classes w/ diverse traffic priority

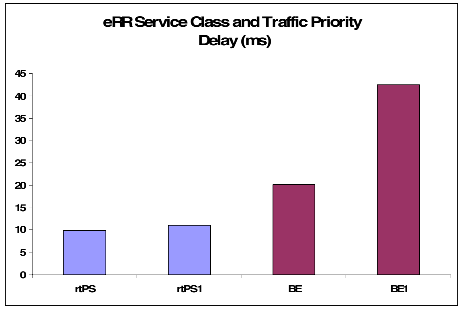

Fig. 6. Delay values for distinct service classes w/ diverse traffic priority

service class, i.e rtPS1 has lower priority than rtPS connection and BE1 also in re spect to BE. Results show the intended differentiation in the scheduling decision as both classes are distinguished in terms of throughput and delay (better values for rtPS classes than BE ones) and traffic prioritization inside each particular class (better performance for rtPS and BE in relation to rtPS1 and BE1 respectively).

6 Conclusions

In this paper it was proposed and evaluated a novel solution based on the simple Round Robin scheduling model defined by the WiMAX Forum. The proposed scheme bases the scheduling decision on priority according to service class, a traffic priority inside the same class, and also a novel third principle using instant RSSI information to distinguish between similar connections. The enhancement proposed to the original scheduler present in the WMF model proved its efficiency in improving important QoS parameters and differentiation of traffic. Another important aspect to retain is the greater granularity, achieved with this enhanced scheduler, more close to the standards specification, in terms of service differentiation, bringing advantages not in capacity, but making possible for operator networks for instance to distinguish different kinds of users and its attributes as well as achieving radio resources optimization.

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