WiMAX DBA Algorithm Using a 2-Tier Max-Min Fair Sharing Policy

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Abstract. IEEE 802.16 leaves important issues like uplink bandwidth allocation to vendors. This paper proposes a WiMAX DBA algorithm using a 2-tier Max-Min Fair Sharing Policy (2tMMFS-DBA). In the first part of the algorithm, bandwidth reservations are set first for rtPS, then for nrtPS and BE applications. Next, the max-min fair sharing policy sets maximum connection demands for bandwidth requests and QoS provisioning. In the second part, the IEEE 802.16 MAC header is modified for piggybacking SS queue status messages to help base stations determine bandwidth allocation. 2tMMFS-DBA prioritizes bandwidth provisioning. An opportunity cost function bounds the cost of allocating bandwidth to different classes so as to maintain selected revenue levels to the service provider. Simulation shows the proposed dynamic provisioning scheme can satisfy the bandwidth requirements for different classes of traffic with overall improved system throughput.

Keywords: WiMax, IEEE 802.16e, QoS, DBA.

1 Introduction

The increasing popularity of cellular phones and similar devices is driving the development of wireless communication technology for voice, media and high capacity data rate services. Accordingly, IEEE 802.16e [1] is expected to support quality of service (QoS) for real time applications such as voice over IP (VoIP), video streaming and video conferencing with different QoS requirements and transmission guarantee. IEEE 802.16e's Mobile Broadband Wireless Access (BWA) is an extension providing for mobile subscriber stations (MSSs) and can even support MSSs moving at vehicular speeds. IEEE 802.16e also provides for combining fixed and mobile broadband wireless access. Compared to wired internet service providers, BWA systems are capable of faster deployment and lower deployment cost.

IEEE 802.16e is currently the most promising medium access control (MAC) protocol for high-speed wireless access in both the developed and developing world. At the MAC layer, each connection belongs to a single service flow type and is

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characterized by a set of QoS parameters. A number of uplink scheduling mechanisms are defined, including unsolicited bandwidth grants, polling and contention procedures. For uplink scheduling services, it supports five service flow types which identify specific sets of QoS parameters: UGS (unsolicited grant service), ertPS (extended real-time polling service), rtPS (real-time polling service), nrtPS (nonreal-time polling service), and BE (best effort). QoS in 802.16e is supported by allocating each connection between the SS and the BS (called a service flow) to a specific QoS class. Among them, UGS, ertPS, rtPS are suitable for real-time multimedia applications such as VoIP services.

Based on the IEEE 802.16 standard [2], WiMAX (Worldwide Interoperability for Microwave Access) provides high-speed data access for various transmission modes, e.g. point-to-multipoint links to portable and fully mobile Internet access. Two types of duplex methods separate uplink (UL) and downlink (DL) communication signals: Time Division Duplex (TDD) and Frequency Division Duplex (FDD). IEEE 802.16 defines two operation modes: the mesh mode and the point-to-multipoint (PMP) mode [3], [4]. In the mesh mode, direct communication between SSs without the need of a BS is supported. For the PMP mode (Fig. 1), multiple SSs and various public networks are connected by a BS.

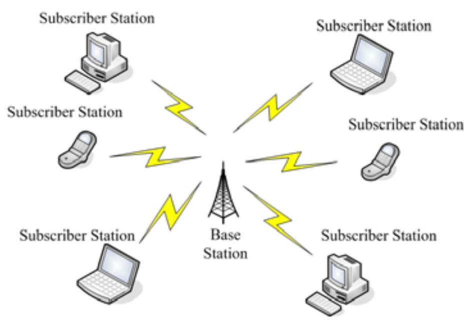

Fig. 1. Topology of WiMAX PMP networks

Implementation of the bandwidth allocation algorithm was not specified in the 802.16 standard [2]. A performance challenge in 802.16 TDD systems is the determination of the ratio of downlink to uplink capacities. TDD can handle flexibly both symmetric and asymmetric broadband traffic. Symmetric traffic using an equal split between uplink and downlink channels may lead to inefficient bandwidth utilization. Asymmetric traffic, such as ADSL, more demand for downloading and less for uploading, makes the bandwidth ratio determination problem even more complicated when the transport layer issue is taken into account. The last mile access for residential users tends to be asymmetric.

