Cyclic polling-based dynamic wavelength and bandwidth allocation in wavelength division multiplexing passive optical networks

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Cyclic polling-based dynamic wavelength and bandwidth allocation algorithm supporting differentiated classes of services in wavelength division multiplexing (WDM) passive optical networks (PONs) is proposed. In this algorithm, the optical line terminal (OLT) polls for optical network unit (ONU) requests to transmit data in a cyclic manner. Services are categorized into three classes: expedited forward (EF) priority, assured forwarding (AF) priority, and best effort (BE) priority. The OLT assigns bandwidth for different priorities with different strategies. Simulation results show that the proposed algorithm saves a lot of downstream bandwidth under low load and does not show the light-load penalty compared with the simultaneous and interleaved polling schemes.

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Wavelength division multiplexing (WDM) passive optical network (PON) has been considered as an attractive solution for next generation broadband access network due to their large capacity, strong security, and high flexibility[1]. Compared with the time division multiplexing (TDM) PONs such as Ethernet passive optical network (EPON)[2] and gigabit-capable passive optical network (GPON), WDM PON has two important differences: it deploys several wavelengths for upstream/downstream transmission, and there are wavelength selective components in the optical distribution network (ODN). Therefore, the bandwidth allocation problem varies from one dimension (time dimension) to two dimensions (wavelength and time dimensions). Clearly, the bandwidth allocation algorithms used in TDM PON[3] cannot be applied to WDM PON directly.

As yet, there are some wavelength and bandwidth allocation schemes proposed by researchers. Associated with wavelength assignment and leap foreword visual clock algorithm, Qiu *et al*. proposed a media access control protocol based on flow for WDM PON[4]. Kim *et al*. proposed a dynamic ratio scheme in WDM PON with loop-back scheme, where part of the downstream light is used for upstream source[5]. The drawback of this scheme was that no statistical multiplexing between the optical network units (ONUs) was possible. Kim *et al*. suggested a batch scheduling algorithm for SUCCESS WDM PON[6]. Hsueh *et al*. proposed the scheduling algorithms with quality of service (QoS) support for SUCCESS dynamic wavelength allocation (DWA) PON which employed DWA to provide bandwidth sharing across multiple physical PONs[7]. Kwong *et al*. proposed a WDM interleaved polling with adaptive cycle time (IPACT) with a single polling table (WDM IPACT-ST)[8]. In the WDM IPACT-ST, transmission windows are assigned to ONUs in a round robin fashion allowing them to transmit in the first available upstream channel. Clarke *et al*. proposed the simultaneous and interleaved polling with adaptive cycle time (SIPACT) algorithm for WDM PON[9]. In the SIPACT, ONUs can be polled simultaneously on separate wavelengths, and then interleaved polling can be employed when it is not possible to poll simultaneously. SIPACT provides statistical multiplexing for ONUs and results in efficient upstream channel utilization. However, the drawback of this algorithm is that it reduces the downstream link capacity when the load is light. And it is not suitable for delay and jitter sensitive services or service level agreements (SLAs) because of the variable polling cycle time.

In this letter, we suggest a cyclic polling-based dynamic wavelength and bandwidth allocation (DWBA) algorithm for differentiated classes of service for WDM PONs. It can eliminate or mitigate the light-load penalty by using a cyclic polling scheme. The traffic is classified into three classes and the classified queue information is used to assign dynamic bandwidth to each ONU.

Figure 1 illustrates the cyclic polling-based algorithm. At the beginning of each cycle, the optical line terminal (OLT) assigns wavelength and timeslot for all ONUs according to the following strategy.

1) The OLT calculates the bandwidth assigned to each ONU by

$$G_i = \begin{cases} R_i, & \sum\limits_{i=1}^{N} R_i \le B_{\text{total}} \\ \left(R_i / \sum\limits_{i=1}^{N} R_i\right) \cdot B_{\text{total}}, & \sum\limits_{i=1}^{N} R_i > B_{\text{total}} \end{cases}, \quad (1)$$

where G_i and R_i denote the grant bandwidth and the request bandwidth of the ith ONU, respectively, and B_{total} is the total bandwidth that can be allocated to all ONUs in each cycle.

