Proceedings of APCC2008 copyright (c) 2008 IEICE 08 SB 0083

Performance Evaluation of Polling Mechanisms in IEEE 802.16 Networks

Fei YIN and Guy Pujolle
LIP6, University Paris 6
104, Avenue du President Kennedy
75016, Paris, France
Email: Fei.Yin@lip6.fr, Guy.Pujolle@lip6.fr

***Abstract*—IEEE 802.16 standard suite defines two main polling modes: unicast polling and contention-based polling. These polling modes are adaptively adopted by different service classes in order to guarantee different performance requirements from different applications, in which the nrtPS (non real-time Polling Service) service class is defined to allow to adopt both the two polling modes. However, the standard does not specify exactly how these polling modes should be used for nrtPS. In this paper, by simulation, we evaluate the performance of the different polling mechanisms. We present a fact that an optimal unicast and contention-based mixed polling mode for nrtPS could allocate the bandwidth more efficiently and achieve better performance.**

I. Introduction

IEEE 802.16 is an emerging suite of air interface standards combing fixed, portable and mobile broadband wireless access specifications. 802.16-2004 [1] standard defines the air interface and MAC (Medium Access Control) protocol for a current fixed wireless metropolitan area network, intended for providing high bandwidth wireless voice and data for residential and enterprise, while 802.16e [2] amendment permit the 802.16 to enable not just fixed, but also portable and mobile operation in licensed and license-exempt frequencies bands below 11 GHz.

In IEEE 802.16 standard, two kinds of stations (fixed or mobile) are defined: the SS (Subscriber Station) delivers voice and data using common interfaces while the BS (Base Station) controls all the communication in the network. A mandatory PMP (Point-to-MultiPoint) operate mode and an optional mesh mode are supported by IEEE 802.16 standards. In a PMP network, a centralized BS is capable of connecting multiple SSs to various public networks, the traffics can only occur between the BS and the SSs. In the mesh mode, the SSs can also serve as routers by cooperative access control in a distributed manner. The communication between the BS and the SSs has two directions: the uplink (from SSs to BS) is shared by the SSs on a demand basis, and the downlink (from BS to SSs) is broadcast-based. In the following sections, we will present a general insight on the MAC operation of IEEE 802.16.

A. Frame structure

The frame in IEEE 802.16 standard is divided into two sub-frames: downlink sub-frame and uplink sub-frame. The two sub-frames can operate in different frequencies using FDD (Frequency Division Duplexing) mode or at different time using TDD (Time Division Duplexing) mode. Fig.1 shows a TDD frame in IEEE 802.16 standard.

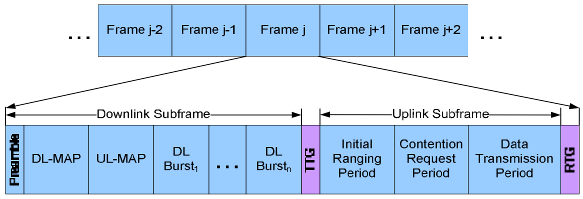

Fig. 1. Frame Structure in TDD mode

The downlink sub-frame starts with DL-MAP (Downlink MAP) and UL-MAP (Uplink MAP). The DL-MAP and UL-MAP contain the correlative information of the intervals' usage in the following downlink and uplink sub-frames respectively. The following downlink bursts carry the data to transmit to SSs.

In the uplink sub-frame, the BS may allocate the bandwidth for different purposes: the bandwidth in the Initial Ranging Period is used for the new SSs to join the channel; the bandwidth in the Contention Request Period is used as the request IEs (Information Element) for the SSs to competitively request uplink bandwidth; the bandwidth in the Data Transmission Period is used as the bandwidth grants in which particular SSs transmit data or uniquely request uplink bandwidth.

B. Polling-Request-Grant mechanism

In IEEE 802.16, a Polling-Request-Grant mechanism is defined for uplink bandwidth allocation: the SS first has to request uplink bandwidth before transmitting the data in a corresponding allocated bandwidth grant. Fig.2 shows the overall procedure of Polling-Request-Grant mechanism.