Chiang [5] proposed an Adaptive Bandwidth Allocation Scheme (ABAS) and Lei [6] proposed a CQQ scheme, dynamically adjust the Downlink/Uplink (DL/UL) bandwidth to match current DL/UL traffic in order to get better channel quality, but the method requires more complicated computing, resulting in reduced practical applicability. Chou [7] proposed the UBAR protocol (uplink bandwidth allocation and recovery), which employs a proportionally fair sharing scheme for efficient bandwidth utilization and further adopts a timeout-based UL-MAP retransmission scheme with uplink bandwidth reallocation algorithms to solve simultaneously bandwidth waste problems. But UBAR increases system complexity by modifying the TDD access mode. With regard to opportunity cost consideration, Bader [8] proposed what can be called the Rev scheme, which spans multiple time slots/frames and optimally allocates them to the different classes of traffic depending on their weights, the real-time bandwidth requirements of their connections, the channel quality conditions and the expected obtained revenues, but this scheme leads to least priority traffic BE starvation, therefore failing to achieve optimized fairness. Thus, Tsai [9] proposed the MMFS-DBA algorithm (a WiMAX DBA algorithm using a Max-Min Fair Sharing Policy). This system results in a real-time drop in calls due to insufficient real-time bandwidth reservation because no classification of real-time and non-real-time application traffic is included at the start.

The remainder of this study will focus on the issue of implementation of an efficient bandwidth allocation algorithm, such as is not specified in the IEEE 802.16 standard. This paper proposes a high performance WiMAX DBA (Dynamic Bandwidth Allocation) algorithm using a 2-tier Max-Min Fair Sharing Policy (2tMMFS-DBA). This algorithm adopts bandwidth reservations and the max-min fair sharing policy (MMFS) for efficient allocation of bandwidth. The rest of this paper is structured as follows: section 2 describes the proposed 2tMMFS-DBA algorithm. Simulation results are found in section 3. A final summary is presented in a concluding section.

2 2tMMFS-DBA Algorithm

The presented 2tMMFS-DBA algorithm is divided into two parts. In the first part of the algorithm, traffic classification, bandwidth reservation and QoS provisioning are performed, i.e. the different bandwidth reservations are set. The max-min fair sharing policy (MMFS) is used for the maximum connection demand for requested bandwidth, with QoS provisioning for rtPS applications. The requested bandwidth is allocated first to rtPS applications, then to nrtPS applications and finally to BE applications. BE applications have the least priority, i.e they have no QoS guarantee. To avoid starvation of BE applications, each applications has a weighting factor to make sure each achieves a relative QoS guarantee, with BE achieving at least a minimum available bandwidth to keep the BE alive in the WiMAX network. In the second part of the algorithm, the two reserved fields of the IEEE 802.16 generic MAC header are modified via monitoring of the SS queue status for urgent packets which need to be transmitted before other packets. It also monitors remaining packets in the SS queue. SSs are also allowed to ask for bandwidth via PiggyBack messages to the BS. Under the condition no requiring additional overhead, this allows the BS to make decisions for efficient allocation of bandwidth.

The 2tMMFS-DBA scheme especially considers QoS priority for optimal allocation of BS bandwidth to the SSs with regard to quality and system performance for real-time application services. The 2tMMFS-DBA method of BS allocation of bandwidth to the SSs improves the current IEEE 802.16 network, providing better QoS quality for multimedia services.

2.1 Bandwidth Reservation for rtPS Connection

This paper proposes a dynamic bandwidth provisioning scheme for future broadband wireless systems. The proposed scheme is designed to accommodate multi-class traffic with multiple connections having different bandwidth requirements and varying channel quality conditions. The main objective of our scheme is to optimally allocate bandwidth or the corresponding time frames for each class of traffic in order to satisfy the bandwidth requirements of their connections. In addition, the proposed scheme uniquely incorporates and bounds the cost (in terms of revenue loss) of bandwidth provisioning through an opportunity cost function. This provides greater flexibility to service providers for determining the levels of bandwidth provisioning to different traffic classes so as to guarantee a certain level of revenue.

