Fast GATE Mechanism with Prediction-based DBA for Differentiated Services on EPONs

I-Shyan Hwang*[a], Zen-Der Shyu[b], Zun-Long Huang[a], and Jhong-Yue Lee[a]
Department of Computer Engineering and Science, Yuan-Ze University [a]
Department of General Studies, Army Academy [b]
E-mail: ishwang@saturn.yzu.edu.tw, {*s949102, s937494, s966043*}*@mail.yzu.edu.tw*

Abstract- *This study proposes a novel Fast GATE Dynamic Bandwidth Allocation (FGDBA) mechanism incorporated with a prediction-based scheme in Ethernet passive optical networks (EPONs). Two phase dynamic bandwidth allocation mechanisms are designed in the proposed FGDBA which also followed by the prediction scheme and fairness bandwidth allocation. The FGDBA mechanism can eliminate idle period problem in traditional DBA mechanism and improve overall PON system performance. The simulation results show that the proposed FGDBA mechanism with prediction-based DBA is able to provide excellent performance as compared with other well-known methodologies.*

Keywords: FGDBA, Dynamic Bandwidth Allocation, EPON, System performance, Differentiated services.

1. Introduction

With the increasing popularity of Internet, the traffic generated by domestic and small business users has been growing constantly over the last couple of years. However, existing access technologies are unable to provide enough bandwidth to current high-speed Gigabit Ethernet local area networks and evolving services. Recently, Ethernet passive optical networks (EPON) have gained more attention from industry due to convergence of low-cost Ethernet equipment and fiber infrastructure. The EPON provides bi-directional transmission. In downstream direction, EPON is a broadcasting media. Ethernet packets are transmitted by the OLT pass through a $1:N$ passive splitter or a cascade of splitters to each ONU. An ONU extracts its data based on the medium access control (MAC) address. In the upstream direction, EPON utilizes time division multiple access (TDMA) coupled with multi-point control protocol (MPCP) mechanism, which include the two MAC messages: GATE and REPORT, to avoid collision [1, 2]. This is achieved by OLT allocating a none-overlapping transmission time slot. The OLT allocates upstream bandwidth to each ONU by sending GATE messages with the form of a 64-byte MAC control frames. GATE messages contain a timestamp and granted time slots which represent the periods that ONU can transmit data. Each ONU may send REPORT messages about the queue state to OLT, so that OLT can allocate upstream bandwidth and time slots to each ONU accordingly. With multiple ONUs share the same upstream bandwidth to transmit data on EPON, any data collision will cause longer end-to-end delay and deteriorate the system performance. Therefore, bandwidth allocation has become a prominent concern of research on EPON, especially with the enormous of bandwidth demand and critical applications.

Bandwidth allocation schemes can be divided into two categories: *fixed bandwidth allocation* (FBA) and *dynamic bandwidth allocation* (DBA) [3]. The straightforward concept of FBA is pre-assigned a fixed time slot to each ONU for transmitting its data once to OLT. The FBA is simple to implement, however, an ONU will occupy the upstream channel for its assigned time slot even if there is no frame to transmit, thus resulting in long delay for all the Ethernet frames buffered in other ONUs. An alternative method, DBA, assigns bandwidth dynamically using queue state information that is received from ONUs. Therefore, DBA schemes can provide more efficient bandwidth allocation for each ONUs to share the network resources.

DBA schemes can be classified into non-predictive and predictive. Each ONU experiences a waiting time from sending REPORT message to sending the buffered frames. In non-predictive schemes, each ONU only reports the already buffered frames to the OLT. Therefore, frames that arrive during the waiting time have to be delayed to next transmission cycle even if upstream channel is free. The predictive schemes take the traffic arrival during waiting time into consideration. When OLT allocates the request bandwidth to ONUs, it adds a credit into the requirement of each ONU. The incoming traffic during the waiting time is expected to be transmitted (or partially transmitted) within current time slot. Accurate traffic prediction is required to avoid longer packet delay and degrade the network performance. Therefore, the predictive schemes are studied in order to decrease packet delay and allocate more bandwidth efficiently.

