

# POPULAR CHANNEL FIRST (PCF) ADMISSION CONTROL (AC) FOR DEPLOYING IPTV SERVICE OVER ETHERNET PASSIVE OPTICAL NETWORK (EPON)

Chuan-Ching Sue, Chi-Yu Hsu, Zhi-Sheng Lin  
 Department of Computer Science and Information Engineering  
 National Cheng Kung University, Taiwan, R.O.C.

## Abstract

Ethernet Passive Optical Network (EPON) is a point to multipoint network architecture and suitable for carrying Internet Protocol Television (IPTV) service because it provisions higher bandwidth for downstream, but it also cannot satisfy the bandwidth requirement of tens of thousands of IPTV channels and carry these channels simultaneously. Previous papers had proposed some multicast mechanisms to carry IPTV over EPON carry, but an effective admission control is required to determine which IPTV channel request has to be admitted to transmit over EPON, to efficiently promote bandwidth usage of EPON and satisfy most user's requirements for IPTV channels. This paper proposes a popular channel first (PCF) admission control (AC) algorithm for determining IPTV channel transmission admission over EPON. As a result, the simulation result of the proposed method shows that the algorithm can improve the bandwidth utilization and can satisfy more IPTV channel requests, and achieve a more scalable IPTV service network and satisfy most user's channel requirements.

## Introduction

The evolution of technologies in access network are expediting much quicker in the recent year, such as DSL (Digital Subscriber Line), Wireless Network (WiFi and WiMAX), Cable Network (Hybrid Fiber Coaxial, HFC) and Ethernet Passive Optical Network (EPON) [1-3]. The downlink and uplink bandwidth increase dramatically. Thus, more and more bandwidth-intensive applications are emerging, such as Voice over IP (VoIP), video-conferencing, interactive gaming and IPTV (Internet Protocol Television) [4].

EPON is considered as the best candidate for the next generation access network technologies in the access technologies. IPTV is considered as the killer application in the new emerging bandwidth-intensive applications. Thus if one can combine the EPON and the IPTV successfully, one will get the benefits. In the following parts, this paper will introduce the IPTV, EPON and the difficulty of deploying IPTV over EPON.

IPTV uses Internet Protocol (IP) to transmit the Television (TV) to end users. The essential properties of the IPTV are (1) Interactive: end users can use the IP network to interactive with the service provider. (2) Multicast [5]: channels are transmitted to the specific group and end users use Internet Group Management Protocol (IGMP) join/leave messages [6] to receive/reject the group. (3) Locally/Private: IPTV is usually deployed in private network. (4) Bandwidth-intensive: per HDTV (High-definition TV) digital stream (MPEG-2 compressed) requires 12-18 Mbps, and per SDTV (Standard-definition TV) digital stream (MPEG-2 compressed) requires 3-8 Mbps [15]. Thus, to deploy IPTV well, it must need the access network with high downlink bandwidth, such as EPON (1Gbps downlink bandwidth).

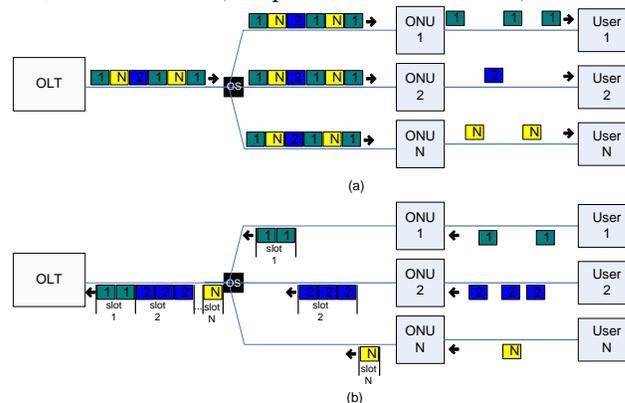


Figure 1. EPON transmission: (a) downlink transmission. (b) uplink transmission

EPON is defined in IEEE 802.3ah, and it is defined for physical layer (OSI Layer 1) and data link layer (OSI [18] Layer 2). EPON includes Optical Line Terminal (OLT), Optical Splitter (OS) and Optical Network Unit (ONU). Fig. 1 shows the transmission of EPON. In EPON downlink transmission (as shown in figure 1a), OLT broadcasts the frames inserted with broadcast or specific logical link identified (LLID) to all ONUs, and the ONU will receive and forward the frames to users if the frame has broadcast LLID or specific LLID matches itself. In other words, the EPON downlink transmission works like the broadcast and select fashion.

In EPON uplink transmission (as shown in figure 1b), time division multiple access (TDMA) is used to share the trunk fiber (OLT to OS). Each ONU will send its frame to OLT only if it gets the transmission rights (time-slot). The famous and simplest way that the OLT allocates the bandwidth to each ONU is the interleaved polling with adaptive cycle time (IPACT) [12]. While the features of EPON are (1) the best candidate of the next generation access network technologies; (2) high downlink/uplink bandwidth up to 1 Gbps; (3) long distance up to 20 Km; (4) compatible with wide-deployed Ethernet devices; (5) multicast natural.

Compare the features of EPON with the properties of the IPTV, and one can know that EPON is suitable for deploying IPTV. However, OSI [18] Layer 1 (physical layer) and OSI Layer 2 (data link layer) devices (OLT and ONU) cannot get the channel request message (IGMP message which is defined in Layer 3), so standard EPON cannot manage the IPTV stream. Thus standard EPON requires some technologies to get the channel request information, such as IGMP proxy/snooping [8-9]. IGMP snooping [10] can snoop Layer 3 IGMP messages, and then set up the multicast mapping table to record the channel request information (user and request channel). While IGMP proxy [11] can process (generates or drops) and snoop Layer 3 IGMP messages. With the multicast mapping table plus the filtering scheme, OLT and ONU can manage the IPTV channels. There two filtering schemes [8-9]: (1) MAC filtering which is based on multicast MAC address (MMAC). (2) reconciliation sub-layer (RS) filtering which is based on multicast logical link identified (MLLID).

## Related Work

Many researches were proposed to deploy IPTV over EPON. In [8-9], a multicast is proposed based on LLID (as shown in figure 2). When the IGMP Join message for group 1 sent from user 1 reaches the OLT, the IGMP Proxy will detect and then use OAM (Operation, Administration and Maintenance) [19] to inform ONU 1 to update the multicast table to record MAC 1 (user 1) request MPort 1 (Group 1). In addition, OLT will set up the information that LLID 1 (ONU 1) needs the MLLID 1 (Group 1). Finally, OLT will send IGMP Join 1 to multicast router for asking Group 1. Then, the multicast stream from the multicast router arrives at the OLT, OLT will filter the MLLID 1 (Group 1), and encapsulate the multicast stream to the frames inserted with MLLID 1. As the frames arrive at the ONUs, ONU 1 will filter MLLID 1 (Group 1), and send it to user 1. The advantages of this scheme are that it only needs one IGMP Proxy at OLT and the central control is simple. The drawback of this scheme is that it does not consider the situation

that many different channel requests may paralyze the EPON downlink.

