Performance Assessment and Comparison between Star-ring based and Tree based EPONs

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Abstract—**In this paper, a meaningful star-ring based EPON architecture is proposed to reduce the local traffic transmitted from ONUs (Optical Network Units) to OLT (Optical Line Terminal) which can provide the bandwidth efficiency. One of ONUs is assigned as a Sub-OLT to control the partial traffic in the ring. In addition, the ONU structure is modified in all optical process to reduce the optical-electrical conversion delay. This paper proposes a star-ring dynamic bandwidth allocation (SR-DBA) scheme on star-ring based EPON, which the SDBA (star dynamic bandwidth allocation) in OLT responds all ONU's EF traffic and Sub-OLT's traffic by tree topology; and the RDBA (ring dynamic bandwidth allocation) in Sub-OLT handles all AF and BE traffics from each ONU circulated along the ring topology. Simulation results show that the proposed scheme bandwidth efficiency, and reduces traffic delay even system traffic in heavy loading.**

Index Terms—Star-ring EPON, SR-DBA, System performance.

I. INTRODUCTION

The Passive Optical Network (PON) technology, which features data deployment through passive components, has gained the most attention in the industry. It deploys a single optical fiber through a passive star coupler (PSC) to transmit signal to multiple premises, typically 16-128 optical network units (ONUs). There are no active components found in PON architecture between the optical line terminal (OLT) that resides in a Central Office (CO) and multiple ONUs; therefore, it is considered a great deployment advantage. Figure 1 shows a traditional tree-based PON structure.

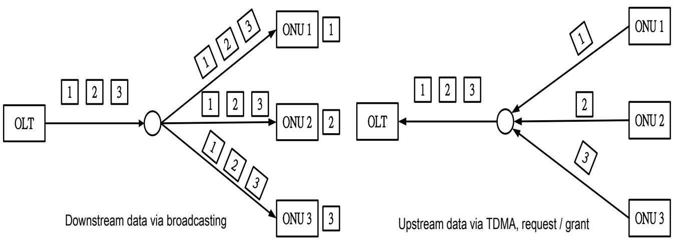

Figure 1 Tree-based EPON structure.

Ethernet Passive Optical Network (EPON) offers low deployment cost and high-speed broadband, thus making it a leading direction for broadband communication research. EPON can support downstream broadcast; data is broadcasted downstream from the OLT to multiple ONUs. Packets transmitted from the OLT go through a splitter before reaching multiple ONUs. When the data reaches the ONU, it accepts the packets that are intended for it and discards the packets that are intended for other ONUs. To avoid packets collisions, the upstream traffic of EPON utilizes Time-division Multiplexing (TDM), in which an ONU can only transmit packets in a dedicated time-slot. Due to the fundamental limitations (uplink shared by more than one ONU) of EPON, numerous dynamic bandwidth allocation (DBA) techniques [1,2,3] were innovated to enhance the efficiency of upstream traffic. The Interleaved Polling with Adaptive Cycle Time (IPACT) [1] mainly uses a polling scheme to deliver packets to the central OLT and then controls the allocation of bandwidth to ONUs based on the Gate and Grant/Request messages provided by the EPON Multi-Point Control Protocol (MPCP) mechanism in EPON. Bandwidth is allocated to each ONU according to the capacity indicated on the Service Level Agreement (SLA); this is also known as the limited bandwidth allocation (LBA). The drawback of LBA is low channel utilization; it is unable to reallocate excessive bandwidth from the lightly loaded ONUs to the other highly loaded ONUs. The excessive bandwidth reallocation (EBR) [2] is the solution to achieve higher channel utilization. It allows the remaining excessive bandwidth to be proportionally allocated to ONUs with those needs and resolves the transmission congestion. Nevertheless, it could also cause other issues when more bandwidth is allocated than demanded and/or the fairness of bandwidth distribution is being questioned [3]. In addition, based on the upstream mechanism of EPON, the OLT computes the bandwidth needed by each ONU upon receiving report message from each ONU. This polling mechanism, however, produces an idle period during each computation. Prediction-based bandwidth allocation may improve both fairness issues and idle period issues. On the other hand, under non-uniform or bursty of traffics, efficiency could be compromised because of inaccurate predictions **[4]**.

