Extra Window Scheme for Dynamic Bandwidth Allocation in EPON ⋆

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Abstract. To ensure efficient data transmission for multimedia services in Ethernet passive optical networks (EPON) which are considered as a promising solution to the last-mile problem in the broadband access network, they employ the media access control (MAC) mechanism by sharing efficiently the bandwidth of all optical network units (ONUs) and by avoiding data collisions in the upstream channel. The representative dynamic bandwidth allocation scheme, Interleaved Polling with Adaptive Cycle Time (IPACT), is considered as a standard approach in services for requests of ONUs. It reduces the performance of the entire network in terms of mean packet delay and packet loss ratio, due to congestion for the case that an ONU has burst traffic or highly loaded traffic. To handle this, the proposed scheme varies the cycle length in the basic period center and guarantees a maximum window size per ONU. In this paper, the proposed scheme demonstrates enhanced performance in terms of mean packet delay and packet loss ratio, of up to 58% and 10%, respectively.

1 Introduction

EPON is a next generation broadband access network selected by the IEEE 802.3ah Task Force [1], as the solution to the last-mile problem, and keeps the advantages of wide Ethernet deployment, while reducing the cost of fiber infrastructure. EPON is composed of an optical line termination (OLT) and several ONUs, such as asymptotic structure, which is a point-to-multipoint network in the downstream direction and a multipoint-to-point network in the upstream direction [2, 7]. To avoid data collision in the upstream channel, it uses the multipoint control protocol (MPCP) for sharing efficiently the upstream bandwidth as exchanging of REPORT and GATE massages. That is, an ONU reports its bandwidth requests to the OLT and then transmits only bandwidth granted by

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the OLT [1]. The bandwidth allocation problem is an important issue for the passive optical network. EPON systems need to use an efficient bandwidth allocation algorithm for providing users guaranteed network services and enhancing the network performance.

In general, bandwidth allocation schemes are classified into static ones and dynamic ones. Static bandwidth allocation (SBA) schemes allocate a fixed time slot regardless of the variable requests for ONUs. DBA schemes allocate a time slot of appropriate size for variable bandwidth requests of each ONU. SBA is more easily implemented than DBA, nevertheless, there is considerable DBA research being conducted [3–11], because SBA is not adaptable to the burst nature of network traffic. DBA uses an interleaved polling mechanism, overlapping upstream and downstream at the same time for using efficiently optical channel and reducing packet delay by exchanging MPCP messages. These polling mechanisms can be classified as interleaved polling and interleaved polling with a stop for upstream transmission. Typical interleaved polling schemes are IPACT [3] and Sliding Cycle Time (SLICT) [4]. In addition, DBA for Quality-of-Service (QoS) [5] and Two-Layer Bandwidth Allocation (TLBA) [6] exists in interleaved polling with a stop.

IPACT is an adaptive cycle scheme with a changable cycle time according to each ONU's bandwidth request. The paper introduces the *gated* service that allocates unlimitedly about requests of each ONU, and variable services such as *limited*, *constant credit*, *linear credit* and *elastic*, which prevent monopolization of the entire bandwidth and reducing bandwidth to waste [3]. SLICT is an improved DBA algorithm based on *limited* and *elastic* services in IPACT [4]. In DBA for QoS [5], the OLT allocates optimized bandwidth via total computation after receiving REPORT messages from all ONUs in order to assure QoS. TLBA [6] first divides the entire bandwidth of a cycle into three priority class (Class-layer allocation), then it computes allocation bandwidth of each ONU after dividing again a class into the number of ONUs (ONU-layer allocation). In this paper, based on interleaved polling having comparatively high network throughput, we propose an efficient algorithm with better performance than existing algorithms.

In this paper, to support the best service in EPON systems, without considering a service level agreement (SLA), we make up for the weak points of *elastic* service in IPACT. The first of them is that some ONUs are allocated instable bandwidth every cycle, the other is that the *elastic* service whose average cycle time is approximately 1.887 ms has more overheads than *limited* service because it uses more cycles for transmission of the same bandwidth. The former is solved into assurance of the maximum window size, the latter is solved by changing the sum of N windows into the sum of $N+1$ windows when the entire bandwidth is computed. According to the proposed scheme, mean packet delay decreases by up to 54.25 % than that of *elastic* service.

