WiMAX DBA Algorithm Prioritizes Bandwidth Provision by Using a Reserved 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 an enhanced WiMAX DBA (Dynamic Bandwidth Allocation) algorithm using a reserved 2-tier Max-Min Fair Sharing Policy (2tMMFS_reserved-DBA) to improve the system performance than our previous 2tMMFS-DBA one. First, the algorithm reserves 10% of the total bandwidth for rtPS application before bandwidth reservations are set for nrtPS and BE applications. Next, the max-min fair sharing policy sets connection demands for bandwidth requests and QoS provisioning. The IEEE 802.16 MAC header is modified for piggybacking SS (Subscriber Station) queue status messages to help base stations determine bandwidth allocation. 2tMMFS reserved-DBA prioritizes bandwidth provisioning. Simulation shows the proposed dynamic provisioning scheme 2tMMFS_reserved-DBA works better QoS quality for rtPS, even for nrtPS applications to satisfy the bandwidth requirements for different classes of traffic with equal or improved system throughput.

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

1 Introduction

Thanks to the rapid expansion of wireless networks and smart devices, popular mobile devices now ship with several integrated wired and wireless network interfaces. For example, Personal Digital Assistants (PDAs) and smartphones are increasingly supporting communications through cellular technologies and Wireless LANs (WLANs). Laptops typically come with built-in Ethernet, Wi-Fi and Bluetooth. The wireless communication revolution brings integrated networks a reality, fundamental changes to data networking, Internet, telecommunication. That is to say, 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

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different time intervals. FDD handles asymmetric data services inefficiently since data traffic often occupies only a small portion of a channel bandwidth at any given time. TDD has better spectral efficiency than FDD and can adjust dynamically the downlink to uplink (DL/UL) ratio. In other words, TDD can handle flexibly both symmetric and asymmetric broadband traffic. This present paper considers only the TDD system.

IEEE 802.16 BWA systems provide for fixed-wireless access networks between subscriber stations (SS) and internet service providers (ISP) through base stations (BS). A BS provides connectivity, management and bandwidth control among SSs, which may be found in traditional wireless or wired local area networks (LAN). BWA provides internetworking access to wireless networks through external antennas. 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 (Figure 2), multiple SSs and various public networks are connected by a BS.

Before SSs send data packets to a BS, one or more connections are established between the application and the BS. Each BS/SS connection is identified by a 16-bit connection identifier (CID). The communication path is bi-directional: DL and UL. Downlinking is from BS to SS, and uplinking is from SS to BS. When using TDD for UL and DL transmissions (Figure 3), the frame is subdivided into UL and DL subframes. Subframe duration is dynamically determined by the BS, with each subframe being composed of a number of time slots. The BS and SSs must be synchronized before data packet transmission. After coordination is established between the BS and the SSs, data packets are transmitted into predetermined time slots. Data cannot be transmitted by an SS until the BS allocates an UL grant. When taking part in contention resolution, an SS can send a bandwidth request. 802.16e thus provides strong QoS support. Although providing the main principles for a QoS architecture that supports multimedia applications, certain important issues like uplink bandwidth allocation are left to the vendors.

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 algorithm using a reserved 2-tier Max-Min Fair Sharing Policy. This algorithm first reserves 10% of the bandwidth for rtPS applications, then adopts bandwidth reservation and the max-min fair sharing policy (MMFS) for efficient allocation of the remaining bandwidth. Section 2 introduces the IEEE 802.16e QoS structure and related studies. Section 3 describes the proposed 2tMMFS-reserved-DBA algorithm. Simulation results are found in Section 4. A final summary is presented in a concluding section.