The traditional PON architecture is bounded by the nature of tree topology, where data must be transmitted from node to central node before it could be redirected to another node which causes performance waste. A ring-based EPON architecture [5] was proposed to overcome the performance issue between node to node because the ring topology provides only one pathway via the same feeder fiber between any two nodes. The numbers of ONU would be a problem in the ring topology because of the distance between ONU and OLT. Moreover, X.F. Sun *et al.* [6] proposes a star-ring network architecture that combines the benefits of tree-based and ring-based topology and offers protection capability for PON architecture. However, the DBA scheme was not discussed in this research.

We propose a bandwidth allocation algorithms for OLT and Sub-OLT in the star-ring architecture and the design ONU and Sub-OLT components of ring network in reference to [3] to ensure that data can be transmitted in the speed of light. This architecture utilizes the traditional tree-based structure within its network to transmit delay sensitive traffic with narrow-band nature. A problem in OLT DBA is the idle time problem in the traditional DBA, as indicated in Figure 2. OLT starts to execute the DBA after it gets all of the ONUs report messages. In addition, it utilizes ring architecture to transmit EF traffic between ONU and all AF and BE traffics to OLT [7]. In ring architecture, data transfer between ONUs accounts for a significant proportion of the traffic. Without an appropriate Sub-OLT DBA that provides higher transmission efficiency, both inefficiency and waste of bandwidth may become issues.

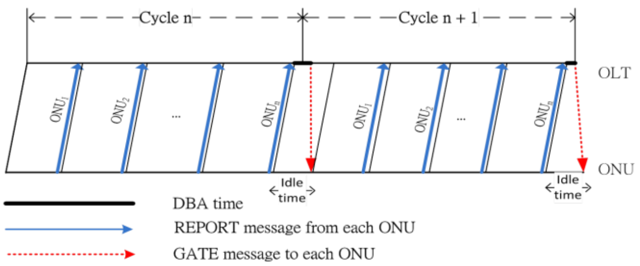

Figure 2 traditional DBA.

The DBA within [5] operates in a ring topology, where OLT controls and dedicates time slot according to the grand/report messages provided by MPCP mechanism on EPON. Report message and data transmitted by ONU are transferred or exchanged from one ONU to the next in a ring, hence, every ONU receives Report message and data frame of other ONUs. The action of data transfer by any ONU will prompt a DBA algorithm to secure the time slot for the next cycle in order to avoid data collision. In other words, the next uplink bandwidth is predicted based on the current needs in the ring and the need of that ONU. A report message will always be placed before the data transmission when any ONU uploads data for transmission to eliminate idle period. This architecture is extremely suitable for local traffic. However, it is inefficient for situations where large volume of outbound data transmission is required.

The method we propose can improve the issues generated in [5,6,7] by categorizing different classes of traffics. The EF traffic of each ONU is sent by tree structure, and AF and BE traffic of each ONU are transmitted by ring architecture. This architecture can enhance the efficiency of transmission between ONUs and distinguish inbound and outbound traffic as well as use feeder fiber to achieve protection function. It is able to improve the utilization efficiency of all classes of traffic in the entire ring.

The rest of paper is organized as follows. Section II describes the proposed scheme which including architecture and DBA. Section III presents the simulation results. Finally, Section IV gives the conclusions of this paper.

II. PROPOSED SCHEME

A. *Architecture*

We propose a star-ring architecture, as indicated in Figure 3, which includes an OLT, some ONUs and one of ONUs is assigned as a Sub-OLT. The EF traffic is transmitted by traditional tree structure. The OLT broadcasts the downstream traffic to each ONU through passive star coupler. For upstream traffic, the OLT designates the uplink time slot to each ONU then respectively uploads the ONU EF traffic through upstream process. The AF and BE traffics are uploaded through Sub-OLT in a single-direction ring, which connects ONUs in a ring topology. Upon receiving the outbound AF and BE traffics from ONU and/or EF traffic in the ring, Sub-OLT uploads the traffic to OLT. For inbound traffic, the Sub-OLT takes the processed traffic and downstream it to the ring for transmission. In order to accomplish the architecture, we need to enhance the functions of ONUs and sub-OLT.