Initially, the SSs who have new connections need to get an admission into the network from the BS. According to the QoS parameters of the new connections, the BS polls the admitted SSs by allocating bandwidth specifically for the purpose of making bandwidth requests. Depending on the connections' service classes and the residual bandwidth in the BS side, these polling intervals may address to individual SSs (unicast polling) or to groups of SSs (contention-based polling). The SSs then utilize these intervals to uniquely or competitively request uplink bandwidth for each connection. On receiving the requests, the BS allocates chunks of mini-slots in the coming MAP as the bandwidth grants to the SSs, by taking into account the demands from all authorized SSs and the available bandwidth in the uplink sub-frame. Finally, the SS decodes the received UL-MAP, determines the honored connections to transmit data.

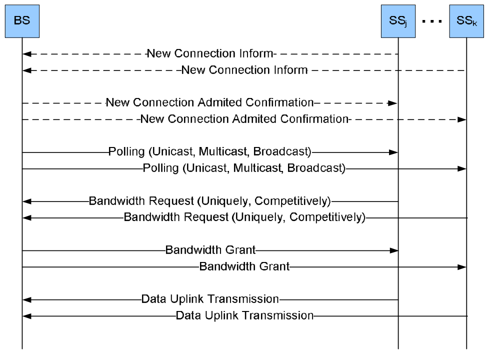

Fig. 2. Polling-Request-Grant Process

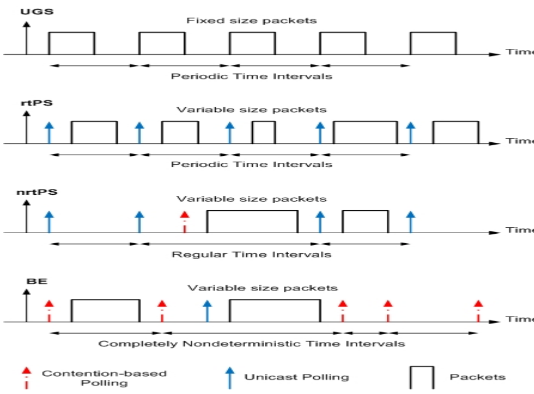

Fig. 3. Scheduling Service Classes

C. Scheduling service classes

As shown in Fig.3, the IEEE 802.16 MAC provides QoS differentiation for the different types of applications through four defined scheduling service types:

- UGS (Unsolicited Grant Service) is designed to support real-time service flows that generate fixed-size data packets on a periodic basis. The BS offers fixed-size data grants on a real-time periodic basis.
- rtPS (real-time Polling Service) is designed to support real-time service flows that generate variable-size data packets that are issued at a periodic intervals. The BS provides periodic unicast polling opportunities to the rtPS connections for bandwidth requests.
- nrtPS (non real time Polling Service) is designed to support delay-tolerant service flows that generate variable-size data packets for which a minimum data rate is requested. The BS allocates unicast polling opportunities on a regular basis, the contention-based polling is also allowed.
- BE (Best Effort) is designed to support data streams for which no minimum service level is required. The BS mainly allocates contention request opportunities.

In this paper, we only focus on the nrtPS service class to evaluate the performance. The rest of the paper is organized as following. In Section II we discuss the efficiency of polling modes in IEEE 802.16 networks, and present the related research works. In Section III we present the simulation model, the experiments configuration, the simulation results and the relative discussion. A conclusion is remarked in Section IV.

II. Problem Statement

The use of polling simplifies the access operation and guarantees that applications can receive service on a deterministic basis if necessary. As we know, in IEEE 802.16 networks, the different polling mechanisms exhibit very different efficiency on performance level. The unicast polling mechanism completely overcomes the request collisions and can guarantee the latency strictly, which is suitable for real time applications. The contention-based polling mechanism suffers from collisions and without delay guarantee, which is suitable for the applications where a minimum data rate is required.

In a system with a large number of SSs, the utilization of unicast polling mechanism has to reserve tremendous bandwidth for polling and then decreases the bandwidth allocated for grants, which makes the uplink throughput degrade. At the same time, more bandwidth requests may not be granted due to the deficiency of bandwidth and are pended in BS scheduler, which makes the delay increase. However, the use of contention-based polling mechanism in this case can avoid heavy polling overhead and get a certain level uplink throughput. Therefore, efficient adoption of different polling modes is a critical issue in IEEE 802.16-based networks. An optimal mixture of unicast and contention-based polling might take advantage of the both strongpoints and be a good solution to guarantee a certain level of uplink throughput and latency.

