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QoS-Aware Multicast for Crowdsourced 360° Live Streaming in SDN Aided NG-EPON

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ABSTRACT The IEEE 802.3ca Task Force group has recently approved the standardization of the next-generation Ethernet passive optical network (NG-EPON) to satisfy future bandwidth demands. NG-EPON architecture classifies the optical network unit (ONU) transmission to allow simultaneous Wavelength-Agile (WA-PON) transmission, which increases the network capacity (50 Gb/s) and flexibility. The recently launched 5G services and related functional standards, new capabilities, and quality of service (QoS) imposed on the optical transport network. The Peer-to-peer (P2P) based live streaming application is the most popular multimedia application in access networks, i.e., Facebook Live, YouTube Live, Twitch, and other streaming and video conferencing services are increasing, especially in global epidemics which requires a higher QoS. Hence, media-based applications require adequate infrastructure resources to meet customer demands such as high bandwidth, low latency, high quality audiovisual, live streaming, and services. Therefore, this paper proposes an SDN enhanced P2P virtual reality (VR) live video streaming application NG-EPON multicast architecture based on 5G-enabled Tactile Internet (TI) and aims to improve the QoS, QoE and provide flexible services to the end-users. Finally, we proposed an SDN-based TI-dynamic wavelength and bandwidth allocation (SD-TI-DWBA) mechanism. Simulation results show that our proposed architecture can improve the system performance and QoS metrics regarding packet delay, jitter, system throughput, and packet loss.

INDEX TERMS NG-EPON, 5G/TI, P2P/VR 360° live streaming, SDN, SD-TI-DWBA, QoS/QoE.

I. INTRODUCTION

Great work is now underway to streamline fifth-generation technologies (5G) supporting high-quality streaming media and entertainment applications. The significant amount of bandwidth demand and reduced delays due to increasing new technologies and services over the past few years, ultra-high-definition video streaming(4K), virtual/augmented reality (VR/AR), mobile fronthaul requires continuous evolution of the wireless network. Optical access will play a vital role in the different types of new services [1]. According to the Cisco Visual Networking Index, by 2021, over 82% of global data traffic will be video content, growing from 73% in 2016. In addition, Worldwide, 0.9% of all entertainment traffic (Internet video and gaming) will be due to VR in 2021, up from 0.1% in 2016 [2]. Despite the statistics mentioned above, the COVID-19 epidemic has led to an increase in online conferencing for work-from-home and education purposes. People mostly use online meeting and online learning events platforms in these pandemic situations, such as google meet, zoom, Microsoft teams, Cisco WebEx, etc. Currently, Internet peer-to-peer (P2P) usage is rising, flooding the internet backbone and stressing Internet Service Providers (ISPs). The live streaming applications have also been exploited to offer video services over the IP, i.e., such as PPLive, YouTube, Facebook, Instagram, Google meet [3]. However, several challenges have been identified and addressed in the design of P2P live video streaming systems, such as high bit rate, low end-to-end latency, packet loss, network congestion, stream synchronization, and service guarantee. The P2P live streaming service needs proper solutions to solve resource limitations in the access network [4]. P2P live streaming is a graceful service because it allows users to watch high-quality videos online and turn anyone into a content provider to share content with other users. Moreover, Broadband wireless technologies (such as 4G and 5G) enable users to send and receive

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multimedia traffic via IP-based networks while maintaining QoS and QoE, mobility, security, and interactivity.

5G enabled Tactile Internet (TI) imagines real-time monitoring, management, and control of remote infrastructure. TI is expected to allow for many new opportunities and applications that will transform our lives and economy [5]. Further, TI will provide a true paradigm shift from content-delivery to skill-set delivery networks, thereby causing a revolution in every section of society [6]. The IEEE 1918.1 tactile internet baseline standard has provided various emerging applications and critical metrics such as [7]: immersive VR, teleoperations, automotive, internet drones, interpersonal communications, and live haptic-enabled broadcast. Virtual reality (VR) applications are increasingly widely used in types of entertainment such as gaming and 360° video streaming.

Moreover, VR is used for military, education, healthcare(telesurgery), education, sports, and many more industries [8]. The VR market expects revenue of 108 billion USD until 2021 [9], and VR HMD headsets are expected to increase fivefold, from 18 million in 2016 to nearly 100 million by 2021. The VR headsets are mostly connected to smartphones and PCs. The next trend is the availability of omnidirectional cameras, making it easy to create customized 360° videos such as GoPro OmniALL and Insta 360° One [10]. As VR-based 360° panorama video technology becomes more common, the need for efficient streaming methods for such videos arises, which provides the user with an interactive experience never imagined before [11]. There has been a significant increase in the production and use of omnidirectional or 360° videos, supported by the latest technological advances in networking and computing and by increasing users' interest in enriching their experience. Currently, many commercial broadcasters and video sharing sites are showing significant attraction in this sector, and video sharing sites offer considerable interest in this domain and the vital video platforms, such as YouTube, Facebook, Vimeo, Twitch, and ARTE, have put in many efforts into promoting 360° video services [12].

The Cisco VNI is predicted the demand for high-speed data services is continuously increasing, and it is expected that global IP data traffic will attain 3.3 ZB by 2021 [14]. Passive optical networks (PONs) are becoming an essential and reliable solution for various applications of access networks due to their high capacity and coverage capability. Different PON technologies exist, but an Ethernet passive optical network (EPON) with 1 Gb/s has been widely accepted and has been the dominant optical access technology for several years [13]. Therefore, the 1 Gb/s-EPON cannot satisfy the requirement of future applications such as mobile fronthaul, control office re-architecture datacenter (CORD), business users, and network virtualization. To satisfy future bandwidth demands, the IEEE 802.3ca task force [NG-EPON] has approved the standardization of 25 Gb/s and 50 Gb/s per wavelength [NG-EPON] and recently introduced ONU channel bonding [15], [16].

Moreover, hybrid EPON has been classified into various design architectures depending on how bandwidth is managed over multiple wavelengths: 1) single scheduling domain (SSD), multi scheduling domain (MSD), and wavelength agile (WA). The dynamic wavelength and bandwidth allocation (DWBA) are a method that has proposed an NG-EPON architecture to satisfy the growing traffic demands in the future. The NG-EPON based recent DWBA schemes (First-Bit DBA and Water-filling DBA are studied while considering one wavelength in the system [13], [17], [18]. Ref [19] introduces a new SDN-based wavelength-agile WA-NG-EPON CORD architecture and water filling DWBA method that meets the QoS requirements of the tactile and non-tactile application on the cloud distribution next-generation optical access networks.

The emerging Software Defined Network (SDN) provides operators with improved resource provisioning, flexibility, and lower operational expenditures. SDN focuses on separating the network's control and data plane functions, where the control plane determines the packet flow through the network, maintains controls and programs the data plane. Furthermore, SDN aims to use the centralized, programmable network model used by the OpenFlow protocol to modify the SDN mechanism in the network. The author [20] has proposed the SDN-EPON architecture and implemented the hard-coded dynamic bandwidth allocation (DBA) module in PON OLTs is modified with the advanced SD-DBA algorithm to accommodate additional global network information and higher granular traffic conditions in ONUs. The SDN-based SIEPON architecture proposed, and the SDN controller manages the optical access networks' resource utilization, flow monitoring, bandwidth assignment, and QoS guarantees [21]. DBA and multimedia service architectural EPON issues have been extensively studied [24]–[28]. Further, SDN and 5G-based multimedia services are studied [22], [23]. However, to the best of our knowledge, few or no studies have been performed presently concerning SDN-based P2P VR-based live video streaming in EPON. Table 1 in some of the above works illustrates our current paper's contributions.

The main contribution of this paper is as follows:

1. First, this paper provides a 5G enabled tactile internet-based VR 360-degree live video streaming low latency architecture presented and described technologies of the IEEE P1918.1 of tactile architecture.

2. Second, we propose a new multicast SD architecture and operational methodology for NG-EPONs to facilitate the development and operation of P2P VR-based 360° live video streaming services on 5G enabled Tactile Internet.

3. Third, we propose SD enhancements to the OLT and ONU architectures to enable streamlined management of NG-EPON systems. The SD-based ONU architecture and mechanism is designed to eliminate P2P VR 360-degree video streaming playout lag and playback lag delay and provide flexible control to the ISP. Additionally, we Use the newly introduced service flow Multicast User Group link identifier (GLID) by IEEE 802.3ca NG-EPON.

TABLE 1. Comparison of existing multimedia services.