2 Related Work

2.1 IEEE 802.16 QoS Structure

QoS is supported by IEEE 802.16e for real time applications, guaranteeing transmission quality. IEEE 802.16e is a connection-oriented MAC protocol [1-2]. At the MAC layer, each connection belongs to a single service flow type and is 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 as shown in Figure 4, which identify specific sets of QoS parameters:

- **UGS (unsolicited grant service):** The UGS is designed to support real-time service flow with a constant bit rate (CBR) at periodic intervals such as T1/E1 transport.
- **ertPS (extended real-time polling service):** The ertPS is designed to support real-time service flow with a variable bit rate (VBR) on a periodic basis (i.e., the BS provides dynamic sized resources to the SS periodically) such as voice over IP (VoIP) without silence suppression.
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rtPS (real-time polling service): The rtPS is designed to support real-time service flow with a variable bit rate (VBR) at periodic intervals such as MPEG video.

nrtPS (nonreal-time polling service): The nrtPS is designed to support non-real-time service flow with minimum throughput guarantee such as FTP, and SSH.

BE (best effort): BE service provides no guarantees and is used for services such as email and HTTP.

The priority among these service flows is UGS > rtPS/rtPS > nrtPS > BE. 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, rtPS, rtPS are suitable for real-time multimedia applications such as VoIP services.

When an SS wants to upload a data traffic flow, it first sends a DSA-REQ (dynamic service addition request) message specifying its QoS requirements to the BS. If uplink bandwidth resources are adequate, the BS will admit the SS and reply with a DSA-RSP (DSA response) message to the SS. After receiving the DSA-ACK reply from the SS, the BS will put the SS on the polling list and then allocate the proper UL-burst duration to the SS according to its bandwidth demand and QoS requirements. The BS scheduler needs to provide polls and/or grants to connections at appropriate times such that the QoS associated with the scheduling service for each connection can be satisfied. In this paper, we consider the rtPS scheduling service, in which the SS asks for bandwidth for a connection by sending a request to the BS within the bandwidth request contention slots in the uplink sub-frame. If the request is corrupted due to collision, the SS enters the contention resolution process. The contention resolution mechanism focuses on analysis of the important metrics regarding collision probability and network throughput among the distributed mobile nodes at a point in time when the network traffic load is near saturation [5-6]. With the BE scheduling service, SSs are also allowed to request for bandwidth via Piggyback Bandwidth Requests.

2.2 Related Study

The 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 (i.e., more demand for downloading and less for uploading).

Chiang [7] considered the impact of improper bandwidth ratio on TCP performance and proposed an Adaptive Bandwidth Allocation Scheme (ABAS) which adjusts the bandwidth ratio, i.e., allocates bandwidths to uplink and downlink channels according to the current traffic profile. The ABAS scheme also cooperates with the scheduler to throttle the TCP source when acknowledgements are infrequent. Lei [8] proposed a CQQ scheme with a bandwidth allocation algorithm with channel quality awareness and QoS guarantee. The CQQ partitions the DL/UL bandwidth according to current DL/UL bandwidth requirements, allocating enough bandwidth to satisfy the connections’ QoS requirements and dispatching more remainder bandwidth to the connections with a better-quality channel. Both Chiang and Lei 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.

In all cases, noise is unavoidable in wireless networks, even when operating in the licensed band. In particular, if the noise source is close to the BS such that the UL-MAP message is destroyed, then the entire UL-subframe is idle and completely wasted since the affected SSs do not know when they can upload MPDUs. This phenomenon is called the idling UL-subframe problem [9]. Further uplink bandwidth-waste occurs when the noise sources are close to some SSs such that they cannot correctly decode the UL-MAP. Such a phenomenon is called the uplink hole problem [9]. Uplink bandwidth waste may also occur when the granted transmission for an SS is much larger than its current demand by at least a MAC header. In this case, the BS should transmit up to a maximum of 2,041 bytes redundant MPDU padding to the BS, a phenomenon that is called the padding waste problem [9]. This problem may be inevitable, especially during the lifetime of an rtPS flow, because: (1) a BS’s uplink bandwidth allocation algorithm
may be imperfectly designed and thus falsely predicts an SS’s current demand or; (2) the SS’s demand may suddenly change due to the drop of some real-time data in queue whose deadline is now expired.

