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RESEARCH ARTICLE

Global P2P BitTorrent Real-Time Traffic Over SDN-Based Local-Aware NG-PON2

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ABSTRACT File sharing is one of the most common uses in Peer-to-peer (P2P) networks and structured P2P systems, such as BitTorrent (BT), which may overcome the limitations of features such as improved scalability, efficiency, and deterministic data location. Recent research has attempted to reduce inter-ISP P2P traffic by including locality awareness into neighbor-selection strategies of popular P2P apps, which prioritize adjacent peers over distant peers when transferring data, reducing server bandwidth burden, and inter-ISP traffic expense. However, the locality awareness P2P exchanged, handled and coordinated by the network infrastructure to turn around traffic as nearest as possible to the end users was proposed for the passive optical network (PON) because of the large amount of bandwidth in only one single fiber. The PON offers many system architectures; in particular, the NG-PON2 with colorless ONUs, adopting time and wavelength division multiple access technology is often recognized as the best access network solution for simplifying network operation, lowering installation costs, and maintenance costs under control. Software-defined networking (SDN) has sparked interest in various fields as a viable research topic, promising better agility, improved automation, security, and lower capital and operating costs. Taking advantage of the SDN's OpenFlow protocol in NG-PON2, centralized control renders more flexible control over the BT traffic (P2P intra-traffic) file sharing application provided by different ISPs. Finally, we evaluated our proposed scheme in real-time traffic share collected by Sandvine's report on 2020 despite the Covid-19 pandemic for different geographic regions, for example; **Global**, **APAC**, **EMEA**, and **AMERICA**.

INDEX TERMS P2P file sharing, NG-PON2, SDN, locality awareness, BT traffic, Sandvine's report.

I. INTRODUCTION

According to the Cisco Visual Networking Index despite the unpredictability of COVID-19 pandemic [1], the total consumer internet traffic in 2021 for fixed network was 179 Exabyte (EB) per month, and among that File Sharing occupied 7 EB share of the fixed network. File Sharing techniques are widely accustomed to give or grant access to digital material or resources such as documents, graphics, multimedia (audio/video), computer programs, e-books and photograph [2]. The data or resources are distributed privately or publicly in the networks with varying levels of sharing privileges. The risk for using File Sharing techniques include, downloading a malware-infected file, downloading an unlawful or copyrighted file, utilizing a file-sharing application that asks for firewall services to be turned off, and it is relatively easy to place sensitive files in a public file-hosting location. However, the advantages of file sharing include easier administration, centralized files for consistency, and the ability to keep data organized. There are several types for File Sharing mechanism, some of which includes Removable storage media, File Transfer Protocol (FTP), Peer-to-peer (P2P) networks [3], [4] and Online File Sharing Service.

P2P networking enables machines to communicate without the need for a central server, i.e., Napster, Gnutella, KaZaA eDonkey200, and BitTorrent. The digital files are located and shared locally among the user's computer. The P2P network structures consist of two types, namely Unstructured and

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Structured networks that can be separated by the degree to which these overlay networks with particular structures or created momentarily [5]. Structured P2P networks in which the overlay network topology is strictly regulated and files are used can overcome the disadvantages of unstructured systems because of their superior scalability, efficiency, and deterministic data location. Unstructured P2P networks are those, where no information about the relevant files are or the data are assigned to the specific nodes. There are three models of unstructured P2P network architecture [6]: 1) Pure P2P network, which is also referred to as a fully peer-to-peer network, similar to Gnutella. There is no centralized dedicated server, hence all peers in this network play the same job. 2) Hybrid P2P network, where networks are primarily arranged in peer-to-peer, but operate in a client-server fashion due to the existence of a centrally powerful device, i.e., KaZaA, eDonKey2000. 3) Centralized P2P network relies on the services of servers for indexing and finding content, like Napster, BitTorrent. Files are distributed among the peers, and once these files are located, the file lookup relay on the server initiates the request and reply processes between the peers.

Napster created by Shawn Fanning was the first P2P file sharing application system [7]–[9]. Initially, Napster technology allowed user to share audio MP3 files with ease. It was based on ''Server Farm'' which primarily uses central indexing for storage of files and the location of all peers. The important criteria is that the peer needs to be first registered with the Server Farm in order to provide the list of files that needs to be shared. When a particular peer needs to download a certain file, it is required to send queries based on keywords. Server Farm then sends the query result which includes a list of files with information about the file (i.e. size of file, encoding rate, peer's bandwidth, etc.) and the peer sharing it. Once the set up among the peers is successful, then only the file can be transferred between them. The strengths of Napster protocol include consistent view of the network, fast with efficient searching and the query result guarantee to be correct. While on the other hand it is prone to failure because the central server requires computation power to handle all queries including irrelevant keywords entered by the user which takes more time to process.

Gnutella was developed after Napster to overcome its short comings [10]–[12]. Unlike Napster which is based on centralized server, Gnutella consists of fully distributed servers which consists of a hierarchical topology that connects each node to a super node called ultra-node, and each ultra-node usually connect to more than 3 other ultra-nodes to make the network topology into hybrid P2P fashion. This is necessary to aggregate the controlling message and the information from the leaf node to ultra-node. There are six controlling messages in Gnutella which monitors the Gnutella traffic in the real time. The advantages of Gnutella protocol are fully distributed network, open protocol and very robust against random node failures. The disadvantages include network management and queries is not efficient.

KaZaA with a completely new architecture was released on 2001 [13], [14]. Its architecture consists of two types of nodes, namely Ordinary nodes (ON) and Super nodes (SN). Both ON and SN are a normal peer run by a user with SN showing an exception with more resources. KaZaA forms a two-tier hierarchy architecture with SN on the top level and ON on the lower level. The ON can be promoted to SN level if it has sufficient bandwidth resources and can be online. The bandwidth requirement for SN is about 160-200 kbps to act as a ''hub'' for all its ON children to keep track of files in those peers. SN exchanges information among other SNs which are roughly in 30-50 other pairs. The benefit of using KaZaA includes efficient search under each SN which also prevents excessive flooding and a lot of content with many users. The disadvantages include queries that are not comprehensive which can miss out files even if it exists, single point of failure and many legal lawsuits against KaZaA.

eDonkey2000 was developed in 2000-2001 by Meta Machine for sharing large files which is also based on P2P file sharing system [15]. It implements hybrid P2P with client-server mechanism. Here the server does not store any data but file reference, forward queries and distributed server list while client can easily find the respective servers via weblinks or server lists. A new client operates after opening a TCP connection to server that sends Hello message while in turn the server will respond with Welcome message consisting of additional information such client ID, server name, total number of users, description, and number of ''visible'' files. The problem with eDonkey2000 includes fakes files in the peers which can mislead other users, high load in the network caused by simultaneous search on many servers which becomes an easy target for DDoS attack. Also, the main intention of users is to download files rather than sharing in the network.