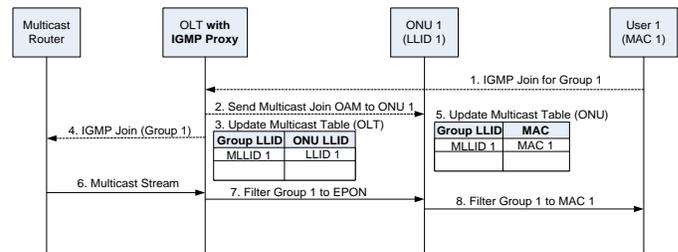


Figure 2. Multicast based on LLID

In [13], they proposed high-definition IPTV broadcasting architecture over Gigabit-capable PON (GPON) (as shown in figure 3). This scheme uses enhanced ONT (optical network unit), which adds IGMP Proxy at the ONT. In addition, based on the users' profile, enhanced ONT can generate IGMP messages to request channel. Because the channels are requested in advance, as ONT receives the IGMP Join message sent by IPTV terminals 1, ONT just updates its multicast table to record MAC 1 (user 1) request MPort 1 (Group 1). Here, MPort (Multicast Port) 1 is similar to the MLLID 1 mentioned before. Finally, ONT can filter the channel to IPTV terminals. The advantage of this scheme is that the channel change time is very short. However, the price is that large bandwidth is wasted even though the channels are not been watching. In addition, because every ONTs need an IGMP Proxy, the cost is high.

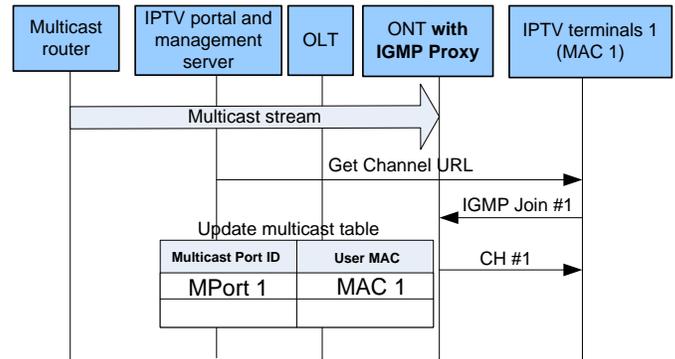


Figure 3. High-definition IPTV broadcasting architecture over Gigabit-capable Passive Optical Network

In [14], they proposed a novel implementation of carrying DVB service in EPON (as shown in 4). This scheme adds IGMP Proxy to OLT and IGMP Snooping to ONU. In addition, OLT is connected to video server and EPG (Electronic Program Guide) server via the gigabit Ethernet network port. Channels are sent to video server for buffering in advance and to EPG server for generating EPG information to users. Users (IP set-top box (STB)) select channels (IGMP Join for

CH1) according to the EPG information. When the IGMP Join for CH1 arrives to ONU 1, the IGMP Snooping will detect and then update the multicast table to record MAC 1 (user 1) request MMAC 1 (Group 1). Besides, the IGMP Join for CH1 will send to OLT, the IGMP Proxy will detect and then update the multicast table to record LLID 1 (ONU 1) needs the MLLID 1 (Group 1). In addition, the OLT will send the IGMP Join to video server. As video server receives the IGMP Join, the video server will send the request channel back to OLT, and the OLT will send the channel to ONU according to the multicast table. Also, ONU will forward channel to IP STB according to its multicast table. The advantage of this scheme is that when the channel already exists in EPON, the channel change time is very short. The drawback is that they do not mention how to control the total number of channel that can enter the EPON. Without a suitable control mechanism, the EPON will be paralyzed.

The ONU is composed of three parts: (1) IPTV Filter. (2) Multicast Table. (3) IGMP Snooping.

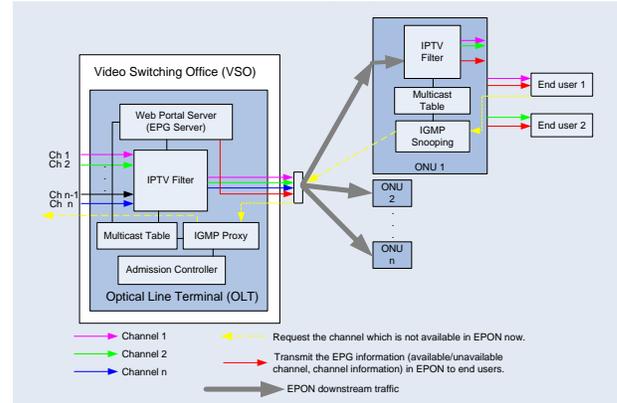


Figure 5. The architecture of IPTV delivery with admission control

OLT is used to process the channel change form ONUs, and achieve communication with multicast router. In the multicast router's view, OLT works like an end user.

The main purpose of Web Portal Server (EPG) is providing EPG information to the end users and recording the request numbers of all channels.

Based on multicast table, IPTV Filter can filter the multicast stream belong to the EPON at the OLT, and filter the multicast stream belong to the end user at the ONU.

Admission Controller can be the Popular Channel First Admission Control (PCF-AC) or First Come First Served Admission Control (FCFS-AC) [17]. The details are introduced in the section 6. Multicast Table is established according to the admission controller and IGMP Proxy.

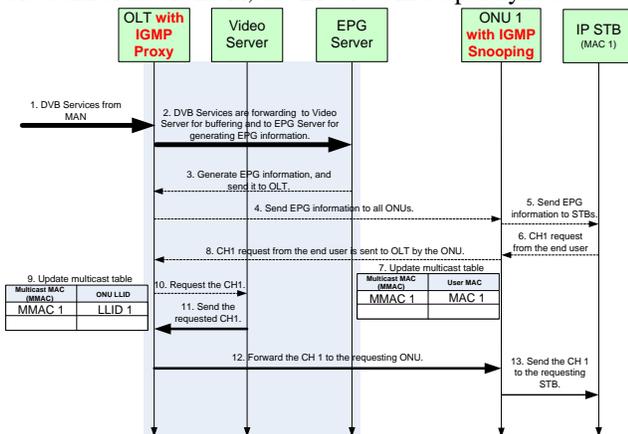


Figure 4. A novel implementation of carrying DVB service in EPON

In the previous works, they give a great contribution that how to make IPTV services deliver over EPON be real. However, they do not provide a channel request model and consider the situation that when there are many different channel requests may paralyze the EPON downlink transmission. Thus, this paper provides a channel request model and develops a good admission control algorithm to provide flexible number of channel, guarantee non-over allocation bandwidth and satisfy the most of the channel requests from users finally.

