Cooperative Dynamic Bandwidth Allocation Algorithm in Virtual Passive Optical Networks

By

Haris Mashood

Fall-2018-MS-CS 00000277139 SEECS

Supervisor

Dr. Arsalan Ahmed

Department of Computing

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Date: 01-Aug-2022

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Advisor : Dr. Arsalan Ahmad

Signature: ____________________

Date: **01-Aug-2022**

Committee Member 1:Dr. Syed Taha Ali

Signature: ____________________

Date: **01-Aug-2022**

Committee Member 2:Prof. Hasan Ali Khattak

Signature: ____________________

Date: **30-Jul-2022**

Committee Member 3:Dr. Salman Abdul Ghafoor

Signature: Salman

Date: **30-Jul-2022**

Dedication

This thesis is dedicated to all those kids who do not have access to quality education and never get the chance to improve their quality of life.

Certificate of Originality

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Abbreviations List

APON	Asynchronous Transfer Mode Passive Optical Network
ATM	Asynchronous Transfer Mode
BBU	Base Band Unit
BF	Bursty Factor
BMap	Bandwidth Map
BPON	Broadband passive optical network
BB	Base Station
CAPEX	Capital Expenditure
DBA	Dynamic Bandwidth Allocation
DBARu	Dynamic Bandwidth Report upstream
DSL	Digital Subscriber Line
EBU	Efficient Bandwidth Utilisation DBA
EFM	Ethernet in the First Mile
EPON	Ethernet passive optical network
FEC	Forward Error Control
FSAN	Full Services Access Network
FTH	Fiber To The Home
GIANT	GigaPON Access Network DBA
GPON	Gigabit Passive Optical Network
IBR	Inconsistent Bandwidth Reporting
ITU	International Telecommunication Union
ITU-T	Telecommunication Standardization Unit of Intentional Telecommunication Union
LTE	Long Term Evolution
MAC	Medium Access Control
MAN	Metropolitan Area Network
ODN	Optical Distribution Network
OLT	Optical Line Terminal
OMCI	Optical network terminal Management and Control Interface
ONT	Optical Network Termination
ONU	Optical Network Unit
OPEX	Operational Expenditure
PMD	Physical Medium Dependent
PHY	Physical

PON	Passive Optical Network
PPBP	Poisson Pareto Burst Process
PSB	Physical Synchronization Block
P2MP	Point-to-Multipoint
P2P	Point-to-Point
QoS	Quality of Service
RR	Round Robin
RSB	Remaining Surplus Bandwidth
RTT	Round Trip Time
RRH	Remote Radio Head
SDU	Service Data Units
SI	Service Interval timer
SLA	Service Level Agreement
TCONT	Transmission Container
TDMA	Time Division Multiple Access
vDBA	Virtual Dynamic Bandwidth Allocation
VNO	Virtual Network Operators
vPON	Virtual Passive Optical Network
WAN	Wide Area Network
WDM	Wavelength Division Multiplex
XGEM	XG-PON Encapsulation Method
XGIANT-D	Deficit XGIANT DBA
XGIANT-P	Proportional XGIANT DBA
XG-PON	Next-Generation Passive Optical Network
XGTC	Next-Generation Passive Optical Network Transmission Convergence

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Abstract

TDM-PON technologies are an attractive solution for a flexible and cost-efficient mobile front haul for C-RAN architecture. This is because these technologies allow for TDM over passive optical networks. However, because TDM-PONs employ a process known as dynamic bandwidth allocation (DBA) to control upstream traffic, it might be difficult for these networks to satisfy the stringent delay requirements that C-RAN imposes on mobile front-haul. On the other hand, ITU TDM-PONs like XG-PON and XGS-PON have not even been investigated for their potential use in mobile front-haul, especially in a virtualized network environment.

Since sharing the PON infrastructure between different network operators and allowing a virtual passive optical network is necessary to save CapEx and efficiently use available resources. Because of this virtualization, separate VNOs can establish individualized frame-level allocations across common PON infrastructure. Granting them the ability to have complete control over the scheduling of their upstream traffic. At the OLT, which shares the upstream capacity of the PON, we implement the coexistence of independent and customized DBA algorithms. A variety of DBA algorithms are tested to investigate the influence the VNOs' choice of DBA has on the quality of the services they provide. Suggesting that the choice of DBA made by the operator affects the performance of the service, namely in terms of packet loss and latency which as mentioned above are stringent requirements of C-RAN architecture.

Keywords: *Passive Optical Networks, Dynamic Bandwidth Allocation, Optical Line Terminal, Optical Line Unit, XG-PON, C-RAN*

Chapter 1

Introduction

The cloud radio access network, also known as C-RAN, is one of the fundamental technologies for the next generation of mobile networks, known as 5G. This technology helps to simplify network administration and makes it possible to coordinate and pool mobile network radio resources. In a C-RAN design, the digital baseband processing units (BBUs) are relocated from mobile base station sites to a central location known as the BBU pool, which feeds a set of dispersed radio units known as remote radio heads (RRHs) [1], this central location is known as the BBU pool. In most cases, RRHs are linked to the BBU pool using a high-speed and low-latency digitized radio-over-fiber link that is referred to as front-haul [2] [for example, the Common Public Radio Interface (CPRI)]. It is necessary to have many high-capacity fiber-based front-haul connections to connect RRHs in numerous locations to the BBU pool. This contributes to an increase in the cost of deploying C-RAN. A functional split of mobile baseband processing [3] offers a solution to the problem of high costs associated with fiber-based front-haul. This solution reduces the capacity required for front-haul, which enables the utilization of low-cost and shared front-haul transport technologies such as switched Ethernet [2], [4], OTN architecture [5], and time division multiplexing passive optical networks (TDM-PONs] [6]. In this research, we concentrate on TDM-PONs because the implementation of the other two technologies in the access network may require a significant amount of time before it is possible.

Copper infrastructure has been swamped by restrictions of bandwidth and reachability, but PON is an at tractive, inventive FTTH-based solution that provides high data rate, greater reach, low power consumption, and reduced operating cost, all of which have enormous potential advantages in the future. Even though fiber is very affordable, the subterranean installation is somewhat pricey due to its location. PONs, or passive optical networks, have been gaining popularity as a potential access technology for several years. The initial Guideline G.983.1 from the International Telecommunication Union (ITU) featured (at the time) popular ATM modern technologies and corresponding ATM-based PONs. Passive optical networks (PONs) have been growing in popularity as a potential access technology. Fiber optics is the most promising candidate for meeting any potential data traffic requirements that may arise in the future [7]. PONs are analogous to FTTH in that they are made up of active components such as optical fiber, connectors, and power splitters, in addition to certain passive components such as OLT and ONUs.

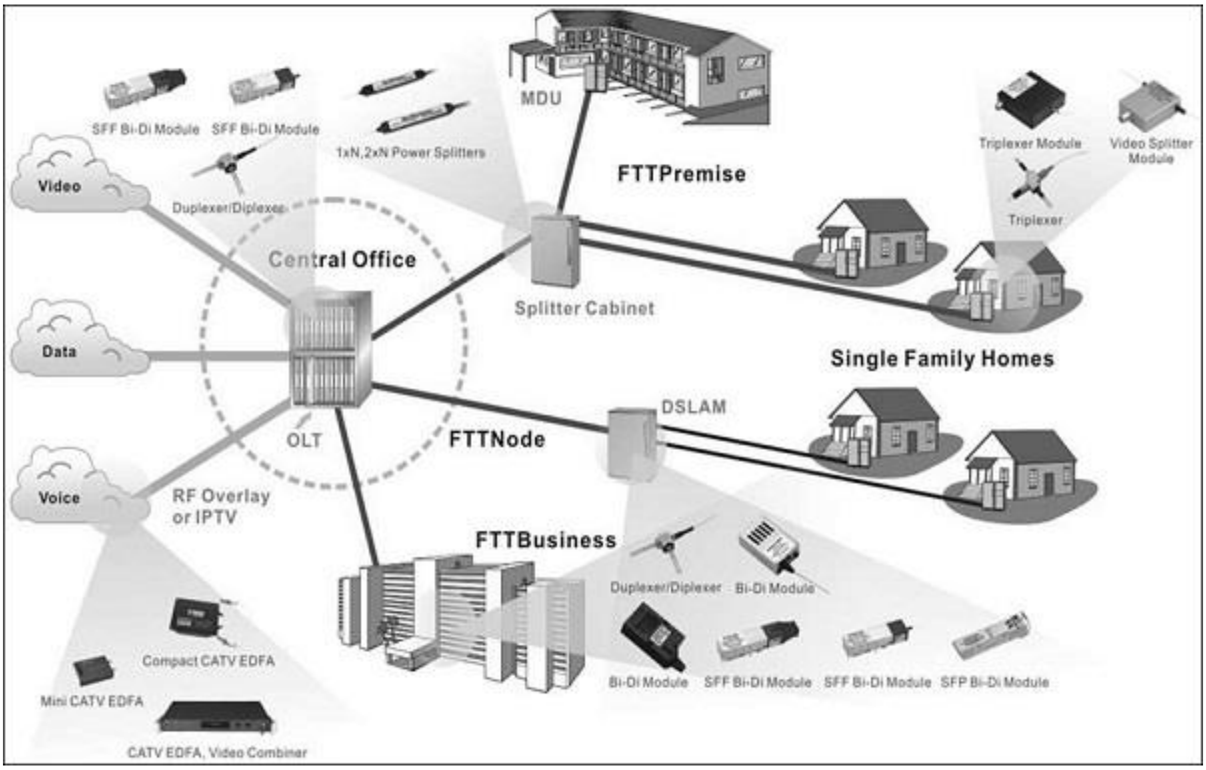
Generally, in optical networks, there are four different components:

1. Core: Network connecting cities

2. Metropolitan: Connection within cities
3. Access: PONs for access network to FTTH
4. Edge: End user, or the connection to different houses

Access networks are sometimes referred to as the "final mile" or "first mile" in popular parlance. Physically connecting the end unit to the immediate router is the responsibility of access networks [8]. Access networks include things like Internet service providers (ISPs), residential networks, corporate clients' networks, ADSL, wireless networks, and FTTH. In access networks, users from residential regions as well as business markets are connected to the central office of the service provider, which then links them to either a MAN or WAN [9]. There are many different kinds of access networks, such as Ethernet, which is a wired LAN technology that makes use of coaxial cables; Digital Subscriber Line (DSL), in which the telephone line brings the connection to homes; Fiber-to-the-Home (FTTH), which brings fiber directly from the central office to the homes; Wireless LANs; 3G and LTE, which offer high-speed wireless communication for mobile devices; and so on.