BitTorrent architecture is shown in Fig. 1, differentiates from other similar file-transfer apps in that, users simultaneously download fragmented files from other users rather than downloading a resource (one or more files) from a single source (e.g., a central server) [16], [17]. As a result, file transfer times are reduced significantly because these groups of users share the same or part of resources that can range from a single host to thousands at a given time. Swarm in BitTorrent (BT) combines a collection of users that are interested in sharing the same resource. These nodes or users are known as ''Peers'' with a central component called ''Tracker.'' These Trackers controls the resource transfers between peers that hold specific or a portion of the resource which by default are obligated to share the resource and complete the file transfer. Bit-torrent primarily consist of two nodes: Seeds nodes are those that possess the entire resource and can share it among other nodes known as Leechers, who do not have the entire resource but are interested to possess resource ultimately. In BitTorrent file sharing system, the system distributes the fragmented files that have been already downloaded. When a leecher acquires all of the leftover resource fragments, it will

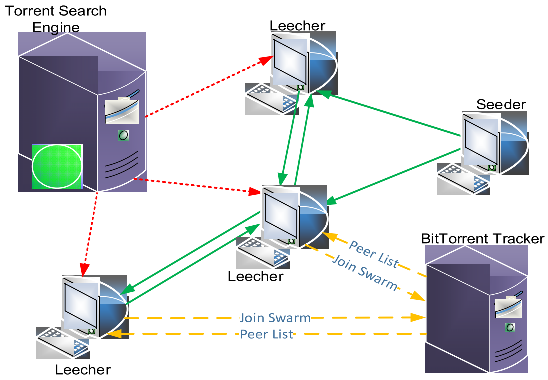

FIGURE 1. BitTorrent Architecture.

automatically become a seed. Trackers are unaware of the content of the resource; the only information they know are peers either hold entire file or specific parts of a file. As a result, knowing a tracker's URL is not enough to start downloading resources. If a peer wishes to join the tracker, it must have the particular meta-data file with a (*.torrent*) extension that enables appropriate data transfer initiation (called Torrent or Meta-data file). Meta-data files are downloaded from one of the indexing servers that stores them, and allow a user to search for torrents based on the resource description encoded in the meta-data file [18]. μTorrent logs, the most popular BitTorrent clients, are collected during resource downloading sessions which includes content name, file size, number and size of each fragment. Additionally, Micro Transport Protocol (μTP)-based clients provide more popular and capable of outperforming over TCP-based clients [19]. The major goal of this μTP protocol is to properly control bandwidth utilization during file transfers while minimizing the impact of file transfers on ongoing transmissions. The goodness of using BT are the users keep their peers connected as seeds, works very well, users need to contribute resources and efficient mechanism for distributing large files to many clients.

Recently, because of the huge quantities of bandwidth transfer possible in a single fiber, the optical network is considered as one of the most widely used access network technologies. Despite the COVID-19 crisis, the global market for fiber optics was estimated to be worth US$4.6 billion in 2020, and is expected to grow to US$8.6 billion by 2027 [20]. Access network connects a private organization (i.e. home, office, etc.) to the public telecommunication network, bridging the end-users to service provider via wireless link or optical fiber with distance covering up to 20 km. The optical access network is named as fiber-to-the-x (FTTx), deployed either as a point-to-point or point-to-multipoint topology. Point-to-point topology overcomes the bandwidth limitation, provides data privacy and security but significantly increases the cost, power consumption and central office (CO) requires high density fiber management. In the point-to-multipoint technique, a feeder fiber is deployed near to the subscriber with passive component optical distribution network to the subscriptions to reduce the initial and maintenance cost, named passive optical network (PON). Different optical access technologies have been developed to achieve PON, including time division multiplexing PON (TDM-PON), wavelength division multiplexing PON (WDM-PON), time and wavelength division multiplexing PON (TWDM-PON), and orthogonal frequency division multiplexing PON (OFDM-PON) [21]. TDM-PON, primarily based on a tree topology, comprises of an optical line terminal (OLT) with the service provider located at the CO which is coupled by optical fiber and an optical passive splitter/combiner to many optical network units (ONUs) connected to the customers. TDM-PON provides point-to-multipoint topology in the downstream direction from the OLT to ONUs. In the upstream direction, TDM-PON employs the multipoint-to-point topology from ONUs to OLT by the time division multiple access (TDMA) to avoid signal collision. To run the TDM in the upstream direction, OLT executes dynamic bandwidth allocation (DBA) [22]–[24] which prevents transmission collisions in the upstream direction and increases the efficiency of the PON upstream bandwidth by dynamically adjusting bandwidth among the ONUs in response to ONU burst traffic requirements [25]–[27].

There are two standardized PON systems, such as Ethernet PON (EPON) [25] and Gigabit PON (GPON) [26] standardized by IEEE in 2004 and ITU-T in 2003, respectively, which offer maximum transmission rates up to 1.25/1.25Gbps in EPON and 2.48/2.48Gbps in GPON. The EPON based on TDM-PON is considered one of the best solutions for access networks due to its simplicity, fast data rate, and low cost compared to another PON [28]. With the increase in traffic, the 10 Gigabit-class PON technologies, such as 10G-EPON [29] and XG-PON1 [30], are enabled to share raw bit rates up to 10Gbps. The ITU-T defined the second next generation PON (NG-PON2) [31], 40 Gbit/s capacity PON system, adopts TWDM technology [32]. TWDM-PON multiplies the available transmission channels with the employment of multiple wavelengths. In other words, the WDM is used in the different wavelength deployments and the TDM is to share the upstream transmission time when multiple ONUs are configured in a same wavelength. Nevertheless, the NG-PON2 system greatly enhances the capacity of the PONs systems to accommodate larger number of subscribers. The NG-PON2 adopts colorless tunable ONU transceivers in order to reduce the computational effort for ONU digital hardware, support the wavelength channels to simplify network operation, reduce installation cost, and keep the maintenance efforts under control [33], [34]. The colorless ONU (or source-free ONU) is a wavelength-independent ONU which cannot decide when to upload a channel network, hence the central office dynamically assigns these colorless ONU to individual wavelength [35]–[37].

