A Novel Two-level Hierarchical Scheduling Scheme for Integrated WiMAX and EPON

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***Abstract*— In this paper, a novel two-level scheduling algorithm for uplink transmission is proposed. The proposed scheme is characterized by using proportional fairness for the transmissions from subscriber stations (SSs) over the WiMAX channels, and a centralized mechanism at the Optical Line Terminal (OLT) for Ethernet Passive Optical Network (EPON) uplink transmission that connects to multiple WiMAX-ONU. The scheduler at the OLT receives a Report message from each WiMAX-ONU, which contains the average channel condition per cell, queues length, and head-of-line (HOL) delay for rtPS traffic. The EPON data frame is then scheduled based on these Report messages at the OLT. Numerical results show that the proposed scheme can satisfy the end-to-end QoS requirements for real-time services. In addition, we will show that the centralized scheduler at the OLT can achieve high throughput in presence of traffic load variation.**

I. Introduction

Access networks have long been taken as bottleneck of the Internet access. Instead of carrying traffic using circuit switching networks, IP-based networks with connectionless datagrams yield much better efficiency and has been solidly extended into other paradigms such as mobility support, QoS differentiation, and video streaming based IPTV services [1], etc. As a result, the next-generation broadband access networks are expected to be all-IP, and the related software artifacts and developed technologies will be centered at IP addressing, signaling, and routing. As shown in the Figure 1, the backbone and access are all IP-based networks. In the front end, the base stations (BSs) provide connectivity and services to mobile and fixed subscriber stations (SSs), while in the wireless backhaul network, the traffic from each BS is carried, which is further relayed to the backbone network. Traditionally, each BS connects to a centralized center, such as a Mobile Switching Center (MSC), that is located at the access network via T1/E1 link.

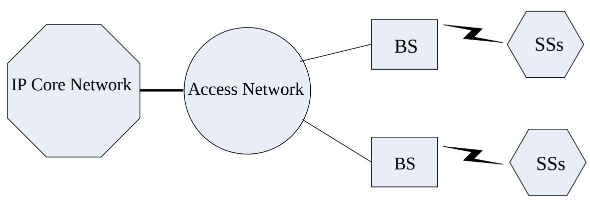

Fig. 1. Next Generation Networks (NGN)

One of the most promising broadband wireless Access (BWA) technologies in Metropolitan Access Networks (MANs) is IEEE 802.16 based World Interpretability for Microwave Access (WiMAX). WiMAX's ability to cover a large area, support quality of service, and utilize radio resources have successfully attracted vendors and research communities to consider it in the last mile. Another candidate for WiMAX BWA technology is Ethernet Passive Optical Networks (EPON). EPON is a cost-effective technology with available bandwidth through low-cost fiber cables with less maintenance and management. In addition, EPON can carry packets easier than other PON technologies [2]. However, EPONs are not efficient when directly connected to homes, schools, and malls, etc, due to the fiber deployment cost, right of way, and lack of mobility support. On the other hand, WiMAX has a high Bit Error Rate (BER) due to channel fluctuation. Thus, in the next-generation broadband access networks, EPON and WiMAX should be integrated so as to multiply their advantages and create a joint design framework that can achieve the best efficiency and operational flexibility. In other words, integration of EPON and WiMAX would provide not only tremendous bandwidth to users but also a mobility support and a large-area coverage.

Link scheduling is an essential component in both homogeneous and heterogeneous networks. In hybrid WiMAX and EPON networks, the scheduler must adopt a policy that takes into account the wireless channel condition of WiMAX and network availability of EPON. In addition, the scheduler should be either centralized at the OLT or completely distributed as multi-hop scheduling. However, the state-of-the-art technologies on for WiMAX and EPON integration has focused on development of architectures [3] [4] and network dimensioning [**?**]. To the best of our knowledge, few proposals have been reported on the task of scheduling uplink transmission in WiMAX-EPON networks. In [5], the authors proposed a QoS-aware scheduling mechanism for hybrid optical and wireless network considering quality of service (QoS) requirements. However, the authors did not consider two-level scheduling algorithms and the length of ONU queues.