Since the beginning of optical communications, fiber-to-the-home (FTTH) has been regarded as the optimal strategy for access networks. This is due to the enormous power that optical fibers provide, as well as their small size, low weight, and resistance to electromagnetic interference [10]. If fiber-to-the-home (FTTH) technology is used in access networks, an all-optical network revolution will ensue (last mile). Since fiber optics are employed across backbone networks, they are also used in Wide Area Networks (WANs), Metropolitan Area Networks (MANs), and Local Area Networks (LANs) (LANs). The fiber-to-the-home (FTTH) internet connection will spur the creation of technologies that have not yet been dreamed of since it will bring about novel potential for the speeds at which data may be sent. Consumers will be able to consolidate all their communication needs thanks to the availability of FTTH internet connections. For example, a consumer can use a broadband FTTH connection using the phone, television, video, and audio streams, as well as virtually any other digital data stream. Figure 1.1 shows a detailed representation of the fiber-to-the-home (FTTH) architectural concept. Such a system would be superior in terms of both cost efficiency and quality to the current practice of providing internet access through many individual lines.



Source: https://www.tutorialspoint.com/ftth/ftth_quick_guide.htm

Figure 1: Architecture of FTTH

More than ten million homes across the world already have access to high-speed Internet via fiber optic cables because of the many advantages that this technology offers over the alternatives now available:

- Easy installation
- Less OPEX cost
- Greater carrying capacity
- Resistant to electromagnetic interference

With these advantages, there are also some disadvantages associated with internet through fiber optics:

- Huge installation cost
- Cannot carry electric power like copper
- Delicate cables, prone to damage
- Increased delay time through bandwidth

1.1 Thesis Structure

The rest of the thesis is organized as follows:

- Chapter 2 provides the history, introduction, and subsequent relevant work that has been done in the literature about Passive Optical Networks, in addition to the various DBA methods.

- Chapter 3 the specifics of virtual Passive Optical Networks as well as the Merging Engine are presented here.
- Chapter 4 provides an analysis of the specifics of the XG-PON simulation module for the sophisticated new version of the NS-3 network simulator.
- Chapter 5 demonstrates how well the several DBAs are doing even though they are all operating at the same time.
- Chapter 6 provides a summary as a conclusion to the thesis and highlights potential topics of investigation for the subsequent work.

Chapter 2

Literature Review

2.1 Introduction and Motivation for PON

Passive access networks were the first to refer to the utilization of optical fibe[11]. Copper was switched out for silica fiber as the transmission medium, and active devices were developed to convert optical signals to electrical ones. This idea is commonly referred to as an Optical Distribution Network (ODN). An OLT is a service provider that is located at the head office. It is a component of the ODN, which is an optical splitter, and its job is to gather and separate optical signals and various ONUs, which are user equipment for the fiber-to-the-home (FTTH) network (access networks). Figure 2 shows the ODN architecture.

Because the present period calls for quick internet surfing and the downloading of substantial gaming files, the business that serves network operators is being forced to update both its services and their networks in order to meet the growing demand of their clients. The price tag is by far the most significant obstacle. Therefore, the technology of passive optical networks, also known as PON, is the most efficient way to provide broadband services at an affordable price. The notion of dividing the Base Station (BS) into two parts, known as the RRH and the BBU, was first considered for use in 3G mobile network architectures. In contrast to the BBU, which housed all of the baseband processing activities, the RRH was situated in the cell site in a location that was closer to the antenna. Its sole purpose was to do radio-related tasks.

The choice to purchase the asset representing the capital expenditure is the most significant decision that every organization must make. The price of the equipment [12] that is involved and the income that is generated both have a role in the decision of whether the service providers will invest money or upgrade their services. The objective is to get as much money as possible from the subscribers while keeping the costs of deployment to a minimum. As a result, internet service providers act quickly to make the most important choice, which is to acquire the necessary network equipment while striking a balance between reducing the amount of money spent on the equipment and increasing the available bandwidth [13]. The initial cost of deploying PON infrastructure is a significant amount of money, which is referred to as capital expenditure (CAPEX). Following the implementation, PON will further require monitoring. The cost of the PON monitoring equipment is the primary concern, and this covers both the initial investment and the ongoing operational costs (OPEX, the cost of system maintenance). Due to the fact that the consumers do not share the components, the PON market is extremely price sensitive. However, the PON technology is still regarded as being beneficial to the economy since, once it has been implemented, the costs associated with its maintenance and operation are significantly reduced. This infrastructure, which illustrates how PON technology may either be P2P or P2MP, is depicted in Fig.3.

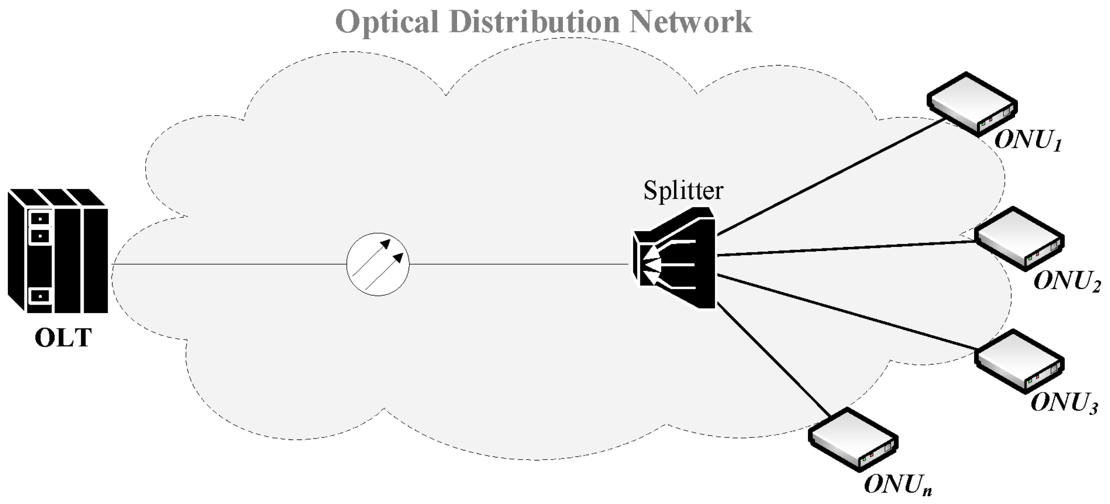


Figure 2: ODN Architecture [14]

2.2 History of PON

That the very first Suggestion G.983.1 released by the International Telecommunication Union (ITU) in 1998 incorporated (then) significant asynchronous transfer mode (ATM) technology and relevant ATM-based PONs. PONs are not just used for gaining access; they also cover metropolitan distances, and they can handle gigabit data speeds. PONs are not just used for gaining access; they also cover metropolitan distances, and they can handle gigabit data speeds.

PON is utilized by telecommunications providers in order to deliver triple-play services to their customers. The initial standard, which was known as the APON/BPON standard and spanned 155 Mbps, was based on ATM technology. The EPON standard, which is based on Ethernet, was initially established by the IEEE in the year 2001. The FSAN group started working on a gigabit speed standard in 2001 [14]. This standard, which would eventually be accepted by the ITU-T, was given the name GPON.

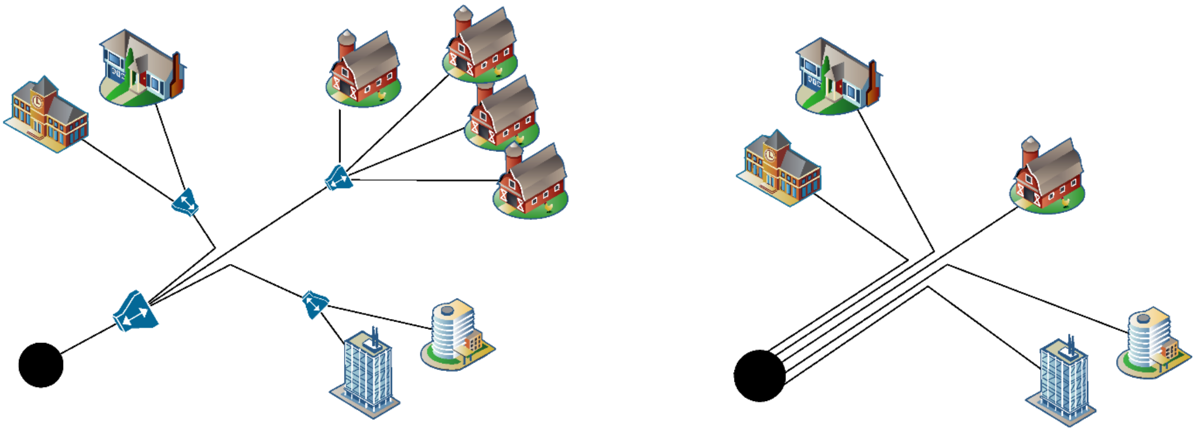


Figure 3: P2P and P2MP infrastructure of PON[14]

2.2.1 APON

In 1995, operators in the field of telecommunications came up with the idea for the FSAN . The ITU-T Recommendations G.983 series was developed to break through the economic barrier that was generated as a result of the introduction of large-scale broadband access networks. Two different technologies, namely ATM and PON, were utilized to accomplish this goal.

The ATM standard was the very first PON benchmark that was established by the ITU. It ensures that different audio, video, and network services may coexist on the same network while maintaining the quality of service that was promised (QoS). A way of switching and transmitting data is referred to as an ATM-PON, which stands for asynchronous transfer mode passive optical network. The conventional ATM-based network converts many streams of incoming data from end users into a single stream of data by using multiplexing. Because multiplexers are active components that use a significant amount of power, the deployment of these devices can contribute to the high cost of fiber.

The Passive Optical Network (PON) provides a solution to this issue since it uses passive optical splitters and couplers in place of active parts. The PON-based FTTH system design is depicted in Figure 4. At this architecture, a PON connects several optical network terminations (ONTs) at the customer end to an optical subscriber unit (OSU) at the optical line terminal (OLT) in the Central Office (CO) [10]. Over ATM networks, high transmission speeds of up to 2.4 gigabits per second (1.5 megabits per second) are possible [14].