## Proposed Architecture

### A. The Introduction of the components

Figure 5 illustrates the architecture of IPTV delivery with admission control. Generally, the OLT is composed of five parts: (1) Web Portal Server (EPG). (2) IPTV Filter. (3) Multicast Table. (4) IGMP Proxy. (5) Admission Controller.

### B. The process of channel join/leave

The channel join with PCF-AC is illustrated in shown in figure 6. User 1 sends IGMP Join for group 1 to ONU 1, and then IGMP Snooping at the ONU 1 detects the IGMP Join for group 1, it will update the multicast table. And then the IGMP Join for group 1 arrive to the OLT, the IGMP Proxy will detect and transmit it to PCF-AC for processing. If the channel request is accepted by the PCF-AC, the IGMP Proxy will update the multicast table to record the request information. Besides, OLT will send IGMP Join for group 1 to multicast router. Finally, multicast stream is forwarded from the multicast router arrives to the OLT. The IPTV Filter at OLT will filter the multicast stream and encapsulated the multicast stream to frames with MLLID 1 inserted to EPON according to the multicast table. When the ONU 1 receives the stream, according to the multicast table, the IPTV Filter at ONU 1 will filter the multicast stream to user 1.

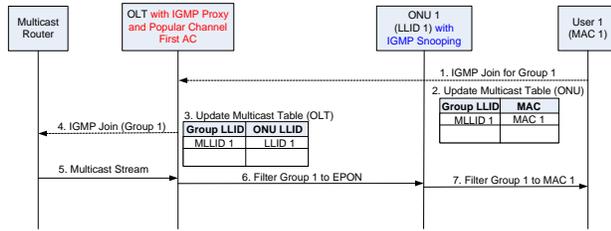


Figure 6. The Process of Channel Join

The process of channel leave is illustrated in figure 7. When the IGMP Leave for group 1 arrives to the ONU 1, IGMP Snooping detects and deletes the MAC 2 from the relationship of user and request channel. When the IGMP Leave for group 1 arrives to the OLT, the IGMP Proxy detects and then discards it. And now user 1 want to leave the group 1, user 1 will send IGMP Leave for group 1. IGMP Snooping at ONU 1 detects it and deletes the relationship of user 2 and group 1. And because it is the last user who want group 1, the ONU 1 has to send Multicast Leave OAM to inform OLT that it does not need the group 1. When the OLT receives the Multicast Leave OAM from ONU 1, it will update multicast table to delete the relationship of group 1 and ONU 1. And OLT will know that the ONU 1 is last user who needs group 1, OLT will send IGMP Leave for group 1 to multicast router to stop forwarding the group 1.

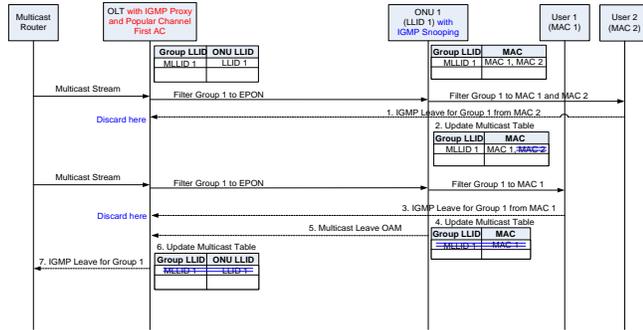


Figure 7. The Process of Channel Leave

## Proposed PCF-AC algorithm

### A. Parameters definition

This paper assumes that the PCF-AC algorithm calculates ever 2 ms (IPACT Maximum Cycle [12]). And the parameter definition is showed in TABLE I.  $B_{CH}$  is the bandwidth required per IPTV channel, which ranges from 3 to 8 Mbps [15]. This paper set this value to 3 Mbps.  $B_{EPON\_D}$  is the total downlink bandwidth of EPON, which value defined in IEEE 802.3ah is 1Gbps [2]. The  $j$ th IPACT cycle is named  $j$ . The channel number is  $k$ . The ACL is the current admitted channel list, which is get from the EPG server. According to the

ACL, the total number of the current admitted channel  $N_{AC}$  can be calculated. The channel request list in the  $j$ th IPACT cycle is  $CRL_j$ .  $N_{UAC}^j$  is the total number of the un-admitted channel in the  $j$ th IPACT cycle, which is get from comparing the  $CRL_j$  and ACL. Threshold is a Threshold to start PCF-AC algorithm. The admitted channel list in the  $j$  IPACT cycle is  $ACL_j$ .

Table 1. Parameter definitions

Symbol	Meaning
$B_{CH}$	The bandwidth required per IPTV channel.
$B_{EPON\_D}$	Total downstream bandwidth of EPON.
$j$	The $j$ th IPACT cycle.
$\alpha$	The percentage of EPON downstream bandwidth used for IPTV.
ACL	The current admitted channel list.
$N_{AC}$	The total number of the current admitted channel.
$C_{IPTV}$	The bandwidth consumption ratio for IPTV.
$PC_{IPTV}$	The possible bandwidth consumption ratio for IPTV.
$CRL_j$	The channel request list in the $j$ th IPACT cycle.
$N_{UAC}^j$	The total number of the un-admitted channel in the $j$ th IPACT cycle.
$k$	Channel number. ( $k = 1, 2, 3, \dots, N$ )
$N_{rmd}^j$	The remainder numbers based on the remainder bandwidth that can be used by those un-admitted channel in the $j$ IPACT cycle.
$\beta_k$	The weight for calculating the popular of the channel $k$ . This value is set according to the requested information saved by the EPG server.
$History_k$	The success request in the past.
Threshold	A Threshold to start PCF-AC.
$N_k^j$	The number of requests for channel $k$ in the $j$ IPACT cycle.
ACL $_j$	The admitted channel list in the $j$ IPACT cycle.
$DefaultPopular_k$	The default popular value of the channel $k$ .
$Popular_k^j$	Popular value of the un-admitted channel $k$ in the $j$ IPACT cycle.

