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Performance Study of Bandwidth Request Mechanisms in IEEE 802.16e Networks

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Abstract: WiMAX (Worldwide Interoperability for Microwave Access) is the IEEE 802.16 standards-based wireless technology that provides fixed and mobile Internet access for Metropolitan Area Networks (MAN). The IEEE 802.16 std. includes medium access control (MAC) and physical (PHY) layer specifications and is consider to be a promising technology. Bandwidth reservation is employed to provide quality of service (QoS) to guarantee different services specified in the standard. A bandwidth request/grant scheme is defined in the IEEE 802.16 standard. There are two types of bandwidth request (BR) mechanisms, i.e., polling and contention resolution, which are defined in the standard. As specified, connections belonging to scheduling classes of extended real-time polling service, non-real-time polling service, and best effort have options to make BRs via both mechanisms, depending on the scheduling decision made by the base station (BS). This paper attempts the comparative study of BR mechanisms for different service classes defined in the standard.

Keywords: Bandwidth request, Contention resolution, QoS, Unicast polling, WiMAX.

I. INTRODUCTION

WiMAX is a cutting edge technology in wireless broadband communication which follows the IEEE 802.16 [1] family. WiMAX developed based on IEEE 802.16e [2] is capable of providing both fixed and mobile broadband access to users for different data flows pertaining to their QoS requirements. This technology is a connection oriented system which is a centralized architecture. There are two modes of operations; point to multi point (PMP) and mesh mode and this paper concentrate on PMP mode. In PMP mode the data transmission between the subscriber stations (SS) is coordinated by base station (BS). Two directions of communication paths exist between BS and SS: uplink (from SS to BS) and downlink (from BS to SS). IEEE 802.16 standard specifies two contention based bandwidth request schemes working with orthogonal frequency division multiplex (OFDM) physical layer specification in PMP architecture, the mandatory one used in region-full and the optional one used in region-focused.

A WiMAX network is based on infrastructure network architecture with BS covering a wide area in a cellular topology. A mobile or fixed SS is connected to a BS through a wireless link. As the Carrier Ethernet technology gains increased popularity among Telecom Operators, Carrier Ethernet backhauling becomes the solution of choice: Ethernet frames are received by the base station and then encapsulated directly into WiMAX frames. The WiMAX standard supports Ethernet encapsulation in the Convergence Sublayer (CS) which treats the Ethernet frames as Service Data Units (SDUs) for the lower layers. These SDUs are classified based on their header fields into different Connection Identifiers (CID) and Service Flow Identifiers (SFID) before being forwarded to the WiMAX Common Part Sublayer (CPS). The CPS packs or fragments the received SDUs and adds a MAC header to form Payload Data Units (PDUs). Finally, the PDUs are forwarded to the scheduler in order to be scheduled in the data burst fields inside the WiMAX frame [3]. The rest of this paper is organized as follows. An overview of WiMAX and the related work are provided in Sections 2 and 3, respectively. The BR mechanisms are explained in Section 4. The Section 5 presents the performance evaluation and simulation results. The Section 6 concludes our discussion.

II. OVERVIEW OF WiMAX

A single cell in WiMax consists of a BS and multiple SSs. The BS schedules the traffic flow in the WiMax i.e., SSs do not communicate among them directly, except in mesh mode. The communication between BS and SS are bidirectional i.e., a downlink channel (from BS to SS) and an uplink channel (from SS to BS). The downlink channel is in broadcast mode. The uplink channel is shared by various SS's through time division multiple access (TDMA). Figure 1 depicts the uplink and downlink subframes [1]. The subframe consists of a number of time slots. The duration of subframes, slots and the number are determined by the BS scheduler. The downlink subframe contains uplink (UL) map and downlink (DL) map. The DL map contains information about the duration of subframes and which time slot belongs to a particular SS as the downlink channel. The UL map consists of information element (IE) which includes transmission opportunities (ToS)[4].

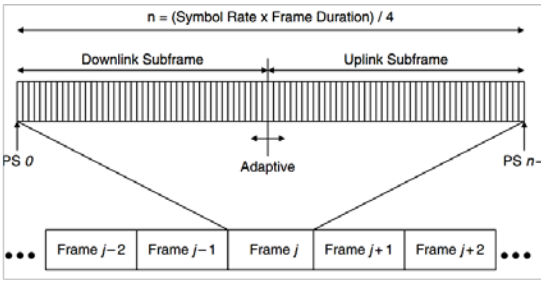

Figure1. TDD frame structure

The 802.16 WiMAX air interface supports two operational modes: a mandatory point-to-multipoint (PMP) mode and an optional mesh mode. In PMP mode, a centralized BS controls all communications among the SSs and the BS, whereas in the mesh mode, SSs can also serve as routers by cooperative access control in a distributed manner. In this article we focus on centralized PMP mode, which is thought to be able to provide better quality of service (QoS) performance than distributed mesh mode; hence, PMP mode is the first choice of WiMAX operators. In a downlink subframe of PMP mode, the BS transmits a burst of MAC protocol data units (PDUs) using time-division multiplexing (TDM); in an uplink subframe of PMP mode, an SS transmits a burst of MAC PDUs to the BS using time-division multiple access (TDMA).

