Dynamic Bandwidth Allocation Method for High Link Utilization to Support NSR ONUs in GPON

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Abstract— **Non-status reporting (NSR) ONUs underutilize link capacity, since they do not inform queue occupancy to the optical line terminal (OLT) as well as traffics in access network are bursty. We suggest a dynamic bandwidth allocation (DBA) method to support NSR optical network units (ONUs) and to improve link utilization based on the Full Service Access Network (FSAN)-compliant gigabit passive optical network (GPON). Also, we simulate it to show how inevitable under-utilization can be reduced through the proposed DBA method.**

***Keywords*— access control, dynamic bandwidth allocation (DBA), gigabit passive optical network (GPON), media access control (MAC), quality of service (QoS)**

I. INTRODUCTION

Deploying a network infrastructure in the access networks, which is required to provider higher bit rates and more flexibility, is very cost sensitive. In the viewpoint of service provider, it is because revenue dynamics in the access networks are different from that in the metro networks. Whereas the metro networks links carry the bit streams of many customers through a shared line, access links carry a single or only a few revenue generating bit streams through each links.

A passive optical network (PON) between service providers and customer premises in access networks can provide a cost efficient and flexible infrastructure [1]. The advantages of using a PON is larger bandwidth, lower maintenance costs through passive components in the physical plant, and reduced deployment costs through sharing of fiber medium.

Technologies of PONs have developed for a few decades, so there are several kinds of the PON technology such as the asynchronous transfer mode (ATM)-based PON (APONs), the broadband PON (B-PON), the Ethernet PON (EPON), the gigabit PON (GPON), and different types of hybrid PONs [1]. However, the EPON and the GPON, which are classified by layer protocol, popular for the Ethernet access technology, since they have several advantages compared to other PON technologies in the view of cost-effectiveness and high bandwidth utilization.

In the view of bandwidth capacity and the line-coding method, whereas the GPON needs no overhead to synchronize between the optical line terminal (OLT) and the optical network units (ONUs) as using non-return-to-zero (NRZ) method, 20% of the bandwidth in the EPON is wasted compared to the GPON since the EPON using the 8b/10b encoding method needs the extra overhead to transform a byte into a 10-bit code word [5]. Since the relative EPON-to-GPON cost is affected by the utilization of the link capacity, the GPON is more attractive for access networks [8]. It is because infrastructure costs is allowable by relative high utilization and shared by many subscribers even though more expensive transmitter in the GPON is used for high sensitivity during relative short time as several tens of nanoseconds [8].

The GPON standards developed by the Full Service Access Network (FSAN) group should support both status reporting (SR) and non-status reporting (NSR) ONUs [12]. NSR ONUs, which are developed in low costs to support only a few functionalities for loose service requirements, do not have the capability to report the queued traffic. In previous study, there are a few GPON DBA method to improve throughput and to differentiate services [2-5], but still some implicit application of dynamic bandwidth allocation (DBA) methods is possible for NSR ONUs albeit with a certain inevitable inefficiency [3][10]. However, if utilization of the GPON is degraded by NSR ONUs, the GPON is not relatively cost-effective than the EPON as [8]. Therefore, we try to reduce inevitable underutilization caused by NSR-ONUs through the proposed DBA method.

II. GPON DYNAMIC BANDWIDTH ALLOCATION

In the GPON downstream, the OLT informs upstream bandwidth allocation without overlaps as Alloc-IDs of each ONUs through transmitting upstream bandwidth map (US_BWmap) field in the GPON transmission convergence (GTC) downstream frame [12]. US_BWmap are built of multiple bandwidth allocations for the individual ONUs or the

ONU T-CONTs. To allocate the right bandwidth for each ONU, DBA is dynamically calculating US_BWmap using parameters offered by the GPON medium access control (MAC) [7]. As the GPON standard, the MAC controller uses information from the DBRu field or a parameter for the number of idle frames in the GPON encapsulation method (GEM) header to statistically allocate bandwidth as shown in Figure 1. The DBRu field of SR ONUs is used to report the status of the ONU queues to the MAC controller. The number of idle frames of NSR ONUs in upstream allocation interval is obtained by traffic monitoring as recognizing idle indication of the GEM header. So, the OLT can allocate bandwidth based on ONU requests through DBRu field for queue status reporting, on measuring upstream traffic through traffic monitoring, or on any combination of the two under the consideration about the Service Level Agreement (SLA). However, the GPON standard leaves the actual implementations for DBA schemes to open.