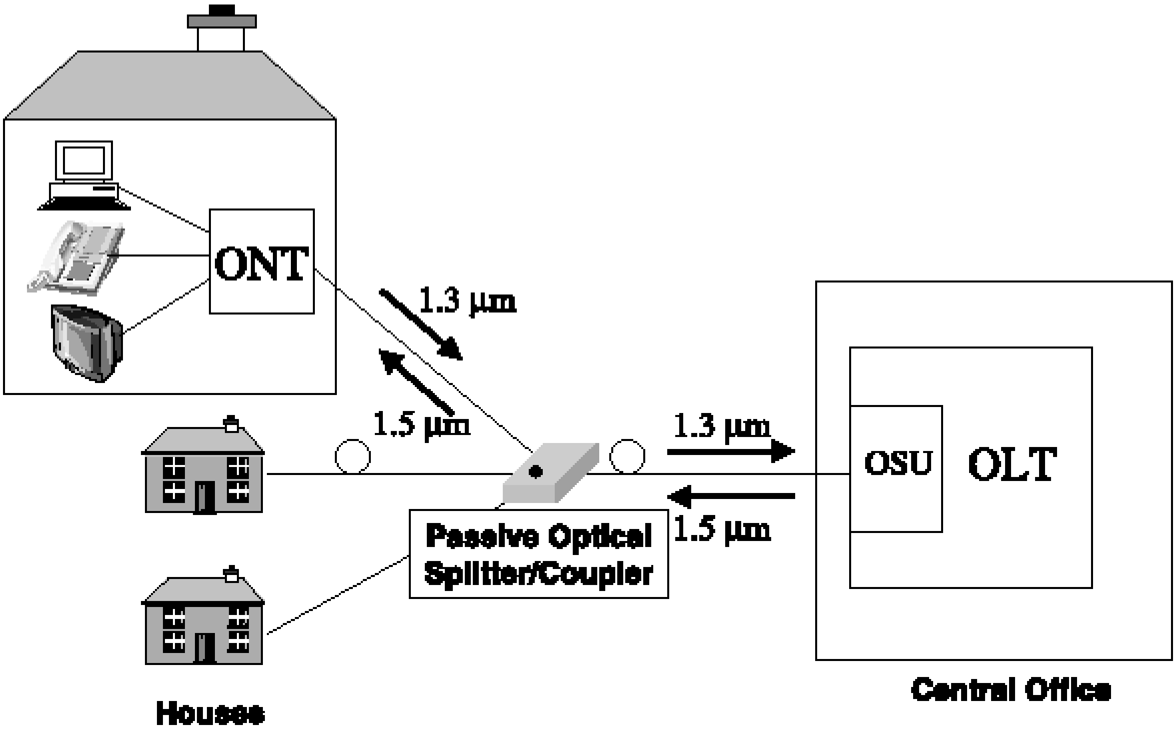


Figure 4: FTTH System Architecture based on PON [10]

2.2.2 BPON

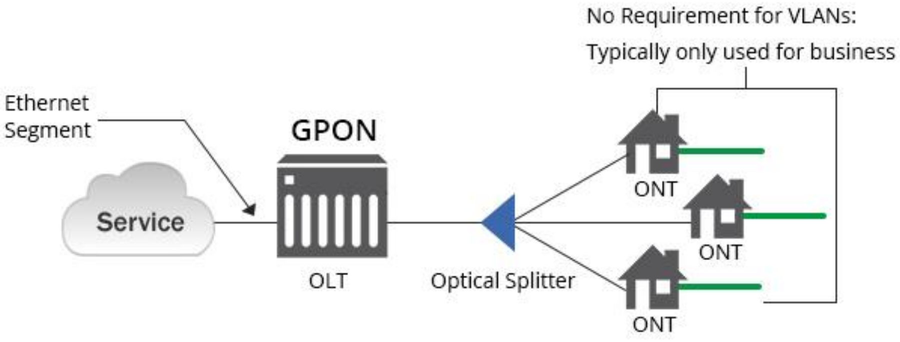
Recommendation G.983.3 provides the definition for "Broadband PON," sometimes known as "BPON." Broadband PON is the name given to the second standard of PON that was established by the ITU. Both the APON standard and the BPON standard have the same transfer data speeds and are backward compatible with one another. Wavelength Division Multiplex was first implemented because to this specification (WDM) [15]. WDM is a type of hybrid multiplex that makes use of a variety of wavelengths for the purpose of transmission in an optical fiber [14]. Different optical signals are represented by wavelengths of varying lengths. The capacity of an optical fiber is increased because to the fact that in this configuration numerous channels are linked to a single optical fiber. In 1999, the American telecommunications operator BellSouth conducted the initial tests of BPON.

2.2.3 GPON

G.984. The ever-increasing needs for bandwidth are the driving force behind the development of new standards for passive optical networks. The fact that there is no opportunity for broadcasting in this is the most significant limitation it has. GPON is capable of transmitting over a wide bandwidth. It has the capacity to provide service coverage up to 20 kilometers.

When it comes to encapsulating a wide variety of data types [16], the GPON standard relies on the GEM encapsulation method. All of the end users or units are given the frames to work with. Each frame had a distinct identification, which served to ensure that the end units would only take the specific frames that were intended for them. The downstream frames are made up of something called a physical control block downstream, or PCBd for short. Within this block is a section that is set aside specifically for ATM cells and GEM. In the upstream route, the TDMA approach is utilized, and the OLT gives varied time intervals to the ONUs that it is communicating with.

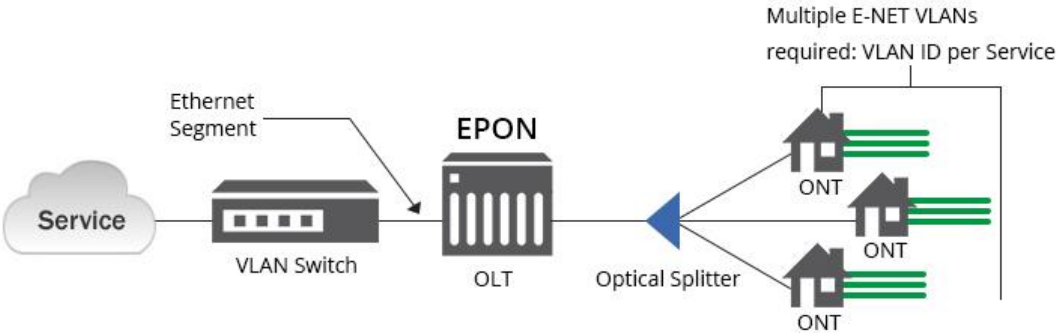
Forward Error Control, often known as FEC, is utilized in order to locate and correct any errors that may have occurred during the transmission. Transmission Containers, also known as TCONTs, are put to use as service carriers in order to make Quality of Service (QoS) possible in the upstream direction. The use of the available bandwidth is increased as a result of these TCONTs. The information that is provided in the TCONT is a representation of the bandwidth demand that is necessary for each TCONT of an ONU. TCONTs are where the information on the quantity of data units is stored. GPON employs optical wavelength division multiplexing, which allows a single fiber to be utilized for transmission in both the upstream and the downstream directions (WDM). In countries such as France, Germany, and others, GPON has been the subject of a variety of experiments.



Source: https://community.fs.com/blog/comparison-of-epon-and-gpon.html

Figure 5: QoS Architecture for GPON

GPON OLT can serve several ONTs using PON. Typically, TDMA is used for the upstream transmission, which occurs from the ONT to the OLT, whereas TDM is used for the downstream transmission, which occurs from the OLT to the ONTs.



Source: https://community.fs.com/blog/comparison-of-epon-and-gpon.html

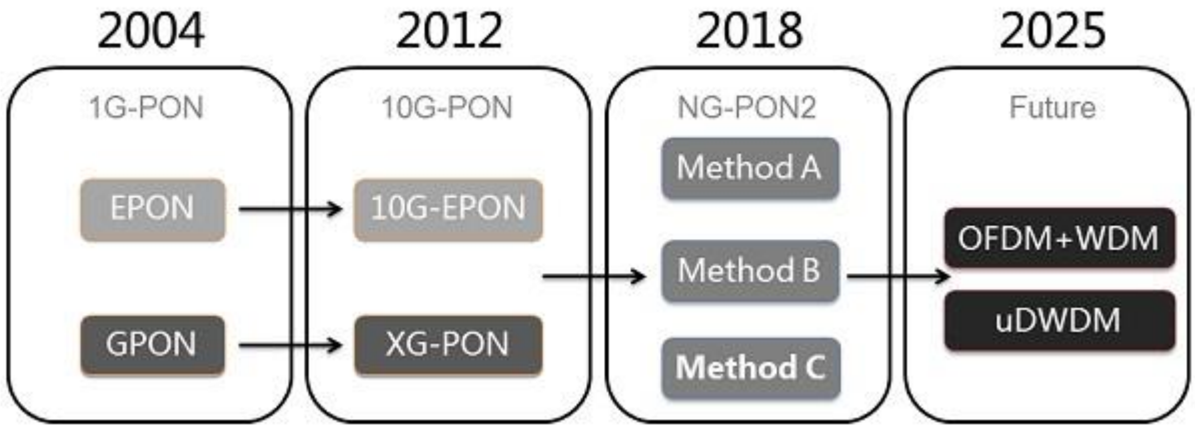
Figure 6: QoS Architecture for EPON

2.2.4 EPON

Connectivity to computer networks can be established via existing telecommunications infrastructure using Ethernet PON. EPON provides internet access, voice over internet protocol (VoIP), and digital TV services to metropolitan areas through the use of fiber optic cables, Ethernet packets (instead of ATM cells), and a single protocol that operates on a single Layer 2 network. It is a network that covers shorter distances. Because EPON's installation is so simple and straightforward, utilizing it does not need a significant financial investment. Standard EPON can support data transfer rates of up to 1.25 Gbps, while the more modern 10G-EPON technology can handle data transfer rates of up to 10 Gbps [17].

The idea of EPON was first presented by EFM, and it was founded on the P2P and P2MP protocols. Ethernet P2P is the most cost-effective option and provides the highest bandwidth, whereas Ethernet P2MP provides a relatively low cost for a comparatively high bandwidth. The Ethernet transport was later expanded to include metro and access networks according to the IEEE 802.3ah EFM standard. Broadband Ethernet services, which are both versatile and cost effective, are made available in the metro as well as the access networks. In order to deliver the best possible quality of service and satisfy the requirements of the apps of the future, several strategies for allocating bandwidth are utilized.

GPON has superior performance when compared to EPON; but, because EPON requires less time and money to deploy, it has become the more popular option. The customer's needs for multi-service, excellent Quality of Service, and security are well met by GPON. Figure 7 shows the evolution of XG-PON.



Source: https://www.tutorialspoint.com/ftth/ftth_xpon_evaluation.htm

Figure 7: Evolution of PON

2.2.5 PON

PON, which stands for "Passive Optical Network," is a point-to-multipoint (P2MP) network that is based on fiber and links end users to fiber (FTTH). PON offers end users access to networks that are fast and have a large capacity, but this comes at the cost of a hefty initial investment in capital. As a result of a rise in the amount of data traffic, operators often build more fiber, which results in an increase in their operational costs. Active and passive components make up its assortment of hardware. Active elements include an Optical Line Terminal (OLT), which is a service provider located at the central office, and Optical Network Units (ONUs), which are located at the customer or user end of the network. Active elements are also known as active components.

