Dynamic Bandwidth Allocation Algorithm for Multimedia Services over Ethernet PONs

Su-il Choi and Jae-doo Huh

ABSTRACT— Ethernet passive optical networks (PONs) are an emerging access network technology that provides a low-cost method of deploying optical access lines between a carrier's central office and a customer site. In this paper, we propose a new algorithm of dynamic bandwidth allocation for multimedia services over Ethernet PONs. To implement the suggested dynamic bandwidth allocation algorithm, we present control message formats that handle classified bandwidths in a multi-point control protocol of Ethernet PONs.

I. INTRODUCTION

Recent developments in telecommunications have produced greatly increased capacity in backbone networks. While the capacity of backbone networks has largely kept pace with the tremendous growth of Internet traffic, there has been little progress in the access network, the so-called last mile, where a bottleneck occurs between the backbone network and the high-capacity local area networks [1]. The only effective solution to this last mile bottleneck is a universal fiber-based infrastructure that is accessible to both businesses and residences. A passive optical network (PON) is a point-to-multipoint optical network with no active elements in the path of signals from source to destination. This PON technology is viewed by many as an attractive solution to the last mile problem [2], [3].

PONs consist fundamentally of an optical line terminal (OLT) located at the central office (or cable headend) and multiple remote optical network units (ONUs) that deliver broadband voice, data, and video services to subscribers. In the downstream transmission, the OLT broadcasts frames, and ONUs selectively receive frames addressed to themselves. In the upstream transmission, time division multiplexing access (TDMA) is used to avoid frame collisions. Each ONU transmits frames to the OLT using timeslots exclusively assigned to itself.

There is a simple TDMA scheme in which every ONU gets a fixed timeslot [1]. While this scheme is very simple, its drawback was that no statistical multiplexing between the ONUs was possible. An OLT-based polling scheme called interleaved polling with an adaptive cycle time [4] uses an interleaved polling approach where the next ONU is polled before the transmission from the previous one has arrived. This scheme provides statistical multiplexing for ONUs and results in efficient upstream channel utilization. However, this algorithm is not suitable for delay and jitter sensitive services or service level agreements (SLAs) because it has a variable polling cycle time.

We propose a dynamic bandwidth allocation (DBA) algorithm for multimedia services over Ethernet PONs. Quality of service does increase the effectiveness of existing bandwidth by prioritizing among packet classes and delivering time-sensitive packets first. Hence, we classified services into three priority categories. To implement the suggested dynamic bandwidth algorithm, we present control message formats which handle classified bandwidths in a multi-point control protocol (MPCP) of Ethernet PONs.

Section II describes the proposed DBA algorithm based on service classification. Section III presents the control message formats of the MPCP protocol for implementing the suggested DBA algorithm. Finally, some concluding remarks are given in section IV.

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II. DYNAMIC BANDWIDTH ALLOCATION

1. Service Classification Strategy

Quality of service is a general concept that incorporates a number of strategies for helping deliver data network traffic in an ordered manner, thereby reducing the impact of packet delay when transmission demand exceeds network capacity.

Three priority levels have been used for classification of services [4]-[6]. We also classify services into three priority categories:

First, the high priority service supports applications that require bounded end-to-end delay and jitter specifications. For example, it is used for voice and constant bit rate video services with low jitter requirements.

Second, the medium priority service implements a traffic class for applications that are not delay sensitive but that require bandwidth guarantees. It is used by variable bit rate services that are non-realtime service.

Lastly, the low priority service is provided to implement a best effort traffic class. It is not sensitive to end-to-end delay or jitter.

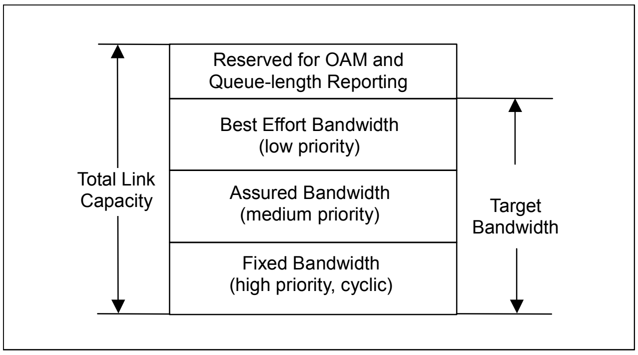

Fig. 1. Ethernet PON bandwidth.

