Peer-to-Peer File Sharing Architecture for Software-defined TWDM-PON

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Abstract

Peer-to-peer (P2P) file sharing application is considered to be a global bandwidth consumer. By localizing the traffic, the internet service provider (ISP) can reduce the bandwidth burden in the feeder fiber, saving time and bandwidth. The passive optical network (PON) is regarded as one of the best future access network technologies that can provide a better environment for P2P applications. In this paper, we propose a P2P intra-traffic file sharing architecture in TWDM-PON with software-defined network (SDN) system to reduce inter- and intra- traffic in PON and ISPs, and improve the quality of service (QoS). In addition, the proposed scheme employs colorless optical network units (ONUs) by dynamically assigning wavelength for transmission to simplify the network operation, reduce installation cost, and enable easier maintenance. Moreover, we implement an integrated SDN with OpenFlow protocol to separate the control plane and data plane, enabling flexible and centralized control of the P2P intra-traffic by the ISP. Simulation results demonstrate that our proposed P2P-DWBA can realize improvements up to 21% in the QoS in terms of packet delay, 23.9% in the jitter, 13% in the throughput, and reduce traffic dropping up to 58% in scenario 6 (5:40:44:11) for the 1.5 ms cycle time.

Keywords: P2P file sharing, TWDM-PON, SDN-OpenFlow, QoS, Colorless ONUs

1 Introduction

File sharing is a method by which users can distribute and provide access to digital media, such as multimedia (audio, images, video, etc.), documents or electronic books. There are two types of file sharing applications: ***centralized file sharing*** (e.g., file transfer protocol and file sync) and ***P2P file sharing*** (e.g., Napster, Gnuttela, BitTorrent). Peer-to-peer (P2P) network is a distribution application for sharing large audio/video/data files between nearby users to save bandwidth and provide less delay [1]. There are two types of P2P systems: ***unstructured*** and ***structured*** [2]. In an *unstructured* system, peers are randomly connected to certain other peer subsets; however, in a *structured* system, peers are organized to search other peers more efficiently. According to [3], in 2016, the total consumer internet traffic for fixed networks was 52,678 petabytes (PB) per month, with P2P file sharing occupying 6,628 PB of the total fixed network traffic; it is forecasted that from 2017-2021, P2P file sharing will continue to occupy more than 6,500 PB traffic each month. The growth in P2P file sharing traffic has raised concerns from internet service providers (ISPs). Furthermore, in recent years, P2P networks have been commonly used for distributed storage, cloud computing, and social networking [4]. As a result, ISPs are facing challenges in transporting the increasing volume of P2P traffic, with short timing and quality-of-service (QoS) requirements, by expanding the existing access network infrastructures [5].

Of late, in access network systems, the optical network has been considered as one of the most promising solutions, due to the enormous bandwidth capacity of a single line fiber. In 2015, optical fibers covered approximately 30% of global household internet users, and this is expected to increase up to 50% in 2020 [6]. The standard passive optical network (PON) architecture consists of a centralized optical line terminal (OLT), multiples of optical network units (ONUs), and an optical splitter [7-8]. There are two standardized PON systems, Ethernet PON (EPON) [9] and Gigabit PON (GPON) [10] standardized by the IEEE in 2004 and ITU-T in 2003, respectively. With the increase in traffic, 10 Gigabit-class PON technologies, such as 10G-EPON [11] and XG-PON1 [12], were defined. As the next step in fiber access evolution, the ITU-T defined the second next generation PON (NG-PON2) [13], TWDM-PON, with 40-Gbit/s capacity to adopt time and wavelength division multiple access (TWDMA) technology. The colorless ONU (tunable transceiver) is adopted by the NG-PON2 for reducing the computational effort of the ONU digital hardware, supporting the wavelength channels in simplifying network operation, reducing installation cost and the maintenance effort [14-15]. The colorless ONU (or source-free ONU) is

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wavelength-independent, and its upstream wavelength assignment can be dynamically changed by the central office, causing the ONUs to work in different wavelengths or share a particular wavelength.

Several schemes have been proposed in recent works for improving the P2P file sharing system performance, such as the introduction of locality awareness in the neighbor selection of popular P2P applications [16], deploying P2P caches [17] to decrease the inter-ISP P2P traffic, analyzing user behavior using the social relations cluster concept [18], and resource allocation adjustment to maintain a high level of QoS [19]. In our previous research [20], we attempted to localize the inter-ISP traffic by designing a new ONU mechanism (patching and caching) to reduce resource consumption and provide increased downstream bandwidth, without buffering and scheduling in the downstream direction by the OLT. Furthermore, in [21], we proposed a software-based application-aware architecture for the OLT and ONUs to enhance the QoS and optimize the P2P streaming performance. In OLT, we designed a software-based controller to provide the ISP with flexible control over the P2P live-streaming traffic and inter-ISP traffic. In ONUs, the software-based application-aware controller is responsible for the packet-filtering processes, and localizes the P2P stream requests from peers to decrease bandwidth consumption, peer playout lag, and playback lag delay. In addition, a new application-aware DWBA was designed to improve the QoS and mitigate inter-ISP traffic. In recent research [22], a new localized multicast-based P2P (LM-P2P) mechanism is proposed for controlling the generation of P2P sessions, based on the peer-location information and multicast efficiency in the OLT. The centralized control node selects a multicast seeder and recommends it to later clients as a seeder for minimizing the P2P streaming traffic for both inter- and intra-OLT traffics.

