Performance Study of Homogeneous Uplink Scheduling in Hybrid ONU-BS Architecture

I-Shyan Hwang and Jhong-Yue Lee

Abstract—**The integration of Ethernet Passive Optical Network (EPON) and Worldwide Interoperability for Microwave Access (WiMAX) is regarded as a promising access solution in realizing fixed mobile convergence (FMC) networks, which uses a single network infrastructure to provide both wired and wireless access services, and a good match of capacity hierarchy between EPON and WiMAX by using EPON as a backhaul (or feeder) to connect multiple disperse WiMAX base stations. Furthermore, the Hybrid ONU-BS Architecture (HOA), which can not only bring economic efficiency to network providers but also supporting better quality of service (QoS) and bandwidth utilization. A critical part of the HOA is packet scheduling, which resolves contention for bandwidth and determines the transmission order of users. For successful realizing HOA deployment, evaluating the performance of packet scheduling algorithms is one of the most importance issues. In this paper, we accomplish a comprehensive performance study of homogeneous uplink scheduling algorithms in HOA. Firstly, we make a classification of queuing scheduling algorithms in MAC layer packet forwarding mode, then simulate in view of a representative number of algorithms and investigate fundamental characteristics in each class of HOA. We evaluate the packet forwarding algorithms abilities for the multiple classes of service, providing QoS guarantees, fairness amongst service classes, blocking probability rate and bandwidth utilization. To the best of our knowledge, no such comprehensive performance study has been reported in the literature. Simulation results demonstrate that none of the current algorithms is capable of effectively supporting all classes of service. We hope that this study will interest readers and stimulate further investigation in the area.**

Keywords- EPON; WiMAX; FMC; ONU-BS; HOA; packet scheduling.

I. INTRODUCTION

Due to the emergence of multi-application services in contemporary network such as IPTV, video on demand (VoD), and peer-to-peer (P2P) services, bandwidth requires be upgraded on the current access network with a low-cost and high-speed solution to provide broadband access services. To this end, access networks are evolving from traditional copper-based ADSL technology to more advanced fiber-based passive optical network technologies, including fiber to the home (FTTH), fiber to the node (FTTN), fiber to the curb (FTTC). Nowadays, in the wire camp, The Ethernet passive optical networks (EPON) [1,2], based on the traditional Ethernet techniques, is regarded as a promising solution f or the next generation fiber-based access technique because it is not only high-speed, cost-effective but also scalable. Meanwhile, in the wireless camp, we also see fast progresses of wireless access technologies, which are evolving from the traditional WiFi technology to more advanced technologies - Worldwide Interoperability for Microwave Access (WiMAX) [3-6] which can provide wider cell coverage, higher access capacity and quality of service (QoS) support. Driven by potentially significant cost reduction by converging network infrastructures and control systems of wired and wireless access networks, fixed mobile convergence (FMC) [7] is envisioned as a future generation of architecture for broadband access. The major motivations behind the integration of EPON and WiMAX involve the potential benefits of the advantages of bandwidth benefit and mobility feature, which uses a single network infrastructure to provide both wired and wireless access services, and good matches of capacity hierarchy between EPON and WiMAX by using EPON as a backhaul (or feeder) to connect multiple disperse WiMAX base stations.

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The EPON provides bi-directional transmissions, one is downstream transmission from optical line terminal (OLT) to optical network units (ONUs); the other is upstream transmission from ONUs to OLT in sequence. In the downstream direction, all the control messages and the data packets are carried and broadcasted from the OLT to each ONU. In the upstream direction, all ONUs share the common transmission channel towards the OLT, only a single ONU may transmit data in its time slots to avoid data collision. Hence, a robust mechanism is needed for allocating time slots and upstream bandwidth for each ONU to transmit data.

The WiMAX technology is based on the IEEE 802.16-2004 which supports two operational modes: point-to multipoint (PMP) mode and mesh mode [8]. In the PMP mode, the subscriber stations (SSs) must register to a base station (BS) before data transmission means that all the SSs are under the control of the BS in a centralized manner. In the mesh mode, SS directly communicates with each other or relays via other SSs in a distributed manner. There are two independent channels - UL channel and DL channel. UL channel is shared by all SSs while DL channel is a broadcast channel that used only by BS. BS is defined as a coordinator to take charge of uplink bandwidth allocation.

