SLA aware Dynamic Bandwidth Allocation for EPONs

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***Abstract*— Ethernet passive optical network (EPON) is one of the most promising broadband access networks. We propose a dynamic bandwidth allocation (DBA) scheme for service differentiation that meets the service level agreements (SLAs). Proposed DBA scheme provides predictable average packet delay and delay jitter of expedite forwarding (EF) traffic without the influence of load variation. Performance evaluation shows the effectiveness of proposed DBA scheme.**

***Keywords*— Ethernet passive optical network (EPON), service level agreement (SLA), dynamic bandwidth allocation (DBA), packet delay, jitter**

I. INTRODUCTION

EPONs appear to be a natural candidate for the next-generation broadband access networks. An EPON comprises of an optical line terminal (OLT) residing in the central office and multiple optical network units (ONUs) near subscribers' locations. In the downstream direction of an EPON, Ethernet frames are broadcast by the OLT and are selectively received by each ONU. While in the upstream direction, all of the ONUs must contend for shared capacity link, and this requires an appropriate access protocol.

In order to achieve statistical multiplexing in EPON architecture, the IEEE 802.3ah has developed a multipoint control protocol (MPCP). The MPCP specifies the control mechanism between the OLT and ONUs connected to a point-to-multipoint segment to allow the efficient transmission of data. Note that the MPCP does not specify any particular DBA algorithm, but simply provides a framework for the implementation of various DBA algorithms. To date, various DBA algorithms to provide differentiated classes of service for EPONs have been proposed [1]-[9].

In this paper, we propose a dynamic bandwidth allocation (DBA) algorithm for differentiated classes of service that meets the service level agreements (SLAs) such as average packet delay, delay jitter, minimum guaranteed bandwidth, maximum limited bandwidth, throughput, etc. Proposed DBA scheme which uses fixed scheduling frame size and two-layer allocation scheme provides predictable packet delay and jitter performance for expedited forwarding (EF) traffic class without the influence of load variation. Section II shows previous works of dynamic bandwidth allocation in EPONs. In Section III, we propose a SLA aware DBA scheme which provides differentiated service in EPONs. Section IV shows detailed simulation of proposed DBA scheme. Final Conclusions are covered in Section V.

II. PREVIOUS DBA SCHEMES FOR EPONS

The MPCP uses two Ethernet control messages, GATE and REPORT, to allocate bandwidth to each ONU. The GATE message is used by the OLT to allocate an upstream transmission window to an ONU. The REPORT message is sent from an ONU to the OLT to request a next time slot of specific size. As illustrated in Figure 1, DBA schemes use one of three types of scheduling frames: variable scheduling frame, fixed scheduling frame, and two-layer scheduling frame [10].

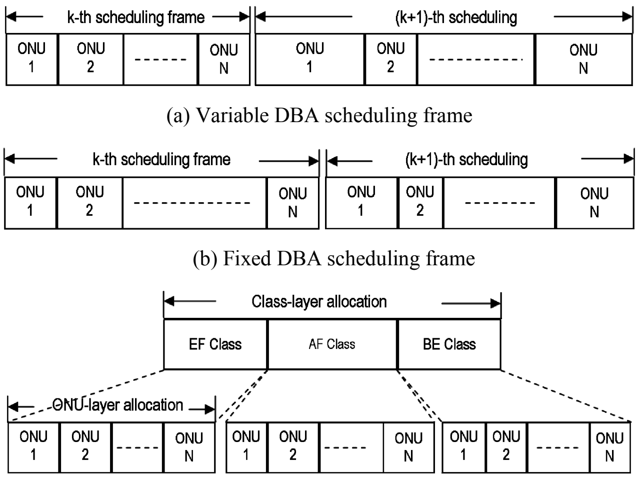

Figure 1. DBA scheduling frames in EPONs.

Several DBA algorithms uses variable scheduling frame size [1]-[3], [6], [9]. The interleaved polling scheme with adaptive cycle time (IPACT) [1] requires the OLT to poll every ONU and dynamically assign its bandwidth before transmission. This bandwidth is allocated according to the buffer occupancy status of the ONU. Any unrequested bandwidth will not be granted therefore the scheduling frame size is not fixed. When the IPACT is applied for differentiated services in EPONs there is a light-load penalty problem. To eliminate the light-load penalty problem a two-stage queue scheme and a constant bit rate (CBR) credit scheme are suggested [2].

