Software-Defined Time-Shifted IPTV Architecture for TWDMA-PON

I-Shyan Hwang, Craiggs Tesi, Elaiyasuriyan Ganesan, Andrew Fernando Pakpahan, and Andrew Tanny Liem

Abstract—**Time-shifted IPTV (TS-IPTV) is one way of implementing that, through IP multicasting. Ethernet passive optical network (EPON) is regarded the best solution due to its high bandwidth provision, low operation and maintenance cost. Software-defined networking (SDN) separates the network control plane from the data-forwarding plane with the promise to dramatically improve network resource utilization. Local-awareness based TWDMA-PON allows for higher bandwidth and optimal flexibility, fiber management, service convergence and resources sharing. In this paper, we propose to integrate SDN into the TWDMA-PON architecture to facilitate an orchestrated multicasting TS-IPTV and using the SDN controller to control and manage the traffic. Simulation results show that the proposed architecture and mechanism improves QoS requirements in terms of mean packet delay, jitter, throughput and packet loss.**

Keywords: TS-IPTV, SDN, TWDMA-PON.

I. INTRODUCTION

Within the global IP traffic, it was predicted that 60% will be occupied by the access network traffic [1] and by the end of year 2021, 82% of all IP traffic will be the video service [2]. Recently, a new delivery method, called Internet Protocol Television (IPTV) widely used by the telecommunication industries, offers more interactivity and better television services to the users globally. Time-shifted IPTV (TS-IPTV) has been defined as enabling the user "to watch a broadcasted TV program with a time-shift i.e., the end-user can start watching the TV program from the beginning although the broadcasting of that program has already started or is even already finished" [3].

In the access network, passive optical network (PON) is considered the most practical system today and an attractive solution to the first-mile problem [4]. Amongst the PON-based network, Ethernet passive optical network (EPON) is the prominent solution for providing diverse multimedia services [5]. EPON has been standardized in the IEEE 802.3ah (1G-EPON) and IEEE 802.3av (10G-EPON) [6] standards. Time and wavelength division multiplexed access PON (TWDMA-PON) is the ultimate solution for the second next-generation PON (NG-PON2) [7]. TWDMA-PON increases the number of channels for data transmission by employing the wavelength division multiple access (WDMA) when deploying different wavelengths in downstream transmission and time division multiple access (TDMA) when one wavelength is shared by multiple ONUs in the upstream transmission time. Multicasting [8] is a bandwidth-conserving mechanism for reducing data network traffic by simultaneously delivering a single stream of information from one source to thousands of viewers and is fundamental to the implementation of IPTV and today's wide range of Internet applications.

Recently, Software-defined networking (SDN) [9] has been attracting a great interest in networking for providing flexibility, simplicity and innovation in the network operation, control and management using a software platform. Furthermore, [10] presents a centralized approach to management of the source-specific multicast using SDN to compute multicast distribution trees for a given set of channels distributed to their customers. Integrating SDN with Openflow protocol, provides dynamic configurations and controlling of data flow, efficient resource provisioning centralized control of the entire network system. This paper presents a new software-defined enhancements to the OLT and ONU architecture to handle TS-IPTV traffic in the TWDMA-PON.

The rest of this paper is organized as follows. Section II describes the proposed system architecture and mechanism. Section III explains the overall system performance evaluation based on the simulation results and Section IV concludes this paper.

II. PROPOSED ARCHITECTURE AND MECHANISM

The main components of the architecture, shown in Fig. 1, are the SD-OLT, SD-ONU, SDN controller, Time-shift IPTV (TS-IPTV) server manager, 3:N star coupler and a MUX/DEMUX. The proposed mechanism emphasizes on the locality-awareness which is the ability to exploit local resources over remote ones whenever possible. The ONU will inform the controller if it does not have the requested channel. The controller will first check for the requested channel in other ONUs. When the channel is located, the controller will redirect it to the user via the closest ONU from which that channel is found. In doing so, the traffic will be regarded as intra (local) traffic, and redirecting that intra traffic will result in decreasing of transmission delay, increasing bandwidth usage while maintaining better QoS for the users. However, if the controller cannot locate the requested channel in any of the ONUs it will first check for it in the OLT. If the channel is not there, the controller will then inform the time-shift IPTV server manager to forward the requested channel from server to the OLT and then to the ONU; then, the ONU will multicast it to the users requesting it. To multicast the IPTV channels, the channel logical link identifier (CLLID) is defined; it is a unique CLLID

