Dynamic Bandwidth Allocation with High Utilization for XG-PON

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Abstract—**In this paper, we propose a dynamic bandwidth allocation with high utilization (DBAHU) algorithm in order to utilize the unused bandwidth of a service class. DBAHU is based on a simple and feasible dynamic bandwidth allocation (SFDBA) algorithm. Like SFDBA, DBAHU uses a common available byte counter and a common down counter for multiple queues of a service class. However, to utilize the unused bandwidth of a service class, an available byte counter can be negative unlike SFDBA. Also, the unused remainder of an available byte counter of a service class is added to available byte counters of other service classes who require more bandwidth. Using simulations, we show that DBAHU is superior to SFDBA in mean delay and frame delay variance.**

Keywords*—*Keywords: Passive Optical Network, Dynamic Bandwidth Allocation, XG-PON

I. INTRODUCTION

XG-PON (10-gigabit-capable Passive Optical Network) consists of an optical line termination (OLT) and multiple optical network units (ONUs). In order to allocate non-collision transmission slots to ONUs, the OLT receives requests from ONUs and performs dynamic bandwidth allocation (DBA).

In the XG-PON technology, the DBA result has to be produced in every frame duration time (FDT) which is fixed to 125 μs [1], [2]. It is very important whether or not a DBA algorithm can be run within the FDT. Many algorithms have been proposed for G-PON and XG-PON DBA [5]–[11]. To the best of our knowledge, however, only a GigaPON access network (GIANT) and an immediate allocation with colorless grant (IACG) algorithm have been physically implemented.

In IACG [8], each queue has an available byte counter and a down counter in order for the fast bandwidth allocation. The drawback of IACG is that an unused bandwidth of a queue cannot be used by another queues because of the dedicated available byte counter. The drawback of IACG is improved by a simple and feasible dynamic bandwidth allocation (SFDBA) algorithm [11].

SFDBA uses a common available byte counter and a common down counter for multiple queues of a service class in order to utilize the unused bandwidth of a queue. Although SFDBA provides good performance, it does not effectively utilize the unallocated bandwidth of a service class. Since an unused bandwidth of a service class cannot be used by another service classes, the bandwidth waste problem still exists in SFDBA. It is desirable that the unused bandwidth of a service class is utilized by other service classes.

In this paper, we propose a new dynamic bandwidth allocation with high utilization (DBAHU) algorithm in order to utilize the unused bandwidth of a service class. DBAHU is based on SFDBA but the unused remainder of an available byte counter of a service class is utilized by other service classes who need an additional bandwidth. Using simulations, we show that DBAHU is superior to SFDBA in mean delay and frame delay variance.

II. SIMPLE AND FEASIBLE DYNAMIC BANDWIDTH ALLOCATION

In this paper, an XG-PON system consists of a single OLT and N ONUs. Each ONU has multiple queues to support multiple service classes. A service class is called as a T-CONT (traffic-container) type in the XG-PON technology. ONU i has a queue q_{ij} for a T-CONT type j. In this paper, for the dynamic bandwidth allocation, we consider three T-CONT types: T-CONT types 2, 3 and 4. For a T-CONT type 1, a static bandwidth allocation is used in the XG-PON technology.

In the downstream direction, broadcasting mechanism is used to transmit frames from the OLT to ONUs. In the upstream direction, a time division multiple access mechanism is used to transmit frames from ONUs to the OLT. Only one ONU can transmit a frame to the OLT at a time. To allocate a non-overlapping transmission time slot to a queue of each ONU, the OLT performs a DBA operation.

Every operation of XG-PON system is synchronized with a FDT that is fixed to 125 μs. In each FDT, the OLT performs the DBA operation for an upcoming single FDT. Also the OLT allocates a dynamic bandwidth report upstream (DBRu) field to a queue of each ONU in each FDT. The OLT builds a bandwidth map (BWmap) which includes the DBA results and the DBRu allocation results in each FDT. Then the OLT broadcasts the BWmap to all ONUs. Each ONU obtains the informations of transmission time slots and DBRu fields of its queues from the BWmap. A queue q_{ij} transmits its frames during its allocated transmission time slot. Also the queue q_{ij} reports its queue length, r_{ij}, to the OLT if the DBRu field is allocated to the queue q_{ij}.

In SFDBA, all queues of a T-CONT type j use a single down counter T_j and a single available byte counter V_j. Also the queues of the T-CONT type j use a service interval parameter S_j and a maximum allocation byte parameter A_j. The down counter T_j is decreased by 1 for each FDT. When the down counter T_j has expired, the down counter T_j is recharged to S_j and the available byte counter V_j is reset to A_j. Let the grant amount of a queue q_{ij} be g_{ij}. In DBA operation, the grant g_{ij} is the minimum of the request r_{ij} and the value of

V_j. Then the OLT immediately decreases each of the request r_{ij} and the value V_j by the grant g_{ij}.