The authors [3] have proposed a DBA scheme in which ONU nodes were partitioned into two groups, underloaded and overloaded, according to their minimum guaranteed transmission window sizes. Hence, total bandwidth saved from underloaded group is reallocated to overloaded ONUs to improve their efficiency. However, with this scheme the OLT still only focuses on how to satisfy bandwidth requests from different ONUs and does not provide a prior service to high-priority traffic.

When fixed scheduling frame size is used, it would be easy to implement a class-based DBA algorithm [4]-[5], [8]. A class-based bandwidth allocation scheme [4] collects REPORT messages from all ONUs before bandwidth allocation. The OLT assigns a fixed bandwidth to the EF traffic in all ONUs regardless of their dynamics. The drawback to this scheme is in the long report collection time; it does not end until reports are received from all of the ONUs. The hybrid slot-size/rate (HSSR) [5] scheme classifies traffic into two priority classes. It also allocates a fixed amount of bandwidth to the high-priority class in order to minimize the delay and the jitter of packets. The major advantage of this scheme is that it can ensure that the high-priority traffic will always be served earlier than the lower priority types within each frame. However, the fixed bandwidth cannot always satisfy the instantaneous traffic demands.

Another class-based bandwidth allocation scheme is the dynamic bandwidth allocation with multiple services (DBAM) [6]. Instead of providing multiple services among ONUs and end users separately, the approach of DBAM is to incorporate both of them into the REPORT/GATE mechanism with class-based bandwidth allocation. DBAM employs class-based traffic prediction to take the frames arriving during the waiting time into account. Hence, the OLT serves all of the ONUs in a fixed round robin order to facilitate traffic prediction.

A two-layer bandwidth allocation (TLBA) [7] scheme provides differentiated services using two-layer scheduling frame. With this scheme, an ONU is allowed to report all of its instantaneous traffic load for each traffic class separately. The OLT first allocates the bandwidth for different traffic classes, then further distributes the bandwidth allocated to one class among all the requesting ONUs. Within the same class, all the ONUs share the bandwidth fairly, following the max-min policy. In this scheme, the OLT maintains a table to store the bandwidth demands from all the ONUs in an increasing order. The drawback is that the service order of the ONUs changes in every scheduling cycle, which could make the waiting time for the EF packet of each ONU change drastically.

A Cyclic polling based bandwidth allocation (CPBA) [8] uses fixed scheduling frame size (1 ms or 2 ms) to allocate upstream bandwidth. This scheme provides a constant and predictable packet delay, and improves jitter performance for EF traffic without the influence of the offered ONU load variation. An application of CPBA is the IPTV channel package delivery architecture [11] for the EPONs. The CPBA scheme decreases the network layer channel zapping time and the ONU-based VLAN and IGMP snooping mechanisms provide delivery of differentiated IPTV channel packages in 10 Gbit/s EPONs.

A hybrid granting protocol (HGP) scheme also provides the different QoS in EPON [9]. This algorithm uses grant-before-report (GBR) scheme for the EF traffic class to minimize the packet delay and jitter for delay and delay-variation sensitive traffic. For assured forwarding (AF) and best effort (BE) traffic classes, HGP uses grant-after-report (GAR) scheme, i.e., the grant always follows the reported information that it is based upon.

To analyse the performance of DBA schemes for differentiated classes of service in EPONs, delay and jitter of several DBA schemes are compared [10]. Among several DBA schemes, cyclic-polling based DBA scheme provides constant and predictable average packet delay and improved jitter performance for the EF traffic class without the influence of load variations.

III. SLA AWARE DBA SCHEME FOR QOS

To support differentiated classes of service with different packet delay and jitter requirements, we use three prioritized service: expedite forwarding (EF) has the highest priority used for strict delay sensitive services. This is typically a constant bit rate (CBR) voice transmission. Assured forwarding (AF), with medium priority for services of nondelay sensitive variable bit rate (VBR) services such as a video stream. Finally, best effort (BE) with the lowest priority for delay tolerant services, which include web browsing, background file transfers and e-mail applications.