In order to provide anytime and anywhere connectivity over the heterogeneous wire and wireless networks the resource management plays a key role to ensure an efficient usage of both optical link and radio spectrum. This is of particular importance for next generation broadband access

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networks which support triple play services (voice, video, and data) to multiple users simultaneously. The integration of optical and wireless networks presents a compelling solution for broadband access due to their complementary features of wide bandwidth and user mobility. Firstly, between different micro-cells, it is efficient to employ EPON as a backhaul to interconnect multiple detached WiMAX BSs so as to enable the communication between different micro-cells. Secondly, the integration can provide much convenience for the system operation and is expected to support better QoS and improve network throughput by employing efficient integrated bandwidth allocation and packet scheduling strategies. Thirdly, the integration can support not only broadband network access but also wider service coverage.

Preliminary research on integration of EPON and WiMAX was described in [9], under the hybrid optical wireless research area. The hybrid networks in [9] employed a passive optical network as a feeder to connect multiple spread WiMAX base stations, the OLT be considered as a central controller and coordinator to perform operations for the whole hybrid network, including packet forwarding and bandwidth allocation, etc. To fully exploit the benefits of integration of EPON and WiMAX, more integration architectures were proposed in [10,11]. These architectures include independent architectures, hybrid architectures, unified connection-oriented architectures, and microwave-over-fiber (MoF) architectures. Moreover, in the hybrid optical wireless architecture, B. Jung et al. [12] confirmed that the Hybrid ONU-BS architecture can support better end to end QoS support and bandwidth utilization than the other integration architecture.

For achieved seamless convergence of EPON and WiMAX in hybrid ONU-BS architecture (HOA), there has some technical issues should be considered in the MAC layer [10]. First, integrated bandwidth allocation and packet scheduling should help to improve delay and throughput. HOA can process full information of bandwidth, and packet scheduling of the ONU and BS. There need a good queuing scheduling to improved delay and throughput performance by optimal utilize both fiber and radio bandwidth resources. Second, an effective QoS mapping mechanism is needed between EPON priority queues and WiMAX connections to provide better class of service (CoS). Consequently, guaranteeing QoS continuity in the integrated network can be achieved by designing an efficient QoS mapper that knows which WiMAX flows should be chosen to EPON priority queues. Third, the integration should make it easy to provide layer 2 (L2) handover because the handover controller located at OLT can handle user mobility in micro cells connected to EPON. Finally, the DBA mechanism in central controller OLT to transmit data from the ONU-BS to the destination tends to affect network performance significantly. Therefore, an effective QoS mapping and uplink scheduling algorism to improve end to end delay and end to end QoS support should be considered.

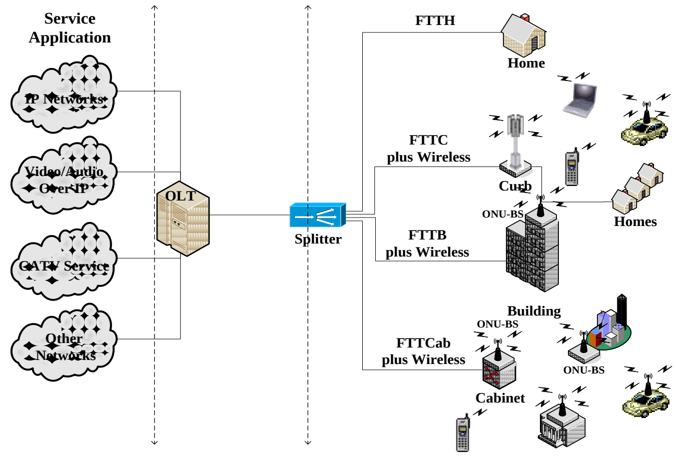

Figure 1. Integrated architecture of FTTx - EPON and WiMAX.

In spite of the numerous scheduling algorithms has been proposed in present network but comprehensive study for comparing such algorithms. The goal of this work is to allow a thorough understanding of the relative performance of representative uplink scheduling schemes and subsequently utilize the results to address their scarcity in designing more efficient schemes. In this paper, we focus our work on implementing homogeneous algorithm for the uplink traffic scheduling in integrated architecture of FTTx - EPON and WiMAX.

