A new Hybrid SPD-based Scheduling for EPONs

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***Abstract*—Dynamic bandwidth allocation (DBA) is a key issue of Ethernet PONs. In order to get higher resource utilization and lower packet delay, the problem is always dissolved into grant sizing and grant scheduling. In this paper, we explore grant scheduling techniques. We propose a modified hybrid online and offline scheduling with the shortest propagation delay (SPD) first policy (we named HSPD) which can compensate for the idle time under light or medium loaded traffic. Meanwhile, the last ONU in offline set is adaptively indicated to transmit REPORT frame first (called LRF), so the idle time can be eliminated especially under heavy loaded traffic. We evaluate the cycle length and average packet delay through analysis and simulations. Compared with the offline SPD first scheduling (we named it OSPD), and online and offline scheduling with excess bandwidth distribution (so-called M-DBA1), we find out our algorithm HSPD-LRF can achieve significant improvements in terms of average packet delay and channel utilization.**

Keywords*—DBA; Online; Offline; Hybrid SPD-based Scheduling (HSPD); Last REPORT First (LRF).

I. INTRODUCTION

Passive optical network is a point-to-multipoint (P2MP) optical network without active elements in the path, where an optical line terminal (OLT) at the center office (CO) is connected to many optical network units (ONUs) at remote nodes through passive elements such as 1:N optical splitters. The network use a single wavelength in each of the two directions—downstream and upstream, and the wavelengths are multiplexed on the same fiber through coarse WDM (CWDM). In the downstream direction, packets are broadcast by the OLT and extracted by the destination ONU. While in the upstream direction all the ONUs share a single wavelength channel by time division multiple access (TDMA). Since the passive optical splitters are not able to inspect the upstream collision, it is the OLT who acts as the arbiter that grant time-slots (transmission windows) to the ONUs by a certain scheme. In order to avoid packets collision and to utilize the upstream channel efficiently, a dynamic bandwidth allocation (DBA) is required. Ethernet PONs (EPONs) technology has been standardized by the IEEE 802.3ah Ethernet in the First Mile (EFM) Task Force, which aims at combining the low-cost equipment, simplicity of Ethernet, the low-cost fiber infrastructure and high bandwidth of PONs. However IEEE 802.3ah does not prescribe any scheme of the upstream data transmission, but devises the multipoint control protocol (MPCP) which defines message-based mechanism to control information exchange between the OLT and ONUs. The shceme of upstream data transmission is left for choice of vendors. Dynamic bandwidth allocation (DBA) algorithms for EPONs have become a key issue and have been paid considerable attention from both industry and academia in recent years.

Basically, DBA algorithms that have been presented in literatures for EPONs can be divided into grant sizing and grant scheduling. The grant sizing determines the size of the upstream transmission window granted for an ONU. While the grant scheduling determines the beginning time of the upstream transmission granted for an ONU. These two aspects can be not separated. Grant sizing algorithms have been proposed in [5]-[9]. In [9], Kramer *et al.* proposed the IPACT algorithm in which the OLT polls the ONUs in a round-robin way and dynamically assigns them bandwidth according to different approaches and indicated that the limited service has the best performances. Many literatures proposed excess bandwidth allocation algorithms [2][5][6], or prediction mechanisms, based on the limited service [7]. Grant scheduling techniques have been proposed in [1]-[4]. The authors in [4] partition the scheduling problem into (1) a scheduling framework and (2) a scheduling policy operating within the adopted framework. McGarry *et al.* [3] outlines two basic

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grant scheduler as online and offline. In an online scheduler any ONU is scheduled for upstream transmission as soon as the OLT receives its REPORT message. In an offline scheduler the ONUs are scheduled for transmission of the next cycle once the OLT has received all REPORT messages from all ONUs. So online scheduling has great efficiency but lacks QoS control since the OLT makes scheduling decisions based on individual request without global knowledge of the current bandwidth requirements of the other ONUs. Offline scheduling allows OLT to take into consideration of the current bandwidth requirements from all ONUs, thus, it enables the wide variety of QoS mechanisms. On the other hand, it conducts idle time in upstream channel since OLT has to wait all REPORT frames from all ONUs.

In this paper, we aim at resolving the idle time issue of offline scheduling. In order to shorten or eliminate the fixed idle time of offline scheduling, we combine the online & offline scheduling based on limited service and sort the overloaded ONUs in ascending order by their propagation delays before scheduling in offline framework. Meanwhile in our proposed scheduling the last ONU is put into the offline scheduling set and the ONU with the largest propagation delay in the offline set transmits REPORT frame before its data in the next cycle. Since the ONUs in offline scheduling always have large enough data transmission window, the idle time can be compensated especially under heavy traffic. Importantly, the whole algorithm is very simple to implement.