Since a single available byte counter is used for a T-CONT type in SFDBA, the unused bandwidth of a queue q_{ij} can be used by another queues of the T-CONT type j. Hence SFDBA increases the bandwidth utilization as shown in [11]. However, the unused bandwidth of a T-CONT type cannot be used by another T-CONT type in SFDBA. We show an example in Fig. 1.

r_{12}	r_{22}	V_2	T_2
50	100	50	5
r_{13}	r_{23}	V_3	T_3
0	0	200	0

Fig. 1. Bandwidth waste example of SFDBA

Suppose that ONU 1 has the highest priority in the scheduling operation in the example. Also assume that $A_2 = A_3 = 300$. Then only the request r_{12} is granted for the T-CONT type 2. Also we have $V_2 = 0$ and $r_{12} = 0$. The request r_{22} cannot be granted until V_2 is recharged despite that $V_3 = 200$ remains unused. Since $T_3 = 0$, V_3 will be recharged to $A_3 = 300$. In this example, $V_3 = 200$ is completely wasted. If we could use the unused amount $V_3 = 200$ for the T-CONT type 2, the request r_{22} should be granted.

In order to solve the bandwidth waste problem of SFDBA, we propose DBAHU algorithm. Like SFDBA, DBAHU uses the down counter T_j and the available byte counter V_j for the T-CONT type j. Also, the service interval parameter S_j and the maximum allocation byte A_j are used for the T-CONT type j. However, the available byte counter V_j can be negative. The OLT can grant the minimum of the request r_{ij} and A_j only if $V_j \geqslant 0$. The OLT immediately decreases each of the request r_{ij} and the value V_j by the grant amount.

To utilize the unused bandwidth of a T-CONT type j, the unused remainder of V_j is added to V_i, where $i \neq j$ and $V_i < A_i$. The unused remainder of V_j means the remaining positive value of V_j when DBA is finished for the T-CONT type j and $T_j = 0$. When the unused remainder of V_j is added to V_i, the priority order is T-CONT types 2, 3 and 4. For example, the unused remainder of V_3 is first added to V_2 and then V_4. When the down counter T_j has expired, V_j is increased by A_j but the maximum of V_j is limited to A_j.

Like SFDBA, since the single available byte counter is used for multiple queues, the upstream channel can be monopolized by a queue. The monopolization can be prevented by limiting the maximum grant size of a queue. Another way to prevent the monopolization is traffic policing using a leaky bucket method [13]. The traffic arrival rate of a queue is controlled by the leaky bucket method. We assume that the leaky bucket method is used in this paper for simplicity, as in [11].

Fig. 2 shows pseudo code of the grant operation of DBAHU. The variable P_j means the scheduling starting ONU number. Also the variable $alloc\_end$ denotes the end of grant operation. The variable F is the remaining bytes of FDT and its initial value is 38,880 bytes when the upstream channel speed is 2.5 Gbps. Scheduling is performed in the order of T-CONT types 2, 3, and 4.

```
// $k$ = ONU number
$k = stop = P_j$;
while(1){
    if ($V_j \geqslant 0$ and $F > 0$){
        $g_{kj} = \min(A_j, r_{kj}, F)$;
        $V_j = V_j - g_{kj}$;
        $r_{kj} = r_{kj} - g_{kj}$;
        $F = F - g_{kj}$;
    } else if ($alloc\_end = 0$ and $F = 0$){
        $P_j = k$;
        $alloc\_end = 1$;
    }
    $k$++;
    $k = k \mod N$;
    if ($k = stop$) break;
}
```

Fig. 2. Pseudo code of grant operation for T-CONT type j

Fig. 3 describes the pseudo code of the V_j update operation. The variable U is the sum of unused remainder of V_i, $i = 2, 3, 4$. That is $U = \sum_{i \in D} V_i$, where $D = \{k | T_k = 0, V_k > 0\}$.

```
$T_j = T_j - 1$;
if ($T_j = 0$){
    $T_j = S_j$;
    $V_j = V_j + A_j$;
    if ($V_j > A_j$) $V_j = A_j$;
}
if ($V_j < A_j$ and $U > 0$){
    $a = \min(A_j - V_j, U)$;
    $V_j = V_j + a$;
    $U = U - a$;
}
```

Fig. 3. Pseudo code of V_j update

For the previous bandwidth waste example of SFDBA, we apply DBAHU. Then we have $g_{12} = 50$, $g_{22} = 100$ and $V_2 = -100$ after scheduling for the T-CONT type 2. The sum of the unused remainder will be $U = V_3 = 200$. After the V_j update operation, we have $V_2 = -100 + U = 100$. Therefore we can say the unused remainder of V_3 is used by the T-CONT type 2.

