BitTorrent Locality-Awareness Application with Colorless ONUs in an Enhanced EPON System

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Abstract

BitTorrent (BT) file sharing is the most popular peer-to-peer (P2P) application and it accounts for a large proportion of the bandwidth utilized worldwide. However, BT ignores the traffic costs for Internet service providers (ISPs) and a large amount of cross-ISP traffic is generated. Thus, ISPs often throttle BT traffic to control costs. Ethernet passive optical network (EPON) is an important primitive technology for the future-oriented next generation access network which aims to provide a suitable environment for P2P services. In this study, we designed an optical line terminal (OLT) with a tracking-server in order to implement a fully functioning BT system that can handle the local BT traffic. We propose the use of a passive splitter redirection capability (PSR) between the OLT and colorless optical network units (ONUs) to support intra-traffic redirection communication in order to achieve traffic localization among ONUs in the enhanced EPON. Our simulation results showed that the proposed architecture can improve the quality of service (QoS) in terms of the mean packet delay, system throughput, and packet loss.

Keywords: BitTorrent, P2P, EPON, Colorless ONU, Traffic localization

1 Introduction

Peer-to-peer (P2P) networking employs a virtual network of computers to replace the server-client concept with a concept based on peers. The two classes of P2P systems are unstructured (i.e., Gnutella) and structured (i.e., BitTorrent (BT)), and file sharing is one of the most popular applications in P2P networks [1]. Unstructured P2P networks such as Gnutella do not assign responsibility for data to specific nodes [2]. Structured P2P networks such as BT can overcome this weakness due to their features of higher efficiency, scalability, and deterministic data location [3]. According to Cisco’s network traffic measurements and forecasts, P2P file sharing applications account for up to 83.5% of the total file sharing traffic and they will account for 60.3% of the total file sharing traffic in 2018 [4].

The difference between BT and other similar file-transfer applications is that users only download fragmented files from other users who share the same resource, which may involve a few to thousands of hosts at the same time. In BT, the group of users who are interested in the same resource (known as “peers”) combine together via a central component (known as a “tracker”). Trackers are responsible for controlling the transfer of resources between peers and the peers are responsible for holding a particular resource or part of a resource that needs to be shared, and they perform the transfer. The two types of BT peers can be defined as “seeds” that possess the complete resource and that only engage in sharing, whereas “leechers” are peers that do not possess the complete resource but they aim to acquire it and share the fragments they have already downloaded. When a leecher obtains all of the remaining fragments of a resource it automatically becomes a seed [5-6].

The current BT implementation is based on random graphs because they are known to be robust. BT is unaware of the locations of the random graphs, which has been a burden to Internet service providers (ISPs) for many years because traffic may unnecessarily cross the ISP network and incur high costs that need to be paid to other ISPs. [7-9]. Recent studies have tried to decrease the amount of inter-ISP P2P traffic by introducing locality awareness into the neighbor selection policies of popular P2P applications. Locality information can be provided by the ISPs and used to prioritize nearby peers over distant peers when exchanging data, thereby vastly decreasing the bandwidth load on the server side and the inter-ISP traffic cost [10-12]. Liu et al. [13] modified the BT system by building locality-awareness into its neighbor selection process, as well as peer choking or unchoking and piece selection processes. This method is clearly advantageous because locality-aware solutions can reduce inter-AS traffic and achieve shorter download times. Le Blond et al. [14] proposed two new strategies called “round robin” and “partition merging” to make

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better use of a small number of inter-ISP connections, thereby dramatically reducing the overheads and slowdown independently of the torrent size, the number of peers per ISP, the upload capacity of peers, or the churn.

Pacifici et al. [15] proposed the used of P2P caches in a similar manner to Web proxy caches in order to decrease the amount of inter-ISP traffic by storing the most popular contents in the ISP's own network. The problem of cache bandwidth allocation was formulated as a Markov decision process to approximate the optimal allocation policy. However, the locality-aware P2P exchanges managed and coordinated by the network infrastructure itself direct the traffic as much as possible to the end users rather than by enhancing the user software for a next generation passive optical network (PON), as first proposed by Di Pascale et al. [16]. Furthermore, using an ISP-friendly P2P architecture in an Ethernet passive optical network (EPON) can direct peers to connect with the nearest neighbors inside the same ISP for traffic localization to improve the quality of service received by reducing the delay time while also optimizing the utilization of ISP resources in multimedia applications [17-18].

