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A Novel Distributed QoS-Based DBA Scheduling Mechanism for Star-Ring Architecture on Ethernet Passive Optical Access Networks

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Abstract—**In this paper, a distributed Dynamic Bandwidth Allocation (D-DBA) scheduling mechanism for star-ring protection architecture is proposed in Ethernet Passive Optical Networks (EPONs). The D-DBA mechanism can effectively resolve the idle period problem and reduce overload of OLT in traditional DBA mechanism. We perform exhaustive simulation experiments to study the performance and validate the usefulness of the proposed mechanism. The simulation results show that the proposed D-DBA mechanism can reduce the packet delay and packet delay variation for high priority ONUs to ensure Quality of Service (QoS).**

Keywords- EPONs; D-DBA; QoS.

I. INTRODUCTION

Ethernet Passive Optical Networks (EPONs), standardized by the IEEE 802.3ah [1] Ethernet in the First Mile (EFM) Task Force, is a promising technology which is proposed to overcome the blockage of bandwidth at the access networks. The EPONs architecture, shown in Fig. 1, consists of two main components, one is the optical line terminal (OLT) resided at the central office (CO), and the other is the multiple optical network units (ONUs) located at customer residence area. Ethernet frames are transmitted by the OLT pass through a 1:N passive splitter to reach each ONU. The passive splitter is generally located far from the CO, but close to the ONUs located at customer residence area.

The EPONs comprise both upstream and downstream data transmissions. In the downstream direction, the OLT broadcasts frames to all ONUs; furthermore, the upstream direction is multipoint-to-point (MP2P) network which only single ONU may transmit data in one timeslot to avoid signal collisions. Some control messages are defined by the IEEE 802.3ah task force through the development of Multi-Point Control Protocol (MPCP) which includes two primary messages - typically the REPORT messages for upstream transmission and the GATE messages for downstream transmission. The ONU sends request bandwidth to OLT by REPORT messages. After OLT receives the messages from ONUs, the OLT sends GATE message to each ONU with the time it should begin to transmit and the size of the assigned time slot. How to design an excellent algorithm for OLT assigning the bandwidth efficiency is one of the important issues on EPONs.

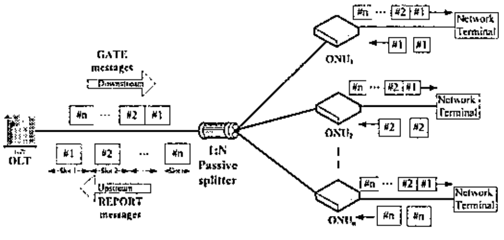

Figure 1. EPONs architecture

The bandwidth allocation on EPONs may be fixed or variable, also called *fixed bandwidth allocation* (FBA) and *dynamic bandwidth allocation* (DBA) [2], based on the arbitration mechanism implemented at the OLT. In data transmission, the FBA scheme assigns fixed timeslots for each ONU at the full link capacity [4,5]; contrast to the FBA [3,6], the DBA [7,8,9] further improves the system performance in more efficient way. The OLT allocates a variable timeslot to each ONU dynamically based on the immediate bandwidth and ensure the quality of service (QoS) by guaranteed service level agreement (SLA).

In order to provide advanced QoS for differentiated services, categorizing the traffic into differential classes is a practical and necessary approach. The EPONs support principal IP-based differentiated services (DiffServ) mechanism to ensure QoS of these applications [10]. For instance, the highest-priority class can be mapped to expedited forwarding (EF) [11], 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 assured forwarding (AF), is intended for services that are not delay sensitive but require bandwidth guarantees, which the AF is typically variable bit rate (VBR) services, such as video stream. Finally, the low-priority class can be mapped to 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 traffic are more delay tolerant but generally have a wide-

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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 delay and jitter guarantee. In EPONs, the carried traffic is greatly influenced by the scheduling discipline which plays an important role in the performance of networks for sharing the available network resources fairly. A scheduling discipline includes two principal functions: first, it decides the order in which requests are serviced, and second, it manages the service queue of requests awaiting service.