The passive elements include a splitter/jointer, which is employed for the purpose of collecting and dividing optical signals. PON does not need the use of any electronic equipment, which results in reduced costs for both operations and initial investment. Unlike copper, optical fiber may deliver a larger bandwidth over a greater distance than can be achieved with copper. Copper infrastructure restricts both the bandwidth available and the packets' ability to reach their destination. There are two approaches that might be taken to circumvent the constraints that are imposed by copper infrastructure. The first alternative is to establish a network that provides fiber optic cable directly to individual homes (also known as FTTH), however doing so creates financial instability. Since the cost of the fiber itself is inexpensive, but the cost of installing it underground is quite high, this technique helps to alleviate the economic burden associated with putting optical fiber in access networks. PON, or passive optical network, is an additional approach that involves the sharing of fiber as well as all of the other equipment.

PONs, which make use of optical fiber, are able to provide high-speed broadband connections for the final mile of a telecommunications network. Due to the fact that all of the ONUs will be required to share the US bandwidth, the performance of a TDMA PONs is heavily reliant on a DBA device.

An efficient DBA device is one that cuts down on the amount of idle time spent on both the channel and the frame. A DBA is necessary in PONs that employ the time division multiple access (TDMA) protocol in order to make effective use of the usable bandwidth of the upstream link. There are two different ways in which the upstream efficiency of a traffic class of an ONU may be improved by using an efficient DBA system. First, if it makes active use of the available bandwidth, the amount of bandwidth that is assigned to it will rise. Second, the channel size may be decreased by raising the polling frequency, giving greater unused bandwidth that is not being used by other ONUs, and increasing the amount of frame idle time available. Many different DBA systems have been filed for both the ITU PONs (GPON and XG-PON) and the IEEE PONs (EPON and 10 G EPON).

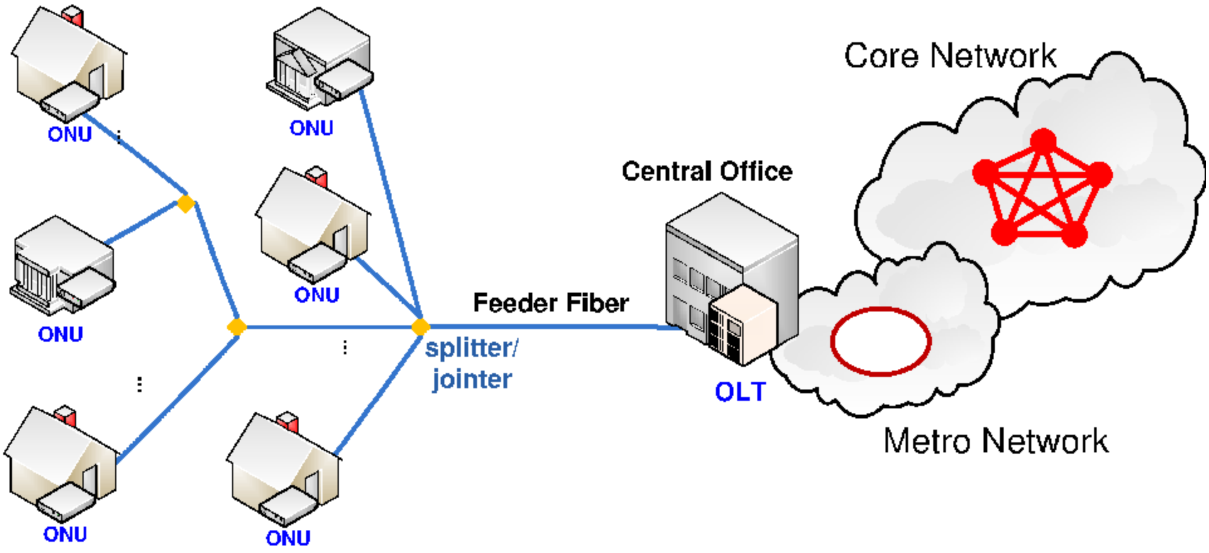


Figure 8: PON Architecture [18]

2.3 Working of PON

Time Division Multiple Access, abbreviated as TDMA, is the protocol that is utilized in the process of broadcasting downstream traffic from the OLT to all ONUs. In order to avoid eavesdropping of any kind, the data are encrypted before transmission. The traffic going from the ONU to the OLT is downstream, whereas the traffic going from the OLT to the ONU is considered to be upstream. The ONUs needs to have a scheduling system that is properly coordinated with one another to prevent the collision of packets with one another. This will allow them to deliver efficient communication in the upstream direction that is not disrupted by collisions. The name of this method of scheduling is known as the Dynamic Bandwidth Allocation (DBA) Algorithm. The DBA is responsible for managing the upstream bandwidth. Polling-based scheduling is the foundation upon which DBA conducts its operations between ONUs and the OLT. Sending a frame in the upstream direction allows ONUs to provide the OLT with information on the buffer occupancy of their respective buffers. This frame is sent once every 125 seconds. OLT will execute the DBA algorithm in order to award allocation to each ONU. This will be done based on the bandwidth occupancy data. Bandwidth is distributed to the ONUs in the form of a Bandwidth Map. The amount of bandwidth distributed is determined by the amount of bandwidth that is demanded as well as the Service Level Agreement (SLA) (BMap). This BMap is transmitted by the OLT in the downstream frame to all of the ONUs. After then, the ONUs will begin the process of transmitting their data in accordance with the timetable and the bandwidth allotment.

2.4 PON Topologies

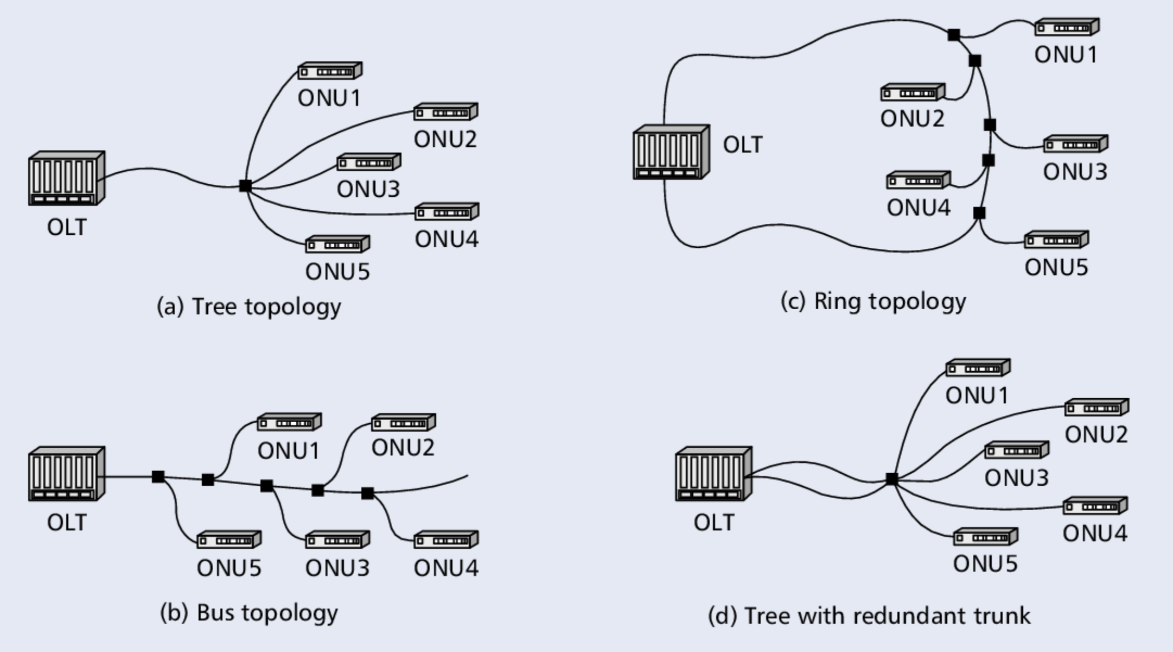


Figure 9: PON Topologies [17]

2.5 Advantages of Passive Optical Networks

- PON makes it possible to have a greater reach between central offices and consumer sites, with lengths of up to 20 kilometers being possible in some cases.
- PON reduces the amount of fiber that has to be deployed at the local exchange office as well as the local loop.
- PON can provide better bandwidth and solutions in the gigabit per second range since it has deeper fiber penetration.
- PON enables video transmission in either IP video or analogue video formats by making use of a separate wavelength overlay, which serves in the downstream as a broad cast network.
- PON does away with the need for active multiplexers at splitting sites, relieving network operators of the burdensome task of maintaining and providing power to active curb-side equipment. PONs replace the active devices that would normally be found in splice trays with smaller passive optical splitters, and then deploy these splitters as an integral part of the production process for optical fiber cables.
- PON is capable of being upgraded to greater data rates or additional wavelengths, making it an optically transparent technology from beginning to finish.

2.6 XG-PON by ITU-T

One of the most recent developments in optical access network standards is the Passive Optical Network, which is capable of transmitting data at 10 gigabits per second (XG-PON). The XG-PON protocol has been carefully standardized in order to deliver comprehensive services to a diverse group of customers across a single optical network.

The XG-PON also offers a Quality-of-Service mechanism, much like the GPON does. For XG-PON, the FSAN working group of the ITU-T has offered several proposals. The following discussion will go over some specifics of the ITU-T standard G.987.x (XG-PON); ITU-T G.987.1 introduces the concurrence of XG-PON with GPON, migration of network, protocol stack, services that are supported and hardware restrictions; ITU-T G.987.2 presents the problems of the Physical Medium Dependent (PMD) layer, such as the wavelength being used and the data rates that are supported; ITU-T G.987.3 focuses on the Transmission Convergence (XGTC) layer; and ITU-T G.987.3 focuses on the It also includes the quality of service and the dynamic bandwidth allocation strategy for the upstream sharing mechanism. There is still another proposal for GPON and XG-PON called ITU-T G.988. This one covers the control interface OMCI as well as ONU administration. Figure 11 shows XG-PON standards along with its specifications.

