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RESEARCH ARTICLE

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QoS-aware dynamic bandwidth allocation algorithm for Gigabit-capable PONS

Abstract The Gigabit-capable passive optical network (GPON) technology is being considered as a promising solution for the next-generation broadband access network. Since the network topology of the GPON is point-to-multipoint, a media access control called dynamic bandwidth allocation (DBA) algorithm is an important factor for determining the performance of the GPON. In this paper, we propose a new DBA algorithm to effectively and fairly allocate bandwidths among end users. This DBA algorithm supports differentiated services—a crucial requirement for a converged broadband access network with heterogeneous traffic. In this article we first reviewed the signaling and configuration of the DBA, and then proposed a new DBA scheme that implemented QoS-based priority for this need to maximally satisfy the requirements of all optical network units (ONUs) and provide differentiated services. Analyses and simulation results show that the new algorithm can improve the bandwidth utilization and realize the fairness for both different ONUs and services.

Keywords access network, dynamic bandwidth allocation, GPON, quality-of-service (QoS), fair allocation, simulation and modeling

1 Introduction

Significant growth in Internet traffic and emerging converged-services has caused an incentive for service providers to upgrade their network facilities. Optical network systems are expected to become a next-generation technology for the access network. Among various optical network systems, one prospective system is the Gigabit-capable passive optical network (GPON), which can support all kinds of services such as voice, high-speed data, and digital video services [1]. The typical topology of passive optical network (PON) systems is point-to-multi-point, which is comprised of an optical line terminal (OLT) and optical network units (ONUs). An OLT typically resides in the central office, while an ONU is usually placed at home or in a building.

In the GPON, only one ONU can transmit packets in the upstream direction during the permitted time slot. The start time and the length of such time slot are assigned by what is called the dynamic bandwidth allocation (DBA) algorithm, residing in the OLT. To facilitate bandwidth allocation, the OLT and ONUs exchange the control packets through the upstream and downstream TC frames, which are defined in the ITU-T G984.3 standard [2]. A diagram of the upstream frame structure is shown in Fig. 1. The frame length is 125 μs. Each frame contains a number of transmissions from one or more ONUs. The BWmap field in the downstream frame (Fig. 2) dictates the arrangement of these transmissions. During each allocation period according to the OLT control, the ONU can transmit from one to four types of PON overheads and user data.

A diagram of the downstream frame structure is shown in Fig. 2. The frame is 125 μs for both the 1.244 16 and 2.488 32 Gb/s downstream data rates. The OLT sends pointers in the PCBd, and these pointers indicate the time at which each ONU may begin and end its upstream transmission. Thus, there is no contention in normal operation.

In this paper, we present a new approach to the problem of bandwidth assignment. We propose to keep the ONU's functionality as simple as possible and move all necessary access control mechanisms to the OLT. Computer simulation results are shown to evaluate the performance of the proposed scheme. In the latter part, we discuss the quality of service issues according to our proposed scheme. With the discussion of the fair allocation of the GPON as the starting point, the issues on bandwidth guarantee and packet-delay are discussed.

2 Methods of dynamic bandwidth allocation

It is the OLT's responsibility to divide the available bandwidth between ONUs. The OLT must assign a

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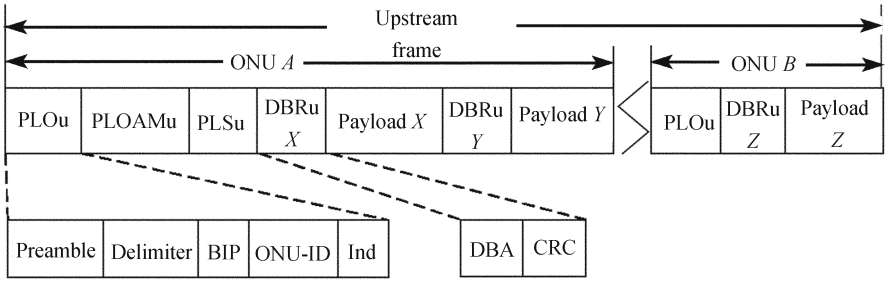