In this paper, we propose a two-level scheduling scheme for the integrated WiMAX and EPON networks. In the first stage from SSs to WiMAX, proportional fairness is exercised to coordinate the transmissions over the WiMAX channel. At the second level, a centralized algorithm at the OLT is developed for the EPON uplink for transmissions among the OLT and multiple ONU-BSs. We claim that it is the first study that has handled the uplink scheduling problem for the EPON-WiMAX integrated networks, where link adaption, queue length, and head-of-line (HoL) delay are jointly considered.

Extensive simulation is conducted to verify the proposed schedule scheme and show that our scheme outperforms the ones without considering queue length and channel conditions.

The rest of the paper is organized as follows. In Section II, the hybrid architecture and system model for EPON-WiMAX networks is presented respectively. In Section III, the proposed scheduling scheme for uplink scheduling is presented in detail. Performance evaluation for the proposed scheme is conducted in Section IV, followed by the conclusion in Section V.

II. System Model

We consider a tree topology for WiMAX and EPON integrated networks. The OLT connects to each ONU-BS by a splitter, and the OLT is responsible for scheduling the uplink traffic among all the ONU-BSs since they share the uplink resources from the splitter/combiner to the OLT, as shown in Figure 2. Since each ONU-BS is accessed by multiple SSs, a scheduling scheme is needed at each ONU-BS to arbitrate the uplink channels among all the SSs in its cell.

A. WiMAX Channel

We consider multiuser diversity in a single cell governed by a single ONU-BS. We assume a Rayleigh fading channel is between the ONU-BS and the SSs, and each SS measures its instantaneous SNR, which is fed back to the ONU-BS. The ONU-BS takes advantage of the received SNR to collect Channel State Information (CSI). The average received SNR for user ss can be expressed as:

$$\overline{SNR_{ss}} = \rho\,(D/d_{ss})^{\alpha}\,k_{ss} \tag{1}$$

where ρ is mean SNR and α is the path loss exponent. Since the noise power is constant, the received SNR will be modeled as an exponential random variable. Further details can be found in [6] [7] [8].

B. EPON Channel

IEEE $802.3ah$ suggests only one optical fiber for upstream and downstream link from the OLT to splitter/combiner. In other words, the topology of EPON is a single fiber point-to-multi-point (P2MP), from the OLT to the ONUs via a splitter (multi-point to point), and from the ONUs to the OLT via combiner. An EPON operates in a full duplex mode with two different wavelengths for upstream and downstream. The wavelength for upstream is at $1310\,nm$, and for downstream is at $1490\,nm$, as shown in Figure 2 [9] [10].

C. Queues in ONU-BSs

For the uplink transmission, each WiMAX's MAC layer receives the traffic from its SSs and puts them in the corresponding queues. Internally, traffic in each WiMAX queue is aggregated and then moved to the ONU's queues. Without loss of generality, suppose we have two SSs in a cell as exemplified in Figure 3. Each SS has four queues in WiMAX's BS. So, the traffic in all queues at the WiMAX's BS will be aggregated into just four queues in the ONU to be sent to the OLT. Then, the OLT may or may not schedule those traffic in the next time slot depending on the scheduling algorithm.

