A Two-Step Scheduling Algorithm to Support Dual Bandwidth Allocation Policies in an Ethernet Passive Optical Network

Ho-Sook Lee, Tae-Whan Yoo, Ji-Hyun Moon, and Hyeong-Ho Lee

ABSTRACT—In this paper, we design a two-step scheduling algorithm to support multiple bandwidth allocation policies for upstream channel access in an Ethernet passive optical network. The proposed scheduling algorithm allows us a simultaneous approach for multiple access control policies: static bandwidth allocation for guaranteed bandwidth service and dynamic bandwidth allocation for on-demand, dynamic traffic services. In order to reduce the scheduling complexity, we separate the process of the transmission start- time decision from the process of grant generation. This technique does not require the timing information of other bandwidth allocation modules, so respective modules are free from a heavy amount of timing information or complex processing.

Keywords—Ethernet, PON, EPON, DBA, SBA.

I. Introduction

The Ethernet passive optical network (EPON) is considered to be a very attractive solution for implementing fiber to the home. It has a point-to-multipoint tree topology that carries 802.3 Ethernet frames between an optical line termination (OLT) and multiple optical network units (ONU) via a passive optical splitter [1]-[4]. To share the upstream bandwidth among ONUs without collisions, robust and efficient medium access control is required [5]-[8].

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In this paper, we propose a two-step scheduling algorithm to support multiple bandwidth allocation policies in an EPON. The proposed scheduling algorithm provides a simple scheduling process to combine static bandwidth allocation (SBA) and dynamic bandwidth allocation (DBA). The main idea of the algorithm is that it separates the process of grant start-time calculation from the process of grant generation. The grant messages are generated by each module according to its own bandwidth allocation algorithm and multiplexed by the scheduler (step one) and then converged with downstream data frames (step two). In this way, we can overcome the scheduling complexity of bandwidth allocation units. The proposed scheduling algorithm does not require the timing information of every bandwidth allocation module, so respective modules need not maintain the timing data of an already scheduled grant. The large processing delay and convergence delay due to multiplexing between modules can be avoided using this algorithm.

II. An Ethernet PON Network

IEEE 802.3ah EFM (Ethernet in the First Mile) recommends the multi-point control protocol (MPCP) for medium access control (MAC) in an EPON. The MPCP is the control functionality of bandwidth requests and the permission in a PON for efficient media sharing with no collision in a point-to-multipoint segment. There are five messages for control: GATE, REPORT, REGISTER_REQ, REGISTER and REGISTER_ACK. Figure 1 shows the formats for GATE and REPORT messages. A GATE message is used for granting the transmission of ONUs, and it includes the grant length and grant start-time fields. A REPORT message is used for a bandwidth request of ONUs. REGISTER_ REQ, REGISTER and REGISTER_ACK messages are used for plug-in registration of newly entered ONUs to the EPON system.

MPCP can support both SBA and DBA schemes. In the case of SBA, the OLT generates a GATE message without a REPORT from the ONUs, so it allocates a fixed amount of bandwidth in a static manner. Obviously, SBA is simple to implement and guarantees a fixed amount of bandwidth without a request overhead so it serves the time-sensitive or constant-rate transmission services such as E1, T1 and POTS (plain old telephone service) quite well. In the case of DBA, on the other hand, it shares the bandwidth in an on-demand manner. The OLT dynamically allocates bandwidth based on the queue status of the ONUs which is informed through a REPORT message. High-bandwidth utilization is a key advantage of DBA, but it performs with only a short delay under low traffic and a longer delay under heavy traffic. Therefore, DBA serves the on-demand, dynamic traffic services quite well.