In the traditional queues, packets are collected by the First-In-First-Out (FIFO) structure, and the Priority Queue (PQ) is a specialization of the queue data structure which is designed based on priority for delivering packets in a different order. However, the drawback of PQ is that the high-priority services always be transmitted first resulting in the lower-priority services maybe starvation. In [12], the author proposed a solution for the PQ scheme that all packets are classified into system queue and Custom Queue (CQ), and the system queue has absolute priority so that the system always processes system queue first and then deals with CQ. The proportion of CQ occupying bandwidth can be pre-defined in accordance with the service type. When the congestion occurs, the CQ can be maintained in the application of the bandwidth in accordance with the ratio corresponding to different services. In addition, the CQ scheme ensures the high-priority services have more chance to access bandwidth and the low-priority services will not be starved because of that still have chance to be transmitted. In [13], the Weighted Fair Queue (WFQ) is proposed and it is a popular scheme because of its bounded delay and guaranteed bandwidth. It allows different scheduling priorities to meet multiplexed data flows. There can be a service weigh associated with each queue. Accordingly, queues receive service according to their associated weights. When congestion occurs, it ensures that any of the data flow can fairly obtain certain amount of bandwidth in order to enhance the system performance.

In the traditional DBA scheme, shown in Fig. 2, each ONU sends its REPORT message to the OLT at the end of its assigned transmission time slot. After OLT gathers the REPORT messages from each ONU, it sends a GATE message to each ONU for next cycle. At this period, all ONUs are idle to wait for the instructions of OLT, and the idle period is the sum of computation time of DBA and round-trip time between OLT and each ONU. Reducing the idle period can improve bandwidth utilization and system

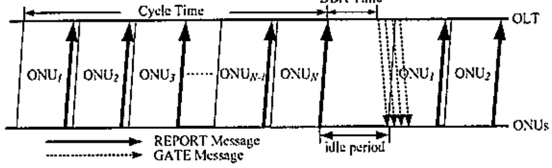


Figure 2. Operation of traditional DBA mechanism

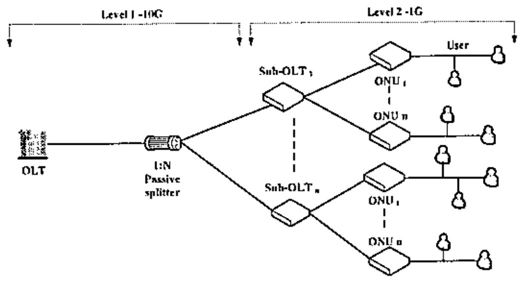


Figure 3. Two-stage EPON access networks

performance. Furthermore, it still has some drawbacks on traditional DBA algorithms; such as the load of OLT is high and the number of guard time is numerous.

The OLT has to gather the REPORT messages from each ONU for scheduling, and subsequently, the OLT needs to make accurate and fair allocation of all ONUs. However, this work is heavy and reducing the load of OLT will improve the system performance of EPONs. Shami *et al.* proposed a cascaded two-stage EPONs architecture [14] which adds a new intermediate level of ONU nodes to the network, termed sub-OLT, to reduce the load of OLT, as shown in Fig. 3. This architecture is excellence in the calculation of an extra stage, which will help reduce OLT hardware difficulty radically. But, increasing the cost is its drawback because the sub-OLT is the extra architecture.

In the ITU-T Recommendation G.983.1, four types of protection network architectures are proposed [15,16]. The first protection type only protects the link between OLT and splitter, and if the failure occurs in OLT or splitter, this protection architecture will not work. The second protection type is to improve the drawback of the first type that builds a backup OLT module. For all the links and nodes, the third protection type is to do a comprehensive protection that data will be simultaneously sent in the working link and the protection link (similar to 1+1 protection). This architecture provides full protection to the network. However, its shortcomings are not only the cost of installation is high, but also the resources are wasted on the ineffectiveness of load sharing between backup nodes and protection link. The fourth protection type is to improve on the third type and especially add up one splitter and one protection link in EPONs. However, the fourth protection type which has the shortcomings that the backup nodes and protection links are unable to share the burden of major nodes and links and its installation cost is the highest.