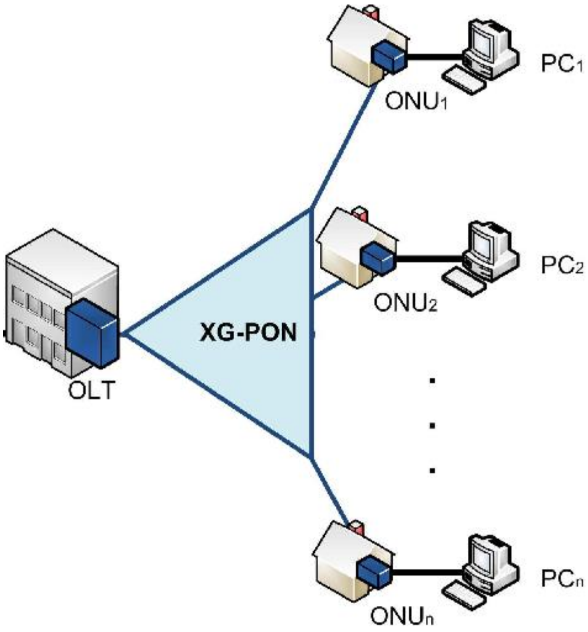


Figure 10: XPON's Network Topology [18]

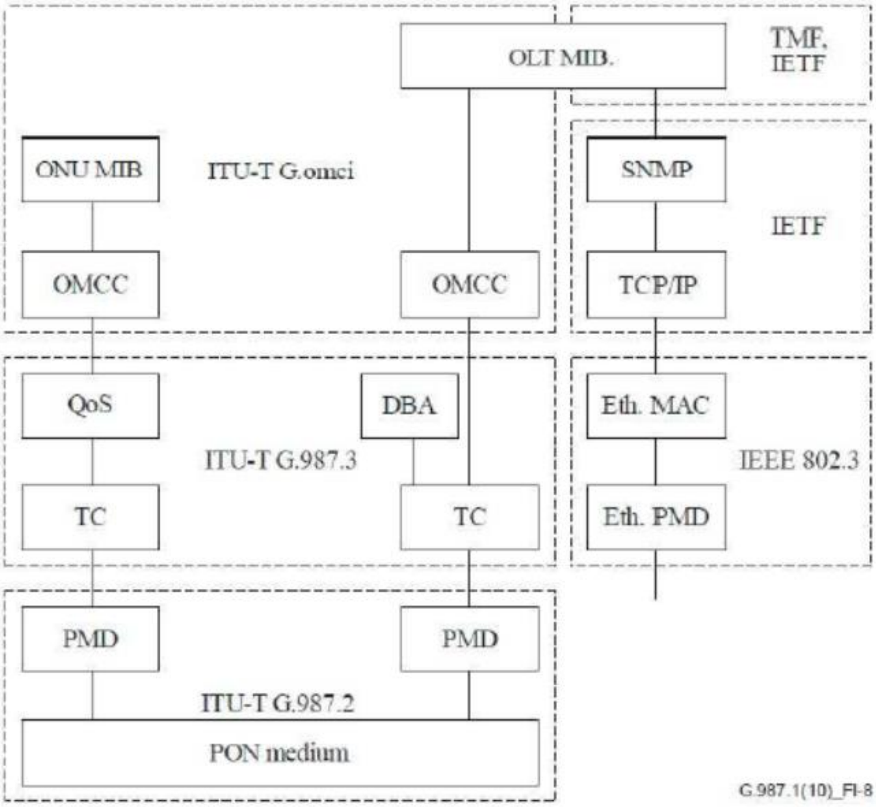


Figure 11: XG-PON Standards Specification

2.6.1 Physical Medium Dependent (PMD) Layer

The PMD layer is the XG-PON standard's designation for the physical layer. The upstream line rate determines which of the two flavors of XG-PON are available: XG-PON1, which has a road with a capacity of 2.5 Gbps, and XG-PON2, which has a path with a capacity of 10 Gbps. Both XG-PON-1 and XG-PON-2 have a downstream line rate of 10 gigabits per second (Gbps). ITU-T G.987.2 has standardized XG-PON1 as Symmetric XG-PON or XGS-PON, whereas ITU-T G.987.2 has standardized XG-PON2 as Symmetric XG-PON or XGS-PON. XG-PON1 is referred to as XGS-PON.

2.6.2 Transmission Convergence (XGTC) Layer

The XG-PON media access control (MAC) protocol is included in the XG-PON transmission convergence layer (XGTC). This layer oversees maintaining the link between the OLT and each ONU to transport the traffic that flows upstream and downstream between the nodes in the network. There is the potential for many connections to exist between the OLT and the ONUs; the name given to each of these connections is the XG-PON Encapsulation Method (XGEM) Port-Id. There is only one connection that may be used to carry either upstream or downstream traffic at any given time. Transmission Containers (TCONT) are groups of connections that belong to the same ONU. These groups of connections are recognized by an identifier that is called Alloc-Id. Transmission Containers can exist. There are three sublayers that make up the XGTC layer. These are the Service Adaptation sublayer, the Framing sublayer, and the Physical Adaptation sublayer.

2.6.3 Service Adaptation Sublayer

This layer is responsible for adapting the traffic coming from higher layers by mapping it to the proper connections, encapsulating and decapsulating data, segmenting and reassembling payloads or service data units (SDU), and inserting padding so that the XGTC frame is filled. Additionally, this sublayer has the capability to encrypt or decode SDUs. This sublayer makes the determination of which connections are required to service based on the QoS characteristics of those connections while the higher layer is being sent. A new XGEM frame is generated by this sublayer, which does so by retrieving data from the queue and appending an XGEM header to it. The XGEM header is made up of the XGEM Port-Id as well as a few additional pieces of information relevant to segmentation and other topics. The service adaption sublayer will retrieve the XGEM Port-Id from the header of the XGEM frame when it is received, and it will then check to see if the connections created corresponding to the XGEM Port-Id are the same as the connections made by OLT and ONU. If this is the case, the data will be sent to the higher levels via this sublayer; however, if it is not the case, this XGEM frame will be discarded.

2.6.4 Framing Sublayer

This sublayer is responsible for regularly generating and parsing any XGTC frames or bursts. Following each 125OLT broadcast of the downstream frame, all ONUs in an XG-PON are sent the frame. And last, for the traffic going upstream, the ONU will transmit a variable-length XGTC frame to the OLT. It is necessary to connect together XGEM frames, payloads from the service adaption layer, and XGTC payloads in order to generate a single downstream XGTC frame. And in order to generate an upstream burst at the ONU side, the framing sublayer creates numerous XGTX payloads. Each payload carries XGEM frames from a single TCONT, and the upstream burst is then generated. After the XGTC frame has been parsed, the payload is then sent on to the service adaption sublayer to be processed.

The queue occupancy reports of the TCONTs that belong to that ONU are included in the header of an upstream XGTC frame. whereas, in the downstream frame, the header consists of a BMap that defines the time to start transmission as well as bandwidth allocations for the TCONTs and the burst profile. Each ONU ought to adjust the timing at which it begins its transmission in order to prevent collisions in the upstream direction. An ONU is only allowed to send one PLOAM (Physical Layer Operations, Administration, and Maintenance) message to the OLT in the header of an upstream XGTC burst. On the other hand, the OLT is allowed to send numerous PLOAM messages to the ONUs in the downstream frame.

2.6.5 Physical Adaptation Sublayer

Forward error correction (FEC), also known as forward error masking, scrambling, and frame demarcation through a physical synchronization block are the primary responsibilities of the physical adaption sublayer (PSB). This sublayer has a one-on-one interaction with the PMD layer. In the downstream, the XGTC frame is used as the basis for the creation of a PHY frame by the physical adaptation sublayer. These actual frames are sent at a rate of 125 times per second. Since XGTC bursts have a duration that can vary, PHY bursts also have a length that can vary when they are transmitted upstream.

2.7 XG-PON QoS

In XG-PON, there are many categories of traffic that are differentiated according to the priority they have for the connection capacity.

- Fixed Bandwidth: The fixed or reserved fraction of the capacity, known as fixed bandwidth, is unaffected by the volume of traffic.
- Assured Bandwidth: This is the percentage of the capacity that is set aside for unsatisfactory traffic demand, despite traffic demand.

- Non-Assured Bandwidth: This is the extra traffic allotted to the TCONT over and beyond the guaranteed bandwidth of the ONU.
- In addition to the ONU's non-guaranteed bandwidth, the OLT also provides the TCONT with "best effort" bandwidth.

The priority given to Fixed bandwidth is the greatest among all these different traffic classifications, while the priority given to Best Effort bandwidth is the lowest. Fixed and Assured bandwidth types are categorized as Guaranteed Bandwidth in XG-PON, whereas Non-Assured and Best Effort bandwidth types are categorized as Non-guaranteed Bandwidth. Following the delivery of the promised share of bandwidth to the ONU by DBA, the non-guaranteed bandwidth is then made available to the ONU. The XG-PON will demand the non-guaranteed bandwidth once the upstream traffic load becomes greater than the connection capacity.

2.8 TCONTs

Transmission Containers. In most situations, there will be four Transmission Containers, each of which will relate to a different traffic class. These traffic containers are matched to the various forms of bandwidth that were explained earlier. There are four total CONTs available. TCONTs are divided into the following five categories, according to the bandwidth that they are assigned:

- Fixed bandwidth is only supported by TCONT-1
- Assured bandwidth is only supported by TCONT-2
- Assured and non-assured bandwidth is supported by TCONT-3
- Best effort is only supported by TCONT-4
- All bandwidths are supported by TCONT-5

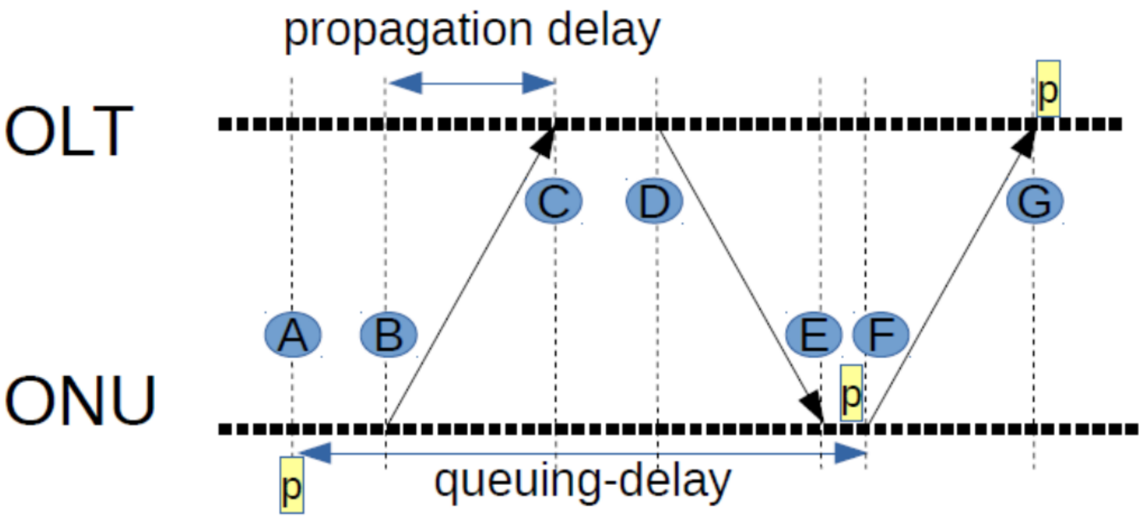


Figure 12: Delays experienced at ONU when a packet arrives for upstream transmission [19]

2.9 Scheduling in XG-PON

Since a single OLT broadcasts traffic in the downstream, scheduling that traffic is a simple activity that can be performed by the OLT and does not require precise instructions from the standards. However, due to the fact that numerous ONUs time-shares the PON(XG) functionality when uploading, which takes a form of a scheduler that is polling-based in the DBA algorithm, the uploading stream cannot be considered a single unit. The algorithm then decides which ONUs are getting served in an upload stream frame, the size of the XGTC burst that will be used for all the ONUs, the transmission start time that will be used for all ONUs, sends frame for downstream to the ONUs (the DBA decisions included in the BW map field), and withhold a short pause time between the continuous XGTC bursts so that it can tolerate clock synchronization errors.