Recently, optical networks have been considered the best solutions for access networks due to the large bandwidth of a single fiber optic. In 2015, fiber optic networks accounted for 20-30% of all household traffic and this will reach 30-50% in 2020 [19]. PON is a telecommunications network that uses a point-to-multipoint fiber where unpowered optical splitters allow a single optical fiber to serve multiple premises. A PON can have many different system architectures but EPON is regarded as the best solution for access networks due to its simplicity, high data rate, and low cost compared with other PONs [20]. An optical line terminal (OLT) is located at the central office with N color optical network units (color ONUs), which are connected in a tree-like topology through a passive 1:N splitter [21-23]. A color ONU is a wavelength-specific ONU where the emission and receiver wavelengths of the color ONUs are specific [24]. However, when using wavelength-specified lasers, no statistical gain can be achieved among ONUs that support different wavelengths [25].

In our proposed method, we use colorless ONUs instead of color ONUs in the traditional EPON. A colorless ONU (or source-free ONU) is a wavelength-independent ONU, where the ONU itself cannot decide to upload a channel network and the upstream wavelength assignment for the colorless ONU can be changed dynamically by the central office [26-29]. One of the main objectives of our proposed method is to reduce the computational effort required by the ONU digital hardware by supporting all of the wavelength channels to simplify the operation of the network, as well as reducing the installation cost and controlling the maintenance requirements. The major contributions of this study are summarized as follows.

1. We propose an enhanced EPON architecture that supports direct patching communication between colorless ONUs to redirect the BT traffic as local traffic.

2. We propose the use of a routing table at each ONU to determine the nearest peer for any BT requests from intra-PON peers, thereby reducing the OLT's load and localizing the traffic but without decreasing the quality of service.

3. We propose a locality-aware dynamic bandwidth allocation (LADBA) method for scheduling the transmission time of intra-network traffic (BT traffic).

The remainder of this paper is organized as follows. In Section 2, we describe the proposed architecture for implementing the BT protocol. In Section 3, we present a performance evaluation based on the proposed architecture. We give our conclusions in Section 4.

2 Proposed Architecture and Operations

Figure 1 shows the proposed architecture for efficiently supporting BT services in an enhanced EPON. In this architecture, we directly consider the communication among ONUs (intra-PON) to reduce the bandwidth required in the feeder fiber. The three basic network elements in our architecture are the OLT, passive splitter redirection capability (PSR), and colorless ONUs. The BT-tracker, transmitter (Tx), and receiver (Rx) are inside the OLT. The BT-tracker is a tracker-server that performs the BT operations for any of the registered peers within the EPON. The PSR comprises passive splitter, multiplexer (MUX) and demultiplexer (DEMUX), and the colorless ONUs include a tunable receiver, tunable transceiver, DEMUX, and MUX. For the downstream transmission, OLT broadcasts the datum/packets through PSR to ONUs tuned at wavelength 1550nm (λ_1). For the upstream transmission, each ONU sends the datum/packets through PSR to OLT tuned at wavelength 1310nm (λ_2). As for BT traffic, ONU sends a request to OLT, then OLT will calculate the bandwidth and sends a grant message to seeder ONU and leecher ONU to switch their transceiver and receiver, respectively in a specific time to wavelength tuned at 1570nm (λ_3).

