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A New Design for Control Method Based on Hierarchical Deficit Round Robin Scheduler for EPON

Y.-C. Cho, J.-Y. Pan

Ying-Chiang Cho*, Jen-Yi Pan
Department of Electrical Engineering,
National Chung Cheng University
Chia-Yi 62102, Taiwan, R.O.C
*Corresponding author: silvergun@mail2000.com.tw
E-mail: jypan@ccu.edu.tw

Abstract: With the development of ICT (Information and Communication Technology), how to use EPON for ensuring an effective and fair bandwidth allocation as well as the quality of service has become an important issue. Our research is based on Cousin Fair Hierarchical Deficit Round Robin Dynamic Bandwidth Allocation (CFH-DRR DBA), which applies the concepts of hierarchical scheduling to reduce extra actions in information controlling and queue switching and DRR (Deficit Round Robin) to attain the goal of cousin fairness. Our research proposes three additional modules to CFHDDR DBA: (1) an admission control module, which limits the sum weight of QoS-controlled flow; (2) a weight partition module, which isolates the sum weight of other interfering flows from QoS-controlled flows; and (3) the quantum adaptation module, which minimizes the access time of QoS-controlled flows through Quantum distribution. With the help of OMNet++ simulation software, this research presents the improvement of CFHDRR by introducing dynamic DDR Quantum. In addition, it proposes admission control and bounded weight to keep the sum of flows within service capacity. The simulation result shows that, while keeping CFHDRR's fairness, the queuing delay is reduced and the cycle time is effectively controlled so that the packet delay of QoS-controlled flows is minimized and QoS of real-time multimedia in EPON is fairly ensured.

Keywords: Ethernet passive optical network (EPON), Dynamic Bandwidth Allocation, Hierarchical Scheduling, Quality of Service (QoS).

1 Introduction

Network transmission devices have been continuously improving to meet the ever-changing market demands. The original copper wire was replaced by optical fiber, increasing the rate of transmission to Giga-bps today and even to 10 Giga-bps in the future [1] [2]. Nevertheless, digital subscriber line [3] and cable modem [4] are still the only two types of network devices that current network operators provide to their consumers. Cable Modem [4], as well as other copper transmission devices, fails to break the bottleneck of Access Networks (ANs). Optical network's low loss, high capacity, bandwidth flexibility, EMC immunity and high confidentiality have made it the ultimate solution for Last Mile and a possible replacement of copper transmission devises. One of the advantage of using passive optical network is that passive components can process data without electricity, making it preferred by network operators when they improve the existing network architecture [1].

2 Problem statement

The principle guiding dynamic bandwidth allocation for Ethernet passive optical network is the quick allocation of upload bandwidth [8]. The following challenges must be dealt with. The first challenge is the scale expandability in dynamic bandwidth allocation. Based on the present data transmission speed and actual use of Ethernet passive optical network, it is certain that the scale of optimal networks will expand in the future. How to design a scheduling method which is both efficient and cost-effective will be one major task. The second challenge is time urgency. Since online audio and video transmission has been widely used, any slightest delays may result in problems for the users. Yet, not all types of transmission have strict requirements on delays. It poses another task, which is how to identify and protect specific QoS flows. The third challenge is fairness. There are a variety of ways to define fairness. Which definition is most suitable for the target environment and how to allocate the bandwidth so as to achieve fairness will also be highly important issues [11].

3 Problem-Solving Strategies

This research proposes dynamic Quantum allocation method based on Cousin Fair Hierarchical Deficit Round Robin Dynamic Bandwidth Allocation (CFHDRR DBA)) [9] [10] [12] [13] [14] [15] [16] [17] [18] [19] [20] [21], which can keep cycle time stable through Quantum dynamic allocation. This method also makes bandwidth more efficient by modifying the ONU single round translimit of the original cousin-fair hierarchical deficit scheduling method. As shown in figure 1, in cousin-fair hierarchical deficit scheduling, the contribution of ONU (Optical Network Unit) is to report consolidated information that are sent to OLT (Optical Line Terminal). Yet, high control message overhead of OLT makes it difficult to limit the cycle time. This research attempts to solve this problem by analyzing constantly the relation between cycle time and Quantum and adjusting Quantum according to Match-T flows. Match-T is a similar concept to packet feature of Token bucket, which consists of packet Source IP, Source Port, Destination IP, and Destination Port.