Fig. 1 GTC upstream frame structure

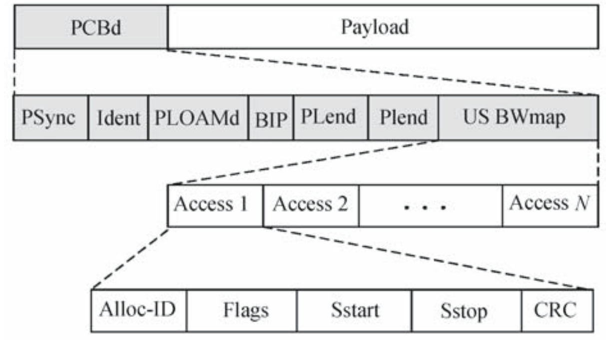


Fig. 2 GTC downstream frame structure

non-overlapping time-slot to every ONU and this assignment can be static or dynamic. The REPORT message existing in the upstream frame is used to report the status of queues at a particular ONU or T-CONT. Based on this information and the SLA, the algorithm makes a decision about the size of a time-slot dedicated to a particular class of traffic in the next granting cycle.

The GPON system supports dynamic bandwidth allocation via status reporting. In every T-CONT, DBA functionalities are performed. There are three mechanisms for signaling DBA reports over the GPON [2]: status indications in the PLOu, piggy-back reports in the DBRu, and ONU report in the DBA payload.

Status indications provide a fast but simple indication of traffic waiting at the ONU. The indication is carried in the PLOu Ind field. There are four single bit reports, one for each type of T-CONT. This is intended to give the OLT a fast alert that DBA supervision is needed at the ONU in question, but it does not identify the particular T-CONTs in question, nor provide any details as to the amount of bandwidth. Piggy-back reports provide a continuous update of the traffic status of a specific T-CONT. This report is carried in the DBRu associated with the T-CONT in question. There are three formats for this type of report (types 0, 1, and 2). These types are optionally supported except type 0. The whole ONU report provides a way for the ONU to send a DBA report on any and all of its T-CONTs in a single transmission. This is carried in a dedicated DBA payload partition that the OLT allocates in the upstream.

3 QoS-aware dynamic bandwidth allocation algorithm

Here we consider a GPON access network with three service classes corresponding to three priorities (i.e. high, medium, and low), which may be mapped respectively to the fixed bandwidth, the assured bandwidth, and the best effort bandwidth service classes in the differentiated service framework. The algorithm presented in this section is divided into two steps. Firstly, the OLT will to the largest extent meet each ONU's requirement. Then, if there is excessive bandwidth, the OLT will proportionally allocate the bandwidth to the medium and low priority services, and it can ensure that medium-priority traffic can always be serviced earlier than lower types.

Let N be the number of ONUs that are discovered automatically, $\mathrm{BW}_{\mathrm{total}}$ the total available bandwidth, $\mathrm{BW}_i^{\mathrm{FIX}}$ the high priority bandwidth for the ith ONU. We assume a maximum assured bandwidth $\mathrm{BW}_i^{\mathrm{MAX}}$ for each ONU

$$\mathrm{BW}_i^{\mathrm{MAX}} = \frac{\mathrm{BW}_{\mathrm{total}} - \sum_N \mathrm{BW}_i^{\mathrm{FIX}}}{N} \tag{1}$$

The advantage lies in that even if there are large numbers of traffic waiting in the higher priority T-CONTs of some ONUs, the OLT will not peculate the bandwidth of other ONU's lower priority services for these ONUs if there is no excessive bandwidth. The high priority grant bandwidth G_i^{H} 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. The G_i^{H} is obtained as

$$G_i^{\mathrm{H}} = \mathrm{BW}_i^{\mathrm{FIX}} \tag{2}$$

The OAM message can be handled as high priority services. In this case, G_i^{H} contains additional bandwidth for the OAM message. The medium priority services in one ONU are served before the low priority services. Hence, the medium priority grant bandwidth G_i^{M} is assigned as follows

$$G_i^{\mathrm{M}} = \min\left\{R_i^{\mathrm{M}}, \mathrm{BW}_i^{\mathrm{MAX}}\right\} \tag{3}$$

where R_i^{M} is the medium priority request bandwidth for the ith ONU. The low priority grant bandwidth G_i^{L} is assigned for the best-effort traffic class and it is assigned as

$$G_i^{\mathrm{L}} = \min\left\{R_i^{\mathrm{L}}, \mathrm{BW}_i^{\mathrm{MAX}} - G_i^{\mathrm{M}}\right\} \tag{4}$$