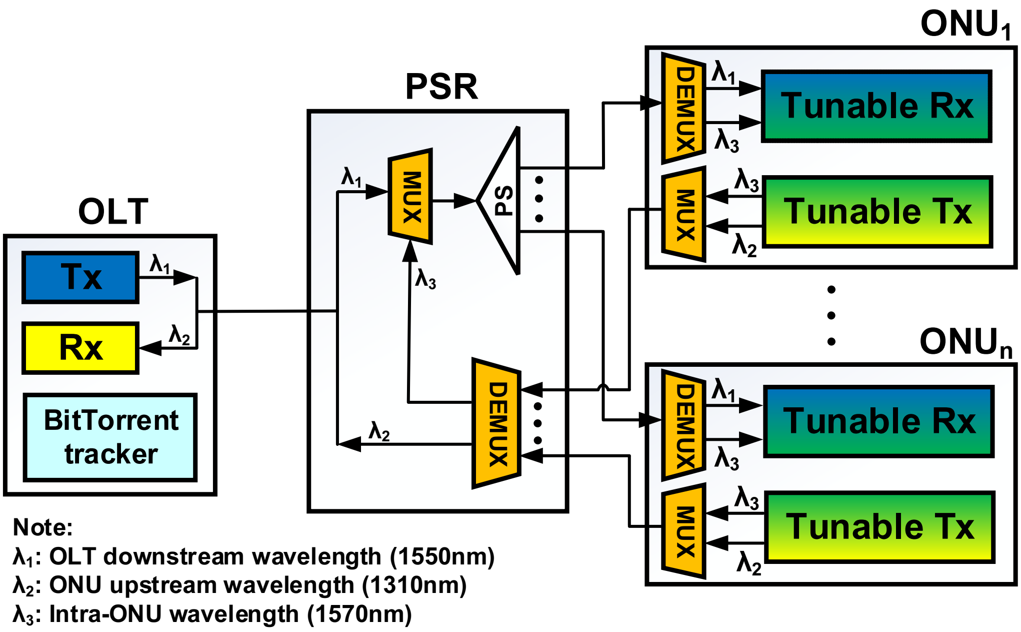


Figure 1. Proposed BitTorrent locality-aware process in the EPON system architecture

2.1 System Architecture

(1) *OLT Architecture:* The OLT comprises the central processing unit (CPU), random access memory (RAM), dynamic bandwidth allocation (DBA), signal copy broadcast, BT-tracker, gigabit Ethernet interface, traffic classifier, and optical distribution network (ODN). The CPU processes the incoming and outgoing packets and the RAM is used as a traffic buffer.

(2) *ONU Architecture:* The ONU comprises the RAM, microprocessor unit, ODN, queues, redirect module table (RMT), class of service, type of service, and user port. The RMT contains routing table information for redirecting the packets based on ingress rules. There are four priority queues in the ONU architecture where three queues are used for expedited-forwarding (EF), assured-forwarding (AF), and best-effort (BE), and the last queue called BT (BT traffic) is referred to as intra-network traffic.

(3) *PSR:* The proposed PSR comprises the MUX, DEMUX, and passive splitter. The OLT transmit the downstream traffic (λ_1) through the power splitter to all of the ONUs, whereas the upstream traffic from the ONUs to OLT is controlled using λ_2. The power splitter distributes the downstream traffic from OLT and redirects the BT intra-network traffic from the ONU and then broadcasts it back to all of the ONUs. The DEMUX takes a single input line and routes it to one of several digital output lines. Therefore, it can distinguish the wavelength needed to redirect the upstream traffic destined to the OLT or pass it through the isolator intra-network traffic to redirect it back to the splitter, which then sends the packet back to all of ONUs.

(4) BitTorrent Tracker (BT Tracker): BT Tracker is a software based application that supports communication between peers using BitTorrent protocol. The BT tracker maintains information (e.g., network location, file location, file name, chunk # etc.) of all the BT. Specifically, the BT tracker identifies the network location of each client either uploading or downloading the P2P file associated with a torrent. BT Tracker also tracks and stores the file location, file name and chunks for each client possesses to assist in efficient data-sharing between clients.

(5) *Routing Table*: Each ONU has an ingress rule, which decides whether a packet can be redirected based on the routing table. A routing table is a data table used to store the particular network destinations and metrics (e.g., leecher IP address, seeder IP address, leecher MAC address, seeder MAC address, and LLID (logical link identity). This table is used to determine the destination of a frame, i.e., either redirecting back or to the OLT. The routing table can be implemented as hardware or software in the ONUs.

2.2 System Operation

(1) *Discovery and Registration Process:* Ethernet network devices attached to the PON medium implement the logical topology emulation (LTE) function based on its configuration, and they emulate either a shared medium or a point-to-point medium. IEEE Standard 802.3 defines the LTE function in the reconciliation sublayer, which is below the MAC sublayer, for holding the existing Ethernet MAC operation. The task performed by this function depends on the tagging of Ethernet frames with unique LLIDs for each ONU. The ONU LLID is assigned by auto-discovery. In a certain time interval, each ONU needs to register in the OLT, which sends a REGISTER message to set up the ONU LLID for each ONU. After the OLT receives the REGISTER_ACK message, the

OLT concurrently determines the ONU MAC and its LLID. Figure 2 shows the REPORT message, where we employ four queues comprising Queue #1 reporting for EF traffic, Queue #2 for AF traffic, Queue #3 for BT intra-network traffic, and Queue #4 for BE traffic. For the GATE message, we employ four grants comprising Grant #1 for EF traffic, Grant #2 for AF traffic, Grant #3 for BT traffic, and Grant #4 for BE.

