An Efficient Bandwidth Management Algorithm for WiMAX (IEEE 802.16) Wireless Network

EBM Allocation Algorithm

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Abstract— **IEEE 802.16 WiMAX (Worldwide Interoperability for Microwave Access) consists of five service classes with different priorities. The priority of real time traffic is higher than that of non-real time traffic. Since bandwidth is limited, it must be allocated in advance to guarantee the throughput of real time traffic in WiMAX network. But WiMAX standard does not provide any algorithm for dynamic allocation of bandwidth to these services. In this paper, a dynamic bandwidth allocation algorithm for WiMAX called Efficient Bandwidth Management (EBM) is proposed. In EBM the bandwidth will be increased in the upcoming frames when the allocated bandwidth is not sufficient to transfer the data. On the other side if the allocated bandwidth is more, then the bandwidth will be decreased in the upcoming frames so that the other services can use this excess bandwidth. This bandwidth increase or decrease is proportional to the remaining data in the queue. EBM increase the throughput of real time traffic as the bandwidth is handled efficiently. The proposed algorithm is implemented in ns-2 and results are compared with traditional IEEE 802.16 WiMAX. The simulation results show that EBM algorithm gives better result for real-time traffic.**

Keywords- Bandwidth Allocation, IEEE 802.16, real time traffic, WiMAX

I. INTRODUCTION

The fast development of wireless communications and networking technologies has greatly improved the mobile and roaming capability of handset devices, such as PDA and cellular phones. As a result, the popularity of multimedia applications on handset devices is overwhelming. WiMAX first standardized in 2004, known as IEEE 802.16, can provide broadband communications over wireless for various types of multimedia traffic, such as video streaming, VoIP, FTP, etc. In 2005 the IEEE 802.16e amendment adds features and attributes to the 802.16 standard for supporting mobility [2]. In comparison to WiFi (IEEE 802.11), WiMAX not only offers larger and dedicated bandwidth, but it also provides different traffic types with different priority classes for meeting individual Quality of Service (QoS) requirements in both (uplink and downlink) directions [1, 2]. IEEE 802.16 architecture consists of one Base Station (BS) and many Subscriber Stations (SSs). All SSs have to be synchronized with BS. SSs are allowed to send data only at scheduled time which is decided by the BS and communicated to all SS in the beginning of each frame in Uplink Map (UL-MAP). Protocols of PHY layer, MAC layer and QOS framework are specified in IEEE 802.16 standard. However, admission control and bandwidth allocation scheme are not defined in the standard and left open area for researchers.

The IEEE 802.16 standard provides good QoS support for five different types of service flows: UGS, ertPS, rtPS, nrtPS, and BE. UGS (Unsolicited Grant Polling) service flow is designed to support real-time transactions that generate fixed-size data packets on a periodic basis, such as VoIP without silence suppression; ertPS (Extended Real Time Polling Service) and rtPS (Real Time Polling Service) service flow are designed to support real-time transactions that generate variable-size data packets on a periodic basis, such as VoIP with silence suppression and MPEG; nrtPS (Non Real Time Polling Service) service flow is designed to support delay-tolerant transactions consisting of variable-size data packets for which a minimum data rate is required, such as FTP; BE (Best Effort) service flow is designed to support non real-time transactions for which no minimum service level is required and therefore may be handled on a space-available basis.

Since real time traffic is Variable Bit Rate (VBR) traffic, data arrival rate changes continuously causing change in bandwidth requirement. As priority of real time traffic is high, BS has to provide sufficient bandwidth to them and it cannot allocate when it doesn't have enough bandwidth. And if the allocated bandwidth in advance to these services is more than the required amount then these extra bandwidth will be wasted. For downlink the BS can easily adjust the assigned bandwidth but for uplink SS should send message in some interval to BS for bandwidth requirement change. Therefore, a proper bandwidth allocation and management algorithm is required to fulfill all QoS requirements. In this paper we propose an Efficient Bandwidth Management Algorithm (EBM) for WiMAX. The EBM takes the remaining data in queue into account for allocating the bandwidth for the real-time traffic.

The remainder of the paper is organized as follows. In the section II we will present the related work done by other authors. The proposed bandwidth allocation algorithm will be described deeply in section III. In section IV, the simulation result and performance analysis will be presented and discussed. Finally, some remark about conclusion is shown in section V.

II. RELATEDWORK

The IEEE 802.16 standard has gain much interest of researchers in past few years. A good number of papers are available on the performance analysis of IEEE 802.16 BWA systems. We found very few study describing their bandwidth allocation algorithm (or architecture) and simulation platform clearly. This section describes the work done by researchers in bandwidth allocation.