The rest of this paper is organized as follows. Section II presents a survey of homogeneous algorithm for uplink scheduling in hybrid ONU-BS architecture. This section also includes our proposed HOB architecture, the justification of selecting representative algorithms and QoS mapping in ONU-BS for our simulation study. Section III describes the simulation framework that includes the simulation parameters, traffic model, and the performance metrics used to evaluate the algorithms and the results and discussion of the experiments results. The conclusions and future work is summarized in Section IV.

II. HOMOGENEOUS ALGORITHM FOR UPLINK SCHEDULING IN HYBRID ONU-BS ARCHITECTURE

This section introduces the proposed hybrid ONU-BS architecture, QoS support mapping and selected representative homogeneous algorithm for uplink scheduling in hybrid ONU-BS architecture.

A. Hybrid ONU-BS architecture

The literature has proposed a wide range of integrated structure; nothing more than makes the EPON Ethernet frames encapsulated as 802.16 MAC PDUs or to adapt an 802.16 network to run EPON MAC protocols. However, both of the above integrated architectures suffered a critical problem of physical unification because of they are not standardized till now. The hybrid FTTx - EPON and WiMAX network architecture is illustrated in Figure 1. In backhaul EPON network, a centralized OLT communicates

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with multiple connected ONU-BSs, such as home, curb and building etc, via a passive optical splitter. In the multiple disperse PMP WiMAX network, an ONU-BS manages channel allocation to SSs as a central controller. In hybrid ONU-BS architecture (HOA), the ONU functions and BS functions are integrated into a single device, namely a hybrid ONU-BS, which handles connections within the wireless network, and connections cross both EPON and WiMAX network. Figure 2 shows an overview of operations implemented in the OLT and the hybrid ONU-BS for uplink scheduler which include admission controller, packet scheduling, QoS mapping, packet classifier, and resource management downlink bandwidth allocation. As the integrated ONU-BS equipment is able to intensively fully acquire the information of the system bandwidth requirements, allocation, uplink scheduling and QoS mapping of packets between WiMAX base stations and the ONU. Therefore, ONU-BS can deploy the most optimal mechanism to meet the bandwidth needs of EPON network and WiMAX network as well as the allocation of packet scheduling. The upstream traffic is first aggregated at an ONU-BS and then forwarded to the OLT, which include QoS mapping and uplink scheduling. For the downstream traffic, packets are first transmitted to the ONU-BS and then forwarded to each subscriber user in the allocated time slots.

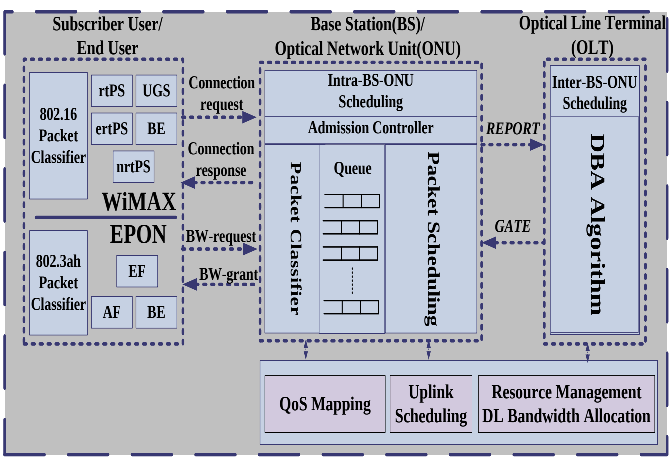

Figure 2. Overview of operations in hybrid ONU-BS architecture.

B. *QoS Mapping Over Hybride ONU-BS*

To support a variety of network services with diverse QoS requirements, we must consider differentiated QoS in MAC design. An effective means is to use priority queuing. As illustrated in Figure 2, uplink traffic are classified into a set of classes by *Packet Classifier* in both BS and ONU according to their QoS requirements and then they are buffered into the corresponding priority queues. The EPON standard supports up to eight priority queues whereas the 802.16 documents specify five classes for 802.16 services. For each 802.16 service class a priority queue is usually maintained at each SS and BS. Since EPON and 802.16 each maintains its own priority queues and follows its own way of classifying packets, there is the issue of how to map the packets in BS queues into ONU queues while maintaining the QoS requirements. This task is carried out by the QoS Mapping module in the hybride ONU-BS.