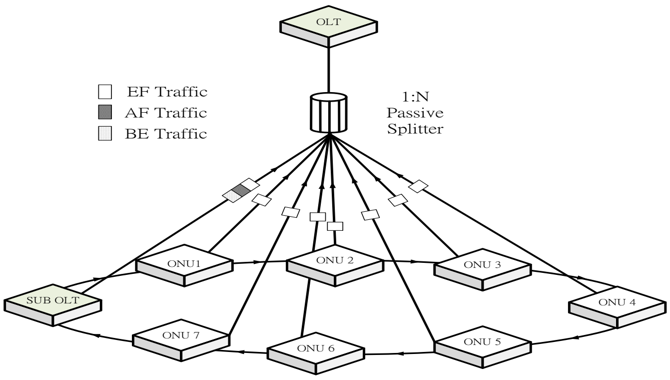

Figure 3 Proposed Star-ring Architecture.

1) *ONU*

Figure 4 shows a hybrid ONU operation which is an important component of star-ring architecture. The upstream and downstream traffics are routed in the ring at wavelength of 1310nm and 1490nm, respectively. When a single direction ring connects to ONUs, downstream (1490nm) and upstream (1310nm) signal enter into incoming port. At this time, a 1x3 splitter is used in ONU to triplicate the signal. The first copy of the signal ONU received is traffic belongs to itself; the signal goes through a filter to filter out the downstream (1490nm) traffic, which is then processed through optical-electrical conversion. The second copy of the signal also goes through a filter to filter out the upstream (1310nm) traffic. It is possible that traffic could be transferred from another ONU to current ONU via the upstream process in the ring thus obtaining the traffic transmitted by another ONU through this method. The last copy of the signal goes through the component CWDM. For the downstream traffic, it will directly connect to another

CWDM (by pass). For the upstream traffic, it will be combined with the 1310nm traffic which the original ONU is expected to upload through a 2x1 coupler. And then, the traffic goes through CWDM to transfer the bypassed downstream traffic to the ring. The EF traffic in the ONU is uploaded through tree topology on the ONU's right hand side.

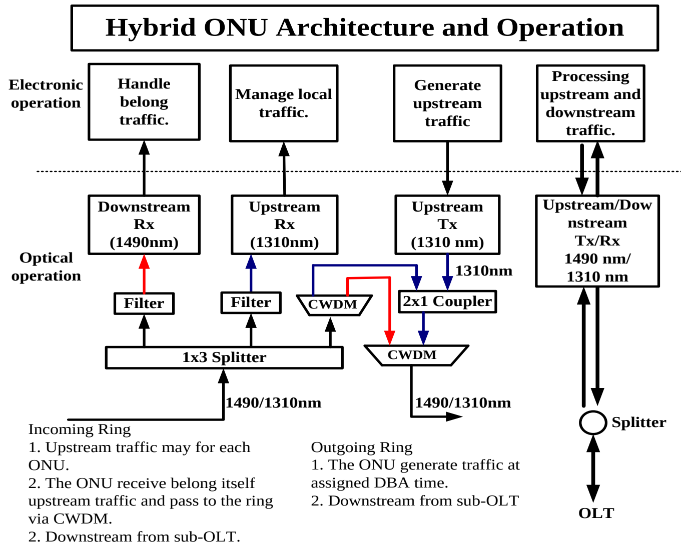

Figure 4 Hybrid ONU architecture and operation.