In recent years, software-defined networking (SDN) has become a potential research interest in several fields, including education, industry, banking, etc. [23]. The SDN promises increased agility, enhanced security, automation, and lower capital (CAPEX) and operating expenditure (OPEX). The SDN focuses on the separation of the control and data plane functions of the network, where the control plane decides the packet flow through the network, and maintains, controls, and programs the data plane. Moreover, the SDN aims to follow the centralized programmable network model in which the OpenFlow protocol is used for adapting the SDN mechanism into the network [24]. The OpenFlow is based on an ethernet switch, with internal flow-tables, and includes a standardized interface to add and remove flow entries. In this paper, by taking advantage of the SDN with OpenFlow protocol in the TWDM-PON, ISPs are rendered more flexible with centralized control over the P2P intra-traffic file sharing application. The major contributions of this paper is to the PON architecture to support direct and redirect communication between ONUs as intra-traffic, by applying the SDN with OpenFlow protocol, the ISP is rendered flexible and has more control over the P2P intra-traffic, for file sharing applications. Moreover, TWDM-PON system is implemented to accommodate numerous users, and significantly improve the system performance.

The rest of the paper is organized as follows: Section II discusses our proposed scheme and its operation. Section III conducts the simulation and evaluates the system performance. Section IV gives the conclusion and future work.

2 Proposed Architecture and Operation

In this section, we propose the SDN peer-to-peer file sharing architecture on TWDM-PON, as shown in Figure 1. The architecture consists of five main network components: the P2P-OLT, P2P SD-controller, P2P application manager (PAM), P2P-ONUs, and 3:N star coupler (3:N SC). The P2P SD-controller configures, controls, and manages the flow tables in the OLT and ONUs through the SD-agent by sending an SD message using a secure protocol interface. The 3:N SC broadcasts the downstream traffic tuned at a wavelength of λ_1–λ_4, upstream traffic tuned at a wavelength of λ_5–λ_8, and intra-traffic tuned at a wavelength of λ_{p2p}.

2.1 System Architecture

P2P-OLT. The P2P-OLT, including the network-to-network interface (NNI), several line OLTs (L-OLTs), the SD-agent, flow tables, and MAC control client, involves the discovery and registration process, REPORT processing, dynamic wavelength bandwidth allocation (DWBA), and GATE generation. The NNI is a physical interface that connects two or more networks using the signaling internet protocol (IP). The L-OLT is a basic logical entity in the OLT device structure, defined in IEEE Std. 802, and is responsible for the physical layer connectivity in the EPON. In the discovery and registration process defined in the multipoint control protocol (MPCP) for the OLT as well as ONUs, the OLT detects the newly connected ONUs, learns the round-trip delay, and the MAC address of each ONU. REPORT processing, sent from the ONUs to the OLT, obtains information on the traffic-queue length for each ONU, before executing the DWBA. The DWBA in OLT is an algorithm for dynamically calculating and assigning bandwidth to each user, based on the information in the REPORT message sent by each ONU. GATE generation is a process that generates a grant message including the grant start time, grant length, grant wavelength, etc., and the broadcast to each ONU.

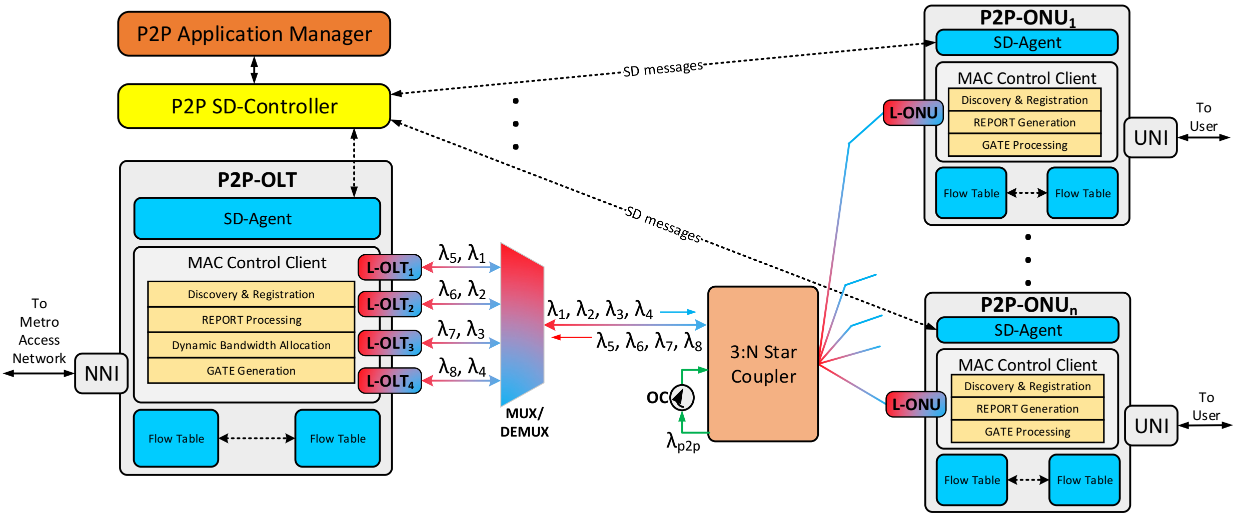


Figure 1. The proposed software-defined P2P File Sharing for TWDM-PON system architecture

