A Proposed Real–Time Scheduling Algorithm for WiMAX Networks

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***Abstract*- Over the past few years, there has been a rapid growth of new services offered to end users on the Internet, such as online video games, video conferences, and multimedia services. WiMAX networks are one prominent viable solution for wireless broadband access that provides last-mile access to the Internet. To satisfy the Quality of Service (QoS) requirements of the applications in an acceptable way, an efficient scheduling algorithm is needed. In the literature, attention was focused on throughput and delay only. Jitter, though of great significance, was not taken into account. In this paper, we consider jitter, in addition to throughput and delay, in order to formulate a three-term dynamic weight function. The jitter and delay terms, in particular, are weighted by specific weighting factors, whose values in real-time applications are different from those in non-real-time applications. Simulation results are obtained by OPNET, and it is shown that the proposed algorithm outperforms two famous previously published algorithms.**

Keywords- WiMAX; QoS; Jitter; Scheduling algorithms; IEEE 802.16

I. INTRODUCTION

Worldwide interoperability for microwave access (WiMAX) networks are a broadband wireless access network technology, designed according to IEEE 802.16 standard [1, 2, 3]. These promising networks possess a multitude of advantageous features such as high data rate, large spanning area, and provision for achieving the required Quality of Service (QoS) of real-time applications. They act as a convenient medium for delivering vital services to end users on the Internet, such as video conferences, online video games, and multimedia services to end users.

The QoS plays a major role in determining network performance. It has three main parameters, namely, throughput, delay, and jitter [4, 5]. A scheduling algorithm is needed to allocate the bandwidth to applications in such a way as to maximize throughput and minimize delay and jitter. The scheduling algorithm should be simple, fair, and efficient.

A good survey about scheduling algorithms in WiMAX networks is presented by So-In et al. [6]. Dhrona et al. [7] have made a comprehensive performance study of uplink scheduling algorithms in point-to-multipoint WiMAX networks, where simulation analysis was carried out using average delay, average throughput, fairness and frame utilization. Recently, Kumar and Gupta [8] perform another comparative descriptive analysis for various scheduling algorithms in WiMAX networks.

Among notable scheduling algorithms for WiMAX networks are [9, 10, 11]: Weighted Fair Queuing (WFQ), Random Early Detection (RED), Fair Queuing (FQ), Deficit Round Robin (DRR), Round Robin (RR), Weighted Round Robin (WRR), and First-In First-Out (FIFO). We have to choose the algorithm which guarantees the best performance. In this respect, an algorithm with dynamic bandwidth allocation is usually recommended. It is also mentioned in [12] that weighted scheduling algorithms are preferred for satisfaction of QoS requirements. The reason is that the weight corresponds to the number of time slots to be allocated to the service class. This number of slots is fixed for each WiMAX frame; hence the weight representing the number of slots is preferably to be an integer. This means that we do not actually need algorithms such as DRR [11, 12] in which floating point numbers are used. Further, the resulting algorithm will be much less sophisticated.

Other recent attempts have been made by Ali and Dimyati [13] and El-Shinnawy et al. [14]. In [13], a scheduling algorithm has been developed on the basis of the

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number of bandwidth requests from Non-Real-Time Polling Service (nrtPS). In [14], a priority scheduling algorithm based on jitter, minimum rate, delay, and class type has been introduced. It was the first time for jitter to appear in a scheduling algorithm, but the treatment was confined to priority algorithms.

Jitter [15] is defined as a measure of the variability over time of the packet latency across a network. It is a very important QoS factor in the assessment of network performance. The cause of jitter occurrence is that a packet can get queued or delayed somewhere in the network. Increasing the jitter value beyond a certain threshold leads to missing packets and serious audio problems in real-time applications.

In the present paper, we include jitter explicitly in a dynamic weight function. To our knowledge, the weight function so formulated implies a new concept. The performance attained is better than other algorithms, in terms of average throughput, average delay, and average jitter.

The rest of this paper is organized as follows. In Section II, an overview of WiMAX networks is given. Scheduling algorithms are reviewed in Section III. Section IV presents the details of the proposed approach. Simulation results are introduced in Section V. Finally, conclusions and trends for future work are reported in Section VI.