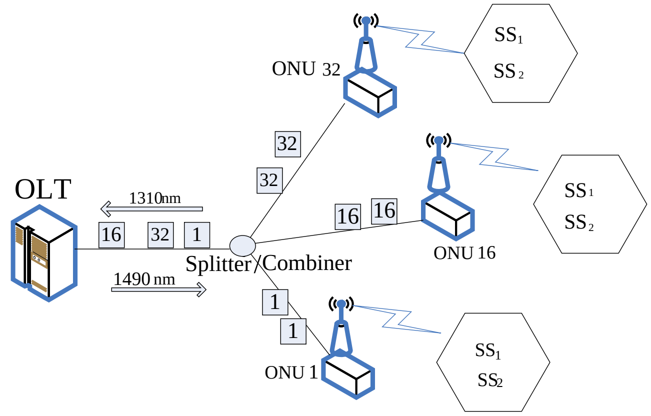

Fig. 2. System Model

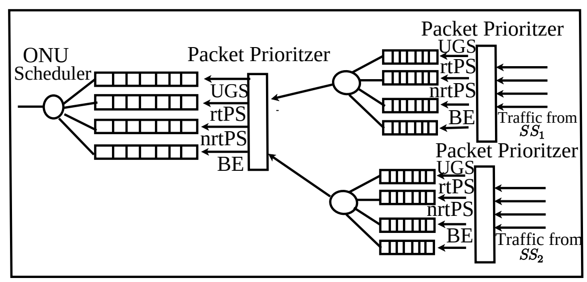

Fig. 3. Queues Mapping

III. The Proposed Scheme

A centralized scheduling algorithm is proposed for EPON uplink transmission. The scheduler at the OLT considers the WiMAX channel condition, ONU queues length, and rtPS HoL delay, in order to allocate the frames for the ONU-BSs. For bandwidth allocation, EPON's frame is divided into two slots. Usually, the UGS queues will be assigned the first slot of the frame, and rtPS or nrtPS queues will take the second slot. In addition, each slot further divides into mini-slots as illustrated in Figure 4.

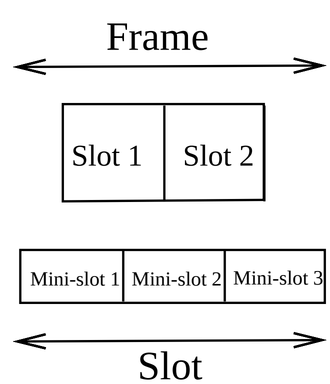

Fig. 4. EPON Frame Structure

In the beginning, the OLT polls each ONU-BS, which sends the Report message containing information about each cell condition, length of rtPS and nrtPS queues, and the head-of-line delay for the rtPS queue. The scheduler does not make a scheduling decision in a scheduling cycle until it receives all Report messages. Once all reports are received, the scheduler starts choosing UGS queues for transmission in a Round Robin fashion. Each UGS queue is granted with fixed number of mini-slot from the first slot of the EPON's frame. The remaining slots are allocated for rtPS and nrtPS. After all UGS packets are received, the scheduler selects rtPS queue m for transmission if it maximizes the following equation:

$$m = \underset{i \in M}{\operatorname{argmax}}\; r_i(t)\, W_i(t)\, h_i(t) \tag{2}$$

where $i = \{1, 2, ..., M\}$ is set of ONU-BSs indices, W_i is length for rtPS queues at ONU-BS i at time slot t, $h_i(t)$ is ONU i the head of line delay of rtPS queue, and $r_i(t)$ is cell condition of ONU-BS i at time t. Cell condition for ONU-BS k can be determined as:

$$r_k = \frac{\sum_{k=0}^{n} C_k M_k}{\sum_{k=0}^{n} C_k} \tag{3}$$

where C_k is maximum number of bits SS_k can transmit, M_k is the traffic load of SS_k, and n is the total number of SSs in a single cell. If the capacity of the first mini-slot, maximum slot size, larger than the length of rtPS m, the bandwidth allocation grants the selected queue its report bandwidth. Otherwise, the BA grants the whole size of the first mini-slot to rtPS m. Then the scheduler repeats Equation 2 over and finds new rtPS m. The new rtPS m is granted the minimum of its requests and the size of the second mini-slot. The scheduling for Grant messages repeats Equation 2 over and over until all the mini-slots are exhausted or there is no further request.

Since nrtPS is not delay sensitive, Equation 2 cannot be applied. Instead, the queue length of nrtPS is used to determine the winner of uplink transmission. nrtPS queues are scheduled for uplink transmission int two ways

1) The remainder of slot must not be wasted after the rtPSs traffic are settled. The nrtPS's queues share the excess mini-slots.
2) After some predefined threshold cycles, the OLT scheduler selects nrtPS queues for transmission and assigns the second slot of EPON's frame to the nrtPS queues. The procedure of assigning the mini-slots is similar to that for rtPS mini-slots. However, neither cell condition nor head-of-line delay is considered.