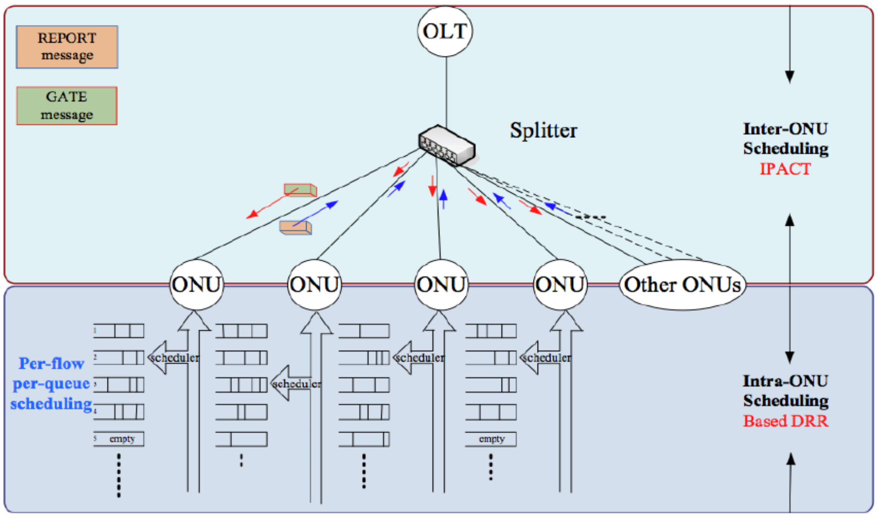


Figure 1: Structure of Adjustable Cycle Control Method based on Hierarchical Deficit Round Robin Scheduling

Our research also proposes an admission control module to Intra ONU scheduler. If a flow is a Match-T flow, when its weight is greater than the weight allocated by the system, its connection will be refused. If a flow is not a Match-T flow, the system will exclude its weight as well as all other non Match-T flows. With a limited sum weight of non Match-T flows, the system is able to allocate enough bandwidth to Match-T flows in every transmission cycle and to send all packets within delay limits. Any changes in the number of flows will cause the system to reconsider the connection requests of new flows according to the sum weight limits: when a new flow is a not a Match-T flow, the system will recalculate the sum weight of non Match-T flows; when a new flow is a Match-T flow, its connection request will be accepted only when the system can allocate enough weight to it.

3.1 Design of an Inter ONU scheduler

This paper proposes a dynamic Quantum allocation method for OLT based on CFHDRR DBA. This method can also be applied to control cycle time. Table 1 describes the parameters used in the above method.

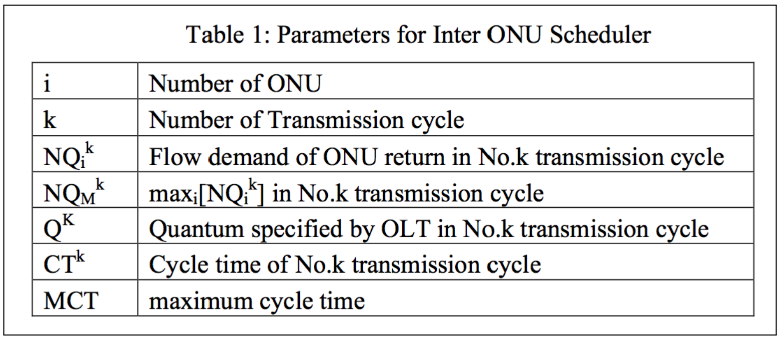


Table 1: Parameters for Inter ONU Scheduler

i	Number of ONU
k	Number of Transmission cycle
NQ_i^k	Flow demand of ONU return in No.k transmission cycle
NQ_M^k	$\max_i[NQ_i^k]$ in No.k transmission cycle
Q^K	Quantum specified by OLT in No.k transmission cycle
CT^k	Cycle time of No.k transmission cycle
MCT	maximum cycle time

After ONU scheduling, Intra ONU Scheduler will report the bandwidth of ONU to OLT, so as to reduce packet transmission of MPCP. One disadvantage of ONU scheduling is that OLT cannot calculate the quantities and weights of flows under each ONU. This research proposes to predict the maximum number of upload data after Quantum adjustment according to the ratio of total upload amount of ONU to Quantum, as shown in Formula 1. In the formula, the total upload amount equals the cycle time. Therefore, this formula can be used to calculate the amount of and proportion of quantum adjustment. This formula can also be applied to limit the cycle time.

