Performance Evaluation of Piggyback Requests in IEEE 802.16

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Abstract—**WiMAX (Worldwide Interoperability for Microwave Access) is a wireless access technology that aims to provide last mile wireless broadband access for fixed and mobile users as an alternative to the wired DSL and cable access. It is specified in the IEEE 802.16 standard. The standard defines several possible bandwidth request methods that can be implemented in an actual deployment of a WiMAX network. In this paper, we will study the performance of two different bandwidth request mechanisms, namely piggyback and broadcast requests and will show in which situations piggybacking performs better than the contention based broadcast bandwidth requests.**

Index Terms—**802.16, WiMAX, piggyback, random access**

I. Introduction

In 1999, the IEEE 802 committee has set up a new working group for outdoor broadband wireless access applications, namely IEEE 802.16. Similar to the IEEE 802.11 Wi-Fi alliance, a forum, the worldwide interoperability for microwave access (WiMAX), responsible for defining interoperability specification was set up. Thus, the IEEE 802.16 networks are often referred to as WiMAX networks.

Currently, there are two different standards, which are certified by the WiMAX forum, the IEEE 802.16-2004 [1] for fixed broadband wireless access and the IEEE 802.16e-2005 [2] for mobile users. Typical deployment scenarios for a WiMAX system are connecting home networks, apartment houses, small companies, or WLAN hotspots to the Internet. In this case, a WiMAX base station (BS) serves a number of subscriber stations (SSs) that each may serve a number of users again. WiMAX provides the possibility to establish one or several connections for every user with individual quality-of-service (QoS) settings. Consequently, a SS has to manage a considerable number of connections and needs to request bandwidth for each of them. The bandwidth can be requested in several different ways, depending on the service class. The IEEE 802.16 MAC protocol defines five service classes, the unsolicited grant service (UGS) for constant bit rate services, the extended real-time polling service (ertPS) for real-time traffic with variable data rate, the real-time polling service, the non real-time polling service, and the best-effort service. Due to the fact that it is not within the scope of the standard how the application demands can be provided to the WiMAX MAC layer for the resource reservation, it is possible that even voice over IP flows have to be transmitted over the best effort service class.

For the best effort class there are basically three different ways of how a subscriber station can request bandwidth: during the bandwidth request contention phase, with unicast bandwidth requests, or piggybacked on previous packets. In this paper, we focus on the usability of piggyback requests. The performance strongly depends on the frame duration, the packet arrival process, the mean packet interarrival time, and the number of users in the system.

The rest of the paper is organized as follows: Section II presents the related work. In Section III an overview of the WiMAX MAC layer is given. This is followed by Section IV where the simulation setup and the results are shown. Finally, Section V concludes this paper.

II. Related work

Several papers have been published focusing on the random access phase for bandwidth requests [3], [4], [5], [6], and [7]. In [3], [4], and [7] it is shown that the backoff window should be set to the number of transmission opportunities per frame or to a multiple of these transmission opportunities. A transmission opportunity is the time it takes to submit one bandwidth request. If the backoff is set to a lower value than the number of transmission opportunities, bandwidth will be wasted. However, the papers just focus on the random access scheme and do not consider piggyback requests. [5], [6] also focus on the random access scheme only. The difference to the papers referenced above is that not only the BE queue is simulated but all other service classes as well and their delay is compared.

The papers [8], [9] present both an analytical approach and a validation of their approach with simulation. However, in [8] it is claimed that the delay is less than one millisecond and it is not clear how the delay is measured and how the authors get to these small delays. In [9] the delay is measured for random access and unicast polling. However, unicast polling can result in a lot of wasted bandwidth, especially in scenarios with non periodic traffic like web browsing.

To the best of our knowledge, no paper has been published so far, focusing on the performance of piggyback requests in IEEE 802.16 networks. In this paper, we will show how many bandwidth requests can be piggybacked on previous packets for different traffic profiles. Furthermore, we will show the performance increase in terms of lower delays between the subscriber station and the base station.

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III. IEEE 802.16 Overview

The IEEE 802.16-2004 [1] defines two possibilities of operation, point-to-multipoint (PMP) and mesh mode. A limitation of the IEEE 802.16-2004 mesh mode is that it is not compatible with the PMP mode. Therefore, a new study group has been created called IEEE 802.16j. In this paper however, we focus on the PMP mode and use the time division duplex (TDD) for the communication in downlink and uplink direction.