To guarantee the real-time application services have higher QoS priority, this paper firstly considers the proportion, i.e. the number of rtPS connections occupying the number of total connections, thereby allowing determination of reserve rtPS connection bandwidth BW_{res_rtPS} as in equation (1). This ensures that rtPS connections have a higher QoS guarantee.

The notation in this paper is as follows:

N_{rtPS} : the number of rtPS connections

W_{rtPS} : the system weighting value for rtPS maximum connections

N_c : the total number of system connections

BW_{tot} : the total system bandwidth for the BS

BW_{res_rtPS} : the bandwidth reservation for rtPS

$BW_{res\_\max}$: the maximum bandwidth reservation for rtPS

$$BW_{res\_rtPS} = \begin{cases} BW_{res\_\max}, & if \quad \dfrac{N_{rtPS}}{N_c} > W_{rtPS} \\ W_{rtPS} \times BW_{tot}, & if \quad \dfrac{N_{rtPS}}{N_c} \le W_{rtPS} \end{cases} \tag{1}$$

Max-Min Fair Bandwidth Sharing

In order to satisfy the maximum bandwidth request for the SS connection, this paper extends the Max-Min Fair Sharing Policy (MMFS), first using equations (2) and (3) to obtain the average bandwidth of the rtPS and (nrtPS +BE) connections, designated respectively BW_{avg_rtPS} and $BW_{avg\_nrtPS+BE}$. Then the Max-Min Fair Bandwidth Sharing policy is executed to satisfy the demands of the maximum bandwidth request of the rtPS and (nrtPS +BE) connections.

$$BW_{avg\_rtPS} = \frac{BW_{res\_rtPS}}{N_{rtPS}} \tag{2}$$

$$BW_{avg\_nrtPS+BE} = \frac{BW_{tot} - BW_{res\_rtPS}}{N_c - N_{rtPS}} \tag{3}$$

It is first determined whether the reserved rtPS bandwidth BW_{res_rtPS} for the rtPS connection is equal to or greater than the entire bandwidth request of the rtPS connection ($BW_{req,i}$). If YES, then there is enough bandwidth for the entire bandwidth request of the rtPS connection, so the reservation bandwidth is allocated to the rtPS connection as in equation (4), where i is the number of SS and δ_i is the bandwidth allocated to SS_i.

$$\delta_i = BW_{req,i} \tag{4}$$

Otherwise, when the reserved rtPS bandwidth BW_{res_rtPS} is less than the entire bandwidth request of the rtPS connection ($BW_{req,i}$), then the reserved bandwidth is insufficient for the entire bandwidth request of the rtPS connection. In this case, i.e. $BW_{req,i} > BW_{avg\_rtPS}$, so the MMFS scheme in equation (2) is executed to allocate the minimum necessary bandwidth $R_{\min}$ to the rtPS connection, otherwise allocating the necessary bandwidth request $BW_{req,i}$ to the rtPS connection, as in equation (5).

$$\delta_i = \begin{cases} BW_{req,i}, & if \quad BW_{req,i} \le BW_{avg\_rtPS} \\ R_{\min}, & if \quad BW_{req,i} > BW_{avg\_rtPS} \end{cases} \tag{5}$$

Similarly, bandwidth is allocated to the nrtPS, BE connection using the same way as in equations (1) to (5). After allocation, the information must be updated as in equation (6). BW_a is the remainder of the available bandwidth. The 2nd part will execute if $BW_a > 0$ in the 1st run of 2tMMFS-DBA scheme.

$$BW_a = BW_{tot} - \sum_{1}^{N_c} \delta_i \tag{6}$$

The first part of the 2tMMFS-DBA scheme is for rtPS application service with the greatest QoS guarantee. Thus, the rtPS service is handled first, calculating the average bandwidth BW_{avg} for each service flow, then executing the MMFS scheme for fair allocation of the bandwidth. After rtPS service traffic allocation is completed, a similar process is performed for non-real-time application service and finally for the BE service.