$$\frac{Quantum}{cycletime} = \frac{Quantum\ adjustment}{cycle\ time\ to\ be\ predicted} \tag{1}$$

When receiving a packet, the packet process module of OLT system will first estimate the bandwidth of ONU demand. It will then identify the NQ_i^k in the report message and send it to the dynamic allocation module. After Q^{k+1} is received from the dynamic allocation module, the system will calculate ONU bandwidth and send ONU bandwidth via GATE message. By doing so, ONU is expected to send all packets in the following round and reduce delay time. In the dynamic allocation module, the packet process module reports NQ_i^k in the ONU report message to NQ_i^k record module. If all requirements for starting a new transmission cycle are met, the system will recalculate the Quantum. CT record module is responsible for recording the time spent by every transmission cycle. Data process module identifies NQ_M^k (i.e. the maximum value of NQ_i^k). Quantum calculation module tests what requirements meet the demand of NQ_M^k under MCT restriction. Such requirements should meet the packet demand of the other flows and should be able to reduce delay time. Suppose, in this round, when NQ_M^k is 1300 and CT^k is 0.5ms, by taking NQ_M^{ki} into formula 4, we can calculate the value of CT^{k+1} when the allocated Q^{K+1}=1300. In this case, the value of CT^{k+1} is 1.3ms. If this value is less than MCT, the value of NQ_M^k is given to Q^{K+1}. Q^{K+1} is included in the GATE message to modify the distribution benchmark. If the value of NQ_M=2600 is greater than MCT, then the value of MCT is taken into formula 3 to calculate Q^{K+1}. Q^{K+1} is included in the GATE message to let ONU modifies the distribution benchmark.

3.2 Design of an Intra ONU scheduler

This paper proposes some additional modules based on CFHDRR DBA, including a flow filter module and an admission module. When a new flow is added, the admission module controls the number of Match-T flows and the weight of non Match-T flows to guarantee delay time is minimum. The admission module also calculates how many data does every Match-T flow store in each cycle and divides the number by weight of flow provided by the flow process module. This allows us to acquire the Quantum value in the next round. This design is intended to reduce waiting time of data so as to minimize queue delay. Parameters used in this method are shown below.

