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Polling Cycle Time Analysis for Waited-based DBA in GPONs

I-Shyan Hwang, Jhong-Yue Lee, Tzu-Jui Yeh

Abstract—**As broadband access is evolving from digital subscriber lines to optical access networks, the Gigabit Passive Optical Network (GPON), can provide huge bandwidth capacity, low cost, simple architecture and easy maintenance, have emerged as one of the most promising access network technologies for future last-mile solutions. To prevent data collision and ensure efficient transmission, the point-to-multipoint topology of GPONs requires a time-division media access control (MAC) protocol to allocate the shared resource of a common upstream transmission medium. Therefore, Dynamic Bandwidth Allocation (DBA) is an open and hot topic in the GPON. However, most proposed DBA plans to ignore the impact of the maximum cycle time for Quality of Service (QoS) ensures maximum delay and jitter of real-time traffic, uplink bandwidth utilization, drop probability and fairness in GPON upstream transmission. In this paper, we propose a Waited-based Dynamic Bandwidth Allocation called WDBA which is predict the arriving real time packet based on the proportion of waiting time for multiple services over GPONs. In addition to ensuring the quality of QoS, our work focus on the fundamental problem of trading-off between upstream channel utilization and maximum polling cycle time with different proportion of Traffic Containers (T-CONTs) traffic in a GPON with multiple ONUs and verify the accuracy of the analysis with simulations. Overall, our numerical results indicate that the packet delay, throughput and drop probability performance is better when the polling cycle time is longer; the fairness is better when the polling cycle time is shorter.**

Index Terms—**Gigabit Passive Optical Network (GPON), Dynamic Bandwidth Allocation (DBA), Quality of Service (QoS), Polling Cycle Time, Waited-based Dynamic Bandwidth Allocation (WDBA).**

I. Introduction

The Gigabit Passive Optical Networks (GPONs) [1] have been widely considered as the best candidate for next-generation access networks since it represents the high bandwidth, increased flexibility, broad area coverage, higher splitting ratios, and economically viable sharing of the expensive optical links. GPON consists of an optical line terminal (OLT) located at the provider central office (CO) and connect to a number of optical network units (ONUs) at the customer premises by a single splitter/ODN, as illustrated in Figure 1.

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Currently, GPON supports several bit rates in both channels such as asymmetric or symmetric combinations, from 155 Mb/s to 2.5 Gb/s. In downstream, The GPON OLT connects all ONUs as a point-to-multipoint (P2MP) architecture, the OLT transmits encrypted user traffics over the shared bandwidth by broadcasting through the 1:N splitter/ODN on a single wavelength (e.g. 1490 and 1550 nm). In upstream, a GPON is a multipoint-to-point (MP2P) network. All ONUs transmit their data to the OLT on a common wavelength (e.g. 1310 nm) through the 1:N passive combiner. The main problem in the link layer of PON networks is occurred in upstream direction, as all users share the same wavelength, and a medium access control protocol (MAC) is necessary to avoid collisions and efficiently allocate uplink access between packets from different ONUs [2]. Therefore, the time division multiple access (TDMA) [3] is be used to provide shared high-bit-rate bandwidth. In a TDMA scheme, time is divided into periodic cycles, and these cycles are divided into as many time slots as the number of ONUs which shares the channel. As a result, each slot is dedicated to one ONU and every cycle is organized in such a way that one slot transports packets from one ONU periodically. Meanwhile, GPON OLT supports dynamic broadband algorithm (DBA), making the distribution of available bandwidth to ONU more flexible. They adapt network capacity to the traffic conditions by changing the distribution of the bandwidth assigned to each ONU depending on the current requirements.