DBA algorithms can be divided into two categories: SR-DBA and NSR-DBA [10][12]. In SR-DBA, the OLT uses upstream data queue occupancy reported by all ONUs to calculate the US_BWmap. Each ONU may have several Transmission containers (T-CONTs), each with its own traffic class. Fixed bandwidth services such as constant bit rate (CBR)-like application are contained and transmitted through T-CONT type 1. T-CONT type 2 supports assured bandwidth and T-CONT type 3 support assured and non-assured bandwidth services. T-CONT type 3 offers better than best-effort services through a guaranteed minimum bandwidth and surplus bandwidth assigned only on request. T-CONT 4, which has least priority, supports best-effort services such as browsing, FTP, SMTP, and etc. T-CONT type 5 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 [12]. By combining the queue occupancy information and the provisioned Service Level Agreement (SLA) of each T-CONT, the OLT can optimize the upstream bandwidth allocation through US_BWmap calculation process through SR-DBA.

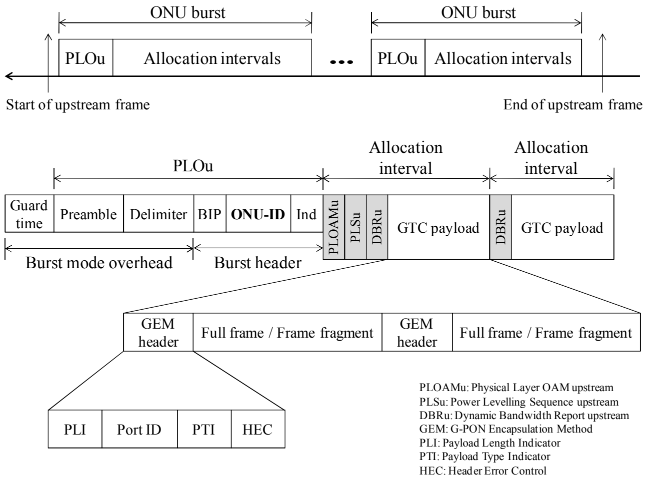

Figure 1. GTC upstream frame structure

Table 1. GIANT MAC Service Parameters

TC	Applications	GPON Service	MAC Parameters
1	CBR	Periodic upon activation	SImax, ABmin
2	VBR	Periodic, validated by requests (Assured)	SImax, ABmin
3	Better than best effort	Periodic, validated by requests (Assured)	SImax, ABmin
		Dynamic based on request and availability (Surplus)	SImin, ABsur
4	Best effort	Used for polling	SImax, ABmin
		Dynamic based on request and availability (Surplus)	SImin, ABsur

In NSR-DBA, ONUs do not provide explicit queue occupancy information. Instead, the OLT estimates the ONU queue status, typically based on the actual transmission in the previous cycle, through monitoring the GEM header which indicates an idle frame [3][10]. For example, if an ONT has no traffic to send, it transmits idle frames during its allocation interval as shown in Figure 1. The OLT would then observe the idle frames and apply its information to allocate bandwidth in the following cycle. However, there are trade-off between latency and utilization for NSR ONUs. In an implicit DBA method for NSR ONUs, there is no difference for traffic in T-CONT type 1, since no reporting is applicable but minimum fixed bandwidth is periodically allocated in FSAN-compliant GPON. However, a DBA directly controls bandwidths for T-CONT types 2-4 and it should be modified to consider that whenever an NSR ONU sends upstream in response to an allocation a burst that does not occupy all the allocated bytes, its queue has empty. In the NSR case, the MAC controller will stop allocating bandwidth only when an empty queue is surmised, which is always accomplished at the expense of an underutilized last allocation [3].

Compared to NSR-based algorithms, SR-based algorithm utilization is higher because the OLT does not overestimate or underestimate the queue occupancy and SR-based algorithm latency is lower because traffic can be granted for transmission once reported by the ONT. However, since the GPON network allows implementation of NSR-based algorithms, we suggest a DBA to efficiently support NSR-ONU and to prevent under-utilization in the GPON.