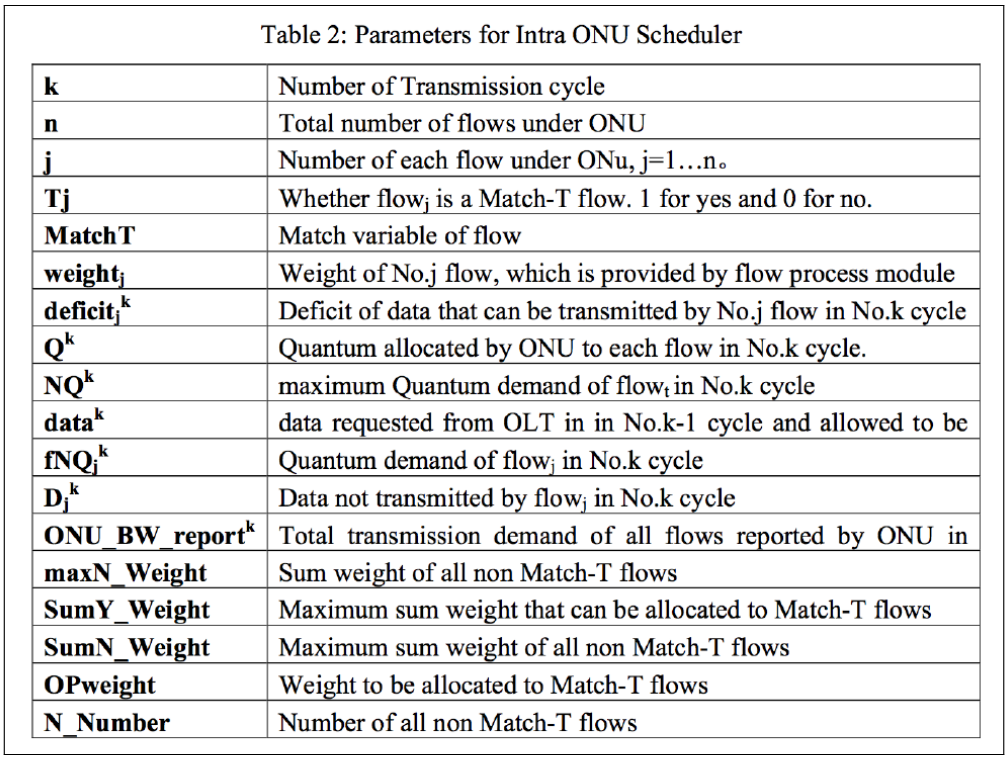


Table 2: Parameters for Intra ONU Scheduler

k	Number of Transmission cycle
n	Total number of flows under ONU
j	Number of each flow under ONu, j=1…n。
Tj	Whether flow$_j$ is a Match-T flow. 1 for yes and 0 for no.
MatchT	Match variable of flow
weight$_j$	Weight of No.j flow, which is provided by flow process module
deficit$_j^k$	Deficit of data that can be transmitted by No.j flow in No.k cycle
Q^k	Quantum allocated by ONU to each flow in No.k cycle.
NQ^k	maximum Quantum demand of flow$_t$ in No.k cycle
data^k	data requested from OLT in in No.k-1 cycle and allowed to be
fNQ$_j^k$	Quantum demand of flow$_j$ in No.k cycle
D$_j^k$	Data not transmitted by flow$_j$ in No.k cycle
ONU_BW_report^k	Total transmission demand of all flows reported by ONU in
maxN_Weight	Sum weight of all non Match-T flows
SumY_Weight	Maximum sum weight that can be allocated to Match-T flows
SumN_Weight	Maximum sum weight of all non Match-T flows
OPweight	Weight to be allocated to Match-T flows
N_Number	Number of all non Match-T flows

When receiving GATE message, to ensure that all requested data from the former round could be transmitted, ONU will send message to packet process model and report the start time and transmission time to data transmission module. Q^K in GATE message will be reported to FLOW bandwidth allocation module. After that, FLOW bandwidth allocation module will allocate $deficit_j^k$ (multiplying Q^K by $weight_j$) of each $flow_j$. Based on the concept of token bucket, this method takes $deficit_j$ as the token to calculate the transmission amount of $flow_j$ (i.e. ftjk) in the next cycle. The transmission amount of all $flow_j$ (i.e. ONU_BW_$report^k$) is summed up with Gather module. After each packet request is transmitted, the method will write a REPORT message. CFHDRR is applied to categorize traffic and FLOW select module is employed to identify Match-T flows. Match-T flows allow factories to send OAM information from OLT to ONU. Source IP, Source Port, Destination IP, and Destination Port are used to describe the categories of selected flows. This method assumes that every flow that is sent to ONU have been categorized and compared. IP utilizes wildcards to express the concept of domain-.192.168.*.*, for example. Flows that meet such requirements are categorized as Match-T flows.

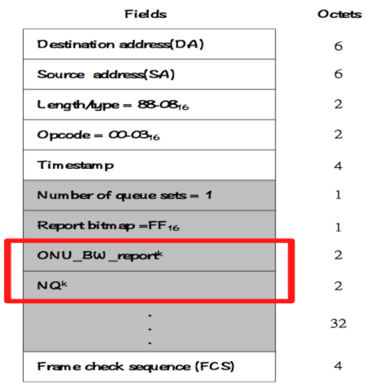
3.3 Design of FlOW admission module

This research applies an admission module to allocate flow weight, which is sent to the flow bandwidth allocation module. However, the method proposed in this paper allocates weight according to preset data provided by network operators. This method may not be able to control delay when there is a large number of flows. We proposes a solution to this problem. Applying the formula below, we can calculate the maximum Q^k (hereafter referred to as Max_Q^k). When there is a large number of flows and the sum weight increases, and Max_Q^k will decrease. If the value of Max_Q^k is less than NQ^k, the method cannot limit delay. Therefore, in order to minimize delay of Match-T flows, we attempts to control the maximum sum weight of non Match-T flows.

$$MaxQ^k = MCT \div \sum_i \sum_j weight_j^i \tag{2}$$

3.4 Revised design of Multi-point control protocol

The method of this research is based on CFHDRR DBA, with similar GATE message. Like CFHDRR DBA, the method also has a 1Byte Quantum field, which will process the 39 Byte Padding of GATE message (not including grant start time and grant length). Using 1 Byte to transmit Quantum won't change the original size of packet and won't impose transmission overhead to data control. There are two Queue report fields, as shown in Figure 2: one is ONU bandwidth demand report (ONU_BW_$report^k$), the other is number of Quantum needed to report the maximum flow (NQ^k). These two fields enable Inter ONU scheduling to function.