Colorless P2P-ONU. The P2P-ONU, including the user-to-network interface (UNI), line ONU (L-ONU), SD-agent, flow tables, and MAC control client, involves the discovery and registration process, REPORT generation, and GATE processing. The UNI is a physical interface for connecting the user to the network. The L-ONU is a basic logical entity in the ONU device structure, and is responsible for the physical layer connectivity in EPON. Each L-ONU contains a tunable transmitter, tunable receiver, and P2P-receiver. The discovery and registration process are implemented in the OLT and ONUs with the same function. REPORT generation is a process that generates a report message with information on each ONU, and sends it to the OLT at a specific time allotted by OLT. GATE processing obtains information, such as the grant start time, grant length, and grant wavelength of the traffic for each ONU, to start upstream transmission.

3:N Star Coupler. It includes an optical coupler and an optical circulator. The optical coupler is a device that splits the optical signal from a fiber to several fibers and reciprocally, combines the optical signals from multiple fibers into one. The optical circulator redirects the optical signal from/to the optical coupler.

P2P SD-Controller. It is an SDN application that manages flow control to enable intelligent networking. The SD-controller, based on OpenFlow protocols, enables the servers to inform the switches, the location to which the packets are to be sent.

P2P Application Manager (PAM). It is a software-based application for managing P2P file sharing application protocols, including Napster, Gnuttela, BitTorrent, etc.

2.2 Colorless P2P-ONUs Architecture

As shown in Figure 2, the colorless ONU architecture consists of the SD-agent, user-to-network interface (UNI), flow table, several queues for different traffic, and a tunable transceiver (transmitter/receiver).

SD-Agent. It is an agent controlled by the P2P SD-controller, and communicates by sending an SD message over a secure channel interface. The SD-agent manages the flow table by adding or removing the flow entries.

UNI. It is a physical interface for users to connect to the network.

Flow Table. Its function is to classify and separate packets, based on the source/destination MAC and IP address, type of service (ToS), and transmission control protocol (TCP)/user datagram protocol (UDP) source port. From a specific TCP/UDP source port, we can classify the traffic as expedited forwarding (EF) traffic, assured forwarding (AF) traffic, P2P traffic or best effort (BE) traffic. Each flow table entry contains the header fields, counters and actions.

Queue. Four queues are used for the EF, AF, P2P, and BE traffic, respectively.

Tunable transmitter. It is tuned at the λ_5–λ_8 wavelength for upstream transmission and in the λ_{p2p} wavelength for P2P transmission.

Tunable receiver. It is tuned at the λ_1–λ_4 wavelength for receiving downstream transmission.

P2P-receiver. It is tuned at the λ_{p2p} wavelength for receiving P2P transmission.

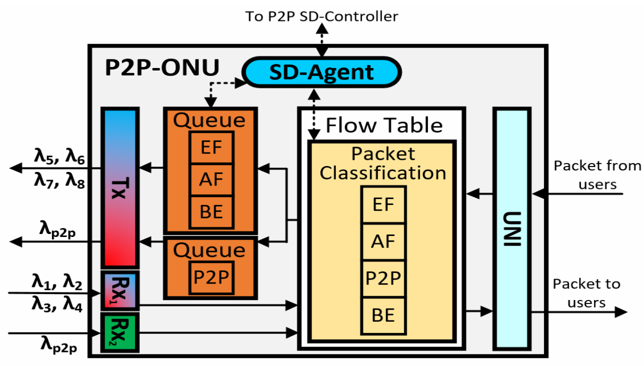


Figure 2. Colorless P2P-ONU architecture

2.3 Dynamic Wavelength Bandwidth Allocation (P2P-DWBA)

A new DWBA algorithm is proposed, *P2P-DWBA*, which is designed to handle traffic allocation shown in Figure 3 to support the intra-traffic with four priority queues at each ONU, namely the EF, AF, P2P, and BE queues. When the OLT receives the REPORT messages, it initially defines the packet and calculates the timeslots required, according to each traffic type. The P2P-DWBA first checks the available and required timeslots for allotting all the requested timeslots for EF traffic. The P2P-DWBA then checks the remaining timeslots and allots a timeslot to AF traffic. After the EF and AF traffic timeslots have been allotted, the P2P-DWBA checks the remaining timeslots and if they are still available, it allots a timeslot for intra-traffic (P2P); finally, the remaining timeslot will be allotted to BE traffic. After the P2P-DWBA calculates the timeslots for all the traffic, the OLT sends a GATE message {*start_time*, *length*, *wavelength*} for each traffic to all the ONUs.

```
i = number of ONUs (64)
wp2p = wavelength for P2P tramission
Tavailable = scheduled time for upstream transmission
Tguard = guard band interval
maxLength = maximum transmission timeslot of ONUi
Report.j.length = j packets (bits) at the ONUi buffer
Bleft = remaining bandwidth
For every wavelength w, where w ∈ {1,…,4} do {
  For every received Report.j.length of ONUk, where k ∈
  {i/w}, j ∈ {EF, AF, P2P, BE} do {
    startTime = Tavailable + Tguard
    if j = P2P then {
      if Report.j.length > maxLength then {
        Report.j.length = maxLength
        GRANT = {startTime-RTTi, maxLength, wp2p}
        Send GRANT message
      } else {
        GRANT = {startTime-RTTi, Report.j.length, wp2p}
        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
    Tavalaible = startTime + Report.j.length
  }
}
```