The rest of this paper is organized as follows. In Section II, we discuss the related work on dynamic bandwidth allocation algorithms. In Section III, we analyze the idle time problem in offline scheduling and present the HSPD-LRF scheduling. In Section IV, we provide the performance result of simulations. In Section V, we conclude the paper.

II. RELATED WORK

Assi *et al.* [5] proposed an excessive bandwidth distribution that left from the underloaded ONUs amongst the overloaded ONUs (so-called DBA1). In order to implement the excessive bandwidth distribution, it for the first time employ a combined online and offline scheduling in which ONUs with requests smaller than its minimum guaranteed window sizes are scheduled immediately while those with larger requests would be scheduled when OLT have received all of the REPORT frames. Since DBA1 grants the total excess bandwidth to the overloaded ONUs, it sometimes mistakenly leaves most of the available bandwidth idle. Based on DBA1, Shami *et al.* in [6] proposed an improved dynamic bandwidth allocation algorithm called M-DBA1 which grants bandwidth to overloaded ONUs based on a comparison of total excess bandwidth saved by underloaded ONUs with total extra demand bandwidth of the overloaded ONUs. Bai *et al.* [8] improved the procedure for allocating excess bandwidth. Nevertheless, the algorithms mentioned above only focus on the grant sizing but not grant scheduling. They did not present any optimal scheduling policy but employed the simple first come first schedule (FCFS) scheme in the hybrid online and offline scheduler.

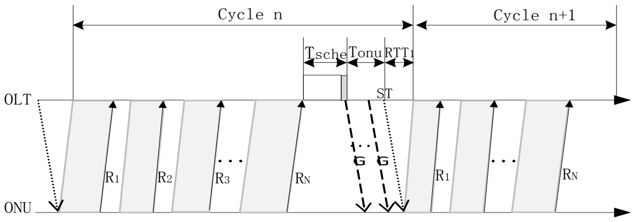
In [2], J. Zheng proposed a mechanism in which OLT always schedules underloaded ONUs before overloaded ONUs as well as possible. OLT maintains a time tracker to record the ending time of last scheduled ONU. When the upstream channel is going to be idle, an overloaded ONU is scheduled without extra excessive bandwidth if necessary. Thus, the upstream transmission channel is not idle between granting cycles.

In [1], McGarry *et al.* presented a scheduling algorithm that employs the shortest propagation delay first (SPD) policy in offline framework. OLT sorts all ONUs in ascending order by their propagation delays before scheduling. Thus, the long round trip propagation delay can be masked by scheduling the near-by ONUs first.

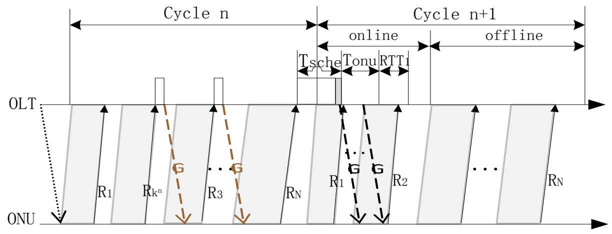
III. HSPD-LRF ALGORITHM

Since an offline scheduler makes scheduling decision for all ONUs at once, this requires that the scheduling algorithm be implemented after the OLT receives the end of the last ONU's REPORT frame. Thus, as illustrate in Figure 1(a), a fixed idle time between scheduling cycles is introduced. It is composite of the followings:

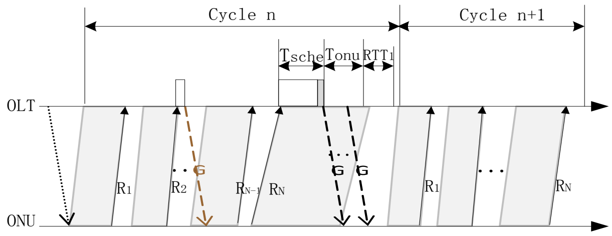
- The computation time of the scheduling in OLT T_{sche}.
- The transmission time for the grant (64 bytes) frame which can be regarded as part of scheduling time T_{sche}.
- The processing time of the ONU scheduled in the next



(a) Offline Scheduling Framework



(b) Online and Offline (Hybrid) Framework



(c) LRF based Online and Offline Scheduling (Hybrid) Framework

Fig. 1 Different scheduling frameworks

cycle T_{onu}.