The percentage of EPON downlink bandwidth used for IPTV is  $\alpha$ . Because Zipf distribution [16] (refer to Equation (1), where  $k$  is the channel number and the  $N$  is the total number of channels) can be the viewing probability of the channel [14], this paper uses the viewing probability multiple the total number of users to see that how much the specific channel has at least one user. In Figure 8 shows that when the Zipf factor  $\omega$  is equal to 0.7 [14], the number of channels which have at least one user is 109. And when the Zipf factor  $\omega$  is equal to 1 [7], the number of channels which have at least one user is 73. Thus, it must provide at least 73 and 109 number of channels when the Zipf factor  $\omega$  is equal to 0.7 and 1. In this paper, the number of channels is set to 109 when Zipf factor  $\omega$  is equal to 0.7, thus  $\alpha$  is 0.327 ( $109*3/1000 = 0.327$ ). And the number of channels is set to 73 when Zipf factor  $\omega$  is equal to 1, thus  $\alpha$  is 0.219 ( $73*3/1000 = 0.219$ )

$$P(x=k) = \frac{1}{k^\omega \cdot \sum_{i=1}^N \frac{1}{i^\omega}}$$

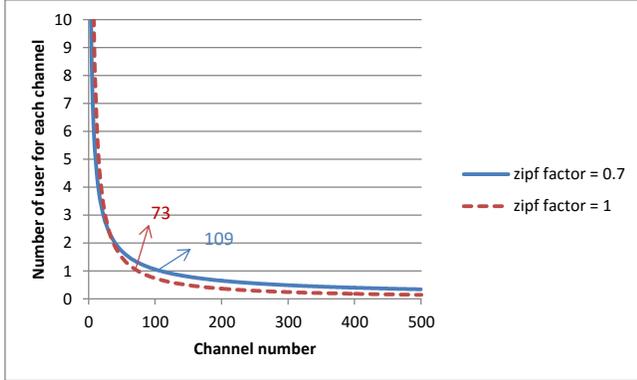


Figure 8. The number of user of each channel when the total number of users is 500 and the Zipf factor ( $\omega$ ) is 0.7 and 1

The bandwidth consumption ratio for IPTV is  $C_{IPTV}$  and its value is calculated as following Equation (2):

$$C_{IPTV} = \frac{B_{CH} \times N_{AC}}{\alpha \times B_{EPON,D}} \quad (2)$$

Whereas the possible bandwidth consumption ratio for IPTV  $PC_{IPTV}$  is calculated as following Equation (3):

$$PC_{IPTV} = \frac{B_{CH} \times (N_{AC} + N_{UAC}^j)}{\alpha \times B_{EPON,D}} \quad (3)$$

The weight for calculating the popular of the channel  $k$  is  $\beta_k$ . This value is calculated according to the requested information saved by the EPG server. As shown in Equation (4),  $History_k$  represents the number of requests for channel  $k$  in the past.

$$\beta_k = \frac{History_k}{\sum_{i=1}^N History_i} \quad (4)$$

The remainder numbers which are derived from the remainder bandwidth that can be used by those un-admitted channels in the  $j$  IPACT cycle are  $N_{imd}^j$ . It is calculated as following Equation (5):

$$N_{imd}^j = \left\lfloor \frac{\alpha \times B_{EPON} - B_{CH} \times N_{AC}}{B_{Ch}} \right\rfloor \quad (5)$$

The default popular value of the channel  $k$  is  $DefaultPopular_k$ .  $DefaultPopular_k$  is calculated as Equation (6), it uses the viewing probability of channel 1 ( $P(x=1)$ ) as a base value. And the smaller value stands for more popular.

$$DefaultPopular_k = \frac{P(x=1)}{P(x=k)} \quad (6)$$

(1) The number of requests for channel  $k$  in the  $j$  IPACT cycle is  $N_k^j$ . And the popular value for the un-admitted channel  $k$  in the IPACT cycle is  $Popular_k^j$ .  $Popular_k^j$  is calculated as Equation (7), it uses  $N_k^j$  and  $\beta_k$  to decrease the value of  $Popular_k^j$  for increasing the popular. It can be classified into these cases: (a) As the  $\beta_k$  is very large, it represents that the channel  $k$  was very popular in the past. Thus, regardless of the  $N_k^j$ , it has to decrease the  $Popular_k^j$  to increase the popular. In Equation (7), the  $Popular_k^j$  decreases when the  $\beta_k$  increases. (b) As  $N_k^j$  is very larger, it represents that many users request the channel  $k$  in this cycle. If the  $\beta_k$  is still small, the value of  $\beta_k (DefaultPopular_k + N_k^j)$  will increase when the  $N_k^j$  increases. Thus, it can decrease the value of the  $Popular_k^j$  to make channel  $k$  more popular. (c) As  $\beta_k$  and  $N_k^j$  is small, it represents that the channel  $k$  was not popular in the past, and less users request it in this cycle. Thus, the value of  $Popular_k^j$  is almost the same as the  $DefaultPopular_k$ . In addition, if  $DefaultPopular_k - \beta_k (DefaultPopular_k + N_k^j)$  is less than zero, the  $Popular_k^j$  is set to zero. Thus, the popular value of channel is smaller, the priority is higher. And the highest priority occurs when the popular value is zero. In addition, when multiple channels with the same popular value, the channel requests arrive earlier has a higher priority.

$$Popular_k^j = MAX \begin{cases} 0, \\ DefaultPopular_k - \beta_k (DefaultPopular_k + N_k^j) \end{cases} \quad (7)$$

To shows the effects of the  $\beta_k$  and  $N_k^j$  in Equation (7), we provide some simple examples: (a) We set  $\beta_k = 0.1$ , five channels (CH-1 to CH-5) and  $N_k^j = 1 \sim 30$  to observe the value of  $Popular_k^j$ , as shown in figure 9. The x-axis is  $N_k^j$  and the y-axis is  $Popular_k^j$ . When the  $N_k^j$  increases. If the  $N_k^j$  is equal to the point of the intersection for the orange line to each lines, the popular for CH-1 to CH-5 is then reversed totally.

(b) We set  $N_k^j = 10$ , five channels (CH-10, CH-20, CH-30, CH-40 and CH-50) and  $\beta_k = 0 \sim 1$  to observe the value of  $Popular_k^j$ , as shown in figure 10. The x-axis is  $\beta_k$  and the y-axis is  $Popular_k^j$ . If the  $\beta_k$  is equal to the point of the intersection for the orange line to each lines, the popular for CH-10 to CH-50 is then reversed totally.