This paper discusses ability of EPON which support differentiated services architecture and offer various levels of quality of service (QoS) [4]. Generally three classes of traffic can be classified: Expedited Forwarding (EF), Assured Forwarding (AF), and Best Effort (BE). While EF services have very strict requirements and demand a constant low end-to-end delay and jitter. AF is intended for the services that are not delay-sensitive but require bandwidth guarantees. Finally, BE traffic is generated by applications that have no strong requirements regarding traffic properties. This study proposes the *Fast GATE DBA* (FGDBA) mechanism based on prediction scheme to eliminate idle period problem in the traditional DBA mechanism. Furthermore, FGDBA uses the prediction method and considers the traffic trend in differential traffic classes. Finally, the efficient excessive bandwidth allocation scheme is incorporated to consider fairness of excessive bandwidth allocation among ONUs to improve system performance.

The rest of this paper is organized as follows. Section 2 describes the related work of DBA on EPON. Section 3 proposes the FGDBA mechanism which incorporates prediction scheme and fairness excessive bandwidth allocation algorithm. Section 4 shows the simulation results as compared with other well-known methodologies. Finally, Section 5 draws conclusions and offers suggestions.

2. Related Work

The DBA has been widely studied for EPONs, which is essential to an efficient EPON network and a key requirement for provisioning in business and residential deployments. The traditional DBA scheme piggybacks REPORT message in the data time slots and starts bandwidth allocation sequence after collecting all REPORT messages. Upon receiving all REPORT messages from active ONUs, it needs consuming DBA time to finish computation and generate grants table in OLT, which is estimated as

$$Idle\_Time = Computation\ time\ of\ DBA + Round\ Trip\ Time \cdot$$

In [5], G. Kramer *et al*. proposed an interleaving polling protocol called IPACT. In IPACT, the polling messages are scheduled in an interleaved manner with the data transmission, which largely reduces the bandwidth overhead caused by propagation delay and thus increases bandwidth utilization of the upstream channel. Each ONU is assigned guaranteed bandwidth in proportion to its service level agreement (SLA) to support quality of service (QoS) in the DBA. In [6], M. Ma *et al*. proposed a bandwidth guaranteed polling protocol, which allowed sharing upstream bandwidth between each subscriber and operator. It could provide bandwidth guarantee for premium subscribers based on SLAs while providing best-effort service to other subscribers.

In limited bandwidth allocation (LBA) [4, 5], the time slot length of each ONU is upper bounded by the maximum time slot length, $B_{\max}$, which can be specified by SLA. When reported queue size is less than $B_{\max}$, OLT grants the requested bandwidth; otherwise, $B_{\max}$ is granted. The drawback of LBA is that no more bandwidth granted to ONUs that already assigned a guaranteed bandwidth $B_{\max}$, even though other ONUs have free bandwidth. The feature of LBA has poor utilization for upstream bandwidth and restricts aggressive competition for upstream bandwidth, especially under non-uniform traffic. In [7], C. Assi *et al*. proposed a couple of DBA algorithms to allocate fairly bandwidth for end users and support differentiated services. It make use of excessive bandwidth of lightly loaded ONUs to meet bandwidth demand of heavily loaded ONUs in each transmission cycle and thus improve performance of limited allocation scheme. In [8], Y.M. Yang *et al*. proposed another DBA prediction scheme which predict in each traffic class but not consider traffic characteristics completely. This drawback will result in the prediction inaccuracy.