- The RTT of the first ONU scheduled in the next cycle RTT_1^{off}.

  So, we get:

$$T_{idle} = T_{sche} + T_{onu} + RTT_1^{off} - T_g \qquad (1)$$

where T_g is the guard time between two consecutive transmission windows of two different ONUs. When the ONUs are scheduled based on SPD first policy, the RTT of the first ONU can be reduced to the minimum value. So, idle time in offline scheduler is shortened. Described as:

$$T_{idle}^{MIN} = T_{sche} + T_{onu} + RTT^{MIN} - T_g \qquad (2)$$

However, the SPD based offline scheduling still has a fixed waste of idle time in upstream channel which reduces the channel utilization. In this paper, we employ a hybrid online and offline scheduling based on limited service and make changes in some aspects to address the idle time issue. First of all, all ONUs are divided into two sets according to their bandwidth requests which is given by (3). Those having bandwidth requests smaller than their minimum guaranteed windows are ascribed to light loaded set K and scheduled as soon as OLT receives their REPORT messages, the others are ascribed to over loaded set M and scheduled all at once according to their propagation delays sorted in ascending order after OLT receives the last REPORT message. Thus, the excessive bandwidth of underloaded ONUs can be used to meet the bandwidth demand of overloaded ONUs in each transmission cycle.

$$ONU_i \in \begin{cases} K, & R_i \le B_i^{MIN} \\ M, & R_i > B_i^{MIN} \end{cases} \qquad (3)$$

As illustrated in Figure 1(b), if the first ONU who has request smaller that its minimum guaranteed window in the n*th* cycle is the k^n *th* to come. So, we get (4), which means the upstream channel idle time caused by the large RTT of the first ONU that belong to set K in the (n+1)*th* cycle and (5) which means the upstream channel idle time caused by the large RTT of the first ONU that belong to set M in the (n+1)*th* cycle. In the following, W_i is the transmission window length (time length) of the i*th* ONU in the n*th* cycle. R_j is the request length (time length) of the j*th* ONU. If both (4) and (5) are obtained simultaneously, we can achieve shorter idle time than the minimum idle time T_{idle}^{MIN} of the SPD based offline scheduling.

$$\sum_{i=k^n+1}^{N}\left(W_i + T_g\right) + T_{idle}^{MIN} + T_g \ge T_{sche} + T_{onu} + RTT_1^{on} \qquad (4)$$

$$\sum_{j \in K^{n+1}}\left(R_j + T_g\right) + T_{idle}^{MIN} + T_g \ge T_{shce} + T_{onu} + RTT_1^{off} \qquad (5)$$

Here, we get：

$$\sum_{i=k^n+1}^{N}\left(W_i + T_g\right) + RTT^{MIN} \ge RTT_1^{on} \qquad (6)$$

$$\sum_{j \in K^{n+1}}\left(R_j + T_g\right) + RTT^{MIN} \ge RTT_1^{off} \qquad (7)$$

A specific situation is when $k^n = N$, that means only the last ONU (the N*th* ONU) has smaller request, so, the transmission window $(W_i + T_g)$ in (6) is nothing. Thus, only when $RTT_1^{on} = RTT^{MIN}$ could we get no longer idle time than T_{idle}^{MIN} if the last ONU is scheduled in online set. Due to this, the last ONU is always put into offline set. That means $ONU_N \in M$. Also we can see from (7) that the more elements in set K, the better.

When the traffic is getting heavier, more and more ONUs belonged to overloaded set M. So, the underloaded ONUs may not be able to compensate the idle time. In this situation, the last ONU of set M is indicated to transmit REPORT frame before its data, see Fig. 1(c). Since the ONUs in set M always has long enough data transmission window, it can always compensate the idle time. Specifically, this is easily executed by redefining the MPCP GATE frame granting to the ONUs. It is assumed that the general GATE frame can offer no more than 3 grants to an ONU, which means the valid range of the GATE number is from 0~3. As shown in Figure 2, the combining of the most significant bit and the third bit from the right of the Number/Flag byte in GATE frame can be defined as the indication of transmitting REPORT first.