As the number of users grow significantly, large amount of data traffic is generated with increasing resource demands, hence creating a burden to the access network. To overcome these issues, internet services providers must manage the network traffic efficiently. One such way is to segregate the intra traffic and inter traffic separately. Localizing the P2P traffic is found to be an efficient way to achieve technical requirements of minimizing traffic through localized multicast of P2P traffic [38]. Further, authors in [39] proposed a new algorithm based on localizing the intra-PON traffic to manage the bandwidth allocation for improving QoS in P2P architecture. More significantly, our research over the years in this sector include enhancing QoS parameters for P2P applications such as live streaming [40]. We have further extended our research [36] specifically on locality-awareness issue for BitTorrent traffic to improve the EPON system using colorless ONU. Moreover, with the enhancement of software defined networks, for flexible management of fiber networks architecture and better resource utilization for locality awareness TWDM-PON, our research [5], [41] further extends to improve the overall QoS for different P2P applications.

Software-defined networking (SDN) over the years has picked up the research interest including education, industry, banking, etc. [42], [43]. Increased agility, greater automation, security, and lower operational expenditures (OPEX) and lower capital expenditures (CAPEX) are all promised by the SDN [44], [45]. The major focus of the SDN is on network's control and data plane functions. The packet flow over the network are determined by the control plane while the data plane maintains, controls and processes packets from one interface to another; moreover, a centralized programmable network model based on the OpenFlow protocol is used to adapt the SDN mechanism in the network [46], [47]. OpenFlow is built on an ethernet switch with internal flow tables and contains a standardized interface to add and remove flow entries, allowing network controllers to determine the routing of network packets across the network of switches [48]. In this paper, by taking the advantages of the SDN's OpenFlow protocol in the NG-PON2, a centralized control renders more flexible control over the BT traffic file sharing application provided by different ISPs.

The objective of our proposed architecture using SDN is to reduce computational effort for the ONU components, supporting all wavelength channels to reduce installation cost, simplify network operation, and keep the maintenance efforts under control. We also try to achieve the locality-aware between ONU-to-ONU communications to decrease the amount of BitTorrent inter-ISP traffic. Furthermore, a BitTorrent dynamic wavelength bandwidth allocation (BT-DWBA) is proposed to schedule the transmission time between BT traffic to provide better quality performance. The expectation of this paper is to conduct the simulation and emulation of operation of BitTorrent protocol embedded in Multi Point Control Protocol (MPCP) of NG-PON2 system based on our OPNET simulation platform with the real time upstream BitTorrent traffic based on each contingent in the real world to provide the global view of BitTorrent protocol for P2P file-sharing applications from 2020 Sandvine's COVID-19 Phenomena Spotlight Report [49].

The remaining sections are organized as follows: In Section II, the proposed SDN-based NG-PON2 P2P file sharing system and the operation are discussed. Section III further explains the overall system performance evaluation, and finally we conclude and provide the future research direction in Section IV.

II. PROPOSED ARCHITECTURE AND OPERATION

The proposed SDN based NG-PON2 P2P file sharing system, shown in Fig. 2, consists of five main components, namely, BT meta-data tracker (BMT), BT SD-controller (BSC), BT-OLT, 3:N Star Coupler, and BT-ONUs, which can efficiently support BT services in enhanced NG-PON2 to direct the communication among ONUs (i.e., intra-PON) to save bandwidth in the feeder fiber. The BT operations of registered peers in the network are tracked and controlled by the BMT tracker server. This BMT is unaware of the resource content, but simply knows which peers currently hold the entire file or specific parts of a file or resource. The BSC configures, controls and manages the flow tables in the OLT and ONUs through the SD-Agent by sending an SD message over a secure protocol interface. The BSC based on OpenFlow protocols allows servers to tell switches where packets should be sent. 3:N Star-Coupler broadcasts the downstream traffic tuned at the wavelength λ_1–λ_4, upstream traffic tuned at the wavelength λ_5–λ_8, and intra traffic tuned at the wavelength λ_{BT}. The function of the extra λ_{BT}wavelength in the Star-Coupler is added and tuned to redirect the intra-PON BitTorrent traffic among the local ONUs (seeds and the leechers) so that the BT services are localized.

In NG-PON2, the ONUs (64) are divided into four pairs of wavelengths (λs), where each ONU transmits four traffic namely Expedited forwarding (EF), Assured forwarding (AF), BT (BitTorrent), and Best effort (BE), respectively, in one cycle. The problem occurs when we want to redirect BT traffic, and we need to change the seeder (sender) and leecher (receiver) to the same wavelength. If we change the wavelength to transmit BT traffic into one of the other four pairs of λs, 1/4 of ONUs (16) will go offline. Therefore, in our proposed architecture, we used four pairs of λs to transmit EF, AF, and BE traffic, and one extra λ to transmit BT traffic. The system modules and operations are described as follows:

A. BT-ONUs MODULES

BT-ONUs modules, shown in Fig. 3, includes the User-to-Network Interface (UNI), S-RAM, Micro Processing Unit (MPU), SD-Agent, Flow Tables, Several Queue, and Tunable Transceiver. UNI is a physical interface to connect the user to the network. MPU is a component to process the downstream and upstream packets. Flow Tables has the function to classify and separate the packet based on μTP source port. The traffic is classified as, AF traffic, EF traffic, BT traffic and finally BE traffic using specific μTP source port. Each flow table entry consists of header fields, counters and actions. Our proposed architecture consists of four queues used specifically for AF, EF, BT and BE traffic that can support up to maximum eight queues. In Each L-ONU contain a set of tunable transceivers and one extra Receiver (Rx2) for BT transmission.