The downstream frame format is a fixed frame of 125 us. This frame periodicity assures the global synchronization of the whole system. Besides, the upstream frame has the same length and can contain information of several ONUs. Each upstream frame contains at least the Physical Layer Overhead upstream (PLOu) field. Besides the payload, it may also contain the physical layer operation and administration and

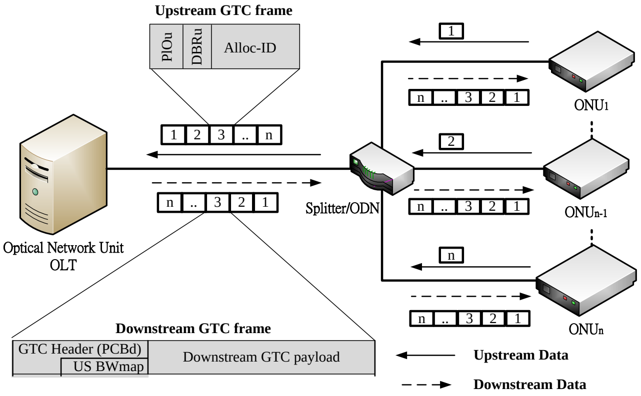

Fig. 1. GPON Architecture.

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management upstream (PLOAMu), the power leveling sequence upstream (PLSu), and the dynamic bandwidth report upstream (DBRu) sections. Furthermore, the GPON specification defines three ways in which one ONU can inform the OLT about its status: sending piggy-backed reports in the upstream DBRu field, using status indication bits in the PLOu field, or including an optional ONU report in the payload. On the other hand, the downstream frame consists of the physical control block downstream (PCBd) field, the ATM partition, and the GPON encapsulation method (GEM) partition. The OLT sends pointers in the PCBd field, each of them indicating the time at which each ONU starts and ends its upstream transmission. This performance allows that only one ONU can access the shared channel at the same time.

The FSAN once seek to control each different traffic stream by means of the MAC protocol to be able to affect the SLA and provide the required quality per user and stream for the QoS support. To the end, logically separate queuing is employed for each flow in each different ONU down to a fine level of resolution. The QoS class is determined by assigning each queue, such as Alloc-ID, to one of five traffic containers (T-CONTs) that follow different service policies [4]: T-CONT1 is based on unsolicited periodic permits granting fixed payload allocations. This is the only static T-CONT not serviced by DBA. T-CONT2 is intended for VBR traffic and applications with both delay and throughput requirements. The availability of bandwidth for the service of this T-CONT is ensured in the SLA, but this bandwidth is assigned only on request to allow for multiplexing gain. T-CONT3 is intended for better than best effort services and offers service at a guaranteed minimum rate; any surplus bandwidth is assigned only on request and availability. T-CONT4 is intended for purely best effort services, and as such is serviced only on bandwidth availability up to a provisioned maximum rate. T-CONT5 is a combined class of two or more of the other four T-CONTs to remove from the MAC controller specification of a target T-CONT when granting access.

Some papers have been investigated the general properties of GPON. The greatest attention is devoted to QoS guarantee by dynamic bandwidth allocation in upstream. Nevertheless, service providers almost always utilized dynamic bandwidth allocation. There is not sufficient attention paid to investigation of an influence of this bandwidth allocation on various period cycle time behaviors. Therefore, we decided to investigate the properties of maximum polling cycle time in case of dynamic bandwidth allocation. Concretely, some key QoS parameters will be observed, i.e. packet delay, jitter, throughput, drop probability and fairness.

Here we focus on an impact of different maximum polling cycle time on QoS parameters in GPON. The allocated bandwidth will be shared between difference maximum polling cycle time and proportion of T-CONTs traffic. The rest of the paper is structured as follows. Section II introduces the Dynamic Bandwidth Allocation for GPON system and section III presents the Waited-based Dynamic Bandwidth Allocation (WDBA) with theoretical explanations. Performance evaluation and detailed analyses are presented in Section IV. Final section concludes the paper and defines future works.