In section 2 of this paper, we describe typical DBA algorithms headed by IPACT and discuss problems with the existing schemes. In section 3, we propose an algorithm that solves above problems. In section 4, we compare and evaluate the performance of the proposed scheme with *limited* and *elastic* services in IPACT. We conclude this paper in section 5.

2 Related Work

In EPON architectures, according to the size of round trip time (RTT) caused by propagation delay that arises from the distance among the OLT and ONUs, network throughput decreases. To avoid this decrease, it is an interleaved polling mechanism that overlaps messages and data without interference. According to this mechanism, bandwidth which excepts for the overheads for messages, can be used very efficiently. Fig. 1 represents an example that works using an interleaved polling algorithm. The OLT sends a GATE message that makes ONU1 transmit 5,000 bytes which it has requested, and the ONU1 reports a request of 8,000 bytes, after it transmits the upstream message during a time slot granted by the OLT. The OLT received a REPORT message and renews the request information in its polling table, transmitting a GATE message to arrive at ONU1 before ONU1 starts transmission in the next cycle. Where a cycle is a period from when the OLT sends a GATE message into ONU1 to when the OLT sends the next GATE message into ONU1.

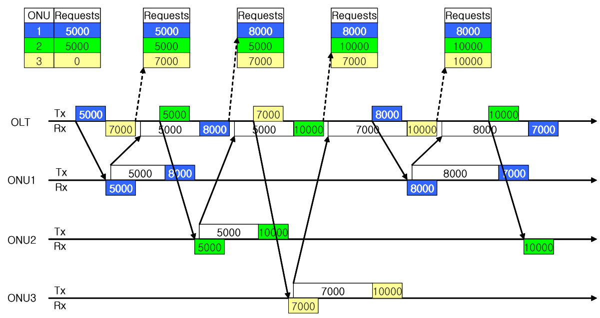


Fig. 1. Interleaved polling algorithm's operation.

IPACT suggests five services according to bandwidth allocation policies. Table 1 summarizes these five services, where $W^{[i]}$ is the size of bandwidth that OLT allocates to the i-th ONU, and $V^{[i]}$ is the size of bandwidth that the $i-th$ ONU requests. Δ is a constant value, and W_{Max} is the maximum window size. The *gated* service that does not limit the size of bandwidth has better performance than others, however, it is inappropriate for high quality services because cycle time becomes unlimitedly longer, according to queue size of ONUs. *Limited* service assures the same maximum window size for all ONUs. If the request bandwidth is smaller than the maximum window size, then the OLT grants only request bandwidth. *Constant credit* service, a modification of *limited* service, allocates additional bandwidth as much as a constant size, when the request bandwidth is smaller than the maximum window size; however, it has an opposite effect of additional overhead because amount of arrival traffic during the waiting time is not regular.

Linear credit service allocates also additional bandwidth as much as a proportion of request bandwidth if this is smaller than the maximum window size. This service improves *limited* service, like *constant credit* service; however, its performances decrease rather than the *limited* service in terms of mean packet delay, average queue size, and mean cycle times according to results in [3]. At last, *elastic* service is designed to allow other ONUs to use the remaining bandwidth after consumed by the previous ONUs. A limit factor is not maximum window size but the entire bandwidth (the number of ONUs times the maximum window size) unlike *limited* service. If the number of ONUs is N, OLT grants the smaller one between the request bandwidth and the remaining bandwidth excluding the size granted of the previous N ONUs. In these five services, *limited* service shows steadily better performance than the others [3].

Table 1. Several services of IPACT.