Papers	DWBA Scheme	Technology	Intra-ISP Traffic	Diffserv	SDN/MEC Enabled	Applications
[3]	No	Hybrid TDM/WDM-PON	Yes	Yes	No	P2P live streaming
[24]	No	TDM-PON	Yes	Yes	No	P2P-Services
[25]	No	Shared TDM-PON	No	Yes	No	VOD Services
[26]	No	TDM-PON	Yes	Yes	No	Live -IPTV
[27]	No	TDM	Yes	Yes	No	IPTV-ZAP Time
[28]	No	TDM	Yes	Yes	No	Music on Demand
This paper	Yes	NG-EPON	Yes	Yes	Yes	VR 360° Live streaming

4. Fourth, we proposed and implemented a novel SD-TI-DWBA scheme to support the QoS services in SD-NG-EPON. The proposed SD-TI-DWBA algorithm aims to improve the system's overall QoS by alleviating inter-ISP traffic. In the proposed DWBA mechanism, a multi-wavelength sharing wavelength-agile mechanism is introduced.

5. Finally, we perform simulation experiments: the proposed SD-TI-DBWA scheme is compared to other non-TI-DWBA programs. The proposed SD-TI-DBWA scheme has improved the overall SD-NG-EPON multicast system delay and packet loss rate.

The remainder of this paper is organized in the following manner. The 5G enabled VR- video streaming TI architecture is presented in section II. The proposed multicast video streaming system model is described in section III. Furthermore, the proposed SD-TI-DWBA model is described in section IV. In section V discusses the performance evaluation and simulation. Finally, section VI brings our conclusion and future work.

II. VR VIDEO STREAMING TACTILE INTERNET ARCHITECTURE

The section aims to provide an overview of the VR-based TI architecture and operations. TI applications are classified into two levels, such as 1) nature of the control environments (like physical, e.g., Telesurgery and Virtual, e.g., VR Gaming); and 2) type of operator-teleoperator combination, and the operator and teleoperator can be either human or machine. Figure 1 Illustrates the VR-based 5G enabled TI low latency architecture. This architecture consists of three domains, such as 1) Tactile edge A master domain (controller); 2) Network Domain (communication), and 3) Tactile edge B of slave domains (controlled). These three domain detailed descriptions are explained below.

A. TACTILE EDGE A MASTER DOMAIN

This primary domain is a human or machine (operator), and a human is a controller, a haptic device, often called the Human System Interface (HSI). In this architecture, HSI included a VR head-mounted display (HMD) device to streamline real-time video feed from the slave. The HSI has converted the human input signal to the haptic input signal through the various tactile coding techniques and provides the haptic feedback from the slave domain to humans. The haptic sensors and actuators are more essential components of master and slave domain communication systems. This device sends and receives real-time physical sensation data (touch and feel). This device is categorized as active and passive.

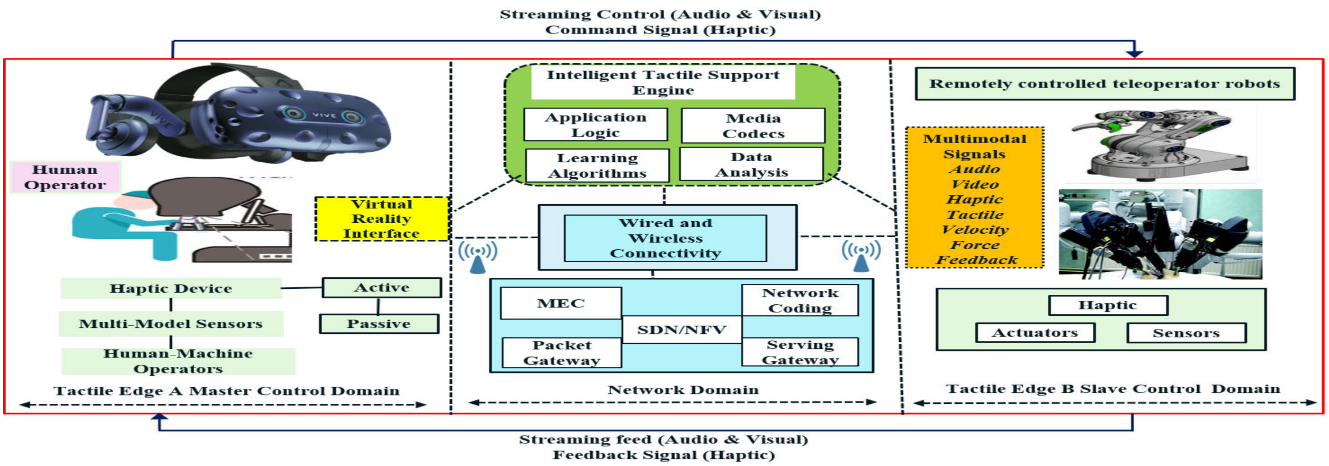

FIGURE 1. IEEE P1918.1-based 5G-enabled low latency VR live streaming TI architecture [7], [29], [30].

Moreover, the multimodal sensor improves the perceptual performance of audio and visual and haptic feedback.

B. NETWORK DOMAIN

This domain connects the master and slave domain via bilateral communications link over any wired/wireless/optical networking technology. TI requires ultra-reliable and ultra-responsive network connectivity to transmit the real-time physical sensation data. The 5G networks must meet these requirements to support emerging TI applications. It provides less than 1 ms and 99.999% reliability and ensures proper operation of TI Edge/cloud computing reduces the latency, and SDN gives the network more agile and flexible. The TI-support engine provides artificial intelligence and a knowledge base, and media, medical data analysis plays a vital role in stabilizing the system [29].

1) APPLICATION LOGIC

The master domain has a ''controller'' function with interfacing devices, multiplexing multimedia signals, and interacting with restricted tactile devices.

2) MEDIA CODECS

It provides digitalization of encoding/decoding functions for haptic (kinesthetic and tactile), audio, and video signals [30].

3) LEARNING ALGORITHMS

It monitors and modifies application parameters to meet the Quality of experience (QoE), regardless of network delays and losses.

C. TACTILE EDGE B SLAVE DOMAIN

The slave domain consists of a teleoperator, such as a slave robot, and is directly controlled by the master domain through various command signals that define position and velocity. The slave domain simultaneously receives VR data and transmits the force signals in the remote environment through kinesthetic force feedback data. The operator is fully immersed in the remote environment. It means recording and streaming the visual feed (usually a set of cameras that provide a full 360° view). Finally, realizing 5G enabled TI-based VR 360° live streaming involves the following functional considerations: latency, reliability, availability; bandwidth; and scalability.

III. PROPOSED 360° LIVE STREAMING SYSTEM ARCHITECTURE AND OPERATIONS

The proposed architecture supports low-latency-sensitive applications like Tactile Internet (P2P VR-based 360° live video streaming, remote robotic surgery, and more services) and mission-critical IoT services. Moreover, the architecture preserves the PON's unified design. It utilizes the programmable state-of-the-art wavelength-agile (WA) PON technology complemented by an effective resource provisioning system to accommodate all forms of media streaming services. Therefore, this MEC and software defined-based multimedia application architecture SD-OLT and SD-ONU module and tactile internet will increase the initial cost of NG-EPON development. However, such modules may benefit ISPs, i.e., reducing and managing inter-ISP expenses and improving QoS and QoE for customers. This paper considered the following QoE, components such as synchronization, bitrate, signaling and propagation delays, and quality level of consecutive chunks.

A. NETWORK ARCHITECTURE WITH GROUP LINK IDENTIFIER (GLID) OPERATIONS

Figure 2 shows our proposed SDN and mobile edge computing (MEC) enabled NG-EPON logical architecture that

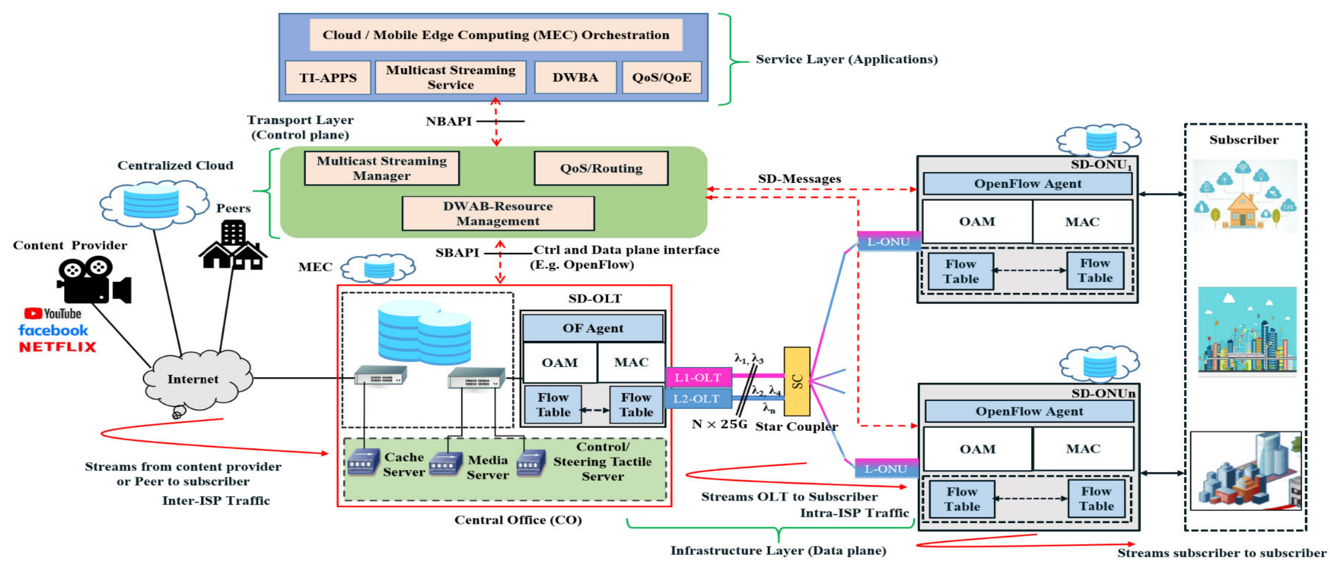

FIGURE 2. Proposed P2P live streaming logical architecture of NG-EPON.