Without loss of generality, the proposed scheduling process for two ONU-BSs and OLT is illustrated in Figure 5. At time $t = 0$, the centralized scheduler at the OLT polls ONU-BS 1 and ONU-BS 2 to send their Report messages. Upon receiving the Report messages, the scheduler allocates fixed bandwidth for the UGS's queues for both ONU-BSs in a Round-Robin fashion. As shown in Figure 5, the OLT schedules ONU-BS 1, and then ONU-BS 2 and so on. As soon as ONU-BS 1 receives the grants, ONU-BS 1 sends its UGS's packets to the OLT, including packet overhead for Ethernet packet. The same procedure as for ONU-BS 1 is taken by ONU-BS 2. When the OLT receives all UGS's packets from the ONU-BSs, the scheduler begins granting the second slot of EPON's frame for rtPS, as discussed in section III.

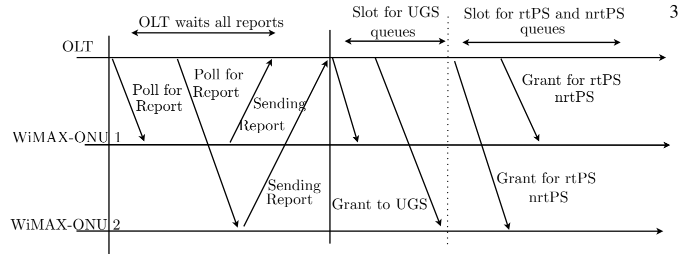

Fig. 5. Scheduling Process

IV. Performance Evaluation

In this section, the centralized scheduling algorithm at the OLT is studied and its performance is evaluated. In order to simulate the proposed algorithm, simulation based on the discrete events is conducted using C++. In our implemented model, one OLT is connected to 14 ONU-BSs in a tree topology. The distance from the OLT to each ONU-BS, including the splitter, is kept constant. The upstream link capacity of EPON is $1Gbps$, while each ONU-BS maximum data rate is $75Mbps$ with a channel width of $20MHz$. In addition, each ONU-BS has three queues for differentiated classes of service. Those queues share $10Mbit$ buffer for traffics coming from all SSs within the same cell. In IEEE 802.16d, the total number of carriers is 256, but only 192 are used for data [11]. Moreover, the duration of the OFDM symbol is 12.6 μs where each physical slot consists of four OFDM symbols [12].

We set the time duration for the WiMAX frame and the EPON frame to be $2.5ms$. Thus, 50 PSs are available for uplink subframe since only uplink transmission is implemented in this work. Maximum mini-slot size of the EPON frame can be found as:

$$T_s = U \left[\frac{T_C}{M} \right] \tag{4}$$

where T_s is maximum mini-slot size, U is uplink EPON capacity, T_C is slot duration, M is number of ONU-BSs [13]. The simulation parameters are summarized in Table I [14] [8].

The scheduler at the OLT aims to maximize the throughput and support differentiated classes of services. EPON's uplink throughput can be calculated in two ways: carried load of EPON link times the link capacity of EPON, or number of transmitting bits over the simulation time. Each $nrtPS$ and $rtPS$ traffic at each SS starts with two connections, and we add two connections when millions of packets have been sent to the OLT. For UGS traffic, the number of connections is set to one for each SS. Figure 6 shows the throughput of the proposed scheme when traffic load is increased. Starting with

TABLE I

SIMULATION PARAMETERS

Number of ONU-BS	14
Number of SSs in each cell	10
Number of PSs	50
Number of OFDM symbols in a slot	4
WiMAX maximum data rate	75Mbps
EPON maximum data rate	$1Gbps$
Buffer size in ONU	10Mbyte
t_c	100000
Frame length	$2.5ms$
Symbol duration	$12.6us$
UGS arrival rate	$10kbps$
rtPS arrival rate	$64kbps$
nrtPS arrival rate	$80kbps$
Pathloss exponent	2