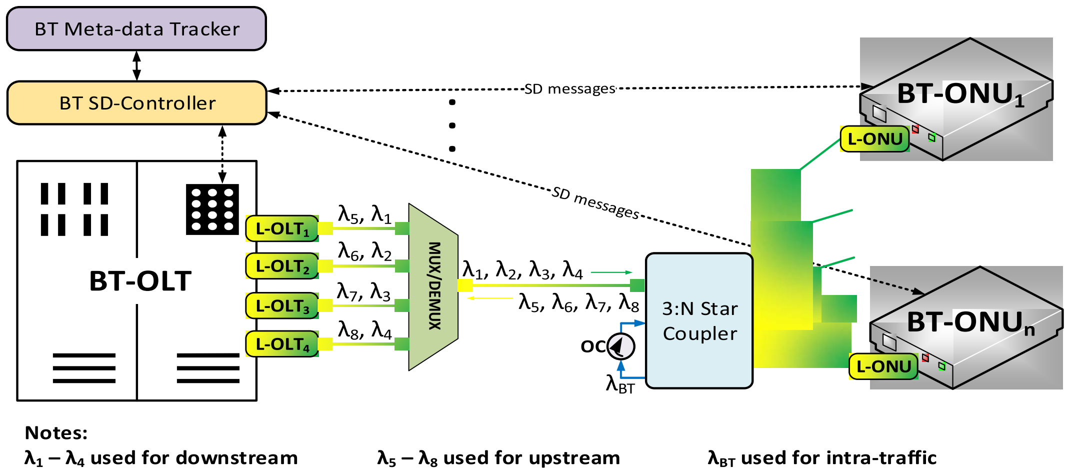

FIGURE 2. Proposed software-defined network-based NG-PON2 P2P file sharing system.

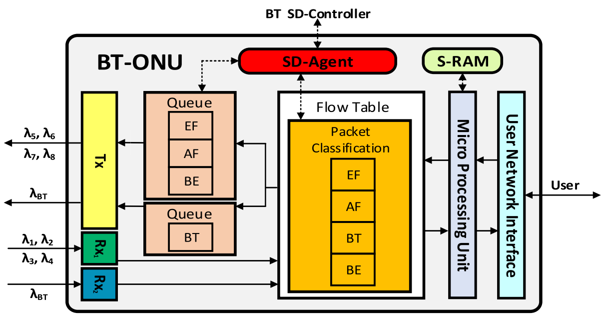

FIGURE 3. Proposed BT-ONU architecture.

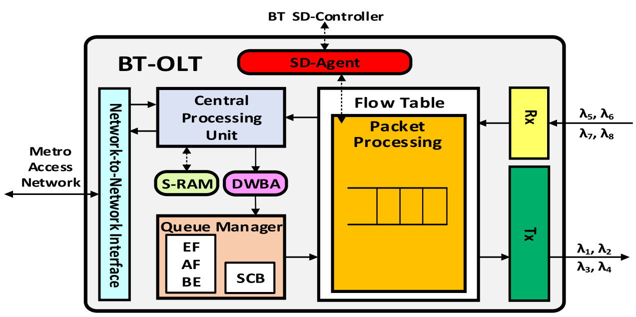

FIGURE 4. Proposed BT-OLT architecture.

B. BT-OLT MODULES

The proposed BT-OLT architecture, shown in Fig. 4, includes the Network-to-Network Interface (NNI), Central Processing Unit (CPU), S-RAM, Dynamic Wavelength Bandwidth Allocation (DWBA), Queue Manager, SD-Agent, Flow Tables and Tunable Transceiver. Using signaling Internet Protocol (IP) mechanism, two or more networks are interfaced by the NNI. The CPU will process the income and outgoing packets. The S-RAM unit is used for buffer memory. The DWBA executed in the BT-OLT is used to dynamically calculate and assign the bandwidth to each user based on the information in *REPORT* message sent by each BT-ONU. The queue manager has two types of buffering separated into each queue: first, it is for the general queue EF, AF, BE by BT-ONU LLID and second is Single Copy Broadcast (SCB) with Priority Queue (PQ) for BT traffic. The BT SD-controller using SD-Agent communicates by sending an SD message over a secure channel interface and also has the function to manage flow table by adding or removing the flow entries. Flow Tables are in charge of recognizing and marking BT packets based on their properties, such as source address, destination address, (μTP src) port, and (μTP dst) port. After marking the BT packets, flow table extracts the packet meta-data to obtain Tracker URL, file count, file name, fragment count, fragment size and fragment hash. At last, flow table is modified and updates the meta-data and each flow table entry contains of header fields, counters and actions. Tunable Transceiver contains the transmitter (Tx) that can be tuned in wavelengths λ_1–λ_4 for sending downstream transmission and the receiver (Rx) can be tuned in wavelengths λ_5–λ_8 for receiving upstream transmission.

C. SYSTEM OPERATION

The proposed architecture extends the BitTorrent protocol implemented between the BT-OLT and BT-ONU based on multipoint-to-point, shown in Fig. 5. MPCP is a control mechanism for point-to-multipoint to allow efficient transmission of data that is implemented in the MAC control layer. Auto discovery mode is used to detect the newest connected BT-ONUs, as well as to learn their round-trip delay and MAC address. Each user request packets from the user network interface (UNI) are mapped into particular colorless BT-ONU, which are further separated by the flow table based on ToS, source/destination address, and μTP into AF/EF/BT/BE queues controlled by the BT SD-controller. ONUs generate the REPORT message for transmitting the ONUs local condition to the BT-OLT in

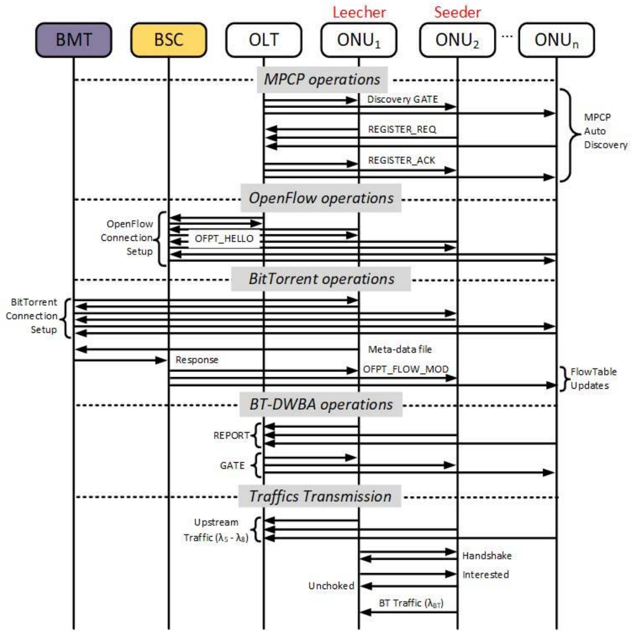

FIGURE 5. Signaling Control of Proposed enhanced NG-PON2 architecture.