1) *802.16e (WiMax)*

WiMAX is a connection-oriented transmission technique under which each service flow is allocated with a unique connection ID (CID) [13]. Based on connection-oriented bandwidth requests, an aggregate bandwidth is allocated to each SS, and this bandwidth is then allocated to each service connection associated with the SS. Each connection in the uplink channel from an SS to the BS is mapped to a scheduling service flow. The 802.16 protocol supports five types of QoS service classes: Unsolicited Grant Scheme (UGS) is equal to multiplayer interactive gaming, Extended Real Time Polling Service (ertPS) just like VoIP and Video conference, Real Time Polling Service (rtPS) being similar to streaming media, Non Real Time Polling Service (nrtPS) and Best Effort Service (BE) such as web browsing, instant messaging and media content downloads. Each of them has their own QoS parameters required, such as minimum throughput requirement, delay and jitter constraints. The UGS service is contention free, and no unambiguous bandwidth request is issued by an SS. An SS issues explicit requests to meet the dynamic transmission need of the rtPS service, which is well suited for real-time services such as VoIP and MPEG video. Unlike the rtPS service, connections of the nrtPS service employ random access transmit opportunities for bandwidth requesting. The targeted services are delay and jitter insensitive such as file transfer. There are neither throughput nor delay guaranties provided to the BE service. The available bandwidth after serving the previous three service flows is allocated to the BE service.

2) *802.3ah (EPON)*

The QoS management is queue-oriented on EPON which includes mapping configuration, scheduling configuration, congestion control configuration and buffer size configuration. An aggregate bandwidth is allocated to each ONU, and then the latter makes a local allocation for the granted bandwidth to up to eight different priority queues in the ONU. The EPON maintains 8 priority queues for facilitating differentiated services, as defined in 802.1q [14]. Each ONU maintains 8 separate priority queues that share the buffering space. The EPONs support principal IP-based differentiated services (DiffServ) mechanism to ensure the QoS of these applications [15]. For instance, the highest-priority class can be mapped to the expedited forwarding (EF) [16] which provides for time-critical characteristic, low loss and bandwidth-guaranteed services that is typically constant bit rate (CBR), such as voice transmission. Furthermore, the medium-priority class can be mapped to the assured forwarding (AF), is intended for services that is not delay-sensitive but require bandwidth guarantees, which is typically variable bit rate (VBR) services, such as video stream. Finally, the low-priority class can be mapped to the best effort (BE), which is neither delay-sensitive nor bandwidth-guaranteed, includes web browsing, background file transfer and e-mail applications. The AF and BE traffics are more delay tolerant but generally have a wide-band nature; however, the EF traffic is very delay-sensitive but tends to be a narrow-band nature. A fixed and properly-sized cycle length with fixed position of EF traffic can provide lower delay and jitter guarantee.

3) Proposed QoS Mapping

In order to provide guaranteed QoS for differentiated services, traffics should be allocated both for the service flows and the queues. Although the overall operational principles of the two types of networks are rather similar, particularly in the aspect of bandwidth request and allocation. WiMAX systems generally allocate bandwidth more finely than EPON systems. In addition, the connection-oriented bandwidth allocation generally shows a more predictable QoS than the queue-based bandwidth allocation, which implies that WiMAX technology is expected to support QoS better than EPON technology. In contrast, EPON technology shows better operational scalability than WiMAX technology as each ONU is required to manage only up to eight priority queues. Because EPON and WiMAX use different operational protocols in spite of similarity in their bandwidth request/grant mechanisms, it may make sense to modify the MAC layer protocols of EPON to also enable to support connection-oriented services as in WiMAX systems. Moreover, the bandwidth should be constrained by the mapping policy of QoS management. As shown in Figure 3, wired and wireless access networks share the queues in the EPON system. Eight queues make up a PON link and each service flow have their own queues. By service self-aware technology, the EPON system classifies the services to three types EF traffic, AF traffic and BE traffic. These services can be mapped to different queues and acquire different QoS. The Table I shows a proposed QoS mapping policy.