II. Dynamic Bandwidth Allocation for GPON System

In the GPON system, there are two forms of DBA process algorithms, which are Non Status Reporting (NSR) and Status Reporting (SR) operation, the GPON standard provides the tools to implement DBA and leaves the actual bandwidth allocation scheme open to different implementations. In NSR DBA, the OLT continuously monitor idle frames and surmise traffic status to allocate a small amount of extra bandwidth to each ONU. ONUs do not provide explicit queue occupancy information. Instead, the OLT estimates the ONT queue status, typically based on the actual transmission in the previous cycle. For example, if the OLT observes that a given ONU is not sending idle frames, it increases the bandwidth allocation to that ONU, otherwise, reduces its allocation accordingly. Therefore, NSR ONUs underutilize link capacity, since they do not inform queue occupancy to the OLT as well as traffics in the access network are bursty. NSR DBA has the advantage that it imposes no requirements on the ONU, and the disadvantage that there is no way for the OLT to know how best to assign bandwidth across several ONUs that need more. In SR DBA, All ONTs report their upstream data queue occupancy, to be used by the OLT calculation process. Each ONT may have several T-CONTs, each with its own traffic class. By combining the queue occupancy information and the provisioned SLA of each T-CONT, the OLT can optimize the upstream bandwidth allocation of the spare bandwidth on the PON. For all of these reasons, an efficient DBA algorithm should be SR DBA for GPON system. Therefore, in this paper, the status reporting is employed, which deals with the bandwidth allocation providing more powerful advantages.

The IEEE 802.3ah Task Force (EPON) developed the multipoint control protocol (MPCP), which controls the communication between the downstream and the upstream channels. GPON systems use a SR DBA mechanism equivalent to EPON system. Therefore, the implementation of a dynamic bandwidth assignment requires the use of the MPCP protocol to distribute the upstream available bandwidth to each ONU. The MPCP protocol is implemented in the MAC layer located inside the OLT and uses five control messages. Among them, two control messages, called Report and Gate, arbitrate the communication between the OLT and the ONUs to assign bandwidth to each of them. In this protocol, the OLT polls ONUs for their queue status and grants bandwidth using the MPCP GATE message, while ONUs reports their status using the MPCP REPORT message [5] and the length of the upstream bandwidth units is not fixed, but dynamically calculated depending on the applied DBA algorithm. In general, ONUs reports the backlog data at the T-CONTs to the OLT in the REPORT control messages at the front of every T-CONT transmission window frame. The calculation of the bandwidth assignment can start once all the REPORT messages have been received. Once the bandwidth assignment and scheduling is completed, GATE messages according to the updated assignment time slot are broadcasted to the T-CONTs, whereby data transmission according to the next cycle frame can proceed. Moreover, ONUs receive GATE message including when and which T-CONT transmits traffic data to the OLT. Figure 2 shows a schematic view of the GPON SR DBA process with the OLT-ONU

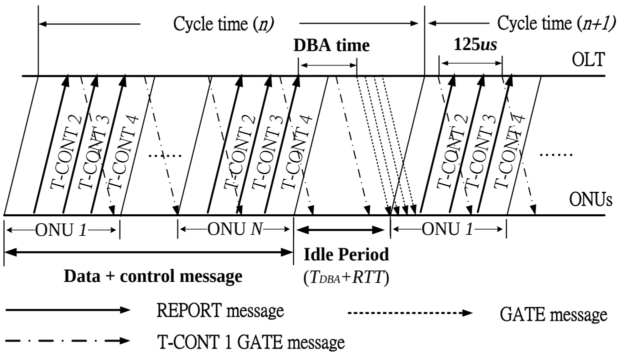

Fig. 2. Idle period issue in a GPON SR DBA polling scheme.

communication resulting in an updated bandwidth assignment.

In general, because of the non-negligible DBA execution time and round-trip time leading the idle period problem in GPON. As shown in Figure 2, the *idle period* is given by

$$Idle\ Period = T_{DBA}+RTT, \quad (1)$$

where RTT is the round-trip time from ONU to OLT and T_{DBA} is the processing time of the DBA algorithm. To elaborate, the idle period is sum of computation time of DBA and the round trip time between OLT and each ONU (N.B. ONUs cannot transmit data during the idle period). Hence, for the DBA scheme, reducing the idle period becomes one of the main challenges issues to address in order to improve bandwidth utilization. Moreover, status report information from an ONU may be outdated will causing another problem - *queue state inconsistency* due to packets that continue to arrive during this waiting time. In a detailed, each ONU experiences a waiting time between sending the REPORT message and sending the buffered frames. Consequently, packets that arrive during the waiting time and transmission time, have to be delayed to the next transmission cycle, potentially leading to stupendous packet delay and delay jitter. The above problems are even worse in Next Generation PON (NG-PON) owing to increased upstream rates and distances between OLT and ONUs. In order to decrease packet delay and improve overall fairness, predictive schemes can be used so that traffic arrival during the waiting time and transmission time is taken into consideration.