efficiently supports multimedia services. The architecture consists of SD-ONUs accepting the downstream signal from SD-ONUs tuned at *1358nm*. The other is to get the loop-back signal from the upstream direction tuned up at *1320nm*, the SC with isolator for redirecting the packets among ONUs, and one OLT [31]. The central optical line terminal (OLT) is located at the root of an IEEE 802.3ca Next-Generation Ethernet PON (NG-EPON)/25G-EPON, and the ONUs reside at a distance of 20 Km at the OLT. To manage data transmissions in EPON's point-to-multipoint (P2MP) topology, a logical topology emulation (LTE) feature is used that, depending on its configuration, can emulate either a shared medium or a point-to-multipoint (PtM) medium by using logical connection identifiers-LLID assigned to SD-ONUs. Moreover, note that IEEE 802.3ca next-generation 25G-EPON has newly initialized an ONU Group link identifier (GLID); in this paper, we are using GLID (I.e., To aid in traffic management, the Nx25G-EPON framework supports grouping multiple LLIDs using the Group link ID (GLID)) [32]. A multi-point control protocol (MPCP) transmission message is used to transmit the data, which is auto-discovery assigns the ONU LLID. Each ONU must register with the OLT within a specified time, and the OLT will send the REGISTER message to configure the ONU LLID for each ONU. When the OLT has received the REGISTER ACK message, it knows both the ONU's MAC address and its LLID. Each ONU can have multiple LLIDs or GLID. Therefore, to multicast the live streaming channels, the channel GLID (CGLID) is defined; it is a unique GLID assigned to each requested channel. When the SD-ONU requests or leaves a channel, the SD-OLT assigns or deletes the Group Logical Link ID (GLLID). ONU's. To control GLLID operations, a table is created in the reconciliation sublayer (RS) of each SD-ONU and SD-OLT. SD-ONU contains the channel name, channel GLID, user MAC address, and user IP address fields, while SD-OLT contains the channel GLID, channel name, and SD-ONU GLID fields. Finally, the SD-OLT dedicates wavelength channels for tactile video streaming traffic and allows for designing and implementing a bandwidth allocation scheme that enables wavelength agile (WA) [17]. WA would improve the network performance and reduce the possible loss of bandwidth by using different wavelengths.

B. MULTICAST SDN CONTROLLER

The optical infrastructure is governed by a centralized SDN controller that interacts with the agents located at the OLT and ONU. The Secure OpenFlow protocol communicates between the SD-controller and the OF switches. The controller can collect network conditions and configure the flow control tables of the switches. The OF-switch uses the flow tables to forward packets. The flow table contains a flow entries list with match fields, a counter, and instructions, and the arriving packets are compared to the match fields in each entry. It is worth mentioning that an EPON connection is used to establish the secure connection from the SD-controller to all ONUs. Finally, the SD-controller is responsible for the DWBA, PON system activation and deactivation, and integrated QoS management with the metro or core network. Therefore, SDN and NG-EPON optical access networks conceive controllable video streaming systems that adapt to the dynamically fluctuating network conditions.

As shown in Figure 3, the SDN-aided NG-EPON multicast system architecture comprises a Media streaming server, SDN, Switches, SDN controller, SD-OLT, SD-ONU, and End-user devices. The media streaming server is responsible for video content storage and scalable video coding (SVC) encoding and streaming. The switches are responsible for communication between the SD-controller, media server, and SD-OLT. We customize the SDN Multicast Manager, DWBA, and QoS routing appropriately in the SDN controller to assist us in regulating the network and selecting video streams. His module deploys the logical multicast trees generated by DWBA and QoS routing module into the OpenFlow network. Since the SDN controller, OpenFlow forwarding rules and configurations have multicast trees incorporated. The OpenFlow switches can collaborate to stream the video layers in a multicast manner when a joining or leaving event occurs (I.e., User join or leave, group, etc.), the multicast management module in SD-OLT changes the associated multicast trees and notifies SDN controller to reconfigure OpenFlow switches to forward packets according to the updated multicast trees. The SD-controller manages the transmission time allocation for each SD-ONU and manages the SD-OLT wavelength.

Further, the SD-OLT and SD-ONU mechanisms are given in Subsections C and D. Finally, the end-user device contains the media player, VR head-mounted display (HMD), and packet receiver. The Packet Receiver processes the packets received from optical access networks. It reassembles them into a single video stream so that the media player and HMD can decode and play back the video stream.

C. SOFTWARE-DEFINED OPTICAL LINE TERMINAL (SD-OLT)

This system was designed to support the NG-EPON standard protocol and enhance the SDN OpenFlow elements and protocols to provide multi-point media access control (MAC) and SDN functionality to the EPON system. The SD-OLT allows centralized PON control and connects the PON system to the multi-access edge computing server on content delivery networks, as illustrated in Figure 2. The SD-OLT has two L-OLT connected to the star coupler (SC) and SD-ONUs. Each L-OLT is configured with a fixed wavelength transceiver that operates on a distinct wavelength pair and is connected to its operation, administration, and management (OAM) and MAC control clients. This combination offers the management infrastructure needed for the NG-EPON system's dynamic bandwidth resource provisioning.

The SDN controller orchestrates the L-OLTs, OAMs, and MAC control clients to distribute wavelength and link rate

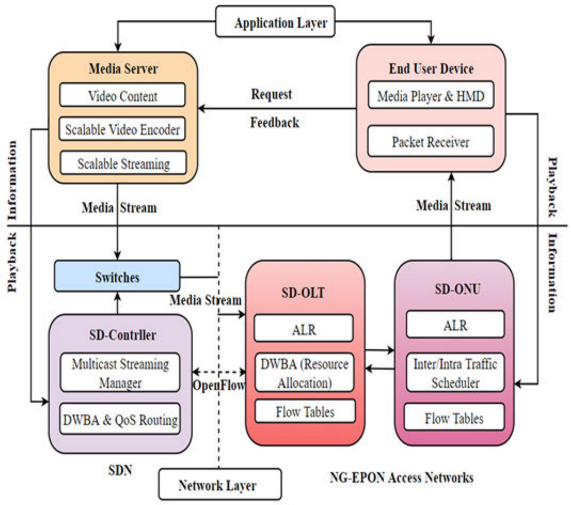

FIGURE 3. The architecture of SDN-aided NG-EPON multicast live streaming.

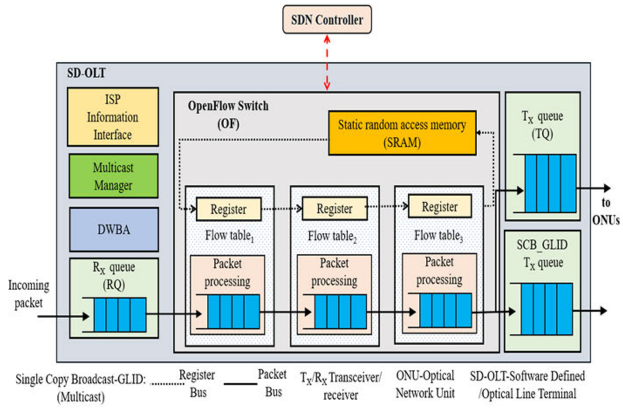

FIGURE 4. Software-defined OLT-OF switch structure.

tuning signaling to SD-ONUs. Moreover, this OAM manages the ALR functionalities. MAC maintains the standard MPCP mechanism enhanced by OpenFlow signaling to augment the PON system with additional functionality that the MPCP does not provide. Figure 4 shows the SD-OLT with OpenFlow switch architecture. SD-OLT has five primary submodules as 1) OpenFlow Switch (OF); 2) OLT buffer; 3) ISP information Interface; 4) Multicast Management; and 5) DWBA, all described as follows. The key function of these submodules mark and multicast the most popular channels or videos, reducing server resource consumption.