Resource management and allocation mechanisms are crucial to guarantee QoS performance in WiMAX networks. Under a centralized PMP architecture, multiple SSs share a common uplink to the BS on a demand basis. This means that if an SS needs some amount of bandwidth, it makes a reservation with the BS by sending a request. On accepting the request from an SS, the BS scheduler should determine and grant it a transmission opportunity in time slots by using some scheduling algorithms, which should take into account the requirements from all authorized SSs and the available channel resources.

Two main methods are suggested in the WiMAX standard to offer transmission opportunities for SSs to send their bandwidth request (BR) messages: centralized polling and contention-based random access. In the first case each SS station is only allowed to send its request when it is polled by the BS; in the latter all SSs contend to obtain transmission opportunities for sending requests using contention resolution mechanisms.

Support for QoS is a fundamental part of t he IEEE 802.16 MAC-layer design. When the service data unit arrives in the IEEE 802.16 MAC layer, the classification process is performed. The classification process is the process that maps the service data unit to the appropriate scheduling class based on the QoS constraints of the service data unit. As specified in the IEEE 802.16 standard, only connections belonging to three scheduling classes (i.e., extended real-time polling service (ertPS), non-real-time polling service (nrtPS), and best effort (BE)) are allowed to have the option to choose between unicast polling and contention resolution for making bandwidth request. Because of the features of each BR mechanism, a scheduling decision made by the BS for the connections in these scheduling classes to transmit BRs may affect the overall bandwidth utilization and delay [5].

III. RELATED WORK

In [6], authors have discussed uplink and downlink packet schedulers for bandwidth allocation process and admission control for QoS. A Markov chain (MC) model for unicast polling is proposed in [7]. The authors proposed the MC analysis that aims to minimize average polling delay while increasing network throughput. Based on the QoS requirements of each scheduling class, the priorities can be given between scheduling classes. Contention resolution has been discussed not only in IEEE 802.16 but also in IEEE 802.11. A classic MC model to analyze contention resolution in IEEE 802.11 has been proposed in [8]. In [9] the authors compared the performance obtained with the contention-based mechanism and that with connections being polled in a round-robin manner. Their results, obtained by assuming a Bernoulli bandwidth request arrival process with a finite number of SSs, show that the former, i.e., using contention, is more efficient than individual polling, in terms of the resources consumed by the bandwidth request process. The performance of the random access protocol of IEEE 802.16e has been studied via an M/G/1 model of the system in [10].

IV. BANDWIDTH ALLOCATION AND REQUEST MECHANISMS IN IEEE 802.16e

There are several different ways in which subscriber station can inform the basestation that it has data to send on the uplink. Most of these methods involve sending a Bandwidth Request Header (BRH) for which the subscriber station must first obtain an up link channel access grant from the base station.
Bandwidth allocation and request mechanisms for the IEEE 802.16 are efficient, low - latency and flexible. Requests are made per connection basis to ensure they can be properly used in fairness algorithms in the BS's UL scheduler. But grants are to the SS, not to the connection. Also there are no explicit acknowledgments sent back to indicate whether a bandwidth request message is successfully transmitted or distorted or how much bandwidth the SS is granted. SSs have the responsibility to determine that its BR was corrupted, and then start a contention resolution process. On the other hand, on receiving a grant within the timeout, the SS will stop contention resolution and use the allocated bandwidth for uplink transmission of data packets or to piggyback an additional request if necessary. Furthermore, the SS might know how much bandwidth is awarded by observing the following grant from the BS. Due to different scheduling algorithms at a BS, a grant may be given at any time.
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. 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 [11].

A. Bandwidth Request

Requests refer to the mechanism that SSs use to indicate to the BS that they need uplink bandwidth allocation. As request may come as a stand-alone bandwidth request header or it may come as a PiggyBack Request. Bandwidth requests themselves need bandwidth to be transmitted. A unicast poll consists of an uplink grant intended by the BS for a specific connection to transmit a bandwidth request. The grant is issued to the SS the connection belongs to, which will eventually schedule a BR PDU for that specific connection. The rtPS scheduling service makes use of the unicast poll mechanism for transmitting bandwidth requests, typically on a periodic basis [12]. Bandwidth Requests are of two types, incremental and aggregate. When the BS receives an incremental Band width Request, it adds the quantity of bandwidth requested to its current perception of the bandwidth needs of the connection. In case of aggregate Bandwidth Request, BS replaces its perception of the bandwidth needs of the connection with the quantity of bandwidth requested. The Type field in the bandwidth request header indicates whether the request is incremental or aggregate. Since Piggybacked Bandwidth Requests do not have a type field, Piggybacked Bandwidth Requests is always incremental. Due to the possibility of collisions, contention based Bandwidth Requests are aggregate requests.

