Two Layer Channel Aware Scheduling for QoS Support in IEEE 802.16/WiMAX Networks

Mohamed Y. Sleem
Electrical Engineering Department
Faculty of Engineering-Suez Canal University
Isamila, Egypt
m.yousefi@scuegypt.edu.eg

Hesham M. ElBadawy
Network Planning Department
National Telecommunication Institute
Cairo, Egypt
heshamelbadawy@ieee.org

Mohamed S. Abo-El-Seoud
Electrical Engineering Department
Faculty of Engineering-Port Said University
Port Said-Egypt
m.samysoud@gmail.com

Abstract— One of the fundamental requirements for IEEE 802.16/WiMAX, to become a key technology for high-speed multimedia service delivery, is QoS (Quality of Service) differentiation. Although different types of QoS classes have been defined by the IEEE 802.16 standard, the scheduling architecture is left to be vendor specific. In this paper, new modifications are purposed, and a detailed simulation study is performed, for different scheduling algorithms which are: RR (Round Robin), WRR (weighted Round Robin) and DRR (Deficit Round Robin). Analysis and evaluation of the performance of each scheduler to support the different QoS classes have been performed. The simulation results show that the purposed channel aware modified DRR scheduler can provide higher service standards to support the QoS in terms of packet loss ratio and bounded delay, which is required by different types of traffic in a time varying channel.

Keywords- IEEE 802.16, WiMAX, scheduling algorithms, quality of service.

I. INTRODUCTION

The increasing demand for high-speed Internet access and multimedia services such as voice over IP, video conferencing and video on demand have led to a rapid growth in demand for broadband networks access. The rapid dissemination of broadband wired access technologies such as leased line based on fiber-optic links and digital for subscriber line (xDSL) access networks aim to support this demand. Meanwhile, access to broadband wired technologies can be too expensive for users who are located in environments such as rural and suburban areas, where, there is slow development of traditional wired technologies. In this way, one of the most promising alternatives for the last-mile access is WiMAX which represents low cost and high scalability [2].

Although IEEE 802.16 standard, known in the trade press as the worldwide interoperability for microwave access (WiMAX), incorporates several advanced radio transmission technologies, it presents very challenging aspects in term of radio resource management. One of the fundamental challenges is the provision of Quality of Service (QoS) guarantees for different categories of applications with various QoS requirements such as packet loss and maximum delay. On the other hand, in the non ideal channel, where fair assignment of resources can be disturbed due to the channel quality, providing the fair resource allocation is another challenge. In these conditions, fair radio resource management through scheduling algorithms plays a key role in QoS provision. However, the standard leaves the QoS support based scheduling algorithms as an open issue to research [2,3].

A bad channel quality might invalidate theoretical fairness and QoS support capability of the scheduler. This approach is not new; channel-awareness at the network layer of either cellular or generic wireless systems has been extensively debated in literature [4]. However, studies on the effect of radio channel impairments on WiMAX scheduling performance are only recently coming out [5,6].

The focus of this paper is to modify and adapt the RR scheduling family (RR, WRR and DRR) to work in any channel conditions, to be used by the base station (BS) of a Point-to-MultiPoint (PMP) WiMAX network for the downlink delivery of multimedia traffic to a set of distributed Subscriber Stations (SSs). This paper depends on the typical approach to the scheduling of downlink data traffic that prefers simplicity to QoS performance; e.g., classical algorithms like Weighted Round Robin (WRR) and Deficit Round Robin (DRR) which are suggested in literature [7]. In [8, 9] a wireless version of DRR for a packet cellular network has been proposed. The modified scheduling algorithms in this paper started from the consideration that traffic treatment differentiation is fundamental and modified the RR family based schedulers, which are able to provide per-class service and protect flows belonging to the most demanding classes. The RR family scheduler design is specifically tailored on WiMAX features: QoS guarantees on a class basis. The ultimate aim is to provide the target QoS in terms of packet loss ratio and bounded delay, in any channel conditions, to each service class while achieving fairness in the treatment of traffic flows belonging to the same class.