Although the nrtPS service is allowed to adopt both two polling modes during operation, the standard does not deliver an explicit explanation how the unicast and contention-based polling should be assigned to the SSs during the polling process. The BS has to poll the SSs by unicast polling, and switch to contention-based polling only when there are no sufficient residual bandwidth to support unicast polling. It is not an efficient polling mechanism. Our goal in this paper is, by simulation, to present the fact that an optimal mixed polling mode for nrtPS could allocate bandwidth more efficiently and the better performance could be always achieved.

The performance analysis of IEEE 802.16 networks has been widely discussed in recent years. Yin et al.[8] and the extension [9] focus on the performance of the non real time application with the contention-based polling mechanism. They analysed the performance based on the size of contention request period, and proposed an optimal size to optimize the performance with which the number of successful bandwidth requests equals to the number of available bandwidth grants. The simulation results with OPNET well proved that higher throughput and less pending bandwidth requests can be obtained with the optimal size. Wu et al.[11] proposed a new polling method for nrtPS to efficiently allocate uplink bandwidth by considering the varying nature of the wireless channel. The author modified the traditional PFS (Proportional Fair Scheduling) algorithm by introducing the QoS guarantees and apply to the nrtPS. The authors also implemented the simulation to prove the effectiveness of their algorithm. Vinel et al.[10] provided both simulation and analytical models for the investigation of specified random access method, which is compared with centralized polling and

Upstream Data Rate	QPSK-640kbps
Downstream Data Rate	64QAM-27Mbps
Time Covered by MAP	10msec, 20msec, 30msec
Mini-slot Size	50μsec
Bytes per mini-slot	4
Unicast Polling Interval	10msec
Polling modes	all-unicast polling all-contention-based polling mixed polling

TABLE I
THE SIMULATION PARAMETERS

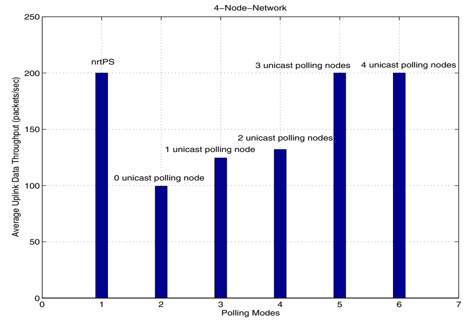

Fig. 4. Uplink Data Throughput of Low Load Network

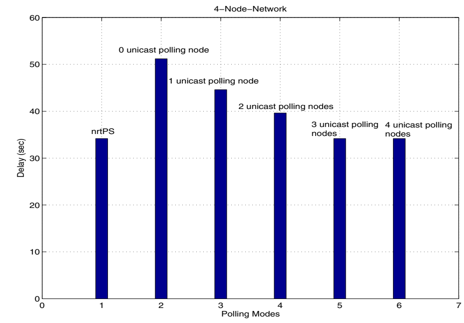

Fig. 5. Delay of Low Load Network

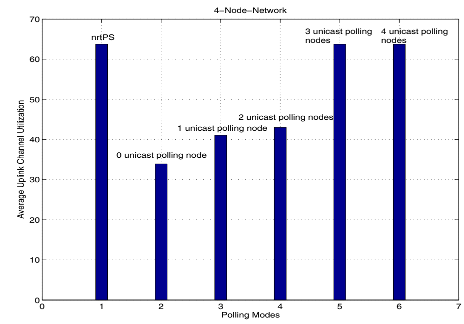

Fig. 6. Uplink Channel Utilization of Low Load Network

station-grouping mechanisms. Lin et al.[5] provided a simple, but nevertheless accurate, analytical model to compute the utilization of transmission opportunity applies to multicast and broadcast polling mechanisms. Chang et al.[6] proposed an adaptive polling approach to switch the polling mode among the unicast polling and the contention-based polling while continuous supporting rtPS. Ni et al.[7] compared two polling mechanisms under PMP mode and demonstrated that random access outperforms polling when the request rate is low. However, its performance degrades significantly when the channel is congested.