III. PROPOSED DYNAMIC BANDWIDTH ALLOCATION

The MAC controller for the proposed method calculates upstream bandwidths based on the associated T-CONT types with four service parameters: SImax, SImin, ABmin, and ABsur as shown in Table I. Each service parameter value is determined by the method of the FSAN-compliant GPON DBA [3]. In Table I, SImax and SImin represent the maximum and minimum service interval expressed in multiples of the GTC frame. And ABmin and ABsur represent the minimum and surplus allocation bytes. The MAC controller ensures that the total allocated bandwidth per service interval will not exceed line capacity. The scheduling priority is in order of the assured

```
// frame_bytes = 19438   // for 1.24Gbps GPON upstream rate.
// ct_idle(i) = the number of GEM idle in frames in a polling cycle.
// i = AllocID, based on T-CONTs map as SLA.
// pt = proportional value for NSR ONU in the next polling.

// for each polling cycle
// inspect all SImax timers
for (each AllocID i) {
  if (frame_bytes >0 && Ba(i) >0) {
    if (NSR_ONU && (T_CONT(i) == 2 || T_CONT(i) == 3))
      if (ct_idle(i) == 0) request(i) = ABmin(i);
      else if (ct_idle(i) > 0)
        request(i) = ABmin(i)*pt;
    Allocation_guaranteed(i);
  }
  if (SImax_timer(i) == 1) {
    SImax_timer(i) = SImax(i);
    Ba(i) = ABmin(i);
  } else
    SImax_timer(i)--;
  if (frame_bytes == 0) break;
}

// process Allocate_guaranteed(i)
Allocation_guaranteed(i) {
  if (!NSR_ONU && T_CONT(i) == 4)
    allocation_bytes = MIN(Ba(i), frame_bytes);
  else
    allocation_bytes = MIN(Ba(i), request(i), frame_bytes);
  Assign(i, allocation_bytes);
  Ba(i) -= allocation_bytes;
  request(i) -= allocation_bytes;
  frame_bytes -= allocation_bytes;
}
```

Figure 2. **MAC algorithm pseudo-code for allocation of guaranteed part of bandwidth**

```
// Surplus Bandwidth Allocation phase
// update T_CONT3 and T_CONT4 requests and inspect SImin timers.
for (each AllocID i) {
  if (frame_byte >0 && Bs(i) >0 &&
      (T_CONT(i) == 3 || T_CONT(i) == 4)) {
    if (NSR_ONU)
      if (ct_idle(i) == 0) request(i) = ABmin(i);
      else if (ct_idle(i) >0) request(i) = 0;
    Allocation_surplus(i);
  }
  if (SImin_timer(i) == 1) {
    SImin_timer(i) = SImin(i);
    Bs(i) = ABsur(i);
  } else SImin_timer(i)--;
  if (frame_bytes == 0) break;
}

for (each AllocID i) {
  if (frame_byte > 0 && (T_CONT(i)==3 || T_CONT(i)==4))
    if (request(i) >0) Allocation_remainder(i);
}

// process Allocation_surplus(i)
Allocation_surplus(i) {
  allocation_bytes = MIN(Bs(i), request(i), frame_bytes);
  Assign(i, allocation_bytes);
  Bs(i) -= allocation_bytes;
  request(i) -= allocation_bytes;
  frame_bytes -= allocation_bytes;
}

Allocation_remainder(i) {
  allocation_bytes = MIN(request(i), frame_bytes);
  Assign(i, allocation_bytes);
  request(i) -= allocation_bytes;
  frame_bytes -= allocation_bytes;
}
```

Figure 3. **MAC algorithm pseudo-code for allocation of surplus part of bandwidth**

bandwidth of the T-CONT type 2, the assured bandwidth of the T-CONT type 3, the surplus bandwidth of the T-CONT type 3, and the surplus bandwidth of the T-CONT type 4.