Here, R_i^{L} is the low priority request bandwidth for the ith ONU. Due to the bursty nature of Ethernet traffic [3,4], some ONUs might have less traffic to transmit while other ONUs require more than the maximum assured bandwidth. This results in a total excessive bandwidth $\mathrm{BW}^{\mathrm{remaining}}$, which is not exploited under the previous approach

$$\mathrm{BW}^{\mathrm{remaining}} = \sum\nolimits_m \left(\mathrm{BW}_i^{\mathrm{MAX}} - G_i^{\mathrm{M}} - G_i^{\mathrm{L}}\right) \tag{5}$$

where m is the set of light-loaded ONUs. To improve the utilization of the upstream bandwidth, one can exploit this remaining bandwidth by fairly distributing it among the highly loaded ONUs. For this reason, we develop the following method to allocate the remaining bandwidth (Fig. 3), where $\mathrm{RW}_{\mathrm{exceed}}^{\mathrm{M}}$ and $\mathrm{RW}_{\mathrm{exceed}}^{\mathrm{L}}$ are the parts of the request bandwidth that are not satisfied by the OLT after the previous allocation, where M and L mean the medium and low priority, respectively.

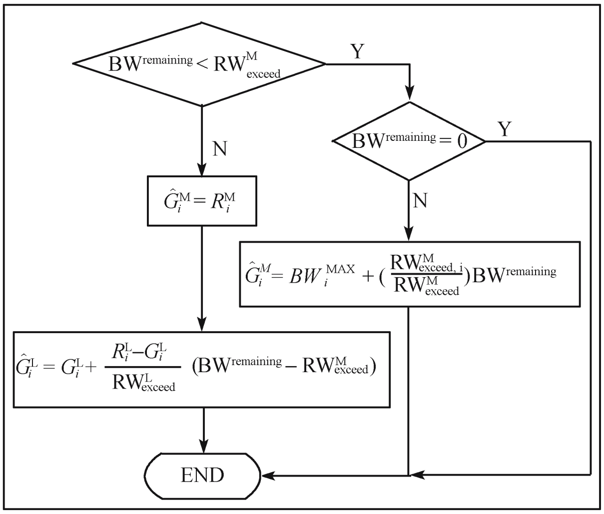


Fig. 3 The allocation scheme for excessive bandwidth

In this scheme, we meet each ONU's requirement firstly (within the maximum assured bandwidth). If there is bandwidth which is not exploited, the OLT will at first distribute it proportionally among the medium priority T-CONTs which are highly loaded and then the low priority T-CONTs.

4 Performance evaluation

The system model is set up with one OLT and 64 ONUs. The downstream and upstream data rates are both 2.5 Gb/s and the link rate from end users to the ONU is 50 Mb/s. The gap time is set as 64 b. Each ONU has a buffer of 10 MB that consists of three queues (T-CONTs), and the distance from any ONU to the OLT is assumed to be fixed and equal to 20 km.

Here, we consider a GPON access network with three service classes corresponding to three priorities (i.e. high, medium and low). The high, medium and low priority services should be allocated the fixed bandwidth, assured bandwidth and best-effort bandwidth, respectively.

The high and medium priority services are assumed to observe the Poisson-distribution. The low priority services (such as Ethernet services) exhibit self-similar characteristics and we assume that they obey the Pareto-distribution. Self-similar traffic is generated with the Hurst parameter of 0.7. The offered loads of the three priority traffics vary between 0.1 to 0.9 at steps of 0.1. And 20%, 30%, and 50% of the traffic are high, medium, and low priority service, respectively. We conducted a simulation with OPNET (a professional simulation tool developed by OPNET Technologies Inc.). The figures of merits include the average and maximum packet delay, the average and maximum delay variation, and network throughput. In Fig. 4, we demonstrate the average packet delay and the maximum packet delay