2) The OLT maintains a variable for every channel that designates the time T^k_{free} for wavelength k when the next transmission is possible on that particular channel. According to the index number of ONUs, the OLT

allocates a channel with the least T_{free}^k and the assigned bandwidth to all ONUs in turn.

Then each ONU reports the bandwidth request following its transmission. After receiving all reports of ONUs, the OLT turns into the next cycle. The cyclic polling-based scheme is useful to support SLA control parameters such as minimum bandwidth/timeslot and maximum bandwidth/timeslot for every ONU. When SIPACT is applied, the requested amount of timeslot is allocated by the OLT. Furthermore, the request-related timeslot allocation is necessary to compensate for the drawback of the fixed polling time when the cyclic polling scheme is applied.

An event-driven packet-based simulation model is developed using C++. Table 1 summarizes the parameters used in the simulation experiments. Here, we set the cyclic polling time (T_{cycle}) to be 2 ms, based on the SLA for ONUs. Specification can be found in Ref. [10]. To obtain an accurate and realistic performance analysis, the synthetic self-similar traffic is generated. When the traffic is generated to an ONU, the frames should be buffered in the ONU until the ONU is allowed to transmit the frames. The frame delay is defined to be the time between the arrival from a traffic source and the departure to the OLT.

Table 1. Simulation Parameters

Description	Value
Number of ONUs N	64
Number of Wavelength (Upstream)	4
Number of Wavelength (Downstream)	4
Line Rate of ONU Link	100 Mb/s
EPON Line Rate	1 Gb/s
Distance between ONU and OLT	5 – 20 km
Network Traffic	Pareto Distribution
Guard Time	1 μs
Cyclic Polling Time T_{cycle}	2 ms
Maximum Cycle Time of SIPACT	2 ms

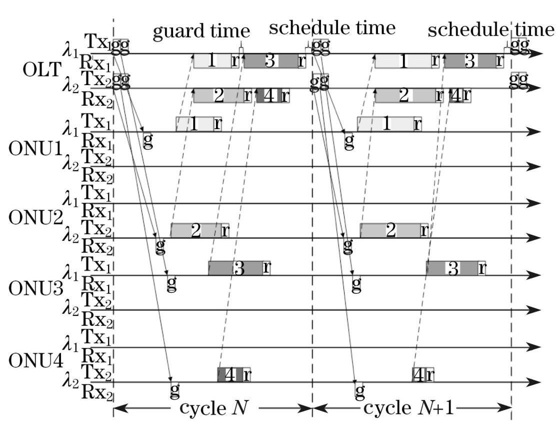

Fig. 1. Cyclic Polling-based DWBA algorithm.

Figure 2 shows the average packet delay for SIPACT and the cyclic polling-based DWBA. From Fig. 2, it is seen that the cyclic polling-based DWBA has a longer packet delay than SIPACT under a low traffic load. It is because the polling cycle time of SIPACT is adaptive and is smaller than that of cyclic polling-based DWBA.

Figure 3 shows the available downstream bandwidth for SIPACT and the cyclic polling-based DWBA. It is seen that SIPACT consumes a lot of downstream bandwidth by transmitting GATE messages to every ONU at each polling cycle, because SIPACT allows a shorter polling time than cyclic polling-based DWBA under a low traffic load.

As to the cyclic polling-based DWBA, the downstream bandwidth used by GATE message can be calculated by

$$B_{\text{gate}} = N \times \frac{L_{\text{gate}}}{R} \times \frac{1}{T_{\text{cycle}}} \times 100\%, \qquad (2)$$

where N is the number of ONUs, R is the total line rate, and L_{gate} and T_{cycle} denote the length of GATE message and the polling cycle time, respectively.

The cyclic polling-based DWBA consumes 0.4096% of the downstream bandwidth steadily. However, the downstream bandwidth consumption of SIPACT is variable with the ONUs traffic load. SIPACT consumes almost 15% of downstream bandwidth under a low traffic load. Namely, large downstream bandwidth is wasted by GATE messages. This is the disadvantage of SIPACT, while the cyclic polling-based DWBA shows better performance.