Service type	DBA Computation Formula
gated	$W^{[i]} = V^{[i]}$
limited	$W^{[i]} = MIN\{V^{[i]}, W_{Max}\}$
constant credit	$W^{[i]} = MIN\{V^{[i]} + \Delta, W_{Max}\}$
linear credit	$W^{[i]} = MIN\{V^{[i]} \cdot \Delta, W_{Max}\}$
elastic	$W^{[i]} = MIN\{V^{[i]}, N \cdot W_{Max} - \sum_{j \equiv (i-N) mod N}^{i-1} W^{[j]}\}$

The existing *elastic* service of IPACT is free from constraints of maximum window size unlike *limited* service. The only limitation is the maximum cycle time. The maximum bandwidth possible during the maximum cycle time is $N \cdot W_{Max}$. It allocates the smaller one between the last N accumulative allocation bandwidth and request bandwidth.Thus, the allocation bandwidth for the i-th ONU is

$$W^{[i]} = MIN\{V^{[i]}, N \cdot W_{Max} - \sum_{j \equiv (i-N) mod N}^{i-1} W^{[j]}\}. \quad (1)$$

Shortcoming of this service is that the present available bandwidth can be limited into zero resluting from allocation size in the previous cycle. On the other hand, when an ONU fully uses available bandwidth, any of the next ONUs cannot be allocated a bandwidth because its available bandwidth can be zero if its previous request is zero and the summation is larger than $N \cdot W_{Max}$ in equation (1). In addition, average cycle time is shortened due to the same effect that $N + 1$ ONUs share the entire bandwidth of N times maximum window size. In other words, it needs more cycles to transmit the same bandwidth, and increases overheads of basic requirements for each cycle, such as guard time, frame gaps, messages, and so on.

Fig. 2 presents the problems occurring when *elastic* service is used. We assume that the number of ONUs is three and the maximum window size is 5,000 bytes. Thus, the available entire bandwidth during a cycle time is 15,000 bytes. Before the OLT allocates bandwidth for ONU1, it knows the previous requests in the table T_1 and grants in the table T_2 information from its polling table. From the table T_2, the sum of the previous grants is 15,000 bytes, and allocation bandwidth of ONU1 becomes zero byte since its request is zero byte. While the OLT is granting zero byte into ONU1, it updates the grant infomation in the grants table T_3. In table T_3, available bandwidth excluding 10,000 bytes, sum of the previous grants from the entire bandwidth is 5,000 bytes; and a request of ONU2 is 7,000 bytes, and then allocation bandwidth is 5,000 bytes. In the same way the OLT grants 5,000 bytes into ONU2, and updates table T_4. Because the available bandwidth in table T_4 is 5,000 bytes and its request is 8,000 bytes, 5,000 bytes is allocated. In table T_5 5,000 bytes is allocated. Although a request in table T_6 is 9,000 bytes, zero byte are allocated because the available bandwidth is zero byte. That is, if *elastic* service is used, any ONU may not be allocated nevertheless it has requests.

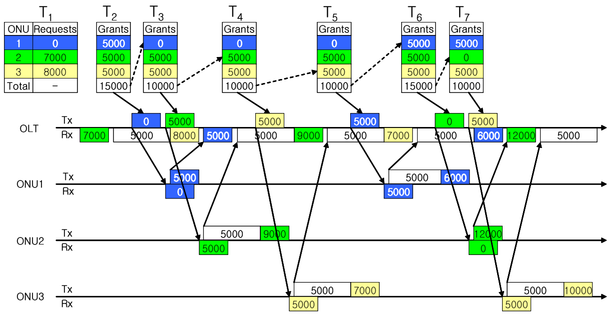


Fig. 2. Non-grant case in *elastic* service.

3 The Proposed Algorithm

In EPON architecture, many users are accessed on an ONU. It is quite probable that the characteristic of users accessed on each ONU is similar. The differences of ONUs' offered traffic loads are clearly heavy and light. So, we treat an EPON system with unbalanced load in each ONU. In the mean time, SLA assures the bandwidth decided according to service contract with users, and it is considered by many researches; however, it sometimes becomes a factor that decreases the efficiency of the access network in terms of resources utilization because it is allowed to transmit bandwidth predetermined by SLA; nevertheless, the network is idle. Therefore, we assume that EPON systems don't use SLA on purpose to maximize utilization of network resource.