To date, in order to decrease packet delay and improve overall fairness, various prediction-based DBA algorithms have been proposed for GPON networks. In the prediction-based DBA algorithms, the extra bandwidth will be allocated to each ONU for the next cycle ($N+1$), the current bandwidth demand in cycle N should be takes into consideration. The assigned bandwidth for the next cycle is calculated by ONU request bandwidth demand plus a prediction term based on the algorithms of each scholars, it may be the constant credit-based [6-7], linear credit scheme [8-10], class-based[11-13] etc. However, most of the above proposals are aware of the fact that delay sensitive traffic should be treated in a specialized manner within the OLT DBA stage. Nevertheless, these schemes do not address the investigation of an influence of this bandwidth allocation on various period cycle time behaviors. In this paper we propose a Waited-based Dynamic Bandwidth Allocation (WDBA) mechanism that uses a different granting scheme for GATE messages to improve QoS support by predict the arriving packet based on the proportion of waiting time and history request bandwidth for multiple services over GPONs. Moreover, the WDBA is adapted to variable scheduling frame size and guarantees a minimum bandwidth for each ONU in every polling cycle and observe that the impact between upstream channel utilization and maximum polling cycle time with different proportion of T-CONT traffic in a GPON.

III. Waited-based Dynamic Bandwidth Allocation Mechanism

The motivation of this paper is to resolve the *idle period problem* and *queue state inconsistency* to improve the uplink bandwidth utilization, reduce the packet latency, and provide better QoS guarantee, regardless of the environment that whether the uplink is under different traffic load and proportion of T-CONT traffic. Moreover, this work focus on the fundamental problem of trading-off between upstream channel utilization and maximum polling cycle time in a GPON system. To achieve this goal, the proposed WDBA scheme, combined the waited-based prediction scheme with Limit Bandwidth Allocation (LBA) and Excess Bandwidth Allocation (EBR) scheme, applies service level agreement (SLA) scheduling policy[7] at each ONU to guarantee Quality of Service (QoS) ensures maximum delay and jitter of real-time traffic, uplink bandwidth utilization, drop probability and fairness in GPON upstream transmission. At the same time, an interleaved scheduling is also introduced, which is our previous work [13] to support different services and the different classes of service require differential performance bounds. The interleaved scheduling can not only resolve the idle period problem caused by MPCP protocol scheduling policy- “grant after report”, but also reduce the packet delay and increase the fairness between heavily-loaded ONUs and lightly-loaded ONUs. Moreover, this paper focus on the relationship between the maximum cycle time and the system performance, instead of only to the QoS as the traditional DBA scheme does. The WDBA mechanism is detailed as follow.

A. *Interleaved Scheduling of WDBA*

The interleaved scheduling of WDBA is proposed to resolve the idle period problem and improve bandwidth utilization by using bi-partition groups transmission. The interleaved scheduling algorithm divides one transmission cycle time into two groups and dynamically adjusts the bandwidth between the first group and the second group to execute interleaved transition to resolve the traditional idle period problem. The first group and the second group will be performed in accordance with the number of the ONU evenly. Moreover, the T-CONT 1 traffic is transmitted with guaranteed fixed bandwidth allocation for time-sensitive applications, and the T-CONT 2 traffic is transmitted with prediction mechanism for the guaranteed assured bandwidth allocation and not time-sensitive applications to alleviate queue state inconsistency problem; recycling the remaining bandwidth from the first group for the second group to obtain maximum performance.