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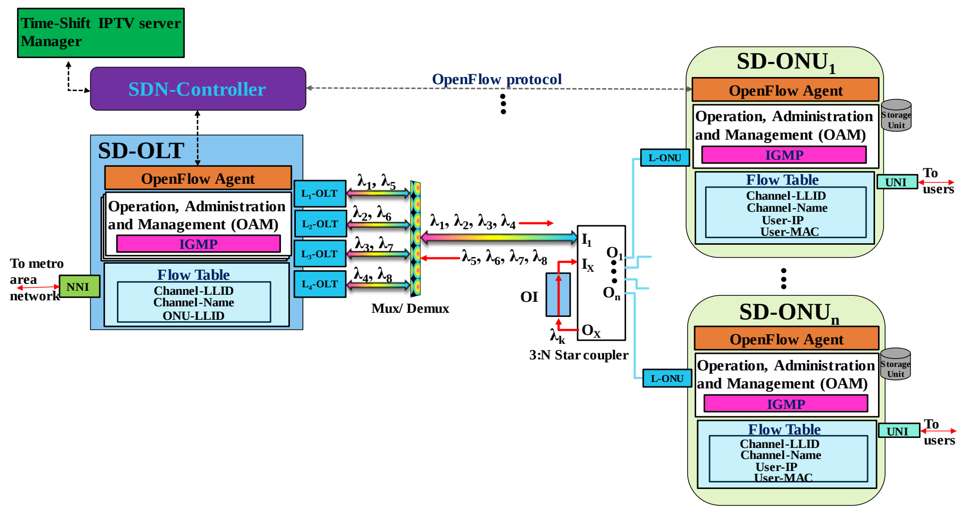

Fig1. The proposed Software-Defined Time-Shift IPTV Architecture for TWDMA-PON.

that is assigned to each requested channel. The CLLID is also independent of the ONU LLID. The mechanism works by assigning of the CLLID to the ONUs that request the channel. In doing so, the OLT can assign more than one CLLID to the ONUs; therefore, the ONUs will accept the frames with the desired CLLID from OLT.

A. *Software Defined OLT*

The proposed SD-OLT enables centralized control of the PON system and connects the PON system into the larger metro area network. The OpenFlow Agent is a software module which allows the abstraction of any legacy network element so that it can be integrated and managed by the SDN controller. OpenFlow Agent enables communication between the SDN controller, the OLT and the ONUs that communication is done via a secured channel using OpenFlow protocol. Through this agent, the controller can have access to overview network topology of the OLT and ONUs, and it can manage the resources they used. The OAM includes the process, activities, tools and standards involved with operating, administrating, managing and maintaining of the network system. The IGMP is a communication protocol used in networks to establish and maintain multicast group membership. The four Line OLT (L-OLT) tunable transceivers are used for transmitting and receiving of data packets. Each L-OLT is equipped with a tunable wavelength transceiver that is connected to the power splitters and the ONUs. The Flowtables provides the packet classification, queuing and forwarding of all the input and output ports. Network-to-Network Interface (NNI) is used for interconnection and specifies the signalling and management functions between diverse networks.

