Performance Analysis of the IEEE 802.16 Broadband Wireless Access systems

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Abstract: In this paper we introduce a bandwidth allocation algorithm and admission control policy for IEEE 802.16 broadband wireless access standard. The proposed mechanism is practical and compatible to the IEEE 802.16. Our scheme provides QoS support to high priority traffic and high throughput in low priority traffic. The simulation show that the proposed scheme includes QoS support for real-time traffic and we presented that BS determine a efficient contention mini-slot size. We have shown the relationship between traffic size and its QoS requirements and the network performance.

QoS, Binary Exponential Back-off(BEB), virtual packet arrival time

1. INTRODUCTION

Broadband Wireless Access (BWA) systems, e.g. IEEE 802.16 standard, provide fixed-wireless access between the subscriber station (residential or business customers) and the internet service provider (ISP) through the base station. BWA systems complement existing last mile wired networks such as cable modem and xDSL. Due to the upcoming air interface technologies which promise to deliver high transmission data rates, BWA systems become an attractive alternative. Their main advantage is their fast deployment which can result in cost savings. For example, such installations can be beneficial in (1) very crowded geographical areas such as cities or in (2) rural areas where there is no wired infrastructure. Without new cable wiring for the whole city, the antenna of the base station and subscriber customers are easily set up at the rooftop of their buildings to form the wireless network. BWA systems are expected to support quality of service (QoS) for real time applications such as video conferencing, video streaming, and voice over IP. Such applications are delay and delay variation sensitive, i.e. in case packets incur large delays and delay variation, the quality of the application is severely degraded.

The IEEE 802.16 broadband wireless access standard developed by the IEEE 802.16 working group on broadband wireless access was recently approved. IEEE 802.16 media access control, which is based on the concepts of connections and service flows, specifies QoS signaling mechanisms (per connection or per station) such as bandwidth requests and bandwidth allocation. However, IEEE 802.16 standard left the QoS based packet scheduling algorithms, that determine the uplink and downlink bandwidth allocation, undefined.

This paper presents a new and efficient QoS architecture, based on priority scheduling and dynamic bandwidth allocation. to propose an efficient scheduling strategy for schedulers in the architecture. The system performance is analytically evaluated and the algorithm is verified through a simulation.roadband Wireless Access (BWA) systems, e.g. IEEE 802.16 standard, provide fixed-wireless access between the subscriber station (residential or business customers) and the internet service provider (ISP) through the base station. BWA systems complement existing last mile wired networks such as cable modem and xDSL. Due to the upcoming air interface technologies which promise to deliver high transmission data rates, BWA systems become an attractive alternative. Their main advantage is their fast deployment which can result in cost savings. For example, such installations can be beneficial in (1) very crowded geographical areas such as cities or in (2) rural areas where there is no wired infrastructure. Without new cable wiring for the whole city, the antenna of the base station and subscriber customers are easily set up at the rooftop of their buildings to form the wireless network. BWA systems are expected to support quality of service (QoS) for real time applications such as video conferencing, video streaming, and voice over IP. Such applications are delay and delay variation sensitive, i.e. in case packets incur large delays and delay variation, the quality of the application is severely degraded.

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2. BACKGROUND : BWA SYSTEMS, IEEE 802.16 MAC PROTOCOL

2.1 BWA System topology

A fixed BWA system includes at least one base station(BS) and one or more subscriber station(SS).

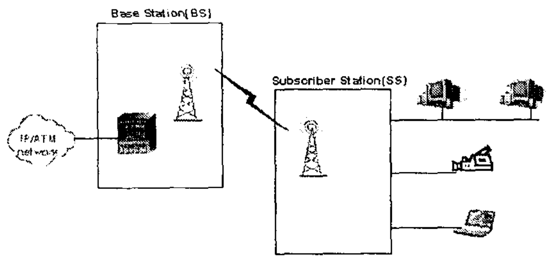

Fig. 3 Broadband wireless access system architecture

The BS is a central node and the SSs located at different distances away from the BS. The downlink channel , define as the direction of data flow from the BS to the SSs, is a broadcast channel, while the uplink channel is a multiple access shared medium. Time in the uplink channel is usually sloteed (mini-slots), providing for time-division multiple access(TDMA), whereas on the downlink channel a continuous time-division multiplexing(TDM) scheme is used. Each SS can deliver voice and data using common interfaces, such as plain and telephony service, Ethernet, video, VoD and other sevices with different QoS requirements