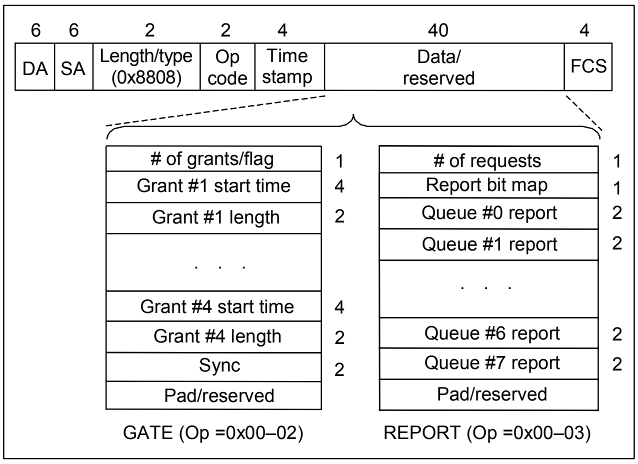

Fig. 1. MPCP control frame format.

III. Two-Step Scheduling Algorithm

1. Step 1: GATE Generation and the Grant Scheduling

The key point of the two-step scheduling algorithm is to separate the process of the transmission start-time decision from the process of GATE generation. Figure 2 shows a block diagram of the proposed scheduling algorithm. The OLT has multiple independent GATE generators for auto-discovery, SBA, minimum bandwidth, and DBA. The generated GATEs are converged using the Grant scheduler which refers to their transmission priorities.

A GATE for auto-discovery is generated for plug-in registration.

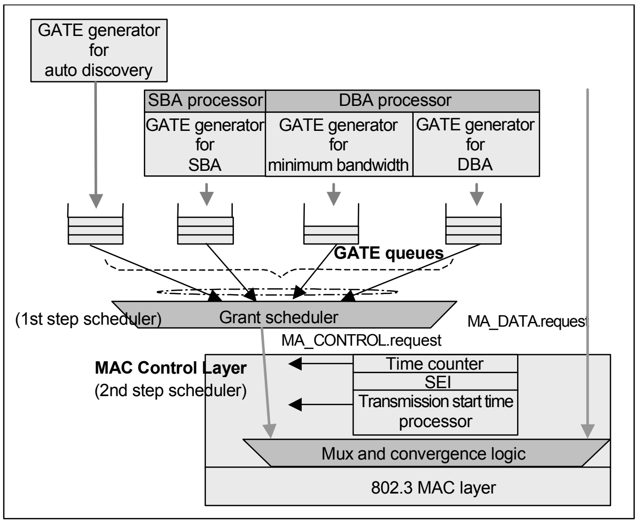

Fig. 2. Block diagram of the proposed two-step scheduling algorithm.

The OLT periodically broadcasts an auto-discovery GATE so that newly entered ONUs can respond with REGISTER_REQ in that period. A GATE for SBA is generated periodically according to SBA rule. The grant length and generation interval is fixed by provisioning. A GATE for minimum bandwidth allocation is used to get a bandwidth request from the ONUs when the OLT uses a DBA algorithm. A GATE is used for the system start-time process and polling for a silent ONU when we employ the DBA policy. The DBA scheme utilizes the rest of the available bandwidth after allocating the SBA and minimum bandwidth. When the OLT receives a REPORT from the ONUs, it allocates bandwidth for each ONU using its own DBA algorithm. In this paper, we applied interleaved-polling [6] as a DBA algorithm.

The Grant scheduler checks the four independent GATE queues sequentially to see whether each queue is empty or not. The SBA GATE queue is the highest-priority queue and is accessed first. If the SBA queue is empty, the Grant scheduler checks the next priority queue, the minimum bandwidth queue. In the same manner, the Grant scheduler executes its scheduling process to the third priority queue, the DBA queue, and to the fourth priority queue, the auto-discovery GATE queue. After this first step scheduling, the MAC control layer decides the grant start-time of the GATE considering the grant length and round-trip time (RTT) of each ONU. A GATE is finally completed by the second step scheduling as is introduced in the next section

2. Step 2: Grant Start-Time Decision

Here, we describe how to decide the value of the transmission start-time in a GATE message. The MAC control layer maintains the time counter, scheduling end-point indicator (SEI) register, and transmission start-time processor. The time counter represents a 4-byte current time and is written to the time-stamp field of each MPCP frame. The OLT synchronizes transmission between an ONU and OLT using this time counter. The SEI register represents the transmission end time using the latest scheduled GATE at the OLT. The SEI register is modified when the GATE message is transmitted using the current time-counter, the previous SEI value, and the grant length of the GATE.

