Grant Scheduling Method to Improve the Channel Efficiency of Ethernet Passive Optical Network

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ABSTRACT

To provide fairness among different ONUs in EPON, the upstream channel remains idle for some time after OLT receives the buffer status from all ONUs every cycle, which decreases the utilization and increases the delay. To solve this deficiency, we present a new grant scheduling method. The method consists of dividing ONUs into several sets where OLT can schedule ONUs in one set while others will be transmitting their traffic. This method will better utilize the bandwidth of EPON. The numerical results show that the larger the number of ONU sets is the smaller the minimum overhead becomes.

Key Words : EPON, Access Network, DBA, Grant Scheduling, Channel Efficiency

I . Introduction

Ethernet Passive Optical Network(EPON) technology has gained a great amount of interest recently as a promising solution for next generation broadband access network due to the convergence of low-cost Ethernet equipment and low-cost fiber infrastructure[1]. A PON is a point-to-multipoint optical access network with no active elements in the signal path from source to destination. Here, all transmissions in the PON are performed between an Optical Line Terminal (OLT) and Optical Network Units (ONUs). Each ONU acts as an access point for multiple subscribers, each of whom has one or more buffers. In the downstream direction, the OLT has the entire bandwidth to transmit data packets and control messages to the ONUs. On the other hand, multiple ONUs need to share the same optical channel for upstream transmission. Unless the OLT schedules time-slots for the ONUs to transmit data, the data streams transmitted from different ONUs may collide. Hence, access to the shared medium must be arbitrated by an MAC protocol[2,3].

Multi-Point Control Protocol (MPCP) is an MAC arbitration mechanism developed by the IEEE 802.3ah task force[4] to support a bandwidth allocation without collision among ONUs. Although MPCP is not concerned with any particular bandwidth allocation, it is meant to facilitate the implementation of various allocation algorithms in EPON. MPCP is a two-way messaging protocol defined to arbitrate the simultaneous transmission of different ONUs and resides at the MAC control layer. The protocol uses two Ethernet control messages, GATE and REPORT, to grant and request bandwidth respectively in its regular operation. Via REPORT messages, each ONU periodically reports its buffer occupancy status to the OLT and requests slot allocation. Upon receiving the messages from all ONUs, the OLT performs the bandwidth allocation algorithm to provide each ONU with its required QoS. Grant instructions are then compiled into MPCP GATE messages, and transmitted to the ONUs[5].

Fixed slot allocation will not utilize network re-

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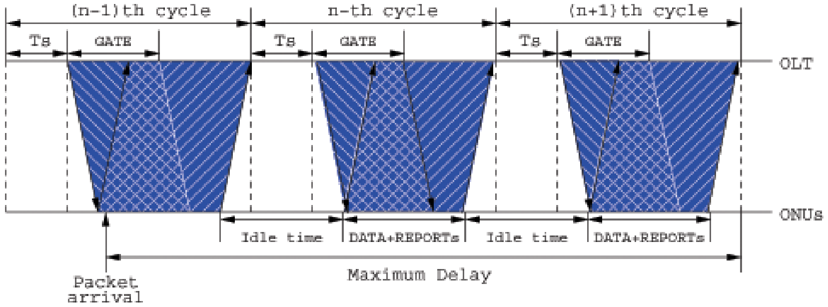

Fig 1. Ordinary grant scheduling method

sources efficiently due to the burstiness of Ethernet traffic. Thus, a Dynamic Bandwidth Allocation (DBA) scheme that adapts the size of the allocated time slot of each ONU to its buffer occupancy status is more suitable. Moreover, a distinguishing feature EPON is expected to support is the ability to deliver QoS requirements[6,7]. Thus, fair bandwidth allocation among different ONUs will be a key requirement for the MAC protocols in EPON. Many DBA algorithms supporting QoS have been discussed in literature[1-3,7-12]. As shown in Figure 1, most DBA algorithms guaranteeing fairness among different ONUs have some idle time, where the PON is not utilized in the upstream direction. The idle time decreases the utilization and increases the packet delay. To solve this deficiency, Assi et al.[3] proposed a modified grant table generating algorithm to increase the utilization of the DBA algorithm they presented. This paper presents a new grant scheduling method to improve the channel efficiency of EPON. The method consists of dividing the set of ONUs into K sets where OLT can schedule ONUs in one set while others will be transmitting their traffic. This method will better utilize the bandwidth of EPON.

Ⅱ. Ordinary Grant Scheduling Method

A PON with N ONUs is considered. Let C_{max} be the maximum granting cycle, where a granting cycle is the time period during which all ONUs can transmit and report to the OLT. Note that making the granting cycle too large will result in increased delay. On the other hand, making the granting cycle too small will result in more bandwidth being waisted by guard intervals, T_g. The guard intervals are necessary to provide protection for fluctuations in the Round Trip Time(RTT) of different ONUs[3].

The grant scheduling method for DBA needs some scheduling time T_s to finish its computation. As shown in Figure 1, the ordinary grant scheduling method results in some idle time where the PON is not utilized in the upstream direction. This idle time is estimated as the sum of RTT and T_s.