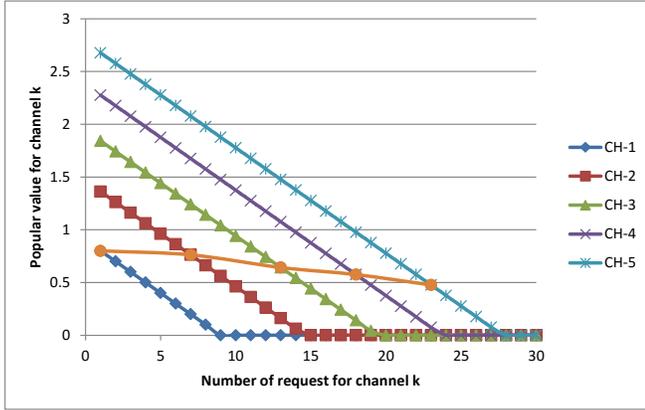


Figure 9. The value of  $Popular_k^j$  when  $\beta_k = 0.1$ , five channels (CH-1 to CH-5) and  $N_k^j = 1 \sim 30$ .

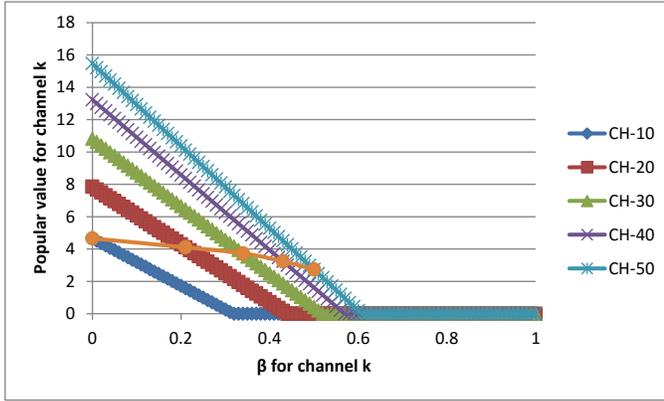


Figure 10. The value of  $Popular_k^j$  when  $N_k^j = 10$ , five channels (CH-10, CH-20, CH-30, CH-40 and CH-50) and  $\beta_k = 0 \sim 1$

## B. Proposed PFC-AC

Proposed Popular Channel First Admission Control (PCF-AC) is listed below. Line 01 to 04 is mainly used for removing those admitted channels and add those channels to the  $ACL^j$ . Line 05 to 06 is used to calculate the popular value of those un-admitted channels. Line 07 determines that if there are still some remainder numbers that can be used by those un-admitted channels. If line 07 is false, go to line 19-20, PCF-AC will reject all un-admitted channels. If line 07 is true, go to line 08 to determine that if possible bandwidth consumption ratio for IPTV is larger or equal than Threshold. If line 08 is false, go line 17-18, PCF-AC will admit all un-admitted channels. If line 08 is true, go to line 09. Line 09 is mainly used to check if the bandwidth consumption is approaching to full load. If line 09 is true, go to line 10, PCF-AC will admit the most popular un-admitted channel. If line 09 is false, go to line 11 to check if bandwidth consumption is less or equal than Threshold. If line 11 is true, to make the bandwidth consumption reaches to the Threshold quickly, go

to line 12, PCF-AC will admit at most the first  $\lfloor Threshold \times N_{md}^j \rfloor$  high popular un-admitted channels. If line 11 is false, to make the bandwidth consumption reaches to the full load slowly, go to line 14-15, PCF-AC will admit at most the first  $\lfloor (1 - C_{IPTV}) \times N_{md}^j \rfloor$  high popular un-admitted channels. Line 21 adds the current  $ACL^j$  to  $ACL$ . Finally, return the  $ACL^j$ .

### Algorithm: Popular Channel First Admission Control (PCF-AC)

01. For all channel k in the  $CRL^j$
02. If channel k is already existed in  $ACL$
03. Remove channel k from the  $CRL^j$
04.  $ACL^j = ACL^j$  union channel k
05. Else
06.  $Popular_k^j = MAX(0, DefaultPop ular_k - \beta_k (DefaultPop ular_k + N_k^j))$
07. If  $N_{md}^j = \left\lfloor \frac{\alpha \times B_{EPON\_D} - B_{CH} \times N_{AC}}{B_{CH}} \right\rfloor$  is larger or equal than 1
08. If  $PC_{IPTV} = \frac{B_{CH} \times (N_{AC} + N_{UAC}^j)}{\alpha \times B_{EPON\_D}}$  is larger or equal than Threshold
09. If  $\lfloor (1 - C_{IPTV}) \times N_{md}^j \rfloor$  is equal to zero
10.  $ACL^j = ACL^j$  union the channel with highest priority in the  $CRL^j$
11. Else If  $C_{IPTV} = \frac{B_{CH} \times N_{AC}}{\alpha \times B_{EPON\_D}}$  is less or equal than Threshold
12.  $ACL^j = ACL^j$  union the channel with first  $\lfloor Threshold \times N_{md}^j \rfloor$  higher priority in the  $CRL^j$
13. Else
14.  $ACL^j = ACL^j$  union the channel with first  $\lfloor (1 - C_{IPTV}) \times N_{md}^j \rfloor$  higher priority in the  $CRL^j$
15. Else
16.  $ACL^j = ACL^j$  union all channel requests in the  $CRL^j$
17. Else
18.  $ACL^j = ACL^j$  union all channel requests in the  $CRL^j$
19. Else
20. Reject all channel requests in the  $CRL^j$
21.  $ACL = ACL$  union  $ACL^j$
22. Return  $ACL^j$

## Simulation Results

### A. Channel Request Model

Users are classified into two types: one will not change channel as the advertisement comes and another will change channel as the advertisement comes. Channels also have two types: one has 3 minutes video section and 20 seconds advertisements and another one has 5 minutes video section and 20 seconds. Channel request model includes (1) Initial surfing: the channel change behavior when the user starts watching TV. (2) General surfing: the channel change behavior for the user when the channel is in advertisement. (3) General mode: general leave a channel when the user

doesn't want to watch TV and general change which the user does not often change channel.

Figure 11 illustrates the channel request model when the channel is not in ad. In the beginning, the timer of each user is set randomly about 1 to 60 seconds. If the user is not watching IPTV as timer is going to zero, the user will have probability 0.9 to start watching IPTV and behaves as initial surfing. Initial surfing supposes that user will have probability 0.9 to change to other channel every 4 seconds.