A. Frame Structure

The standard defines a time separation into frames with a length between 2 ms and 20 ms. Due to the fact that we use TDD, each frame is split into a downlink and an uplink subframe which is shown in Figure 1. Between the two subframes, a transmission time gap is introduced for half duplex stations to switch from the reception of packets to transmission.

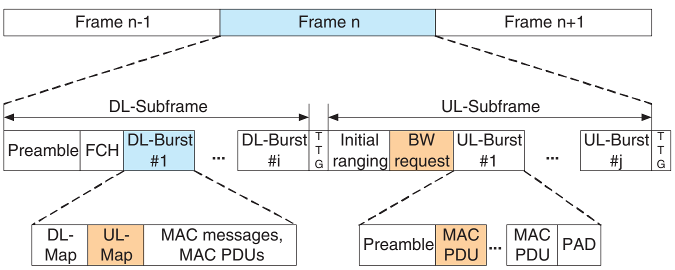

Fig. 1. WiMAX TDD frame structure

Each downlink frame starts with a preamble followed by a frame control header (FCH). Afterwards, the first data burst is transmitted which contains information about the complete frame. First, the downlink map (DL-Map) defines the remaining part of the downlink frame and assigns the data bursts to the different subscriber stations. The uplink map (UL-Map) on the other hand comprises the bandwidth allocations in uplink direction. The following downlink bursts include normal data transmissions.

The uplink subframe starts with a number of slots for initial ranging and bandwidth requests. The initial ranging phase is needed for network entry and the bandwidth request phase is one possibility to request uplink bandwidth. The bandwidth request phase is split into transmission opportunities. According to the standard, the transmission opportunities can be dedicated explicitly to a single SS, to a group of SSs, or to all SSs by the base station. If it is assigned to a group of SSs (multicast transmission opportunities) or to all SSs (broadcast transmission opportunities), a random access mechanism is used.

B. Bandwidth Allocation and Request Mechanisms

Requests are used by the SSs to indicate to the BS that they need uplink bandwidth. For constant bit rate UGS connections, the bandwidth requirements do not change during a connection. Here, the requirements will be exchanged when the connection is established. When on the other hand a SS using a best effort service needs to request bandwidth, there are two possibilities, a polling scheme or the optional piggyback.

The polling scheme can further be subdivided into three parts, unicast, multicast, and broadcast polling. For unicast polling, the BS allocates bandwidth in the UL-MAP which is explicitly reserved for bandwidth requests for this station. If the station does not have to transmit any data, the allocation is padded. If we have insufficient bandwidth to individually poll each station, multicast and broadcast polling can be used. Here, the BS reserves bandwidth in the uplink frame. This bandwidth is described as the number of transmission opportunities, where one opportunity is the time needed to transmit a bandwidth request. SSs wanting to transmit a bandwidth request have to content for these transmission opportunities. This might result in collisions. The mandatory method of the contention resolution shall be supported based on a truncated binary exponential backoff. The initial backoff window and maximum backoff window are defined by the BS and transmitted in the uplink channel descriptor (UCD) messages. The UCD messages are sent in regular intervals and contain information about the backoff window and burst profiles. A contention transmission is considered to be lost if no data is granted within a timeout called T16.

For the first transmission attempt, the backoff is set to W_{min}. In case of a collision, W_{min} is doubled. After the i^{th} successive collision, the subscriber station chooses the backoff between 0 and $2^i W_{min}$. The window is doubled until the maximum $W_{max} = 2^m W_{min}$ is reached. Here, m is referred to as the maximum backoff stage. After a successful transmission, the window is set to the initial value W_{min}.

W_{min} should be set according to the number of transmission opportunities reserved for random access in a frame. Let k be the number of transmission opportunities per frame. Then, W_{min} should be set to k or a multiple of k [9]. In our simulation scenarios W_{min} is set to k.

When using piggyback request, the bandwidth is requested piggybacked on previous data frames. A bandwidth request for packet n can be piggybacked on packet $n-1$ if the packet has arrived between the bandwidth request of packet $n-1$ and the transmission of packet $n-1$. Considering a constant packet interarrival time with an interval shorter than the WiMAX frame size, only bandwidth for the first packet of the data stream has to be requested during the contention phase and all other bandwidth requests can be piggybacked. The percentage of piggyback request and the resulting delay will be shown in the next section.