2.2 IEEE 802.16 MAC Protocol

The Physical layer operates at 10-66 GHz (IEEE 802.16) and 2-11 GHz (IEEE 802.16a) with data rates of 32-130 Mbps depending on the channel frequency width and modulation technique. IEEE 802.16 architecture consists of two kinds of fixed (non-mobile) stations: subscriber stations (SS) and a base station (BS). The BS regulates all the communication in the network, i.e. there is no peer-to-peer communication directly between the SSs. The communication path between SS and BS has two directions: uplink channel (from SS to BS) and downlink channel (from BS to SS). When the system uses time-division multiplexing (TDM), for uplink and downlink transmissions, the frame is subdivided into an uplink subframe and a downlink subframe as Fig. 2.

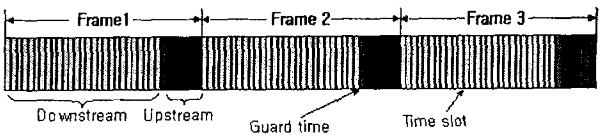

Fig. 2. System Model

The duration of these subframes is dynamically determined by the BS. Each subframe consists of a number of time slots. SSs and BS have to be synchronized and transmit data into predetermined time slots. The uplink channel is divided into a sequence of mini-slots. Since all the SSs have synchronized with the BS clock, the BS controller can uniquely number each mini-slot will arrive at a particular SS. SSs send requests in the uplink channel to BS. In the downlink channel, The BS uses a combination of acknowledge(ACK) and grant(GR) mini-slots to acknowledge requests from SSs and to grant access to data slots. Following we will specify some basic characteristics of the common IEEE 802.16 MAC protocol to create a framework for designing the QoS architecture. Note that only MAC protocols that are necessary for the design of the QoS architecture are described.

A. Classes of Uplink Service

To support QoS, IEEE 802.16 defines four QoS services: Unsolicited Grant Service(UGS); Real-Time Polling Service(rtPS); Non-Real-Time Polling Service(nrtPS) and Best Effort(BE) service. UGS service is prohibited from using any contention requests, there is no explicit bandwidth requests issued by SS. The BS must provide fixed size data grants at periodic intervals to the UGS flows. UGS service can be used for constant bit-rate(CBR) for CBR-like service flows such as T1/E1. However, the reseved bandwidth may be wasted when a corresponding UGS flows is inactive. The rtPS and nrtPS flows are polled through the unicast request polling. However, the nrtPS flows receive few request polling opportunities during network congestion and are allowed to use contention requests, while the rtPS flows are polled regardless of network load and frequently enough to meet the delay requirements of the service flows, moreover, rtPS flows prohibited from using any contention requests. Real-time Polling Services(rtPS) can be used for rt-VBR-like service flows such as MPEG video, Non-real-time Polling Service(nrtPS) can be used for not-real-time service flows with better than best effort service such as bandwidth-intensive file transfer.

B. Bandwidth Allocation and Request Mechanisms

Request refer to the mechanism that SSs use to indicate to the BS that it needs uplink bandwidth allocation. Bandwidth requests are always per connection. there are numerous methods by which the SS can get the bandwidth request message to the BS. Regarding the grant of the bandwidth requested, there are two modes of operation for SSs: Grant per Connection mode(GPC) and Grant per Subscriber Station mode(GPSS). In the first case, the BS grants bandwidth explicitly to each connection, it is mostly suitable for few users poer SS, whereas in the second case the bandwidth is granted to all the connections belonging to the SS. The latter case(GPSS) allows SS to re-distribute bandwidth among its connections, maintaining QoS and service-level agreements. It is suitable for many connections per terminal and allows more sophisticated reaction to QoS needs, which may be useful for real-time applications that require a faster response from the system

In GPSS mode, BS sees the requests for each connection: based on this, grants bandwidth(BW) to the SSs(maintaining QoS and fairness), SS scheduler maintains QoS among its connections and is responsible to share the BW among the connections(maintaining QoS and fairness). SS may use BW in a way unforeseen by the BS.

In addition, in order to meet the QoS requirements, the BS must adopt a scheduling algorithm among difference services to reduce QoS violation probability. Each QoS flow matches to exactly one QoS service. If a SS has special bandwidth requirement not specified in the QoS service profile, it could dynamically request a service by sending a dynamic service addition request message to the BS. Moreover, after a QoS flow is established, an efficient mechanism can be adopted to efficiently utilize the bandwidth.