Figure 3. P2P-DWBA scheme

2.4 Signaling Control Operation

In the signaling control operation, shown in Figure 4, the connection between the ONUs and OLT is based on the multipoint control protocol (MPCP). The MPCP is a control mechanism for point-to-multipoint (P2MP) implemented in the MAC control layer to enable efficient data transmission. The auto-discovery mode is used for detecting newly connected ONUs, and for learning the round-trip delay and the MAC address of the ONU. The OLT sends a *discovery GATE* to the entire ONUs to create a transmission opportunity for undiscovered ONUs, which respond to the OLT by sending a *REGISTER_REQ*. The OLT then replies the messages to the ONUs by sending a *REGISTER*. Finally, the ONUs send a *REGISTER_ACK* to complete the discovery mode. OpenFlow connection is established between the SD-controller and SD-agents by sending *OFPT_HELLO* messages each side. If the connection fails, an *OFPT_ERROR* message is sent. Flow tables are used to classify and separate traffic into EF, AF, P2P, and BE, and are managed by the SD-controller through the SD-agent in the ONUs. The SD-controller cooperates with the PAM to determine, whether the request packet is P2P traffic. If it is P2P traffic, the SD-controller sends an *OFPT_FLOW_MOD* message to modify and update the flow table in the source and destination ONUs. Henceforth, the ONU source places the packet into the P2P queue and waits for sending a *REPORT* message to the OLT. After the OLT receives the *REPORT* message, the P2P-DWBA starts to calculate the timeslots for all the ONU traffic. Then, the OLT sends a *GATE* message with the starting time, time length, and wavelength to all the ONUs.

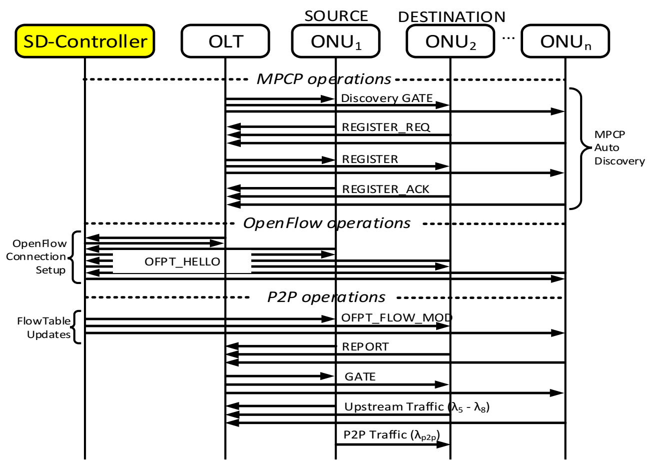


Figure 4. Signaling control operations

2.5 System Operation

The system operation of our proposed scheme is shown in Figure 5. User network interface (UNI) in the colorless ONU receives a request from user. Flow table separates the packet based on the source/destination address, ToS and TCP/UDP into the EF/AF/BE/P2P queues controlled by P2P SD-controller. ONUs generate the REPORT message and transmit to OLT in the previous assigned timeslots. The received REPORT message at OLT is parsed and demultiplexed to the OLT's REPORT processing, then passes it to the DWBA to execute bandwidths 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, calculated by the DWBA, and the granting wavelength λ_{p2p} for P2P traffic for P2P transmission. Next, OLT broadcasts the GATE message to all ONUs while the received GATE message in the ONU is parsed and demultiplexed to the ONU's GATE processing, which is responsible to allow transmission to begin within the timeslot assigned by OLT.

