An Adaptive QoS Architecture for IEEE 802.16 Broadband Wireless Networks

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Abstract

In this paper, we propose a new QoS architecture for PMP 802.16 systems operating in TDD mode over WirelessMAN-OFDM physical layer. It includes a call admission control policy and a hierarchical scheduling algorithm. The CAC policy we propose adopts a Min-Max fairness approach making efficient and fair use of available resources. The proposed scheduling algorithm flexibly adjusts uplink and downlink bandwidth to serve unbalanced traffic while considering adaptive modulation and coding (AMC) scheme. The efficiency of the proposed QoS architecture is revealed through simulation.

Keywords: IEEE 802.16, QoS, TDD, OFDM, scheduling, CAC, Min-Max fairness, performance evaluation.

1 Introduction

The IEEE 802.16 standard [2] defines a connection-oriented MAC protocol where all the transmissions occur within a context of a unidirectional connection. Each connection is associated to an admitted or active service flow (SF) whose characteristics provide the QoS requirements to apply for the PDUs exchanged on that connection. Depending on the service to be tailored to each user application, the connection is associated with one of the following scheduling services supported by the 802.16 MAC protocol: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Non-real-time Polling Service (nrtPS), and Best Effort (BE) [2]. The standard proposes several techniques that can be used by the SS to inform the BS of its uplink bandwidth requirement. Since the SS receives the allocated bandwidth as a whole in response to a per-connection requests, it cannot know which request is honored.

Note that, when considering TDD mode the size of the superframe [2] is constant whereas the downlink and the uplink subframe sizes shall vary within the shared frame according to what is specified in the mapping messages (DLFP and UL-MAP). However, in most related research works [4, 5] emphasis is on UL scheduling. To the best of our knowledge, [3] is the only research work that has proposed a scheduling algorithm considering simultaneously uplink and downlink bandwidth allocation. Actually, our proposal was partially inspired by what was proposed in this work since we choose to perform a simultaneous scheduling between UL and DL.

The remaining of this paper is organized as follows. The CAC and scheduling procedures we propose are described in Section 2. In Section 3, we provide simulation results of our proposal. Finally, Section 4 concludes the paper.

2 Uplink and downlink scheduling

2.1 Hierarchical scheduling structure

As a starting point, we can consider the two-layer hierarchical scheduling structure proposed by Chen *et al* [3]. In first layer scheduling, the authors have suggested a combination of a transmission direction based priority where they choose to attribute to DL a higher priority than UL and a service class based priority applying the following scheme: $rtPS > nrtPS > BE$. For DL and UL UGS connections, they have chosen to apply a fixed bandwidth allocation strategy. In second layer scheduling, they have proposed the use of Deficit Fair Priority Queuing (DFPQ) algorithm. In the scheduling structure we propose, we conserve the hierarchical aspect of scheduling while avoiding the use of cyclic algorithms like DFPQ. A strict priority scheme is then applied: DL_{UGS}> UL_{UGS}> DL_{rtPS}> UL_{rtPS}> DL_{nrtPS}> UL_{nrtPS}> DL_{BE}>UL_{BE}. As for the SS, the scheduling procedure is easier since the only connections to be managed are those it establishes with the BS in the UL direction.

2.2 The BS scheduling algorithm

Let S_{pkt}, S_{gmh}, and S_{crc} denote the size (in bytes) of an IP packet, a generic MAC header, and a CRC field, respectively. For a given connection j, N_i is the number of packets that are transmitted during the i last frame intervals and B_{max} and B_{min} stand for the Maximum Sustained, and the Minimum Reserved Traffic Rate, respectively. Let B denote the rate to be considered during the scheduling procedure; with $B_{min} \leq B \leq B_{max}$. B corresponds to the maximum actual rate at which the connection is allowed to transmit its data. Let Q_i and R_i denote the number of packets that are waiting in the queue of connection j and the amount of its requested bandwidth (in bits). The use of R_i is meaningless in the case of an UGS connection. In the beginning of each frame interval i, the number of packets n_i to transmit per connection j should be calculated given N_{i-1}, B, S_{pkt}, and Q_i when j is a DL connection or R_i when j is a non-UGS UL connection. Indeed to compute n_i, we shall consider the three following cases:

- **Case 1:** j **is a DL connection:** The idea is that the scheduling policy tries to offer to connection j the possibility of transmitting a number n_i of packets big enough to guarantee to connection j the maximum rate allowed by the CAC module. Obviously, this does not imply that n_i can be bigger than the number of packets waiting in the queue of connection j:
$n_i = \min\left(\left\lceil \frac{B*i*T_{frame}}{S_{pkt}*8} \right\rceil - N_{i-1}, Q_i\right)$.

- **Case 2:** j **is an UL UGS connection:** In this case the scheduling policy should offer to connection j the possibility of transmitting a number n_i of packets big enough to guarantee to connection j to reach the Maximum Sustained Traffic Rate specified in its service flow: $n_i = \left\lceil \frac{B_{max}*i*T_{frame}}{S_{pkt}*8} \right\rceil - N_{i-1}$.