Field	Octet
Destination address	6
Source address	6
Length/type = 88-08	2
Opcode = 00-02	2
Timestamp	4
Number of queue sets	1
Report bitmap	[1]
Queue #1 report EF	[2]
Queue #2 report AF	[2]
Queue #3 report BT	[2]
Queue #4 report BE	[2]
Pad = 0	0-39
Frame check sequence (FCS)	4

(a) REPORT

Field	Octet
Destination address	6
Source address	6
Length/type = 88-08	2
Opcode = 00-03	2
Timestamp	4
Number of grants/flags	1
Grant #1 start time	[4]
Grant #1 length	[2]
Grant #2 start time	[4]
Grant #2 length	[2]
Grant #3 start time	[4]
Grant #3 length	[2]
Grant #4 start time	[4]
Grant #4 length	[2]
Pad = 0	0-39
Grant #1 λ_2	[1]
Grant #2 λ_2	[1]
Grant #3 λ_3	[1]
Grant #4 λ_2	[1]
Frame Check Sequence (FCS)	4

(b) GATE

Figure 2. REPORT and GATE message structures

(2) *Operation of the BT Protocol in EPON:* Figure 3 shows the implementation of the proposed architecture for the BT operation protocol in the OLT as the server and the ONUs as clients. The operation of the BT protocol can be explained as follows. First, the BT-tracker in the OLT collects peer information for each ONU and then transfers the information to the redirect table in each ONU. The information includes the downstream and upstream rate, IP address, and port for the BT client application. Next, ONU_1 requests that the OLT provides information for every ONU in the same PON to allow ONU_1 to find a suitable peer. The OLT will respond to each request with a list of available ONUs that have the data/file, and ONU_1 then begins exchanging handshake messages with ONU_2 (which has the data/file). ONU_1 can communicate with several ONUs and download multiple segments of the data/file at the same time. Furthermore, OLT sends an interested message to indicate that it wants to download segments so ONU_2 will grant ONU_1 access by sending an unchoke message. During the remainder of the flow, ONU_1 must download as many segments as it can. When the requested segments are marked as BT traffic, this means that the segments are in the other ONUs or the other user indifferent subnets, but still in the same PON.

(3) *Proposed LADBA Scheme:* Figure 4 shows the signaling process by the proposed LADBA. After the OLT receives the REPORT messages, it calculates the bandwidth required according to each traffic type (EF, AF, BT, and BE). Next, the OLT sends a GATE