the previous assigned timeslots. The received REPORT message at the OLT is parsed and demultiplexed to the OLT's REPORT processing, then passes it to the BT-DWBA to execute bandwidth and timeslots calculation for the next cycle. OLT generates the GATE message with timeslot identified as granting values, such as starting time, time length, and wavelength for each EF, AF, BT and BE traffic calculated by the BT-DWBA, and the granted wavelength uses λ_{BT} for BitTorrent traffic transmission. The details of BT-DWBA will be discussed in the C2 section. Next, OLT broadcasts the GATE message to all BT-ONUs while the received GATE message in the ONU is parsed and demultiplexed to the BT-ONU's GATE processing responsible for transmission to begin within the timeslot assigned by the BT-OLT.

D. BitTorrent OPERATION

Our proposed BitTorrent entire operation can be shown in Fig. 5. The BT-OLT sends a discovery *GATE* to all BT-ONUs for allowing undiscovered BT-ONUs to transmit. Undiscovered BT-ONUs respond to the BT-OLT by sending a *REGISTER_REQ*, then BT-OLT replies the message from BT-ONUs by sending a *REGISTER* to BT-ONUs. At last, BT-ONUs send a *REGISTER_ACK* to end the discovery mode. The OpenFlow connection between the SD-Controller and SD-Agents is established by sending the *OFPT_HELLO* message each side. If the connection fails, then sends an *OFPT_ERROR* message. Flow Tables is used to classify and separate the traffics into EF, AF, BT and BE, which is managed by the SD-Controller through SD-Agent in BT-ONUs. The BMT controlled by BSC collects the meta-data of each peers in BT-ONU, then sends the meta data to flow tables in each BT-ONUs. Meta-data contains Tracker URL, file count, file name, fragment count, fragment size and fragment hash. At beginning, the leecher will download the unique meta-data file with the .torrent extension in order to properly initiate the data transfer. The BitTorrent specification makes no assumptions about how .torrent files should be distributed among users. The .torrent files are typically downloaded from one of the indexing sites that keep them, allowing a user to search for torrents based on the description of the resource. After downloading the meta-data file, the leecher will connect to BMT to get the information of the other peers (seeder) which have pieces fragment of the file in the same PON network. BMT will response information of all fragment's seeders to BSC and BSC sends an *OFPT_FLOW_MOD* message to modify and update the Flow Table in the respective ONU leecher and seeders. Henceforth, leecher will place BT traffic queue in the REPORT messages sent to the OLT, then BT-DWBA in the OLT will specify the packet and calculate the required timeslot according the EF, AF, BT and BE queues. After the BT-DWBA calculate all the timeslots for all traffics, the OLT will sent a GATE message with starting time, length and wavelength for each traffic to all ONU. The leecher and seeder ONU will changed the wavelength into λBT prior to the same starting time and length based on the GATE message sent by OLT. Leecher starts to exchange a handshake message with the seeders, then leecher sends an interested message to indicate that it wants to download fragments file, and the seeder grants to access the fragments file by sending an unchoked message. During the remainder of the flow, the leecher downloads as many segments as it can. Our proposed Star Coupler with Optical Circulator (OC) will localized and redirect the intra-PON BT traffic among the local ONUs (leecher and seeder).

E. Bit-Torrent DYNAMIC WAVELENGTH BANDWIDTH ALLOCATION (BT-DWBA)

A new DWBA algorithm is proposed for our scheme designed to handle Bit-Torrent traffic allocation, called BT-DWBA, pseudo shown in Fig. 6. Our proposed BT-DWBA scheme supports the BitTorrent intra traffic with four priority queues at each BT-ONU, which are EF, AF, BT, and BE queues, respectively. As the *REPORT* messages are received by the BT-OLT, it will specify the packet first and calculate the required timeslot according to each traffic type i.e., EF, AF, BT, and BE. According to traffic priority, the BT-DWBA first allocates the required timeslots for EF traffic after checking the timeslot availability. Thereafter, the BT-DWBA checks its remaining timeslot and allocates the timeslot to AF traffic. After the EF and AF traffic timeslots have been allocated, the BT-DWBA checks the remaining timeslot and if the timeslot is still available, then the BT-DWBA allocates the timeslot for BitTorrent traffic, and finally, the remaining timeslot will be allocated to the BE traffic. After the BT-DWBA calculates the timeslots for all traffics, the BT-OLT sends a *GATE* message with {*start_time*, *length*, *wavelength*} for each traffic to all ONUs.

```
i = number of ONUs (64)
wBT = wavelength for BT transmission
Tavailable = scheduled time for upstream transmission
Tguard = guard band interval
maxLength = maximum transmission timeslot of BT-ONUi
Report.j.length = j packets (bits) at the BT-ONUi buffer
Bleft = remaining bandwidth
For every wavelength w, where w ∈ {1...4} do {
    For every received Report.j.length of BT-ONUk, where k ∈ {i/w},
    j ∈ {EF, AF, BT, BE}
    do {
        startTime = Tavailable + Tguard
        if j = BT then {

            if Report.j.length > maxLength then {
                Report.j.length = maxLength
                GRANT = {startTime-RTTi, maxLength, wBT}
                Send GRANT message
            } else {
                GRANT = {startTime-RTTi, Report.j.length, wBT}
                Send GRANT message
            }
        } else {
            if Report.j.length > maxLength then {
                Report.j.length = maxLength
                GRANT = {startTime-RTTi, maxLength, w}
                Send GRANT message
            } else {
                GRANT = {startTime-RTTi, Report.j.length, w}
                Send GRANT message
            }
        }
        Bleft = maxLength – Report.j.length
        maxLength = Bleft
        Tavailable = startTime + Report.j.length
    }
}
```

FIGURE 6. Pseudo-code for BT-DWBA.

TABLE 1. Simulation parameters.