B. Pathak *et al.* [17] proposed a distributed ring-based EPONs architecture which is excellent for increasing optical power transmission in the ring. At each ONU, the downstream and LAN traffic is first demultiplexed by the WDM coupler, shown in Fig. 4, and the LAN wavelength is received and processed at the node. Signaling is generated at the ONU and it is transmitted to the next ONU. Moreover, this paper proposed an error free architecture which bypasses the signal of failed ONU to next ONU and terminates at OLT by ring architecture. However, this paper still has some

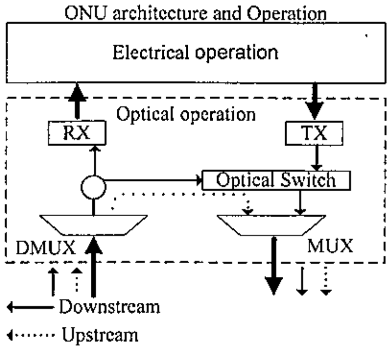


Figure 4. The ONU operation for ring-based EPON architecture

drawbacks that only consider the failure is occurred in nodes but not in the links.

Other than ITU-T protection schemes, Sun *et al.* proposed a star-ring EPONs architecture to provide protection in opposition to fiber link failure between the remote node (RN) and the ONUs, thus the OLT is transparent to such fiber failure [18]. This paper has excellence in fiber link failure in star-ring architecture; however, the DBA mechanism was not considered in this proposed architecture.

This paper designs an ONU as sub-OLT without increasing the extra cost, and the sub-OLT is warehouse which can share OLT work and store AF and BE traffic for each ONU. On the other hand, for designing a suitable DBA mechanism in star-ring architecture, this paper also proposes a distributed QoS-based DBA scheduling mechanism to solve the idle period, EF jitter and OLT loading problems for star-ring architecture on EPONs. In the OLT side, the DBA mechanism will content with sub-OLT bandwidth request after EF bandwidth request for each ONU. The proposed DBA mechanism allocates bandwidth request in star-ring architecture using QoS-based DBA mechanism to improve related delay performance and idle period without degrading QoS support for other service types. We conduct detailed simulation experiments to study the performance of the proposed scheduling mechanism and validate its effectiveness.

The rest of this paper is organized as follows. Section 2 proposes a distributed QoS-based DBA scheduling mechanism for star-ring architecture. Section 3 presents a detailed performance analysis. The final conclusions are drawn in Section 4.

II. Proposed D-DBA Mechanism for Star-Ring Architecture

In this paper, we propose a distributed QoS-based DBA scheduling mechanism for star-ring architecture [18], shown in Fig. 5, to design an efficient mechanism for resolving idle period problem and reducing overload of OLT. Firstly, we design an ONU as sub-OLT in the star-ring architecture that the highest priority traffic (EF) of each ONU is sent to OLT by tree structure, and the minor priority traffic (AF and BE)

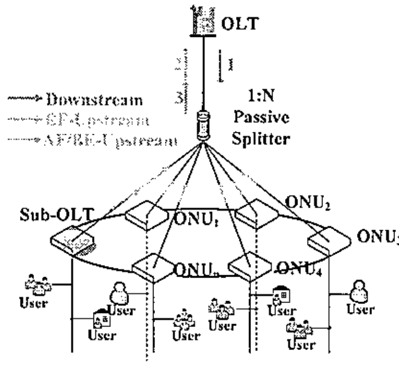


Figure 5. Star-ring architecture

of each ONU are transmitted to sub-OLT by ring architecture. The sub-OLT provides local DBA scheduling mechanism which can decrease the load of OLT. Secondary, in the ring-based architecture, after ONU combines the backlog with received data, it will send whole data to the next ONU. Finally, the sub-OLT will receive the upstream data from each ONU to process the intra-ONU scheduling.

In order to formularize this D-DBA scheme, it is helpful to consider some necessary parameter definitions which are summarized in Table I.