The main difference between the existing work [15] and the modified algorithms in this paper is the simulation environment, where the modified algorithms simulated using MATLAB which is a stable simulation tool.

The paper is organized as follows. Section II gives details of the proposed channel-aware scheduler; Section III and IV present results and conclusion, respectively.

II. CHANNEL AWARE QoS-BASED SCHEDULING

The modified channel-aware QoS scheduling algorithms were implemented with the following QoS support features:
i. An error-free service scheduler that decides how to provide service to flows depending on their channel conditions.

ii. A compensation technique that is used to make the BS aware of the channel state, to avoid losing a packet in a bad channel.

iii. Separate per-class packet queues used to support UGS, rtPS, nrtPS, and BE traffic flows.

iv. Means of monitoring and predicting the channel state of each waiting flow.

Fig. 1 shows the modified channel aware QoS scheduling architecture where each block is explained in details below:

A. Classifier

Packets addressed to SSs are sorted by the Packet Classifier and buffered into per-class queues according to the class of service they belong to. The Classifier puts a timestamp on incoming packets of each connection with their arrival time. This information is exploited by the Buffer manager to assess when the packet timeout expires. Queues are managed by the BS scheduler on a per frame basis [11].

B. Bandwidth Requests with CINR reports

To implement a perfect channel-dependent scheduling, each SS monitors its channel state continuously, predicts its future channel state, and sends this information to the scheduler in the BS. The compensation block is the component that makes BS aware of the channel state. It gathers information on the channel quality that the BS receives through the bandwidth request (BR) messages sent by SSs (messages normally used by SSs for bandwidth requests, including a Carrier to Interference and Noise Ratio (CINR) report [1]).

The monitored channel quality is compared against the allowed values of signal-to-noise ratio and receiver sensitivity for each transmission mode (modulation/coding scheme), as specified by the standard [1] at a given Bit Error Rate (BER). As soon as the received power level becomes lower than the receiver sensitivity threshold for a given modulation/coding scheme and BER, the SS requests a change to a more robust downlink transport mode. This change of downlink operational burst profile can go on until the most robust modulation/coding scheme (i.e., binary phase shift keying [BPSK] modulation with 1/2 coding rate) is chosen. After that, if the received power is lower than the receiver sensitivity, the channel is considered "bad" and the packet is not transmitted (awaiting later compensation). So a channel is considered "good" as long as there is the possibility of finding a more robust modulation/coding scheme that is capable of coping with the adverse channel conditions.

C. Channel error Compensator

At the beginning of each frame, the Compensator classifies a flow (i.e., a CID) as sensing a "good" or a "bad" channel, on the basis of the CINR reports from the relevant target SSs. Accordingly, all the CIDs destined to an SS sensing a lossy channel are marked as "banned". When the error-free scheduler selects the Head of Line (HOL) packet from queue i, it interacts with the Compensator to check whether the CID of the selected packet is banned or not. If it is banned (i.e. it would be delivered over a bad channel), then the Scheduler looks for a packet belonging to a non banned flow of the same class (this means in the same queue) to transmit instead of the HOL packet [11].

D. Buffer Manager

Due to the compensation mechanism, packets can be delayed in the queues while waiting for radio links to become error-free again. To avoid bandwidth waste due to overdelayed packets sent over the wireless medium, it is necessary to keep the queues clean. Thus, at each frame beginning, the Buffer Manager removes all those packets buffered for a time longer than their maximum tolerated delay [11].

E. Scheduler

The scheduler in the BS is based on the traditional RR family with some modifications to adapt them to work in the WiMAX environment. The three modified algorithms are:

1. Modified Round Robin (MRR): Traditional RR serves each priority queue, starting with the highest priority queue that contains packets, services a single packet, and moves to the next lower priority queue that contains packets, servicing a single packet from each, until each queue with packets has been serviced once. It then starts the cycle over with the highest priority queue containing packets [8].