Fields	Octets
Destination address(DA)	6
Source address(SA)	6
Length/type = $88\text{-}08_{16}$	2
Opcode = $00\text{-}03_{16}$	2
Timestamp	4
Number of queue sets = 1	1
Report bitmap =FF_{16}	1
ONU_BW_$report^k$	2
NQ^k	2
. . .	32
Frame check sequence (FCS)	4

Figure 2: Report message

4 Simulation techniques and targets

Using OMNet++ [23] [24] [25] [26] [27] as simulation tool, this paper revises modules for Ethernet passive optical network and achieves the expected simulation target. The major revisions are presented below:

1. Revise REPORT message and information contained in GATE message In CFHDRR, REPORT message carries only the demand of bandwidth for ONU. This research proposes to add maximum demand Quantum, which allows OLT to control cycle time.

2. Add an packet analyzer The original module categorizes different flows and transmit upstream packets. In order to identify different flow features, this research will add a packet

analyzer to analyze Match-T flows and to calculate the demanded Quantum, which is helpful for the decision of bandwidth allocation.

5 Simulation and verification

The simulation environment consists of one OLT and N ONUs. Each ONU has Q series, which represents a flow in the ONU. The transmission rate of EPON is Rate_epon Mb/s. The transmission rate of the access line between users and the ONU is Rate_u Mb/s. Each line has the same downstream rate. Network traffic types of EPON are CBR and TCP Session, and our version is TCP-Reno. We utilize network traffic under TCP communication protocol as well as CBR traffic under UDP communication protocol. CBR sends 800 Byte packets each 0.8ms. CBR traffic is distributed in four ONUs and TCP, which serves as background traffic, also to four different ONUs, and each with three flows.

5.1 Simulation lab 1 - Control Cycle Time

To prove that our method can ensure dynamic allocation of Quantum to ONU, control cycle time within a specific length, and observe the influence of burst flows on cycle time. As shown in Figure 3, in this experiment, numbers of flows remain steady at 2ms within every ONU. Two burst CBR flows increases cycle time at the 0.5th second to almost 2.8ms. But in the following cycle, cycle time is brought back to be lower than the maximum cycle time because OLT automatically adjusts the allocated Quantum.

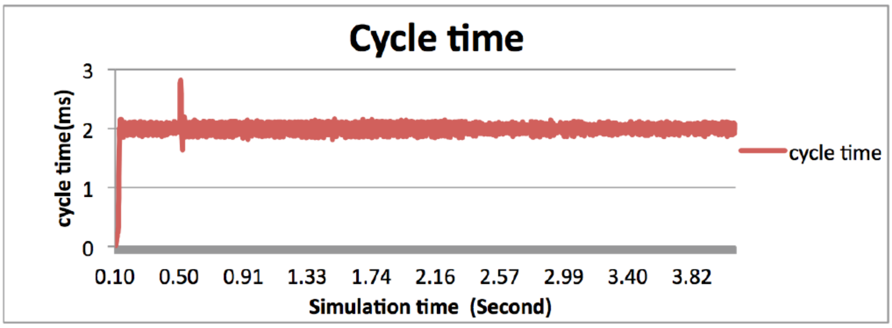
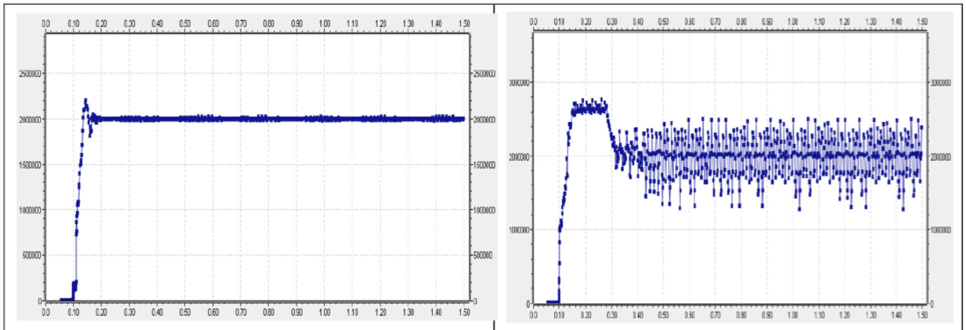