II. ON WIMAX NETWORKS

WiMAX networks have two basic operation modes [6, 7, 8]: point-to-multipoint (PMP) connection and mesh connection. In the PMP mode, the communications between all subscriber stations (SSs) are organized and passed through the base station (BS), while in the mesh mode, the communication can be achieved directly between subscriber stations. WiMAX provides five service classes to support the variation of QoS requirements for different applications [1, 6, 7]. The first class is an unsolicited grant service (UGS), which is used to support real-time applications with constant data rate such as VoIP(Voice over Internet Protocol) without silence suppression. The second class is an extended real-time polling service (ertPS) class, which is designed to support real-time applications with variable data rate such as VoIP with silence suppression. The real-time polling service (rtPS) is the third service class type. rtPS focuses on real-time applications with variable data rate such as a Moving Picture Experts Group (MPEG) compressed video. The fourth service class is a non-real-time polling service (nrtPS) class, which is designed for non-real-time variable bit rate traffic such as file transfer protocol (FTP). The fifth class is the best effort (BE) at, which applications do not make use of any specific QoS requirements.

WiMAX is based on the principles of orthogonal frequency division multiplexing (OFDM) [1], which is a suitable modulation access technique for non– line-of-sight (NLOS) conditions with high data rates. However, in WiMAX the various parameters pertain to the physical layer, such as the number of subcarriers, pilots, and guard band. The WiMAX physical (PHY) layers defined in IEEE 802.16 standard are: wireless MAN-SC (single carrier), wireless MAN SCa, wireless MAN-OFDM (orthogonal frequency division multiplexing) and wireless MAN-OFDMA (orthogonal frequency division multiple access). Details about these layers can be found in [1, 2]. OFDMA WiMAX frame is divided into two subframes: uplink subframe and downlink subframe separated by a Transmit-receive Transition Gap (TTG) and a Receive-transmit Transition Gap (RTG). The structure of the WiMAX frame is shown in Figure 1 [1, 2, 6].

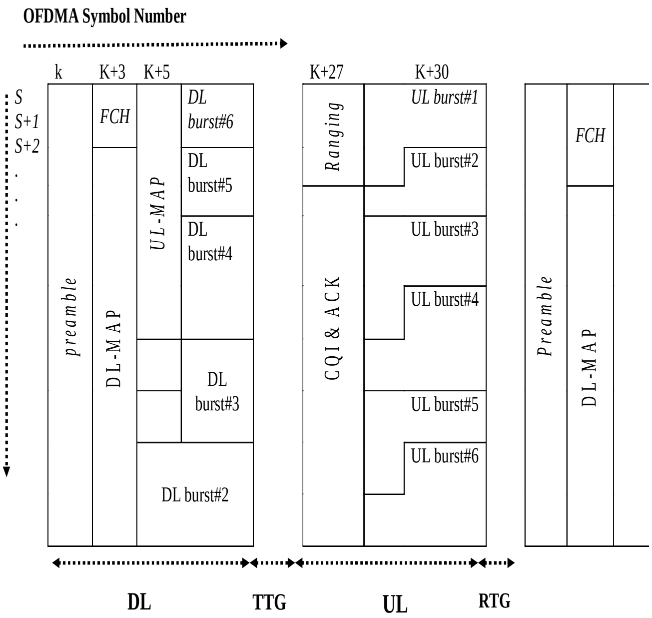

Figure 1. WiMAX Frame Structure

WiMAX provides a Media Access Control (MAC) layer that uses a grant request mechanism to authorize the exchange of data. Thus, a better exploitation of the radio resources, in particular with smart antennas, and independent management of the traffic of every user is allowed [16]. MAC layer in WiMAX has actions [1, 2, 6], i.e., provides QoS, responsible of security and key management, and provides power saving mode and idle mode operations. MAC layer is divided into three sub-layers. First, a convergence sub-layer is designed as a link between the higher layers and WiMAX MAC layer. This is done by mapping data from the upper layers to the appropriate MAC layer. Second, a common part sub-layer, which is responsible for bandwidth allocation, connection establishment and maintenance for all QoS requirements. Third, a security sub-layer, which is developed for authentication, security key exchange, and encryption. To ensure good performance of WiMAX networks for the different requirements of QoS in real-time applications, a suitable bandwidth allocation algorithm is needed. In the starting of each WiMAX frame, the scheduling algorithm computes the bandwidth allocation

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for each subscriber station to send this information in UL-MAP.