B. *Software Defined ONU*

The SD-ONUs link subscriber to the network through its user network interface (UNI). An OpenFlow Agent is also integrated in each of the ONUs that enables it to communicate with the SDN controller via a secure OpenFlow channel. Each ONU has its own operation, administration and management (OAM) with the Internet Group Management Protocol (IGMP). In the proposed architecture, the multicasting of the requested time-shifted IPTV channels is done by the ONU; this is where the IGMP will play its role of facilitating acquiring and relinquishing membership into multicast groups. The SDN controller is the software that manages all the shared resources of the underlying network infrastructure and performs all complex functions including routing, naming, policy declaration and security checks, and the controller is responsible for controlling and configuring the deployment of multiple L-OLTs and OAMs in the OLT. It is also responsible for updating the Flowtables in both the OLT and ONUs. A MUX/DEMUX is included to either split or combine the optical signals which drive one or more wavelength(s). The proposed star coupler with 3:N ports, where two inputs (i.e., I_X and O_X) are connected to each other via an optical isolator (OI). Its function is redirecting of the upstream traffic from O_X to I_X and broadcasting it to the entire ONUs through the N output ports. Transmission from O_X to I_X is only in one direction to prevent unwanted feedback. The I_1 is used for the downstream inputs port channel from OLT to all ONUs and vice versa. The O_1, …, O_n outputs ports are also used to broadcast signals to each ONU.

C. *Operation in the OLT*

The Flowtable with channel-LLID, channel-name and ONU-LLID in the proposed OLT architecture are modified to handle the time-shifted IPTV traffic. The multipoint control protocol (MPCP) controls the point-to-multipoint fiber network in the upstream channel and provides the signalling infrastructure to coordinate the data transmission from ONUs to the OLT. Two types of message are used to facilitate arbitration: GATE and REPORT. The OLT uses GATE messages to issue transmission grants, which contains the transmission start time and transmission length of the corresponding ONU; while ONUs use REPORT messages to report their bandwidth requirements to the OLT. The DBA algorithm implemented in the OLT uses these reports and gate messages to construct a transmission schedule and conveys it to the ONUs. When the ONU forwards a user's request to OLT, the OLT will first execute the Extract (packet) function to get the channel name from the packet. After extracting the channel name, the controller will check OLT's Flowtable to see if the requested channel name already existed or not. This is done when OLT executes the Check (channel_name) function. If that channel already exists in OLT, then OLT will execute the request_LLID (channel-name) to assign a unique LLID to the new channel. Controller will then update the OLT's and ONU's Flowtables before OLT broadcasts the requested channel data to the ONUs. If, however that channel does not exist, OLT will inform the controller, the controller will send a request message to the IPTV server manager to send the requested channel to the OLT. OLT will then repeat the above process to assign a unique LLID to the new channel and add the new channel to its Flowtable. The controller will update the OLT's and ONU's Flowtable before OLT starts broadcasting the data channel.

D. Operation in the ONU

When the user sends a request to ONU, ONU will receive it via the UNI interface. The request will be forwarded to the Flowtable for classification. The flow entries contain match fields, actions and a priority assigned by the controller to classify the data packets based on the type of service (ToS) table that the controller maintains, that is how the Flowtable knows which request belongs to which traffic type (EF, AF, TS-IPTV, BE). After classifying the packets, IGMP will check if the user wants to leave or join the multicast channels. IGMP leave message is sent to ONU when user wants to leave a multicast group and IGMP join is sent when user wants to join. If it is a join request, the controller will first authenticate the user by checking the user's information, such as user-IP and user-MAC addresses in the ONU's Flowtable. Once the user is authorized to receive the channel, the controller will send a controller-to-switch message to execute the Extract (packet) function so that ONU can extract the channel name from the packet; and then check (channel-name) function to check whether the channel name exists in the Flowtable; otherwise, that ONU will send an asynchronous message to the controller. The controller based on its data statistics collected from the ONUs will determine which ONU has that channel in its local storage unit closest to the user. Then it will send a controller-to-switch message to the ONU to redirect that request to the ONU with that channel through the 3:N star coupler, then finally can be sent to the users. Therefore, the traffic will be handled as intra traffic. If the requested channel does not exist in any of the other ONUs, the request will be forwarded to the OLT. If there are no other request for that particular channel, OLT will executes the functions Stop (channel_name, user_MAC) and Remove_flowtable (CLLID, channel_name, user_MAC) to stop broadcasting of the channel to the ONU and the controller will update the OLT's and ONU's Flow Table. Note that TS-IPTV contents can only be