For decreasing the delay of real-time traffic, Zhu Peng, et al. [4] proposed an effective adaptive bandwidth mechanism for real-time polling service (rtPS), which can decrease the delay and needs lesser buffer size. In this mechanism, a SS will request time slot not only for present data in the queue but also on the data which will arrive in the queue in between t0 and t1. Here, author used the of "Differential time grant" method. The analytical model and simulation show that, this adaptive algorithm provided better results with respect to the number of packets waiting at SS and average delay as compared to the widely accepted weighted scheduling algorithm. In this paper the author decrease the delay but didn't talk about throughput of rtPS service and also the effect on other services. On the other hand Cheng-Yueh Liu, et al. [7] tried to lower the delay caused by collision of request packets for extended real-time polling service (ertPS) and proposed a scheme that utilizes contention-free periods to allocate slots for bandwidth request. The performance is validated via mathematic model and simulation and the result shows the scheme reduces the bandwidth request delay and increases certain amount of throughput. This methodology is not suitable for large number of stations. Also Chia-Hsing Hsieh, et al. [9] proposed a bandwidth control protocol for QoS control in TDD-mode WiMAX network. According to this algorithm when allocated bandwidth to real-time service is not sufficient, it borrows bandwidth from non-real time traffic. And the borrowed bandwidth will not be returned unless the allocated resource to the real time traffic is enough. The parameters used for bandwidth control are Signal-to-Interference Ratio (SIR) and queue length after scheduling, minimum reserved rate, and maximum sustained rate, requested and allocated bandwidth to all services. The author proposed two methods for bandwidth control: BC-General and BC-Reactive. Both of these methods takes bandwidth from non-real time service and allocate to real-time service. The result shows that the BC-General and BC-Reactive have better performance than the original protocol for rtPS class when the load of the network is high, while the performance for BE class is worst.

Amir Esmailpour, et al. [5] proposed a packet scheduling and bandwidth allocation strategies. The proposed scheme makes the bandwidth allocation for the TDD mode of operation of the IEEE 802.16 standard, and supports all types of service flows as indicated by the standard. It follows the variable transmission rate and signaling mechanism rules and regulations through dynamic adjustments of the bandwidth allocation. They used 2-tier packet scheduling algorithm and Dynamic Bandwidth Allocation (DBA) algorithm which adjusts resource allocation based on traffic and network characteristics (fairness and utilization). The solution provides QoS support to all traffic classes defined by the standard, and it dynamically changes the bandwidth allocation based on the traffic characteristics and service demands. Simulation results show that the proposed solution can deliver QoS support and be fair to all classes of service in a WiMAX network.

For internet attached TCP traffic, Chih-He Chiang, et al. [6] built a performance model by separating uplink and downlink paths in TDD-based WiMAX network so that the model becomes two independent optimization problems. The authors focused on BE scheduling service, which aims to provide efficient service for the majority of existing Internet applications, such as Web browsing, FTP, P2P file sharing, etc. and adjust the downlink to uplink bandwidth ratio according to current traffic profile. The author focus only on TCP flows and allows both downloading and uploading. Therefore, the result can serve as the lower bound of the performance when both UDP and TCP traffic co-exist in the network. The performance is validated via ns-2 simulations and results show that this scheme outperforms static allocation in terms of higher aggregate throughput. Also Eun-Chan Park, et al. [11] proposed a hybrid approach combining proactive bandwidth allocation with piggyback bandwidth request. The algorithm is taking TCP characteristic into account like TCP data and TCP ACK. The proposed framework removes the unnecessary bandwidth-request delay, and also decreases signaling overhead involved in the bandwidth-request. The proposed algorithm had been implemented in OPNET simulator. Simulation results show that this approach significantly increases downlink TCP throughput and uplink bandwidth efficiency. Similarly, T.L. Sheu, et al. [8] proposed an adaptive bandwidth allocation (ABA) model for Internet-attached WiMAX network. This first reserves the unsolicited bandwidth for constant bit-rate traffic (UGS). Then, polling bandwidth is allocated for rtPS to meet their end-to-end delay constraints and for nrtPS to meet their minimum throughput requirements. Finally, the remaining bandwidth, if any, is allocated for BE traffic to avoid any possible starvation. A four-dimension Markov chains is built to analyze the performance of the proposed algorithm. The performance shows the good results for average delay, average throughput, and average packet drop ratio by varying traffic parameters. In this paper the author does not provide any simulation scenario to verify the proposed mechanism.