3. QOS ARCHITECTURE FOR IEEE 802.16 MAC PROTOCOL

IEEE 802.16 can support multiple communication services (data, voice, video) with different QoS requirements. The media access control (MAC) layer defines QoS signaling mechanisms and functions that can control BS and SS data transmissions. On the downlink (from BS to SS), the transmission is relatively simple because the BS is the only one that transmits during the downlink subframe. The data packets are broadcasted to all SSs and an SS only picks up the packets destined to it. One of the modes of uplink arbitration (from SS to BS) uses a TDMA MAC. The BS determines the number of time slots that each SS will be allowed to transmit in an uplink subframe. This information is broadcasted by the BS through the uplink map message (UL-MAP) at the beginning of each frame. UL-MAP contains information element (IE) which include the transmission opportunities, i.e. the time slots in which the SS can transmit during the uplink subframe. After receiving the UL-MAP, each SS will transmit data in the predefined time slots as indicated in IE. The BS uplink scheduling module determines the IEs using bandwidth request PDU (BW-request) sent from SSs to BS. In IEEE 802.16 standard, there are two modes of transmitting the BW-Request: contention mode and contention-free mode (polling). In contention mode, SSs send BW-Request during the contention period. Contention is resolved using back-off resolution. In contention-free mode, BS polls each SS and SSs reply by sending BW-request. Due to the predictable signaling delay of the polling scheme, contention-free mode is suitable for real time applications. IEEE 802.16 defines the required QoS signaling mechanisms described above such as BW-Request and UL-MAP, but it does not define the Uplink Scheduler, i.e. the mechanism that determines the IEs in the UL-MAP. Fig. 3 shows the existing QoS architecture of IEEE 802.16. Uplink Bandwidth Allocation scheduling resides in the BS to control all the uplink packet transmissions.

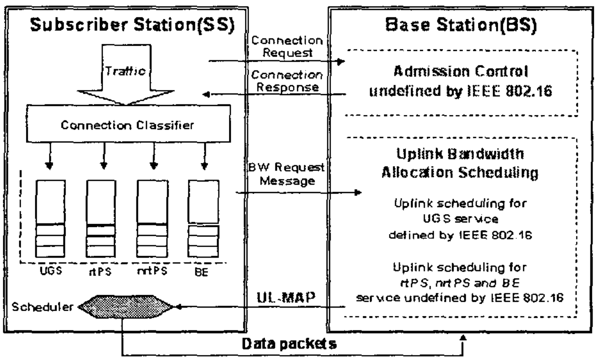

Fig. 3 QoS architecture of IEEE 802.16

Since IEEE 802.16 MAC protocol is connection oriented, the application first establishes the connection with the BS as well as the associated service flow (UGS, rtPS, nrtPS or BE). BS will assign the connection with a unique connection ID (CID). The connection can represent either an individual application or a group of applications such as multiple tenants in an apartment building (all in one SS) sending data with the same CID. IEEE 802.16 defines the connection signaling (connection request, response) between SS and BS but it does not define the admission control process. All packets from the application layer in the SS are classified by the connection classifier based on CID and are forwarded to the appropriate queue. At the SS, the Scheduler will retrieve the packets from the queues and transmit them to the network in the appropriate time slots as defined by the UL-MAP sent by the BS. The UL-MAP is determined by the Uplink Bandwidth Allocation Scheduling module based on the BW-request messages that report the current queue size of each connection in SS.

In summary, IEEE 802.16 defines: (1) the signaling mechanism for information exchange between BS and SS such as the connection set-up, BW-request, and UL-MAP and (2) the uplink scheduling for UGS service flow. IEEE 802.16 does not define: (1) the uplink scheduling for rtPS, nrtPS, BE service flow and (2) the admission control