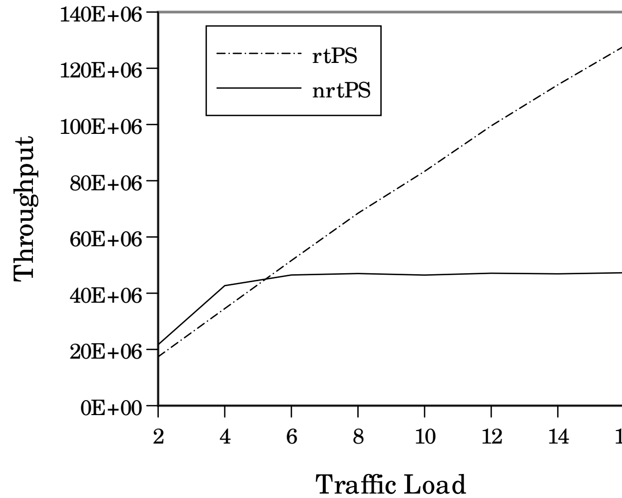

Fig. 7. Comparison of nrtPS and rtPS Throughput

two connections for rtPS and nrtPS, the maximum transmitted bits from UGS, rtPS, and nrtPS queues are 4% of the total capacity. When the traffic load is 16, the maximum number of bits is almost 17% of EPON's capacity. The scheduler serves all UGS queues in each frame, so almost all packets in the queues will be transmitted to the OLT. For rtPS queues, the scheduler first chooses non-empty queues with relatively best channel conditions, thus the throughput is sharply increased. Therefore, the proposed scheme efficiently utilizes the uplink capacity.

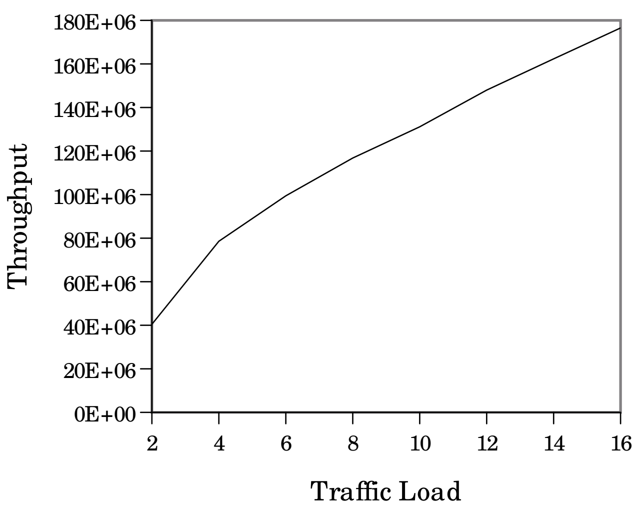

Fig. 6. Achievable Throughput versus Traffic Load

The comparison of throughput between rtPS and nrtPS traffic is shown in Figure 7. From load 2 to 4, the remaining mini-slots of rtPS allocation is large, resulting more nrtPS traffic scheduled for transmission. As a result, nrtPS achieves better throughput than rtPS. As the load increases, more rtPS packets are received by ONU-BSs. Thus the throughput improves since mini-slots are exhausted with rtPS traffic. So, less nrtPS packets are then transmitted in the rtPS's allocation slot.

To validate our work, it is an important to investigate the proposed scheduling scheme with varying SSs. In the simulation model, we reduce the number of connections for UGS, rtPS, and nrtPS at each SS to balance the system. Then, we increase the number of SSs in each cell from 10 to 40. It is observed from Figure 8 that the obtained throughput is 0.106 $Gbps$ when SSs equal 10. Above 10 SSs, the throughput is actually improving with the increase of SSs because our scheduling scheme can carry efficiently most packets in ONU-BSs. Noticeably, the scalability of the scheduler algorithm can be achieved. Figure 9 shows the average delay for UGS and