C. Homogeneous Uplink Scheduling

TABLE I
PROPOSED QOS MAPPING

Priority	EPON	WiMAX	Service
1	BE	nrtPS and BE	FTP, Web, E-mail
2	AF	rtPS and ertPS	Real-time streaming, VoD
3	EF	UGS	VoIP

In hybrid ONU-BS architecture, all service flow share the same memory buffer of fixed size in ONU-BS for WiMAX and EPON traffic requirements. For a simple Strict Priority (SP) scheduling policy, the high priority packet can preempt the memory reserved for packets of lower priorities when the corresponding buffer is full. On the other hand, the lower-priority packet will be dropped when packet arrives and finds that the corresponding buffer is full. Therefore, in SP scheduling policy low-priority packets may get starvation when the proportion of high-priority traffic is high. For supporting QoS requirements, after the mapping configuration, scheduling policy and congestion control policy should be configured. This is conducted by the *Admission Control* module which only buffers admitted packets into ONU-BS queues. Admission control is one of the effective mechanisms to satisfy the demand for bandwidth request and enhance the efficiency of the system. Many admission control mechanisms can be found in the literature for both EPON [17] and WiMAX [18] but in integrated EPON and WiMAX architecture, however this issue will be considered in this paper, we do a *Homogeneous Uplink Scheduling* to discuss the starvation problem faced by low-priority service traffics, end to end delay and QoS support ability in HOA which is shown as Figure 3.

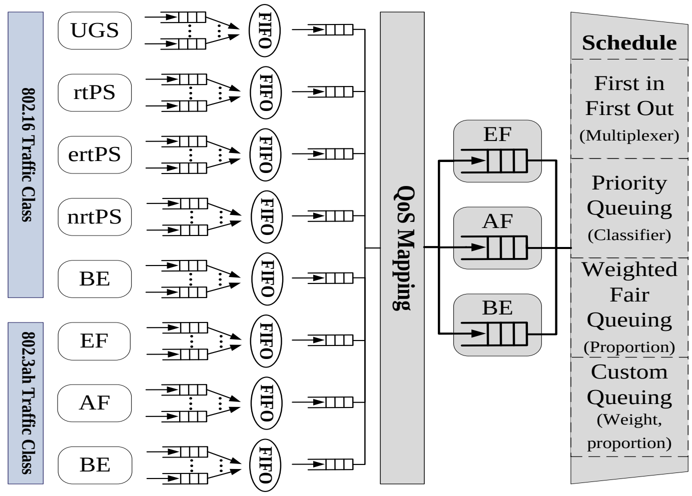

Figure 3. Homogeneous uplink Scheduling operations in hybrid ONU-BS.

First in first out (FIFO) queuing is the most basic queue scheduling discipline. In FIFO queuing, all packets will be served by the coming time, is also referred to as first-come, and first served queuing. Priority queuing (PQ) is the basis for a class of queue scheduling algorithms that are designed to provide a relatively simple method of supporting differentiated service classes, which means that the ONU-BS serves a higher-priority queue to exhaustion before serving a lower-priority queue when a slot arrives. Weighted fair queuing (WFQ) is the basis for a class of queue scheduling disciplines that are designed to address limitations of the fair queuing, which means that the ONU-BS set differentiated weights to decide each available proportion of bandwidth by different priority traffic. The proposed Innovated Custom queuing (ICQ), which will meet the minimum delay of highest priority traffic but sacrificing the low priority traffic bandwidth requirements. The ICQ is constructed by one System Queue (SQ), for high priority traffic, and multi-Custom Queue (CQ), which includes mediums and low priority traffic. Moreover, ICQ set up two levels of scheduling - in the first level, scheduling is constructed based on FIFO to collect differentiated class of traffic into different priority queue. In the second level, system queue has absolute priority so that the system always processes system queue first and then deals with CQ for DiffServ mechanism. Here, the main function of second level is WRR which is to allocate bandwidth according to the weight and queue length to decide the available bandwidth for multi-CQ.