The composition of an Ethernet PON bandwidth is shown in Fig. 1. The OLT assigns the upstream bandwidth on the basis of categorized user traffic. As bursty data traffic becomes the dominant component of network traffic, we assume an OLT can grant sufficient bandwidth for high priority and medium priority services. Time division multiplexing (TDM) services, which require a cyclic nature, low latency, and low jitter, are not automatically supported. Hence, DBA for Ethernet PONs must give cyclic bandwidth for TDM services [7].

2. Dynamic Bandwidth Allocation Algorithm

For our DBA algorithm, we use strict priority scheduling because an EPON must be compliant with bridging as defined in IEEE 802.1D [8], including compliance with the class of service mechanisms in this standard. A higher priority input which contains traffic will be serviced before a lower priority input. We suggest a new DBA algorithm as follows:

Let n be the number of ONUs that are discovered automatically, B_{total} the total bandwidth, B_{target} the target bandwidth, and B_{betc} the bandwidth for the best effort traffic class. Bandwidth for operations administration and maintenance (OAM) and queue-length reporting is reserved and assigned prior to other bandwidths. This bandwidth may be allocated consecutively to gather all of the reports within a short period. The OLT then reassigns the bandwidth periodically according to the ONU reports.

Step 1. The high priority grant bandwidth, GH_i, is assigned for high priority services. This bandwidth can be used to provide existing services (DS-1, E-1, etc). It means that fixed bandwidth is assigned for high priority services regardless of whether or not there are frames to send. Hence, the GH_i, which has a cyclic property, is obtained as

$$GH_i = BH_i, \tag{1}$$

where BH_i is the high priority provisioned bandwidth for the i-th ONU. The OAM and queue-length reporting can be handled as high priority services. In this case, GH_i contains additional bandwidth for OAM and queue-length reporting.

Step 2. The medium priority services are served before the low priority services. Hence, the medium priority grant bandwidth GM_i is assigned as follows:

$$\text{If } \sum_{i=1}^{n} RM_i \le B_{target} - \sum_{i=1}^{n} GH_i, \quad GM_i = RM_i \tag{2}$$

$$\text{else if } \sum_{i=1}^{n} RM_i > B_{target} - \sum_{i=1}^{n} GH_i, \quad GM_i = \frac{RM_i}{\sum_{i=1}^{n} RM_i}\left(B_{target} - \sum_{i=1}^{n} GH_i\right), \tag{3}$$

where $RM_i = QM_i / T_{update}$ is the medium priority request bandwidth for the i-th ONU. QM_i is the medium priority queue length from the i-th ONU.

Step 3. The low priority grant bandwidth GL_i is assigned for the best effort traffic class. By using (1)-(3), B_{betc} is obtained as

$$B_{betc} = B_{target} - \sum_{i=1}^{n} (GH_i + GM_i). \tag{4}$$

Then, GL_i is obtained as

$$GL_i = \frac{RL_i}{\sum_{i=1}^{n} RL_i} B_{betc}, \qquad (5)$$

where $RL_i = QL_i / T_{update}$ is the low priority request bandwidth for the i-th ONU. QL_i is the low priority queue length from the i-th ONU.

III. MULTI-POINT CONTROL PROTOCOL

The multi-point control protocol (MPCP) specifies a control mechanism between a master unit and slaves units connected to a point-to-multi-point (P2MP) segment to allow efficient transmission of data. The MPCP is defined as a function of the media access control (MAC) control sublayer [9]. The MPCP uses messages, state machines, and timers to control access to a P2MP topology. Every P2MP topology consists of one OLT plus one or more ONUs. Each ONU in the P2MP topology contains an instance of the MPCP protocol, which communicates with an instance of the MPCP in the OLT. Control messages for the MPCP are GATE, REPORT, REGISTER_REQ, REGISTER, and REGISTER_ACK. In Ethernet PONs, point-to-point emulation is used for compliance with the IEEE 802.1 standard.

1. Control Messages

We suggest GATE and REPORT message formats for useful multimedia services over Ethernet PONs.

The GATE message provides for broadcasting time stamps, ONU discovery, continuous ranging, and dynamic time slot allocation. The slot allocation technique is a variable TDMA scheme based on allocating a variable number of continuous time-slots to ONUs based on their slot requests or service level agreements.