III. EARLIER SCHEDULING ALGORITHMS

To meet the QoS requirements of multimedia applications, a scheduling algorithm is needed to allocate the bandwidth to users to satisfy upper bounds on delay and jitter and to maximize throughput. Scheduling algorithms can be classified into two categories [6]: channel-aware algorithms, and channel-unaware algorithms. In channel-aware algorithms, channel information, such as signal strength, signal-to-noise ratio, and received signal power, affects the bandwidth allocation decision. In channel-unaware algorithms, however, no channel information is used. Many aware schedulers are proposed in the literature: examples are modified largest weighted delay first (M-LWDF) [17] and Link Adaptive largest weighted throughput (LWT) [18].

Also, the channel-unaware schedulers are the subject of many research papers. In [6, 10], the weighted family RR algorithm is proposed. This algorithm assigns one allocation for each connection in each serving cycle. In [6, 7, 10] WRR assigns a weight value to each connection then serves connections according to their allocated bandwidth based on weight. The main problem of WRR is that when the traffic has a variable packet size, it provides incorrect percentage of bandwidth allocation. DRR [11, 16] solves the problem of WRR by using two variables for each queue, deficit counter (DC) and quantum (Q). Deficit weighted round robin (DWRR) [18] is the same as DRR but with a new weight variable for each queue and the Q value depends on the weight value. Another modification on DRR, named modified deficit round robin (MDRR) [20], is operated in the same way as DRR but with adding a new parameter called a queue priority.

The above-mentioned scheduling algorithms have the following drawbacks. First, in weighted scheduling algorithms, the bandwidths are assigned statically and do not vary with the burst changes. Second, no enough attention is given to jitter causing problems in real-time applications. Finally, priority scheduling algorithms caused starvation in low priority classes. According to [6] and to the best of our knowledge, no scheduling algorithms take jitter delay into account in weighting function when taking the bandwidth allocation decision.

IV. THE PROPOSED ALGORITHM

In WiMAX networks, the BS is responsible for the scheduling of service classes for uplink and downlink directions. The scheduling algorithm works on the bases of the bandwidth requests of SSs in the uplink direction. The proposed approach is used as an uplink scheduling algorithm in the MAC layer of BS. This approach is a type of weighted scheduling algorithms with a dynamic weight equation defined in terms of the parameters: throughput and delay as well as jitter. These parameters characterize the QoS of the application at hand.

For each type of applications, the importance of these parameters is varying. In real-time applications which belong to rtPS service class in WiMAX, the QoS parameters are all important and none of them can be dispensed with. But, in non-real-time applications, which belong to nrtPS class in WiMAX, throughput is the only important parameter, since non-real-time applications are insensitive to delay and jitter.

The problem under consideration is concerned with the development of a real-time scheduling algorithm for WiMAX networks. The bandwidth is to be allocated among n queues; that is, n subscriber stations. The proposed method depends on the formulation of a dynamic weight function in terms of the three QoS parameters: throughput, delay, and jitter. To this end, a weight Wi is assigned to queue i as a positive factor of the form:

$$W_i = \frac{N_i}{\sum_{j=1}^{n} N_j} \quad , i=1,2,\ldots\ldots,n \qquad (1)$$

In (1), N_i is expressed as the sum of three terms corresponding to contributions of throughput, delay, and jitter, respectively. Specifically, we propose the following formula for a weight function N_i:

$$N_i = T_i + D_i + J_i \quad , \quad i=1,2,\ldots\ldots,n \qquad (2)$$

The first term T_i, in (2), is the fractional throughput contribution to N_i, defined as:

$$T_i = \frac{X_i}{\sum_{j=1}^{n} X_j} \qquad (3)$$

where X_i is the minimum reserved traffic rate for queue i. The second term D_i is the fractional delay contribution

$$D_i = \frac{(\alpha_i Y_i / L_i)}{\sum_{j=1}^{n} (\alpha_j Y_j / L_j)} \qquad (4)$$

where Y_i is a time-varying average delay, L_i is the given maximum latency, and α_i is a positive delay weighting factor. In (4), the ratio Y_i/L_i (less than unity) expresses the proportion of the delay of a particular queue relative to the maximum acceptable delay of the network. Further, the ratio Y_i/L_i is weighted by a factor α_i, whose value varies according to the subscriber station (value of i). This is justifiable since each subscriber station is devoted to a particular application. The third term Ji is the fractional jitter contribution,

$$J_i = \frac{(\beta_i Z_i / K_i)}{\sum_{j=1}^{n} (\beta_j Z_j / K_j)} \qquad (5)$$

where Zi is a time-varying average jitter, K_i is the given maximum jitter and βi is a positive jitter weighting factor. The terms in (5) can be interpreted in the same way as in (4).