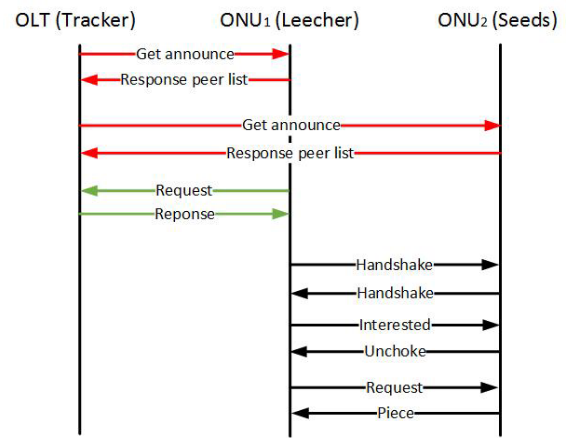


Figure 3. BT operation in the EPON

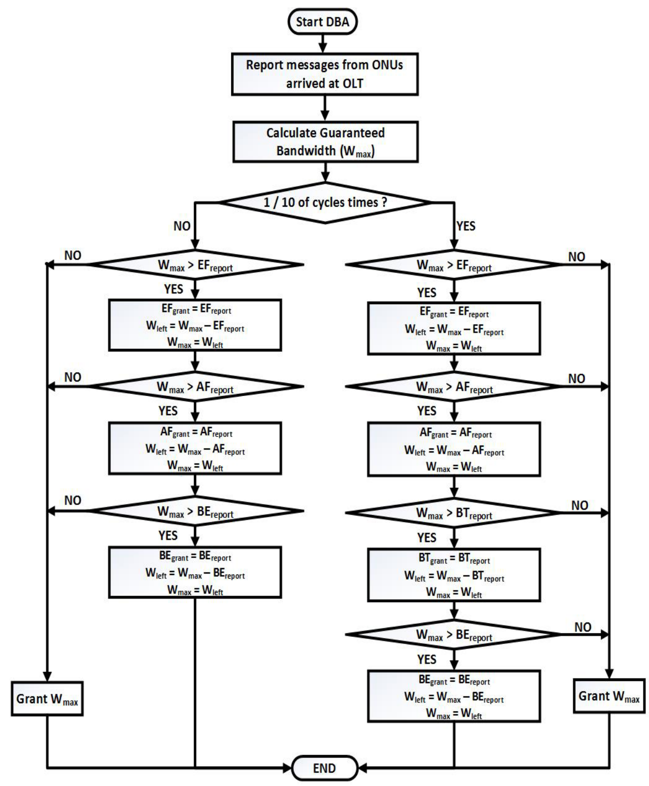


Figure 4. Proposed locality-aware dynamic bandwidth allocation (LA-DBA) scheme

message containing the grant start time, length, and wavelength for each traffic type. In our architecture, EF, AF, and BE are transmitted using wavelength λ_2. Furthermore, in order to transmit the BT traffic, OLT only sends a grant to transmit in wavelength λ_3 every 1/10th of the transmission cycles. Therefore, although the OLT receives BT reports from Queue #3, it will not send the grant for wavelength λ_3 unless the condition is satisfied. We delay the BT traffic because it covers a shorter distance compared with the inter-network traffic. In the OLT, the buffer manager component has four types of buffer with different LLIDs for control, where it uses the "first in, first out" method for downstream transmission, which is employed as a priority-aware queuing mechanism. Thus, the highest priority is always given to the EF packets, followed by AF, BT, and BE.

3 System Performance Evaluation

The proposed architecture was analyzed to evaluate the packet delay, system throughput, and probability of dropping packets. The system model was specified in the OPNET simulator with one OLT and 32 ONUs. The downstream and upstream channel rates were set at 1 Gbps between the OLT and ONUs. The distance from the OLT to ONUs was uniform in the range from 10 km to 20 km. The ONU buffer size was set to 10 Mb. The traffic models for AF and BE were self-similarity and long-range dependence, respectively. These models were utilized to generate highly bursty BE and AF traffic classes with a Hurst parameter of 0.7, and the packet sizes were uniformly distributed at between 64 and 1518 bytes. The high priority traffic used a Poisson distribution where the EF packet size was fixed to 70 bytes and the BT packet size was uniformly distributed at between 64 and 1518 bytes, with a Hurst parameter of 0.7. The simulation parameters are shown in Table 1.

Table 1. Simulation Parameters

Parameters	Value
Number of OLT	1
Number of ONUs	32
Up/down link capacity	1 Gbps
OLT-ONU distance (uniform)	10-20 km
Max cycle time	1 ms, 1.5 ms
Guard time	5 µs
DBA Computation	10 µs
Control message length	0.512 µs
ONU buffer size	10 Mb
AF and BE packet size (bytes)	Uniform (64, 1518)
EF packet size (bytes)	Constant (70)
VoIP packet size (bytes)	Uniform (64, 1518)

The simulation scenarios for our proposed architecture were as follows. The packet inter-arrival time for EF was fixed at 125 µs. The AF traffic was fixed at 15.6 Mbps (~50%) and the remainder was shared according to EF, BT, and BE. We selected six traffic profiles for the simulations, as follows. Scenario I: EF occupied 5%, BT occupied 10%, and BE occupied 35% (5%, 10%, and 35%). Scenario II: EF occupied 10%, BT occupied 10%, and BE occupied 30% (10%, 10%, and 30%). Scenario III: EF occupied 20%, BT occupied 10%, and BE occupied 20% (20%, 10%, and 20%). Scenario IV: EF occupied 5%, BT occupied 20%, and BE occupied 25% (5%, 20%, and 25%). Scenario V: EF occupied 10%, BT occupied 20%, and BE occupied 20% (10%, 20%, and 20%). Scenario VI: EF occupied 20%, BT occupied 20%, and BE occupied 10% (20%, 20%, and 10%). The simulation results were compared with those obtained using the original interleave polling with adaptive cycle time (IPACT) DBA [30]. We also compared different redirect ratios of 10% and 20% as the intra-network traffic in each scenario. The traffic scenarios are shown in Table 2.