Figure 2 depicts the GATE message format. The OLT periodically generates time stamped GATE messages to be used as global time references. To discover unknown ONUs, the OLT multicasts a GATE message to all registered and unregistered ONUs. In this case, the destination address contains a reserved multicast address (IEEE 802.3 full duplex PAUSE: 01-80-c2-00-00-01). The OLT assigns individual grant windows to registered ONUs by specifying the grant level, grant start time, and grant length fields. A GATE message contains grants for an ONU. A grant level is divided into low priory (LP), medium priority (MP), and high priority (HP).

Figure 3 shows the REPORT message format. REPORT messages are generated in the ONU MAC control client. The ONU transmits frames during assigned grants and requests additional bandwidth using REPORT messages. The REPORT message provides multiple queue length information on each ONU.

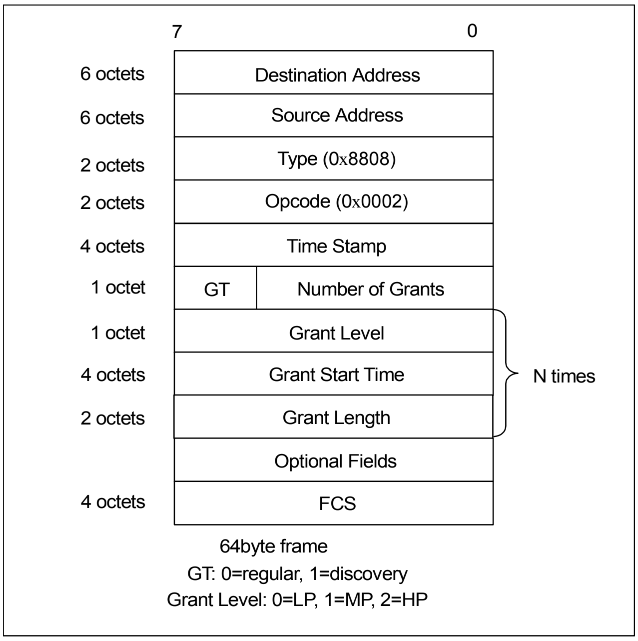

Fig. 2. GATE message.

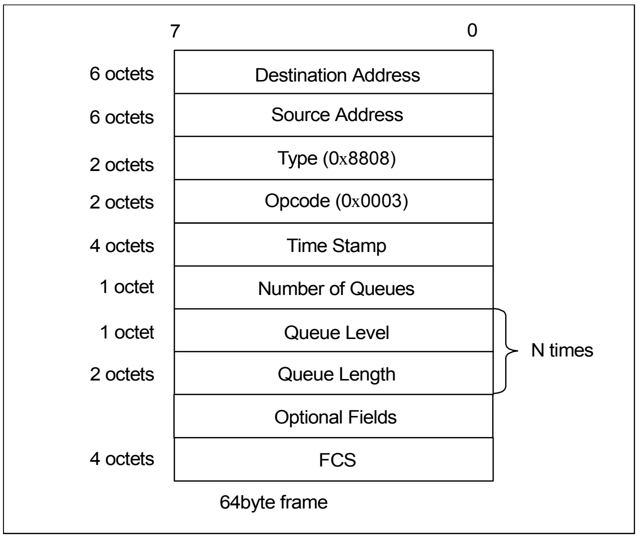

Fig. 3. REPORT message.

2. MPCP Allocation

A centralized scheduler called an MPCP allocator performs MPCP allocation. The MPCP allocator transmits and receives control frames using MAC control primitives. Figure 4 shows the functional blocks of OLT and ONU. The slot calculator of the MPCP allocator calculates grant bandwidth from the queue information of each ONU. The grant generator then generates grants for each ONU and transmits grants using a GATE message. The grant operation is similar to the PAUSE mechanism defined in the IEEE 802.3 standard. The ONU transmits frames only during the time indicated in the grant. The MPCP requestor of each ONU checks the multiple buffering status and reports queue lengths using a REPORT message. The ONU MAC control enables physical layer transmission at the start of a grant duration and disables it at the end of the grant duration by using the SingnalIndication() function.

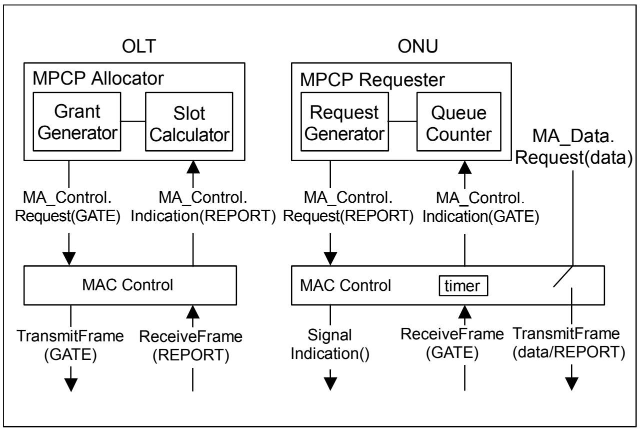

Fig. 4. Functional blocks of OLT and ONU.