The sum of unexploited bandwidth of lightly-loaded ONUs is called *excessive bandwidth* B_{excess}. For every transmission grant cycle, each ONU requests bandwidth corresponding to its total backlog. If the requested bandwidth is smaller than guaranteed bandwidth, the B_{excess} is pooled together with all other lightly-loaded ONUs whose requested bandwidth is less than their guaranteed bandwidth. In efficient bandwidth allocation algorithm (EBR) [9], it redistributes available

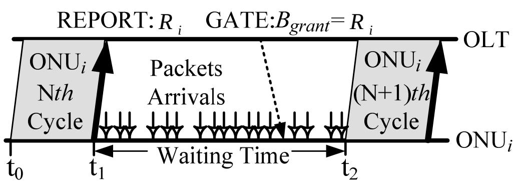

Figure 1. Packets arrivals during waiting time

bandwidth to heavily-loaded ONUs in proportion to each request and results in better performance in terms of packet delay. Then, the heavily-loaded ONU*i* obtains an additional bandwidth $B_{add,i}$ from B_{excess} as follows:

$$B_{add,i} = \frac{B_{excess} \times R_i}{\sum_{h \in H} R_h} \tag{1}$$

, where H is the set of heavily-loaded ONUs, h is a heavily-loaded ONU in H and R_i is the bandwidth requested by ONU*i*. However, the drawbacks of EBR are unfairness and excessive bandwidth allocated to ONUs than that requested, which is defined as *redundant bandwidth problem* [10].

The DBA with multiple services (DBAM) is a prediction-based LBA that executes prediction according to linear estimation credit [11]. The linear estimation credit of each ONU is based on the ratio of the ONU*i* waiting time ($t_2 - t_1$) over the time length of current interval ($t_2 - t_0$), which is shown in Fig. 1. OLT allocates time slots for multiple services among ONUs according to each bandwidth requirements and SLA limits. In fact, packet delay will be improved by DBAM in uniform traffic flows. However, the drawback of DBAM is lacks to use historical data for reference in next cycle of traffic amount. And overall performance is deteriorated in non-uniform traffic flows due to prediction model not considers the traffic trend; this will also causes prediction inaccuracy in DBAM.

3. Proposed FGDBA Algorithm

For the traditional DBA scheme, upon receiving

Table 1. Definition of parameters

Parameters	Definition
$B^{availiable}$	Available transmission bandwidth in the *nth* cycle
$B^{request}$	Requested BW of each ONU in the n*th* cycle
D_i^C	Traffic variance value of every class in each ONU, where $C \in \{EF, AF, BE\}$
$\overline{V}$	Mean value requested TW of historical cycles in each class
T^{cycle}	Maximum cycle time in each cycle
N	Number of ONUs in the system
$C^{capacity}$	Link capacity of OLT (bit/s)
$R_{i,n}^c$	Requested BW of ONU$_i$ after prediction in the n*th* cycle, where $C \in \{EF, AF, BE\}$
S	Guaranteed BW from the SLA in each ONU
$G_{i,n+1}^{phaseI}$	Granted (n+1)*th* cycle upload BW of ONU$_i$ in Phase I
$G_{j,n+1}^{phaseII}$	Granted (n+1)*th* cycle upload BW of ONU$_i$ in Phase II

all REPORT messages from active ONUs, it needs process time to finish computation and generate grants table in OLT. The idle period is sum of computation time of DBA and round-trip time between OLT and each ONU. Reducing idle period can improve bandwidth utilization and system performance. In this section, a *Fast GATE Dynamic Bandwidth Allocation* (FGDBA) algorithm is proposed to resolve this problem in EPON system, shown in Fig. 2. Two phase mechanisms are designed in FGDBA and followed by prediction scheme and fairness bandwidth allocation. The definition of parameters is summarized in Table 1.