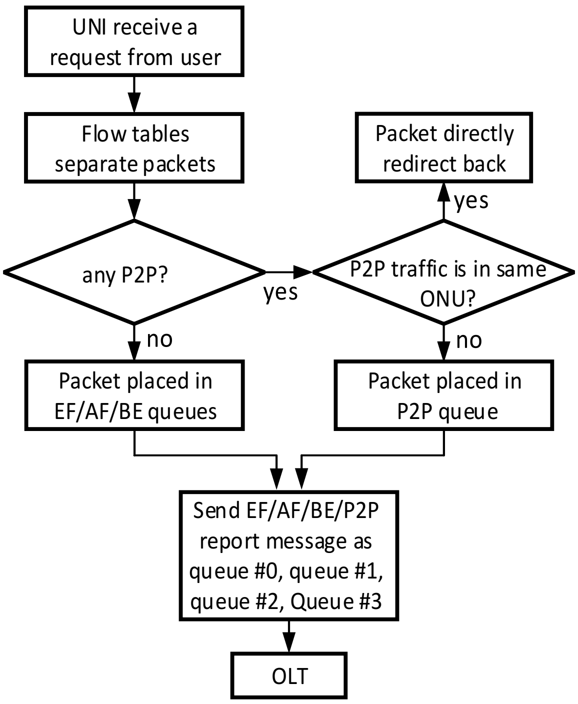


Figure 5. System operation

3 Performance Evaluation

In this section, we compare the system performance of the proposed scheme with the IPACT scheme [25] in terms of EF, AF, P2P, BE packet delays, jitter, system throughput and dropping. The system model is set up in the OPNET simulator with one OLT and 64 ONUs, as shown in Table 1. The downstream and upstream channels are set 4 Gbps, and the distance from ONUs to the OLT is assumed to be 10-20 km, and each ONU has a finite buffer of 10 Mb. In the extensively studied traffic model, most networks are characterized as self-similarity and long-range dependence that are utilized to generate the highly burst BE and AF traffic classes with a Hurst parameter of 0.7; the AF and BE packet sizes are uniformly distributed between 512 and 12144 bytes, the P2P packet size is uniformly distributed between 9600 and 12144 bytes, and the EF packet size is constantly distributed with 560 bytes. For the traffic profile shown in Table 2, we simulated three scenarios for IPACT which are scenario 1 (EF_5%, AF_60%, BE_35%), scenario 2 (EF_5%, AF_50%, BE_45%), and scenario 3 (EF_5%, AF_40%, BE_55%). In addition, we simulated six scenarios for our proposed P2P-DWBA: S1 (EF_5%, AF_60%, BE_31.5%, P2P_3.5%), S2 (EF_5%, AF_50%, BE_40.5%, P2P_4.5%), S3 (EF_5%, AF_40%, BE_49.5%, P2P_5.5%), S4 (EF_5%, AF_60%, BE_28%, P2P_7%), S5 (EF_5%, AF_50%, BE_36%, P2P_9%), and S6 (EF_5%, AF_40%, BE_44%, P2P_11%), respectively.

Table 1. Simulation parameters

Parameters	Value
Number of OLTs	1
Number of ONUs	64
Number of wavelengths	4+1(P2P)
Up/Down link capacity	4 Gbps
OLT-ONU distance (uniform)	10-20 km
Max cycle time	1.0 ms, 1.5 ms
Guard time	1 µs
Tuning time [26]	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)
P2P packet size (bytes)	Uniform (9600, 12144)

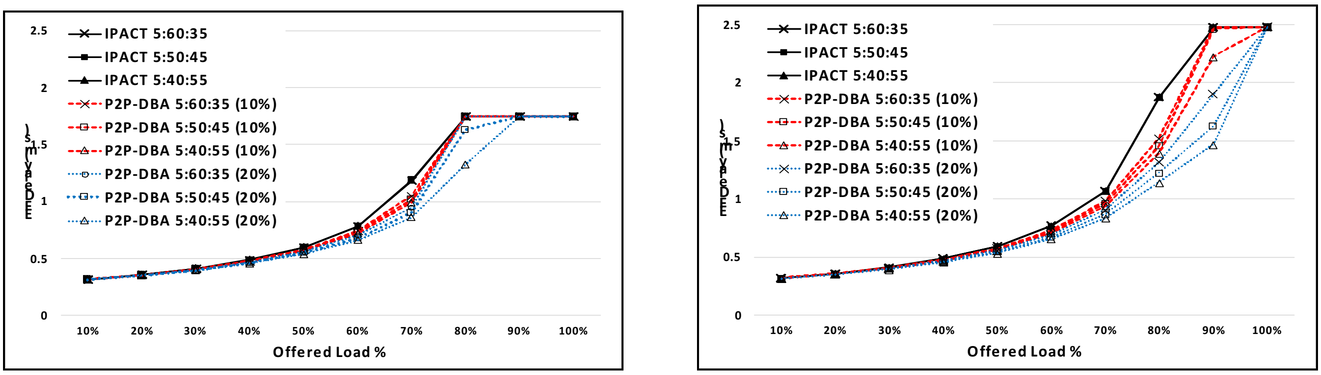
Table 2. Traffic profile

	Scenario	EF	AF	BE	P2P
IPACT	5:60:35	5%	60%	35%	-
	5:50:45	5%	50%	45%	-
	5:40:55	5%	40%	55%	-
P2P-DBA	S1-5:60:35 (10%)	5%	60%	31.5%	3.5%
	S2-5:50:45 (10%)	5%	50%	40.5%	4.5%
	S3-5:40:55 (10%)	5%	40%	49.5%	5.5%
	S4-5:60:35 (20%)	5%	60%	28.0%	7.0%
	S5-5:50:45 (20%)	5%	50%	36.0%	9.0%
	S6-5:40:55 (20%)	5%	40%	44.0%	11.0%