In the considered environment, if the system uses the *limited* service in IPACT, it cannot respond to the purpose for requests of ONUs with unbalanced load, because all ONUs have the same maximum window size. For example, in case that an ONU' traffic load is high and the other is light, packet transmission delay of the ONU is much increased since its maximum window size is limited and overheads by light loaded ONUs increase. *Elastic* service is more adaptable than *limited* service. However, according to bandwidth that is allocated to the last $N-1$ ONUs, the present ONU cannot be guaranteed in bandwidth allocation. When the number of ONUs is 16 and the cycle time is $2ms$, in case of using this scheme, average cycle time is not more than $1.887ms$. Thus, the *elastic* service cannot be a counterplan of *limited* service. To solve this problem, we improve *elastic* service so that it can assure the maximum window size for each ONU and its average cycle time can increase by increasing the entire bandwidth.

We allow the OLT to guarantee bandwidth up to the maximum window size for the ONU that requests more bandwidth than the maximum window size. For instance, in the case that an ONU requests less bandwidth than the maximum window size, the OLT grants bandwidth on demand; otherwise, the OLT grants bandwidth up to the maximum window size. It inherits the strength of the *limited* service. And we inherit the strength of the *elastic* service that uses efficiently entire bandwidth. Unlikely the *elastic* service, by adding an extra window to an entire bandwidth in a cycle, it allows $N+1$ ONUs to share $N+1$ windows. The extra window is only used in DBA computation and is excluded from composing a cycle. Consequently, allocation bandwidth for the i-th ONU computed by this scheme is

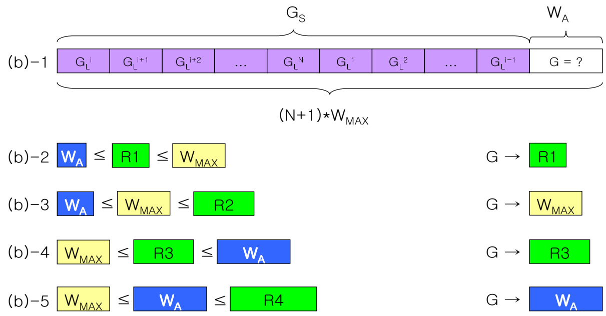
$$W^{[i]} = MIN[V^{[i]}, MAX\{W_{Max}, (N+1)W_{Max} - \sum_{j\equiv(i-N)modN}^{i-1} W^{[j]}\}]. \quad (2)$$

The pseudo code in Fig. 3(a) is that the OLT computes bandwidth to grant to the $i-th$ ONU after receiving the REPORT message from the ONU. Where W_{Max} is the maximum window size for an ONU and W_A is available window size for the current ONU. The number of ONUs is N, G_L^i is the last grant size for $i-th$ ONU, and G_S^N is a summation of the last N grant sizes. If a request is more than maximum window size and is more than the available window size, then the OLT grants the larger window size between two window sizes; otherwise, it grants as much as the request bandwidth. Then G_S^N, the sum of previous N grants, is renewed into the sum of the recent N grants, the G_S^N minuses a grant for the $i-th$ ONU in the previous cycle and pluses a grant for the ONU in this cycle. For similar computation in the next cycle, an array G_L^i saves the grant information in this cycle.

To help understanding, we represent the grant situation in Fig. 3(b), where the OLT decides grant bandwidth by a relation about a request Ri, an available window size W_A and maximum window size W_{Max}. (b)-1 shows that the OLT computes the available window size, which is $N+1$ times the maximum window size minus the recent N grants, where G_L^i is the last grant size for $i-th$ ONU

Input: ONU_ID i, Request_Size R
Output: Grant_Size G
BEGIN
$W_A \leftarrow (N+1) * W_{MAX} - G_S^N$
If $R > W_{MAX}$ and $R > W_A$
  $G \leftarrow Max(W_{MAX}, W_A)$
Else $G \leftarrow R$
$G_S^N \leftarrow G_T - G_L^i + G$
$G_L^i \leftarrow G$
Return G
END

(a) Pseudo code



(b) Granted bandwidth

Fig. 3. Pseudo code and bandwidth granting in the proposed scheme.

and G_S^N is the sum of the last N grant sizes. When the OLT receives a request R1 from an ONU in (b)-2, it grants all of R1 since R1 is more than W_A and less than W_{Max}. In (b)-3 since R2 is more than W_A and W_{Max}, the OLT grants bandwidth as much as W_{Max}. In (b)-4 and (b)-5, if the request is more than W_{Max}, the OLT grants bandwidth not more than W_A.