The proposed DBA does not mention about T-CONT type 1 traffic, but fixed and periodic bandwidth for T-CONT type 1 traffic will be allocated based on service rate of the SLA to support strict service delay requirements. Bandwidth for T-CONT type 2 to 4 will be allocated by the MAC controller and we can deploy here the proposed DBA to support NSR ONUs with information about idle GEM frames.

Since the assured bandwidth means the fixed average bandwidth over a specified time interval [3], bandwidth utilization can be increased by handling available bandwidth for surplus through immediate bandwidth allocation in service interval.

Figure 2 shows the pseudo-code of the proposed DBA method for guaranteed bandwidth allocation. In Figure 2, *i* is the AllocID, based on T-CONT map as SLA and *ct_idle(i)* represents the number of GEM idle in frames for AllocID *i* in a polling cycle. The *frame_bytes* is the available frame bytes and its initial value is 19,440 for the 1.24416 Gbits/s upstream rate. The *request(i)* is the stored queue length of the T-CONT having AllocID *i*. It is assumed that every time a queue report for AllocID *i* arrives, the reported length is stored in the *request(i)* of the request matrix. *N* is the number of active ONUs. The *pt* is proportional value for NSR ONU to allocate bandwidth in the next polling cycle.

In Figure 2, we insert a code for NSR ONUs, but it only controls bandwidth allocation for T-CONT 2 and T-CONT 3. It is because T-CONT type 1 contains CBR traffic and serves independent with other T-CONTs as shown in Table I. To simplify a code complexity, we use *request(i)* for bandwidth allocation for NSR ONUs through substituting the required minimum bandwidth multiplied by the proportional value *pt* to *request(i)*. Also, whereas guaranteed bandwidth of T-CONT type 4 of SR ONUs is used for polling, the proposed method does not allocate bandwidth for T-CONT 4 of NSR ONUs since NSR ONUs do not need to poll. Instead of adjusting polling flag of a code in Figure 2, we use ABmin for T-CONT type 4 of SR ONUs by setting a constant value for byte the PLOu overhead and the DBRu.

The pseudocode for the surplus bandwidth allocation in Figure 3 is the almost same with that of guaranteed bandwidth allocation as shown in Figure 2. However, in a code of surplus part of the proposed DBA, bandwidths for NSR ONUs are allocated *ABsur(i)* or zero. It is because the US_BWmap calculation without statistical queue information makes underutilization to be larger. Allocated bandwidths for NSR ONUs may reduce latency, but it causes high underutilization since data traffics in access networks are burst and we cannot expect when buffer is occupied. Service providers will not consider NSR ONUs for high quality services and they will use NSR ONUs to only support loose services in the view of throughput and latency. So link utilization is more important in coexistence of SR and NSR ONUs. In the proposed method, we try to increase utilization within maintaining performance for SR ONUs.

In Figure 3, for the surplus bandwidth allocation to T-CONT 3 and T-CONT 4, setting all SImin parameters equal and varying the ABsur parameters,

In the DBA operation, even if there are parameters for the maximum service interval for the guaranteed and minimum service interval for the surplus, both allocation method for the guaranteed and the surplus immediately allocate when there are space to assign in a polling cycle while subtracting calculated *allocation_bytes* from *request(i)*, *frame_bytes*, and required service bandwidths *Ba(i)* and *Bs(i)*.

If *frame_bytes* is not exhausted, *Allocation_remainder(i)* redistributes remained bandwidth to AllocID *i* of ONU as T-CONT map which is ordered by the priority and the ONU group. Instead of dividing *N*, we fully assign remainder some AllocID *i* to avoid a waste of bandwidth in case that lot of overhead are generated to encapsulate small size of payloads. Through *Allocation_remainder(i)*, the newly arrived frames can be served without the polling operation and burden traffics can be transmitted and processed. The AllocID for remainder will denote T-CONT type 5 to have the ONU select a T-CONT to serve in order of T-CONTs 2, 3, and 4 until the added time slot is exhausted.