3.1 Mean Packet Delay

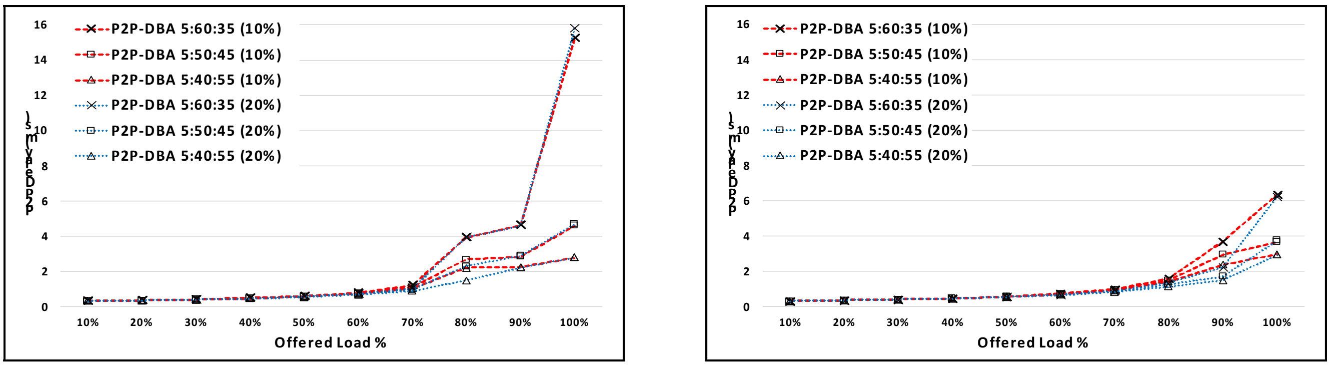
The simulation results for the EF delay, shown in Figure 6, demonstrate that our proposed scheme has better performance for the EF traffic, compared to the IPACT (without P2P traffic) for 1.0-ms and 1.5-ms cycle times, respectively. Because there is no P2P delay in IPACT, we compared our proposed P2P-DWBA for the P2P delay alone. As shown in Figure 7, the P2P traffic in scenarios S4-S6 performed marginally better than in scenarios S1-S3 for 1.0-ms cycle time. For 1.5 ms cycle time, it is clear that the P2P delay in scenarios S4–S6 outperforms that in S1–

S3. In scenarios S1 and S4, for a 1.0-ms cycle time and traffic load at 70-100%, the P2P delay suddenly increased to more than 5 ms because the AF traffic (60%) is more than those in the other scenarios, and our proposed DWBA prioritizes the EF, AF, P2P, and BE traffic, respectively. Figure 8 shows the average delay reduction percentage for all traffic (EF, AF, BE) between our proposed P2P-DWBA and the IPACT. The proposed scheme improves the EF delay by 9.3%, AF delay by 9.7%, and BE delay by 20.5%, for S6 with a 1.0-ms cycle time. For the 1.5-ms cycle in S6, the proposed scheme can improve the EF delay up to 14.3%, AF delay up to 14.4%, and BE delay up to 21.2%, respectively. Moreover, when the cycle time increases to 1.5 ms, the delay time for all traffics are lower than those with a cycle time of 1 ms.



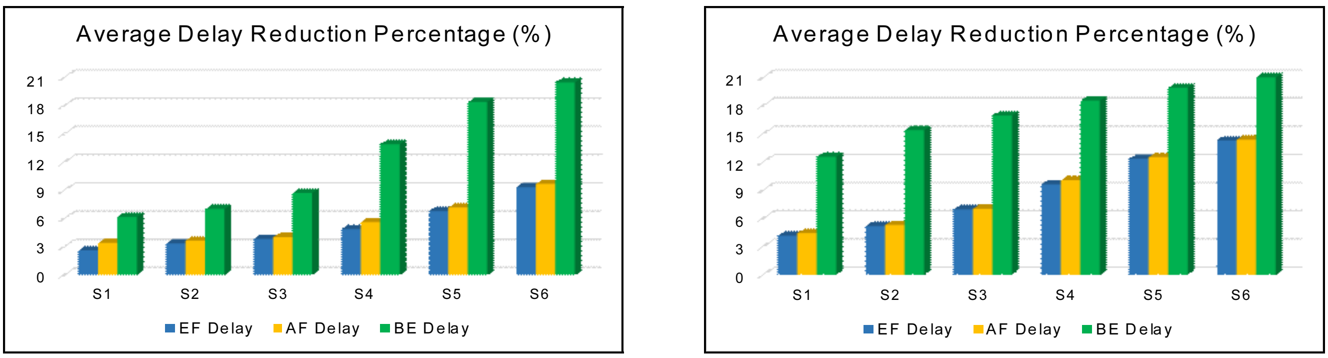
(a) (b)

Figure 6. EF delay for (a) 1.0 ms cycle time (b) 1.5 ms cycle time



(a) (b)

Figure 7. P2P delay for (a) 1.0 ms cycle time (b) 1.5 ms cycle time



(a) (b)