The D-DBA scheme, shown in Fig. 6, comprises two operations: at the beginning of each transmission cycle, each

TABLE I. Definition of Parameters

T_{cycle}	Maximum cycle time in each cycle.
$B_{available}$	The available bandwidth in cycle time.
B_{remain}	The remaining available bandwidth.
$R^{total}_{sub-OLT}$	Sub-OLT total request bandwidth.
R^{EF}_{i}	EF request bandwidth of ONU*i*.
$R^{EF}_{sub-OLT}$	EF request bandwidth of sub-OLT.
R^{AF}_{SQ}	AF request bandwidth in System Queue (SQ).
R^{AF}_{HQ}	AF request bandwidth in High Priority Queue (HQ).
R^{AF}_{LQ}	AF request bandwidth in Low Priority Queue (LQ).
R^{BE}_{FIFO}	BE request bandwidth in FIFO Queue.
$C_{capacity}$	Bandwidth available in a cycle.
$G^{total}_{sub-OLT}$	The total granted bandwidth of sub-OLT.
$G^{EF}_{i,n+1}$	EF granted bandwidth of ONU*i*.
$G^{EF}_{sub-OLT}$	EF granted bandwidth of sub-OLT.
G^{AF}_{SQ}	AF granted bandwidth in System Queue (SQ).
G^{AF}_{HQ}	AF granted bandwidth in High Priority Queue (HQ).
G^{AF}_{LQ}	AF granted bandwidth in Low Priority Queue (LQ).
G^{BE}_{FIFO}	BE granted bandwidth in FIFO Queue.

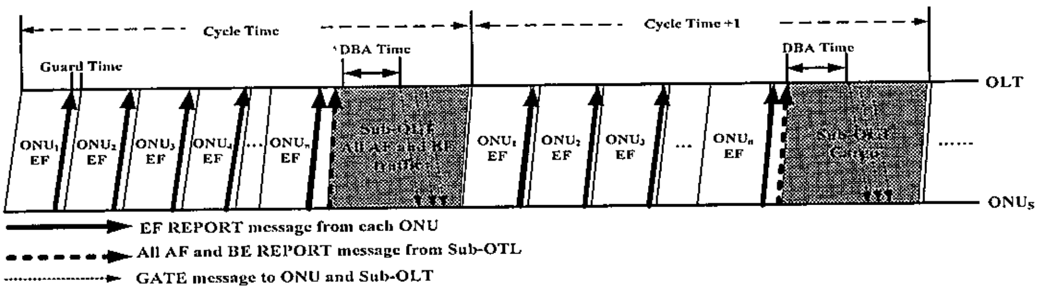


Figure 6. Operation of the proposed D-DBA

ONU sends its EF traffic and REPORT message to OLT, and after the sub-OLT sends REPORT message to OLT, the OLT performs dynamic bandwidth allocation (DBA) for each ONU. At this time, the sub-OLT can send packets which comprise AF and BE traffic of each ONU to OLT; afterwards, the OLT will send GATE message to each ONU for next cycle. The advantages of D-DBA scheme are to reduce the idle period and overhead of OLT to improve the system performance of EPONs.

A. Scheduling for the OLT

The transmission cycle time is the sum of transmission time and guard times for all ONUs. In one transmission cycle time, we assume that each ONU can transmit REPORT message to the OLT. The available bandwidth initialized is expressed as (1).

$$B_{available} = C_{capacity} \times (T_{cycle} - Ng) - N \times 512 \qquad (1)$$

where $C_{capacity}$ is the OLT link capacity (bits/sec), T_{cycle} is the maximum cycle time, g is the guard time, and N is the number of ONUs with control message length of 512 bits (64 bytes).

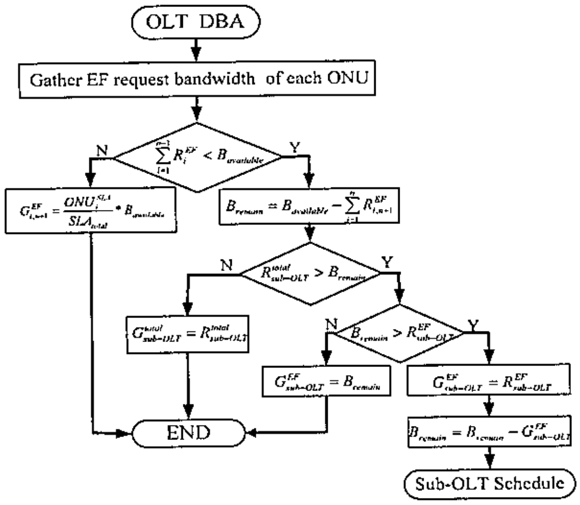


Figure 7. Flowchart of OLT

The flowchart of OLT schedule is illustrated in Fig. 7. Here we define some parameters as follows: B_{remain} is remaining available bandwidth, $R^{total}_{sub-OLT}$ is sub-OLT total request bandwidth, R^{EF}_{i} is EF request bandwidth of ONU*i*. If the request bandwidth of each ONU EF traffic, $\sum_{i=1}^{n-1} R^{EF}_{i}$, is higher than $B_{available}$, the OLT will allocate the EF request bandwidth according to SLA for each ONU. The formula is illustrated as follows:

$$G^{EF}_{i,n+1} = \frac{ONU^{SLA}_{i}}{SLA_{total}} * B_{available} \qquad (2)$$

Otherwise, the OLT will satisfy the EF request bandwidth of each ONU firstly to avoid packet delay. The remaining bandwidth, B_{remain}, is described as follows:

$$B_{remain} = B_{available} - \sum_{i=l}^{n} R^{EF}_{i,n+l} \qquad (3)$$

If the total request bandwidth of sub-OLT, $R^{total}_{Sub-OLT}$, is lower than B_{remain}, the OLT will allocate bandwidth for sub-OLT according to the request bandwidth; otherwise, the OLT will compare the EF request bandwidth of sub-OLT with B_{remain}. If the EF request bandwidth of sub-OLT, $R^{EF}_{sub-OLT}$, is higher than B_{remain}, the OLT will grant B_{remain} to Sub-OLT; otherwise, the OLT will satisfy the EF request bandwidth of Sub-OLT firstly. The remaining bandwidth becomes as $B_{remain} = B_{remain} - G^{EF}_{sub-OLT}$.

B. Scheduling for the Sub-OLT

The sub-OLT is designated from one of the ONUs and its scheduling function is illustrated in Fig. 8. The sub-OLT includes two levels of scheduling. In the first level, it is constructed based on the Custom Queue and BE Queue for DiffServ mechanism. The AF traffic is stored in Custom Queue which includes System Queue, High-Priority Queue and Low-Priority Queue. The System Queue can improve

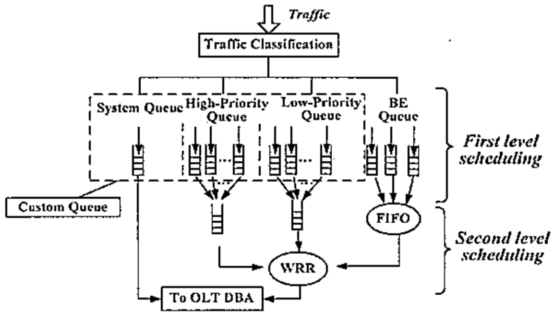


Figure 8. Scheduling function of Sub-OLT

packet delay for AF traffic and the BE traffic is most delay tolerant and it is stored in FIFO Queue. In the second level, it includes Weighted Round Robin (WRR) and FIFO Queue. Here, the main function of second level is WRR which is to allocate bandwidth according to the weight. When the queue length of Low-Priority Queue is higher than the assumed threshold, the differential ratio of WRR is based on Table II, to allocate bandwidth for each queue; otherwise, the WRR will satisfy the request bandwidth of High-Priority Queue and Low-Priority Queue firstly, and then satisfy the request bandwidth of FIFO Queue.

The flowchart of sub-OLT is illustrated in Fig. 9. If the remaining bandwidth, B_{remain}, is not higher than R_{SQ}^{AF}, the sub-OLT will allocate bandwidth for system queue according