The grant start-time is fixed in the following way. Es is the content of the OLT's SEI register, Tc is the current time counter, Tdur is the grant length of a permitted ONU, and Tprop is the propagation time between the OLT and an ONU (= RTT/2). It is assumed that the system has finished the discovery process and thus the OLT and ONUs are already synchronized. The absolute time relation between the OLT and a synchronized ONU can be referred to in Figs. 3 and 4.

The value of the grant start-time field is decided as follows.

If Es > Tc + RTT then
Grant start-time = Es – RTT
Es = Es + Tdur

In this case, as shown in Fig. 3, the upstream channel is already reserved by other ONUs until a further time. Thus the grant start-time should be Es – RTT, and the permitted ONU has to wait for a period of time. The OLT transmits the GATE message at the current time, Tc, and the ONU starts to transmit an upstream data-frame at Es – RTT after waiting Es – RTT – Tc from the GATE-received time. The SEI register is updated considering the grant length, Tdur.

If Es <= Tc + RTT then
Grant start-time = Tc
Es = Tc + RTT + Tdur

When the upstream channel is free at the current time, the permitted ONU can start transmission immediately without any delay, as illustrated in Fig. 4. In the above case, the grant start-time is set to the current time, Tc. The amount of bandwidth dissipation, Tc + RTT – Es, is not serious because this case indicates a non-busy status of the network.

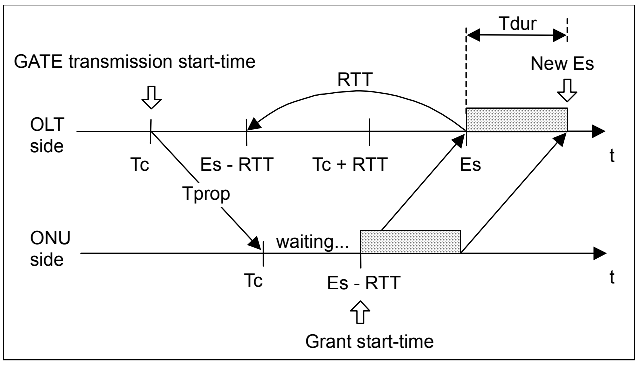

Fig. 3. Grant start-time decision when the upstream channel is reserved.

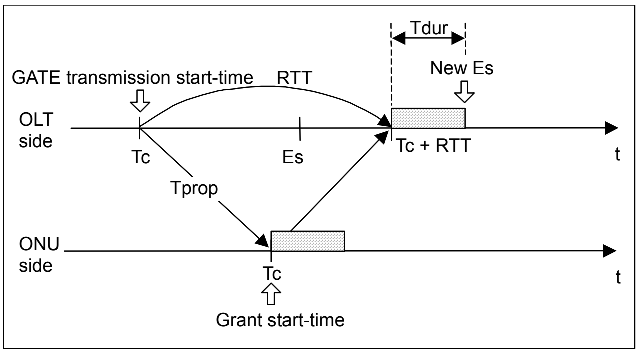

Fig. 4. Grant start-time decision when the upstream channel is free.

IV. Modeling and Simulation Results

For performance verification, we established the EPON model using an OPNET simulator. Table 1 shows the modeling environments. For the static traffic, we made up 10% of the total bandwidth using a constant-bit-rate traffic model. For dynamic traffic, we allocated the rest of the bandwidth (90%) using the general Poisson traffic model. The frame lengths are regulated using exponential distribution.

Table 1. Modeling environments.