3.1 FGDBA Algorithm Phase I

In phase I, FGDBA compares S with requested bandwidth $B^{request}$ of each ONU*i* to deal with DBA in this cycle. When $B^{request} \le S$, then executes the phase I DBA process and following by prediction and bandwidth allocation. OLT transmits GATE message without delay and arranges this ONU*i* to send data in idle period. In the other ONUs that requested bandwidth is larger than SLA which will starts the phase II DBA

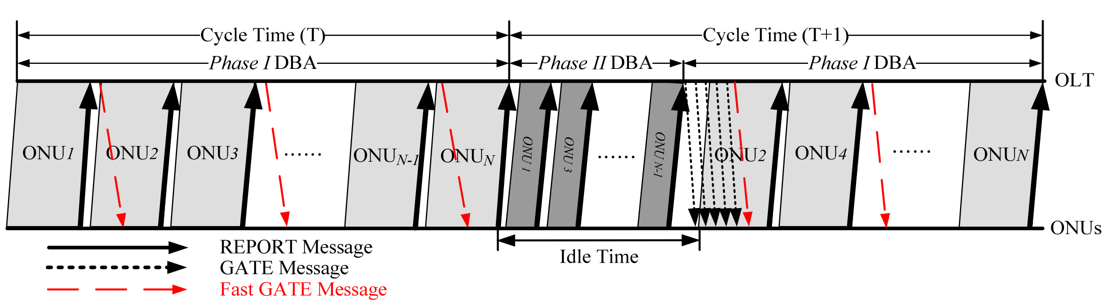

Figure 2. Operation with proposed Fast GATE DBA mechanism

process after all REPORT messages are collected. Therefore, FGDBA can eliminate idle period problem and enhance system performance by improving the bandwidth utilization in EPON. The detail with prediction scheme and granted bandwidth algorithm are described in followed subsection.

3.1.1 Prediction scheme for lightly-loaded ONUs. For considering the possible packets arrive during waiting time, FGDBA takes account of EF, AF, and BE traffic characteristics to enhance the prediction accuracy in each ONU. Moreover, the EF class is constant and none-busty traffic mode, so the proposed prediction scheme used difference between $R_i^{EF}(t)$ at current time and $R_i^{EF}(t-1)$ at previous time of the *i*-th ONU. On the other hand, the AF and BE traffic behavior consider with busty mode and require variation in fluctuation. In this case, FGDBA can predict different between AF or BE traffic requested bandwidth at current time and a mean value requested bandwidth of historical cycles. The operation for differentiated traffic in Phase I prediction scheme can be expressed as follows:

$$\begin{cases} D_i^{EF}(t) = R_i^{EF}(t) - R_i^{EF}(t-1) \\ D_i^{AF}(t) = R_i^{AF} - \overline{V}_{i\in historical\ cycle}^{AF} \\ D_i^{BE}(t) = R_i^{BE} - \overline{V}_{i\in historical\ cycle}^{BE} \end{cases} \tag{2}$$

Upon calculates traffic variance value in each ONU, this prediction scheme can get D_i^C, where $C \in \{EF, AF, BE\}$. Furthermore, If $D_i^C(t) > 0$, the tend of demand increase progressively, then executes prediction and updates the new request bandwidth. Otherwise, don't execute prediction because of the demand tends to decrease. The prediction scheme operation can be expressed as follows:

$$IF\ D_i^C(t) > 0, Then\ R_i^C = R_i^C + D_i^C \tag{3}$$

After prediction in each class of the lighted-loaded ONUs, all requested bandwidth in this phase can be summarized as $R_i = R_i^{EF} + R_i^{AF} + R_i^{BE}$, where R_i represents the sum of differentiated traffic load after being predicted from phase I DBA of ONU*i* in the nth cycle.

3.1.2 Limited bandwidth allocation with SLA. After prediction scheme, in order not to assign too much bandwidth than SLA S, and reserve surplus bandwidth into the phase II DBA, the proposed FGDBA limits bandwidth allocation in phase I as $G_{i,n+1}^{phaseI} = \min(R_i, S)$, where $G_{i,n+1}^{phaseI}$ is GATE message of the phase I DBA for the ONU*i* in the next cycle. Finally, OLT calculates the bandwidth based on each traffic class as follows:

$$\begin{cases} G_{i,n+1}^{EF} = \min\left(G_{i,n+1}^{phaseI}, R_{i,n}^{EF}\right) \\ G_{i,n+1}^{AF} = \min\left(G_{i,n+1}^{phaseI} - G_{i,n+1}^{EF}, R_{i,n}^{AF}\right) \\ G_{i,n+1}^{BE} = G_{i,n+1}^{phaseI} - G_{i,n+1}^{EF} - G_{i,n+1}^{AF} \end{cases} \tag{4}$$