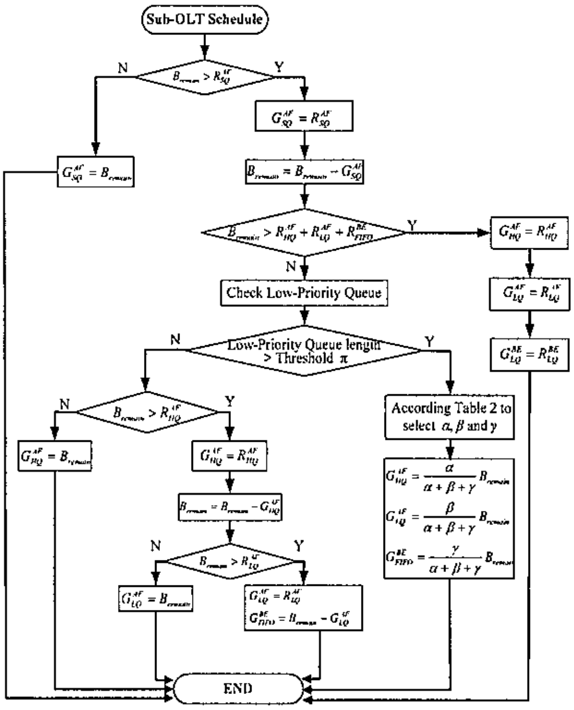


Figure 9. Flowchart of Sub-OLT

TABLE II. WEIGHTS OF QUEUE LENGTH BETWEEN BE AND AF

Queue length	α	β	γ
Threshold(π) < Queue length < 60%	7	2	1
60% < Queue length < 80%	6	3	1
80% < Queue length < 100%	5	4	1

to the remaining bandwidth; otherwise, the sub-OLT will satisfy the request bandwidth of system queue firstly, and the remaining bandwidth becomes $B_{remain} = B_{remain} - G_{SQ}^{AF}$.

Furthermore, the sub-OLT will compare the request bandwidth of High-priority Queue, Low-priority Queue and FIFO Queue with remained bandwidth, B_{remain}. If the request bandwidth of $R_{HQ}^{AF} + R_{LQ}^{AF} + R_{FIFO}^{BE}$ is not higher than B_{remain}, the sub-OLT will allocate bandwidth to each queue according to the request bandwidth; otherwise, if remaining bandwidth, B_{remain}, is lower than $R_{HQ}^{AF} + R_{LQ}^{AF} + R_{FIFO}^{BE}$, the sub-OLT will check the queue length of Low-priority Queue firstly. If the queue length of Low-priority Queue is higher than threshold, π, the granted bandwidth of High-priority Queue (G_{HQ}^{AF}), Low-priority (G_{LQ}^{AF}) and FIFO Queue (G_{FIFO}^{BE}) are according to the ratio of remaining bandwidth, B_{remain}, where α, β and γ are defined in Table II and shown as follows:

$$G_{HQ}^{AF} = \frac{\alpha}{\alpha+\beta+\gamma} B_{remain}$$
$$G_{LQ}^{AF} = \frac{\beta}{\alpha+\beta+\gamma} B_{remain} \qquad (4)$$
$$G_{FIFO}^{BE} = \frac{\gamma}{\alpha+\beta+\gamma} B_{remain}$$

Otherwise, if the queue length of Low-priority Queue is lower than threshold, π, the sub-OLT will compare the request bandwidth of High-priority Queue, R_{HQ}^{AF}, with remaining bandwidth, B_{remain}. If the remaining bandwidth, B_{remain} is lower than R_{HQ}^{AF}, the granted bandwidth becomes $G_{HQ}^{AF} = B_{remain}$; otherwise, the sub-OLT will satisfy the request bandwidth of R_{HQ}^{AF} firstly, and the remaining bandwidth becomes as $B_{remain} = B_{remain} - G_{HQ}^{AF}$.

Next, the sub-OLT will compare the request bandwidth of Low-priority Queue, R_{LQ}^{AF} with remaining bandwidth, B_{remain}. If the remaining bandwidth, B_{remain}, is lower than R_{LQ}^{AF}, the granted bandwidth becomes $G_{LQ}^{AF} = B_{remain}$; otherwise, the sub-OLT will satisfy the request bandwidth of R_{LQ}^{AF}. Finally, the sub-OLT will satisfy the request bandwidth of R_{FIFO}^{BE}.