Equation 2 is valid for both real- and non-real time applications; this implies that the weighting factors α_i and β_i should take on different values of the two types of applications. The values of α_i and β_i for real-time applications should be greater than those for non-real-time applications. The reason is the fact that real-time applications are more highly sensitive to delay and jitter. There is no apparent way for systematically determining the value of α_i and β_i. Therefore, we resort to a trial-and-error method. The criterion for the choice of the values of α_i and β_i depends on the performance of the algorithm in WiMAX networks. We begin with arbitrary initial values of α_i and β_i , and estimate the network performance in terms of throughput, delay, and jitter. When the performance is not satisfactory, the values of αi and βi are changed in a prescribed random manner, until a satisfactory network response is arrived at. These final values of αi and βi are then fixed and made use of in the bandwidth allocation operation of the algorithm. The simulation results to follow demonstrate the idea.

The computational scheme of the proposed algorithm is summarized in the following consecutive steps:

1) Values for the delay weighting factor α_i and the jitter weighting factor β_i are selected.
2) For each queue, get the values of Y_i and Z_i.
3) Calculate the values of T_i (in (3)), D_i (in (4)), and J_i (in (5)).
4) Calculate the three-term weight function N_i according to (2).
5) Calculate the weight W_i by virtue of (1).
6) Divide the bandwidth of the uplink subframe among the n queues based on the relationship:
   $$(BW)_i = W_i * (UL)_{BW} \quad (6)$$
   where BW_i is the bandwidth reserved to queue i and UL_{BW} is the total bandwidth of the uplink subframe.
7) The value of the bandwidth of each queue is sent to SS.
8) The service for the queue is continued until the bandwidth is ended.
9) The service is moved between the queues using round robin mechanism.

V. SIMULATION SETTING AND EXPERIMENTS

Simulation in this paper is performed by the OPNET simulator [21]. The network used consists of four WiMAX service classes: ertPS, rtPS, nrtPS and BE with applications: VoIP, video conference, FTP and HTTP, respectively. The traffic parameters for each service class are listed in table1.

TABLE I. TRAFFIC PARAMETERS

Service class	*Minimum reserved traffic rate in bps*	*Maximum sustained traffic rate in bps*	*Maximum latency in msec*	*Maximum jitter in msec*
ertPS	25000	64000	20	150
rtPS	64000	500000	30	160
nrtPS	45000	500000	100	300
BE	1000	64000	N/A	N/A

The simulation results are obtained using several scenarios by varying the number of SSs. Each scenario consists of one BS serving a number of SSs in PMP mode of operation. The frame duration is 5 msec, with 50% for each uplink and downlink subframe. A random topology in 1000 x 1000 m square space is used. The number of SSs varies from 10 to 60 with ratio 2:3:3:2 SSs for service classes ERTPS:RTPS:NRTPS:BE, respectively. The proposed weighted scheduling algorithm is compared with both MDRR [20] and WRR [6, 7, 10]. The throughput, delay, and jitter are considered as performance metrics. The simulation time is 10 minutes

Figures 2, 3, and 4 show the simulation results for the average throughput, average delay, and average jitter, respectively, as functions of the number of SSs, for the proposed algorithm together with the other two algorithms WRR and MDRR, it is clear from these figures that the proposed approach exhibits a better performance than WRR and MDRR since it has:

- A higher throughput
- A lower delay
- A lower jitter

In Figure 2, it is to be noted that the differences between the average throughput values in the three scheduling algorithms are not appreciable, because the throughput in the three algorithms is defined using the same concept.