2.2 Evaluation of SS Queue Status

A request may be corrupted due to a collision when SSs perform bandwidth requests. Kim [10] proposed modifing the IEEE 802.16 generic MAC header in order to let an SS pass the message to the BS by transmitting data, so the BS allows the SS bandwidth request if no collision occurs. This idea is extended in the second part of the 2tMMFS-DBA algorithm, using two reserved bits in the IEEE 802.16 generic MAC header, one for the Critical Data bit (CD), the other for the Backlogged Data bit (BD) as shown in Fig. 2. As a result, with no additional SS overhead, the BS gets important information via an SS Piggyback message which monitors the packet status of the SS queue, including evaluation of critical data and/or backlogged data packets in the SS queue. The CD bit is for urgent packets that need to be transmitted in the SS queue. The BD bit is for packets not yet transmitted in the SS queue. The BS can use this information to allocate bandwidth more efficiently.

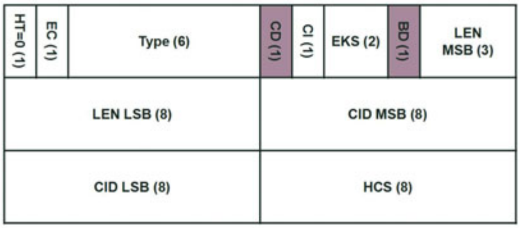

Fig. 2. IEEE 802.16 generic MAC header

Because of real-time service must take more better care of packet delay time, therefore rtPS need higher QoS priority to guarantee quality. Accordingly, the second part of the 2tMMFS-DBA system, with reference to [9], [11], calculates the rtPS packet delay expiry time $Deadline_k$ as in equation (7) and the expected Remain Time $RemainTime\, t_r$ for packet send-out as in equation (8). In equation (7), the rtPS packet delay expiry time $Deadline_k$ is the packet arriving time $ArrivalTime\, t_0$ plus $MaxLatency$. In equation (8), the expected Remain Time $RemainTime\, t_r$ for packet k to send out, is $Deadline_k$ minus the system current time $CurrentTime\, t_c$, where k is the transmitting packet number. The Critical Data CD bit is set to “1” if $RemainTime\, t_r$ is not more than one $Frame\, Duration$ time, as equation (9). This means that it is urgent that the packet be sent out.

$$Deadline_k = ArrivalTime\, t_0 + MaxLatency \tag{7}$$

$$RemainTime\, t_r = Deadline_k - CurrentTime\, t_c \tag{8}$$

$$If \quad t_r \le Frame\, Duration \;\; then\; CD\; bit = \;\text{"1"} \tag{9}$$

After the full run (rtPS, nrtPS, BE) of the first part of the 2tMMFS-DBA algorithm, the rest of the bandwidth BW_a is assigned averagely to the critical rtPS service flow in the SS queue. In equation (10), $BW_{ins,i}$ indicates the insufficient bandwidth request for rtPS service connection i after running of the first part of 2tMMFS-DBA. In equation (11), α_i is the average proportion to the rest of the bandwidth BW_a for the insufficient request bandwidth for rtPS service connection. The goal of equation (12) is to limit the obtained bandwidth so that is not greater than the original request bandwidth for rtPS service connection. Then equation (13) is used to update the rest of the bandwidth $BW_a^{'}$. Similar methodology is used to allocate bandwidth to the critical nrtPS and BE connections as in equations (10), (11) and (12).