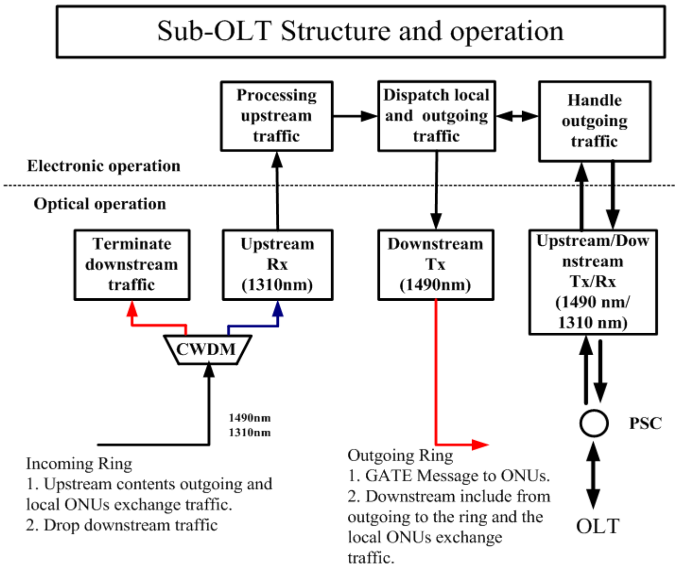

Figure 5 Sub-OLT structure and operation.

2) *Sub-OLT*

Components of Sub-OLT can be divided into two sections shown in Figure 5:

(1) Tree section: Uplink of EF traffic is managed by traditional tree structure; traffic is uploaded to the OLT by each ONU and Sub-OLT, respectively.

(2) Ring section: Since star-ring architecture features single-direction route, incoming and outgoing interfaces exit in the traffic uploaded on Sub-OLT. When traffic from ring comes into the Sub-OLT, the upstream traffic (1310nm) and downstream traffic (1490nm) will be filtered, respectively, by CWDM. If the downstream traffic has reached the end node of ring, it will be dropped. For the portion of the downstream traffic that has gone through an optical-electrical conversion and belongs to traffic of ring, it will go through another optical-electrical conversion. If the optical-electrical converted downstream traffic is not ring traffic, it will be transmitted to OLT through tree topology.

B. *Dynamic Bandwidth Allocation (DBA)*

In this section, we will discuss the SR-DBA (star-ring dynamic bandwidth allocation) in our proposed architecture has two parts: SDBA (star dynamic bandwidth allocation) for tree side executed in the OLT, and RDBA (ring dynamic bandwidth allocation) for ring side executed in the Sub-OLT.

1) *SDBA (star dynamic bandwidth allocation) in OLT*

In the proposed architecture, ONU transmits upstream data on a different time slot by time-division multiplexing (TDM) to avoid collision. Since each ONU has different requests, fixed time slot for uploading will lead to waste of bandwidth and insufficient bandwidth. Another problem is the idle time we have mentioned in the previous section. To solve these concerns, we propose an operation framework for the SDBA that the OLT manages EF traffic of each ONU and traffic of Sub-OLT by traditional tree structure. Each ONU will upload EF traffic and report message at given time slots. Since EF traffic has priority over other traffics (AF and BE), we will give each ONU the priority to upload EF traffic when scheduling time slot through SDBA. The remaining time will be served for AF and BE traffics in Sub-OLT. Upon receiving the EF traffic lastly loaded, SDBA begins to compute the upload time for next cycle. At the same time, Sub-OLT is given the remaining time to upload data. By the time when data upload completes, the ONUs should also have received the upload allocation grant for the next cycle, as indicated in Figure 6. This operation framework will effectively resolve the idle period issue and reduce the extra idle time generated during DBA computation.

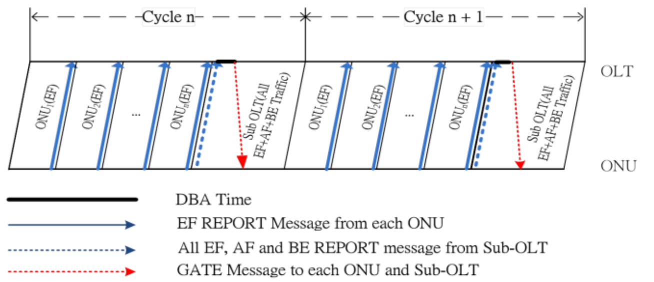

Figure 6 Star dynamic bandwidth allocation (SDBA) in OLT.

2) *RDBA (ring dynamic bandwidth allocation) in Sub-OLT*

Figure 7 Shows the RDBA scheme. In the proposed ring-architecture, the data transmitted is uni-direction via channel (1310nm) at the same feeder fiber. All ONUs send report messages to Sub-OLT at same time; if one of ONUs wants to send report message to the Sub-OLT, the signal will pass around ONUs and drops at the Sub-OLT. When signal arrives at the next ONU, the next ONU data already send to next and next ONU. So far, Sub-OLT receives all ONU report messages in short time without collision. After each ONU report message has been transmitted, each ONU traffic will send behind the report message. However, the proposed Sub-OLT scheme will reduce idle period time during Sub-OLT receives all ONU report message and computation.