Parameters	Values
Splitting ratio	1 : 16
Total link capacity	1 Gbps
SBA cycle time	2 ms
Average frame length	512 Bytes
* Distance	8 km
* Round trip time	35 µs

** We assume that all ONUs are at the same distance from the OLT.*

Figures 5 and 6 compared the queuing delay of the proposed two-step scheduling algorithm with SBA- and DBA-only algorithms. The offered load is a regulated total-bit-ratio at the aggregate point of the OLT, based on total system bandwidth. The proposed scheme successfully follows the performance of pure SBA or DBA. When an OLT uses the proposed algorithm, the queuing delay shows little degradation compared to pure algorithms. This is due to the fact that pure algorithms use the total link capacity, while the multiple-BA policy shares bandwidth in the proposed scheme.

Figure 7 shows the frame delay variation of the proposed scheme. The delay variation shows how much the frames preserve their arrival rate. In the case of SBA, the values of the

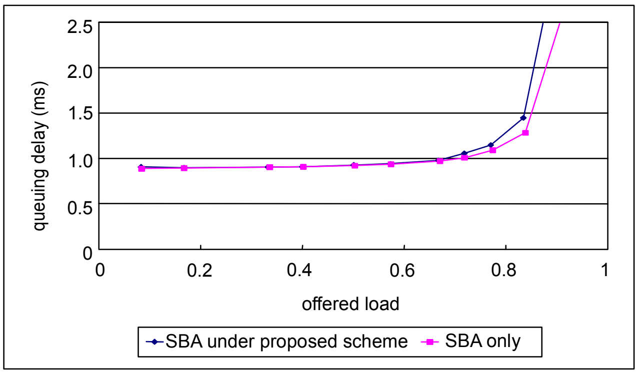

Fig. 5. Delay performance of SBA service.

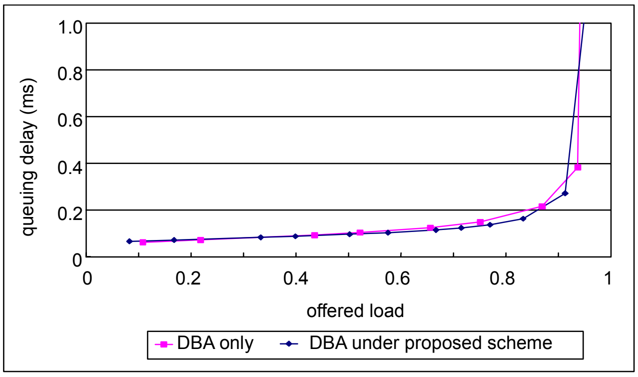

Fig. 6. Delay performance of DBA service.

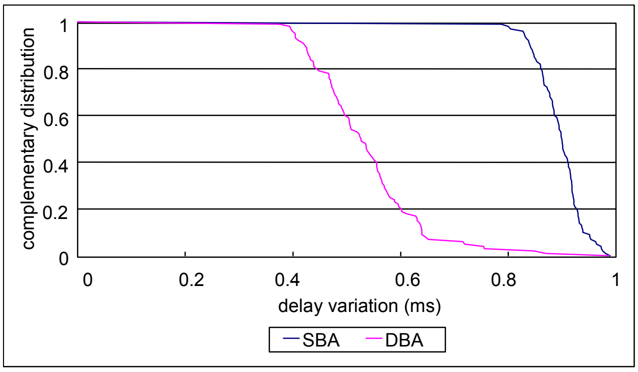

Fig. 7. Delay variation of the proposed two-step scheduling algorithm.

frame delay are distributed from 0.8 ms to 1 ms, while DBA is more widely distributed, from 0.4 ms to 1 ms. SBA preserves its original traffic pattern well, so it is applicable for constant bit rate services in a PON system.

V. Conclusion

The proposed two-step scheduling algorithm makes it possible to apply different bandwidth allocation algorithms for different services simultaneously. We can consider more than one BA policy according to the traffic characteristics serviced in an EPON system. By separating the transmission start-time decision of GATE and GATE generation, the scheduling process becomes simpler and can more easily handle the variable-sized Ethernet frames so that each scheduling module doesn't have to know the time information of the other modules. From the simulation, we found the proposed two-step scheduling algorithm shows similar queuing delay performance characteristics and service characteristics as SBA-only or DBA-only scheme.

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