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B. Dynamic Bandwidth Allocation of WDBA

The WDBA mechanism is proposed to resolve the idle period problem, and enhance the QoS for differentiated services and improve bandwidth utilization by using prediction, LBA and EBR in the GPON system. The flowchart of the WDBA mechanism is illustrated in Figure 3, after receiving whole REPORT messages from each ONU, the total available bandwidth B_{av} can be calculated as $r \times (T_{Cycle}^{Max} - N \times T_g) - N \times 16$, where r is the transmission speed of the GPON in bits per second, T_{Cycle}^{Max} is the maximum cycle time, N is the number of ONUs, T_g is the guard time and the control message length is 16bits (2Byte) [1] for the GPON system. Initially, the available bandwidth for each group and the minimum guaranteed bandwidth ($B_{min}= B_{av}/N$) for ONU$_i$ are evenly distributed. After calculating minimum guaranteed bandwidth threshold, the WDBA executes the prediction mechanism based on the proportion of waiting time, historical and current traffic status information, which is expressed in equation (2).

$$\begin{cases} P_{T2} = R_i^{T2} + (\overline{H_i^{T2}} \times (T_{waiting,i} \div T_{cycle,i})) \\ P_{T3} = R_i^{T3} + (R_i^{T3} - \overline{H_i^{T3}}),\ R_i^{T3} - \overline{H_i^{T3}} > 0 \\ P_{T4} = R_i^{T4} + (R_i^{T4} - \overline{H_i^{T4}}),\ R_i^{T4} - \overline{H_i^{T4}} > 0 \end{cases}, \tag{2}$$

where P_T represents predict index R_i^T represents bandwidth request of each T-CONT of ONU$_i$, and $\overline{H_i^T}$ is the average bandwidth requirements of the history ten cycle of each T-CONT of ONU$_i$, where $T \in$ {T-CONT 1, T-CONT 2, T-CONT 3, T-CONT 4}. For the T-CONT 2 and T-CONT 3 traffic, the predict index can be update when the $R_i^{T3} - \overline{H_i^{T3}}$ is bigger than zero, otherwise, the predict index is equals to request bandwidth.

During dynamic allocation, the allocated timeslot will be adapted to the requested bandwidth. To prevent the bandwidth wasted, the limited bandwidth allocation mechanism follow SLA and compares the minimum guaranteed bandwidth threshold with the predicted index of each ONU to get the grant bandwidth index (G_{Ti}), which is expressed in equation (3).

$$\begin{cases} G_{T2} = \min(P_{T2}, B_{\min}) \\ G_{T3} = \min(P_{T3}, B_{\min} - P_{T2}) \\ G_{T4} = \min(P_{T4}, B_{\min} - P_{T2} - P_{T3}) \end{cases}. \tag{3}$$

In the Excessive Bandwidth Reallocation (EBR) mechanism, the excess bandwidth can be collected from lightly-loaded ONUs and redistributed among the heavily-loaded ONUs. The sum of underutilized bandwidth of lightly-loaded ONUs is called excessive bandwidth (B_{excess}), which can be expressed as follow:

$$B_{excess} = \sum\nolimits_{j \in L} (B_{\min} - \sum_{i=2}^{4} G_{Ti}),\ B_{\min} > \sum_{i=2}^{4} G_{Ti}, \tag{4}$$

where L is the set of lightly-loaded ONUs and j is a lightly-loaded ONU in L. In the end, a heavily-loaded ONU obtains an additional bandwidth based on the EBR mechanism. If the bandwidth has not yet been distributed to the heavily-loaded ONUs after B_{excess} has been allocated, the remaining available bandwidth (B_{remain}) can be reserved for the next group of ONUs for DBA. The B_{remain} is expressed in equation (5) as follows:

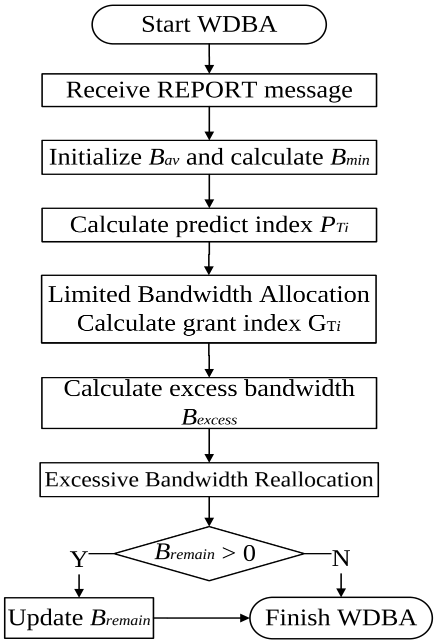

Fig. 3. Flowchart of WDBA.

$$B_{remain} = B_{excess} - \sum\nolimits_{j \in H} (\sum_{i=2}^{4} G_{Ti} - B_{\min}),\ B_{\min} < \sum_{i=2}^{4} G_{Ti}, \tag{5}$$

where H is the set of heavily-loaded ONUs and j is a heavily-loaded ONU in H. Therefore, the WDBA can support QoS and enhance system performance for differential services and efficiently reallocates excessive bandwidth in GPON.