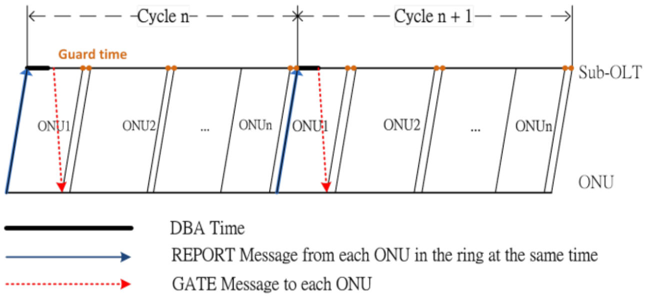

Figure 7 Ring dynamic bandwidth allocation (RDBA) in Sub-OLT.

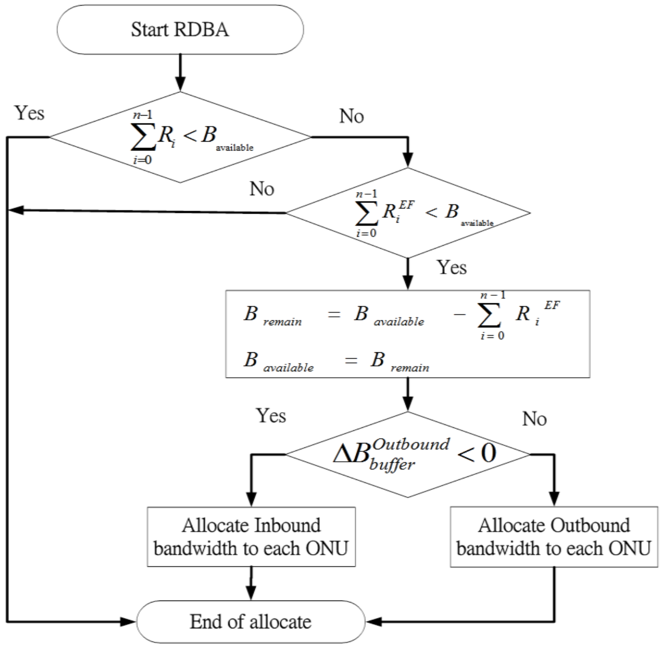

Figure 8 RDBA flow chart.

The proposed RDBA can pre-determine the available bandwidth. When available bandwidth is sufficient to support the request of all ONUs, RDBA will allocate the satisfied time slots to each ONU. In the contrary, when available bandwidth is not sufficient, RDBA will allocate available bandwidth to EF traffic as priority. The remaining available bandwidth will be recomputed for AF and BE traffics. Meanwhile, the RDBA will observe the status of outbound buffer. If the amount of data in outbound buffer continuous to decrease, it means the request for outbound bandwidth is reducing. When the outbound bandwidth decreases, RDBA will determine whether or not to prioritize the bandwidth allocation for inbound traffic. If the available bandwidth is insufficient to support AF or BE inbound traffics, the RDBA will end the process. If the amount of data in outbound buffer continues to escalate, it represents that there is an increasing need for outbound bandwidth. Consequently, the RDBA will allocate the remaining available bandwidth to outbound traffic, which is also classified as AF and BE. If the available bandwidth is insufficient to support AF or BE outbound traffic, the RDBA process will also end as indicated in Figure 8.