We propose a DBA algorithm using two-layer scheduling scheme, called as CPBA-SLA, to meet the SLA requirements from the end-users. Especially, average packet delay specification is considered for SLA-aware scheduling algorithm. Priority-based scheduling is exploited and fixed scheduling frame is considered for predictable quality of service (QoS). Several bandwidth parameters are determine by the service level agreement (SLA) between the end user and service provider: average packet delay, d^c_{avg}, for EF traffic class; fixed bandwidth, $g^c_{i,fix}$, only for EF traffic class which includes system management control messages; minimum guaranteed bandwidth, $g^c_{i,\min}$, for each traffic class; maximum bandwidth limitation, $g^c_{i,\max}$, for each traffic class. Thus the minimum guaranteed bandwidth and maximum bandwidth limitation of *i*-th ONU are $g_{i,\min} = g^{EF}_{i,\min} + g^{AF}_{i,\min} + g^{BE}_{i,\min}$ and $g_{i,\max} = g^{EF}_{i,\max} + g^{AF}_{i,\max} + g^{BE}_{i,\max}$ respectively.

The packet delay is defined as the time between packet arrival and packet departure in the queue of an ONU. Then, the average packet delay of EF traffic class d_{avg} may be estimated as

$$d_{avg} \approx \begin{cases} \frac{1}{2} T_{poll} & \text{one-stage queue} \\ \frac{3}{2} T_{poll} & \text{two-stage queue} \end{cases} \quad (1)$$

where T_{poll} is the polling time [10].

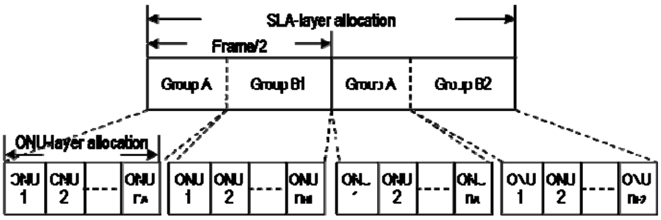

Figure 2. SLA-based DBA scheduling frame.

Figure 2 shows the proposed two-layer bandwidth allocation scheme. After receiving the required average packet delay, d_{avg}, for EF traffic class of each ONU, the OLT performs SLA-layer allocation first, and performs ONU-layer allocation in each subframe. For example, group A includes ONUs which requires the average packet delay of EF traffic class as 0.5 ms. Other ONUs which requires the average packet delay of EF traffic class as 1 ms is partitioned into two groups, B1 and B2. It is assumed that B1 and B2 have the same minimum guaranteed bandwidth.

In the SLA-layer allocation, the scheduling timeslot for each group is obtained as follows:

$$T_A = \frac{T_{poll}}{2} \cdot \frac{\sum_{A} g_{i,\min}}{\sum_{A \cup B1} g_{i,\min}} \quad (2)$$

$$T_{B1} = T_{B2} = \frac{T_{poll}}{2} \cdot \frac{\sum_{B1} g_{i,\min}}{\sum_{A \cup B1} g_{i,\min}} \quad (3)$$

where T_A is the timeslot for group A, T_{B1} and T_{B2} are the timeslots for group B1 and B2 respectively.

After receiving the bandwidth request for interval (n+1) for each service class, OLT performs bandwidth allocation for each ONU considering priority based bandwidth request information. For each class, the excessive bandwidth, $g_{n+1}^{c,ex}$, saved by M (underloaded ONUs) and demanded bandwidth, $g_{n+1}^{c,dem}$, demanded by N (overloaded ONUs) are given as:

$$g_{n+1}^{c,ex} = \sum_{k \in M} (g_{k,\min}^{c} - r_{k,n+1}^{c}),\ c \in \{EF, AF, BE\} \quad (4)$$

$$g_{n+1}^{c,dem} = \sum_{l \in N} (r_{l,n+1}^{c} - g_{l,\min}^{c}),\ c \in \{EF, AF, BE\} \quad (5)$$

where $r_{i,n+1}^{c}$ is the requested bandwidth for class c traffic of i-th ONU in cycle (n+1).