3.2 FGDBA Algorithm Phase II

FGDBA calculates available bandwidth $B^{availiable}$ as

$$B^{availiable} = C^{capacity} \times \left(T^{cycle} - Ng\right) - N \times 512 \tag{5}$$

, where $C^{capacity}$ is the OLT link capacity (bit/s), T^{cycle} is the maximum cycle time, g is the guard time, N is the number of ONUs and control message length 512 bits. In phase II, FGDBA algorithm considers the remaining available bandwidth which calculates the overall available bandwidth and granted bandwidth for ONU*i* in the phase I. The remaining available bandwidth B^{remain} can be expressed as

$$B^{remain} = B^{availiable} - \sum_{i\in assigned}^{m} G_{i,n+1}^{phaseI} \tag{6}$$

, where m is number of assigned bandwidth of lighted-loaded ONU*i* in phase I. FGDBA still considers prediction and fairness of bandwidth allocation which will improve overall system performance.

3.2.1 Prediction scheme for heavily-loaded ONUs. In phase II, this proposed scheme also improves the reliability of prediction by considering the traffic behavior. Hence, when the overall bandwidth requirements $B^{request}$ is smaller than B^{remain}, the requested bandwidth of EF, AF and BE will be obtained extra bandwidth, respectively. This operation can be expressed as:

$$IF\ D_j^C(t) > 0, Then\ R_j^C = R_j^C + D_j^C \tag{7}$$

, where j is one of the heavily-loaded ONUs in the phase II. Otherwise, when overall bandwidth requirements $B^{request}$ is larger than B^{remain}, due to overall bandwidth of the time slots is not sufficiently, only the EF traffic class prediction will be considered and expressed as:

$$IF\ \ D_j^C(t) > 0\ \ ,Then\ \begin{cases} R_j^{EF} = R_j^{EF} + D_j^{EF} \\ R_j^{AF} = R_j^{AF} \\ R_j^{BE} = R_j^{BE} \end{cases} \tag{8}$$

, where $D_j^C(t) > 0$ means the bandwidth requirement demand has increase while execute prediction and getting the new request bandwidth. Otherwise, the bandwidth requirement demand has decrease and doing nothing. After prediction in each class of the heavily-loaded ONUs, all requested bandwidth can be summarized as $R_j = R_j^{EF} + R_j^{AF} + R_j^{BE}$.

3.2.2 Fairness dynamic bandwidth allocation. After finishing prediction requirement for each ONU in phase II, FGDBA assigns uplink bandwidth for each ONU fairly. The operation of fairness bandwidth allocation and granted bandwidth for ONU*j*, $G_{j,n+1}^{phaseII}$, in next cycle is given as follows :

$$G_{j,n+1}^{phaseII} = \min\left(B^{remain} \times \frac{S}{\sum_{k\in\ unassigned} S_k}, R_{j,n}\right) \quad (9)$$

, where $R_{j,n}$ is the sum of differentiated traffics after being predicted of ONU*j* in n*th* cycle, $S/\sum_{k\in unassigned} S_k$ is proportion of ONU*j* which is granted bandwidth from available bandwidth B^{remain}. Furthermore, the granted bandwidth for EF, AF and BE classes are described as follows:

$$\begin{cases} G_{j,n+1}^{EF} = \min\left(G_{j,n+1}^{phaseII}, R_{j,n}^{EF}\right) \\ G_{j,n+1}^{AF} = \min\left(G_{j,n+1}^{phaseII} - G_{j,n+1}^{EF}, R_{j,n}^{AF}\right) \\ G_{j,n+1}^{BE} = G_{j,n+1}^{phaseII} - G_{j,n+1}^{EF} - G_{j,n+1}^{AF} \end{cases} \quad (10)$$

Finally, the remaining available bandwidth becomes $B^{remain} = B^{remain} - G_{j,n+1}^{phaseII}$ and the remain requested bandwidth becomes $R^{remain} = R^{remain} - R_{j,n}$. The process continues until all ONUs have been assigned.