For utilizing the remaining or unused bandwidth, David Chuck, et al. [10] propose a scheme, named Bandwidth Recycling, which recycles the unused bandwidth of each SS while keeping the same QoS guaranteed services and introducing no extra delay. It allows the BS to schedule a complementary station for each transmission stations. Each complementary station monitors the entire UL transmission interval of its corresponding TS and standby for any opportunities to recycle the unused bandwidth. In this scheme, when a SS has unused bandwidth, it will transmit a special message, called releasing message (RM), to inform its corresponding Complementary Station (CS) to recycle the unused bandwidth. The author also proposed a priority scheduling algorithm. Mathematical analysis and simulation by Qualnet 4.5 are used to evaluate the proposed scheme. Besides the naive priority-based scheduling algorithm, three additional algorithms have been proposed to improve the recycling effectiveness. Our mathematical and simulation results confirm that our scheme cannot only improve the throughput, but also reduce the delay with negligible overhead and without degrading the QoS requirements. Also Li-Ping Tung, et al. [12] Proposed a simple and flexible bandwidth reservation scheme at the SS, called Multi-stage Self-correction Bandwidth Reservation (MSBR), to make effective use of the bandwidth without violating the QoS requirements for real-time traffic under the proposed cost model. The MSBR scheme introduces the concept of Decision Period for bandwidth reservation to reduce the control message overheads. The proposed method also adopts the RLS algorithm to predict the traffic arrival and applies the MSBR method to capture the traffic dynamics for bandwidth reservation. Simulation results demonstrate that the proposed MSBR scheme utilizes the bandwidth efficiently without violating the QoS requirements of real-time services.

This paper aims to propose an Efficient Bandwidth Management Algorithm for WiMAX. The proposed algorithm is inspired by Bandwidth Control Protocol (BCP) given in [9]. BCP concentrates on SIR and Queue length to allocate the bandwidth for rtPS class, whereas the EBM takes the remaining data in queue into account for allocating the bandwidth for the rtPS class. EBM is a dynamic bandwidth allocation algorithm which increases the bandwidth when the allocated bandwidth is not enough to transfer the data. The objective here is to consider the current context of the network to assign proper bandwidth for queues of real time traffic.

III. EBM Algorithm For Wimax

The proposed EBM algorithm consists of two parts: Call Admission Control (CAC) and Bandwidth Allocation. The CAC mechanism determines whether a new request for connection can be granted or not according to the remaining bandwidth. The admission control method is not defined in the standard and is left as an open choice for the manufacturers. With this mechanism, the BS will assign a minimum required bandwidth to each service flow [1, 2]. The bandwidth is allocated according to the priority of service class, i.e. the bandwidth is allocated first to highest priority class.

A. Call Admission Control

The CAC mechanism follows the First-In-First-Served (FIFS) basis to admit the coming requests. If the bandwidth is enough for serving the request, this request will be allowed to enter the system, otherwise it will be denied by CAC immediately. The procedure of CAC will be described as follows:

$$B_{assign} = \sum_{\forall\, service} \sum_{i=1}^{n} B_i^{service}$$

$$B_{req} + B_{assign} \leq B_{total} \tag{1}$$

Where $B^{service}$: the bandwidth assigned to particular service,
B_{req}: the bandwidth required by the service,
B_{assign}: the total bandwidth assigned to all service,
B_{total}: the total bandwidth of BS.

For all requesting service according to Eq. (1) EBM algorithm will check the available bandwidth for the current service. If the condition is true then the requested bandwidth will be granted to the service and B_{assign} will be increased by B_{req}.

B. Bandwidth Allocation

The bandwidth is allocated according to the priority of service class i.e. the bandwidth is allocated first to highest priority class. The module have five different service classes: UGS, ertPS, rtPS, nrtPS, BE. The proposed algorithm consists of two parts: Initial Bandwidth Assignment and changing the required bandwidth for next frame. For downlink bandwidth allocation, we use the queue information for various traffics. Each service associated with a queue, which shows how much data needed to send. According to required bandwidth (B_{req}), the bandwidth will assign to the particular service. First it allocate bandwidth to high priority services (UGS, ertPS and rtPS), and if bandwidth available then it allocate to nrtPS and BE services. The process of Initial Bandwidth Assignment is given below:

// Initial Bandwidth Assignment
$B_{UGS} \leftarrow$ Sum of all B_{req} of UGS class
$B_{ertPS} \leftarrow$ Sum of all B_{req} of ertPS class
$B_{rtPS} \leftarrow$ Sum of all B_{req} of rtPS class
$B_{nrtPS} \leftarrow$ Sum of all B_{req} of nrtPS class
$B_{BE} \leftarrow$ Sum of all B_{req} of BE class
$if\,(B_{UGS} > 0)$
    Allocate requested bandwidth to UGS class
    $B_{avail} = B_{avail} - B_{UGS}$
$if\,(B_{avail} > B_{ertPS})$
    Allocate requested bandwidth to ertPS class
    $B_{avail} = B_{avail} - B_{ertPS}$
$if\,(B_{avail} > B_{rtPS})$
    Allocate requested bandwidth to rtPS class
    $B_{avail} = B_{avail} - B_{rtPS}$
$if\,(B_{nrtPS} > 0 \text{ and } B_{avail} > B_{nrtPS})$
    Allocate requested bandwidth to nrtPS class
    $B_{avail} = B_{avail} - B_{nrtPS}$
$if\,(B_{BE} > 0 \text{ and } B_{avail} > B_{BE})$
    Allocate requested bandwidth to BE class
    $B_{avail} = B_{avail} - B_{BE}$

For Downlink after the first round of bandwidth assignment, the frames of rtPS class will be assigned some slots to send. After sending the frame, if the queue of this class is not empty, their frames may be delayed and discarded. This means the bandwidth allocated is not enough. Also the time gap between bandwidth assignment and actual transmission, some data may come in queue [4]. BS should allocate some extra bandwidth to the service. Here, we are calculating the remaining data in the queue just after the transmission. So that whole data in the queue (date remaining and data which come in the time gap) can be transmitted in one frame. Therefore, the bandwidth assigned will be increased/ decreased before the start of next frame.

Assume Q is the queue associated with real-time services (rtPS), B_{rtPS} is the amount of bandwidth assigned to that service in previous frame, D is the amount of data remaining in the queue after transmission of frame.

// Calculation of remaining data after transmission of frame
$if(B_{rtPS} < Q)$ // this situation means the allocated bandwidth of rtPS class is not enough.
    $D \leftarrow Q - B_{rtPS}$
$else\ if(B_{rtPS} > Q)$ // this situation means the allocated bandwidth of rtPS class is more than enough.
    $D \leftarrow B_{rtPS} - Q$
// changing required bandwidth for next frame. This portion is the part of Bandwidth Management function.
$if(D < 0)$
    $B_{rtPS} = B_{rtPS} - D$
$else$
    $B_{rtPS} \leftarrow B_{rtPS} + D$

For uplink bandwidth allocation the SS send the bandwidth request to BS. The bandwidth request message consist minimum bandwidth required for SS. After receiving the message from SS the BS will update B_{req} with the same procedure as downlink. The existing module send bandwidth request message only once at the time of connection. But for Variable Bit Rate (VBR) traffic the data arrival rate changes continuously. So the bandwidth needed by service change, and SS should send message in some interval to BS about bandwidth requirement. If BS does not have sufficient bandwidth for real time traffic it borrows the bandwidth from non-real time traffic.

Efficiency of EBM algorithm of bandwidth allocation can be calculated by:

$$\eta = 1 - \left(\sum_{i=1}^{n} \frac{Q_{ser}^{i-1} - B_{ser}^{i-1}}{Q_{ser}^{i}} \right) \quad (2)$$

IV. Result And Analysis

A. Experimental Setup

Based on PMP system in TDD mode for an IEEE 802.16 network, we will use ns-2 [13] to simulate the proposed EBM allocation algorithm. The module used for WiMAX simulation is given in [3]. To focus on the performance of the protocol, it will be implemented only on the downlink. The length of the frame is set to 5msec and the bandwidth of the system is set to 20MHz as defined in the standard. We have used ten SS and one BS, and run the simulation for 100 seconds. Important parameters used in simulation are summarized in table I.

TABLE I. Parameters for Simulation

Simulation Parameter	Value or Mode
Channel bandwidth	20 MHz
Frame duration	5 ms
System	TDD mode
Total Downlink Bandwidth	7.48 Mbps (QPSK ¾)
DL/UL Ratio	3:2
Simulation Time	100 Sec

The network setup used for the experiment is shown in Figure 1. We have assigned the each type of service between the different pair of SS and BS for downlink packet transmission. Five classes of packets are transmitted from BS to each SS. As we can see from Table II, the arrival rate for packets of UGS class is 320Kbps (One 200byte packet for each 5msec). The arrival rate of other classes varies from 128Kbps to 1280Kbps and the arrival process is random. The priority order of the services are UGS, ertPS, rtPS, nrtPS, and BE.