Table 2. Traffic Scenarios

Traffic Profile	EF	AF	BT	BE
S1	5%	50%	10%	35%
S2	10%	50%	10%	30%
S3	20%	50%	10%	20%
S4	5%	50%	20%	35%
S5	10%	50%	20%	30%
S6	20%	50%	20%	20%

3.1 Mean Packet Delay

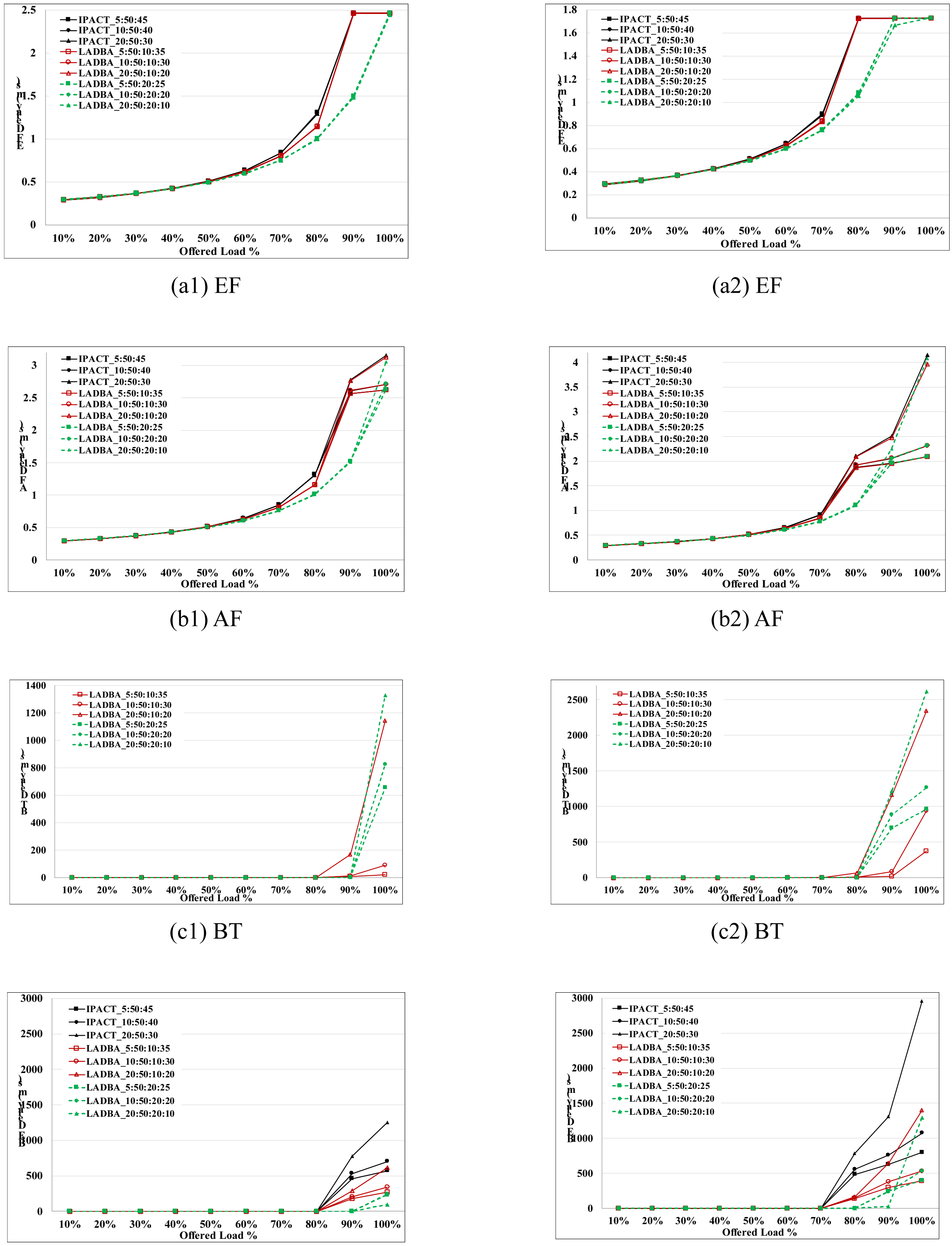
The packet delay refers to the time required for the packets to arrive randomly at the ONU after waiting for slots. Each packet must wait for time slots in order to be transmitted in the upstream direction and the waiting time is called the packet delay, which comprises the polling delay, granting delay, and queuing delay. We show two types of BT redirect ratios and three types of traffic profile scenarios in Figure 5. The packet delays with the BT redirect ratio for EF, AF, BT, and BE, as well as the overall packet delays were better than those using IPACT (BT redirect ratio for 0%). When the offered load was 60% to 90%, the scenario with the high ratio of BT and a BT redirect ratio of 20% obtained the greatest improvement in the packet delay for each packet. The values obtained were very low and they were acceptable in all cases.