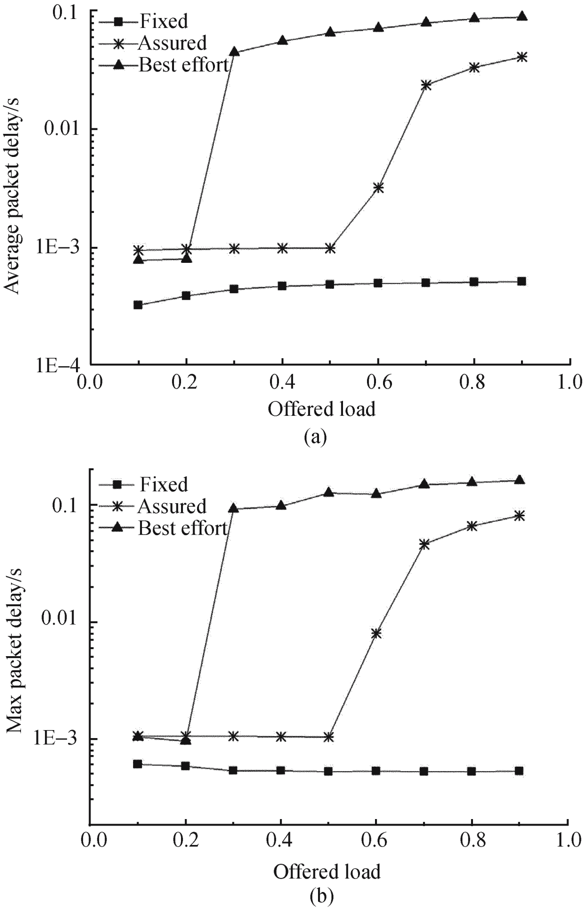


Fig. 4 Packet delay under offered load
(a) Average packet delay; (b) maximum packet delay

for different priority services of our proposed scheme as a function of an ONU's offered load. In this simulation all ONUs had identical load.

As shown in Fig. 4, we can find that the proposed scheme can provide different access services for different sources. The highest priority services allocated with the fixed bandwidth meet very low average and maximum packet delay. The delay performance of medium priority services is very good below the offered load of 60%. As the offered load increases up to above 70%, the experienced delay of medium priority services has notable increase compared to that of the fixed bandwidth services. The reason is that such scheme will always guarantee a fixed bandwidth to the highest priority services and as the offered load increases, the remaining available bandwidth for the assured bandwidth services and the best-effort bandwidth services acquire less relatively.

Furthermore, the delay of the best-effort bandwidth services has a sharp increase as the offered load reaches 30%. This is because the remaining bandwidth, which is not exploited by light-loaded ONUs, always serves the medium priority services earlier than the low priority services.

Compared with the interleaved polling with the adaptive cycle time (IPACT) algorithm in Ref. [5], the result of which is shown in Fig. 5, our proposed DBA scheme shows better performance. In the case of heavy network load, the average packet delays of all kinds of services of the IPACT scheme all exceed 1.0 s, which is much higher than that of the new scheme.

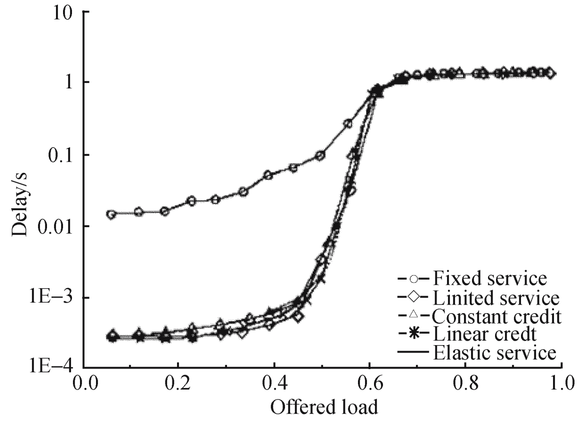
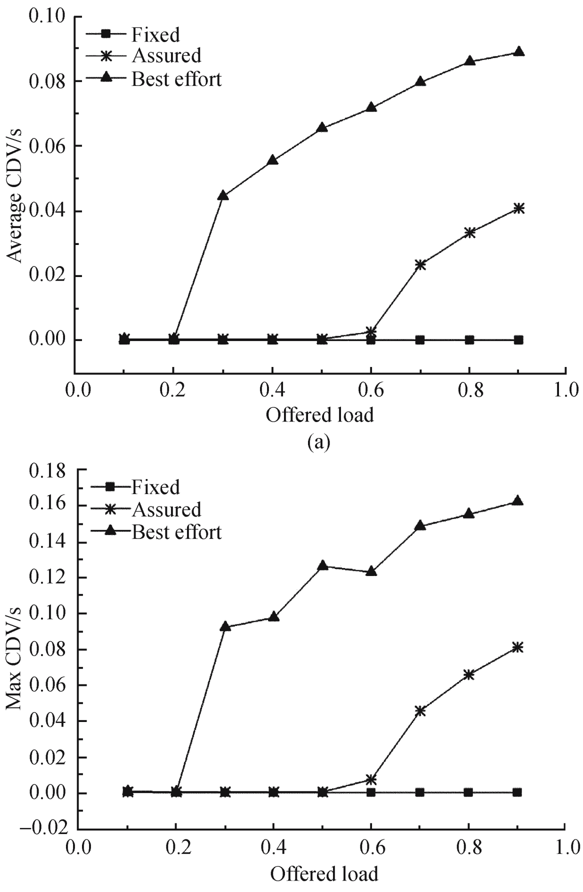