If the user is watching IPTV now, the user will have probability 0.5 to continue watching IPTV. And then if the user is surfing, the user will have probability 0.9 to continue surfing and probability 0.1 to stop surfing. If the user stop surfing and the user behaves as initial surfing, the user will ask new channel. If the user stop surfing and the user behaves as general surfing, the user will request the channel before starting general surfing. And the timer is reset randomly about 1 to 60 seconds.

If the user is not surfing, user will have probability 0.9 to watch the same channel and probability 0.1 to request new channel. And the timer is reset randomly about 1 to 60 seconds.

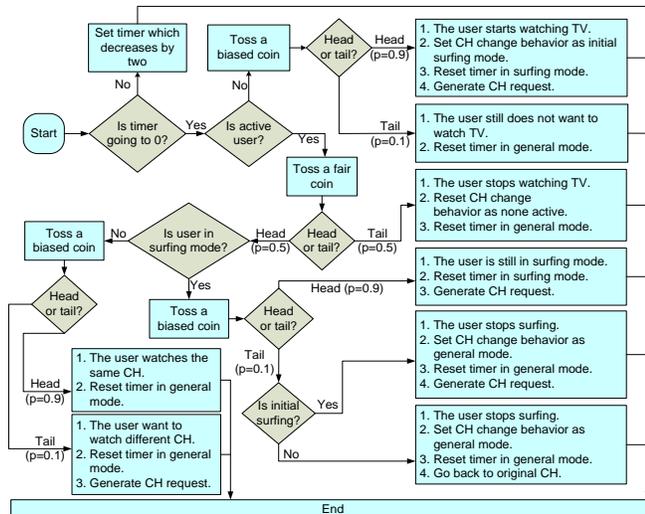


Figure 11. The channel request model when the channel is not in ad

Figure 12 illustrates the channel request model when the channel is in ad. The main difference between figure 11 and figure 12 is that if the user is not surfing and the user is a type of watching advertisement, the user will not request new channel. Otherwise, the user will start general surfing. General surfing is similar to initial surfing, but the general surfing will go back to the channel before starting surfing as the user stops general surfing.

### A. Based on Channel Request Model in Part A

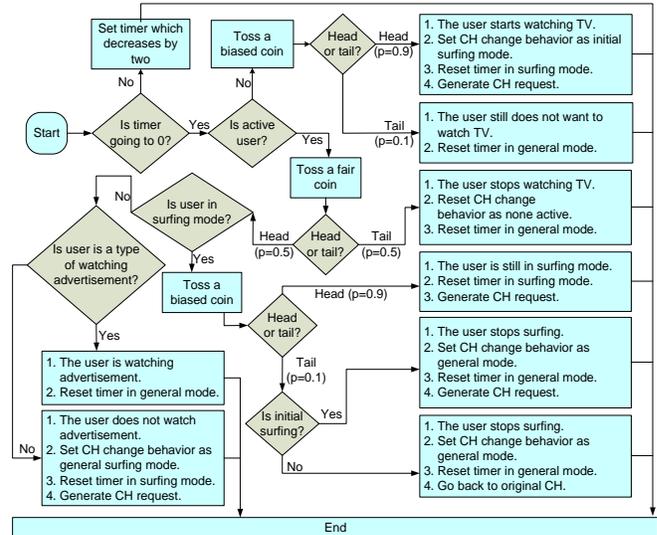


Figure 12. The channel request model when the channel is in ad

Table 2. Parameter definitions

Symbol	Value
$B_{CH}$	3 Mbps
$B_{EPON\_D}$	1 Gbps
$\alpha$	0.219, 0.327
N	500
User	500
Threshold	0.1, 0.2, 0.3, ..., 0.9, 1

The parameter value for simulation is illustrated in table 2.  $B_{CH}$  is the bandwidth consumption per channel, which is set to 3 Mbps.  $B_{EPON\_D}$  is the EPON downlink bandwidth, which is set to 1 Gbps.  $\alpha$  is the percentage of EPON downstream bandwidth used for IPTV, which is set to 0.219 and 0.327 according to the part A in the section IV. N is the total number of channels, which is set to 500. User is the total number of users, which is set to 500. Threshold is the timing to start the partial reject in the PCF-AC, which is set to 0.1 to 1 to observe the admitted rate. In addition, channel request model is introduced in part A of section V. A half of users watches the ad and the other doesn't watch the ad. A half of channels is set to video section = 3 min and ad section = 20 seconds and the other one is set to video section = 5 minutes and ad section = 20 seconds. Total run time is 10 minutes.

Figure 13 shows the admitted rate under different Threshold. The x-axis is Threshold and the y-axis is the admitted rate. We compare proposed PCF-AC and FCFS based AC (FCFS-AC). The number in the brackets after PCF-AC or FCFS-AC stands for the value of the Zipf factor. First, compare PCF-AC(0.7) with the FCFS-AC(0.7), we can observe that the admitted rate of PCF-AC(0.7) is larger than FCFS-AC(0.7). This is because PCF-AC will partial reject some un-popular channel requests to save bandwidth for those more popular channel requests. In addition, the admitted rate

is very close between PCF-AC(0.7) and FCFS-AC(0.7) when the Threshold is 0.9 and 1. This is because that the PCF-AC(0.7) starts partial reject mechanism too late, the popular value of admitted channel for PCF-AC(0.7) and PCF-AC(1) is similar. Thus, the admitted rate is closer when the Threshold is 0.9 and 1. Second, compare PCF-AC(1) with the FCFS-AC(0.7), we can observe that there are the same phenomenon as the PCF-AC(0.7) and PCF-AC(1).

Figure 14 shows the average person online in different Threshold. The x-axis is Threshold and the y-axis is the average person online. Regardless of the value of Zipf factor, the PCF-AC can server more person than FCFS-AC.

In figure 13, for Zipf factor is set to 0.7, the admitted rate is worst when the Threshold is set to 0.7 and better when the Threshold is set to 0.4. Here, we compare the bandwidth consumption and the admitted rate in minute. Fig. 15 is the bandwidth consumption from 0~60 seconds when the Zipf factor = 0.7 and the Threshold = 0.4. The x-axis is seconds, and the y-axis is the bandwidth consumption rate. The first number in the brackets after PCF-AC or FCFS-AC stands for the value of the Zipf factor. The second number in the brackets after PCF-AC or FCFS-AC stands for the value of the Threshold. We can observe that the bandwidth consumption of PCF-AC is increase to full load slower than the FCFS-AC. And after the bandwidth consumption reaches full load, the popular value of channels admitted by the PCF-AC is more popular than the FCFS-AC. Thus, the admitted rate in minute of PCF-AC is higher than the FCFS-AC under the situation of full load, as shows in Fig. 16.