III. SIMULATION MODEL AND RESULTS

We build an IEEE 802.16 simulation network by using OPNET [3] simulator with DOCSIS[4] (Data Over Cable Service Interface Specification) module. We simulate a simple PMP topology involving a central BS and a number of SSs. Table I shows the simulation parameters. The duplexing scheme chosen is TDD. An application with an 80-byte packet issued per 10 milli-second is run at the top of each SS. To be simplicity, we only consider bandwidth allocation in one channel.

The simulations are implemented to study the performance of all-unicast, all-contention-based and the mixed polling mechanisms. We execute a series of experiments by setting the different number of unicast polled and contention-based polled SSs in the network, in which the optimal polling mode is presented. In order to evaluate the influence to the performance introduced by network size and MAP size, we repeat all the experiments in networks with different number of SSs and different MAP size.

A. Low load network

In this case, the uplink bandwidth is enough that all the SSs might be uniquely polled and all the bandwidth requests from the SSs could be granted by the BS. Notice the fact that we only consider the bandwidth allocation in one channel, then we do the experiments in a network of 4 nodes to simulate the low load network. The impacts of uplink throughput, delay and uplink channel utilization for all-unicast, all-contention-based and different mixed polling modes are show in Fig.4, Fig.5 and Fig.6 respectively. The x-axes are the polling modes and the y-axes are the related performance parameters. The curves reveal the following facts: 1) The performance upgrades with the number of unicast polling nodes increases. 2) The all-contention-based polling mechanism gets the worst performance on uplink throughput, uplink channel utilization and delay. 3) The all-unicast polling mechanism gets the best performance. 4) The nrtPS actually adopts all-unicast polling mode. There is no contention-based polling issued in nrtPS since the unicast polling is preferential and the bandwidth is sufficient. 5) The same thing happens to the 3-node unicast and 1-node contention-based polling mechanism, in which the 1-node contention-based polling is exactly the unicast polling. That is why we observe that in the figures, the performance of all-unicast, nrtPS, 3-node unicast mixed polling mechanisms are completely same.

B. High load network

Now we observe the performance in the high load system in which not all the bandwidth requests from the SSs could be granted by the BS. We perform the simulations in a 20-node network to evaluate the performance of polling mechanisms in a high load network. As we discussed in section II, the use of an optimal unicast and contention-based mixed polling mode in high