IV. Performance Evaluation

In order to evaluate the performance of piggyback requests, we conducted a comprehensive simulation study using the OPNET Modeler [10] simulation environment. Our simulation model accounts for both, the MAC and the PHY layer. We configure the WiMAX cell with a frame size of 5 ms and use TDD with an uplink subframe duration of 50 percent of the frame. However, the performance of piggyback requests would be similar for another frame size or FDD. In this simulation study, we just use the best effort QoS class with a round robin scheduling unit. Further simulation settings are shown in Table I.

TABLE I
IEEE 802.16 SIMULATION SETTINGS

parameter	value
frame size	5 ms
duplexing	TDD
uplink subframe duration	50 % of the frame
duration of an OFDM symbol	50 μs
bits per OFDM symbol	200
overall bandwidth	3.84 Mbps
OFDM symbols per transmission opportunity	2
Initial Ranging transmission opportunity	1
Bandwidth Request transmission opportunity	4
QoS class	best effort
scheduling	round robin
request mechanisms	broadcast, piggyback

The remainder of this section is split into two parts. In the first part, we evaluate the performance of piggyback requests for constant and lognormal packet interarrival times from 2 ms to 100 ms. The packet size is set to 29 Bytes.

For the second set of scenarios we evaluate the performance of piggyback requests by using a standard http model [11]. The settings of the http model can be found in Table II.

TABLE II
HTTP TRAFFIC MODEL PARAMETERS

component	distribution	parameters
main object size	truncated lognormal	mean = 10710 Bytes std. dev. = 25032 Bytes minimum = 100 Bytes maximum = 2 MBytes
embedded object size	truncated lognormal	mean = 7758 Bytes std. dev. = 126168 Bytes minimum = 50 Bytes maximum = 2 MBytes
number of embedded objects per page	truncated pareto	mean = 5.64 max = 53
reading time	exponential	mean = 30 sec.
parsing time	exponential	mean = 0.13 sec.

A. Piggyback requests with constant and lognormal packet interarrival time

In our first simulations we want to evaluate the percentage of piggyback requests compared to normal bandwidth requests using the random access phase. Therefore, we consider a VoIP stream with different, constant packetization intervals between 2 ms and 12 ms. As shown above in Table I, the frame size is set to 5 ms where 2.5 ms are used for the uplink subframe. The percentage of piggyback requests can be approximated using Equation 1.

$$PB_{req} = \begin{cases} 100 & : \quad fs < t_0 \\ 0 & : \quad t_0 > 2 \cdot fs \\ \frac{fs \cdot 2 - t_0}{fs} & : \quad else \end{cases} \tag{1}$$

fs denotes the frame size and t_0 is the packet interarrival time of the VoIP flow. If the packet interarrival time is shorter than the frame size, all bandwidth requests can be piggybacked on previous packets. The percentage of piggybacked request is decreasing linearly down to 0 percent for a packet interarrival time larger than 10 ms. The simulation and analytical results are shown in Figure 2.

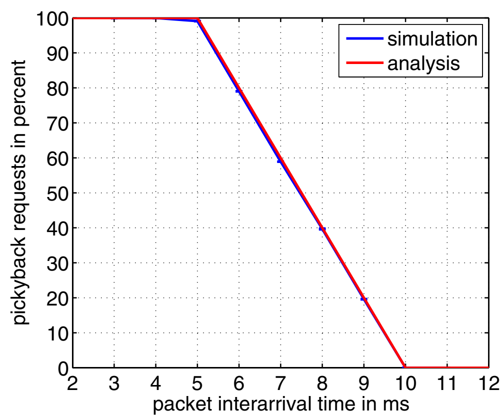

Fig. 2. Percentage of piggyback requests using a 5 ms frame size and a constant packet arrival process

The result shows that for standard VoIP codecs like the ITU-T G.711 with a packet interarrival time of 10 ms, no bandwidth request can be piggybacked. Therefore, the VoIP streams have to be identified by the WiMAX network in order to schedule them in the UGS or ertPS QoS class.

For the next simulation scenario, we are assuming a lognormal distributed packet interarrival time. The variation coefficient is set to 1 and we vary the mean interarrival time between 5 ms and 100 ms. The percentage of piggyback requests is illustrated in Figure 3.