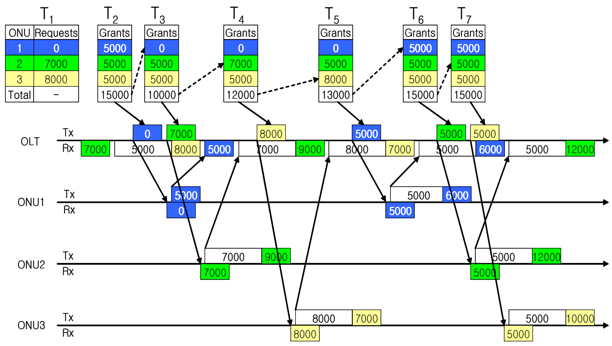


Fig. 4. Operation in Extra Window scheme.

Fig. 4 shows an example which the Extra Window scheme operates. Since the number of ONUs is 3, the available entire bandwidth is the sum of 4 windows and each ONU is guaranteed up to bandwidth of 5,000 bytes. The previous requests T_1 and grants T_2 are similar to that shown in Fig. 2. In T_2, since the sum of previous grants is 15,000 bytes and a request of ONU1 is zero byte, the grant bandwidth is zero byte. While the OLT grants zero byte into ONU1, it updates the last grant information in table T_3. From table T_3, available bandwidth of entire bandwidth minus 10,000 bytes, a sum of the previous grants, is 10,000 bytes. Since a request of ONU2 is 7,000 bytes, grant bandwidth is 7,000 bytes.

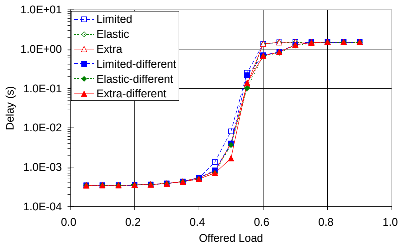
In the same way, while the OLT is granting 7,000 bytes to ONU2, it updates the last grant information in table T_4. In table T_4, available bandwidth is 8,000 bytes, and a request of ONU3 is 8,000 bytes. Thus, all of 8,000 bytes are granted to ONU3. In table T_5, 5,000 bytes is granted for ONU1. In table T_6, 5,000 bytes are granted for ONU2 while zero byte is granted in Fig. 2. In the table T_7 5,000 bytes are granted for ONU3. Therefore, the Extra Window scheme can guarantee bandwidth as much as the maximum window size, in contrast to *elastic* service, in case that a request exists.

4 Performance Evaluations

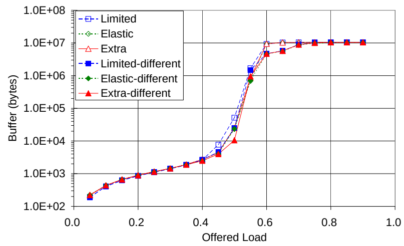
In this paper, we consider an EPON system consisting of an OLT and 16 ONUs, and each ONU contains 32 users. The data rate of access link from a user to an ONU is 100 Mbps, and the rate of the upstream link from an ONU to the OLT is 1 Gbps. The propagation delay between the OLT and each ONU is 5 ns/m, and distance between the OLT and ONUs ranges from 0.5 to 20 km. The length of the average cycle time is $2ms$, and a guard time between ONUs is 5 μs. We assume that the queue size for each ONU is 10 Mbytes. For generating self-similar traffic, after gathering user data generated by ON/OFF periods according to the Pareto distribution, an ONU receives the aggregated user traffic streams. The average offered load for ONUs is varied from 0.05 to 0.9. We consider two different ways of setting the load. The first is the case that the offered load of all ONUs is equal, the other is the case that the offered load of ONUs is mutually different. In both cases, we compare the proposed scheme with the *limited* and *elastic* service of IPACT.