1) OPENFLOW SWITCH (OF-SWITCH)

An OF switch is responsible for data forwarding according to the flow table entries. The SD-controller provides the matching rules and actions/instructions through the southbound interfaces. The collection of matching rules is designed to recognize and extract the TI-P2P (360°) live streaming packet from the other packets. These process outputs include some essential information such as the channel ID, the channel title, the source/destination address, the user datagram protocol (TCP/UDP) source *(src)*, and the destination *(dst)* port. Once the incoming packet is analyzed, the SD-OLT (OLT-table) verifies the packet information to determine if the live-streaming packet belongs to the most popular channel. If the packet is the most popular video channel chunk, the stream is placed in the GLID-SCB queue. Each SD-ONU can receive and store the stream in its buffer when a packet (i.e., the most popular video channel chunk) is sent from the GLID-SCB queue. Further, the OF switch will also be used to reroute localized packet mechanism peer-stream requests within the same ISP, thereby helping to reduce interdomain traffic costs. Finally, SRAM is utilized to store data-plane functions.

2) SD-OLT BUFFER

This buffer maintains the video chunk of the frequently play most popular channel. In live streaming, OLT does not need to maintain all the videos in the buffer, unlike video on demand (VoD). Caching the complete live channel is impractical, as the video chunk is inaccessible until the content provider generates it. The cached video channel chunk is the portion that peers still have to play. Therefore, the amount of buffer to preserve or keep the most popular video channel chunks is not substantial compared to VoD. Hence, we introduced the media and cache server separately in this paper because the buffer size is small. The cache server maintains the most popular video and contents temporarily for the other applications. It also reduces the inter ISP traffic.

3) ISP INTERFACE

This interface maintains vital information, including storing important information, such as routing table, topologies, traffic patterns, roundtrip time (RTT) among peers, and available bandwidth. This information assists network operators in managing the OpenFlow switch via the SD-controller to modify the matching rules as needed.

4) MULTICAST MANAGEMENT

This functionality maintains the multicast information manager information such as user information (UI), multicast group (MG), Multicast Traffic sharing rate (MTSR), Traffic Sharing Density (MTSD), and Multiact local peer and client (MLPC). The UI function maintains the user database like user Id, SD-ONU-GLID, and user login information based on the OpenFlow flow table data entries. This MG group is managed the SD-ONU GLID, multicast membership information, session information (JOIN or LEAVE the session), an identifier of the MG group of peers which receive streaming data. (Note that the MG group is configured the SD-OLT domain). Therefore, the multicast group of the video contents communicates to the multicast peer using a UDP protocol in the application layer. Accordingly, multicast packets must be handled efficiently in SD-OLT and SD-ONU. The SD-OLT assigns al group link identifier (GLID) or multicast LLID to the MG in the downstream transmission to transfer packets through a multicast session. Next, the MTSR represents the

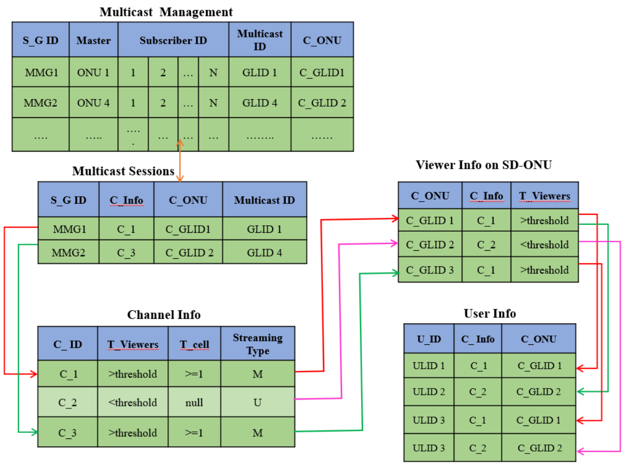

FIGURE 5. Multicast group (MG) user mapping activity.

number of SD-ONUs or GLID (Group of SD-ONUs based on IEEE 802.3ca policy) joining the multicast session.

Moreover, the MTSR is generally used to measure multicast efficiency (effective bandwidth allocation and provide effective throughput). For example, the number of watchers, who are watching the same television channel or videos Live IPTV, is the MTSR of that channel (multicast session). The MTSD functionality represents the normalized multicast service efficiency that can be provided by session [33]. Finally, MLPC is based on the local multicast peer's IP address that provides streaming data to the peer clients.

The MG module of the multicast information manager (MIM) monitors all incoming requests for live video and regulates the start and termination of the user multicast session. Simultaneously, it manages all active users' information in multiple tables, such as Multicast Sessions Channelnfo, ViewerInfo and, UserInfo, as shown in Figure 5. The MG group table contains the service group id (S_G_ID), master ONU index, subscriber, multicast id, and the channel ONU (C_ONU), i.e., it maintains specific viewers for particular C-ONU information. The Multicast Sessions table stores information about currently running multicast sessions, such as the Group Service Id (which is dynamically generated by Media Server), Channel Info (C info), multicast address Id, and the Channel _ONU (C_ONU) associated with the service. The ChannelInfo table stores the necessary information about all active channels or videos being viewed within the service region surrounded by the core network, such as the channel id (C_id), the total number of viewers, the total number of cells (T_Cell), and the status of streaming type status, such as unicast or multicast. The ViewersInfo on the SD-ONU table contains information about viewers who have viewed a specific video within a specific C_ONU coverage area, as defined by the channel. The UsersInfo table contains the user_id (ULID-User Linke Identifier), the user's mobile number, the user's C_ONU, and the ChanelInfo (C_Info) being watched.

5) DWBA

This module performs the dynamically assigned wavelength and bandwidth allocation. SDN controller dynamically manages the wavelength assignment. Moreover, the P2P-TI DBA inter and intra traffic scheduling techniques are used. The details of the proposed DWBA scheme can be found in section III.

Further, the SD-OLT architecture shows the incoming packet of the pipeline processing to the Internet. When users use P2P live-streaming software, they become a streaming node and join the network. The first step is to download the peer-list root server's channel lists. The user then registers with the peer-list root server and requests an initial list of peers watching the channel. The peer can then communicate with other peers to obtain more lists to add to the current one. In this way, the root server's signaling overhead is reduced. When an incoming packet enters the OF switch, it is processed against the entries in Flow Table$_1$(see Figure.4). As soon as a flow entry is discovered, the packet is directed to Flow Table$_2$ by the instructions set. These steps are repeated until the final flow table. In our design, Flow Table$_1$ distinguishes and marks P2P-TI live-streaming packets based on their source, destination, and TCP/UDP src/dst ports. The matched P2P live-streaming packet is then forwarded to Flow Table$_2$ for further processing. The flow entry in Flow Table$_2$ extracts packet metadata such as channel name, channel ID, bitrate, etc. Flow Table$_3$ modifies the packet and updates the metadata after receiving it from Flow Table$_2$. If the packet has successfully passed through the entire pipeline process, it is forwarded to the SCB_GLID port and stored in the SD-OLT buffer; if not, it is queued in the Tx queue. For instance, if the peer-to-peer live-streaming protocol evolves, a controller can easily update new matching rules.

D. SOFTWARE-DEFINED-OPTICAL NETWORK UNIT (SD-ONU)

Every L-ONU is outfitted with a tunable transceiver that can be tuned to any of the two-wavelength that make up the

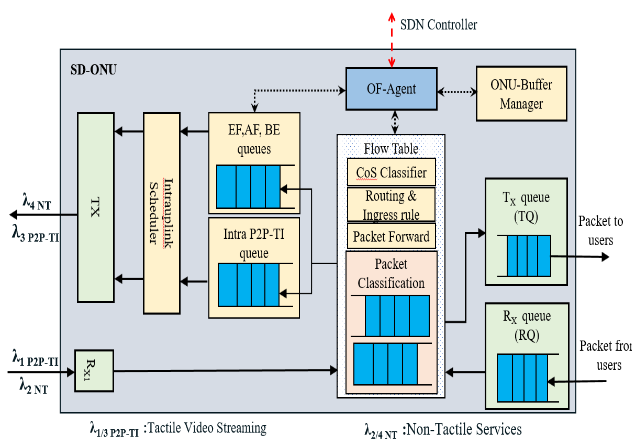

FIGURE 6. SD-ONU architecture.

PON system. The SD-ONUs link subscribers to the network through its user network interface (UNI). The MAC control client is responsible for the administration of the PON system on a basic level, such as registering the SD-ONU with the SD-OLT, receiving GATEs, and issuing REPORTs under the MPCP protocol standard.

As is shown in Figure 6, the SD-ONU logical architecture in this paper consists of three submodules: OpenFlow switch (OpenFlow Agent and Flow Table), Tunable transceiver, Intrauplink scheduler, and ONU buffer. These modules are used to classify and process the live P2P-TI packets on ONU based on the network traffic flows, i.e., Src/Dest TCP port that the peers are using, protocol type, and the IP address.

The main contribution of these submodules:

1. These submodules help identify P2P-TI packets and locate the most-requested P2P live streaming channel.
2. It seeks to reduce the P2P-TI packet delay time by serving the request locally, which reduces the overall delay time.