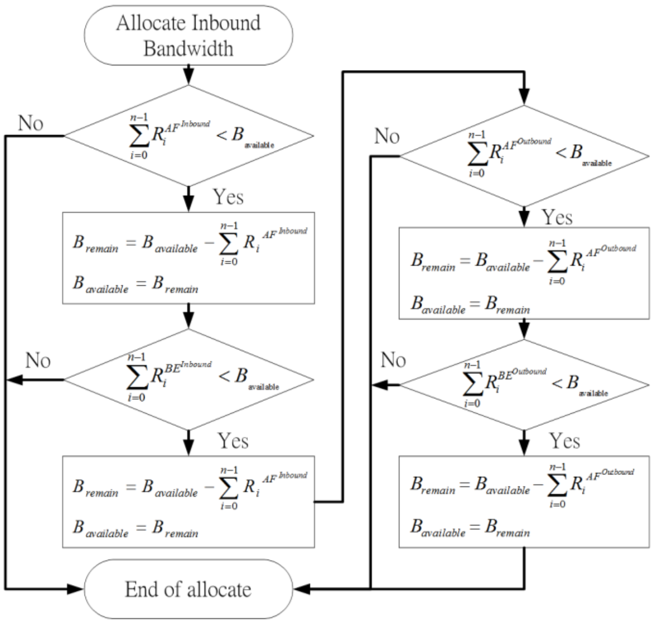

Figure 9 Allocate Inbound Bandwidth flow chart.

Figure 9 illustrates the detail of Sub-OLT allocates the inbound bandwidth algorithm. In this proposed algorithm, Sub-OLT allocates the inbound bandwidth to all ONU which includes the AF and BE traffic requests, respectively. If remaining bandwidth is sufficient, Sub-OLT will allocate outbound bandwidth request from all ONUs continually. Finally, each ONU will be assigned an upload time totally based on report message.

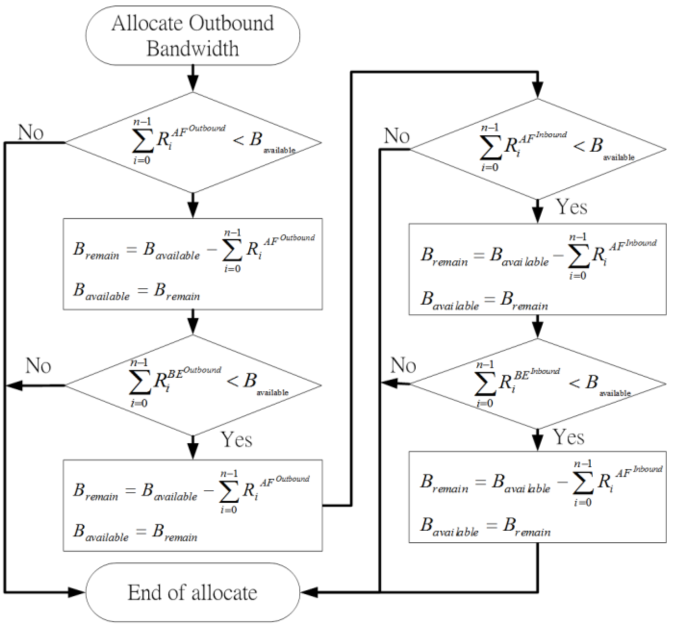

Figure 10 Allocate Outbound Bandwidth flow chart.

Figure 10 illustrates the detail of Sub-OLT allocates the outbound bandwidth algorithm. In this proposed algorithm, the Sub-OLT allocates the outbound bandwidth to all ONUs including the AF and BE traffic requests, respectively. If the remaining bandwidth is sufficient, Sub-OLT will allocate the inbound bandwidth request from all ONUs continually. Finally, each ONU will be assigned an upload time totally based on report message.

III. PERFORMANCE ANALYSIS

TABLE I. SIMULATION SCENARIO

Number of ONUs	32
Upstream/downstream link capacity	1*Gbps*
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* (*64 bytes*)
Sub-OLT/ONU buffer Size	10*MB*
Simulation Time	12 *seconds*

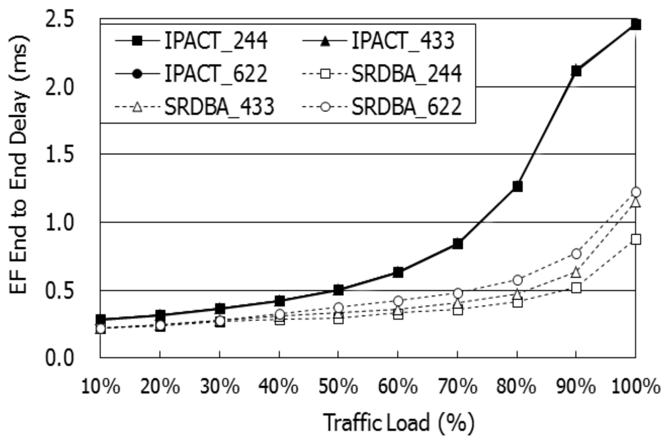

Figure 11 EF End to End Delay (ms).