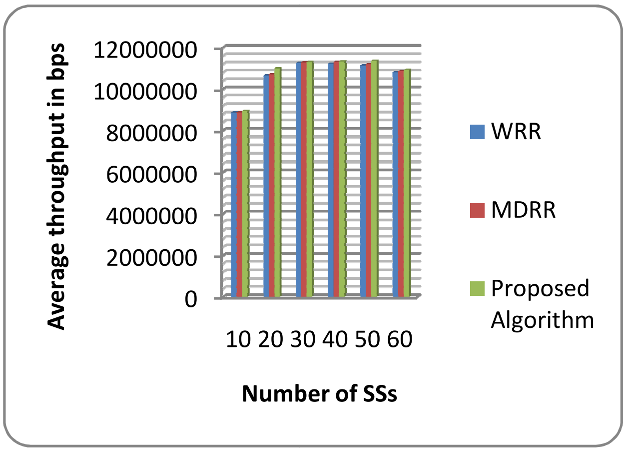

Figure 2. WiMAX average throughput *vs.* number of SSs

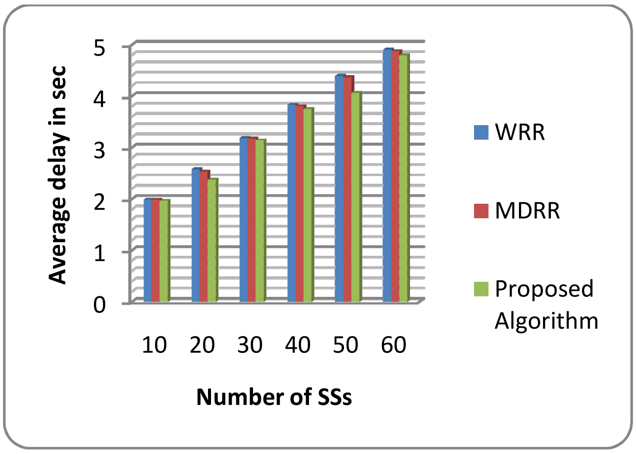

Figure 3. WiMAX average delay *vs.* number of SSs

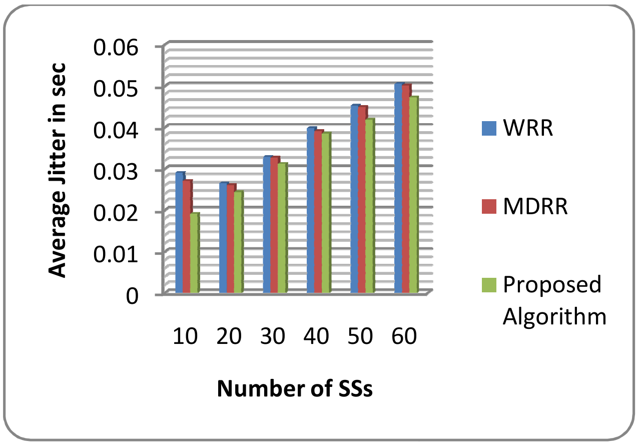

Figure 4. WiMAX average jitter *vs*. number of SSs

The relative superiority of the proposed algorithm can be attributed to the inclusion of jitter, in addition to throughput and delay, in the weight function Ni (equation 2). Besides, the values of the weighting factors αi and βi are chosen in such away that both delay and jitter are given greater attention in real-time applications than in non-real-time applications. In this specific application, it is found that the best possible values of αi and βi are in the ratio 1:5 and 1:3, respectively, in non-real-time and real-time applications.

VI. Conclusion and Future Work

An uplink dynamic channel-unaware weighted scheduling algorithm for WiMAX networks has been proposed. It has advantages of conceptual soundness and computational simplicity. A weight function, for each queue, is formulated as the sum of the respective contributions of the QoS parameters: throughput, delay, and jitter. The inclusion of jitter is the essential modification that results in a more comprehensive weight function. Weighting factors αi and βi are introduced in the expressions of delay and jitter contributions, respectively. The values of these factors in the real-time applications should be different from those in non-real-time applications. There is no obvious strategy to choose the values of αi and βi ; therefore, a trial-and-error technique is resorted to. The proposed algorithm is simulated using OPNET. Comparison is made with two powerful algorithms: WRR and MDRR. The results demonstrate that our algorithm outperforms the other two, with respect to throughput, delay, and jitter, as functions of the number of subscriber stations.

In a future research work, a systematic method for the choice of αi and βi will be devised. In addition, the algorithm will be extended to the channel-aware case. An interesting challenging task will be focused on the application of the algorithm to the newly established Long-Term Evolution (LTE) networks [22].

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