1) OPENFLOW SWITCH (OF-SWITCH)

The OF-Switch consists of two main parts: 1) OpenFlow Agent and 2) Flow Table. The OF-agent is responsible for communication with the SDN controller via the SD-Messages to manage the flow table. The Flow Table is responsible for matching the incoming packets according to the matching rules and executing the corresponding actions based on the ingress rule and routing table. In this case, to separate and process the P2P-TI packets based on the network flow entries. Further, the ingress rule has classified the packet and decided the traffic is intra-PON traffic or inter-traffic based on the routing table list. The routing table determines whether a P2P live-streaming packet is located within the same subnet (ONU), EPON system, or Internet.

Furthermore, we can classify traffic originating from a specific TCP/UDP source port as expedited forwarding (EF), assured forwarding (AF), peer-to-peer-tactile Internet live streaming (P2P-TI), and best effort (BE) traffic. Then, the OF-Switch separates the live streaming so that OLT and other ONUs can identify live-streaming traffic. In each flow table entry are header fields and counters.

2) TUNABLE TRANSCEIVER

It is tuned at the $\lambda_{3P2P-TI} - \lambda_{4NT}$ wavelength for upstream transmission and $\lambda_{1P2P-TI} - \lambda_{2NT}$ downstream transmission.

3) ONU-BUFFER

The buffer map performs a similar purpose to the caching scheme when it comes to our architecture. It will supply consumers with the segments required for streaming a video on the Internet. It is possible to keep only the most popular videos or a large segment of videos in an ONU buffer map located at each ONU. Moreover, ONU can also cache up to a few minutes of video chunks for popular live streaming. These segments may have just been played or will be in a few minutes.

4) INTRAUPLINK-PON SCHEDULER

It signifies that the requested segments are in another buffer map or that the other users are in a different subnet, but they are still in the same PON if the requested segments are tagged as intra-PON traffic. According to our proposed scheduling approach, the four different queues must be scheduled for the ONU. Based on our assumptions, P2P-TI live-streaming traffic is given a higher priority in this article than AF traffic. Contrary to popular belief (one buffer for all traffic types), the proposed intrauplink scheduler provides a buffer for each traffic type [15]. The scheduler attempts to serve first prioritize in EF traffic, followed by P2P-TI live streaming, AF, and BE traffic.

IV. PROPOSED SD-TI-DWBA

The QoS aware resource managements in EPON are widely investigated in the literature [34]. In addition, the SDN wavelength, link rate, and overall orchestration mechanism have been investigated the literature [29]. SDN-based tactile internet resource provision in smart hospitals using NG-PON$_2$ is studied in Ref [35]. The SD-TI-DBWA mechanism is used in S-OLT in our proposed architecture to dynamically allocate bandwidth across two pairs of wavelengths, regardless of the time windows/slots for upstream data transmission at each SD-ONU. Because the proposed technique employs an offline DBWA approach, the SD-OLT will begin allocating wavelengths and bandwidth after receiving REPORT messages from all SD-ONUs. In other words, each SD-ONU may transmit only at the wavelength(s) assigned to it during the allotted time window to avoid optical distribution network collisions (ODN). After collecting and extracting all REPORT messages, the S-OLT will acquire information on each SD-queues, ONU's bandwidth requirements, and so on via the SDN controller.

The DWBA is responsible for allocating multiple available channels and timeslots to various SD-ONUs. In addition, according to [36], the DWBA can be divided into three categories:1) single scheduling (SSD), 2) multi scheduling (MSD), and 3) wavelength-agile (WA) schemes. The WA-agile domain was chosen for this proposed mechanism because studies show that user traffic behavior in access networks varies according to busy hours and high or low-priority traffic [37]. WA-PON enables complete wavelength

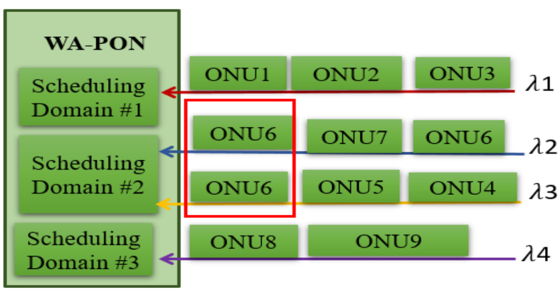

FIGURE 7. WA-PON architecture.

assignment and sharing flexibility, as an ONU can be assigned an unlimited number of wavelengths at any given time. Many ONUs can transmit concurrently as long as their allotted wavelengths do not overlap. For example, during the day, some SD-ONU(s) providing tactile services, i.e., SD-ONU(s) serving office buildings, may have higher bandwidth than other SD-ONU(s) serving residential customers. Additionally, by adopting SDN in SD-OLT, network operators can alter the wavelength and bandwidth allotment to each SD-ONU adaptively in accordance with the service level agreement (SLA).

TABLE 2. Parameter and definitions.

Parameters	Descriptions
T_cycle	Maximum cycle time
$B_{available}$	Available bandwidth in T_cycle
B_{remain}	Remaining available bandwidth
R_i^{TI}	TI bandwidth request Report of ONU$_i$
$G_{priority}^{NTI}$	NTI bandwidth request Report of ONU$_i$
$G_{i,n+1,}^{TI}$	TI bandwidth granted of ONU$_i$ in cycle n+1
λ_1^{TI}	Wavelength 1 tactile internet
λ_2^{NTI}	Wavelength 2 non-tactile internet

The SD controlled dynamic resource allocation scheme to manage the wavelength, link rate, and time of an NG-EPON to minimize the system's low latency. Moreover, the aim of this proposed SD-TI-DWBA scheme, which supports all types of haptic feedback and AR/VR HD,4K video streaming and aims to achieve low latency guarantees for tactile and non-tactile services.

The proposed SD-TI-DWBA consists of three modules: 1). SD-DWBA operations, PON activation/deactivation, wavelength, link-rate management, and QoS management in the network. 2). SD-time management, DWBA scheduling mechanism, manages the Inter/Intra SD-ONU traffic scheduling and transmission time allocation, granting sizing for each CoS of each SD-ONU. It is responsible for grant scheduling the upstream channel. 3). The wavelength-agile (WA) technique, WA-PON, enables complete wavelength assignment and sharing flexibility, whereby any number of wavelengths could be allocated to any ONU at a specific time. The number of ONUs can transmit concurrently as long as their assigned wavelengths do not overlap, as illustrated in Figure 7. Notice in this figure that ONU6 has much more data to transmit than ONU1 and ONU8, so we assign ONU6 two wavelengths and ONU1 and ONU8 each one. In this case, ONU6, ONU1, and ONU8 can transmit simultaneously; at the same time, ONU6 and ONU7 can share the same wavelengths [36], [38]. Table 2 summarizes parameter specifications for the SD-TI-DWBA mechanism.

A. SD-TI-DWBA

1. The SDN manages the wavelength, transmission link rate, and time of an NG-EPON to reduce the system's latency and energy.

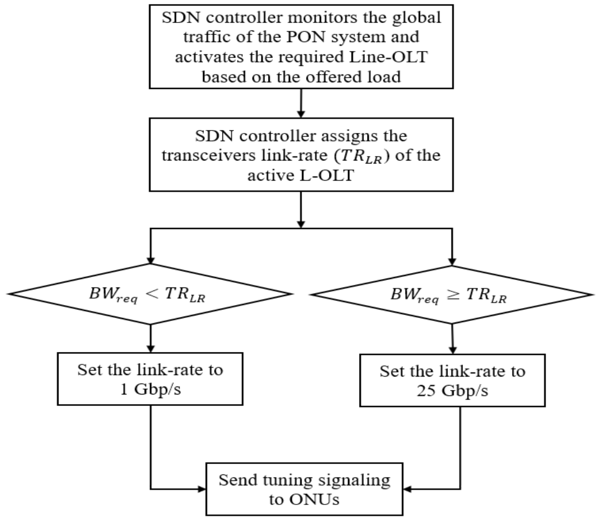

FIGURE 8. Proposed transceiver (L-OLT) link-rate configuration.

2. The SDN process the PON system activation and monitoring, which initiates the registration procedure by activating the L-OLT with the available link-rate in the SD-OLT.
3. Initiates the OAM process detection in L-OLT and registers discovered ONUs with the SDN controller. Further, the SDN controller registers the newly added SD-ONU in its database.
4. Finally, the SD-OLT begins the DBA process based on the ONU REPORT and OLT GATE message. Finally, the SDN controller monitors the overall PON system traffic, manages the active L-OLT network load, and adjusts the link rate.