IV. PERFORMANCE EVALUATION

In this section, the system performance of WDBA mechanism is compared between maximum pooling cycle time: 1 millisecond, 1.5 millisecond and 2 millisecond in terms of the throughput, end-to-end delay, drop probability, jitter and fairness for 16 ONUs. The GPON simulation model, set up by the OPNET modeler network simulator, the upstream/downstream link capacity is 1.24Gbps, the OLT-ONU distance is 10-20km, the buffer size is 10MByte, the guard time is 1.8μs and the computation time of DBA is 10μs. The service policy follows the first-in first-out (FIFO) principle. The T-CONT 1 traffic has the deterministic efficacy with limits is anticipated. For the traffic model considered, an extensive study has shown that most network traffic can be characterized by self-similarity and long-range dependence (LRD) [14]. The packet size generated each time for T-CONT 2, T-CONT 3 or T-CONT 4 traffic is 64, 500, 1500 bytes with probability of 60%, 20% and 20%, respectively [15]. The traffics with minimum assured bandwidth and with additional non-assured bandwidth of T-CONT 3 are assumed to distribute evenly. In order to observe the effective of high priority traffic, the proportion of traffic profile is analyzed by simulating the six significant

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scenarios in (T-CONT 1, T-CONT 2, T-CONT 3, and T-CONT 4) with (10%, 60%, 20%, 10%, 1621), (10%, 40%, 30%, 20%, 1432), (40%, 30%, 20%, 10%, 4321) and (40%, 40%, 10%, 10%, 4411), respectively. The simulation parameters are summarized in Table I.

A. Throughput

Figure 4 shows the throughput comparisons of T-CONT 2, T-CONT 3 and T-CONT 4 of different maximum pooling cycle time in 16 ONUs with different proportions of traffic profile for different traffic loads. Figures 3 show that the proportion of traffic will lead greater impact to average and T-CONT 2 throughput. When the proportion of high priority traffic is higher, the average throughput is better than the others proportion ratio, the main reason is that the LBA in WDBA follow the SLA policy and the T-CONT 2 has highest priority to get the bandwidth. Moreover, the traffic flow of T-CONT2 is higher result in higher bandwidth throughput of T-CONT2. Moreover, the maximum polling cycle time will affect the system throughput when the traffic loading exceeding 50%, and result in greater impact of higher proportion of high-priority traffic scenario.

B. Packet delay

Figure 5 shows the packet delay comparisons of average and T-CONT 2 packet delay of WDBA in 16 ONUs with different proportions of traffic profile for different traffic loads. The packet delay d is equal to d=d_{poll}+d_{grant}+d_{queue}, packet delay(d) consists of polling delay(d_{poll}), granting delay(d_{grant}) and queuing delay(d_{queue}). Simulation results show that the average packet delay of WDBA in 1ms maximum polling cycle time have relatively poor performance because of they can not transmit more data in short cycle time. In the different proportion of traffic, the scenario 1621 has the worse performance and begin to increase when the traffic load exceeding 50%, the scenario 4321 has the best performance, the reason is that the T-CONT 2 in WDBA will be transmitted early, so that the T-CONT 2 can get more resource and higher service level but has worse performance in other T-CONT traffic.

C. Drop probability, Jitter and Fairness

Figure 6 compares the drop probability, jitter and fairness of the WDBA in 16 ONUs with different proportions of traffic profile for different traffic loads. Simulation results show that the blocking probability of WDBA scheme in scenario 1432 is worst and the scenario 4321 has the best performance except traffic loading is 100%, the reason is that scenario 1432 has lower total throughput and the allocated bandwidth of T-CONT 3 and T-CONT 4 must wait for the remaining unused bandwidth given from T-CONT 2. Therefore, the traffic data of T-CONT 3 and T-CONT 4 will be queued in the buffer especially for T-CONT 4.