Under the ordinary grant scheduling method, the minimum overhead $O_{\min}$ in the upstream direction is studied. Ignoring the inter-frame gaps between Ethernet frames, we can estimate

$$O_{\min} = \frac{T_s + RTT + N \times T_g}{C_{max}}. \qquad (1)$$

Let d_{max} be the maximum delay of real-time traffic. Owing to the intra-ONU scheduling, it is reasonable to assume that the reported real-time traffic is scheduled to be transmitted during the next cycle. As shown in Figure 1, if a real-time packet arrives to an ONU immediately after the ONU sends a REPORT to the OLT, and if the ONU is the first one sending a REPORT during the $(n-1)$-th cycle, then the packet will be reported at the n-th cycle and transmitted to the OLT during the $(n+1)$-th cycle. If this packet is the last one being transmitted during the $(n+1)$-th cycle, the maximum delay d_{max} is

$$d_{\max} = 3C_{\max} - T_s - \frac{RTT}{2}. \quad (2)$$

To meet a delay requirement d_{req} of real-time traffic, from (2) we have

$$C_{\max} = \frac{1}{3}\left(d_{req} + T_s + \frac{RTT}{2}\right). \quad (3)$$

In this case, from (1) and (3) the minimum overhead is

$$O_{\min} = \frac{6\,(T_s + RTT + N \times T_g)}{2\,(d_{req} + T_s) + RTT}. \quad (4)$$

For example, when $d_{req} = 2ms$, $N = 16$, $T_g = 1\mu s$, $T_s = 50\mu s$ and $RTT = 200\mu s$, an ordinary grant scheduling method waists too much bandwidth as overhead, say, $O_{\min} = 37.1\%$.

Ⅲ. Proposed Grant Scheduling Method

This paper presents a new grant scheduling method (See Figure 2) to improve the channel efficiency of EPON. This method consists of dividing the set of ONUs into K sets where OLT can schedule ONUs in one set while others will be transmitting their traffic. In Figure 2, the scheduling period T_{sp} is the time during which all ONUs belonging to a set can transmit and report to OLT. Note that the length of scheduling period is not fixed, but varies according to the traffic load and its maximum is assumed to be $C_{\max}/K$. Now, under our proposed grant scheduling method, the minimum overhead is studied in the upstream direction. The minimum overhead $O_{\min}$ can be estimated as follows:

$$O_{\min} = \frac{N \times T_g}{C_{\max}}. \quad (5)$$

As shown in Figure 2, if a real-time packet arrives to an ONU belonging to Set k immediately after the ONU sends a REPORT to OLT and the ONU is the first one sending a REPORT within the set during the $(n-1)$-th cycle, then the packet will be reported at the n-th cycle and transmitted during the $(n+1)$-th cycle. Moreover, if this packet is the last one being transmitted in Set k during the $(n+1)$-th cycle, the maximum delay $d_{\max}$ can be estimated as follows:

$$d_{\max} = \left(\frac{2K+1}{K}\right)C_{\max} + \frac{RTT}{2},\ K \geq 2. \quad (6)$$

To meet a delay requirement d_{req} of real-time traffic, from (6) we have

$$C_{\max} = \frac{K}{2K+1}\left(d_{req} - \frac{RTT}{2}\right),\ K \geq 2. \quad (7)$$

In this case, from (5) and (7) the minimum overhead is

$$O_{\min} = \frac{2\,(2K+1) \times N \times T_g}{K(2d_{req} - RTT)},\ K \geq 2. \quad (8)$$

When $K = 2$, $d_{req} = 2ms$, $N = 16$, $T_g = 1\mu s$, $T_s = 50\mu s$ and $RTT = 200\mu s$, the minimum overhead for the proposed method is 2.1%. The pro-

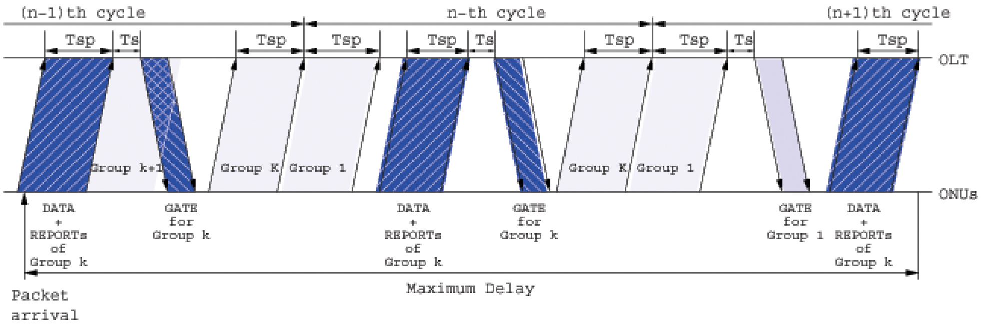

Fig 2. Proposed grant scheduling method

posed method will better utilize the bandwidth of EPON.