AC. Thus, the admitted rate in minute of PCF-AC is similar to the FCFS-AC under the situation of full load, and the gap of admitted rate in minute is closer, these results are showed in figure 18.

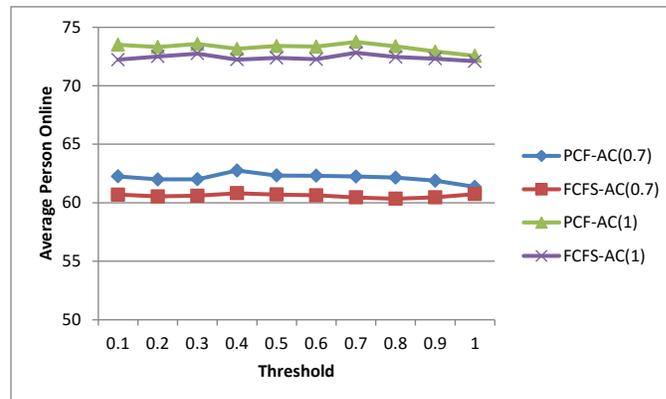


Figure 14. Average person online in different Threshold

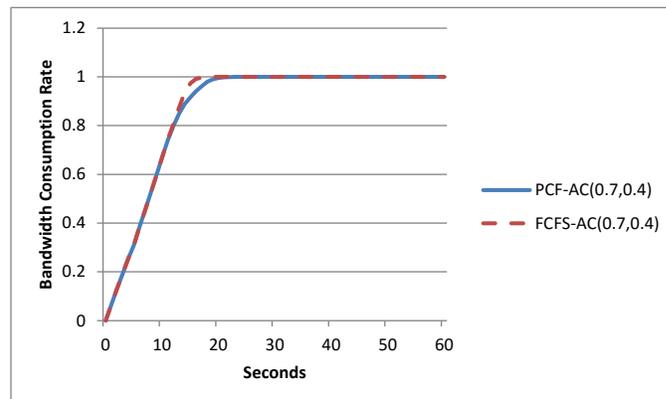


Figure 15. Zipf factor = 0.7, Threshold = 0.4, the bandwidth consumption from 0~60seconds

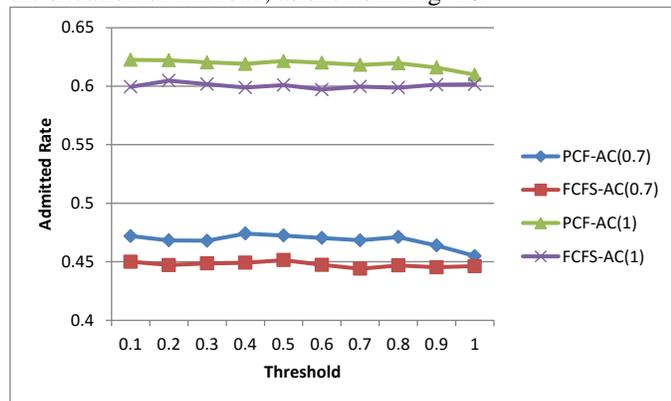


Figure 13. Admitted rate under different Threshold

Figure 17 illustrates the bandwidth consumption from 0~60 seconds when the Zipf factor = 0.7 and the Threshold = 1. We can observe that the bandwidth consumption of PCF-AC is similar to FCFS-AC. This is because that PCF-AC starts partial reject in the moment when the bandwidth reaches to full load. And after the bandwidth consumption reaches full load, the popular value of channels admitted by the PCF-AC is similar to the FCFS-AC. But there still some difference, the popular value of channel admitted by PCF-AC is still more popular than the channel admitted by FCFS-

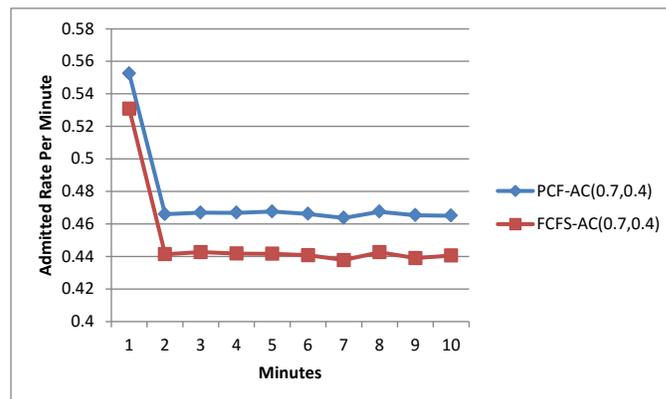


Figure 16. Zipf factor = 0.7, Threshold = 0.4, the admitted rate in minute

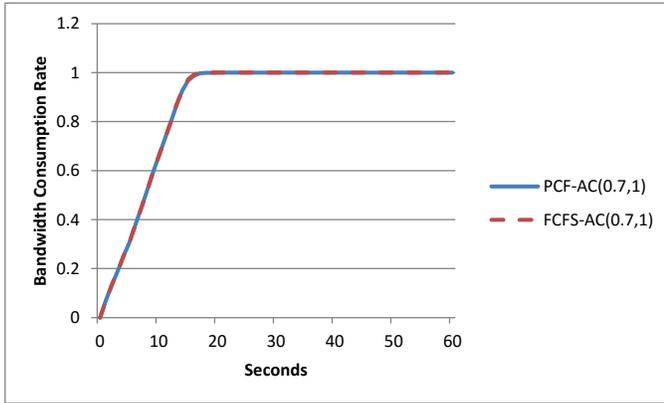


Figure 17. Zipf factor = 0.7, Threshold = 1, the bandwidth consumption from 0-60seconds

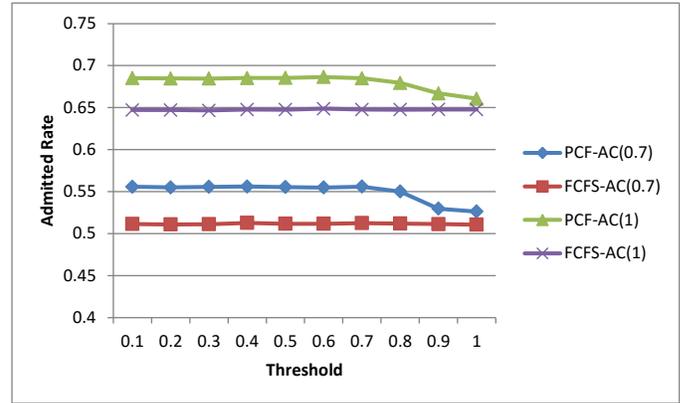


Figure 19. Zipf factor = 0.7 and 1, the admitted rate under different Threshold.