III. Performance Evaluation

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Number of ONU-BSs	32
Upstream/downstream link capacity	1Gbps
Finite Buffer (each ONU-BS)	10M
OLT to ONU-BS distance (uniform)	10-20km
Maximum transmission cycle time	1*ms*
Guard time	5*us*
Computation time of DBA	10*us*
Control message length	0.512*us*

In this section, we present the results of simulation experiments conducted to evaluate and understand the end-to-end packet delay for each priority traffic, drop probability and EF jitte of of the homogeneous uplink scheduling for hybrid ONU-BS architecture. The system model is set up in the OPNET simulator with one OLT and 32 ONU-BSs. The downstream and upstream channels are both 1 Gb/s. The distance from an ONU to the OLT is assumed to range from 10 to 20 km and each ONU has a finite buffer of 10M. For the traffic model considered here, an extensive study shows that most network traffic can be characterized by self-similarity and long-range dependence (LRD) [19]. This model is utilized to generate highly busty BE and AF traffic classes with the Hurst parameter of 0.7, and packet sizes are uniformly distributed between 64 and 1518 bytes. On the other hand, high-priority traffic (e.g., voice applications) is modeled using a Poisson distribution and packet size is fixed to 70 bytes [20]. The simulation scenario is summarized in Table II.

A. *End to End Delay*

Figure 4 compares the average end-to-end packet delay from ONU-BSs to OLT among the FIFO, PQ, WFQ and ICQ scheme for EF, AF and BE traffic, respectively. The PQ scheme has better performance than FIFO and WFQ scheme in Fig. 4(a) and (b). Because of the PQ scheme make EF traffic to have priority transmission, as so the end-to-end delay can be decreased. In Figure 4(c), the PQ shows poor BE end to end delay because the resource of lowest priority be snatched by high priority traffic.

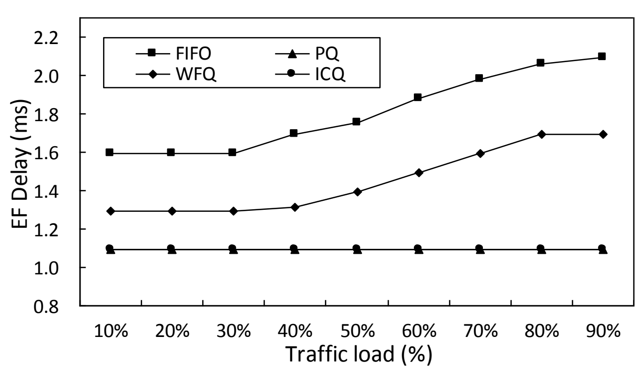

Figure 4. (a) EF end to end delay for FIFO, PQ, WFQ and ICQ.

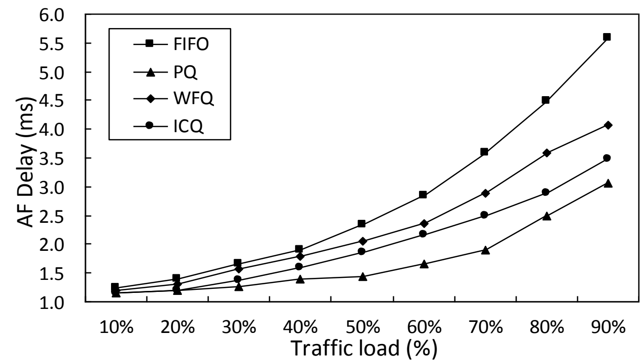

Figure 4. (b) AF end to end delay for FIFO, PQ, WFQ and ICQ.

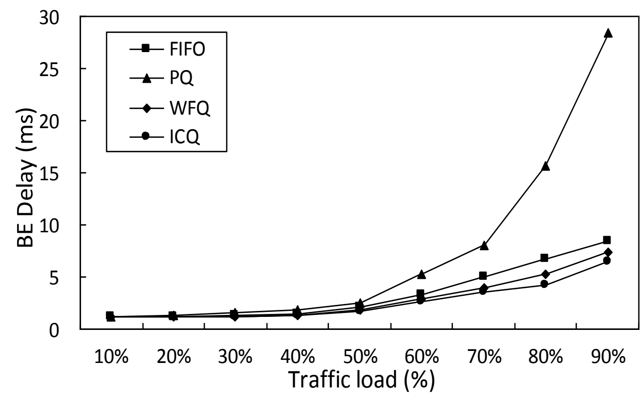

Figure 4. (c) BE end to end delay for FIFO, PQ, WFQ and ICQ.