- **Case 3:** j **is a non-UGS UL connection:** The bandwidth requirements of non-UGS connections must be explicitly formulated by the SS scheduler, which is the better-informed of the UL queues status. This bandwidth request, corresponding here to the parameter R_i, is formulated during the (i-1)th frame interval and represents the amount of bandwidth needed during the i^{th} frame interval. However, the BS scheduler must check whether R_i exceeds what has been fixed by the CAC module; in which case, it performs a kind of shaping by choosing the minimum between what has been requested by the SS scheduler and what would normally be planned by the BS scheduler in order to guarantee the maximum rate allowed by the CAC module for connection j for the i last frame intervals:
$n_i = \min\left(\frac{R_i}{S_{gmh}+S_{pkt}+S_{crc}}, \left\lceil \frac{B*i*T_{frame}}{S_{pkt}*8} \right\rceil - N_{i-1}\right)$.

2.3 Admission control policy

The admission control mechanism is performed when an SS or a BS attempts to establish a new active connection and also when an SS uses a more or less robust DL or UL burst profile. The admission control mechanism proceeds as follows:

1. It accepts all BE addition requests since they don't have any QoS requirements.

2. It checks whether it is possible to guarantee the Maximum Sustained Traffic Rate for all the considered non-BE connections: existing connections and the one attempting to be established. To do that : (1) it first computes the ceiling number n of packets to serve per frame for each connection as follows: $n = \left\lceil \frac{B_{max}*i*T_{frame}}{S_{pkt}*8} \right\rceil$, (2) then it calculates the overhead resulting from the transmission of these n packets. If the available bandwidth allows such grants—for all the considered connections—then the new connection is accepted and the available bandwidth B corresponds to B_{max}, otherwise:

3. It checks whether it is possible to guarantee the B_{min} for all the considered non-BE connections. If it is not possible, the connection addition request is rejected, otherwise B is set to B_{min} and:

4. If there is a remaining amount of bandwidth, then it is shared among existing rtPS and nrtPS connections since only these services have specific QoS requirements and may have better rates than B_{min}.

3 Performance Analysis

In this section, we study the performance of the proposed CAC and scheduling solution for different scheduling services in networks involving multiple SSs using the same or different modulations. The network considered here is composed of one BS and three SSs. We assume that the three SSs have the same channel conditions and use the

	SF parameters			Simulation Time (frame interval)		
	B_{max} (Mbps)	B_{min} (Mbps)	S_{pkt} (B)	0-1000	1000-4000	4000-8000
UGS	5	5	1500	√	√	√
rtPS	6	2	1500	√	√	√
nrtPS	3	1	1500	√	√	√
BE	0.7	0	1500	√	√	√
UGS	2.5	2.5	1500		√	√
rtPS	5	3	1500		√	√
nrtPS	7	2	1500		√	√
BE	0.3	0	1500		√	√
UGS#1	1	1	1500			√
UGS#2	3	3	1500			√
nrtPS#1	1.5	0.5	1500			√
nrtPS#2	2.5	0.5	1500			√

Table 1. Scenario parameters

same modulation type[1]. They enter the network at different time intervals. Each of them tries to establish a set of connections with the BS and vice versa. The parameters of these connections as well as their durations are reported in Table 1. Figure 1 depicts the goodput of each connection during the simulation time. In the first time interval (from frame 1 to frame 1000), only SS1 is connected to the BS. Its connections are granted the maximum rate specified in their respective service flows. When SS2 enters the network, we note that SS1 UGS connection conserves the same rate while SS1 rtPS and nrtPS connections goodputs decrease and reach values a little bit more than their respective minimum reserved rates. Both BE connections succeed however to have the maximum sustained traffic rate specified in their SFs. At frame 4000 (corresponding to 40s after the beginning of the simulation), SS3 joins the network. Only two of the four connections it attempts to establish with the BS are accepted by the CAC module. The network has reached its maximum capacity. Indeed, all connections are getting granted only the minimum reserved rate and this explains the CAC decision since accepting another connection would have degraded the QoS of existing ones. After granting UGS and polling connections, the remaining bandwidth allows nevertheless SS1 and SS2 BE connections to send some data.

4 Conclusion and future work

Despite including the possibility of QoS support, 802.16 MAC protocol does not include a complete solution to offer QoS guarantees for various applications. Issues such as resource management and scheduling are still open. In this paper, we have proposed a new adaptive QoS architecture for PMP 802.16 systems operating in TDD mode over WirelessMAN-OFDM physical layer. The proposed architecture includes a CAC module and a hierarchical scheduling structure. The CAC module we have proposed flexibly adjusts the grants boundaries to the connections QoS requirements while making efficient and fair use of the dynamic channel capacity via a Min-Max fairness approach. The proposed scheduling procedure adapts the frame-by-frame allocations to the current needs of the connections with respect to the grants boundaries fixed by the CAC module.

[1]Due to space limitations we are not able to provide details about the different modulations scenario.

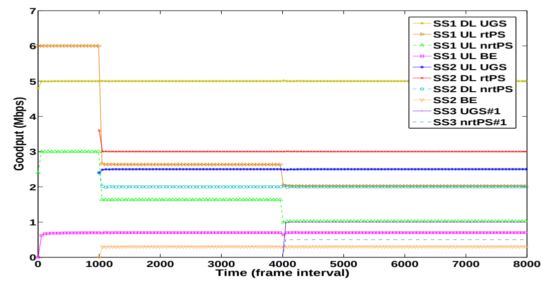

Figure 1. Multiple SSs Scenario

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