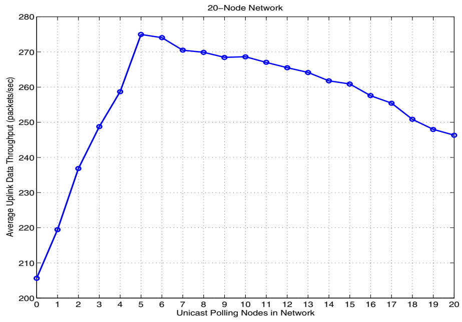

Fig. 7. Average Uplink Data Throughput of High Load Network

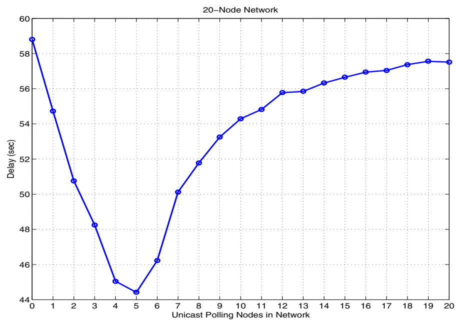

Fig. 8. Delay of High Load Network

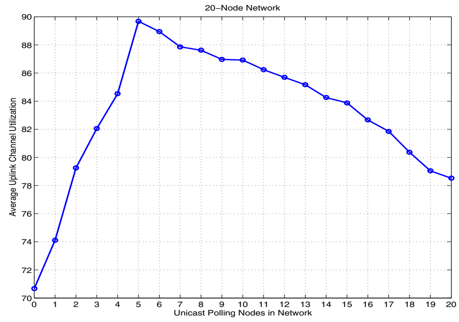

Fig. 9. Average Uplink Channel Utilization of High Load Network

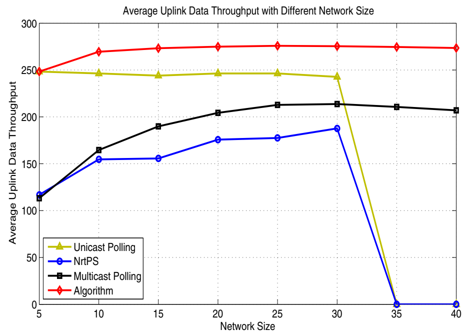

Fig. 10. Average Uplink Data Throughput with Different Network Size

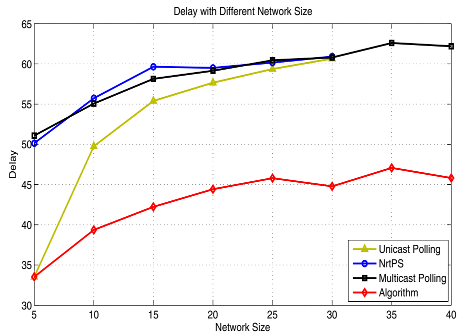

Fig. 11. Delay with Different Network Size

load systems will make the SSs to get a real-time basis uplink transmission but does not occupy much polling bandwidth, and then guarantee a certain level of uplink throughput. In order to find out the optimal mixed polling, we execute a series of simulations by setting different number of unicast polled and contention-based polled nodes in network. The results of the uplink throughput, the delay and the uplink channel utilization are shown in Fig.7, Fig.8 and Fig.9 respectively. The x-axes are the the number of unicast polled nodes in the network. The y-axes are the related performance parameters. We can notice that the performance of different polling modes exhibits an unstable behavior with the unicast polling nodes increases, which is different from what are showed in the low load networks. The all-contention-based polling mechanism still gets the worst performance, whereas the all-unicast polling mode does not achieve the best performance again. In particular, as shown in the figures, as the number of unicast polled nodes increase, the performance upgrades to a maximum value, where the 5-node unicast and 15-node contention-based polling mode is adopted in network. Further increases of the number of unicast polling nodes lead to an eventually significant performance degradation. Specially, as shown in Fig.9, the optimal mixed polling mechanism only occupies 10% of uplink bandwidth for polling and gets 90% for the uplink data transmission, while the all-unicast polling only gets 78% for uplink data transmission but reserves 22% for unicast polling. Our results prove that an optimal unicast and contention-based mixed polling mode can allocate the resource more efficient and then can obtain the best performance in a high load network.

C. *Performance comparison with different network size*

As mentioned before, the optimal mixed polling mode performs the best performance in high load networks. In this section, we do the performance comparison in different network size to verify its ubiquity by repeating the simulatioins in section III-B in networks with size from 5 nodes to 40 nodes. Fig.10, Fig.11 and Fig.12 show the uplink throughput, the delay and the uplink channel utilization for all-unicast polling, all-contention-based polling, the nrtPS and the optimal mixed polling mode. The x-axes are the network size. The y-axes are the related performance parameters. We notice that the all-contention-based polling mode gets worse performance than nrtPS only in low load network whereas the nrtPS always gets the worst performance in high load networks. The optimal mixed polling mode in all neworks always achieves the best performance with highest uplink throughput, highest uplink channel utilization and lowest latency.