Compared to the results for a constant packet interarrival time, the number of piggyback requests is much higher. For a mean interarrival time of 10 ms, still 54 percent of the

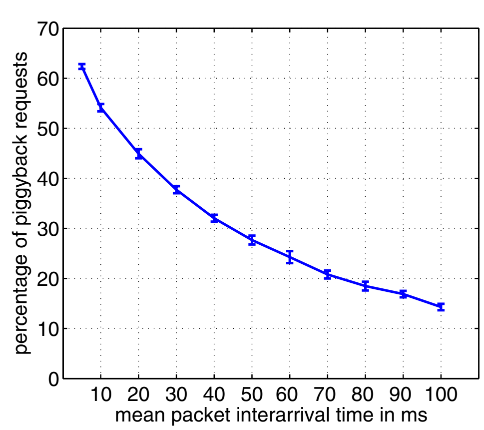

Fig. 3. Percentage of piggyback requests using a 5 ms frame size and a lognormal packet arrival process with a variation coefficient of 1

bandwidth requests are piggybacked on previous packets. Concluding these first two results, it is obvious that for VoIP traffic with a constant packet interarrival time which is normally 10 ms or even higher, no bandwidth can be requested using piggybacking. However, for a traffic flow with lognormal packet interarrival time, a large number of requests can be piggybacked. The percentage of piggyback requests is further evaluated for http traffic later in this section.

Now, we want to take a look on the impact of piggyback requests on the delay. Therefore, we are configuring the simulation scenarios with the same two traffic generation processes as for the first results.

First, we evaluate the end to end delay for a single WiMAX subscriber station in an empty cell. The end to end delay is measured from the time a packet arrives at the MAC layer of the subscriber station until it will be forwarded to the IP layer of the receiving station. We increase the packet interarrival time from 5 ms to 15 ms. The results are plotted in Figure 4. As you can see, if the packet interarrival time is similar to the frame size or a multiple of the frame size, the delay variation is higher with a minimum delay of 5.3 ms and a maximum delay of 10.3 ms. This depends on the start times of the packet generation processes. A packet arrival just after the contention phase results in the maximum delay of 10.3 ms and in contrast, if the packet arrives just before the beginning of the bandwidth request phase a delay of 5.3 ms will be achieved. With piggybacking, a slightly lower minimum delay is achieved for a packet interarrival time of 5 ms. The reason is that new packets may arrive at the subscriber station right after the bandwidth request interval and if at least one packet is still in the buffer, waiting for transmission, then the packet can be transmitted at the beginning of the next uplink phase, resulting in a delay of 5.1 ms.

For packet interarrival times between 5 ms and 10 ms, the performance of piggyback request in terms of delay is better than without piggyback requests. However, the performance increase of around 0.5 ms is not really satisfying. Therefore, we increase the number of users to 4. The mean delay is

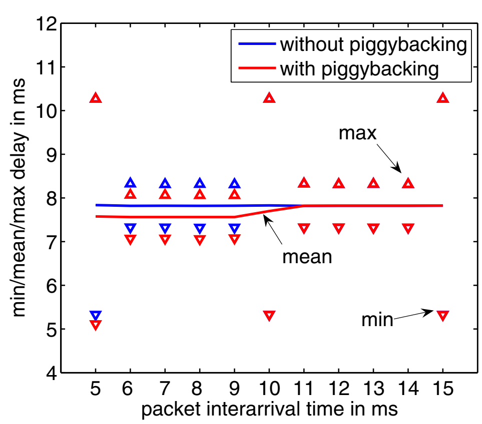

Fig. 4. Uplink transmission delay for one user with and without using piggyback

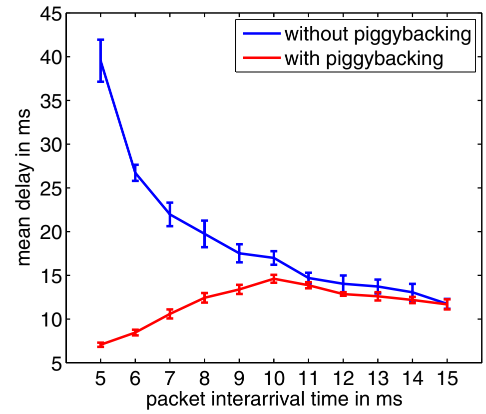

Fig. 5. Transmission delay for four users with and without using piggyback

shown in Figure 5. This time, the mean delay is plotted with a confidence level of 0.9.