Ⅳ. Numerical Results

In this section we compare the performance of the grant scheduling methods for various K's. The case of $K=1$ corresponds to the ordinary grant scheduling method. It is assumed that $N=16$, $T_s=50\mu s$, $RTT=200\mu s$ and $d_{req}=2ms$. Unless otherwise mentioned, the length of guard interval T_g is assumed to be $1\mu s$.

Figure 3 shows that the larger the number of ONU sets is the larger the maximum cycle time guaranteeing the delay requirement of real-time traffic becomes. As mentioned before, making the granting cycle longer will result in higher utilization. For various K's and T_g's, Figure 4 shows the minimum overhead in the case that the delay requirement of real-time traffic is guaranteed. The minimum overhead for the ordinary grant scheduling method $(K=1)$ is much larger than that for the other cases, because the ordinary method has some idle time where the transmission channel is not utilized in the upstream direction. This idle time is equal to a round trip propagation delay, plus the scheduling time. The proposed method improves upon this by allowing OLT to schedule ONUs in one set while others will be transmitting their traffic. Figure 3 and Figure 4 show that the larger the number of ONU sets is the larger the maximum cycle time guaranteeing the delay requirement of real-time traffic becomes, and so the minimum overhead will be smaller. If the number of ONU sets is K, then the maximum slot size B_{max} available for one ONU is

$$B_{max}=\frac{C_{max}(1-O_{max})}{K}$$
$$=\begin{cases}\frac{1}{3}\left(d_{req}-2T_s-\frac{5}{2}RTT\right)-N\times T_g, & K=1,\\ \frac{1}{2K+1}\left(d_{req}-\frac{RTT}{2}\right)-\frac{N\times T_g}{K}, & K\geq 2.\end{cases}$$

For various K's and T_g's, Figure 5 compares the maximum slot size available for one ONU. Figure 4 and Figure 5 show that the larger the number of ONU sets is the smaller the minimum over

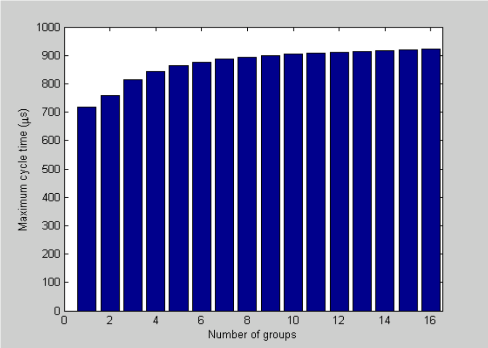

Fig 3. Maximum cycle time C_{max}

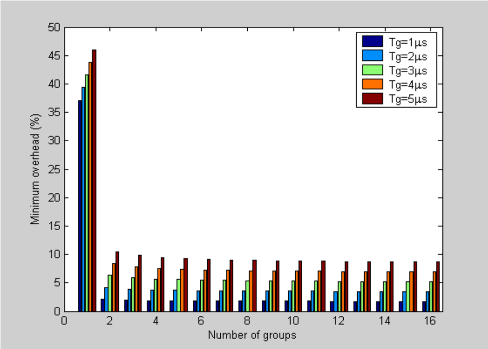

Fig 4. Minimum overhead O_{min}

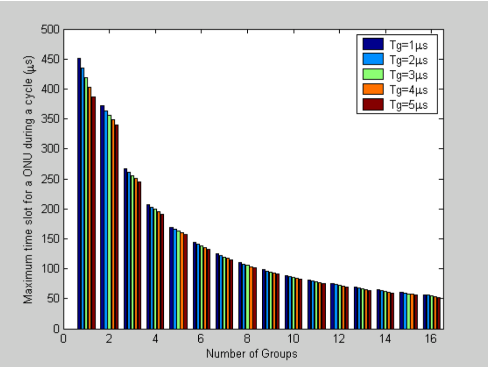

Fig 5. Maximum slot size B_{max} available for one ONU

head becomes however, the maximum slot size B_{max} available for one ONU will be smaller, which may have negative impact on the performance of DBA. Hence, the number of ONU sets K should be determined considering the tradeoff between the overhead and the maximum slot size available for one ONU. In our numerical example, since the minimum overhead decreases very slowly as K increases for $K \geq 2$, the adequate value of K is 2. Note also that, as the inter-ONU gap T_g decreases, the minimum overhead $O_{\min}$ also decreases(see Figure 4), and so $B_{\max}$ increases(see Figure 5).

V. Conclusions

This paper has presented a new grant scheduling method to improve the channel efficiency of EPON. The method consists of dividing ONUs into several sets where OLT can schedule ONUs in one set while others will be transmitting their traffic. It is known that making the granting cycle longer results in the increased delay and the decreased overhead. We have analyzed the numerical results about the maximum cycle time guaranteeing the delay requirement of real-time traffic and the minimum overhead in such cases. The numerical results show that the larger the number of ONU sets is the smaller the minimum overhead becomes, however, the maximum slot size available for one ONU will be smaller. Considering the tradeoff between the minimum overhead and the maximum slot size avaliable for one ONU, the optimum number of ONU sets should be determined.

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