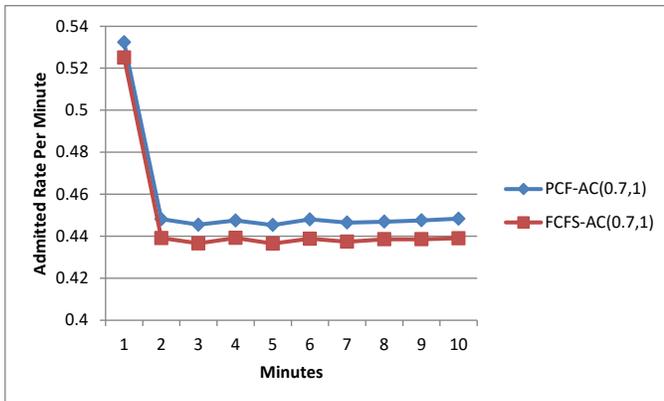


Figure 18. Zipf factor = 0.7, Threshold = 1, the admitted rate in minute.

### C. Verification of the PFC-AC

To illustrate the advantage of our PCF-AC, this paper adjusts the simulation parameters as: (1) total number of users = 1275, each user only requests one channel and the user will not leave the channel as the user is watching. (2) First, there is one request; second, there are two requests; third, there are three requests; ...; And fiftieth, there are fifty requests. Namely, there are total 1275 requests from the 1275 users.

Figure 19 shows the admitted rate under different Threshold when the Zipf factor = 0.7 and 1. We can observe that the admitted rate of PCA-AC and FCFS-AC is similar when the Threshold = 0.9 and 1. This is because that PCF-AC starts partial reject too late, and the popular value of admitted channels are similar, only small part is different.

Figure 20 shows the bandwidth consumption from 1 request to 50 requests when Zipf factor = 0.7, Threshold = 0.6 and 1. We can observe that the bandwidth consumption of PCF-AC(0.7, 0.6) reaches the full load slowest. This is because that PCF-AC(0.7, 0.6) starts partial reject when the bandwidth consumption is larger than the 0.6. While PCF-AC(0.7, 1) is minor then FCFS-AC(0.7, 0.6) and FCFS-AC(0.7, 1). This is because that the PCF-AC(0.7, 1) admits one un-admitted channels in a cycle when the bandwidth consumption is nearly full load.

Figure 21 illustrates the bandwidth consumption from 1 request to 50 requests when Zipf factor = 1, Threshold = 0.6 and 1. The results have the same situation as Fig. 20.

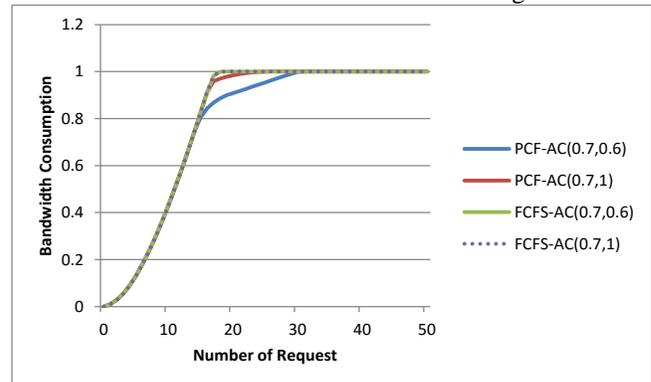


Figure 20. Zipf factor = 0.7, Threshold = 0.6 and 1, the bandwidth consumption from 1 request to 50 requests.

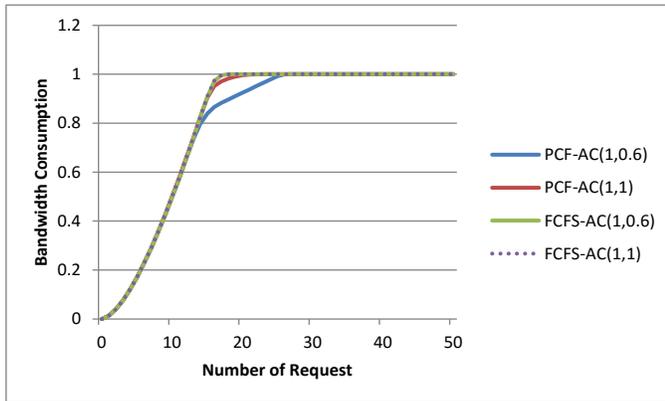


Figure 21. Zipf factor = 1, Threshold = 0.6 and 1, the bandwidth consumption from 1 request to 50 requests

## Conclusions

In this paper, the proposed PCA-AC algorithm has better performance than FCFS based on various threshold, such as admitted rate, average person online and use bandwidth efficiently. In addition, the proposed channel request model considers the real behaviors of watching tradition TV, e.g. initial surfing when the user starting watching TV, general surfing when the channel is in advertisement, general leave a channel when the users do not want to watch TV and general change in which users do not frequently change channel.

## Acknowledgments

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## Biographies

**CHI-YU HSU** received the B.S. and M.S. degree in Department of Management Information System from National Pingtung University of Technology and Science, Pingtung, Taiwan, R.O.C. Currently, he is a Ph.D. candidate in Department of Computer Science and Information Engineering from National Cheng Kung University, Tainan, Taiwan,



R.O.C. He also is a founder of the Sunshine Tech. R&D Co., Ltd. and WoT Technology Inc. His research areas include Internet of Things, Web technology, Property Management System, and System Integration. Mr. Chi-Yu Hsu may be reached at [cyhsu@stech.tw](mailto:cyhsu@stech.tw).

**CHUAN-CHING SUE** became a Member (M) of the IEEE in 1998, and received a B.S. and Ph.D. in electrical engineering from National Taiwan University, Taipei, Taiwan, R.O.C., in 1994 and 2001, respectively. He is currently a Full Professor in the Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, Taiwan, R.O.C. His Current research interests are fault-tolerant WDM networks and high-speed computer networks. Professor Sue may be reached at [suecc@mail.ncku.edu.tw](mailto:suecc@mail.ncku.edu.tw).

**ZHI-SHENG LIN** received M.S. in Computer Science and Information Engineering from National Cheng Kung University, Tainan, Taiwan, R.O.C., in 2010. His research focuses on admission control scheme for integrating IPTV services over Ethernet Passive Optical Network (EPON).