Figure 3: Response of OLT to burst flow and cycle time

5.2 Simulation lab 2 - Different scheduling methods and control of cycle time

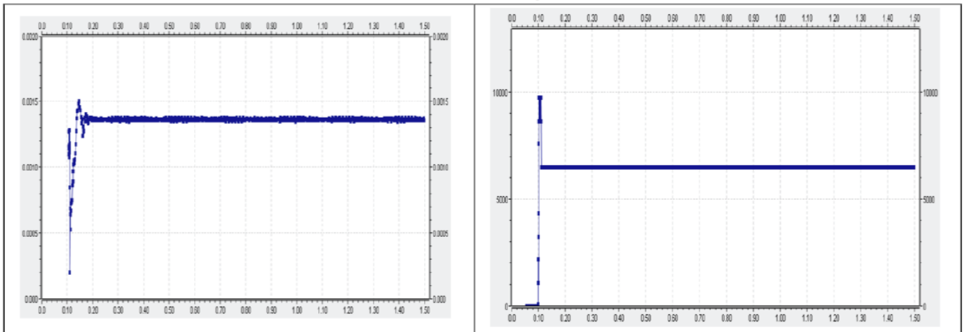
Figure 4(a) shows our method can efficiently control cycle time. The simulation experiment begins at the 0.1th second, and flows are added each 0.01 second until the 0.15th second. In Figure 4(b), another method adjusts cycle time to a fixed length, which is inefficient and unstable compared with our method.

Figure 5 shows (a) delay of Match-T flows and (b) packet size of these flows after utilizing our method. Figure 5(a) shows that, in case of full load, our method is able to limit latency of Match-T flows to be less than 1.5ms. Figure 5(b) shows the packet size of Match-T flows in series. Figure 6 shows (a) delay of non Match-T flows and (b) packet size of these flows. In Figure 6, some of the latencies are longer than 1.5ms, which means our method does not reduce latency of non Match-T flows.



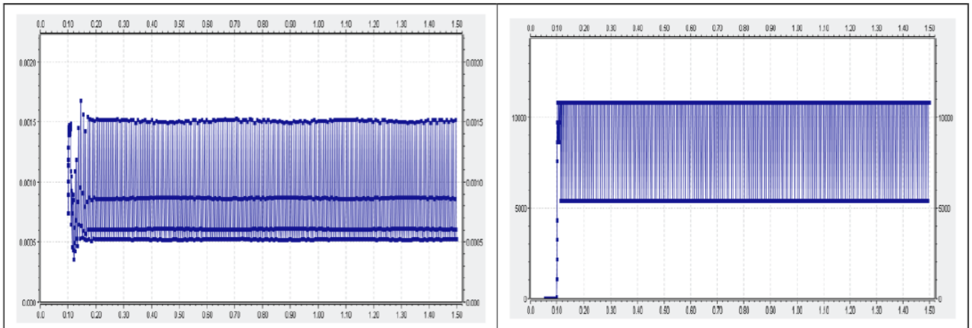
(a) (b)

Figure 4: Comparison of cycle time control



(a) (b)

Figure 5: delay of Match-T flows and packet size of these flows



(a) (b)

Figure 6: delay of non Match-T flows and packet size of these flows

5.3 Simulation lab 3 - Delay

We continues to examine whether our research can reduce the delay of Match-T flows. Figure 7 shows the delay of each packet in every cycle. The dots represents delays of packets in each cycle. The vertical axis is delay time, using second as its base unit of time. The horizontal axis is experiment time. All flows start at the 0.1th second. In this experiment, packet delays of Match-T flows remain steady within 0.3ms to 0.8ms. As shown in Figure 8, packet delays of non-target packets remain steady within 0.7ms to 1.2ms.

In this simulation experiment, we set the server IPs of voice calls to reduce delays of flows.