Then, the OLT performs SLA aware bandwidth allocation as follows:

$$g_{i,n+1}^{c} = \begin{cases} g_{i,fix}^{c} & r_{i,n+1}^{c} \le g_{i,fix}^{c} \\ r_{i,n+1}^{c} & g_{i,fix}^{c} < r_{i,n+1}^{c} \le g_{i,\min}^{c} \\ g_{i,\min}^{c} + g_{i,n+1}^{c,ex} & r_{i,n+1}^{c} > g_{i,\min}^{c} \end{cases} \quad (6)$$

with

$$g_{i,n+1}^{c,ex} = g_{n+1}^{c,ex} \times \frac{g_{i,n+1}^{c,dem}}{g_{n+1}^{c,dem}} \quad (7)$$

where $g_{i,n+1}^{c,ex}$ is the reasonably shared extra bandwidth for class c traffic of i-th ONU in cycle (n+1). Finally, the total bandwidth for i-th ONU is obtained as

$$g_{i,n+1} = \min\{\sum_{c} g_{i,n+1}^{c}, g_{i,\max}\} \quad (8)$$

After OLT performs inter-ONU scheduling scheme, it is desirable to further employ an intra-ONU scheduling scheme to perform differentiated classes of service in EPONs.

IV. SIMULATIONS

We conducted the simulation with the network model which includes one OLT and 16 ONUs. The distance from the OLT to any ONU is fixed and equal as 20 km. The link rate between the OLT and the ONUs is 1 Gb/s, and that from end uses to the ONU is 100 Mb/s. The gap time is set as 1 μs.

Since EF service is narrowband, a T1 connection which consumes 4.48 Mbit/s of bandwidth was used. The remaining load was evenly distributed between the AF and BE services. To closely emulate the self-similar property of AF and BE traffic, we generated detailed self-similar traffic models using a Pareto distribution for all ONUs. To simplify the simulations, we also assumed that the total network load was evenly distributed amongst all of the ONUs and that the ONUs were equally weighted.

Let us assume that some ONUs (ONU_{1ms}) need the average EF packet delay as 0.5 ms and others (ONU_{2ms}) need it as 1 ms. Thus, the upstream timeslots are allocated every 1 ms and 2 ms for ONU_{1ms} group and ONU_{2ms} group respectively. Figure 3 shows the average packet delay when cyclic polling based DBA scheme with SLA (CPBA-SLA) is applied. The simulation result shows that average packet delay of EF traffic class meets the SLA without the effect of load variation.

The packet delay variation, known as jitter, can be divided into two categories, intrawindow jitter and interwindow jitter [9]. Since EF traffic is non-bursty, it is reasonable to assume that the inter-arrival time of two successive EF packets is greater than the transmission time of the first EF packet as seen by the ONU. Hence the intrawindow jitter is defined as the packet delay variation of two consecutively departed EF packets from the same ONU in the same transmission window. The interwindow jitter is the variation of first departed EF packet between two consecutive transmission windows and maps the distribution property of total EF delay sequence for the ONU.