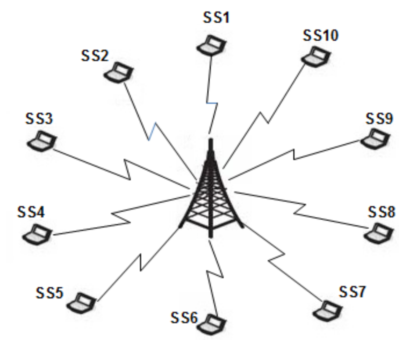

Figure 1. Simulation Topology

TABLE II. Data Traffic Setting [9]

Packet Type	Traffic Type	Bit Rate	Packet Size
UGS	UDP/CBR	320Kbps	200 Byte
ertPS	UDP/VBR	128 to 1280 Kbps	200 to 1000 Byte
rtPS	UDP/VBR	128 to 1280 Kbps	200 to 1000 Byte
nrtPS	UDP/VBR	128 to 1280 Kbps	200 to 1000 Byte
BE	UDP/VBR	128 to 1280 Kbps	200 to 1000 Byte

B. Simulation Result and Analysis

Figure 2 describes the bandwidth allocation for EBM and IEEE 802.16. In former the bandwidth will be allocated according to requirement of data. For ex., at a given instant, the allocated bandwidth to the service is 500 and data in the queue (Queue Length) is 700, after sending the frame the amount of data remaining in the queue will be 200. In the next following frame the bandwidth assigned will be 700. And suppose the bandwidth assigned is more the data in the queue then in the following frame the bandwidth will be decreased accordingly. But it is not the case in IEEE 802.16.

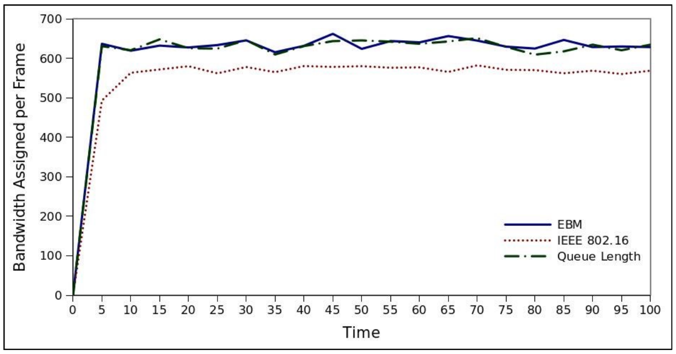

Figure 2. Bandwidth Allocation for rtPS class

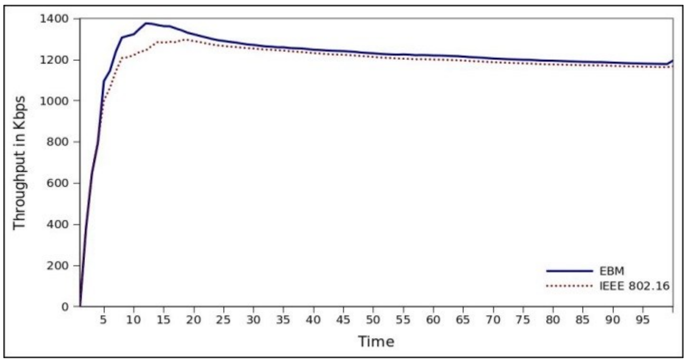

Figure 3. Throughput for rtPS class

As shown in Figure 3, in overall scenario the EBM algorithm performs batter than the traditional protocol for rtPS class. In the initial phase when time stamp is very low the traditional protocol is inefficient to allocate the bandwidth for rtPS service and does not respond quickly to the bandwidth requirement, on the contrary EBM algorithm responds instantaneously. Thus the throughput is high for EBM algorithm in the early phases. However, the throughput of non-real time class has no improvement. This is because the bandwidth of this class has been assigned to rtPS class to handle the problem caused by variable load of real-time traffic.

The efficiency of allocated bandwidth for all classes is calculated by using eq. (2), for EBM algorithm the overall efficiency is 95%, while for traditional IEEE 802.16 protocol is 89%.