Figure 4 shows the available upstream bandwidth for SIPACT and the cyclic polling-based DWBA. It is seen that the available upstream bandwidth of cyclic polling-based DWBA is constant with various offered ONU loads. However, that of SIPACT is various with different offered ONU loads, because of the various polling time

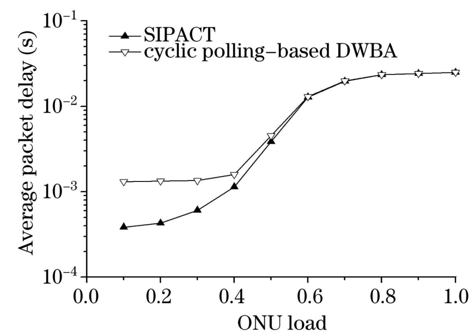

Fig. 2. Average packet delay.

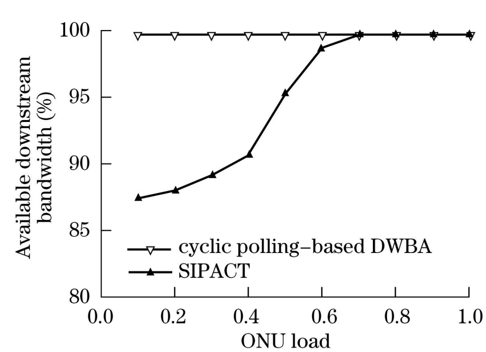

Fig. 3. Available downstream bandwidth.

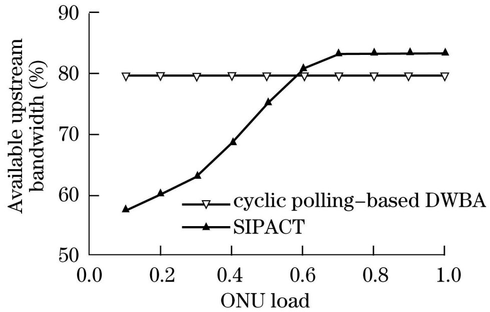

Fig. 4. Available upstream bandwidth.

of SIPACT. When the traffic load is low, the available upstream bandwidth of cyclic polling-based DWBA is much larger than that of SIPACT.

Subsequently, we will give the bandwidth allocation scheme considering the class of service. Here, the services of ONUs are classified into three priority categories: expedited forwarding (EF) service supporting applications that require bounded end-to-end delay and jitter specifications, assured forwarding (AF) service implementing a traffic class for applications that are not delay sensitive but require bandwidth guarantees, best effort (BE) service providing a best effort traffic class. Each ONU maintains three separate priority queues for different service classes. Packets are first segregated and classified and then placed into their appropriate priority queues. To support differentiated classes of services, a priority-based scheduling scheme proposed in Ref. [11] for bandwidth management and fair scheduling of different traffic classes is employed in the ONU.

Now, we suggest a cyclic polling-based DWBA algorithm using classified queue information. Let N be the number of ONUs. The grant bandwidth G_i for the ith ONU is obtained as follows.

1) Let G_i^{EF} denotes the bandwidth assigned for EF priority services. A fixed bandwidth is assigned for EF priority services regardless of whether there are frames to be sent. Therefore, we have $G_i^{\mathrm{EF}} = B_i^{\mathrm{EF}}$, where B_i^{EF} is the EF priority guaranteed bandwidth for the ith ONU. Furthermore, the bandwidth of the EF priority services is no more than the guaranteed bandwidth at any time.

2) Let G_i^{AF} denote the bandwidth assigned for AF priority services. Because AF priority services are served before BE priority services, the AF priority grant bandwidth G_i^{AF} is assigned as

$$G_i^{\mathrm{AF}} = \min\left(R_i^{\mathrm{AF}}, \left(B_{\mathrm{total}} - \sum_{i=1}^{N} G_i^{\mathrm{EF}}\right) \frac{R_i^{\mathrm{AF}}}{\sum_{i=1}^{N} R_i^{\mathrm{AF}}}\right), \quad (3)$$

where R_i^{AF} is the AF priority request bandwidth for the ith ONU.