Now we describe the polling method of DBAHU. The polling mechanism of DBAHU is the same as that of SFDBA. A queue q_{ij} has a polling flag PF_{ij}. The DBRu field is allocated to the queue q_{ij} when its $PF_{ij} = 0$. If the DBRu field is allocated to the queue q_{ij}, the flag PF_{ij} is set to 1.

When the down counter T_j has expired, the flag PF_{ij} is reset to 0.

In addition, DBAHU can allocate an additional DBRu field to a queue q_{ij} even when $PF_{ij} = 1$. The efficiency of DBA increases as the polling frequency increases. However, the DBRu field consumes the upstream bandwidth. To increase the DBA efficiency and to mitigate the bandwidth waste due to DBRu fields, DBAHU allocates the additional DBRu slot only when a specific condition meets. In DBAHU, the OLT allocates the additional DBRu field to the queue q_{ij} if $g_{ij} > 0$ after the grant operation and if $PF_{ij} = 1$.

III. PERFORMANCE EVALUATION

Now we compare performance of DBAHU and SFDBA using simulations. We applied the additional DBRu field scheme of DBAHU to SFDBA for a fair comparison. We consider an XG-PON system with $N = 16$ where the maximum ONU line rate is 200 Mbps and the upstream channel rate is 2.5 Gbps. Suppose that the maximum round trip time between the OLT and ONUs is 200 μs, and the ONU response time is 35 μs. The size of a queue q_{ij} is 1 Mbytes.

For the T-CONT type 2 of SFDBA, we set $S_2 = 5$ and $A_2 = 7812 \times N$. For the T-CONT types 3 and 4, we set $S_3 = S_4 = 10$. Also we use $A_3 = A_4 = 15624 \times N$. For the T-CONT type 2, 100 Mbps is given to a queue q_{i2} in average. For the T-CONT types 3 and 4, 100 Mbps is given to queues q_{i3} and q_{i4}, respectively. For DBAHU, we use the same parameters.

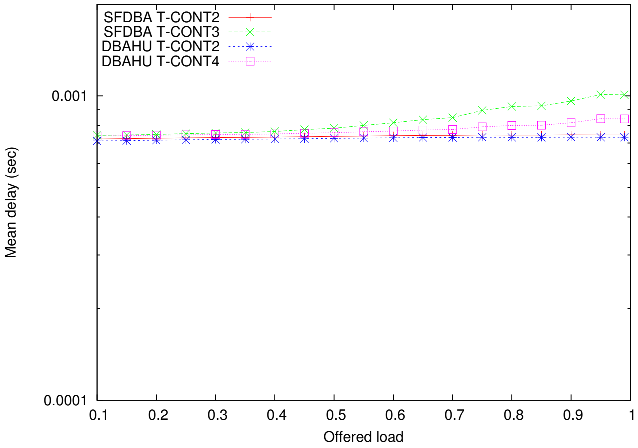

Fig. 4. Mean delay of T-CONT types 2 and 3

As in [11], we use the self-similar traffic model where each ONU is fed by a number of Pareto distributed on-off processes. The shape parameters for the on and off intervals are set to 1.4 and 1.2, respectively. Hence, the Hurst parameter is 0.8. The frame size follows the tri-modal distribution [12], where the frame sizes are 64, 500, and 1500 bytes and their load fractions are 60%, 20% and 20%, respectively as in [6]. We use an unbalanced traffic that the load rate of ONU i, $i < N/2$, is different from that of ONU j, $j \geqslant N/2$. In simulation, for $i < N/2$, the load rate of ONU i is fixed to 0.8. For $i \geqslant N/2$, we vary the load rate of ONU i from 0.1 to 0.99. For all ONUs, the load fractions of their queues are same. That is the load rate of a queue q_{ij} is 1/3 of the load rate of ONU i, where $j = 2, 3, 4$.

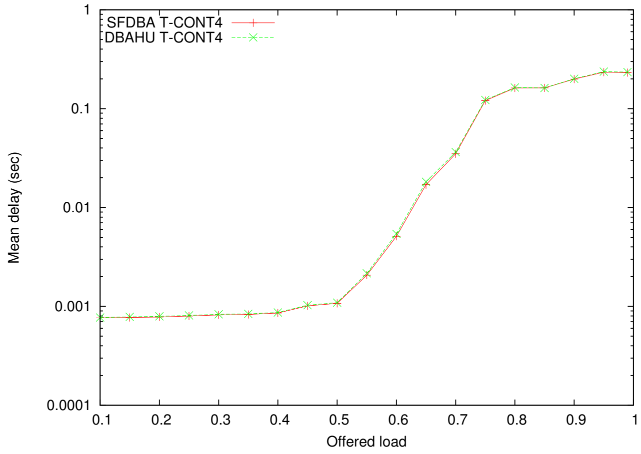

Fig. 5. Mean delay of T-CONT type 4

Each simulation is ended when the total number of frames transmitted by ONUs exceeds 10^9 for every algorithm. Figs. 4 and 5 show the mean delay of each algorithm for each T-CONT type. Note that the offered load means the input traffic load of a single ONU i in the figures where $i \geqslant N/2$.