B. Bandwidth Grants

Bandwidth grants are addressed to the SS's Basic CID, not to individual CIDs. Since it is nondeterministic which request is being honoured, when the SS receives a shorter transmission opportunity than expected (scheduler decision, request message lost, etc.), no explicit reason is given. In all cases, based on the latest information received from the BS and the status of the request, the SS may decide to perform backoff and request again or to discard the SDU. An SS may use Request IEs that are broadcast, directed at a multicast polling group it is a member of, or directed at its Basic CID. The SS should transmit in an interval defined by a Data Grant IE directed at its Basic CID. In a Data Grant IE directed at its Basic CID, the SS may make bandwidth requests for any of its connections. The SS local scheduler decides which connections get the granted bandwidth.

C. Polling

Polling is a process where the BS periodically allocates part of the uplink channel capacity that is issues a "grant" or "transmission opportunity" in the

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uplink map to each participating subscriber station that wants to send data. Polling may be done either individually (unicast) or in groups (multicast). Polls may be unicast or multicast or broadcast according to the CID specified in the uplink map transmit opportunity information element. If a poll is multicast or broadcast then one of the contention bandwidth request methods is specified to collect the bandwidth request responses. Unicast polls are directed towards a single CID associated with a single subscriber station. Polling is done on SS basis. Bandwidth is always requested on a CID basis and bandwidth is allocated on an SS basis. On the other hand, broadcast polls are issued by the BS to all uplink connections, which contend for their use in a random access manner. We refer to a bandwidth request (carried by a BR PDU) sent in response to a broadcast poll from the BS as a contention bandwidth request. The BE and nrtPS scheduling services are the only ones which make use of broadcast polls[12].

D. Contention Resolution

The contention resolution mechanism is primarily used in Multicast Polling. The 802.16-2004 and 802.16e standards define the mechanism that is used by the connections in the BE, nrtPS and ertPS classes that are not polled individually. Thus when these connections have some packets in the uplink buffers, and no slots are allocated for them, they must compete with each others to get an allocation. This method is known as the contention resolution mechanism. When an SS wants to enter the contention resolution process, it sets its internal backoff window equal to the backoff start value advertised in the uplink channel descriptor (UCD) message. Then, the SS chooses randomly a number within the window. The SS must then wait for this number of request opportunities before sending a request. If no data grant has been given within a specified interval, the SS considers the request is lost. Then, it increases its internal backoff window by a factor of two and chooses a new random number. This process is continued until the internal window of the SS reaches the backoff end value declared in the UCD message. Then, the SS will drop the protocol data unit (PDU) and start from the beginning with the next PDU. For bandwidth requests, if the SS receives a unicast Request IE or Data Grant Burst Type IE at any time while deferring for this CID, it shall stop the contention resolution process and use the explicit transmission opportunity.

V. PERFORMANCE EVALUATION AND SIMULATION RESULTS

This section of the paper discusses the simulation environment and performance characterization of IEEE 802.16e network. Selected simulation results are discussed.

A. Simulation environment

The air interface simulated hereafter is the WirelessMAN-OFDM whose physical parameters are specified in the standard. The simulation tool employed is Qualnet 5.0.2. The uplink-downlink ratio is set as 1:1 and admission control is basic. The simulated scenario has a single cell with a BS and multiple SSs. Each SS handles a single service type either as transmitter or receiver. Duration of the simulation time is 300 seconds. The performance is studied by increasing the number of SSs, thus increasing the services for polling and contention resolution bandwidth requests. Real time services streamed as constant bit rate (CBR) traffic and that of non real time services are variable (VBR) traffic.

TABLE 1. SIMULATION PARAMETERS

Property	Value
Simulation time	300 Sec
Channel bandwidth	20 MHz
FFT size	2048
Antenna model	Omni directional
BS antenna gain	30 dBi
SS antenna gain	0 dBi
BS antenna height	12 m
SS antenna height	1.5 m