3) Let G_i^{BE} denote the bandwidth assigned for BE priority services. Then, G_i^{BE} is obtained as

$$G_i^{\mathrm{BE}} = \min\left(R_i^{\mathrm{BE}}, \left(B_{\mathrm{total}} - \sum_{i=1}^{N} (G_i^{\mathrm{EF}} + G_i^{\mathrm{AF}})\right) \frac{R_i^{\mathrm{BE}}}{\sum_{i=1}^{N} R_i^{\mathrm{BE}}}\right), \quad (4)$$

where R_i^{BE} is the BE priority request bandwidth for the ith ONU.

4) Then, the total grant bandwidth G_i is obtained as

$$G_i = G_i^{\mathrm{EF}} + G_i^{\mathrm{AF}} + G_i^{\mathrm{BE}}. \quad (5)$$

In the simulation, we used the same parameters as summarized in Table 1. There are three main modes corresponding to the most frequent frame sizes: 64 B, 582/594 B, and 1518 B. For EF priority services, emulation of a T1 connection is considered. This service consumes 4.48 Mb/s of bandwidth. For AF priority service, variable bit rate (VBR) video streams that exhibit properties of self-similarity and long-range dependence (LRD) is considered. For BE priority service, non-real-time data transfer is considered.

The network performance of the cyclic polling-based DWBA is compared with that of SIPACT when strict priority scheduling defined in IEEE 802.1D is applied to each ONU. From Fig. 5, we can see that the average packet delay of SIPACT is variable with the ONU loads. As the traffic load decreases from moderate to very light, the average delay increases significantly. This phenomenon is referred to as light-load penalty. From Fig. 6, it is seen that the average packet delay of cyclic polling-based DWBA for EF priority class is constant with various offered ONU loads. Furthermore, the cyclic polling-based DWBA does not show the light-load penalty.

Figure 7 shows the average delay jitter of a randomly selected ONU at different loads for both SIPACT algorithm and cyclic polling-based DWBA. It is seen that the average delay jitter of cyclic polling-based DWBA is constant and smaller than that of SIPACT algorithm when the traffic load increases from moderate to very heavy. Therefore, it is useful for predicting the delay property of import service for end-users without considering the load variation.

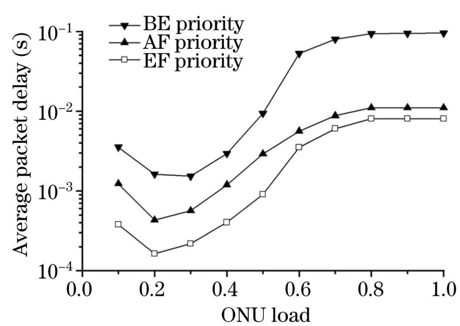

Fig. 5. Average packet delay of SIPACT.

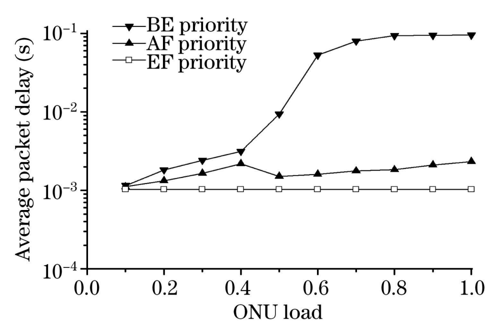

Fig. 6. Average packet delay of cyclic polling-based DWBA.

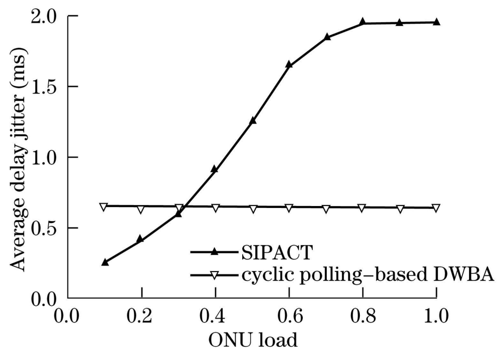

Fig. 7. Average delay jitter.

In conclusion, when the traffic load is low, the cyclic polling-based DWBA algorithm for differentiated classes of services can save a lot of downstream bandwidth without showing the light-load penalty compared with the SIPACT algorithm.

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