As we can see from Figs. 4 and 5, the proposed method is better than SFDBA in mean delay for T-CONT types 2 and 3. The mean delay is improved up to 16.6% especially for the T-CONT type 3. Figs. 6 and 7 illustrate the frame delay variance of each algorithm for each T-CONT type. Figs. 6 and 7 show that the proposed method is better than SFDBA in frame delay variance for T-CONT types 2 and 3. Both methods are comparable for the T-CONT type 4 in mean delay and frame delay variance.

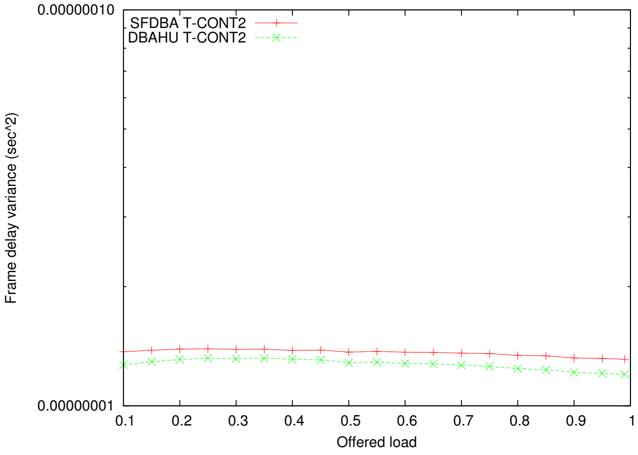

Fig. 6. Frame delay variance of T-CONT type 2

Fig. 8 illustrates the frame loss rate of each algorithm for the T-CONT type 4. The frame loss rate of DBAHU is comparable to that of SFDBA. For the T-CONT types 2 and 3, the frame loss rates are zero for both methods.

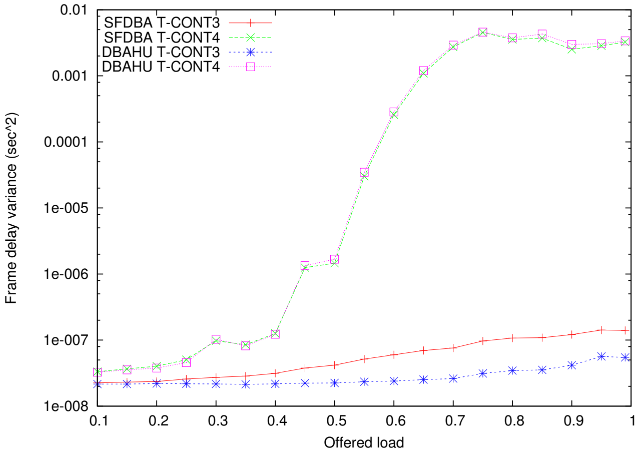

Fig. 7. Frame delay variance of T-CONT types 3 and 4

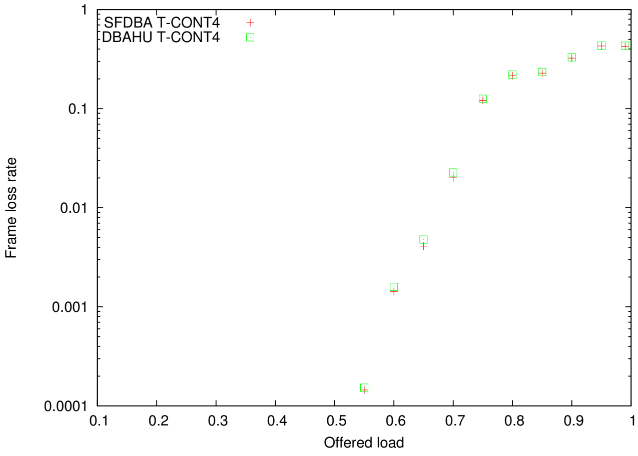

Fig. 8. Frame loss rates of T-CONT type 4

IV. CONCLUSION

We have proposed DBAHU for the dynamic bandwidth allocation of XG-PON by modifying SFDBA. In SFDBA, an unused bandwidth of a T-CONT type cannot be used by another T-CONT types. In order to solve the utilization problem of SFDBA, the available byte counter can be negative in DBAHU. Also the unused amount of the available byte counter a T-CONT type is added to the available byte counters of another T-CONT types. Using simulations, we have shown DBAHU is better than SFDBA in mean delay and frame delay variance of the T-CONT types 2 and 3.

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