4. Performance Evaluation

In this section, the system performance of the proposed FGDBA mechanism with EBR [9] and DBAM [11] schemes are compared in terms of average end-to-end delay and jitter performance. The system model is set up in the OPNET simulator with one OLT and 32 ONUs. 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 infinite buffer. The service policy is in first-in first-out (FIFO) discipline. 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) [12]. This model is utilized to generate highly busty BE and AF traffic classes with the Hurst parameter of 0.7 [11], 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 [5]. In order to show the effect of high priority traffic, the proportion of traffic profile is analyzed by simulating the four significant scenarios in (EF, AF, BE), which is (20%, 40%, 40%), (40%, 30%, 30%), and (60%, 20%, 20%) respectively. The simulation scenario is summarized in Table 2.

Table 2. Simulation scenario

Number of ONUs in the system	32
Buffer in each ONU	Infinite
Upstream/downstream link capacity	1Gbps
OLT-ONU distance (uniform)	10 – 20 *km*
Maximum transmission cycle time	2 *ms*
Guard time	5 μs
Computation time of DBA	10 μs
Control message length	0.512 μs

4.1 End-to-end delay

Figure 3(a) compares the average end-to-end delay vs. traffic load among the FGDBA, EBR and DBAM. The results show that the proposed FGDBA outperforms the other two schemes in every traffic profile. In this case, the DBAM has the worst performance because of serious prediction inaccuracy when the traffic has high variation. The EBR can adjust the excessive bandwidth, but cannot avoid redundant bandwidth problem that results in longer end-to-end delay. In Fig 3(b), the proposed FGDBA has almost the same EF end-to-end delay as that of EBR and DBAM until the traffic profile scenario 622 exceeds load 80%. However, the DBAM is more suitable for stable traffic, such as EF class, in high traffic load. On the other hand, as shown in Fig. 3(c), the FGDBA can handle fluctuating traffic, such as AF and BE in every traffic profile scenario.

4.2 Jitter performance

Figure 3(d) shows the comparison of delay variance of EF class under DBAM, EBR and FGDBA. However, the EF jitter of FGDBA is not as good as that of other two schemes, especially under high traffic load. The reason is that the upstream order of FGDBA will be changed between phase I and phase II, which result in higher delay variance.