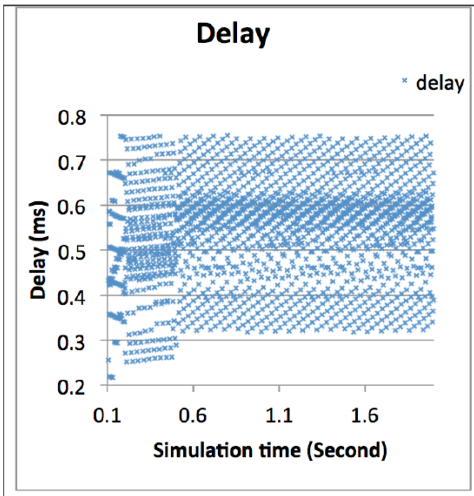


Figure 7: Packet delays of Match-T flow

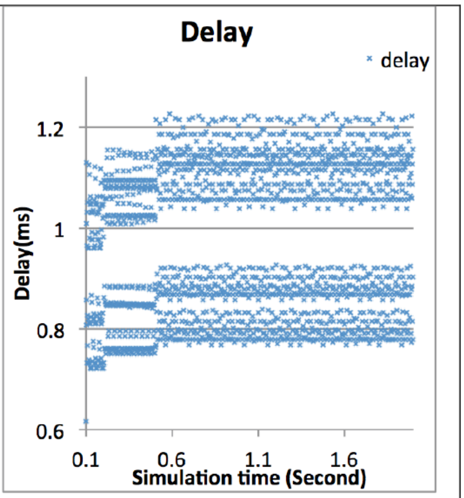


Figure 8: Packet delays of non Match-T flows

Figure 9 shows the delay of each packet in every cycle after some adjustments were made to Match-T and all other factors remain unchanged. As shown in Figure 9, packet delay is reduced and most delays were even less than 0.5ms. Due to reduced delay, cycle time is also decreased to 0.9-1ms.

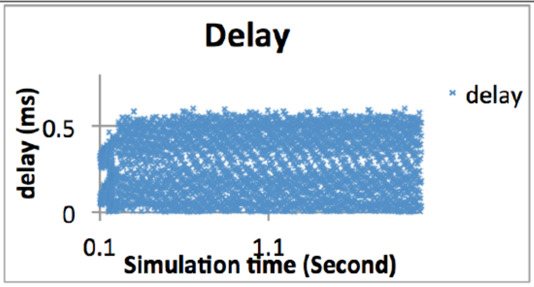


Figure 9: Packet delays of Match-T flows

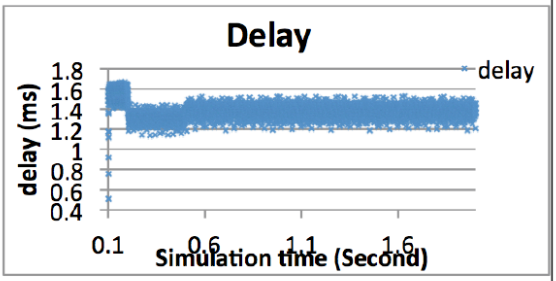


Figure 10: Packet delays of non Match-T flows

Simulation test result proves that categorization of target flows greatly reduce packet delays. This method may increase delay of non Match-T flows at the same time and flow delay may increase in the end. As shown in Figure 10, delays were longer, increasing by 0.3ms at average level. To solve this problem, we proposes Quantum allocation method to ensure that ONU can send all Match-T flows in each cycle. Other non Match-T flows have to wait longer if their requested relatively big Quantum. Increasing the delay of non Match-T flows enables us to better restrict the delay of Match-T flows.

5.4 Simulation lab 4 - Cycle time and average delay time

We also test the performances of our method when numbers of flows are different. As shown in Figure 11, with the same number of flows, changes in packet size and packet frequency don't lead to changes in average delay(1 3). However, as number of flows increases, delay will also increase. This result shows that a larger number of flows requests a larger bandwidth, a longer transmission cycle, and a longer delay.

5.5 Simulation lab 5 - Fairness

Figure 12 is a comparison of throughput between two flows with different weights. New flows added at 0.3th, 0.5th, and 1th second will decrease throughput. The figure below also shows that the ratio of these two flows remains relatively stable during the whole experiment.