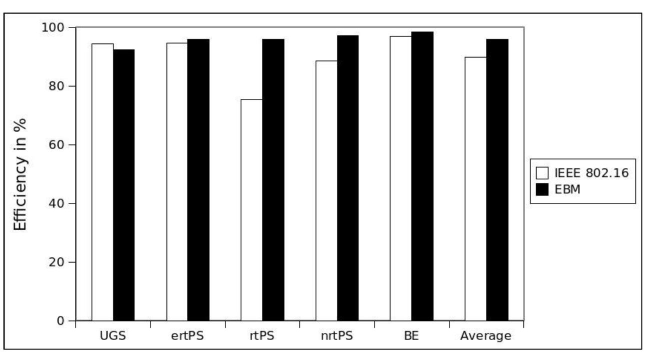

Figure 4. Efficiency of Bandwidth Allocation

V. CONCLUSION

In IEEE 802.16, if the maximum bandwidth allocated for each class is not enough, then the QoS cannot be guaranteed and if it is too much then the resources may be wasted and hence it is not reliable. In this paper EBM algorithm has been proposed for the variant load requirement. EBM uses the remaining data in the queue after scheduling as a standard for bandwidth control. EBM is a dynamic bandwidth allocation algorithm which increases the bandwidth when the allocated bandwidth is not enough to transfer the data. The simulation results shows, the efficiency of EBM algorithm is 98% in terms of allocating the bandwidth to real-time traffic also the throughput of EBM is much higher as compared to traditional IEEE 802.16 WiMAX.

REFERENCES

[1] IEEE,"IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access System," IEEE Std. 802.16-2004,Oct.2004.

[2] IEEE,"Draft Amendment to IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access System, "IEEE P802.16e/D12,Oct. 2005.

[3] Jenhui Chen, Chih-Chieh Wang, Frank Chee-Da Tsai, Chiang-Wei Chang, Syao-Syuan Liu, Jenjhong Guo, Wei-Jen Lien, Jui-Hsiang Sum, and Chih-Hsin Hung, "The Design and Implementation of WiMAX Module for ns-2 Simulator", Published in ACM *WNS2'06,* October 10, 2006, Pisa, Italy.

[4] Zhu Peng, Zhu Guangxi, Shi Haibin, Lin Hongzhi, "A Novel Bandwidth Scheduling Strategy for IEEE 802.16 Broadband Wireless Networks", IEEE 1-4244-1312, May. 2007.

[5] Amir Esmailpour and Nidal Nasser, "Dynamic QoS-Based Bandwidth Allocation Framework for Broadband Wireless Networks", Published in IEEE Transactions On Vehicular Technology, Vol. 60, No. 6, July 2011.

[6] Chih-He Chiang, Wanjiun Liao, Tehuang Liu, Iam Kin Chan, and Hsi-Lu Chao, "Adaptive Downlink and Uplink Channel Split Ratio Determination for TCP-Based Best Effort Traffic in TDD-Based WiMAX Networks", IEEE JOURNAL Vol. 27, NO. 2, February 2009.

[7] Cheng-Yueh Liu and Yaw-Chung Chen, "An Adaptive Bandwidth Request Scheme for QoS Support in WiMAX Polling Services", The 28th International Conference on Distributed Computing Systems Workshops, IEEE 1545-0678, 2008.

[8] T.L. Sheu, K.C. Huang, "Adaptive bandwidth allocation model for multiple traffic classes in IEEE 802.16 worldwide interoperability for microwave access networks", Published in IET Communications, received on 2nd January 2010, revised on 8th April 2010, IET Commun., 2011, Vol. 5, Iss. 1, pp. 90–98.

[9] Chia-Hsing Hsieh, Tsung-Ju Wu, Hann-Tzong Chern, "Bandwidth Control Protocol in WiMAX Network", International Symposium on Parallel and Distributed Processing with Applications, IEEE 978-0-7695-4190, July 2010.

[10] David Chuck and J. Morris Chang, "Bandwidth Recycling in IEEE 802.16 Networks", IEEE Transiction on mobile computing, Vol. 9, No. 10, OCTOBER 2010.

[11] Eun-Chan Park, Jae-Young Kim, Hwangnam Kim and Han-Seok Kim, "Bidirectional Bandwidth Allocation for TCP Performance Enhancement in Mobile WiMAX Networks" published in IEEE, 978-1-4244-2644-7/08, 2008.

[12] Li-Ping Tung, Yeali S. Sun, and Meng Chang Chen, "Dynamic Bandwidth Reservation Scheme in 802.11 and 802.16 Interworking Networks" Published in IEEE WCNC 2011 – MAC, 2011.

[13] The Network Simulator ns-2. http://www.isi.edu/nsnam/ns/, September 2007