Fig. 5 Mean packet delay obtained from the IPACT algorithm

In Fig. 6, we present the average and maximum delay variation of different services as a function of offered load. From this figure, we can find that our proposed scheme can provide guaranteed delay variation for the fixed bandwidth services while the delay variation met by the best-effort services is also limited. For the assured bandwidth services, the delay variation is less than 3 ms when the offered load is below 60% and it has a little increase when the offered load is bigger than 0.7.



(a)

(b)

Fig. 6 Delay variation under offered load
(a) Average delay variation; (b) maximum delay variation

Now we investigate the throughput of the network illustrated in Fig. 7. The x-axis is normalized offered load of an individual ONU and the y-axis represents the total throughput of different priority services.

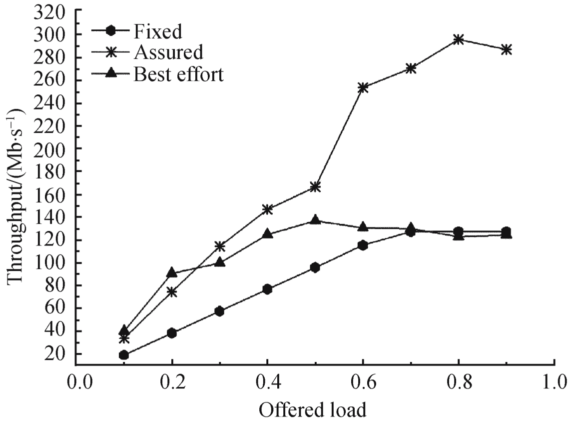


Fig. 7 The throughput of all ONUs for each priority service offered load

For the fixed bandwidth services, when the offered load is below 0.7, the available bandwidth is enough to satisfy the demands of all ONUs. Thus, the throughput of the fixed bandwidth services is equal to its traffic load. If the load of an ONU exceeds 0.7, the total bandwidth demand is larger than the available bandwidth. Since the available bandwidth cannot meet all demands and some of them are blocked by the OLT, some packets are delayed in the ONU buffer. Simultaneously, more and more packets arrive at the ONU buffer until the buffer is full and has to drop packets.

For the assured bandwidth services, if the offered load is less than 0.8, the available bandwidth is sufficient to accommodate all ONUs and the throughput of this class is close to its traffic load, which is about 300 Mb/s. Once the offered load exceeds 0.8, some packets of this class may be dropped and its throughput decreases. As the offered load increases, the medium priority services possess much more bandwidth than the low priority services.

In Fig. 7, the throughput of the best effort bandwidth services decrease at offered load 0.5, and at 0.8 and 0.9. Its throughput is even lower than that of the fixed bandwidth services.

5 Conclusions

In this paper we discussed the bandwidth allocation operation issues that must be dealt within a GPON access network. Specifically, to drive the cost of an access network down and to provide heterogeneous QoS guarantee to different sources, it is very important to have an efficient, simple and scalable DBA solution.

We proposed a QoS-aware scheduler scheme for DBA to support heterogeneous QoS requirements. Firstly, we allocate bandwidth for different priority services in each separate ONU within the maximum assured bandwidth. Secondly, if there is surplus bandwidth, we can proportionally allocate the bandwidth to medium priority services of all ONUs that are highly loaded and then to the low priority services. This scheme improves the bandwidth utility to optimize the delay variation tolerance. Since the OLT allocates a maximum assured bandwidth to every ONU despite the heavy offered load of some ONUs, the minimum throughput of each ONU can be guaranteed. A future research direction is to investigate the service sources and the queue performance of different services at the ONU side.

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