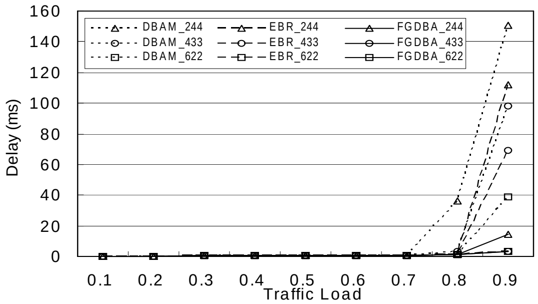

Figure 3(a) Delay for total traffic

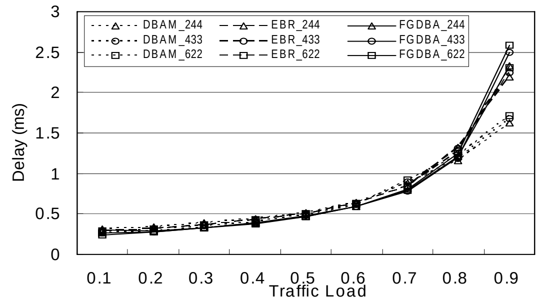

Figure 3(b) Delay for EF traffic

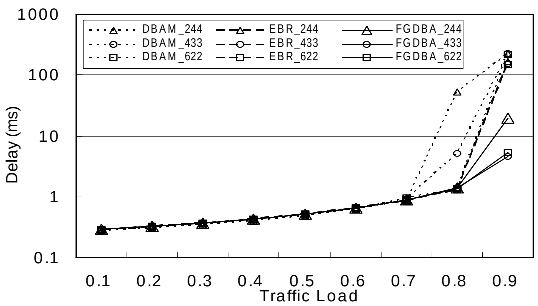

Figure 3(c) Delay for BE traffic

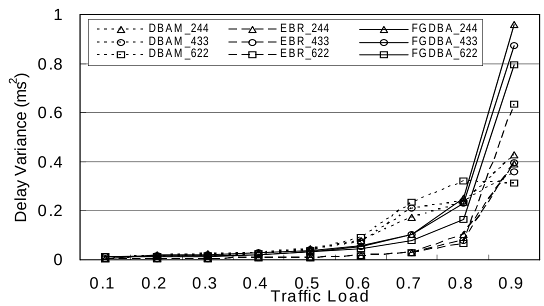

Figure 3(d) EF delay variance

5. Conclusions

In this study we discuss and evaluate the crucial issues that can improve the performance in EPON specifically. The FGDBA mechanism provides early to send message in order to reduce the end to end packet delay. FGDBA resolve the idle period problem in traditional DBA scheme and also enhance the system performance and throughput. Not only to allocate bandwidth for three-class traffic adaptively, but also consider predicting requested traffic behaved. Simulation results show that the proposed algorithm offers better performance in terms of average packet delay and jitter performance for different traffic profile in comparison to other algorithms.

References

[1] G. Kramer and G. Pesavento, "Ethernet passive optical network (EPON): Building a next generation optical access network," *IEEE Communications Magazine*, pp. 66–73, Feb. 2002.

[2] K.S. Kim, "On the evolution of PON-based FTTH solution," *Information Sciences*, vol. 149, no. 1-3, pp. 21–30, Jan. 2003.

[3] G. Kramer B. Mukherjee, and G. Pesavento, "Ethernet PON(Ethernet PON): design and analysis of an optical access network," *Photonic Network Communications*, vol. 3, no. 3, pp. 307-319, July 2001.

[4] G. Kramer, B. Mukherjee, S. Dixit, Y. Ye, and R. Hirth, "Supporting differentiated classes of service in Ethernet passive optical networks," *J. of Optical Networks*, vol. 1, no. 8, pp. 280-298, Aug. 2002.

[5] 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.

[6] M. Ma, Y. Zhu, and T.H. Cheng, "A bandwidth guaranteed polling MAC protocol for Ethernet passive optical networks," *IEEE INFOCOM'03*, vol. 1, pp. 22-31, Apr. 2003.

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

[8] Y.M. Yang, J.M. Nho, N.P. Mahalik, K. Kim, and B.H. Ahn, "QoS provisioning in the EPON systems with traffic-class burst-polling based Delta DBA," *IEICE Transactions on Communications*, vol. E89-B, no. 2, pp. 419-426, Feb. 2006.

[9] J. Zheng, "Efficient bandwidth allocation algorithm for Ethernet passive optical networks," *IEE Proceedings Communications*, vol. 153, no. 3, pp. 464-468, June 2006.

[10] I.S. Hwang, Z.D. Shyu, L.Y. Ke, and C.C. Chang, "A novel early DBA mechanism with prediction-based fair excessive bandwidth allocation scheme in EPON," *Computer Communications*, vol. 31, no. 9, pp. 1814-1823, Jun. 2008.

[11] Y. Luo, and N. Ansari, "Bandwidth allocation for multiservice access on EPON," *IEEE Communications Magazine*, vol. 43, no. 2, pp. S16-S21, Feb. 2005.

[12] W. Willinger, M.S. Taqqu, and A. Erramilli, "A bibliographical guide to self-similar traffic and performance modeling for modern High-Speed Networks," Stochastic Networks: Theory and Applications, Royal Statistical Society Lecture Notes Series, Vol. 4, Oxford University Press, 1996.