The image illustrates all of the various delays that a packet, let's call it p, encounters from the moment it approaches a queue at ONU (point A) to the time it reaches the desired and required OLT when sent in the upload stream. These delays might occur anywhere along the path from the ONU to the OLT (point G). On the other hand, as can be seen in the image, p is the sole item that stays in the ONU queue between circles A and F while the scheduler at the OLT is occupied with its activity. Hence, delay Total may be described in terms of the queuing-delay, delay queue as, delay-Total = delay-queue + delay-propagation + delay-processing,onu (2.2) where, delay-queue = 2 delay-propagation + delay-processing,olt (2.3)

An actual XG-PON scheduling, and provision mechanism can be complicated since it can handle and support multiple ONUs, and all the ONUs can have more than one logical or non-tangible upload stream link. To be successful, an actual XG-PON scheduling, and provision mechanism needs to adhere to DBA scheduling policies.

2.10 DBA and Scheduling Mechanism

OLT makes use of a downstream schedular in order to determine what data are going to be broadcast in a down stream frame. In accordance with the QoS parameters, the downstream schedular will determine which connections are to be established and which data are to be sent. OLT makes use of a DBA algorithm in order to schedule the upstream traffic, which then divides the available upstream bandwidth across the several TCONTs. In G.983.4, DBA was standardized, and as a result, it offers a significant amount of transmission capacity in the upstream direction. The queue occupancy data that the DBA algorithm gets from the ONUs, coupled with QoS parameters and the service history of TCONTs, are the factors that influence the allocation decision that is made by the DBA algorithm. The DBA algorithm is responsible for completing a variety of different duties.

To prevent synchronization issues and packet collisions, it is necessary for it to choose which TCONTs will be served and then reserve a guard band, which is a brief period of time between each of the XGTC frames. It sets the amount of bandwidth that will be allocated as well as the time at which it will begin.

The start time is the point in time at which the upstream data from ONUs that are located at varying distances from the OLT are synchronized. After all of this work has been completed, it is subsequently broadcast to ONUs using a BMap during the downstream transmission. The ONUs will subsequently forward the transmission schedule to the TCONTs that are relevant to them.

The DBA algorithm is of high importance to the overall network performance as well as the quality of service factors. The QoS characteristics and requirements of the various network service providers each call for a unique DBA algorithm. Various DBA algorithms are available. The next text will go through a few of the DBA algorithms.

2.10.1 Algorithm: Round Robin

Round Robin algorithm is known to be the simplest, oldest, and very commonly rehearsed algorithms that was built for systems focusing on TDMA. It is also one of the most widely used algorithms overall. It is a DBA technique that does not take QoS into consideration. It is not a technique for scheduling based on priority in any way. It does so in a round-robin fashion during each cycle, providing a constant amount of bandwidth to each of the TCONTs. It is very common to mention Round Robin as the algorithm without DBA. This schedule provides a level playing field for all of its customers.

Take, for example, the server-client configuration depicted in figure, which consists of a single server (OLT) and a number of clients (ONUs). For each client, there is a queue with a length L that is used to temporarily hold any incoming packets. The Round Robin scheduling method will go around to each client in a cyclical fashion like (ONU1,ONU2,...ONUn), giving each client the opportunity to broadcast. The chance for transmission is restricted due to the fact that the upstream frame is of 125, which results in a total bandwidth of 2.48832 Gbps. It is possible to calculate the transmission rate using the formula R i,RR = R total /N, where Rtotal is the total bandwidth that the system occupies and N is the number of customers.

2.10.2 GIANT

In 2006 [20], the Giga-PON Access Network, often known as GIANT, was the first DBA system to be implemented. It is a priority-based system that, upon the expiration of its Service Interval (SI) timer, provides fixed bandwidth to TCONT-1, assured and on demand bandwidth to TCONT 2, assured and non-assured bandwidth to TCONT-3, and best effort bandwidth to TCONT-4. Because of the many forms of bandwidth, these two categories of traffic are distinct from one another. TCONT-1 and TCONT-2 are given the promised bandwidth, whereas TCONT-3 and TCONT-4 are given the surplus bandwidth that is left over (RSB). Because it waits for the buffer occupancy report from ONU to reach OLT and then distributes the grants to the TCONTs while the channel is idle, GIANT experiences a significant amount of latency. This wait time leads in a high queuing delay for users.

XGIANT By presenting XGIANT as an addition to GIANT, an improvement is made to the overall performance in terms of mean latency and packet loss [21]. In XGIANT, the OLT does not wait for the buffer occupancy report; rather, it assigns slots to all of the TCONTs with their own SI timers that have expired and guarantees that the capacity is being used to its fullest potential. Following are a few different XGIANT variations.

2.10.3 XGIANT-D

XGIANT-D is an additional optimization that may be applied to XGIANT. It guarantees fairness with regard to queuing delay (mean) and provides tight preference to the benefit of traffic that makes the best effort. It is equipped with a type fairness policy (intra-TCONT) that recognizes each traffic type as its own separate traffic class [22]. The first-served TCONT is independently changed in a round-robin fashion in the sort of fairness known as intra-TCONT type fairness. A dynamic threshold has been implemented in XGIANT-D, which allows for the bandwidth devoted to each BestEffort traffic class to be dynamically adjusted. This threshold is determined by the overall amount of idle bandwidth as well as the total number of TCONTs that have not been provided. The threshold is changed such that BestEffort connections that have a large volume of bursty traffic receive a greater share of the available bandwidth than those that do not have bursty traffic. Additionally, it provides a decreased rate of packet loss. This DBA offers the lowest mean latency for the highest priority TCONT, which is important for stringent priority. As a result, it uses the TCONT with the lowest priority, which is best effort, and it ensures a shorter mean delay for it.

2.10.4 XGIANT-P

XGIANT-P is another optimization that may be applied to XGIANT. Additionally, it assures fairness in terms of the mean queuing delay as well as the tight priority for traffic that makes the best effort [22]. In addition to that, it possesses an intra-TCONT type fairness policy, which views each traffic type as its own separate traffic class. The XGIANT-P is likewise an optimized version of the XGIANT DBA. It adheres to the propagation policy, which guarantees that all of the TCONTs are treated fairly and get the same queuing time. In order for the XGIANT-P to be able to deliver the additional grant to TCONT-4 and thus have a lower latency than the GIANT for BE traffic, a Bursty Factor (BF) has been incorporated into it. It is ensured that a weighted DBRu effects the bandwidth allocation for each T 4 by using BF, which indicates the burstiness of all BestEffort, much like a weighted round robin scheduler would.

2.10.5 Efficient Bandwidth Utilization

The EBU [23] algorithm makes use of the available but utilized b/w and distributes it to TCONTs that are already operating at capacity. In the scenario of being underloaded, EBU demonstrates a little improvement over GIANT in terms of both TCONT-2 and TCONT-3. It prioritizes allocating the greatest amount of available bandwidth to the most resource hungry TCONTs throughout each allocation cycle. EBU is plagued by an issue known as Inconsistent Bandwidth Reporting (IBR), which is responsible for the large increase in latency and frame loss experienced by TCONT-4 traffic class. A teller for bytes and a SI, are included in each queue that the EBU maintains.

Only when the SI timer value has expired can EBU make use of the remaining non utilized b/w, which is then included in to the counters of the other TCONTs. Because of the issue with the IBR, there is a very significant latency and loss of frames recorded for TCONT-4, which is its primary flaw. This is because the unused bandwidth is not being utilized. However, in the cases of TCONT-2 and TCONT-3, EBU demonstrates strong performance. This results in a less amount of bandwidth being allocated to TCONT-3 and TCONT-4, since the additional bandwidth that is not being used is "borrowed" from one TCONT and then "refunded" in the subsequent frame cycle.

If there is more traffic on TCONT-2 than expected the grant that was allotted to it might not be distributed to TCONT-4. This would cause significant delays since EBU would consider TCONT-4 to be idle. As a result of the overloaded condition, EBU approaches a state of continual delay and packet loss. TCONT-3 starts off with a shorter delay than TCONT-2 does since EBU gives TCONT-3 a larger grant.

Chapter 3

Methodology

3.1 Introduction to vPON

A single operator is responsible for deciding how the DBA mechanism works in a typical PON. It will not be possible for other operators to exercise influence over the upstream DBA procedures of their own customers. They do not have the capability of scheduling the burst allocation for their ONU customers [24]. By allowing network operators to share PON infrastructure, a concept known as virtualization may be implemented, which results in increased resource utilization and a decreased need for initial capital expenditure. This makes it possible for various service providers or VNOs to share the connection capacity that is available.

This virtualization makes it possible for distinct services to coexist, as well as for many service providers to run their operations over the same physical infrastructure while retaining complete control over the scheduling of their upstream traffic. In a PON system that is shared, each frame is distributed between several distinct Virtual Network Operators (VNOs) [25]. The frame is divided, and various network slices are allotted to the various virtual network operators. Therefore, virtual network operators arrange their available capacity atop a shared infrastructure, inside of each transmission frame. According to the research in, upstream transmission can enable fronthaul operations since several bursts within a frame are permitted. The virtual DBA administrator (vDBA) [26] grants complete control over the network capacity in a network slice to the VNOs that are using it so that they may operate their own upstream DBA process.