Parameters	Value
Number of OLT	1
Number of ONUs	64
Number of wavelengths	4 pairs + 1 (BT)
Up/Down link capacity	4 Gbps
OLT-ONU distance (uniform)	10–20 km
Max cycle time	1.0ms/1.5ms
Guard time	1 µs
Tuning time [50]	100 ns
DWBA Computation	10 µs
Control message length	0.512 µs
ONU buffer size	10 Mb
AF and BE packet size (bytes)	Uniform (512, 12144)
EF packet size (bytes)	Constant (560)
BT packet size (bytes)	Uniform (9600, 12144)

III. PERFORMANCE EVALUATION

Our simulation is based on the real-time traffic share collected by Sandvine's report published in 2020 during the Covid-19 pandemic [49], and we compared the system performance of our proposed scheme with that of the IPACT scheme [50] in terms of EF, AF, BT, BE packet delays, system throughput dropping, and jitter. The simulation parameters are listed in Table 1. We set up the system model in the OPNET simulator with a single OLT and 64 ONUs. The downstream and upstream channels are set to 4 Gbps data rate capacity, and the distance from the ONUs to the OLT is assumed to range from 10 km to 20 km. Each ONU had a finite buffer size value of 10Mb. Our extensive study of the traffic models finds that most of the networks are characterized by long-range dependence and self-similarity, which are utilized to generate the highly burst AF and BE traffic classes with a Hurst parameter of 0.7 with packet sizes uniformly distributed between 512 bits and 12144 bits, and the BT packet sizes uniformly distributed between 9600 bits and 12144 bits. Finally, the EF packet size was constantly distributed at 560 bits. The traffic profiles are shown in Table 2. Four geographic regions were simulated: **Global**; Asia-Pacific (**APAC**); Europe-Middle-East-Africa (**EMEA**); and **AMERICA**. The traffic ratios of the IPACT scheme were distributed as **Global** (EF 5%, AF 40%, BE 55%), **APAC** (EF 5%, AF 35.5%, BE 59.5%), **EMEA** (EF 5%, AF 30%, BE 65%), and **AMERICA** (EF 5%, AF 37.5%, BE 57.5%). The traffic ratios of our proposed BT-DWBA are **Global** (EF 5%, AF 40%, **BT 5%**, BE 50%), **APAC** (EF 5%, AF 35.5%, **BT 4.5%**, BE 55%), **EMEA** (EF 5%, AF 30%, **BT 8.5%**, BE 56.5%), and **AMERICA** (EF-5%, AF 37.5%, **BT 3.5%**, BE 54%).

TABLE 2. Traffic profile (in %).

	Regions	EF (Voice)	AF (Video)	BE	BT
IPACT	Global	5	40	55	-
	APAC	5	35.5	59.5	-
	EMEA	5	30	65	-
	AMERICA	5	37.5	57.5	-
BT-DWBA	Global	5	40	50	5
	APAC	5	35.5	55	4.5
	EMEA	5	30	56.5	8.5
	AMERICA	5	37.5	54	3.5

A. MEAN PACKET DELAY

The packet delay refers to the time required for the packets to arrive randomly at the ONU after waiting for some slots due to the polling delay, granting delay and queuing delay. Figures 7, 8 and 9 compare the mean packet delays of the proposed scheme with IPACT for cycle times 1.0ms and 1.5ms, respectively, in different four geographic regions. The result for EF delay (Fig. 7), AF delay (Fig. 8) and BE delay (Fig. 9), which we can be observed that our proposed local-aware BT-DWBA scheme has better performance in all regions when compared to IPACT (without BT traffic) for 1.0ms and 1.5ms cycle time, respectively. When we compare each scenario for different regions, we can conclude the **EMEA** scenario has shorter packet delay in terms of EF, AF and BE than other regions (Global, APAC and AMERICA) for both

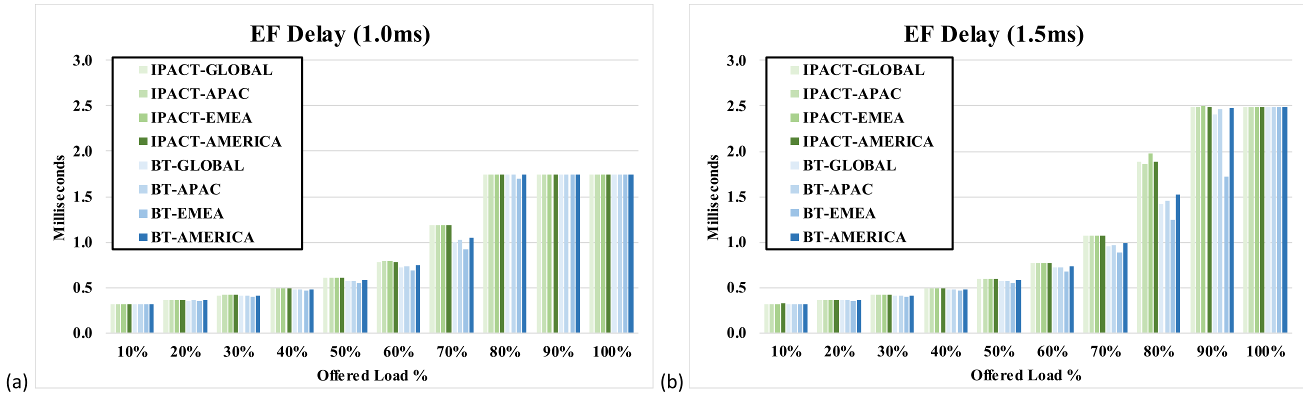

FIGURE 7. EF traffic delay for 1.0 ms and 1.5 ms cycle time.

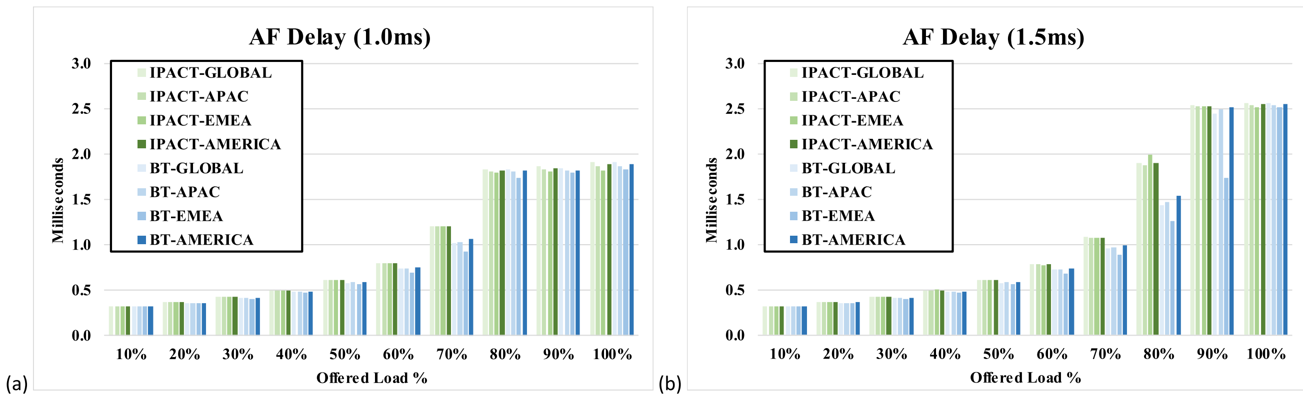

FIGURE 8. AF traffic delay for 1.0 ms and 1.5 ms cycle time.