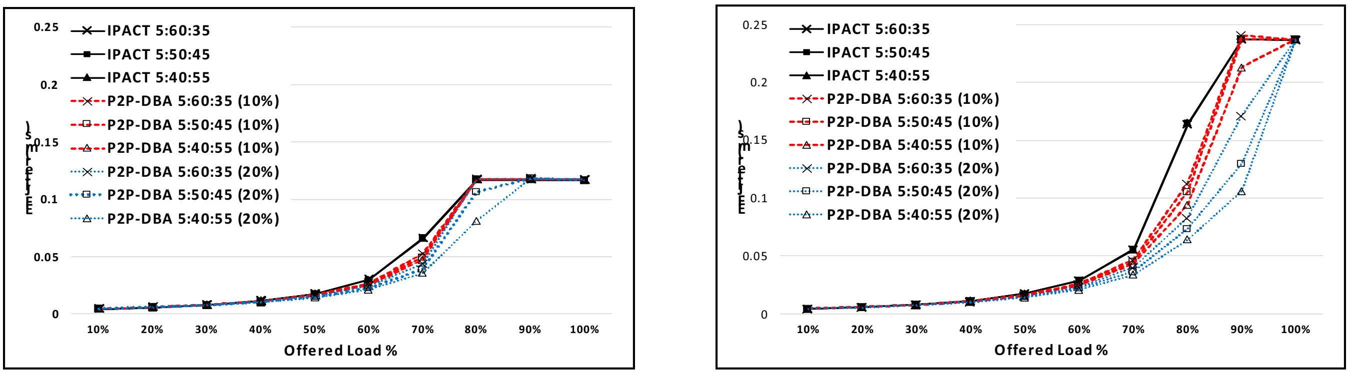
Figure 8. Average delay improvement for (a) 1.0 ms cycle time (b) 1.5 ms cycle time

3.2 Jitter

In general, less jitter is highly desirable, and can be obtained in different environments and calculated as follows:

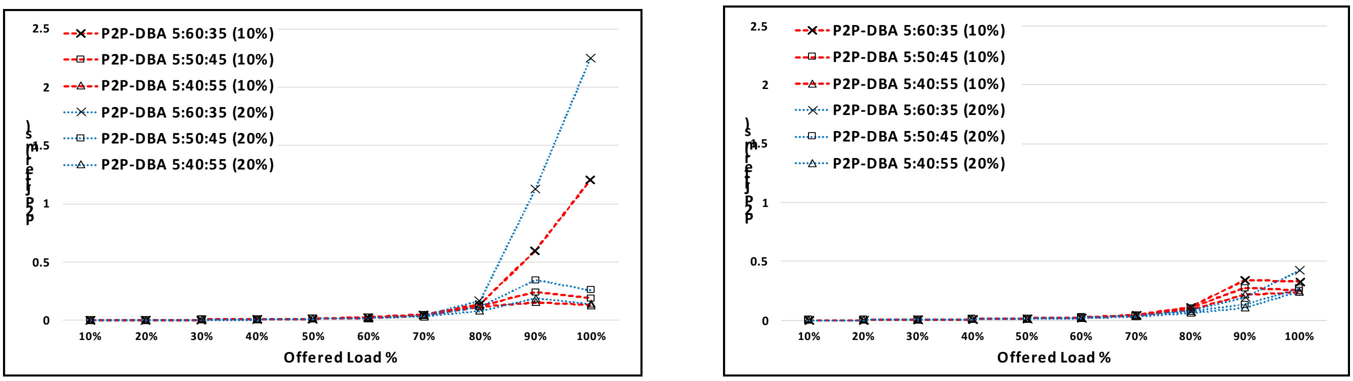
$$\sigma^2 = \sum_{k=1}^{N} (d_k^{EF} = \bar{D})^2 / N\,,$$

where σ^2 is the delay variance, d_k^{EF} is the delay time for traffic packets, k, $\bar{D}$ is the average delay time for traffic packets, and N is the total number of traffic packets received. Figure 9 shows that the EF traffic jitter is slightly better, in Scenario 6 (5:40:55(20%)) when the traffic load is 70-100%. When the cycle time is increased to 1.5 ms, the delay time obviously higher than the 1.0 ms cycle time. Thus, the proposed scheme can guarantee the audio quality for communication over the internet. Figure 10 shows that for scenarios 1 and 4 at 1.0-ms cycle time and a traffic load of 70-100%, the P2P traffic jitter increases suddenly to more than 0.5 ms because the AF traffic (60%) is higher than those in the other scenarios, causing the remaining AF, P2P and BE traffic be sent in the next cycle. When the cycle time is 1.5 ms, this problem is alleviated because the timeslot provided by the OLT is sufficient to send all the AF traffic.



(a) (b)

Figure 9. EF Jitter for (a) 1.0 ms cycle time (b) 1.5 ms cycle time

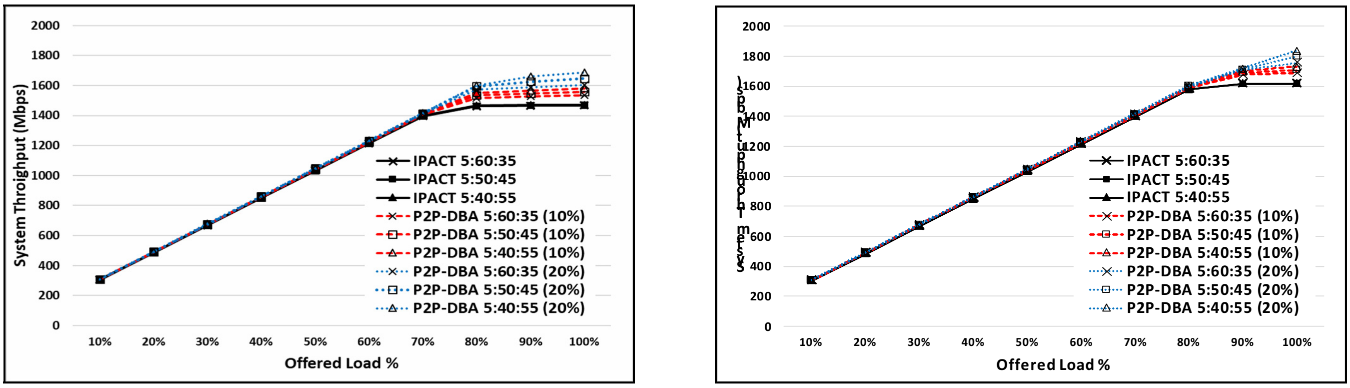


(a) (b)