3.2 Jitter

Jitter refers to variations in the packet transit delay caused by queuing, contention, and serialization effects on the path through a network. In general, higher levels of jitter are more likely to occur on slow or heavily congested links. Thus, if the jitter is excessively high, the packet will be set aside and delayed. Therefore, a human cannot hear a clear voice via a telephone. High jitter will produce audible gaps and if a number of sequential packets are idle, these packets will be dropped. Thus, less jitter is highly desirable. Figure 6 shows the jitter obtained in different environments and calculated as follows:

$$\sigma^2 = \sum_{k=1}^{N} \frac{(d_k^{EF} - \overline{D})^2}{N},$$

where σ^2 is the delay variance, d_k^{EF} is the delay time delay time for EF packet, k, $\overline{D}$ is the average delay time for EF traffic, and N is the total number of EF packets received. The EF traffic jitter results showed that there was less jitter with a large traffic load and



(a1) EF

(a2) EF

(b1) AF

(b2) AF

(c1) BT

(c2) BT

(d1) BE

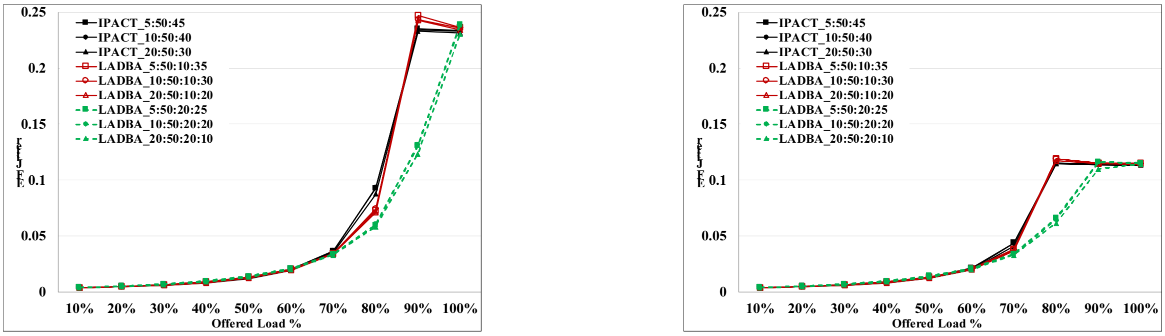
(d2) BE

Figure 5. Packet delays with EF (a1), AF (b1), BT (c1), and BE (d1) for 1.5 ms, and EF (a2), AF (b2), BT (c2), and BE (d2) for 1.0 ms

high BT redirect ratio. When the cycle time increased to 1.5 ms, the delay time was obviously higher than that with a cycle time of 1 ms. Thus, the locality-aware architecture can guarantee the audio quality for communication over the internet.