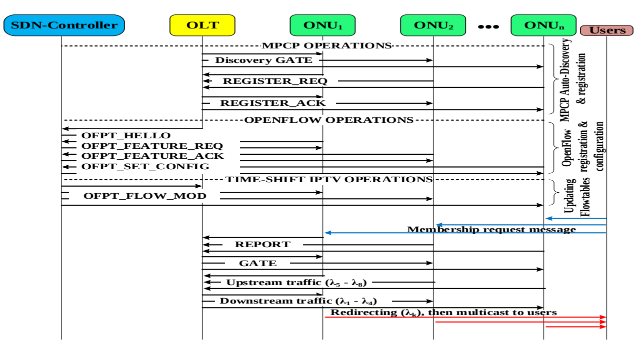

Fig 2. MPCP and OpenFlow Signaling Operation.

stored in IPTV servers for a limited time period and then be erased for new programs, and the addition of the storage unit in the proposed ONU will solve that problem by storing the most frequently requested channels, which makes full use of the TWDMA-PON system downstream broadcasting mechanism.

E. MPCP and Openflow Signaling Operation in the Proposed Architecture

Figure 2 shows the signalling control operations. The operation of the proposed architecture begins when the OLT starts up and initiate auto-discovery and registration of the ONUs by using MPCP protocol. During the auto-discovery and registration of the ONUs, the OLT will send a discovery GATE messages to the ONUs. The ONUs will reply OLT with a REGISTER-REQ message after receiving the discovery GATE message. After receiving the REGISTER-REQ from the ONUs, the OLT will reply with a REGISTER_ACK message to confirm the ONUs has been registered and connected to the OLT. After all the ONUs have established connection with the OLT, the OLT and the ONUs will start to initiate connection with the SDN-Controller using OpenFlow. The OpenFlow Agents in the OLT and ONUs will initiate the symmetric communication by sending OFPT_HELLO messages to the controller. Upon receiving the message, the controller will also reply the OLT and ONUs with OFPT_HELLO message. After the controller, OLT and ONUs have exchanged OFPT_HELLO messages successfully, the connection setup is done and the standard OpenFlow messages can be exchanged over the connection. The controller will send the FPT_FEATURE_REQ message to obtain information about the OLT an ONUs, and they will reply with an OFPT_FEATURE_ACK message. The controller is able to read and write the OLT's ONU's configuration by sending the OFPT_SET_CONFIG message to OLT and ONUs, whom they will also reply by sending the OFPT_SET_CONFIG message to inform the controller about their features and Flowtable condition. Controller will send OFPT_FLOW_MOD messages to OLT and ONUs to update their Flowtables.

III. PERFORMANCE EVALUATION

Table I Experimental scenarios.

Scenarios	EF	AF	BE
Original IPACT- 10:40:50	10%	40%	40%
Original IPACT- 10:50:40	10%	50%	50%
Original IPACT- 10:60:30	10%	60%	60%
Case1- 10:40(10%):50	10%	36%	36%
Case2- 10:50(10%):40	10%	45%	45%
Case3- 10:60(10%):30	10%	54%	54%
Case4- 10:40(20%):50	10%	32%	32%
Case5- 10:50(20%):40	10%	40%	40%
Case6- 10:60(20%):30	10%	48%	48%

The system model is set up using the OPNET simulator with one OLT and 64 ONUs. We compare the system performance of the proposed scheme with IPACT scheme [11]. The downstream and upstream channels between the OLT and ONUs are set to 4 Gbps and the distance between them is uniform ranging from 10 to 20 km. Each ONU has a 10 Mb buffer size. Furthermore, the self-similarity and long-range dependence are used to generate highly burst BE and AF traffics with a Hurst parameter of 0.7. AF and BE packet sizes

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are uniformly distributed 512and 12144 bytes, and the EF packet size is constantly distributed with 560 bytes. They are six traffic scenarios, shown in Table I, were designed and analysed for various EF service, AF service, and BE service proportions.