The delay variance σ^2 is calculated as $\sigma^2 = \sum_1^N (d_i^{T2} - \bar{d})^2 / N$, where d_i^{T2} represents the delay time of T-CONT 2 packet *i* and *N* is the total number of received T-CONT 2 packets. Simulation results show that the delay variance for T-CONT 2 traffic increases as the traffic load increases especially in scenario 4411. The T-CONT 2 jitter of WDBA is increasing when the traffic load exceeding 50% for scenario 1621, and exceeding 70% for the others. The reason is that the transmission order of each ONU is sequential and that the T-CONT 2 jitter of WDBA is depends on the cycle time when the proportion of high priority traffic is higher the jitter getting worse.

The global fairness index *f* (0≦f≦1) has been addressed [16] which is defined as:

Table I. Simulation scenario

Number of ONUs in the	16			
Upstream/downstream link	1.24 Gbps			
OLT-ONU distance (uniform)	20 km			
Buffer size	10 MB			
Maximum transmission cycle	1ms, 1.5ms, 2ms			
Guard time	1.8 μs			
Computation time of DBA	10 μs			
Traffic proportion	T1	T2	T3	T4
	10%	40%	30%	20%
	10%	60%	20%	10%
	40%	30%	20%	10%
	40%	40%	10%	10%

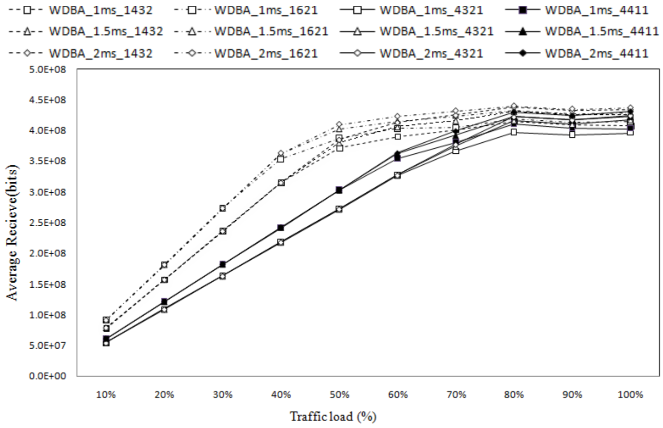

Fig. 4. (a)Average throughput.

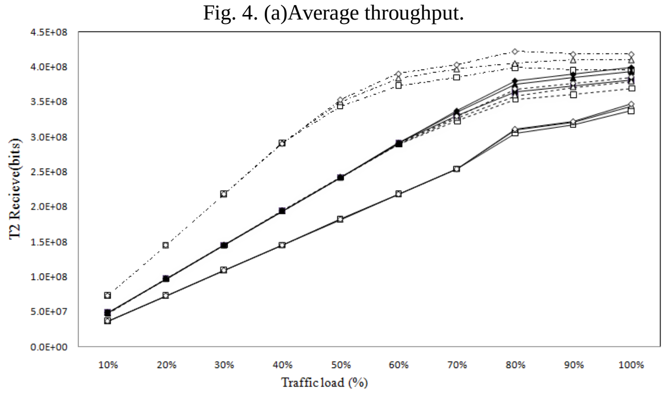

Fig. 4. (b)T-CONT 2 throughput.

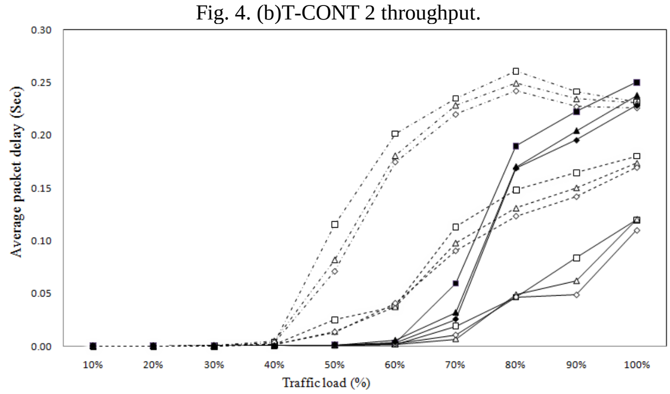

Fig. 5. Average packet delay.