We compare the results of mean packet delay in Fig. 5(a). The term '-different' in the legend represents a simulation result for the different load case. When the same load is offered to all ONUs, *limited* service has the longest mean packet delay, and the performance of *elastic* and Extra Window are almost equal. When loads are 0.6 and 0.65, improvement of performance is remarkable. When the same load is offered, since the queue of each ONU is almost full in the case of load more than 0.6, all packets through the queue have long queuing delay. When loads are mutually different, the packets of the ONUs with light load are not accumulated and have low delay. Thus delay with relatively different load for ONUs is lower than that of the case with the same load. In the simulation of different load, e.g., at 0.5, the proposed Extra Window scheme shows lower delay up to 58.1% than the *limited* service, and up to 54.25% than the *elastic* service.

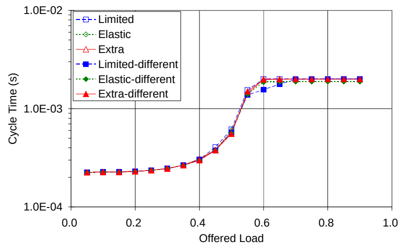
Fig. 5(b) shows a change of the average queue length for all ONUs. We know that the average queue length and the mean packet delay are proportional, and the former shows the similar trend to the later. When offered load is more than 0.4, since the *limited* service on average has heavy use of the queue, the mean packet delay becomes high. At the loads of 0.6 and 0.65, it shows the similar results due to the same reason with the mean packet delay. In the proposed Extra Window scheme, at the load of 0.5 reduces queue occupancy is reduced



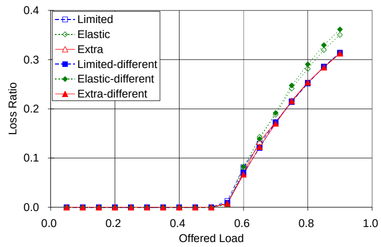
(a) Mean packet delay



(b) Average queue length



(c) Average cycle time



(d) Mean packet loss ratio

Fig. 5. Performance of proposed scheme and IPACT.

up to 58%, compared to that of the *limited* service, and up to 55.6% compared to that of the *elastic* service.

Fig. 5(c) shows the comparison of the average cycle time. When the offered load is less than 0.6, the average cycle time is long in order of *limited* > *elastic* > Extra Window; however, in the other load, in order of Extra Window > *elastic* > *limited*. In addition, *limited* service shows that two simulations have different results at a load of approximately 0.6. Thus in case of the same load, since all ONUs have similar requests, granted slots increase constantly; however, in case of the different load since ONUs' slots with relatively low packet load is small, total cycle time is reduced. In this case, the total time of a cycle cannot be used all because light loaded ONUs don't occupy the guaranteed maximum window according to *limited* service. Therefore, it has more overheads due to such factors as guard time since it needs more cycles than the other services for equal bandwidth. The Extra Window scheme demonstrates better performance in the mean packet delay and the average queue length, when its offered load is light, and in heavy load, it shows better performance with maximal use of cycle time.

In Fig. 5(d), according to the increase in offered load, it shows the packet loss ratio. The packet loss ratio of *elastic* service is highest, then one of *limited* service is middle. When the former variable results are compared totally, *elastic* service has better performance than *limited* service; however, it has higher packet loss. Finally, Extra Window scheme has the lowest packet loss ratio, moreover it has the most valuable performances among three services.

5 Conclusion

In this paper, we consider that EPON is a system that variable users access with similar pattern in an ONU. In this environment, the existing IPACT reduced the total network performance, such as packet loss, since an ONU in burst traffic situation results in relatively lower throughput than the others. In this paper, the proposed Extra Window scheme solved the shortcomings of existing *elastic* service in IPACT, and shows advanced performance up to 58% in terms of mean packet delay. In addition, it has good performance in terms of packet loss ratio and variation in mean packet delay among ONUs.

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