Fig 4 shows the proposed QoS architecture that completes the missing parts in the IEEE 802.16 QoS architecture. At the BS we add: a detailed description of the Uplink Bandwidth Allocation Scheduling part (scheduling algorithm that which supports all types of service flows), and admission control part. At the SS we add the Traffic management module. Here is a brief description of the connection establishment using the QoS architecture in Fig 4: (1) An application that originates at an SS establishes the connection with BS using connection signaling. The application includes in the connection request the traffic contract (bandwidth and delay requirement), (2) The admission control part at the BS accepts or rejects the new connection and (3) If the admission control part accepts the new connection, it will notify the Uplink Bandwidth Allocation Scheduling part at the BS and provide the token bucket parameters to the traffic management module at the SS. After the connection is established, the following steps are taken: (1) Traffic management enforces traffic based on the connection's traffic contract, (2) At the beginning of each time frame, the data packet analysis module collects the queue size information from the BW-requests received during the previous time frame. the data packet analysis module will process the queue size information and update the traffic management table, (3) the Packet Allocation module retrieves the information from the traffic management module and generates the UL-MAP, (4)BS broadcasts the UL-MAP to all SSs in the downlink subframe and (5) SS's scheduler transmits packets according to the UL-MAP received from the BS.

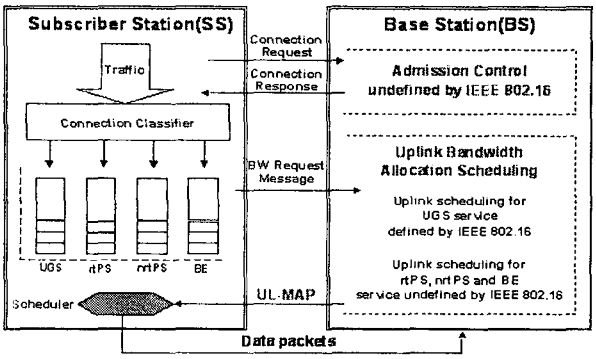

Fig 4. Proposed QoS architecture of IEEE 802.16

4. PROPOSED QOS ARCHITECTURE OF IEEE 802.16

For each of the UGS, rtPS, nrtPS, BE service, multiple connections are aggregated into their respective service flow. The schedule process is divided into two steps. The first step is performed in the BS. According to the information of the request from the SS. Then the SS's uplink scheduler is responsible for the selection of appropriate packets from all queues and sends them through the uplink data slots granted by the BS's Packet Allocation Module. The BS must provide fixed size data grants at periodic intervals to the UGS flows. The SS transmits BW-request of rtPS flows by BS's Poll. But IEEE 802.16 is not defined for poll' method in BS. Our paper propose Polling policy for rtPS flows and contention mini-slot size in contention period.

4.1 Uplink Scheduler of SS

SS's uplink scheduler transmits data PDU using uplink data slot granted by BS. For rtPS connection, SS's scheduler transmit UGS packets to append rtPS's virtual packet arrival time. BS's Data Packet Analysis Module(DPAM) received uplink data from SS obtains rtPS's virtual packet arrival time at UGS packets of each SS. DPAM can find the rtPS deadline information. Based on this deadline information, the BS's Uplink Bandwidth Allocation Scheduling will know exactly when to schedule packets such that packets' delay requirements are met. We apply the arrival-service curve concept to determine the packets' arrival and deadline. The packets' deadline is their arrival time plus the connection's maximum delay requirement. Therefore, BS can determine order of Poll based on this information.

The nrtPS uses either contention-free mode or contention mode. If SS receives poll by BS and doesn't have rtPS connection in queue, the nrtPS connection can transmit BW-request. The BE uses only contention mode. If SS wins contention mode, SS can transmit BW-request for BE connection. In IEEE 802.16, BS can control contention mini-slot size in frame. If contention mini-slot size increases, uplink data slot will decrease. If contention mini-slot size decreases, uplink data slot will increase. Therefore, we propose that BS determine a efficient contention mini-slot size. Contention resolution proposed in IEEE 802.16 is similar to general contention resolution of wireless network. The mandatory method of contention resolution which shall be supported is based on a truncated binary exponential backoff, with the initial backoff window and the maximum backoff window controlled by the BS.