$$BW_{ins,i} = BW_{req,i} - \delta_i \tag{10}$$

$$\alpha_i = BW_a \times \frac{BW_{ins,i}}{\sum_{SS_i \in\, rtPS \,\wedge\, CDbit=\text{"1"}} BW_{ins,i}} \tag{11}$$

$$\delta_i^{'} = \begin{cases} \delta_i + \alpha_i, & if \;\; (\delta_i + \alpha_i) < BW_{req,i} \\ BW_{req,i}, & if \;\; (\delta_i + \alpha_i) \ge BW_{req,i} \end{cases} \tag{12}$$

$$BW_a^{'} = BW_a - \sum_{1}^{N_{rtPS}} \delta_i^{'} \quad (13)$$

After the above process, the Backlogged Data BD bit in the IEEE 802.16 generic MAC header is changed to “1” if there is rtPS service still left in SS queue, as in equation (14). For BSs receiving this information (i.e. BD marked to “1”), the rest of the bandwidth $BW_a^{'}$ is assigned averagely to the rtPS service flow in the SS queue. $BW_{ins,i}$ is the insufficient request bandwidth for rtPS service connection i after full run of the first part of 2tMMFS-DBA. In equation (15), β_i is the average proportion to the rest of the bandwidth $BW_a^{'}$ for the $BW_{ins,i}$ for rtPS service connection. Equation (16) ensures the obtained bandwidth is not greater than the original request bandwidth for rtPS service connection. Then equation (17) is used to update the rest of the bandwidth $BW_a^{'}$. Similar methodology is used to allocate bandwidth to the critical nrtPS and BE connections as in equations (14), (15) and (16).

$$If \;\; sizeof(SS_i \in rtPS) > 0 \;\; then\; BD\; bit = \;"1" \quad (14)$$

$$\beta_i = BW_a^{'} \times \frac{BW_{ins,i}}{\sum_{BDbit="1"} BW_{ins,i}} \quad (15)$$

$$\delta_i^{"} = \begin{cases} \delta_i^{'} + \beta_i, & if \;\; (\delta_i^{'} + \beta_i) < BW_{req,i} \\ BW_{req,i}, & if \;\; (\delta_i^{'} + \beta_i) \geq BW_{req,i} \end{cases} \quad (16)$$

$$BW_a^{"} = BW_a^{'} - \sum_{1}^{N_{rtPS}} \delta_i^{"} \quad (17)$$

3 Simulation Results

This paper focuses on the IEEE 802.16 point-to-multipoint (PMP) mode, which is the primary operating mode of WiMAX for residential users. Under PMP, the IEEE 802.16e wireless network with a central BS serves several SSs and each SS communicates with the BS directly (Fig. 1).

To evaluate performance, 2tMMFS-DBA functionality is simulated by the SIMSCRIPT II.5 language for numerical analysis. The system weighting value is 0.3. The BS bandwidth is 20 Mbps. The entry possibility of UGS, rtPS, nrtPS, BS is 30%, 50%, 70%, 100%, respectively. This means for example, if the number of the connections =100, then UGS gets 30 (=100*30%), rtPS gets 35 (=(100-30)*50%), nrtPS gets 24.5(=(70-35)*70%) and BE gets 10.5(=(35-24.5)*100%). In order to obtain more detailed simulation values, the number of SSs is increased by 5.

Compared with Bader’s Rev scheme [8], Fig. 3 shows that dropping rate of the proposed algorithm is 12.44% lower (better) for rtPS connections when the number of SSs is over 35. At the same time, it is 2% higher (worse) for nrtPS connections, 1.17% higher (worse) for BE connections. Fig. 5 shows that the throughput of the proposed algorithm is 1.2 Mbps higher (better) when the number of SSs over 10.