III. PERFORMANCE ANALYSIS

TABLE I. SIMULATION SCENARIO

Number of ONUs	32
Number of wavelength	1
Upstream/downstream link capacity	1Gbps
OLT - ONU distance (uniform)	10-20*km*
ONU - ONU distance (uniform)	1*km*
Maximum cycle time	2*ms*
Guard time	5*us*
Control message length	0.512*us*

In this section, the system performance of the proposed D-DBA algorithm was analyzed by simulating under the scenario to make the differentiation on service level agreement (SLA) and ensure the quality of service (QoS). In this paper, the AF traffic of high priority ONUs (G1 group) was stored in *System Queue*. Otherwise, the AF traffic of low priority ONUs (G2 group) was stored in *High-priority Queue* and *Low-priority Queue*. We compare G1 and G2 groups to analyze the average end-to-end delay, throughput and EF jitter. The performance evaluation was examined by the OPNET simulation tool. One wavelength channel was adopted, and the link capacity was 1Gb/s. The distance from one ONU to the OLT was assumed to be 10-20 *km*, and each ONU had an infinite buffer and the service policy was first-in first-out. For the traffic model, an extensive study shows that most network traffic can be characterized according to self-similarity and long-range dependence (LRD). This model was adopted to generate highly bursty BE and AF traffic classes with the Hurst parameter of 0.7. The packet sizes were uniformly distributed between 64 and 1518bytes. Additionally, high-priority traffic (e.g. voice applications) was modeled by a Poisson distribution, and the packet size was fixed to 70bytes. In order to show the effect of high priority traffic, the proportion of traffic profile was analyzed by simulating the three significant scenarios, which was (20%, 40%, 60%) of the total generated traffic was considered for high-priority traffic, and the remaining (80%, 60%, 40%) was equally distributed between low- and medium-priority traffic respectively. The simulation scenario is summarized in Table III.

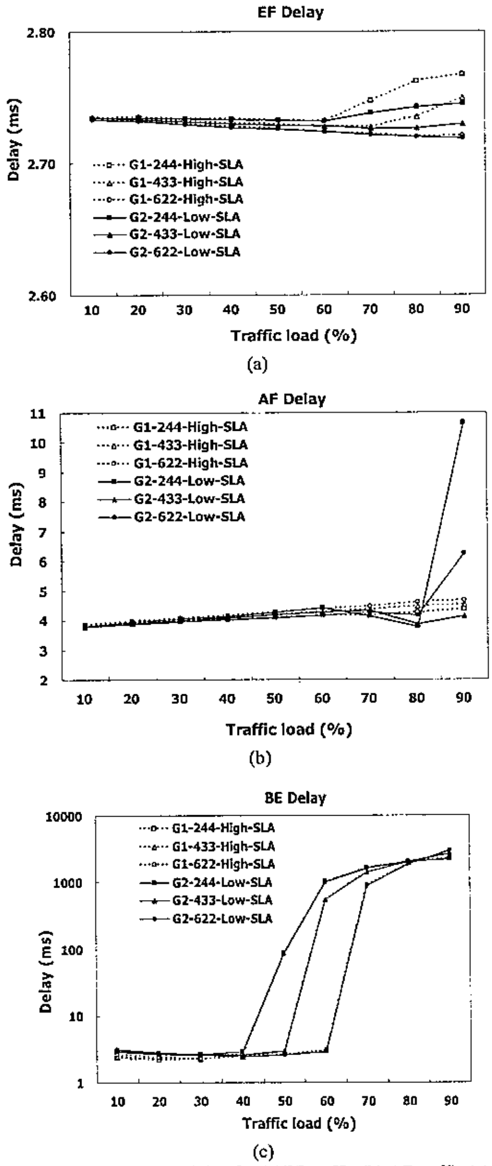


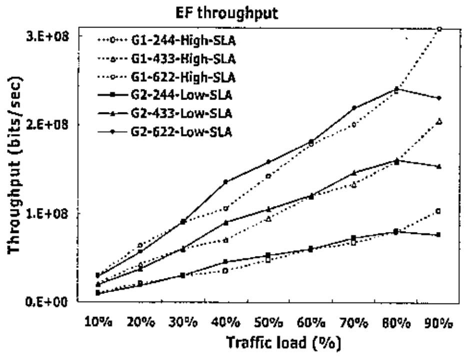
Figure 10. End-to-End delay for (a)EF traffic (b) AF traffic (c) BE traffic