4.2 Uplink Bandwidth Allocation Scheduling

After SSs transmit UGS packets by uplink data slot, BS's Data Packet Analysis Module(DPAM) separates UGS data and rtPS's virtual packet arrival time. This information manages at Traffic Management Module and uses the Polling schedule in next frame. the rtPS is time-bouned data. Therefore, BS is apt to give Poll to SS coming up close to deadline

In this work, we assume BS has the ability to detect collision in each contention period mini-slot. The BS broadcasts a common back-off window size "B" to all the competing SSs. SSs will then randomly choose a reservation slot numbered between 1 and B to transmit its request. We first assume that there are N SSs in the system and BS broadcasts a back-off window size B. Since each user will choose between 1^{st} and B^{th} reservation slots to send its bandwidth reservation, the probability of choosing a given slot is p=1/B. As a result, the probability of a given slot that is not selected by any SS is given by:

$$P_{NS} = (1-p)^N \tag{1}$$

The probability of a successful transmission is equal to the probability that a given slot is selected by a single user. Thus, the system throughput is given by:

$$P_{th} = Np(1-p)^{N-1} \tag{2}$$

To maximize system throughput, we have:

$$\frac{dP_{th}}{dp} = N(1-p)^{N-1} - N(N-1)p(1-p)^{N-2} = 0$$

$$p = \frac{1}{N} \tag{3}$$

$$\therefore p = \frac{1}{B} = \frac{1}{N} \Rightarrow \mathrm{N = B}$$

In other words, when BS broadcasts a back-off window size 'B' which is equal to the number of competing SSs N maximum throughput can be obtained. Therefore, BS is efficient that contention period size is equal to the number of SS.

5. SIMULATION

In this section, we evaluate performance of our scheme for IEEE 802.16. The system model for analysis consists of one base station and numbers of subscriber stations(SS). Several assumptions have been made to reduce the complexity of the simulation model :

- The effects of propagation delay are neglected.
- The channel is error-free that means that each transmitted packet was successfully and correctly received at its destination.
- BS have the ability to detect collision.

In addition, each SS is assumed to be a Poisson traffic source and the packet size(including overhead) is variable. The parameters used for performance evaluation are listed in Table 1.

Table 1. Simulation Parameter

Meaning	Value(802.16)
Number of SS	20
Preamble(beacon)	3us
Each MAP	5us
Downlink DATA	8us
Register Contention(RC)	1us
Contention Period	Number of active station
Average data packet size	Each traffic 100~200byte
Fixed frame size	1ms
PHY rate	50Mbps

To evaluate the performance of the protocol, we designed an Broadband Wireless Access Systems simulator and implemented it in C++. In the following, we report and comment on (in terms of MAC protocol mechanisms) the simulation results we obtained with the arrival processes and operation parameter settings in Table 1. All the simulation experiments will discuss in this section.

Fig. 5 shows throughput for four different types of packet by average packet size. In this figure, we can see that the same maximum throughput can be obtained by selecting proper packet size of UGS and rtPS flows. Because the nrtPS and BE flows are low priority class of traffic, they are affected by the UGS and BE flows(high priority class of traffic. The high priority traffic is constantly allocated uplink data slot granted by BS.

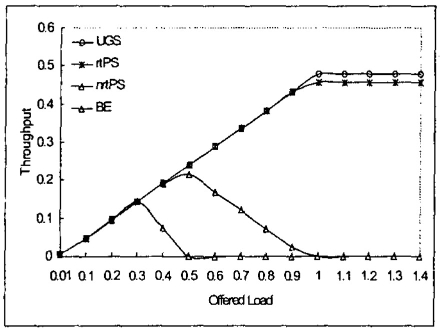

Fig.5 Throughput by average packet size(average packet size = 150byte)

Fig. 6 depicts the throughput for the nrtPS and the BE flows when contention mode is the BEB and proposed scheme. When the BEB algorithm uses, contention period mini-slot size is 100 mini-slot. As shown in this figure, the BEB algorithm offers a higher throughput than the proposed scheme under heavy traffic load because of longer contention period mini-slot.

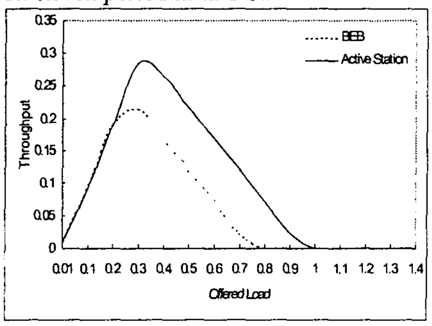

Fig. 6 BEB algorithm and the proposed scheme

6. CONCLUSION

In this paper, we have proposed a QoS architecture for IEEE 802.16 standard. We have presented a packet scheduling and contention mini-slot size in contention free mode and contention mode. The proposed mechanism is practical and compatible to the existing IEEE 802.16 standard. The simulation shows that the proposed mechanism provide QoS support in terms of bandwidth request and allocation for all type of traffic classes as defined by the standard.

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