Here, piggybacking shows a much better performance than the random access mechanism. The reason is the large number of collisions in the random access bandwidth request phase due to the fact that the number of transmission opportunities is set to 4. For an interarrival time of 5 ms, all four subscriber stations content for channel access and the collision probability is over 90 percent. The collision probability decreases when using larger packet interarrival times and results in a smaller mean delay for the bandwidth requests without piggybacking. On the other hand, the mean delay in the system with piggybacking rises because the percentage of piggyback request decreases with an increasing packet interarrival time. For a packet interarrival time larger than 10 ms, both delays, with and without piggyback requests, are similar because only a few bandwidth request can be piggybacked on previous packets. The delay still decreases because the collision probability in the contention phase also decreases and almost no request has to be retransmitted.

Finally, we are taking a look at the mean delay for lognormal distributed packet interarrival times. The results for four users in the system are shown in Figure 6.

The x-axis is set to the mean packet interarrival time in milliseconds and the y-axis shows the mean delay. The delay is measured for three different variation coefficients. However, the influence of the variation coefficient on the delay is negligible. Similar to the scenario with constant packet interarrival time, the delay difference between with and without piggybacking depends on the percentage of piggyback requests.

Concluding these results we can say that the performance increase with piggybacking is influenced by the traffic arrival process and the number of stations in the system. The highest performance gain was achieved for short, constant packet interarrival times with four subscriber stations in the cell. Now, we want to evaluate the performance of piggyback requests for a web traffic model.

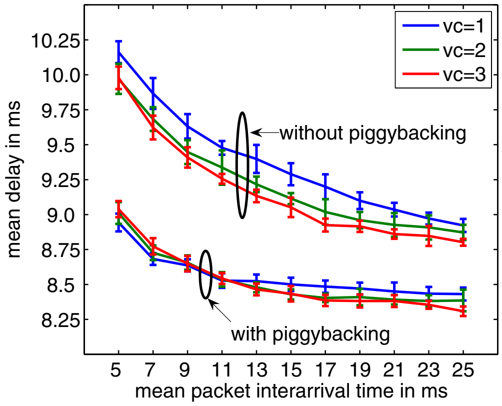

Fig. 6. Mean delay for four users with and without piggybacking using a lognormal packet arrival process with different coefficients of variation (vc)

B. Piggyback requests for web traffic

We configure the scenario according to the web traffic model shown in Table II. Like in the previous subsection, we first figure out the percentage of piggyback requests in a scenario with one subscriber station. In order to get a high percentage of piggyback requests, the subscriber station acts as the web server. Table III shows the results. The minimum, maximum, and mean percentage of piggyback requests are taken from 50 simulation runs. We have added five clients, using the ITU-T G.711 voice codec, to produce background traffic.

TABLE III
PERCENTAGE OF PIGGYBACK REQUESTS WITH THE SS ACTING AS THE WEB SERVER

background traffic	minimum	maximum	mean
no	38.053	82.618	60.048
yes	26.460	83.566	46.887

The large number of piggybacked bandwidth requests result from the number of embedded objects. If we set some background load, the percentage of piggybacked bandwidth requests decreases from 60 percent down to around 47 percent. The reason for this decrease is the number of collisions during the bandwidth request contention phase. If a bandwidth request collides, it will take at least one more frame to transmit the next bandwidth request. Arriving packets during this period are requested normally.

Finally, we want to see the impact of the high percentage of piggyback requests on the delay. Table IV shows the delay for the four different scenarios.

TABLE IV
WEB TRAFFIC DELAY WITH THE SS ACTING AS THE WEB SERVER

background traffic	PB	minimum	maximum	mean
no	enabled	14.545	28.848	21.883
no	disabled	16.155	28.975	22.0355
yes	enabled	29.46	57.265	39.223
yes	disabled	25.181	57.905	43.2598

If we add background load, the transmission delay for both scenarios, with and without piggybacking, almost doubles due to collisions during the normal bandwidth request phase. However, the difference between piggybacking and not-piggybacking is with 4 ms or 10 percent more obvious in the scenario with background load.

V. CONCLUSION

In this paper, the performance of piggyback requests has been evaluated. Therefore, the percentage of piggyback requests and the influence on the delay was determined for different traffic models. Simulation results have shown that the performance increase by using piggyback requests is most obvious in scenarios with a large number of users and short packet interarrival times. Here, a large number of collisions occur in the contention based bandwidth request phase which can be avoided by using piggybacking. The scenarios with the web traffic model have shown that a large number of bandwidth requests can be piggybacked on previous packets.

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