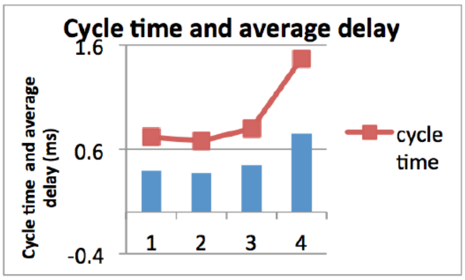


Figure 11: Cycle time and average delay

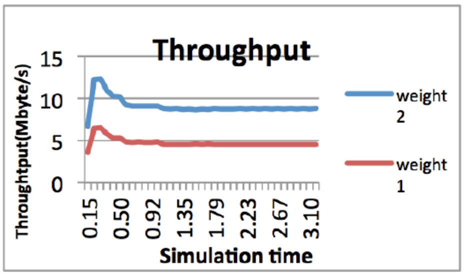
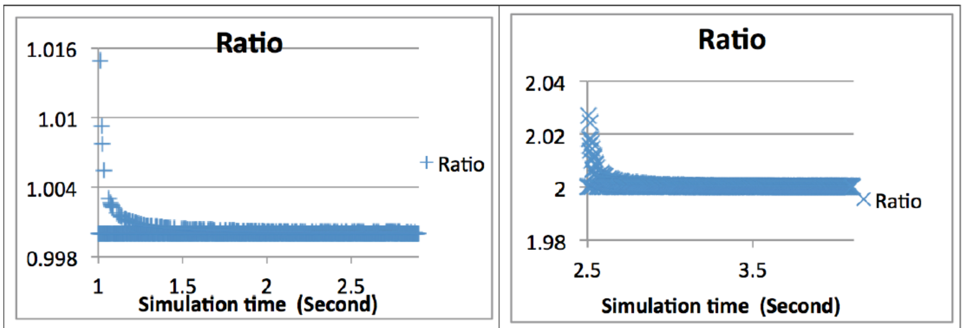


Figure 12: comparison of throughput between two flows with different weights



(a)

(b)

Figure 13: Ratio of queues with different weights in ONU

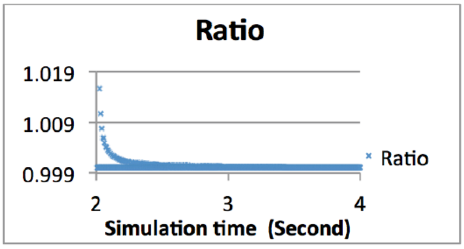


Figure14: Ratio of transmission flows with same weight in different ONU

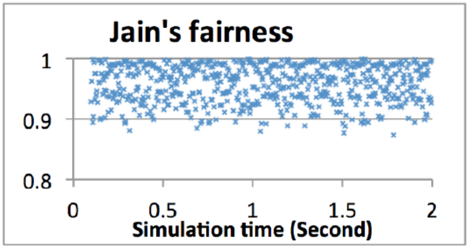


Figure15: Jain's fairness index

In Figure 13(a), the vertical axis is the ratio of data transmitted by two ports in each cycle. The weights of the two ports are all 1. In this experiment, although the starting ratio is relatively large, it gets closer to 1 over time. In Figure 13(a), the vertical axis is the ratio of data transmitted by two other ports in each cycle. The weights of these two ports are different. In this experiment, although the starting ratio is also relatively large, it gets closer to 2 over time.

Figure 14 shows the ratio of transmission flows with same weight in different ONU. The ratio also gets closer to a fixed value over time.The above simulation experiment shows that, with different of same ONU, our method can achieve almost perfect cousin fairness over time. In Figure 15, every dot represents a Jain's fairness index in 10 transmission cycles. Since these fairness index remain steady between 0.9-1, our method is proven to be able to guarantee allocation fairness.

6 Conclusions

Innovations in internet service have pushed up the demand for network bandwidth. The development and application of Ethernet passive optical network technology make it a possible option to meet the demand. Meanwhile, how to ensure an efficient and fair allocation of bandwidth becomes an important issue [13] [16] [30] [31] [32] [33]. This paper proposes a dynamic Quantum allocation method to control cycle time based on Cousin Fair Hierarchical Deficit Round Robin Dynamic Bandwidth Allocation. This method is intended to reduce the overhead of information and to ensure cousin fairness. In addition, with the help of GATE message, it serves to report and calculate the demand of March-T flow Quantum that are sent back by ONU, guarantee fairness of transmission, and reduces packet delay of Match-T flows.

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