B. Simulation Results

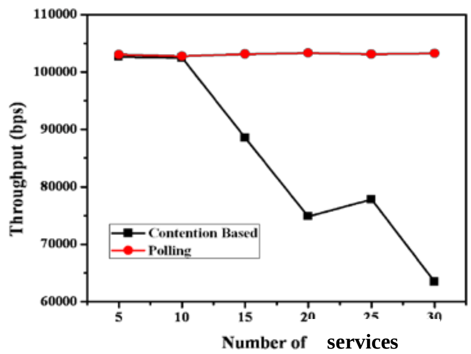

Figure 2. Throughput for CBR services

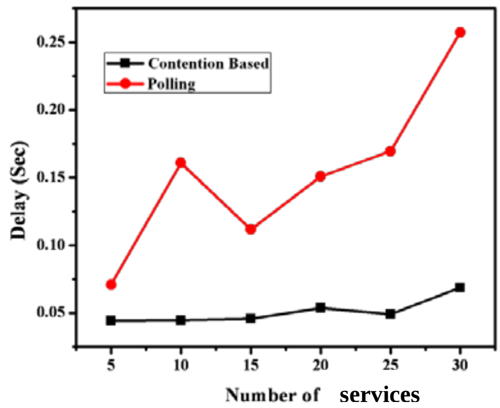

Figure 3. Delay for CBR services

From the Fig.2 and 3, it is observed that the CBR services exhibits normal throughput for polling BR type, since rtPS and UGS do not rely on contention resolution [12]. Bandwidth is assigned by the BS to each SS as a whole, i.e., without any hint as for which connections it is intended, which may be utilized for real time connections according to the resource scheduler of that SS.

As the number of services increase, throughput for the real time services (Fig.4 and 5) is affected due to congestion. The contention bandwidth requests, transmitted in response to broadcast polls from the BS, may collide resulting in failure of BR and SSs, which initiate the bandwidth request mechanism, cannot detect collisions, directly or indirectly [12].

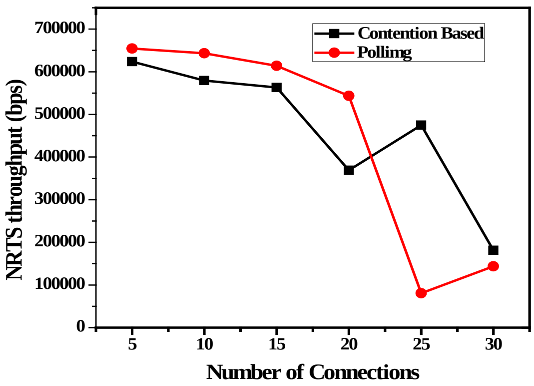

Figure 6. Throughput for non-real time services

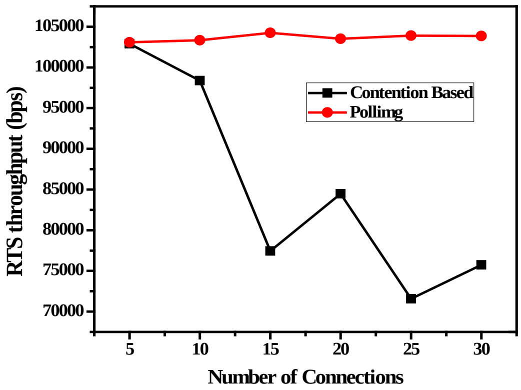

Figure 4. Throughput for real time services

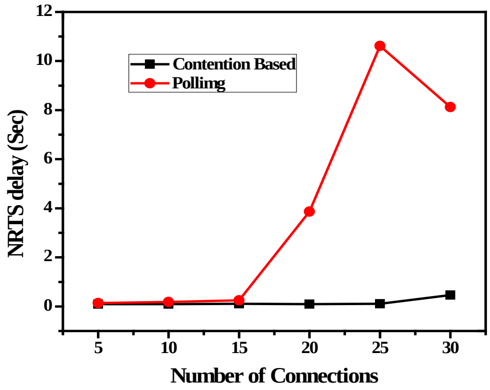

Figure 7. Delay for non-real time services

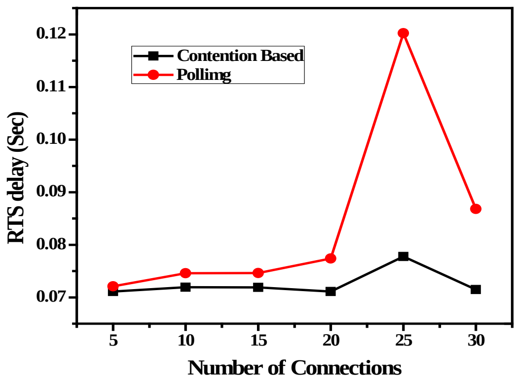

Figure 5. Delay for real time services

For non-real time services, BE and nrtPS connections are comparatively affected by the contention resolution BRs (Fig.6 and 7), both in terms of throughput and delay of the packets. In case of packet delay, the contention resolution BR outperforms the polling BR in all service types.

VI. CONCLUSION

In this paper the effect of implementation of two types of BR mechanisms for WiMAX network is studied by considering throughput and delay as performance metrics. The performances of polling and contention resolution BR mechanisms are compared for real time and non real time services. The simulation results conclude that the packet delay is significantly improved by employing contention based bandwidth request

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