A. End-to-End Delay

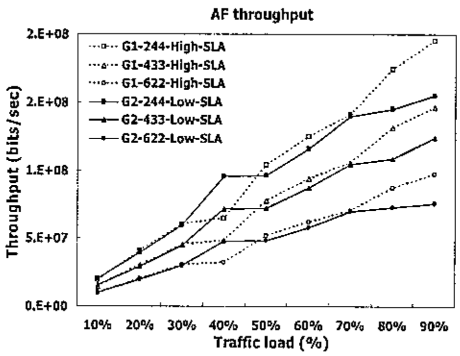
Figure 10(a) analyzed the average EF delay vs. traffic load among the G1 and G2 groups. Simulation results show that the average end-to-end packet delays for EF traffics keep in 2.7 *ms*, the reason is that the D-DBA algorithm will satisfy the EF request bandwidth of each ONU firstly. In Figure 10(b), we analyzed the average AF delay vs. traffic load among the G1 and G2 groups. In this case, the DBA algorithm will satisfy the AF request bandwidth of G1 firstly, which lead to the G1 outperforms the G2. In Figure 10(c), the results show that BE traffic for G1 and G2 are similar. However, the BE packet delay increased when the ratio of BE traffic rose.

B. Throughput

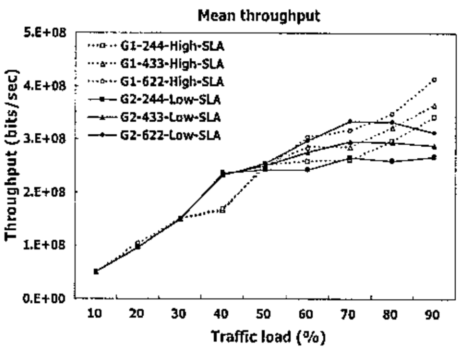
Figure 11 analyzed the average EF, AF and mean throughput vs. traffic load among the G1 and G2 groups. Simulation results show that the average throughput for EF traffics increased when the traffic load rose. In this case, the G1 throughput performance is similar to G2, the reason is that OLT will priority service the EF request bandwidth of each ONU no mater in G1 and G2 group. In the sub-OLT scheduling function, it allocates AF request bandwidth based on the service level agreement for each ONU. For the reason,



(a)



(b)



(c)

Figure 11. Throughput comparison between the G1and G2 (a)EF throughput (b) AF throughput (c) mean throughput

the G1 group can achieve more bandwidth than G2 group. Therefore, the G1 group outperforms the G2 group which was shown in Fig. 11 (b) and (c).

C. *EF Jitter Performance*

Figure 12 shows the comparison of the jitter performance for EF traffic among the G1 and G2 groups. Simulation result shows that the delay variance is decreased when the traffic load rise especially in the traffic scenario (60%, 20%, 20%). The reason is that the EF traffic always transmission

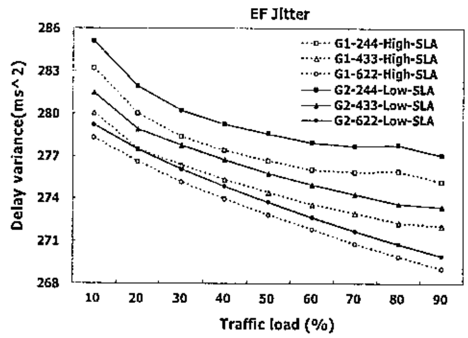


Figure 12. EF delay variance

in the beginning of the cycle time to reduce transmission jitter. Moreover, when the proportion of EF traffic (CBR) is increased, the network status tends to stabilize. On the other hand, when the traffic load increase the cycle time tends to stabilize which will lead to the jitter performance is improved in D-DBA mechanism.

IV. CONCLUSIONS

In this paper, we proposed a distributed Dynamic Bandwidth Allocation (D-DBA) mechanism to reduce idle period on EPONs system. The D-DBA operates on star-ring architecture that the highest priority traffic (EF) of each ONU is sent to OLT by tree structure, and the minor priority traffic (AF and BE) of each ONU are transmitted to sub-OLT by ring architecture. In the OLT side, the DBA mechanism will content with sub-OLT bandwidth request after EF bandwidth request for each ONU. The advantages of D-DBA mechanism are to reduce the idle period and overhead of OLT to improve the system performance of EPONs. The simulation results show that the proposed D-DBA mechanism can reduce the packet delay and packet delay variation for high priority ONUs to ensure Quality of Service (QoS).

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