B. *Packet Drop Probability*

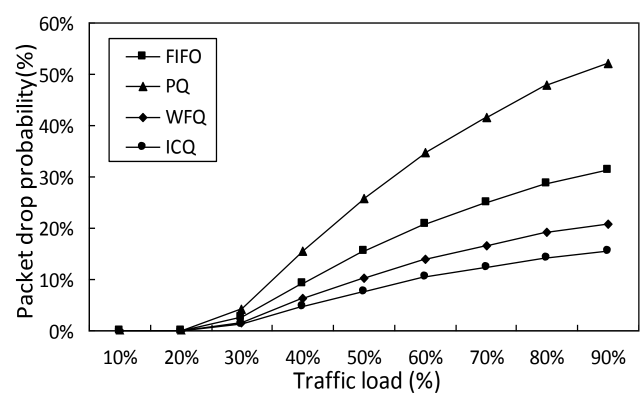

Figure 5. Packet Drop probability for FIFO, PQ, WFQ and ICQ.

Figure 5 compares the packet drop probability vs. traffic load for FIFO, PQ, WFQ and ICQ scheduling mechanisms with 10MB buffer size in each ONU-BS. Figure 5 shows that the proposed ICQ scheme has the better performance and the PQ scheme has the worse dropping performance. The whole scheduling scheme begin to drop packet after the traffic load of 30%, especially for the PQ scheme because of the low priority traffic in PQ will got starvation. When the network load is above 30%, we observe considerable packet loss due

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to buffer overflow. In spite of the ICQ scheme is still a better performance on packet loss ratio. The reason is that the ICQ can be an efficient and flexible bandwidth distribution queuing schedule.

C. EF jitter

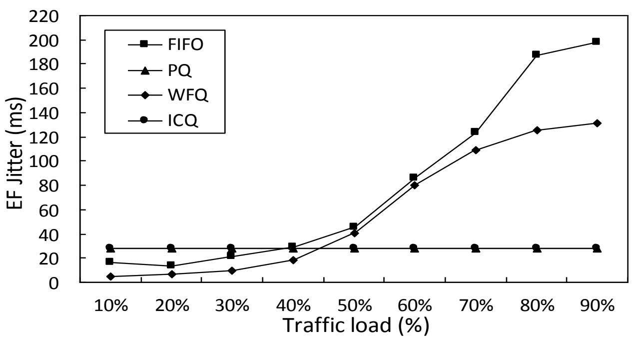

Figure 6. EF jitter for FIFO, PQ, WFQ and ICQ.

Figure 6 shows that the EF jitter performance of the FIFO, PQ, WFQ and ICQ for different traffic loads. The delay variance σ^2 is calculated as $\sigma^2 = \sum_1^N (d_i^{EF} - \bar{d})^2 / N$, where d_i^{EF} is the delay time of EF packet i and N is the total number of received EF packets. Simulation results show that the delay variance for EF traffic increases as the traffic load increases except PQ and ICQ scheme. The reason is that the PQ and ICQ transmissions whole high priority traffic of every ONU-BSs in the beginning of transmission cycle time sequentially.

IV. CONCLUSIONS

As a cost-effective, bandwidth benefit, mobility, and scalable solution to the broadband access network, integrated of EPON and WiMAX architecture - hybrid ONU-BS architecture (HOA) have the capability to deliver integrated broadband services by efficient fixed mobile convergence. This paper presents a comprehensive performance evaluation of a number of algorithms for the uplink traffic in HOA networks. Existing proposals of scheduling schemes have been focus on homogenous categories; which include FIFO, PQ, WFQ and proposed Innovated Custom queuing (ICQ). Representative schemes from homogenous categories have been evaluated with respect to major distinguishing characteristics of the HOA. Based on the simulation results, we conclude that the ICQ scheduling scheme, minimum delay of highest priority traffic but sacrificing the low priority traffic bandwidth requirements, can provides the desired performance with respect to all the QoS requirements and characteristics of the HOA.

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