As mentioned above, to manage the wavelength and transmission link rate (T_{LR}), the SDN controller's active L-OLT traffic load and SD-ONU buffer status periodically collect and store the statistical information in their database. This statistical data is utilized to determine the optimal wavelength and link rate configuration. However, traffic circumstances must be dynamically modified by system provisioning. The SDN controller must thus determine the required number of active transceivers $\boldsymbol{TR_{active}}$ based on traffic load.

$$\boldsymbol{TR_{active}} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{4} \boldsymbol{ONU\_load_{i,j}}}{\boldsymbol{W_{throughput}}}, \tag{1}$$

where ONU load, N, j, and $W_{throughput}$ denote the required ONU data, the number of registered SD-ONUs, the number of recognized traffic types by the SD-ONU, and the maximum available throughput with the maximum link rate, respectively.

After the active transceiver is configured, the SDN controller must be set the active L-OLT transmission line rates ($\boldsymbol{TR_{lr}}$). We use the link rate (LR) as a minimum of 1 Gbps and a maximum of 25 Gbps.

$$TR_{link\_rate} = \begin{cases} 1G & if\ BW_{req} < TR_{LR} \\ 25G & if\ BW_{req} \geq TR_{LR} \end{cases}, \tag{2}$$

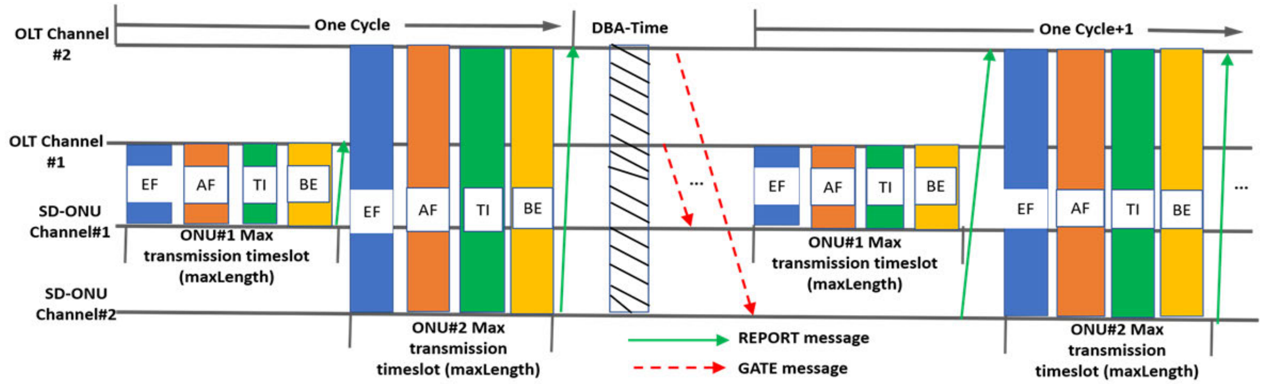

FIGURE 9. SD-OLT DBA flowchart.

where TR_{lr}, *1G, 25G*, denoted the bank of transceiver transmission link-rate and represented the threshold of the requested downstream bandwidth of all ONUs on that particular wavelength, respectively. And also, the SDN controller maintained the transmission time allocation on each SD-ONU from the SD-OLT using the DBA agent. Figure 8 illustrates the transceivers (L-OLT) and link-rate configuration process.

B. SD-TIME MANAGEMENT WITH DWBA SCHEDULING MECHANISM

In the proposed SD-DWBA scheme, we assume that TI traffic is wavelength λ_1^{TI} and NTI traffic wavelength λ_2^{NTI}. However, both λ_1^{TI} and λ_2^{NTI}, are eventually shared for all traffic as needed. Here, we use the wavelength agile approach to reduce the latency. Thus, each ONU contains the aggregate buffers' dwelling units for TI ($\sum_{i=1}^{N} R_i^{TI}$) and NTI ($\sum_{i=1}^{N} R_i^{NTI}$) traffic in its REPORT message. Consequently, the SD-ONU allocated the intertraffic and intratraffic scheduling to meet the QoS services on each CoS class.

The SDN controller manages the transmission times allocation for each SD-ONU via the DWBA agent in the SD-OLT in the proposed multicast architecture. Further, DWBA dynamically assigns bandwidth to every SD-ONU in accordance with its requests. In the proposed SD-DWBA, after receiving all REPORT messages from each ONU, the SD-OLT computes bandwidth allocation. Then, the SD-OLT implements the proposed SD-TI-DWBA, which is calculated the total available bandwidth ($B_{available}$) for each SD-ONU and maximum transmission window (W_{max}).

$$B_{available} = TR_{lr} \times (T\_cycle - N{\cdot}T_g) - N \times 512, \quad (3)$$

where $B_{available}$ represents the total available bandwidth of T_cycle in bytes, TR_{lr} represents the transmission transceiver link-rate (speed) of the NG-EPON, T_{cycle} is the default polling cycle time, T_g is the guard time, and the control message length is 512 bits (64 bytes) in the NG-EPON system. The

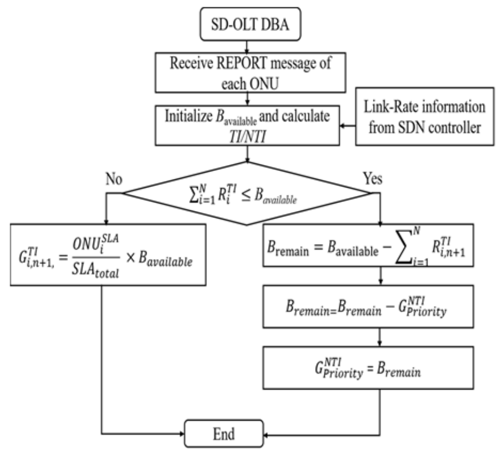

FIGURE 10. The timing diagram of the SD-TI-DWBA scheme.

DBA assigns the maximum transmission window limit.

$$W_{max} = \frac{B_{available}}{N}. \quad (4)$$

W_{max} varies depending on the traffic type (EF, AF, TI-P2P and BE,), with higher priority traffic taking precedence over lower priority traffic.

The proposed SD-TI-DWBA mechanism: The SD-TI-DWBA traffic priority and transmission time slot management operations are illustrated in Figure 9. Here are two active wavelengths channel#1 and channel#2) and two active SD-ONUs (SD-ONU#1 and SD-ONU#2). SD-ONU#1 is connected to channel#1, and SD-ONU#2 connected channel#2 in one cycle. An all SD-ONU must send a REPORT message to the OLT in order to be assigned an upstream transmission timeslot. When OLT receives REPORT messages from all SD-ONUs, it obtains buffer occupancy information for each SD-ONU. This information is used by OLT to calculate and allocate bandwidth for each traffic type (i.e., EF, AF, TI-P2P, and BE). This polling process is used to determine the state of each SD-ONUs buffer. After receiving all REPORT messages, the DBA may compute the upstream transmission timeslot assigned to each SD-ONU. As a result, once the calculation is complete, the OLT sends GATE messages to all SD-ONUs via the corresponding channel. The GATE messages include upstream transmission timeslots that the SD-ONUs can send their buffered packets from subscribers. The SD-TI-DWBA mechanism has the advantage of reducing idle time, delay, and OLT overhead, thereby improving the SD-NG-EPON system's performance.

The SD-OLT DBA scheme is illustrated in Figure 10. At first, the OLT collects each ONU's TI request bandwidth and then determines the granted bandwidth $G_{i,}^{TI}$ for TI traffic for the cycle $n+1$, $G_{i,n+1}^{TI}$, depending on the SLA for each SD-ONU sum of TI and NTI traffic bandwidth request, $\sum_{i=1}^{N} R_i^{TI}$, and $\sum_{i=1}^{N} R_i^{NTI}$, Then, we first compute the R_i^{TI} can be calculated as $\sum_{i=1}^{N} R_i^{NTI}$, is bigger than $B_{available}$. The formula is illustrated as follows:

$$G_{i,n+1,}^{TI} = \frac{ONU_i^{SLA}}{SLA_{total}} \times B_{available}. \tag{5}$$

Otherwise, to avoid delays in high-priority traffic packets, the SD-OLT will satisfy each ONU's TI bandwidth request and then calculate the remaining available bandwidth, B_{remain}. They B_{remain} can be expressed in the following manner:

$$B_{remain} = B_{available} - \sum_{i=1}^{N} R_{i,n+1}^{TI}. \tag{6}$$

Therefore, $B_{available}$ adjusts the size of R^{TI} to find the real amount of bandwidth allotted for tactile traffic. The OLT allocation the remaining bandwidth for non-TI queues according to the SLA.

$$B_{remain} \leq R^{NTI} \tag{7}$$
$$G_{priority}^{NTI} = G_{priority}^{NTI} \tag{8}$$
$$B_{remain} = B_{remain} - G_{priority}^{NTI} \tag{9}$$

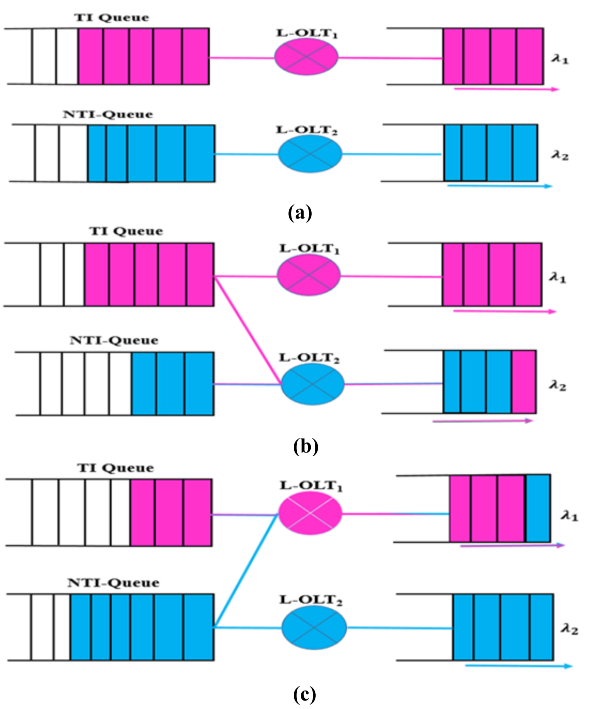

FIGURE 11. (a) TI and NT queues are sending dedicated wavelengths. (b) TI queues are transmitted over both wavelengths, while NT-TI queues are transmitted only. (c) NT queues are transmitted over both wavelengths, while TI queues are transmitted over only one.