Figure 10. P2P Jitter for (a) 1.0 ms cycle time (b) 1.5 ms cycle time

3.3 System Throughput

Figure 11 compares the system throughput between the proposed P2P-DWBA and the IPACT, at 10-100% offered loads with different cycle times (1.0 ms and 1.5 ms, respectively). The results demonstrate that the system throughput of the proposed P2P-DWBA is better than that of the original IPACT traffic for both cycle times; for the 1.0-ms cycle, improvement up to 4.7%, 6%, 7.4%, 9.4%, 12%, and 14.7% for S1–S6, respectively; whereas for the 1.5-ms cycle, improvement up to 4.2%, 5.5%, 6.7%, 8.5%, 11%, and 13.4% for S1–S6, respectively.

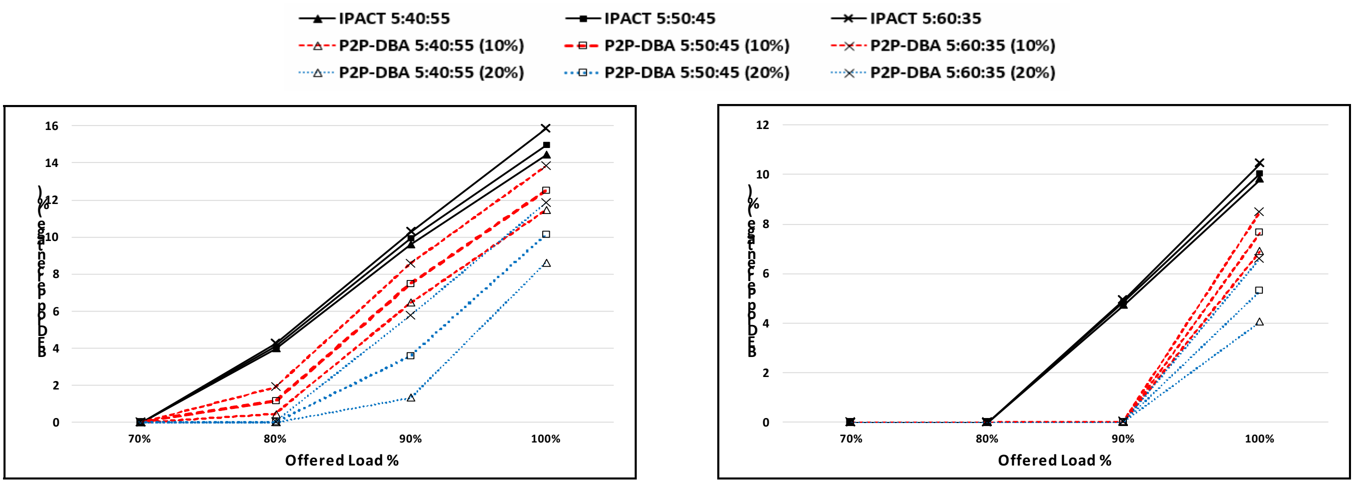


(a) (b)

Figure 11. System Throughput for (a) 1.0 ms cycle time (b) 1.5 ms cycle time

3.4 Traffic Dropping

From Figure 12, improved performance in the BE drop can be observed for both 1.0-ms and 1.5-ms cycle times. Simulation results demonstrate that BE traffic dropping can be reduced, when the P2P traffic ratio is higher (20% BE traffic), compared to that with a lower P2P traffic ratio (10% BE traffic). Comparing the 1.0-ms and 1.5-ms cycle times in S6 (5:40:44:11), it is obvious that the BE traffic dropping, at a cycle time of 1.0 ms, reduces up to 40%, and that at a cycle time of 1.5 ms reduces up to 58%. This is because, when the BE traffic ratio is smaller, the EF and AF traffic ratios are higher, causing the lower priority traffic to be dropped in order to satisfy the higher priority traffics.



(a) (b)

Figure 12. Traffic Dropping for (a) 1.0 ms cycle time (b) 1.5 ms cycle time

4 Conclusion

In recent years, the immense popularity gained by P2P applications has imposed a severe burden on ISPs and the internet backbone. In this paper, a new architecture and resource allocation scheme have been proposed for localizing intra-P2P traffic. The proposed DWBA and SDN-controller can handle and enhance the required bandwidth for P2P service. The simulation results show that our proposed scheme can guarantee the QoS by maintaining the traffic delay below 5 ms. It can be improved that the BE packet delay up to 21%, throughput up to 13%, and dropping up to 58%, in scenario 6 (5:40:44:11) for a cycle time of 1.5 ms. Moreover, our proposed scheme can be further extended to multi-PONs and be able to handle other P2P applications in the future work, such as P2P VoD, P2P IPTV, P2P live-streaming, etc.

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