Because of air interference and dynamic queue state changes in SSs, the three bandwidth-waste problems mentioned above are inevitable. Surprisingly, IEEE 802.16 does not provide any mechanisms to deal with these problems. Chou [9] 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 the three bandwidth waste problems. But UBAR increases system complexity by modifying the TDD access mode.

With regard to opportunity cost consideration, Bader [10] 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 [11] 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. Therefore, our previous paper proposed a 2-tier Max-Min Fair Sharing Policy (2tMMFS-DBA) [12] to deal with this problem, but better QoS was obtained only for rtPS applications.

3 2tMMFS_Reserved-DBA Algorithm

The presented 2tMMFS_Reserved-DBA algorithm is divided into two parts. The first part of the algorithm, before bandwidth reservation, reserves 10% of the total bandwidth for the rtPS connection, and then performs traffic classification, bandwidth reservation and QoS provisioning, 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 application 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_reserved-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_reserved-DBA method of BS allocation of bandwidth to the SSs improves the current IEEE 802.16 network, providing better QoS quality for rtPS, even for nrtPS applications than 2tMMFS-DBA one does.

3.1 Bandwidth Reservation for rtPS Connection

This paper proposes a dynamic bandwidth provisioning 2tMMFS_reserved-DBA algorithm to improve the system performance relative to our previous 2tMMFS-DBA 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 first reserves 10% of the total bandwidth for the rtPS connection before bandwidth reservation, after which it 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.
- $BW_{max}$: the maximum bandwidth reservation for rtPS.
3.1.1 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 Equation (2) and Equation (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.

\[
BW_{avg,rtPS} = \begin{cases} 
    BW_{res,rtPS} + 10\% \times BW_{req,i} & \text{if } \frac{N_{rtPS}}{N_i} > W_{rtPS} \\
    W_{rtPS} \times 90\% \times BW_{req,i} + 10\% \times BW_{req,i} & \text{if } \frac{N_{rtPS}}{N_i} \leq W_{rtPS}
\end{cases}
\]  

(1)

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 (\( BW_{req,rtPS} \)). 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 \( \delta_i \) is the bandwidth allocated to SS,

\[
\delta_i = BW_{req,i}
\]

(4)

Otherwise, when the reserved rtPS bandwidth \( BW_{res,rtPS} \) is less than the entire bandwidth request of the rtPS connection (\( BW_{req,rtPS} \)), 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).

\[
\delta_i = \begin{cases} 
    BW_{req,i} & \text{if } BW_{req,i} \leq BW_{avg,rtPS} \\
    R_{min} & \text{if } BW_{req,i} > BW_{avg,rtPS}
\end{cases}
\]

(5)

Similarly, bandwidth is allocated to the nrtPS, BE connection using the same way as in Equation (1) to Equation (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\_reserved-DBA scheme.

\[
BW_a = BW_{res} - \sum_{i=1}^{N_s} \delta_i
\]

(6)

The first part of the 2tMMFS\_reserved-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.

3.2 Evaluation of SS Queue Status

A request may be corrupted due to a collision when SSs perform bandwidth requests. Kim [13] proposed modifying 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\_reserved-DBA algorithm which is the same as used in the 2tMMFS-DBA algorithm [12], 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 Figure 5. 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.

![Figure 5 IEEE 802.16 Generic MAC Header](image-url)
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 Equation (14), Equation (15) and Equation (16).

If $\text{sizeof}(SS_i \in \text{rtPS}) > 0$ then $\text{BD bit} = "1"$  \hspace{1cm} (14)

$$\beta_i = \frac{BW_{a}' \times BW_{\text{req}, i}}{\sum_{k \in \text{rtPS}, CTD0 = 0} BW_{\text{req}, k}}$$  \hspace{1cm} (15)

$$\delta'_i = \begin{cases} \delta'_i + \beta_i, & \text{if } (\delta'_i + \beta_i) < BW_{\text{req}, i} \\ \frac{BW_{\text{req}, i}}{BW_{\text{req}, i}}, & \text{if } (\delta'_i + \beta_i) \geq BW_{\text{req}, i} \end{cases}$$  \hspace{1cm} (16)

$$BW_{a}' = BW_{a}' - \sum_{i} \delta'_i$$  \hspace{1cm} (17)

4 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 (Figure 2).