C. WAVELENGTH AGILE-MECHANISM

WA-PON is a hybrid EPON comprised of MSD and SSD PONs. In WA-EPON, the OLT can simultaneously allocate a single wavelength or multiple wavelengths to different ONUs based on their demands. Tunable lasers should be used if an ONU wants to broadcast various wavelengths. In WA-EPON, the OLT grants access to a multi-wavelength ONU to transmit its queued data. To schedule transmission effectively, an arbitrator is required to avoid collisions in the upstream direction. Further, the WA-PON architecture and operation are shown in Figure 7. Figure 11 shows the NG-EPON wavelength agile inter-channel or adaptive multichannel wavelength

TABLE 3. Simulation parameters.

Parameter	Value
Number of SD-OLT	1
Number of SD-ONU-AP	64
Number of Wavelengths	2
Up/Downlink capacity	1/25 Gbps
OLT-ONU distance	10–20 km
Max cycle time	1.0 ms
Guard time	1 µs
Tuning time	100 ns
DWBA Computation	10 µs
Control message length (bytes)	64
Average Video bit rate	128Kbps, 500kbps, 1 Mbps
Peer arrival rate (peak hours)	200/h
Application processing delay	0.01 ms
ONU buffer size	10 Mb
TI/NTI packet size (bytes)	(64, 1518)
Non-TI (EF) packet size (bytes)	Constant (70)
Non-TI AF, BE packet distribution	Uniform
TI-P2P live streaming traffic distribution	Pareto

TABLE 4. SD-TI-DWBA traffic profile.

Scenarios	EF	AF	TI	BE
NT-DWBA (10:40:50)	10%	40%	-	50%
NT-DWBA (10:50:40)	10%	50%	-	40%
NT-DWBA (10:60:30)	10%	60%	-	30%
S1-TI-DWBA (10:40(20%):50)	10%	32%	8%	50%
S2-TI-DWBA (10:50(20%):40)	10%	40%	10%	40%
S3-TI-DWBA (10:60(20%)30)	10%	48%	12%	30%
S4-TI-DWBA (10:40(40%)50)	10%	24%	16%	50%
S5-TI-DWBA (10:50(40%)40)	10%	30%	20%	40%
S6-TI-DWBA (10:60(40%)30)	10%	36%	24%	30%

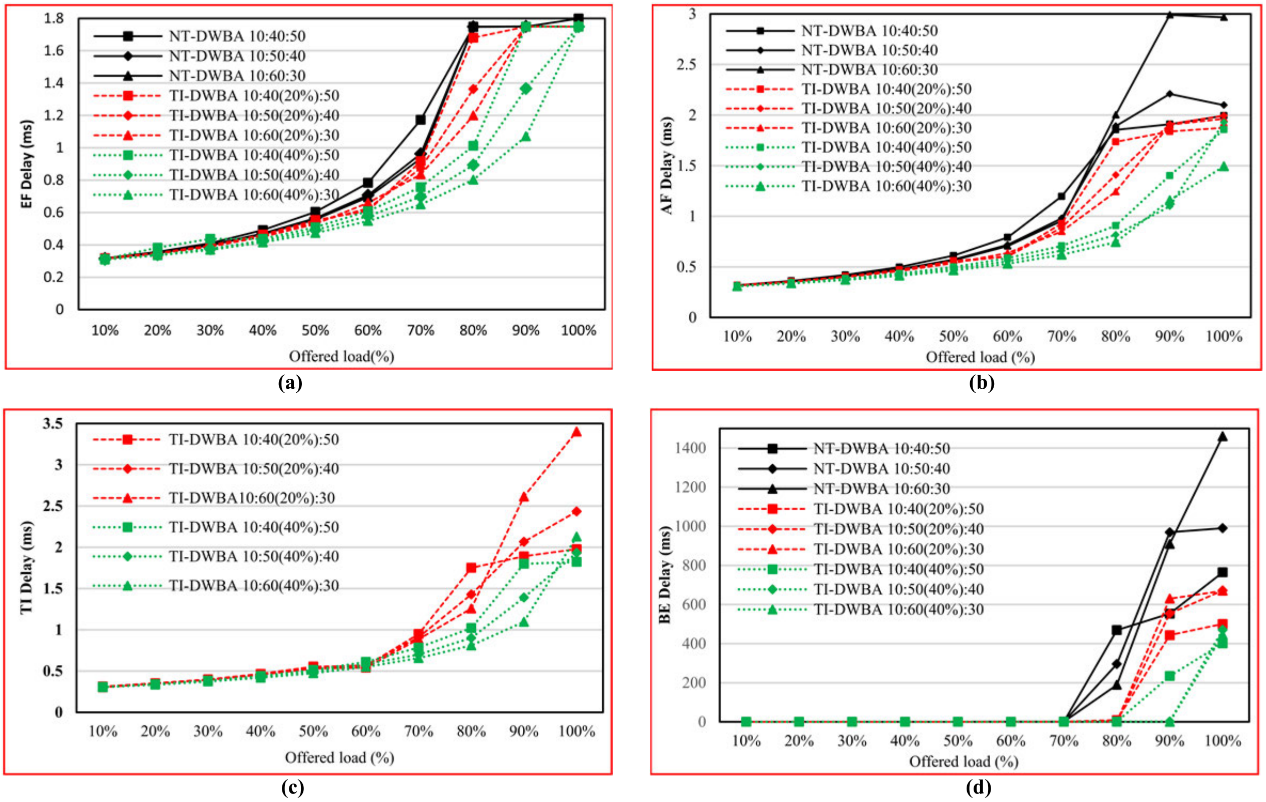

FIGURE 12. (a) EF mean packet delay. (b) AF mean packet delay. (c) Tactile- P2P live streaming mean packet delay. (d) BE mean packet delay in cycle time 1.0 ms.

sharing mechanism. The SDN controller monitors the overall traffic and activates and deactivates the L-OLT based on the traffic conditions. The SDN is more intelligently help to the wavelength agile management based on this timeslot allocation. Figure 11(a) when $R^{TI} = R^{NTI}$, TI and NTI queues are transmitted on his dedicated wavelength. Figure 11(b) when $R^{TI} > R^{NTI}$, the WA-agile is performed in this stage, the TI queues are transmitted on both wavelengths, and NTI queues are transmitted one wavelength. The same approach for Figure 11(c), when $R^{NTI} > R^{TI}$, transmitting over the tactile wavelength from the non-tactile queue up to the predefined threshold value. Therefore, the WA-agile mechanism enhances the overall systemQoS performance.

V. PERFORMANCE EVALUATION

This section analyzes the proposed mechanism for the mean packet delay, jitter, queue length, throughput, and packet loss ratio. The proposed SD-TI-DWBA was compared with the system that uses Non-TI-DWBA. The proposed mechanism was modeled using an OPNET simulator with 64 SD-ONUs and an SD-OLT with 2 L-OLTs. The efficient downstream/upstream channel rate between SD-OLT and SD-ONU is dynamically assigned 1 or 25 Gbps. The distances from the SD-ONUs to the SD-OLT are assumed to be between 10 to 20 km, and each ONU has a 10 MB buffer. The maximum transmission cycles are 1.0 *ms*. The AF, TI, and BE network traffic models are based on self-similarity and long-range dependence. The recent studies in [39] have assumed that tactile internet traffic is Pareto distributed. This model will originate with high-burst AF, TI, and BE traffic with a Hurst parameter of 0.7 and a packet size uniform (AF and BE), Pareto (TI-P2P-live streaming traffic) distributed between 64 and 1,518ytes. The high-priority traffic (EF) model uses the Poisson distribution with fixed packet size (70 bytes). Moreover, the video-transmission rate of TI-P2P live. Streaming is set to 500 kbps and 1 Mbps from scenarios S1-S6. The simulation parameters are summarized in Table 3.