They generate their own separate virtual BMap to arrange allocation of the ONUs belonging to their clients. The VNOs may use the same DBAs or they may use distinct ones. Each individual vDBA is responsible for the generation of its individual virtual bandwidth map, which remains subsequently joined at the optical line termination by the ME and turned into a singular physical bandwidth map for the entirety of the upstream transmission. It is easier for VNOs and other service providers to tailor their offerings to the requirements of their customers thanks to this development. Following the slicing of a single frame, each operator is given a distinct section of that frame to use for the transmission of their data. Following that, the users that belong to that operator will begin transmitting in the slots of the frame that were allotted to them by the merging engine. Because of this, there is a significant impact not just on the operators but also on the users. Because the resources are shared, there is less investment required, as opposed to the operators having to install the entire fiber infrastructure on their own. Users may now enjoy the services up to a particular range and even in far-off locations thanks to advancements in technology.

When you give the operators full power over the network capacity, you open the door to several potential problems. Some of these problems, such as the synchronization of vDBA and the scheduling of unused capacity[27], are discussed in along with the operators' proposed remedies.

3.2 Virtual Dynamic Bandwidth Allocation Algorithm

The objective of the vDBA architecture is to include into a PON a mechanism that slices upstream capacity allocation in order to provide various tenants (for instance, VNOs) with the ability to precisely arrange ONU burst allocation inside each frame. [28] Higher-layer mechanisms are able to offer an average capacity allocation that represents the ensured rate allocation of the VNOs; nevertheless, they do not allow the VNOs the ability to precisely plan their capacity. This is despite the fact that higher-layer processes are also able to do so.

A VNO has the flexibility to arrange its own allotment of capacity within each frame thanks to the vDBA's provision of this capability. As a result, the VNO is able to select the DBA algorithm that is most suited to the service that it wants to deliver. Each VNO has the capability of running one or more vDBA algorithms in order to satisfy the requirements of its individual clients. The capacity that is shared by VNOs inside each upstream frame may be utilized more effectively thanks to the virtualization of DBA in this way.

The device functions with an upstream DBRus; the transmission containers, also known as TCONTs, in each ONU are created by the merging engine block and sent from that location to the vDBAs that are relevant to those TCONTs. The scheduling information is sent from the vDBAs to the merging engine in the form of a virtual BMap. The merging engine then returns the precise location of the required grants for the TCONTs of each individual customer. Following the collection of all virtual BMaps, the merging engine next executes an algorithm in order to combine those virtual BMaps into a single physical BMap, which is subsequently disseminated to all ONUs. Then, in accordance with the established rules of the PON, the ONUs adhere to the scheduling particulars that are recorded in the BMap.

3.3 Capacity Sharing Mechanism

Intra-frame sharing is the name of the technique for capacity sharing that is utilized in our work. Because of this process, the VNOs will have the opportunity to share each frame with one another. This is accomplished by first dividing the guaranteed bandwidth share of the total capacity among the VNOs. This step is the first step in the process. After then, the same thing happens with the non-assured bandwidth, and it is distributed to all of the VNOs and so on. while in [28], each VNO is given one whole upstream frame in a manner similar to a round-robin rotation that occurs periodically.

Consequently, our findings demonstrated an improvement over the method described in [28]. When allocating one frame to each VNO, a reliance of the latency on the number of VNOs is created. This dependency is eliminated when using our vDBA technique, however, because it is not necessary. Second, it is ineffective to statically allot a frame per VNO to bandwidth because empty space from one VNO cannot be utilized by users belonging to other VNOs. This is a problem that our technique also overcomes and is one of the reasons why it is effective. However, by utilizing that strategy, a greater capacity may be offered to a particular VNO, which in turn decreases the total latency. Instead, our vDBA possesses the capability to provide latency output isolation in relation to the allocation of VNO capacity.

The connection capacity is completely shared among the operators, which enables the operators to provide individualized services to the end users of the network. Because of this, VNOs now have the capacity to completely design their own capabilities, which brings up a new problem. If a VNO had spare capacity on any given frame, keeping it unallocated would not benefit the VNO in any way since the merging engine will transfer it to other VNOs who are likely to be its rivals. Therefore, it is in your best interest to provide the merging engine a frame that has been fully allocated. This will ensure that there is no unused space that might potentially cause problems. However, this has the overall effect of lowering the efficiency of the PON upstream, which is an issue.

As a result of the VNOs being required to share their unused bandwidth with other VNOs, there is now a problem with the virtual PON's incentive structure for sharing. This issue is discussed in [29], along with the solution to the problem, which is a proposal for a sharing platform that is both economically viable and operationally effective. The multi-tenant PON is treated as a market, and the approach of auctioning shared resources is utilized to monetize the mechanism for resource distribution. The VNOs that demand a return on their investment in exchange for an incentive are given access to the VNOs' surplus capacity.

3.4 Merging Engine

We have assumed that each vDBA function is the same, and that it operates independently. However, there may be allocation conflicts for their virtual BMaps; if this is the case, the merging engine will relocate them across the frame so that they do not overlap. It's possible that different merging engine algorithms will provide different outputs. These outputs might, for instance, prioritize efficiency in capacity allocation or delay. After collecting all of the virtual BMaps, the job of the Merging engine is to execute an algorithm that combines all of those virtual BMaps into a single physical BMap, which is then sent to all of the ONUs. In order to prevent any conflicts between the transmission, which would then extend the transmission mechanism, it must create a collision-free allocation (where ONUs are attempting to assign capacity at the same time). The Bmaps are moved across the frame when the merging engine is used so that any overlap of transmission requests may be eliminated.

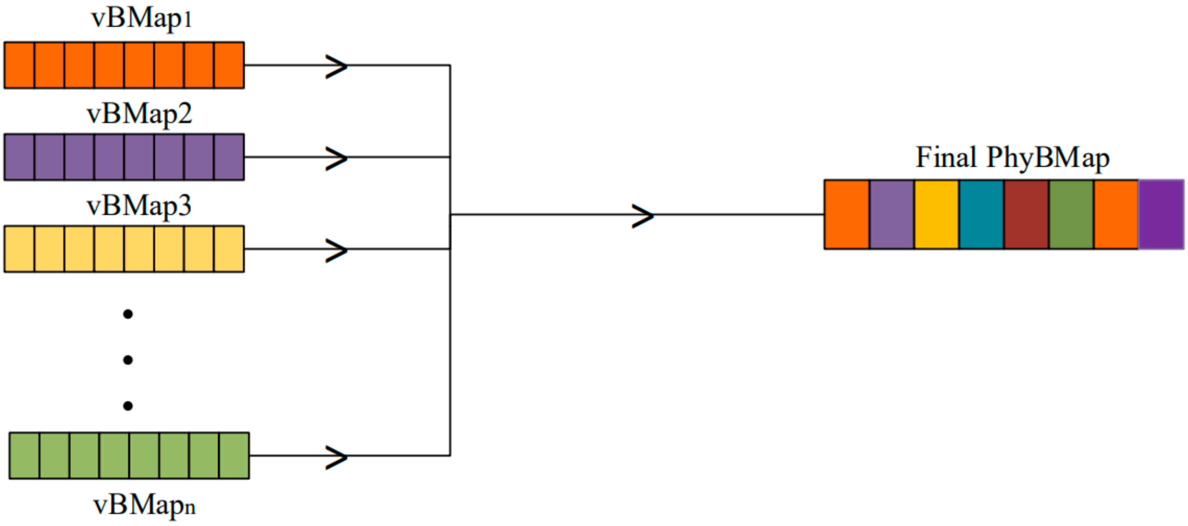


Figure 13: Merging Engine Merging BMaps

The Merging Engine is responsible for the challenging task of integrating multiple virtual bandwidth maps that were sent in separate transmissions by the DBAs of the VNOs into one final allocation. This involves resolving any conflicts that exist between the virtual BMaps (i.e., situations in which both are attempting to allocate capacity at the same time) [26]. This process of the merging engine is broken down into its component parts and illustrated in Fig.13. From this figure, it is possible to deduce that several vBMaps are generated by the VNOs, and that these vBMaps are then merged into a single Physical Bmap by the merging engine.

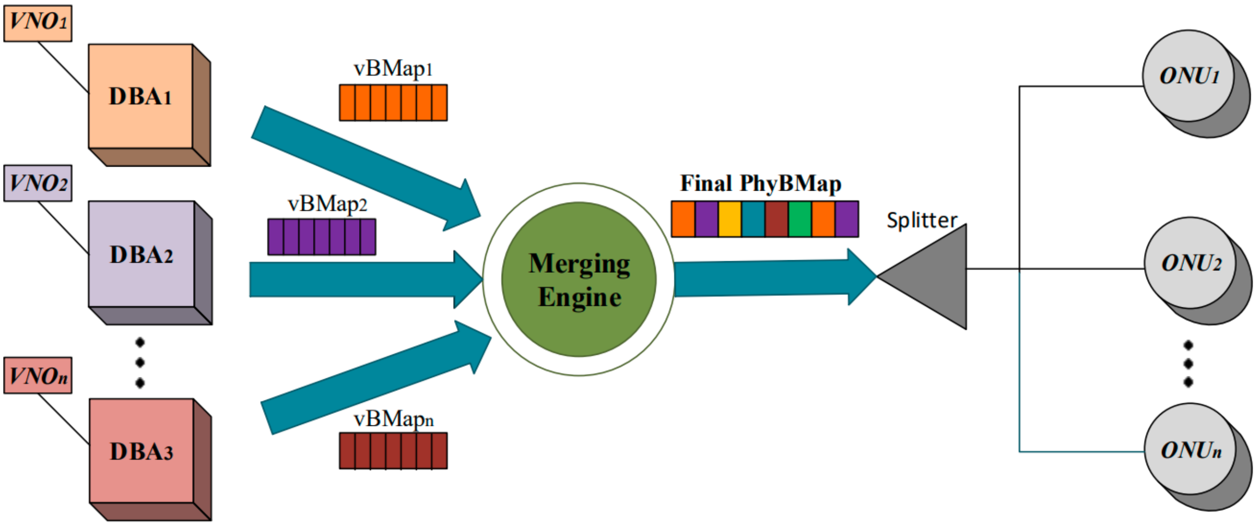


Figure 14: vDBA mechanism's system architecture

3.5 Working of vPON

The system architecture of the virtual DBA method is depicted in Figure 14. In a vDBA, VNOs are delegated complete ability to schedule traffic and choose the DBA in accordance with the demand of their customers. Every VNO will be in charge of autonomously operating their proprietary virtual dynamic bandwidth allocator. VNOs working that are operational under the similar allocator places limitations on the operators' ability to provide particular services. Making the VNOs completely novel and coordinating separate DBAs that are impacted by the requirements of the subscribers allowed us to achieve our goal of creating a flexible environment.