3. Link Efficiency

In the Ethernet PON architecture, 1490 nm and 1310 nm wavelengths are used in the downstream and the upstream directions, respectively. The packets are formatted according to the IEEE 802.3 standard and are transmitted downstream at 1 Gbps. The number of ONUs in a PON influence link efficiency because guard bands must separate traffic from different ONUs.

Assume that the gate-report cycle is 2 ms, the guard-band is 1 µs, and 16/32/64/128 ONUs are connected to a PON. A single logical link identification is assigned for each ONU. The downstream and upstream overheads shown in Table 1 reveal that overheads for DBA of Ethernet PONs are negligible. The downstream GATE overhead, *DO*, upstream guardband overhead, UO_1, and upstream guardband plus REPORT overhead, UO_2, are obtained as follows:

$$DO = \frac{n}{2\text{ms}} \times 64\text{byte} \times \frac{8\text{bit}}{\text{byte}} \times \frac{1}{1\text{Gbps}} \times 100\%, \qquad (6)$$

$$UO_1 = \frac{n}{2\text{ms}} \times 1\mu\text{s} \times 100\%, \qquad (7)$$

$$UO_2 = \frac{n}{2\text{ms}} \times \left(1\mu\text{s} + (64\text{byte} \times \frac{8\text{bit}}{\text{byte}} \times \frac{1}{1\text{Gbps}}) \right) \times 100\%, \qquad (8)$$

where n is the number of ONUs.

Table 1. Downstream and upstream overheads.

No. of ONUs	Downstream overhead	Upstream overhead	
	GATE	Guardband	Guardband+REPORT
16	0.4 %	0.8 %	1.2 %
32	0.8 %	1.6 %	2.4 %
64	1.6 %	3.2 %	4.8 %
128	3.3 %	6.4 %	9.7 %

IV. CONCLUSIONS

We proposed a new DBA algorithm that efficiently manages various kinds of user traffic by categorizing them into three types. This DBA algorithm is suitable for multimedia services because classified bandwidths are assigned to ONUs. We also presented control message formats of the MPCP protocol for implementing the suggested DBA algorithm in Ethernet PONs.

REFERENCES

[1] G. Kramer, B. Mukherjee, and G. Pesavento, "Ethernet PON (ePON): Design and Analysis of an Optical Access Network," *Photonic Network Comm.*, vol. 3, no. 3, July 2001, pp. 307-319.

[2] G. Pesavento and M. Kelsey, "PONs for the Broadband Local Loop," *Lightwave*, vol. 16, no. 10, Sept. 1999, pp. 68-74.

[3] B. Lund, "PON Architecture 'Futureproofs' FTTH," *Lightwave*, vol. 16, no. 10, Sept. 1999, pp. 104-107.

[4] G. Kramer, B. Mukherjee, and G. Pesavento, "Interleaved Polling with Adaptive Cycle Time (IPACT): A Dynamic Bandwidth Distribution Scheme in an Optical Access Network," *Photonic Network Comm.*, vol. 4, no. 1, 2002, pp. 89-107.

[5] ANSI/IEEE Std. 802.17, *IEEE Standard for Resilient Packet Ring Access Method and Physical Layer Specifications*, Proposed Draft 1.0 (Darwin), Jan. 29, 2002.

[6] M. Fine, K. McCloghrie, K. Chan, S. Hahn, C. Bell, A. Smith, and F. Reichmeyer, *Differentiated Services Quality of Service Policy Information Base*, Internet-Draft draft-ietf-diff-pib-0.9.txt, June, 2002.

[7] V. Bemmel, "MPCP and TDM Services," IEEE 802.3ah EFM, St. Louis, MO, Mar. 12, 2002: URL (http://www.ieee802.org/3/efm/public/mar02/bemmel_1_0302.pdf).

[8] ANSI/IEEE Std 802.1D, *Part 3: Media Access Control (MAC) Bridges*, 1998.

[9] IEEE Draft P802.3ah/D1.0TM, *Media Access Control Parameters, Physical Layers and Management Parameters for Subscriber Access Networks*, Aug. 19, 2002.