The performance evaluation shows the comparison between SR-DBA and IPACT [6]. The simulation scenario is shown in Table I. In this scenario, generating portion of EF, AF and BE traffics are assumed as 20%, 40% and 40% (2,4,4), respectively. However, we also have more different traffic percentage including 40%, 30% and 30% (4,3,3) and 60%, 20% and 20% (6,2,2), respectively. In Figure 11, it demonstrates that the SR-DBA EF end to end delay is always lower than the delay found in IPACT scheme. The SR-DBA remains steady even when near 80% traffic loading.

In the SR-DBA, the AF traffic is transmitted to Sub-OLT via ring topology. After Sub-OLT receives the gate message from OLT, the Sub-OLT transmits these AF traffic to the OLT which, means that the SR-DBA scheme will increase more delay time for AF traffic. In Figure 12, the IPACT is better than the SR-DBA in terms of AF End-to-end delay when the traffic loading is under 70%. The reason is that the SR-DBA transmits AF and BE traffics through the ring structure; unlike IPACT, transmitting to the OLT directly. However, when loading is higher than 80%, the proposed SR-DBA will be more steady and better than the IPACT.

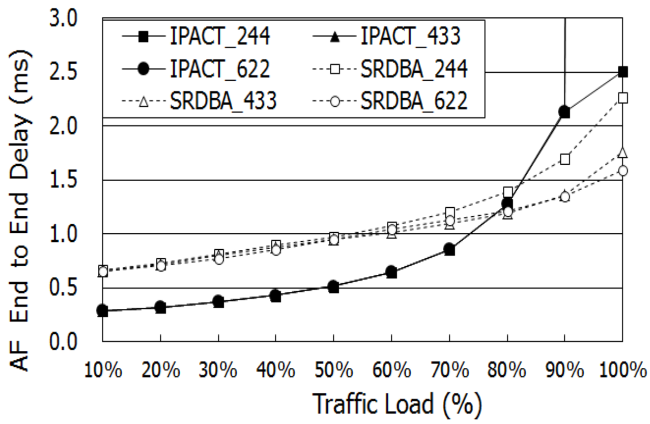

Figure 12 AF End to End Delay (ms).

In Figure 13, the SR-DBA is better when the traffic loading exceeds 80%. The BE traffic has the lowest priority amongst traffics transmitted through the ring in the proposed algorithm. When loading is 100%, the SR-DBA is still stable and has lowest delay in comparison with the IPACT.

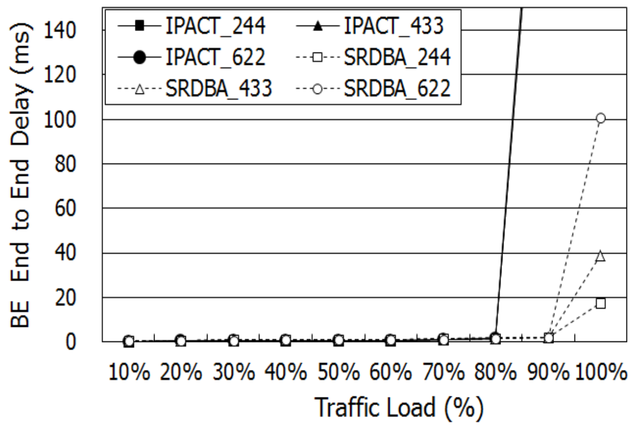

Figure 13 BE End to End Delay (ms).