To evaluate performance, 2tMMFS_reserved-DBA functionality is simulated by the SIMSCRIPT II.5 language for numerical analysis, with related system and QoS parameters as in Table 1. The system weighting value is 0.3. The BS bandwidth is 20 Mbps. The reserved bandwidth for rtPS is 2 Mbps (= 20 × 10%). 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 50 (= (100 – 30) × 50%), nrtPS gets 70 (= (70 – 35) × 70%) and BE gets 10 (= (35 – 24.5) × 100%). In order to obtain more detailed simulation values, the number of SSs is increased by 5.

The following result analysis is under the observation when the number of SSs is over 20. Compared with Bader’s Rev scheme [10], Figure 6 shows that dropping rate of the proposed algorithm is 7.66% lower (better) for rtPS connections. It is 5.83% lower (better) for nrtPS connections, 13.63% lower (better) for BE connections. Compared with Tsai’s MMFS scheme [11], Figure 7 shows that dropping rate of the proposed algorithm is 3.52% lower (better) for rtPS connections. It is 1.26% lower (better) for nrtPS connections and 1.98% lower (better) in BE connections. Compared with our previous 2tMMFS scheme [12], Figure 8 shows that dropping rate of the proposed algorithm is 3.11% lower (better) for rtPS connections. It is 0.63% higher (worse) for nrtPS connections and 1.23% lower (better) in BE connections. Figure 9 shows that the
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Table 1 System Parameters

<table>
<thead>
<tr>
<th>System Parameters</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Number of BS</td>
<td>1</td>
</tr>
<tr>
<td>Number of SSs</td>
<td>10 ~ 50</td>
</tr>
<tr>
<td>Packet size</td>
<td>200 Byte</td>
</tr>
<tr>
<td>Maximum delay time</td>
<td>15 ms</td>
</tr>
<tr>
<td>Distance</td>
<td>150 m</td>
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<tr>
<td>System bandwidth</td>
<td>20 Mbits</td>
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<tr>
<td>UGS service</td>
<td>64 kbits</td>
</tr>
<tr>
<td>rtPS service</td>
<td>0.12 ~ 0.42 Mbits</td>
</tr>
<tr>
<td>nrtPS service</td>
<td>0.6 ~ 2.4 Mbits</td>
</tr>
<tr>
<td>BE service</td>
<td>2.4 Mbits</td>
</tr>
</tbody>
</table>

Figure 6 Dropping Rate for Rev vs. 2tMMFS_reserved

Figure 7 Dropping Rate for MMFS vs. 2tMMFS_reserved

Figure 8 Dropping rate for 2tMMFS vs. 2tMMFS_reserved

throughput of the proposed algorithm is 1.22 Mbps higher (better) than Rev one, 0.10 Mbps lower (worse) than MMFS one, and 0.06 Mbps lower (worse) than 2tMMFS one. The results show that the proposed 2tMMFS_reserved-DBA algorithm delivers better QoS for the prioritized rtPS users, even for nrtPS users, with approximately equal or better system throughput.

5 Conclusion

There is no doubt that future broadband wireless systems will support a wide range of multimedia applications for mobile users. However, to maximize user experience, bandwidth provisioning is critical. This paper has proposed the 2tMMFS_reserved-DBA algorithm, which improves the system performance of our previous 2tMMFS-DBA scheme. The proposed system first reserves 10% of the total bandwidth for the rtPS connection prior to bandwidth reservation, and then 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_reserved-DBA algorithm delivers better QoS for the prioritized rtPS, even for nrtPS applications with approximately equal or superior system throughput.

Acknowledgements

This research was supported by National Science Council of Taiwan under project number NSC 99-2218-E-277-001.

References


Biographies


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