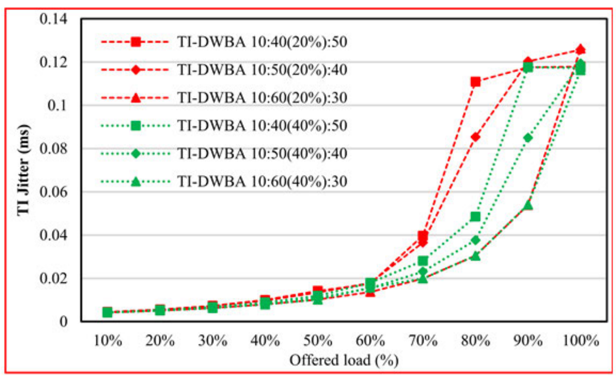

FIGURE 13. TI jitter in 1.0 (ms).

Four scenarios shown in Table 4 are designed and analyzed with various EF, AF, TI, and BE service proportions to show the effectiveness of high-priority traffic management.

A. MEAN PACKET DELAY

When packets arrive at the ONU at random times, the mean packet delay occurs. Each packet must wait for time periods in the upstream direction before transmitting. The packet delay is consists of the polling delay, the granting delay, and the queuing delay [40]. However, for TI-P2P live-streaming, the mean packet delay includes the foregoing variables plus application-specific processing delay. This processing time varies with hardware and flow-table design. Our simulation used a 0.01 ms processing delay.

Figure 12 shows the mean packet delays for EF, AF, TI-P2P live different streaming scenarios versus the offered load with 64 ONUs, respectively. The simulation results show that with intra traffic, the P2P-live streaming delay with a 1 Mbps video transmission rate improves dramatically. It can be seen that by utilizing the OF switch to regulate P2P live-streaming traffic, the mean packet delay for all packet classes can be decreased in all scenarios. By deploying the SD-NG-EPON architecture and buffer (cache) at the ONU, network operators can reduce costly inter-ISP traffic while simultaneously improving streaming quality as streaming arrives locally. The proposed architecture with the proposed SD-TI-DWBA reduced the mean packet delay for TI-P2P live-streaming by 20.62% when the offered load was 100% in the S3 scenario. Additionally, despite the high P2P live-streaming traffic rate (S3), the proposed architecture with a mean packet delay of less than 3.5ms for P2P live-streaming maintains a video transmission rate of 1 Mbps while meeting the EF and AF traffic requirements.

B. TI-P2P JITTER

The TI-P2P delay variance, or TI-P2P jitter, can be calculated as $\sigma^2 = \sum_{I=1}^{N}(d_i^{TI-P2P} - \overline{d})^2/N$, where d_i^{TI-P2P} denotes the delay time of the TI-P2P packet, $\overline{d}$ represents the average delay time of the TI traffic, and N indicates the total number of received TI-P2P packets. Figure 13 shows the TI-P2P jitter versus the offered load performance for SD-TI-DWBA under the different scenarios with 1.0 cycle times. The TI-P2P jitter has a trend similar to that of the TI-P2P delay. As the offered load increases, the variance of the TI-P2P mean packet delay increases, resulting in an increase in TI-P2P jitter to approximately 0.11 to 0.13 for all scenarios. As a result, it can be inferred that traffic OF switch localization has a considerable effect on the performance of the TI-P2P jitter. Hence, the proposed SD-TI-DWBAarchitecture offers better jitter performance when traffic load is less than 100% due to OF switch traffic localization methods.

C. SYSTEM THROUGHPUT

The system throughput is the sum of the data rates given to all network terminals. The system throughput in this proposed architecture is the sum of transmission between the ONU and OLT communication and local traffic throughput. The local traffic refers to traffic handled by ONUs without reference to feeder fiber or OLT. The OLT transmits TI-P2P channel data one time, and the ONU is liable for multicasting the data to users in the proposed design.

The system throughput is computed by multiplying the PON line rate (i.e., 2×25 Gb/s) TI management and encapsulation overheads. Figure 14 shows the system throughput SD-TI-DWBA and NT-DWBA in different scenarios versus the offered load with 500kbps and 1 Mbps video-transmission rate, respectively, with 64 ONUs. The system throughput of all proposed scenarios at high loads is more than 1 Gb/s. The ONUs handles a portion of the traffic locally via OF Switch and buffer cache and execute multicasting. Therefore, when the share of local traffic increases, the system's throughput increases proportionately. As a result, increasing the video transmission rate increases system throughput, as certain peers exchange streams locally without transmitting them to the OLT or the Internet. As a result, the suggested architecture is scalable; as the video transmission rate grows, the system throughput also increases.

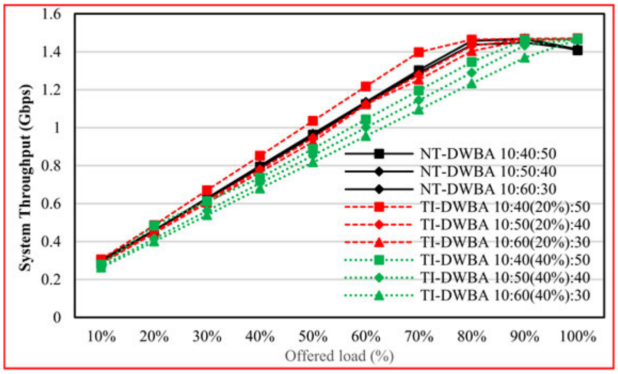

FIGURE 14. Overall system throughput in 1.0 (ms).

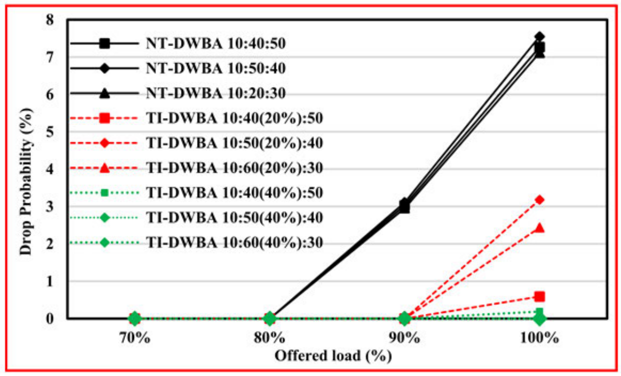

FIGURE 15. Overall system drop probability in 1.0 (ms).

D. PACKET LOSS RATIO

The ONU buffer size constraint causes packet loss. Placing packets in the queue causes the queue to fill, forcing packet dropping. Figure 15 compares the average BE packet loss probability in the different scenarios versus the offered load with 64 ONUs. The packet loss probability for high priority traffic such as EF, AF, and TI-P2P live streaming is zero in all scenarios. The packet losses of NT-DWBA for the offered load below 80% in all scenarios are zero. On the other hand, when the offered load exceeds 90%, SD-TI-DWBA scenarios S1, S2, S3, S4, S5, and S6 begin to drop packets, and the packet drop ratio reduces when compared to NT-DWBA and SD-TI-DWBA because of proposed mechanism manages a portion of the request locally. Moreover, the BE packet losses of the SD-TI-DWBA and NT-DWBA in the case of high traffic loads were different in all scenarios, which indicates that the proposed architecture will not affect the packet loss.

VI. CONCLUSION

This paper presents the 5G enabled tactile internet-based 360° VR video streaming architecture. We have proposed a new multicasting mechanism to deliver 360° TI-P2P live streaming traffic over a MEC-enabled software-defined NG-EPON architecture to enhance the overall QoS. IEEE 802.3ca based, a unique GLID is assigned to a group of intra-TI-P2P channels to build a multicast mechanism and handle user TI-P2P requests with streaming protocols. The proposed architecture SDN multicasting controller and the OF switch-based redesigned at the OLT and ONU. The redesigned OF switch-based ONU is responsible for multicasting the received frames from the OLT to the end-user. It can provide the ISP with better software-based traffic analysis and centralized control to improve overall QoS and bandwidth utilization. The proposed multicasting SDN controller module at the OLT, which aims to localize the overlay P2P live-streaming network by saving the most viewed video channel chunk, can optimize intra-ISP traffic, and hence the expensive inter-ISP traffic.

Moreover, the SDN controller orchestrates dynamic resource allocation to resolve conflicts between P2P live streaming, active wavelength management, connection rates, timeslot allocations, and QoS performance. Finally, the SD-TI-DWBA assigns appropriate timeslots and wavelength agile to packets based on their priority to ensure that QoS requirements are met. The presented simulation results show that the proposed architecture improves the system performance in response to requests as intra-TI-P2P traffic by the ONU multicasting mechanism. It addresses live-streaming startup delays as well as playback continuity. In the future, we will evaluate and compare the different DWBA mechanisms (i.e., machine learning prediction DWBA) and services in the proposed architecture.

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