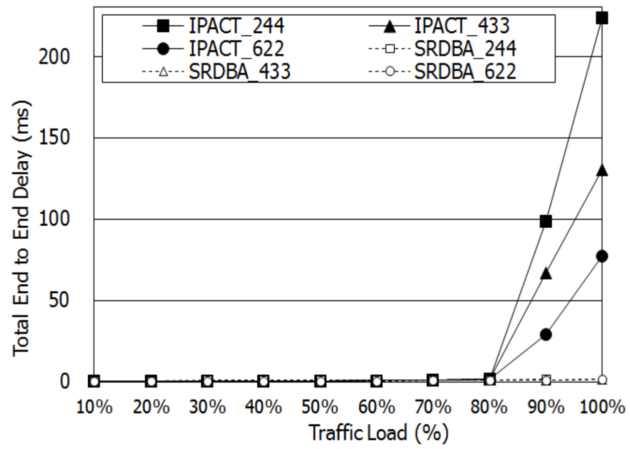

Figure 14 Total End to end delay.

Figure 14 shows the average delay of EF, AF and BE traffics. The IPACT is less efficient than the SR-DBA when traffic load is higher than 80%. The reason is that BE traffic end to end delay is lower than the SR-DBA at traffic loading is over 80%.

In Figure 15, we can see that the IPACT gets the similar results in traffic distribution 244, 433, and 622. It is just like EF end to end delay which we discussed in 3.1.1; however, the IPACT is unsteady. Our algorithm has better system performance in overall situation. It generates better results and steady even when traffic load is heavy.

Figure 16 is the comparison of drop probability. The SR-DBA separates the traffic into two parts that the EF to OLT and the BE to Sub-OLT. The simulation result is better and the ONU queue buffers will share the load by these two channels. In the IPACT, some BE packets will be dropped when the loading is over 90%; moreover, dropping rate will be extremely high at 100% full load.

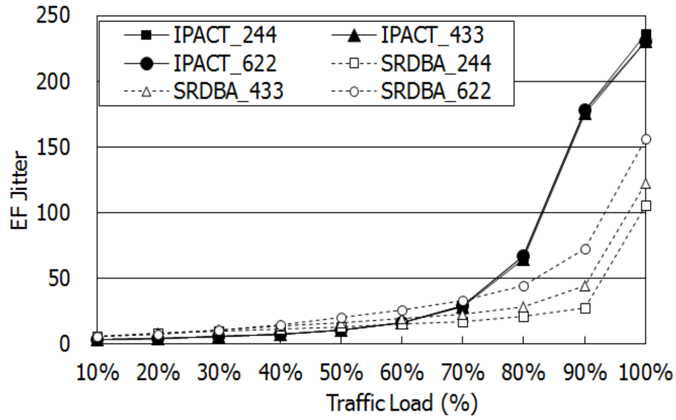

Figure 15 EF Jitter.

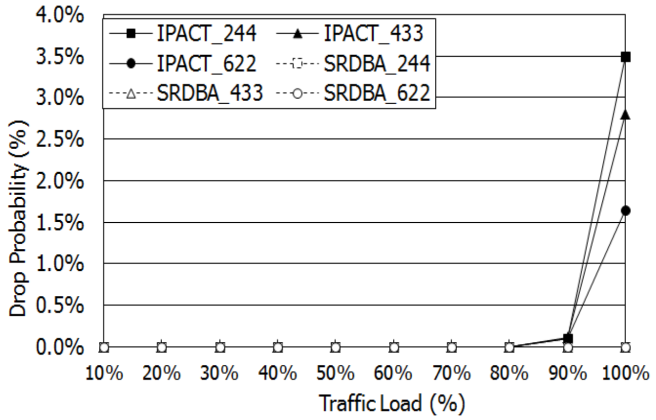

Figure 16 Drop probability.

IV. Conclusions

In this paper, a meaningful star-ring based EPON architecture is proposed to reduce the local traffic transmitted to OLT and enhance bandwidth efficiency. This research also proposed a Sub-OLT component to control the partial traffic in the ring. In addition, we modify the ONU structure in all optical process to reduce the optical-electrical conversion delay. 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 to ensure Quality of Service (QoS). In this paper, we proposed a Sub-OLT DBA in Star-Ring architecture. By improving the components of ONU, the SR-DBA work successfully. The aims of this paper are to improve the end to end delay, jitter, and system performance, lower the block probability and enhance the performance between ONUs.

Acknowledgment

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