3.3 System Throughput and Packet Loss

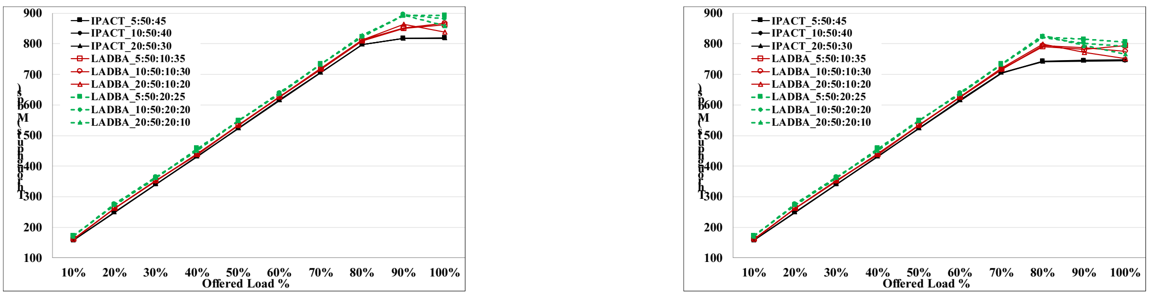
A system is said to be scalable when the performance improves after adding hardware in proportion to the capacity added. In this study, scalability refers to the



(a) (b)

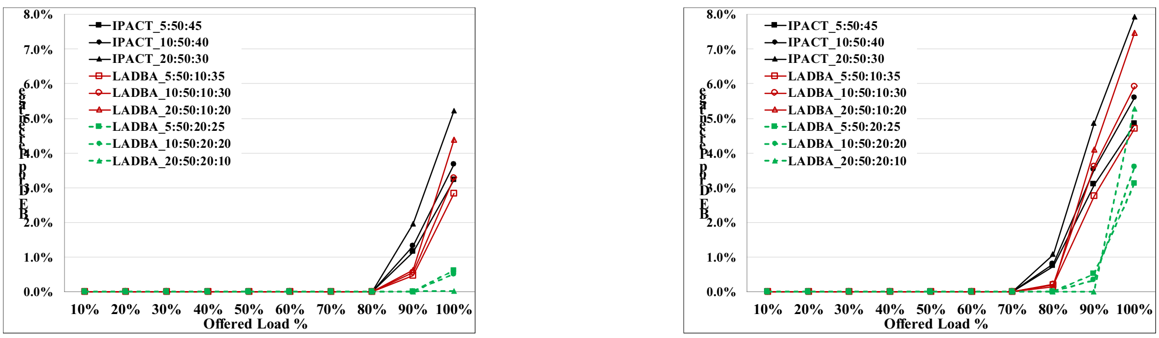
Figure 6. Jitter with cycle times of: (a) 1.5 ms and (b) 1.0 ms

capacity to increase the total throughput under an increased load when resources (typically hardware) are added. The system throughput in the proposed architecture is the sum of the traffic between the OLT and ONUs as well as between ONUs. Figure 7 shows the system throughput in different scenarios versus the offered loads and different cycle times. The results show that the system throughput using the proposed architecture with BT and redirect traffic performed better than the original IPACT traffic at a cycle time of 1 ms. When BT packets were included, the total system throughput was increased because of the use of a unique wavelength by the BT packets. When the cycle time was 1.5 ms, this was also the best option considering the throughput and BE packet loss. Employing a large bandwidth for BT and a high ratio for the BT redirect traffic obtained better performance and the BE packet loss improved, as shown in Figure 8. Clearly, the redirect number could be increased with a higher BT redirect traffic ratio. The BE packet loss was also less with a higher BT redirect traffic ratio and lower BT bandwidth because the lower priority traffic was dropped in order to satisfy the needs of high priority traffic. Therefore, we conclude that our proposed method is scalable because the overall system throughput improved with a higher network load. However, in scenario one, both schemes appeared to obtain almost equal performance in terms of the system throughput in the large network conditions.



(a) (b)

Figure 7. System throughput with cycle times of: (a) 1.5 ms and (b) 1.0 ms



(a) (b)

Figure 8. BE drop percentage with cycle times of: (a) 1.5 ms and (b) 1.0 ms

4 Conclusion

In recent years, there has been a major increase in the popularity of P2P applications on the Internet, which has imposed a great burden on the Internet backbone and increased costs for ISPs. In this paper, we proposed a new architecture based on the construction of PSR between OLT and colorless ONUs that we set a localization ratio for redirecting intra-network traffic in the colorless ONUs to improve the overall performance of PON to support P2P services. The proposed LADBA method can handle the BT packets and decrease the bandwidth required for BT services. An extra receiver is required in the ONU and excessive bandwidth usage might still occur, but our proposed architecture can maintain the traffic delay at below 5 ms. Furthermore, the transmission of BT can be dynamically adjusted based on the amount of BT traffic, and how to embed the BT traffic into upstream transmission wavelength to save the network resource will be for our future work.

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