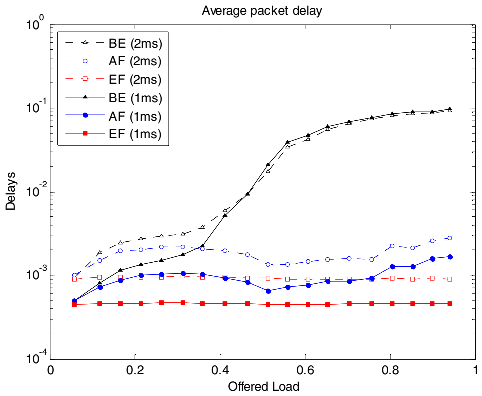

Figure 3. Average packet delay of CPBA-SLA

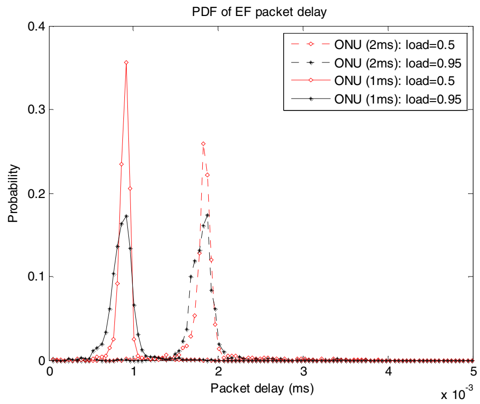

Figure 4. PDF of first departed EF packet delay of CPBA-SLA

Figure 4 shows the probability density function (PDF) of first departed EF packet delay of ONUs. With heavily loaded condition (load = 0.95), CPBA-SLA provides average packet delay and average absolute value of interwindow jitter of EF traffic service as (0.91 ms, 0.26 ms) and (1.85 ms, 0.28 ms) for ONU_{1ms} and ONU_{2ms} respectively. The average value of interwindow jitter of ONU_{1ms} is similar with that of ONU_{2ms}. Hence, EPONs with CPBA-SLA algorithm would provide predictable delay and jitter performance without the influence of load variations.

V. Conclusions

In this paper we proposed a dynamic bandwidth allocation scheme for differentiated classes of service of EPON which meets the service level agreements such as bandwidth, packet delay, and jitter. Cyclic polling based DBA scheme considering SLA and QoS provides predictable average packet delay and delay jitter of EF traffic class without the influence of load variation.

References

[1] G. Kramer, B. Mukherjee, and G. Pesavento, "Interleaved polling with adaptive cycle time (IPACT): a dynamic bandwidth distribution scheme in an optical access network," *Photonic Network Communications*, vol. 4, no. 1, pp. 89-107, Jan. 2002.

[2] G. Kramer, B. Mukherjee, S. Dixit, Y. Ye, and R. Hirth, "Supporting differentiated classes of service in Ethernet passive optical networks," *Journal of Optical Networking*, vol. 1, nos. 8 & 9, pp. 280-298, Aug. & Sep. 2002.

[3] C. M. Assi, Y. Ye, S. Dixit, and M. A. Ali, "Dynamic bandwidth allocation for quality-of-service over Ethernet PONs," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 9, pp. 1467-1477, Nov. 2003.

[4] S. I. Choi and J. D. Huh, "Dynamic bandwidth allocation algorithm for multimedia services over Ethernet PONs," *ETRI Journal*, vol. 24, pp. 465-468, Dec. 2002.

[5] J. Xie, S. Jiang, and Y. Jiang, "A dynamic bandwidth allocation scheme for differentiated services in EPONs," *IEEE Optical Communications*, vol. 42, pp. 32-39, Aug. 2004.

[6] Y. Lou and N. Ansari, "Bandwidth allocation for multiservice access on EPONs," *IEEE Optical Communications*, vol. 43, pp. 16-21, Feb. 2005.

[7] F. An, H. Bae, Y. Hsueh, M. Rogge, L. Kazovsky, and K. Kim, "A new media access control protocol guaranteeing fairness among users in Ethernet-based passive optical networks," in Proc. IEEE OFC (Atlanta, GA, USA, Mar. 2003), pp. 134-135.

[8] S. I. Choi, "Cyclic polling-based dynamic bandwidth allocation for differentiated classes of service in Ethernet passive optical networks," *Photonic Network Communications*, vol. 7, no. 1, pp. 87-96, Jan. 2004.

[9] A. Shami, X. Bai, C. Assi, and N. Ghani, "Jitter performance in Ethernet passive optical networks," *Journal of Lightwave Technology*, vol. 23, no. 4, 1745-1753, Apr. 2005.

[10] S. I. Choi, "An analysis of the delay and jitter performance of DBA schemes for differentiated services in EPONs," *Journal of the Optical Society of Korea*, vol. 13, no. 3, pp. 373-378, Sep. 2009.

[11] S. I. Choi, "IPTV delivery architecture in 10G EPONs using ONU-based multicast emulation," *Journal of the Optical Society of Korea*, vol. 12, no. 2, pp. 69-78, June 2008.