IV. PERFORMANCE EVALUATION

In simulation, T-CONT 1 traffic such as CBR service is assumed that it is generated by 5% in line capacity, independently to queue occupancy since it must be offered with fixed allocation in the required service interval. It operates with SImax=1 and T-CONT 1 traffic is also assumed that it is fully served in utilization evaluation. Generating portion of T-CONT 2, T-CONT 3, and T-CONT 4 are assumed that 15%, 40%, and 40%, respectively. Each traffic is generated in proportional to traffic loads. The assured and surplus services are included in the amount of data generation of T-CONT 3 and T-CONT 4. T-CONT 2 assumes that SImax=5, ABmin=400 and T-CONT 3 assume that SImax=10, ABmin=400. T-CONT 4 for SR ONU assumes that SImax=10, ABmin=7 because its bandwidth is for polling, However T-CONT 4 for NSR ONU assumes that SImax=10, ABmin=400 as the same with T-CONT type 3 because queue information is not reported to the OLT and there are no space unless bandwidth for best effort service is allocated. Whereas T-CONT type 3 and T-CONT type 4 for SR ONUs use SImin=5, ABsur=800 and SImin=5, ABsur=1200, respectively, SImin and ABsur of T-CONT 3 and T-CONT 4 for NSR ONUs are both zero.

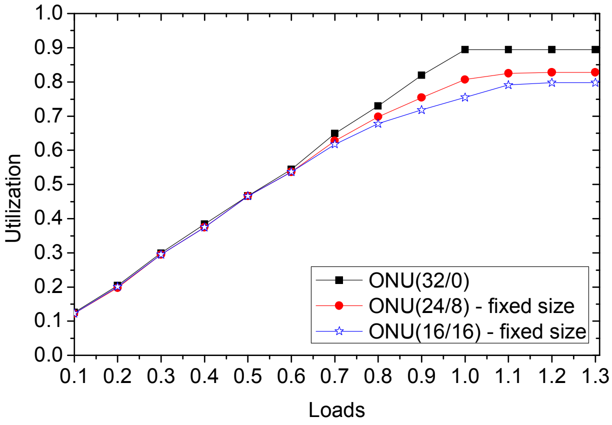

Figure 4. **Utilization to compare SR DBA and NSR DBA. ONU(24/8) means 24 SR ONUs and 8 NSR ONUs.**

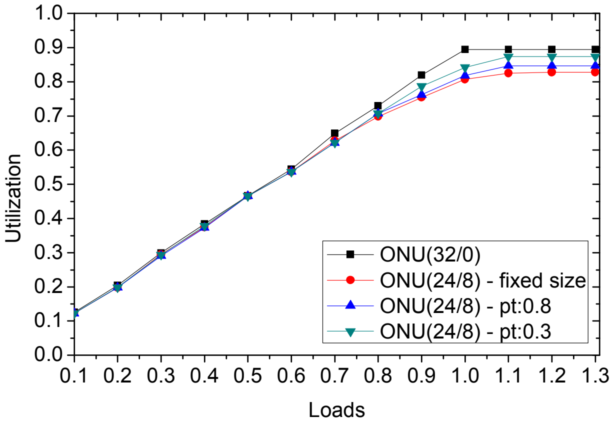

Figure 5. **Utilization in case of 24 SR ONUs and 8 NSR ONUs as bandwidth allocation slot size.**

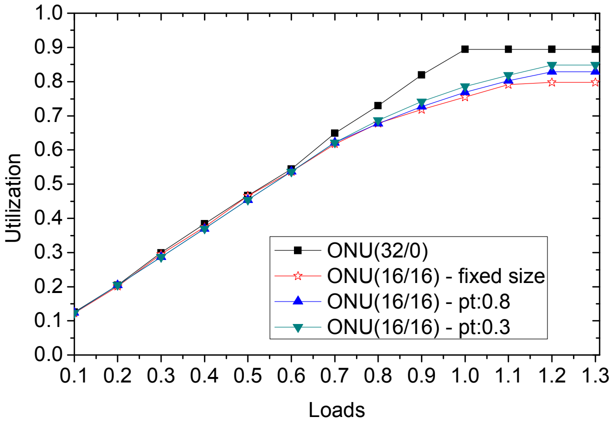

Figure 6. **Utilization in case of 16 SR ONUs and 16 NSR ONUs as bandwidth allocation slot size.**

Traffic generation is bursty, and data generation interval for T-CONTs are random based on SLA requirement [12]. The almost 32 bit for polling in 1.244Gb/s is needed for overhead including preamble of PLOu header and guardtime since 26ns is needed for overhead of the ONU burst in [8]. BIP, ONU_ID, and Ind fields have each 1 byte, but there are no PLOAMu and PLSu in the ONU burst as shown in Figure 1. DRBu in an allocation interval is set 1byte and mode-0 to transmit only queue information [12].