Specially, the uplink throughput and uplink channel

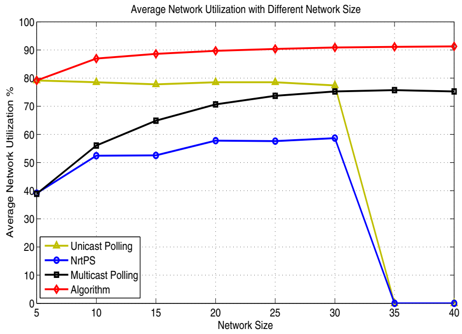

Fig. 12. Average Uplink Channel Utilization with Different Network Size

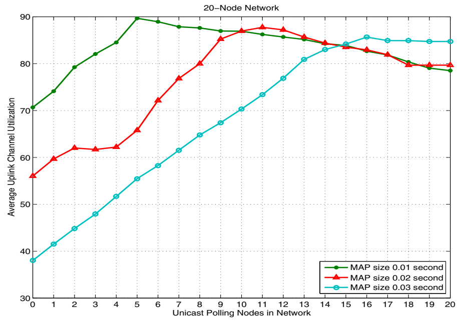

Fig. 14. Average Uplink Channel Utilization with Different MAP Size

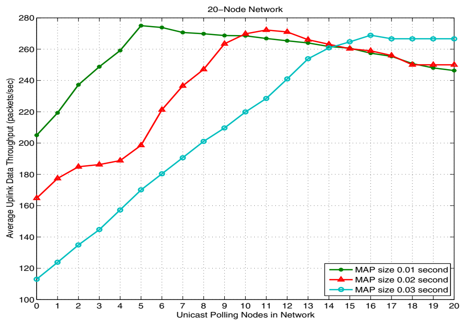

Fig. 13. Average Uplink Data Throughput with Different MAP Size

utilization of the all-unicast polling mode and the nrtPS in the networks more than 30 nodes are 0. That is an extreme situation: the unicast polled nodes are so many that all the uplink bandwidth are reserved for the polling and there is not sufficient residual bandwidth can be allocated for even one bandwidth grant, which makes the SSs can not be allocated the uplink opportunities to transmit data (the uplink channel utilization is 0). Even under this extreme condition, the optimal mixed polling mechanism still works well and gets the best performance by adjusting the number of unicast polling nodes and contention-based nodes.

D. Performance comparison with different MAP size

Since the MAP size influence the total bandwidth uplink sub-frame, we repeat the simulations of section III-B with different MAP sizes to evaluate the performance. Fig.13 and Fig.14 show the uplink throughput and the uplink channel utilization in 20-node network with MAP size of 0.01, 0.02 and 0.03 seconds. The x-axes are the the number of unicast polled nodes in the network. The y-axes are the related performance parameters. We can find the fact that there is always an optimal mixed polling mode and the optimal point is differentiation for the different MAP size. We can also verify that the best performance can be achieved with this optimal mixed polling mode.

IV. Conclusion

The IEEE 802.16 defines different polling mechanism for different QoS requirement, enabling systems to allocate bandwidth for an adaptive manner. In our paper we used simulation models to evaluate the performance of different polling mechanisms defined in IEEE 802.16. We found that the all-unicast polling mechanism performs very good in low load conditions but works worse in high load conditions since it takes too much bandwidth for unicast polling. We also present an optimal unicast and contention-based mixed polling mode. By use of this optimal mixed polling mode in networks with different MAP sizes and loads, we notice that the bandwidth utilization are significantly efficient and higher performance could always be achieved. Furthermore, this optimal mixed polling mechanism can also work well and get better performance even under the extreme condition. Here we only evaluate the optimal mixed polling mechanism for nrtPS by simulation, an accurate mathematic analysis and the extend version to other scheduling service classes will be presented in the future works.

References

[1] *IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems*. 2004.

[2] *IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems*. 2005.

[3] *OPNET Technologies Inc*. http://www.opnet.com/.

[4] *Data-Over-Cable Service Interface Specifications DOCSIS 3.0: MAC and Upper Layer Protocols Interface Specification*. 2007.

[5] Lidong. Lin, Weijia. Jia and Wenyan. Lu, *Performance Analysis of IEEE 802.16 Multicast and Broadcast Polling Based Bandwidth Request*. IEEE WCNC 2007.

[6] Ben-Jye. Chang and Chien-Ming. Chou, *Adaptive Polling Algorithm for Reducing Polling Delay and Increasing Utilization for High Density Subscribers in WiMAX Wireless Networks*. 10th IEEE ICCS 2006.

[7] Qiang. Ni, Alexey. Vinel, Yang. Xiao, Andrey. Turlikov and Tao. Jiang, *Investigation of Bandwidth Request Mechanisms under Point-to-Multipoint Mode of WiMAX Networks*. IEEE Communications Magazine, 2007.

[8] Fei. Yin and Guy. Pujolle, *Uplink Throughput Optimization for Delay-tolerant and Contention-based Application in IEEE 802.16 Broadband Wireless Access Networks*. FGCN 2007.

[9] Fei. Yin and Guy. Pujolle, *Performance Optimization for Delay-tolerant and Contention-based Application in IEEE 802.16 Networks*. EURASIP Journal on Wireless Communications and Networking, 2007.

[10] Alexey. Vinel, Ying. Zhang, Qiang. Ni and Andrey. Lyakhov, *Efficient Request Mechanism Usage in IEEE 802.16*. IEEE GlobalCom 2006.

[11] Jing Wu, Jeong-Hoon Mo and Ting Wang, *A Method for Non-real-time Polling Service in IEEE 802.16 Wireless Access Networks*. IEEE VTC Fall 2007.