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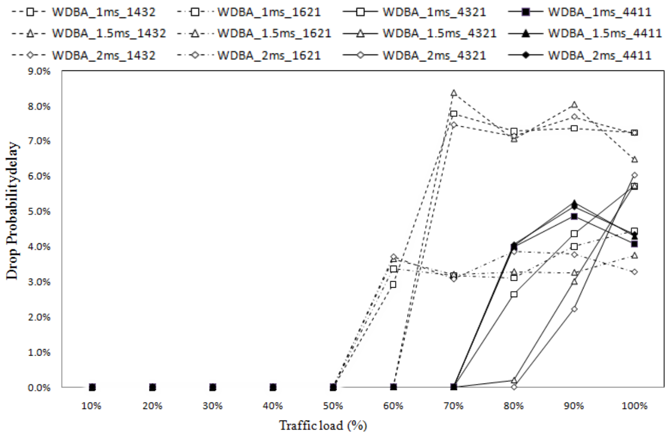

Fig. 6. (a) Drop probability.

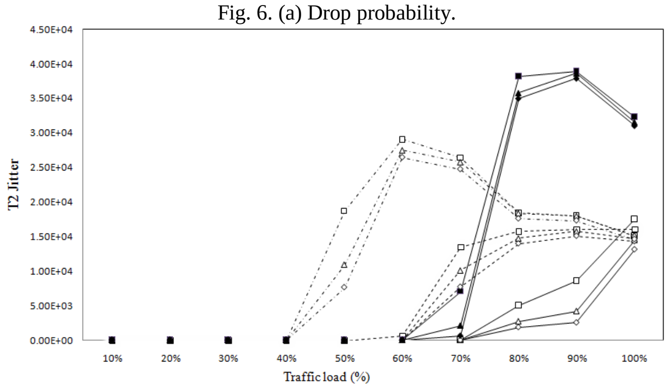

Fig. 6. (b) T-CONT 2 Jitter.

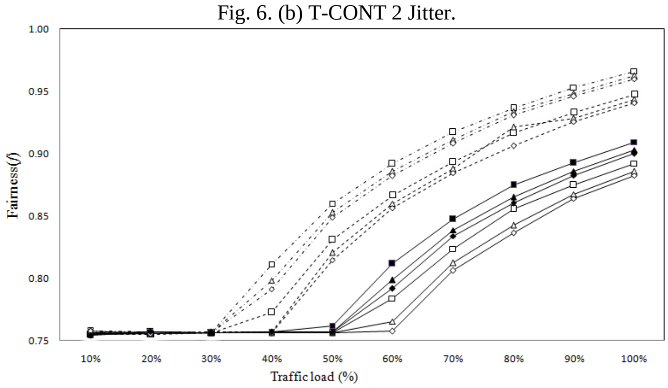

Fig. 6. (c) T-CONT 2 Jitter.

$$f = \frac{\left(\sum_{i=1}^{N} G_{[i]}\right)^2}{N\sum_{i=1}^{N} G_{[i]}^{\ 2}}, \qquad (6)$$

where N is the total number of ONUs and $G[i]$ is the ratio between the granted bandwidth of ONUi and requirement of ONUi. Simulation results show that the proportion of high priority traffic is higher and the shorter maximum polling cycle time will leading good fairness. The reason is that the high proportion of VBR traffic will cause significant changes in the system data flows compared with the high proportion of CBR traffic.

V. Conclusion

In this study, important factors that can improve the performance of GPON are discussed and evaluated. The WDBA mechanism executes an interleaved transmission process to automatically adjust cycle time to resolve the idle period problem for traditional DBA scheme, enhancing the system performance to reduce end-to-end packet delay and improving the throughput. In performance evaluation, the proportion of T-CONTs and the different maximum polling cycle time will lead different simulation result. The packet delay, throughput and drop probability performance is better when the polling cycle time is longer; the fairness is better when the polling cycle time is shorter.

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