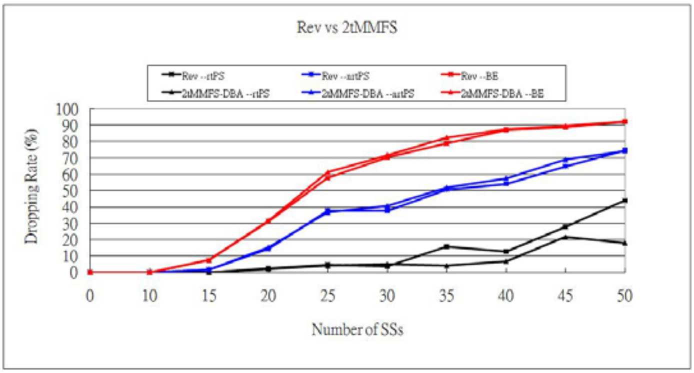

Fig. 3. Dropping rate for Rev vs 2tMMFS

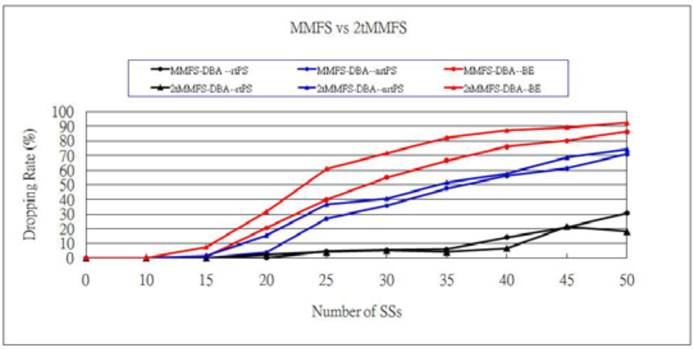

Fig. 4. Dropping rate for MMFS vs 2tMMFS

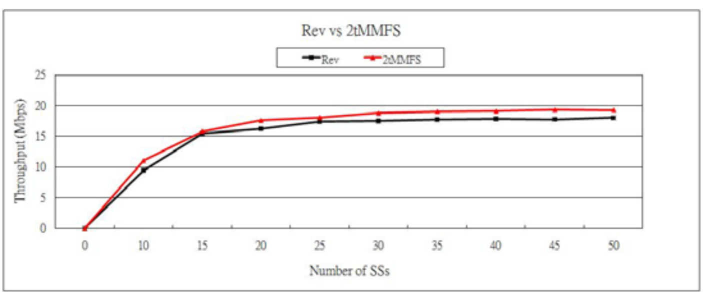

Fig. 5. Throughput for Rev vs 2tMMFS

Compared with Tsai's MMFS scheme [9], Fig. 4 shows that dropping rate of the proposed algorithm is 5.35% lower (better) for rtPS connections when the number of SSs over 35. At the same time, it is 4.15% higher (worse) for nrtPS connections and 10.57% higher (worse) in BE connections. Fig. 6 shows that the throughput of the proposed algorithm is 0.17 Mbps higher (better) when the number of SSs over 10. The results show that the proposed algorithm delivers better QoS for the prioritized rtPS users, with overall better system throughput.

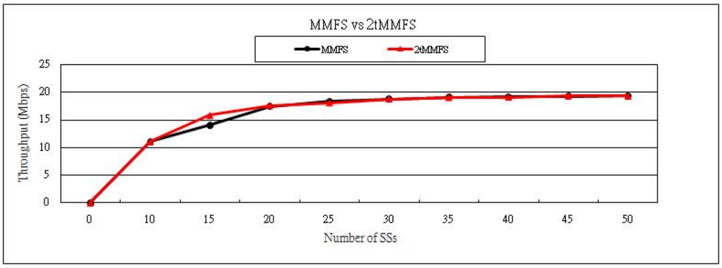

Fig. 6. Throughput for MMFS vs 2tMMFS

4 Conclusions

Future broadband wireless systems will support a wide range of multimedia applications for mobile users. However, to maximize user experience, bandwidth provisioning is critical. In this paper, a novel bandwidth provisioning scheme for broadband wireless network is proposed. The proposed scheme allows for prioritized bandwidth provisioning to different classes of traffic for support of multiple connections with different bandwidth requirements. It also incorporates a unique opportunity cost function to bound the cost of allocating bandwidth to different classes so as to maintain certain revenue levels to the service provider. Simulation results reveal the presented 2tMMFS-DBA algorithm efficiently allocates bandwidth for improved urgent multimedia requirements and provides higher QoS guarantees in IEEE 802.16e networks, with overall enhanced system throughput.

Fixed class weights, however, cannot achieve optimized fairness since the performance of each class is not fixed due to the varying bandwidth requirements and varying channel quality conditions. Thus, our future work will study a dynamic weight update scheme to compute dynamically the weights of different classes of traffic based on their performance history in order to maximize inter-class fairness. This way, the resulting fairness will be more adaptive to the performance of the classes since it is based on their performance history.

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