The MRR scheduler checks the CINR for each packet before serving to avoid sending and losing this packet in bad channel and Checks if the HOL packet is overdelayed to be discarded or not.

The flow chart of the channel aware MRR scheduler is shown in Fig. 2, where Q_i is the queue of each scheduling service (Q_0 for UGS, Q_2 for rtPS, Q_3 for nrtPS and Q_4 for BE), CINR is the carrier to interference plus noise ratio and CINR_{th} is the threshold CINR where if CINR < CINR_{th}, the channel is considered "bad" and the packet is not transmitted (awaiting later compensation).

2. Modified Weighted Round Robin (MWR): In traditional WRR packets are first classified into various service classes that can be assigned a different percentage of bandwidth and then it is serviced in round robin order. WRR ensures that all service classes have access to at least some configured amount of network bandwidth to avoid bandwidth starvation. In order to provide the correct percentage of bandwidth to
each class, all packets in tall queues must have the same size or the mean packet size is known in advance [12].

The MWRR scheduler, similar to MRR, checks the CINR for each packet before serving to avoid sending and losing this packet in bad channel and Checks if the HOL packet is overdelayed to be discarded or not.

![Fig. 2 Channel aware MRR flow chart.](image-url)

![Fig. 3 Channel aware MWRR flow chart.](image-url)

The flow chart of the channel aware MWRR scheduler is shown in fig. 3, where $w_i$ is the weight of each scheduling service ($w_1$ for UGS, $w_2$ for rtPS, $w_3$ for nrtPS, $w_4$ for BE).

3. Modified Deficit Round Robin (MDRR): Traditional DRR uses round-robin service with a quantum of service assigned to each queue; differently from traditional round-robin scheme if a queue was not able to send a packet in a given round because of its large packet size, the remainder from the quantum (deficit) is added to the quantum for the next round. DRR maintains for each queue ($Q_i$) a deficit counter ($DC_i$) and a quantum ($q_i$). DRR works serving queues in turn; each time a $Q_i$ is selected, $DC_i$ for that queue is incremented by the $q_i$ value, packets are sent out if their size is less than $DC_i$. Each time a packet is extracted from $Q_i$, $DC_i$ is decremented by the packet size [9,12].

The flow chart of the channel aware MDRR scheduler is shown in fig. 4, where the only two differences from the traditional DRR scheduler are:

1. Checking the CINR for each packet before serving to avoid sending and losing this packet in bad channel.
2. Checking if the HOL packet is overdelayed to be discarded or not.

![Fig. 4 Channel aware MDRR flow chart.](image-url)
III. RESULTS AND ANALYSIS

Extensive simulations for different scheduling algorithms are conducted by using MATLAB. In the simulation, an IEEE 802.16 WMAN-OFDM network composed of one BS and up to 50 SSs with Rayleigh flat fading channel is configured. The simulation parameters are given in Table 1. The simulations had been repeated 400 times with different random seeds and the average value was calculated.

The assumptions employed in simulations are:
A1: The wireless channel quality of each connection remains constant on a per-frame basis; that is, the BS assumes that the report sent by the SS at the frame beginning is valid for the entire duration of the subsequent frame. Anyway, the channel quality is allowed to vary from frame to another. This corresponds to a block-fading channel model, which is suitable for slowly varying wireless channels.
A2: Perfect channel state information is available at the BS, i.e., CINR reports are correctly received.