Since bandwidth for a NSR ONU is allocated lesser than a SR ONU, connecting a NSR ONU to network is not efficient in throughput and delay perspective [3][10]. Therefore, in coexistence of SR and NSR ONUs, utilization improvement is a parameter for network link performance. In this paper, we only try to improve bandwidth utilization in network, which includes NSR ONUs, within the assumption that NSR ONUs are only for loose service and they are developed in low-cost.

In Figure 4, under-utilization is occurred by NSR ONUs since they do not report their queue occupancy. If traffics are not burst, we may think that utilization of the case in coexistence of SR and NSR ONUs will be close to that of the case for only SR ONUs as loads are increasing. However, since traffics are bursty in access networks compared to MAN and WAN and NSR ONUs do not report information about queues occupancy, inevitable bandwidth for idle NSR ONUs will be allocated by MAC controller at the OLT. As shown in Figure 4, as increasing the number of NSR ONUs, network utilization is decreased. In Figure 4, MAC controller adjusts on-off allocation with ABmin for NSR ONUs implicitly mentioned in [10]. Since we do not want to waste bandwidth, only guaranteed bandwidth ABmin will be allocated for NSR ONU. Whereas guaranteed bandwidth for T-CONT 4 of a SR ONU is allocated for polling, we set T-CONT 4 of a NSR ONU to have some ABmin for data transmission. Because data in T-CONT 4 of NSR ONUs never be transmitted to the OLT, unless some bandwidth for data transmission is allocated.

In the GPON MAC, idle counting parameter informs how many GEM frames are idle through traffic monitoring for idle indication in GEM header. Using this parameter, whenever the proposed DBA recognizes idle traffic for NSR ONU, MAC controller allocates variable size of the minimum bandwidth per a polling cycle. In Figure 5, we adjust the proposed algorithm to support NSR ONUS, using a proportional value for idle NSR ONUs, to multiply it to the minimum bandwidth denoted by the parameters ABmin and SImax, in the next polling cycle. When the minimum bandwidth for NSR ONUs is stored to *request(i)* and used, the updated bandwidth allocation will be reset to the minimum bandwidth to process more data traffics if there is no idle frame in the next polling cycle and the updated. Since the proposed method only allocates full size of the ABmin, total amount of inevitable wasted bandwidth is decreased and utilization is increased. However, since bandwidth for NSR ONUs are allocated as much as the minimum, latency may be increased. However, latency and utilization are trade-off condition [10]. This simulation is assumed that NSR ONUs developed are low-cost device and they are only required for loose service.

In Figure 6, utilization of ONU(16/16) compared to ONU(24/8) is decreased earlier, but utilization at the saturation point is close to the ONU(24/8) through a proportional value to reduce the inevitable wasted bandwidth allocation by burst traffic property. At high loads, since burden traffics exist, a coefficient affects to utilization if latency is allowable about service requirements.

NSR ONUs under-utilize network performance since they do not report their queue information. If throughput and latency requirements are not strict when NSR ONUs are assumed that they only for loose service with low costs, they can be existed with SR ONUs in the same network and utilization can be increased by the proposed method controlling size of the minimum bandwidth slot ABmin for NSR ONUs in FSAN-compliant GPON DBA.

V. CONCLUSION

Since relative cost-effectiveness is affected by utilization, the GPON is a promising technology for access networks in cost-effectiveness perspective. However, if there are NSR ONUs for low costs or un-premium services, utilization of networks is severely degraded by unpredictable burst and idle traffics. To reduce inevitable underutilization, we suggest a DBA to increase link utilization of SR ONUs and to support NSR ONUs through reducing upstream allocation slot size in case sudden idle traffics. Through simulations, we show that utilization can be increased by the proposed DBA method in coexistence of SR ONUs and NSR ONUs compared to the common implicit DBA with a strict predefined payload size for NSR ONUs

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