IV. Performance Evaluation

To evaluate the performances such as the average cycle time, the average packet delay and channel utilization of the proposed LRF-based hybrid scheduling which we call HSPD-LRF, a simulation model comprising an access network with one OLT, and 16 ONUs was developed using C++. Here, channel utilization was defined as the ratio of the sum of pure data transmission windows to the cycle time. The pure data transmission window did not include the overheads, such as Preamble, IPG and the REPORT frame that attached. In the simulation, the equal weighted limited grant sizing with excess bandwidth distribution [6] is employed. In addition, the traffic of each ONU was generated with the properties of self-similarity and long-range dependence, and the Hurst parameter was set to 0.8. The maximum cycle time was assumed to be 2ms. The guard time between two consecutive transmission windows of two different ONUs was 1μs. The corresponding minimum guaranteed window size, B_i^{MIN}, was set

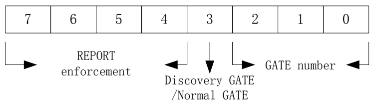


Fig. 2 Number/Flag byte in MPCP GATE

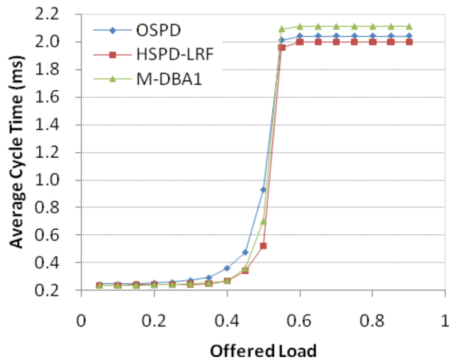


Fig. 3 Average cycle time versus traffic load

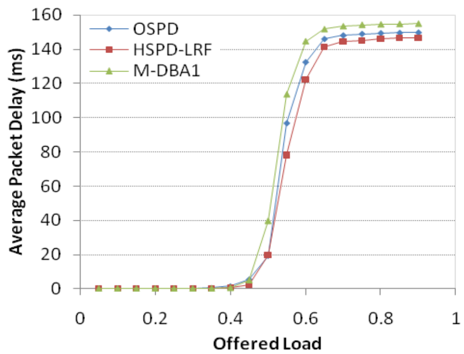


Fig. 4 Average packet delay versus traffic load

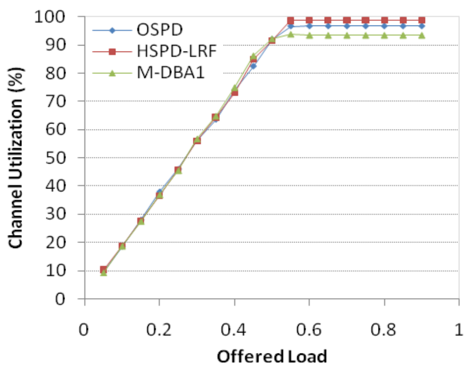


Fig. 5 Channel utilization versus traffic load

to15500 bytes. In order to explicit the impact of the diversity of propagation delays, the one-way propagation delays between the ONUs and the OLT were randomly generated according to a uniform distribution with a minimum value of

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10μs and a maximum value of 200μs to represent the distance between 1km and 20km. Among others, one ONU had the minimum propagation delay, 10μs, and another had the maximum propagation delay, 200μs. The performances of the offline SPD based scheduling (OSPD) and the so-called M-DBA1 algorithm were also illustrated as comparison.

Figure 3 shows that the overall cycle time of the proposed algorithm is shortened compared with OSPD scheduling. When the traffic load is getting heavier (load > 0.4), HSPD-LRF has the shortest cycle time because it efficiently eliminates the idle time. Figure 4 shows the average packet delay versus offered load. Again the proposed algorithm has the best performance for all traffic load. Figure 5 is the channel utilization. Under heavy traffic load, the proposed algorithm achievs about 98.6% channel utilization which actually means there is no idle time wasted because the channel utilization was calculated using the pure data transmission windows without the overheads and the REPORT frames, which in fact occupy the upstream channel.

V. CONCLUSION AND FUTURE WORK

This study has presented a modified hybrid online and offline scheduling algorithm for EPONs, in which the underloaded ONUs are scheduled instantaneously without any delay, and the idle time issue is solved by adaptively employing the last REPORT first scheme when the traffic load is getting heavier. Specifically, the whole algorithm is executed simply since it only needs to sort the overloaded ONUs once before they are scheduled in offline mode as well as the OLT indicate the last ONU in overloaded set to transmit REPORT before its data based on slightly modified MPCP GATE frame when necessary. Through simulation results, the proposed algorithm has demonstrated that it can significantly improve the network performance in terms of packet delay and channel utilization as compared with the SPD-based offline scheduling and the well known M-DBA1 algorithm proposed in [6]. However, this study only investigated the network performances of the single channel EPON system. In the future work, the authors will investigate the issues in the multi-channel EPON, such as WDM EPON system.

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