<table>
<thead>
<tr>
<th>TABLE I. SIMULATION PARAMETERS</th>
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<tr>
<td>Simulation Parameter</td>
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<tr>
<td>FREQUENCY BAND</td>
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<td>CH. FADING MODEL</td>
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<td>Tx POWER</td>
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<td>DUPLEX MODE</td>
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<td>B.W.</td>
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<td>MAC FRAME DURATION</td>
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<td>DL SUBFRAME DURATION</td>
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<td>UGS TRAFFIC MODEL</td>
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<td>rtPS TRAFFIC MODEL</td>
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<td>nrtPS TRAFFIC MODEL</td>
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<td>BE TRAFFIC MODEL</td>
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A. Results Validation

The presented work maybe validated via the comparison with the previous published work in [14].

In [14], performance evaluation of Deficit Round Robin was done, which showed that the DRR based downlink scheduler Implementation in WiMAX has supported WiMAX QoS by providing each QoS class average delay value as it should be.

Fig. 5 shows the average delay of rtPS traffic class for channel unaware version of the modified DRR model and [14], when increasing the number of active SSs from 6 to 30. As can be seen, the average delay in the paper’s study was lower than the average delay in [14].

B. Scheduling delay and loss ratio results

The performed simulation aimed to show the adverse effects of wireless channel impairment on scheduler performance, and then the benefits that can be obtained while utilizing the proposed compensation scheme. The following parameters are monitored: scheduling delay and loss ratio.

The results in Fig. 6 show the scheduling delay by varying the buffer size for all schedulers. The UGS traffic class achieves the minimum scheduling delay among other traffic classes. This is because UGS has constant bit rate (CBR) and receives a constant amount of bandwidth.

The scheduling delay of UGS traffic increases as the buffer size increases until 2048 bit, any further increase in buffer size doesn’t increase the scheduling delay. This means that the buffer size greater than 2048 bit is seen by the UGS traffic as an infinite buffer. Also, for each scheduler, the UGS, rtPS, nrtPS and BE traffic classes of MDRR achieves the minimum scheduling delay than the corresponding traffic classes of MWRR and MRR.

Fig. 7 shows the scheduling delay for MDRR and MWRR schedulers when the number of active SSs increase from 5 to 50. As can be seen, all curves increase smoothly as the number of users increase. Under overload (no. of active SSs greater than 15) the scheduling delay is nearly constant for delay sensitive classes (UGS and rtPS). This is due to compensation mechanism where overdelayed packets are cleaned from the buffer periodically.

Also it can be notice in the same figure that each traffic class in MDRR has less delay than the corresponding traffic class in MWRR. This is because WRR provides the correct percentage of bandwidth to each class, if only all the packets size is the same or when the mean packet size is known in advance.

Fig. 8 shows the packet loss ratio of each traffic class for MDRR and MWRR schedulers when the no. of active SSs increase from 5 to 50.
For MDRR, it can be shown that BE and nrtPS traffic classes achieve less packet loss ratio than UGS and rtPS. This is because the buffer size of BE and nrtPS is larger than that of UGS and rtPS traffic classes, where BE and nrtPS traffic classes are sensitive to loss and less sensitive to delay.

In MWRR scheduler UGS curve cross the BE curve at 25 SSs. This is due to the variations in packet size, which degrades the behavior of the MWRR scheduler. For rtPS traffic class, as the no. of active SSs is less than 10, the packet loss ratio of MDRR is less than that of WRR, however, as the no. of active SSs is greater than 10, the behavior of the two schedulers is nearly the same.

IV. CONCLUSION

This paper has presented a scheduling solution for the 802.16 base station working in PMP mode. Our solution is based conceptually on a new modifications applied to the round robin scheduling family which makes it fast and simple to implement. The simulations have confirmed the correctness of the modified channel aware scheduling approach. A technique for channel error compensation coupled to the modified RR family scheduling algorithms to preserve QoS differentiation in downlink traffic delivering, even in non ideal channel conditions. The simulation results also proved that the channel aware MDRR scheduler behaves better in terms of packet loss ratio and bounded delay than the two other purposed schedulers (WRR and RR) under non ideal channel conditions.

REFERENCES