A. Packet Delay

Figure 3 shows AF delay versus different traffic loads. The proposed architecture has better performance for all traffics (EF, AF, TS-IPTV, BE) in terms of packets delay compared with IPACT for 1.5 ms cycle time. As the traffic load is increased for all scenarios, the delays also increased except for the BE which delay increases only when the traffic load is above 80% because the DBA has to satisfy the traffic with a higher priority than BE. Furthermore, by increasing the intra traffic request, especially for AF traffic, its delay is decreased.

B. System Throughput

Figure 4 shows the system throughput versus the traffic load. The system throughput between the proposed TS-IPTV-DBA and the IPACT with different traffic loads for 1.5ms cycle time. The results showed that the system throughput of the proposed TS-IPTV DBA with TS-IPTV traffic and ONU redirect traffic is better than that of the original IPACT traffic for both cycle times. When the number of requests is handled as intra traffic increases, the system throughput is increased.

C. Packet Drop

Figure 5 depicts the BE drop versus the traffic load for different scenarios. The number of packet losses for IPACT is occurred when the traffic load is above 90%. However, for the proposed scheme, packet loss is occurred only when the traffic load is above 90% for 1.5ms cycle time. Therefore, to maintain the necessary QoS performance in high traffic scenarios, if the buffer is full, the low-priority BE packets are dropped. The scenario with the 1.5ms cycle time has a lower packet loss ratio because the ONUs had more time to transmit their buffered packets.

IV. CONCLUSION

This paper has proposed a Software-defined time-shifted IPTV architecture based on next generation PON (NG-PON2). The proposed architecture employs SDN which orchestrates and facilitates the whole network operation including the redirection of intra traffic locally, and a new enhanced architecture and DBA allocation scheme is proposed to guarantee the QoS of intra-PON traffic. Simulation results showed that the proposed architecture can be reduced the delays compared to IPACT and is maintained below 5ms, also the packets loss was substantially reduced. It improved the BE packet delay up to 98%, system throughput up to 13%, and packet loss up to 3.6%, for a cycle time of 1.5 ms. Moreover, in the future our proposed architecture can support other video streaming services such as VoD, P2P IPTV.

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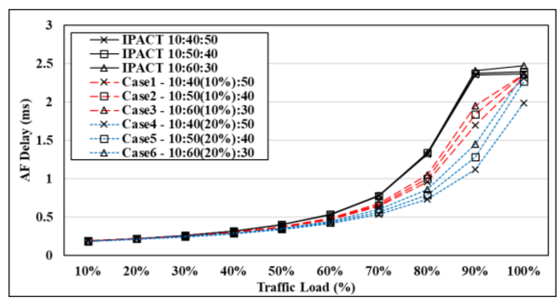

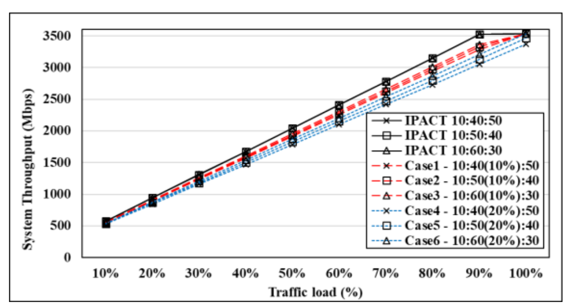

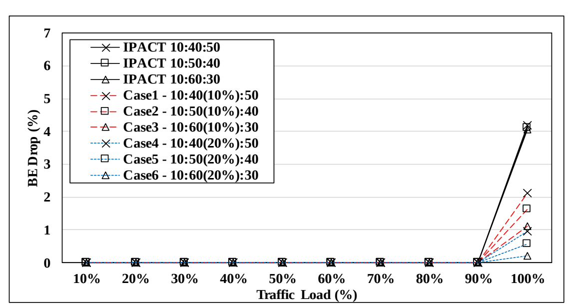

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