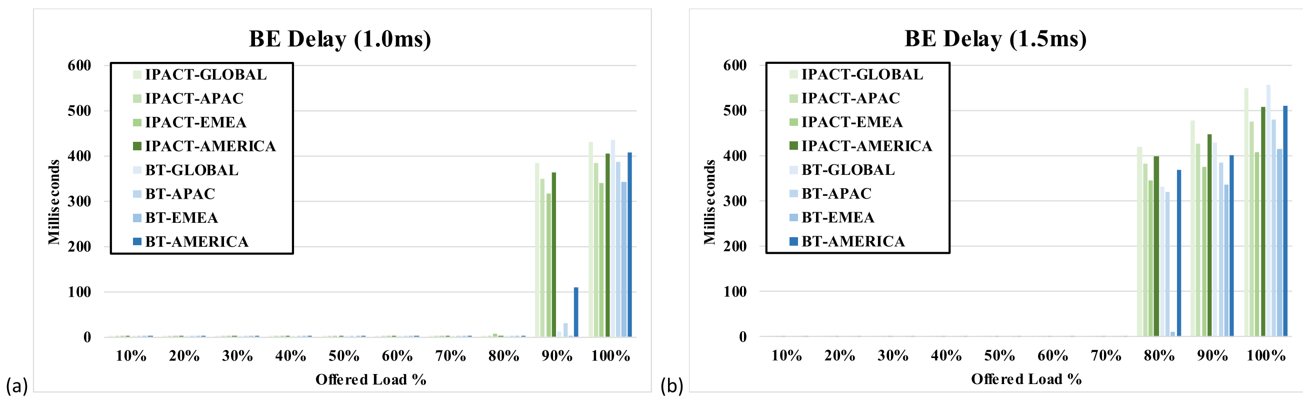

FIGURE 9. BE traffic delay for 1.0 ms and 1.5 ms cycle time.

cycle times. Our proposed architecture with BT-DWBA can be improved up to 23.41% for BE traffic, 11.87% for AF traffic and 11.87% for EF traffic for **EMEA** region compared with original IPACT scheme for 1.5 ms cycle time. From the simulation results we can prove that when we redirect more BT traffic without transmitting to OLT, then it will decrease all traffics delay. It is also worth noting that when the queue length exceeds the given timeslots and the queue saturates, the mean packet delay saturates as well.

B. SYSTEM THROUGHPUT

The system throughput is the sum of the total traffic between the OLT and ONUs as well as inter-ONUs. Figure 10 shows the system throughput compared between our proposed BT-DWBA and the IPACT for cycle times 1.0ms and 1.5ms, respectively, in different four geographic regions Global, APAC, EMEA and AMERICA, respectively. The results showed that the system throughput of the proposed BT-DWBA with BbT traffic and redirect traffic

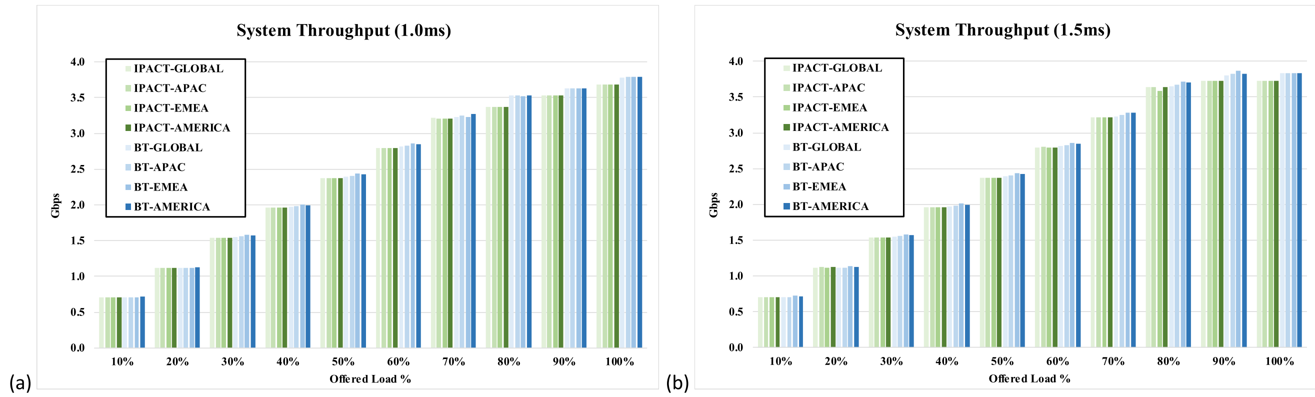

FIGURE 10. System throughput for 1.0 ms and 1.5 ms cycle time.