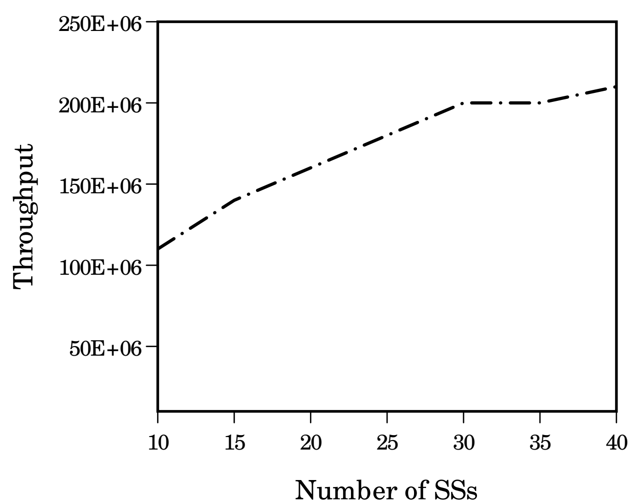

Fig. 8. Achievable Throughput versus SSs

rtPS traffic as the number of SSs is increasing. When there are 10 SSs in each cell, the average delay for UGS traffic is below $20ms$. In addition to UGS, the rtPS average delay is also below $20ms$ when the number of SSs is 10. The average delay for UGSs increases sharply when there are more than 25 SSs in the WiMAX cell. If there are 40 SSs in each cell, the average delay for UGS traffic will probably be above $100ms$. On the other hand, the scheduler significantly keeps the rtPS average delay under $40ms$ when there are 40 SSs. Therefore, the benefit of considering the HoL delay, queue length, and channel condition for rtPS can be realized.

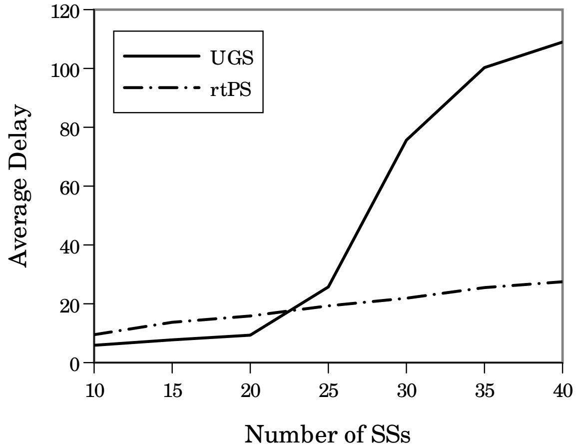

Fig. 9. Average Delay for Real Time Traffic versus SSs

Another QoS requirement that needs to be studied here is packet drop ratio with increasing number of SSs in each cell. Figure 10 shows the packet loss ratio for all types of traffic. At light load, UGS and rtPS dropping packet ratio is less than 1%, while it is zero for the case of nrtPS. Even though ONU-BSs can receive more packets from rtPS traffic than UGSs when the load is varying from 10 to 35, their packet loss is very close, providing an evidence of the efficiency of rtPS scheduling. When there are more than 35 SSs, the packet loss ratio for both UGS and rtPS is above 15%, and for nrtPS is around 10%. At high load (more than 35 SSs) the high-priority traffic preempts low-priority traffic, consequently, the enqueued and incoming nrtPS traffic are dropped.

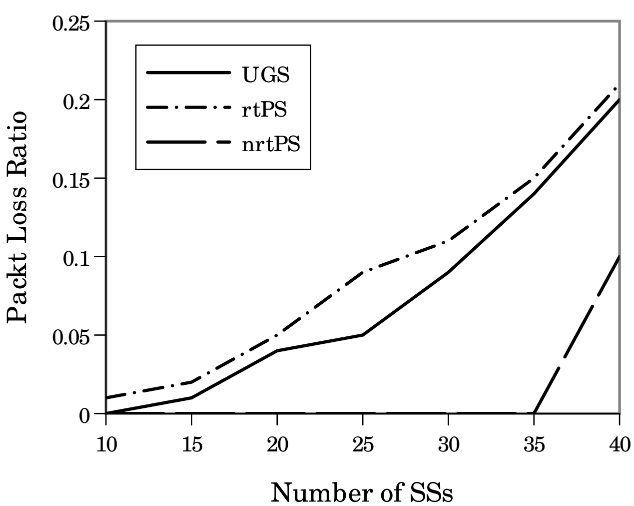

Fig. 10. Packet Loss Ratio versus SSs

V. CONCLUSION

In this paper, two-level uplink scheduling schemes for converged WiMAX and EPON networks are presented. First, proportional fairness is adopted to be the scheduler for uplink transmission at the ONU-BS. In the second level, a centralized scheduler for the uplink transmissions with QoS provisioned at the OLT is proposed. Three priority queues at each ONU-BS for UGS, rtPS, and nrtPS are modeled with QoS requirements for each type of service. The performance of the scheduler for the uplink transmission is studied in terms of the throughput, average delay, and dropping packets. The proposed scheme could satisfy delay requirement for real-time traffic, specifically rtPS. In addition, the scheduler utilized EPON uplink capacity in the aspects of achievable throughput in a highly loaded system.

VI. ACKNOWLEDGEMENT

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