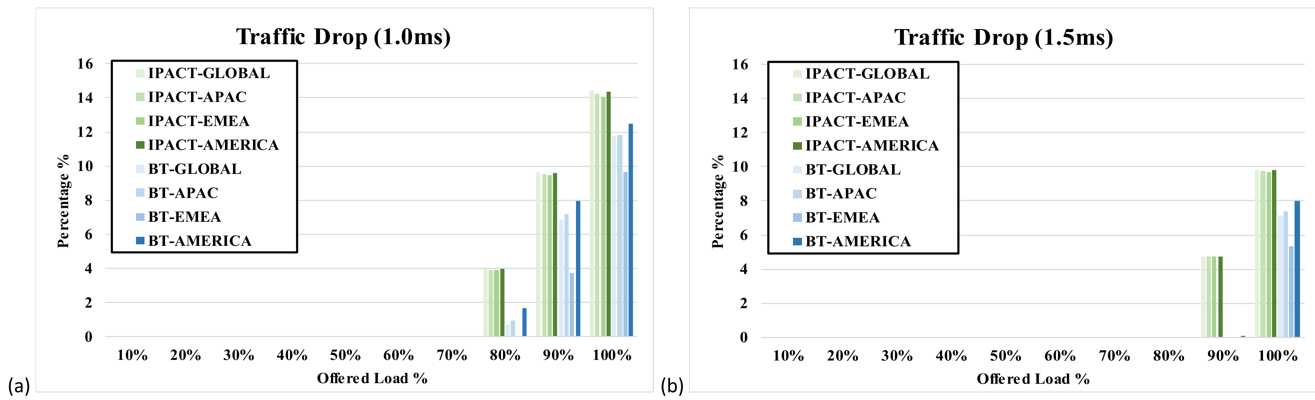

FIGURE 11. Traffic dropping for 1.0 ms and 1.5 ms cycle time.

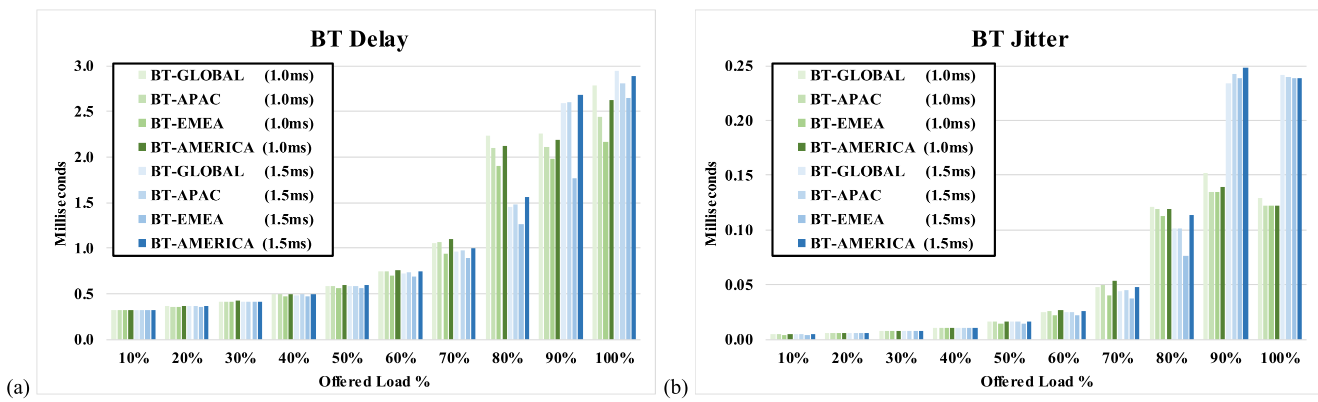

FIGURE 12. (a) BT traffic delay (b) BT Jitter for 1.0 ms and 1.5 ms cycle time.

performed better than the original IPACT traffic. From the simulation result we compare between IPACT scheme and our proposed BT- DWBA scheme in average of offered load from 50% to 100%, we got the improvement up to 2.24% for Global, 2.44% for APAC, 2.42% for EMEA, and 2.80% for **AMERICA** in 1.0ms cycle time. For 1.5ms cycle time, we have improved up to 1.30% for Global, 1.63% for APAC, 2.84% for **EMEA** and 2.20% for AMERICA.

C. TRAFFIC DROPPING

Figure 11 compares the traffic dropping of the proposed scheme with IPACT for cycle times 1.0ms and 1.5ms, respectively, in different four geographic regions. The local-aware BT-DWBA can reduce the traffic dropping which only occur in BE traffic because of the priority. Simulation result show that in **EMEA** scenarios which BT traffic is larger than other scenarios, then the traffic drop percentage is lower than the small BT traffic ratio scenarios (Global, APAC and AMERICA). The drop percentage BE traffic result for the higher BT traffic ratio (100%) can be reduced to 27.2%, 24.2%, **45.2%**, 18.6% for Global, APAC, **EMEA**, AMERICA, respectively as compared to IPACT scheme in 1.5ms cycle time. We also can observe that when the AF traffic is higher while the BE traffic is less, then the BE traffic dropping will increase in all conditions (90%∼100%). As AF traffic has the highest priority which leads to let other traffics to wait and queue in order to assure the demands of the high-priority traffic.

D. BT TRAFFIC DELAY AND JITTER

Figure 12 shows the mean packet delay and jitter of BT intra-traffic. We can observe that the **EMEA** scenarios which have bigger percentage for redirect BT traffic can outperform all other scenarios in both 1.5ms and 1.0ms cycle time. We conclude to redirect more traffic to local ONUs without transmitting to OLT for getting best result. Jitter is a fluctuation in packet transit time induced by queuing, contention, and serialization effects on the network path. higher degrees of jitter are more likely to occur on slow or extremely congested networks in general. As a result, if the jitter is too great, the packet will be set aside and delayed. As a result, reducing jitter is extremely desirable. For the simulation result, we can observe for all scenarios when the offered load below 80% the BT jitter for 1.5ms cycle time have smaller than 1.0ms cycle time. But when the offered load increased to 90% and 100%, the BT jitter for 1.5ms contrarily have bigger jitter than 1.0ms cycle.

IV. CONCLUSION

Our research paper proposes BitTorrent P2P local-aware TWDM file sharing based on SDN to enhance system performance in real-time traffic share in the Covid-19 pandemic era. We focused on presenting a novel architecture for a PON system for better bandwidth utilization in the access network, while ensuring better QoS performance. The local-aware BT-DWBA and SDN-Controller are capable of handling and boosting the required bandwidth for BT intra-services. Although our suggested design requires an extra wavelength to carry the extra BT traffic, it is necessary to improve the overall system performance for all traffic. As we draw some conclusions from our simulation results, our system model reduces traffic delays by up to 23.41% for BE traffic, 11.87% for AF traffic, and 11.87% for EF traffic. Similarly, the throughput can be increased up to 6% and while reducing the traffic dropping to 45% in **EMEA** scenario for 1.5 ms cycle time as it has the highest BitTorrent traffic ratio when compared to other regions. Furthermore, we plan to extend our proposed architectures to handle other P2P applications, such as P2P IPTV, P2P VoD, P2P live streaming etc.

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