For the ONU's to make their vBMap, the vDBAs are responsible for getting the buffer reports from their respective ONUs, which is then sent to the ME. The vBMaps from all the virtual operators generate a physical bandwidth map, which is later broadcasted to all ONUs, showing their transmission schedule. The ME that is placed at the optical line termination is responsible for generating a collision-free allocation by combining the several BMaps that were transmitted by VNOs.

The capacity that is shared by VNOs inside each upstream frame may be utilized more effectively thanks to the virtualization of DBA in this way. Because of this, there is a significant influence not only on the operators, but also on the users, because the assets are split, which causes a lower spending than if each user were required to install their own complete fiber infrastructure. As a result of the expectations of the customer, it is now possible for various services to coexist on a single fiber that has been installed.

Chapter 4

Results

This chapter provides information on the network simulator that was utilized by our team during the simulations. In the NS3 network simulator [30], a module has been built that simulates XG-PON in a manner that is consistent with the standards. This simulation module is developed on a sequence of G.987 ideas for an open-source and fully accessible simulation environment that came from the ITU-T FSAN group. The XG-PON simulation module, which is a separate module from the rest, is the one that is used for all of the assessments. This chapter provides an overview of the simulation environment as well as the fundamental concepts that are necessary for the simulation module.

4.1 4.1 XG-PON Simulation module in NS3

The XG-PON package was developed using the C++ programming language, and it is comprised of around 22,000 lines of code and 72 separate classes. Any simulation would be incomplete without speed as a core component. A downstream data throughput of 10 Gbps is supported by the XG-PON module, and an up speed rate of 10 Gbps/2.5 Gbps is also supported. If the XG-PON module is simulated with the highest possible level of precision at the expense of simulation speed, the research community will not benefit very much from the simulation.

It is not possible to simulate data transfer at the byte or bit level because of the huge bandwidth of XG-PON as well as average speed of clock of the processors. Due to this fact that NS3 simulates data at the packet level, the module is also simulated at the level of packet. In the discussed simulation, OLT is represented as a node that is linked to an external device. ONUs are also considered to be nodes, and there may be anywhere from hundreds to a maximum of 1023 of them, each of which is connected to the user equipment. In the ODN, the ONUs and OLT are connected to the channel that serves as the physical link. The Optical Distribution Network is structured like a tree and comprises optical fibers, splitters and joiners, and reach extenders.

4.2 NS3 Network Simulator

The networks are getting bigger and more complicated as time goes on, which is why it is very necessary to have a simulation of the network that is extremely precise. The use of simulation is extremely valuable for goals like scalability, reproducibility, prototype development, and teaching.

The NS3 [30] network simulator, which is a platform for simulation, has been utilized by our team. The NS3 network simulator is a cutting-edge example of open-source software. NS3 was developed from the ground up and does not have any compatibility with NS2, which was the version that came before it. To conduct all of the modules and simulation tools, C++ is used as a library, and the main program in C++ links to that library. Similar to how C++ programs can be imported as NS3 modules, Python applications can do the same thing. NS3's architecture is quite similar to that of machines running Linux. NS3 has many useful and appealing characteristics, like scheduler (real time) that enables variety of "simulation-in-the-loop" applications for communicating with real-time systems, a strong focus on the reusing of application and code, strong virtualization and test bed support, a new simulation parameter configuration attribute system, automated memory management, and a customized tracing system [31]. It can also be seen that NS3 accomplish significantly better than competing parties in terms of performance and the overhead for memory [32]. Models for the network nodes, devices, communication channel, protocols, packets, and their headers are all included in NS3, just as they are in any other network simulation tool.

Educative and research purposes account for the vast majority of NS3 usage. It is free for anybody to use, do research on, or create with, as it is distributed under the GNU General Public License version 2.

4.3 PPBP Application Module

There have been a lot of different tools developed to model and simulate the traffic on the internet. Some are based on stochastic process models, while others are based on the parameterization of traffic. There are a relatively limited number of traffic generators accessible in NS3. The actions of users have a direct bearing on the amount of traffic that is generated on the network.

Poisson Pareto Burst Process (PPBP) [33] is a traffic model that generates NS3 simulations of genuine internet traffic. The PPBP traffic model is utilized, and long range dependency and a Hurst parameter of 0.4 are also included in its configuration. This traffic model represents the traffic on the Internet by using LRD, which is the same thing as saying that it aggregates network traffic. In PPBP, the word "poisson" refers to a random occurrence, while "pareto" refers to the "80-20 rule," which states that 20 percent of factors are responsible for 80 percent of the effects. In PPBP, bursts arrive according to a poisson process with a rate p, and the length of the bursts follows a pareto distribution with a Hurst parameter H that is in the range of 0.5 to 0.9, along with a mean Ton and a burst intensity r. Burst intensities are determined according to the poisson process (constant bit rate).

The Hurst parameter, denoted by the letter H, is frequently utilized in the research that has been conducted in order to adjust the burstiness of an application traffic model so that it more accurately represents real models of Internet traffic. This thesis makes use of the PPBP application component in many the applications related to it, applications like P2P video or Internet traffic (mobile), under complicated and extensive-scale network conditions. This is possible due to the PPBP application module's accurate modeling of long-range dependence, its easily configurable NS3 interface, and its utilization of the simulation platform's low computational and memory resources. In order to carry out the necessary research, a basic network with just two nodes that are only connected to each other by a single link is studied. The capacity of the connection has been adjusted to 10 Mbps. The formula for calculating the average number of active bursts is E[n] = Ton p. (1) The formula for calculating the overall rate of PPBP is as follows: Ton p r (2).

When the number of loads (operators) increases, the burst intensity, which is the data rate of each burst, also decreases. This has the effect of slowing down the overall pace of traffic, which in turn causes a reduction in the amount of traffic that is created.

Chapter 5

Discussion

This chapter provides an illustration of the performance of the service for a variety of circumstances. As was said before, we have set a few of the simulation's settings. The amount of traffic ranges anywhere from 0 to 3 gigabits per second. We have chosen traffic up to 3 Gigabits per second to demonstrate the delay and packet loss ratio for both the underloaded and the overloaded circumstances. This will allow us to assess the various DBA algorithms operating independently and remark on the choice of DBA. We have assumed that each ONU has the same propagation delay, which we have determined to be 0.4. To test the XG-PON module, we used the NS3 emulator.

We [11] have considered one optical line terminal and sixteen optical network units for the scheme with two virtual operators and fifteen units for the situation with three operators, assuming that the network load will be distributed evenly among them. We have used the PPBP traffic paradigm with prolonged scale dependency, and the value for the Hurst parameter is 0.4. The increase in traffic causes a higher number of frames to arrive at each ONU, which leads to an increased amount of queue up gap and the loss of frame for TCONTs 3 and 4, which are classes with the lowest priority at ONU [34].

The maximum capacity of the connection has been set at 2.15 gigabits per second. One BMap can have a upper limit of 512 traffic containers planned in it, and frames are transmitted after an interval of 125 seconds. Every optical unit has a queue that can store one megabyte (MB) worth of traffic. Each simulation is conducted for a duration of 15 seconds. Given that TCONT-1 is allocated the fixed bandwidth, the relevant simulations have not been carried out. Each vDBA is responsible for servicing three different TCONTs: the Assured, the Non-Assured, and the Best-Effort TCONT. The VNOs' supplied traffic loads have been balanced out to be equivalent to one another.

We have findings for two different scenarios, the first one being when there are two operators, and the second one being when there are three operators. This demonstrates that increasing the number of operators does not have an impact on the system's performance because each of them is executing their own customized DBA. PON clients have varying levels of traffic load because during any particular time period, some customers may be overloaded while other customers may be underloaded. As a consequence of this, we have performed an analysis of the findings taking into account both of the circumstances. The next paragraphs will detail the outcomes of the situation in which there are two operators.

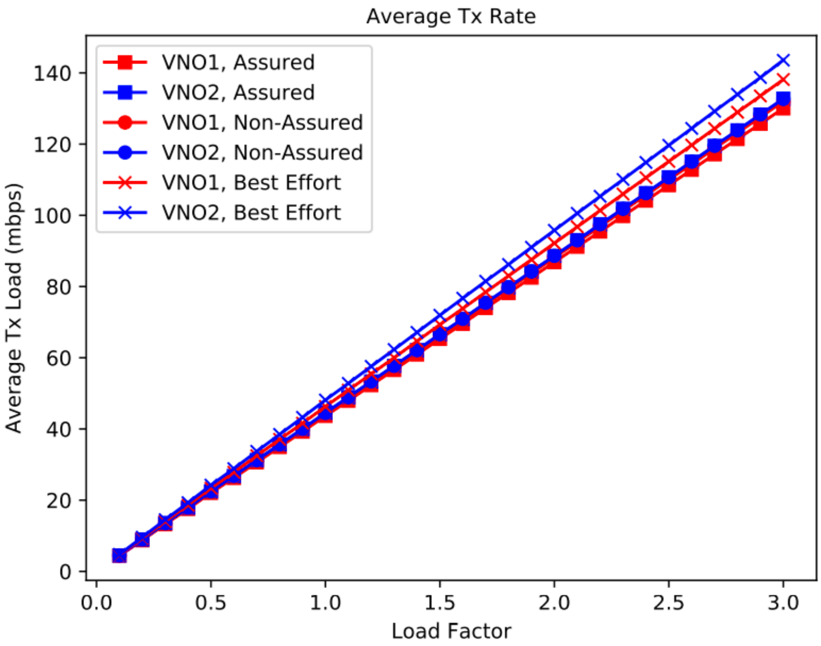


Figure 15: Average Traffic Load

Figure 15 depicts the amount of traffic that was created for each load. In the scenario when there are two VNOs, this is the amount of traffic that is produced at each traffic load expressed as a percentage of the average transmission rate. The total number of sources is calculated to be 48, which makes sense given that there are 16 ONUs. Because of this, the amount of traffic load created by each source is 44.7 Mbps.

5.1 VNO1 = GIANT, VNO2 = GIANT

The average latency and the ratio of lost frames are both going to be examined below for both of the operators who are executing the GIANT algorithm at the OLT.

The findings are depicted in Figure 16 for two different VNOs, both of which used GIANT for the upstream transmission. This demonstrates the consolidation of the same DBA at the OLT. As a result of the fact that both DBAs are operating in isolation from one another, the results are overlaid. It has been noticed that TCONT-2 has the smallest amount of delay as a result of the ensured assignment of bandwidth. Due to the fact that it is given a higher priority and so receives greater allocation, it exhibits a consistent latency even when there is larger volume of traffic.

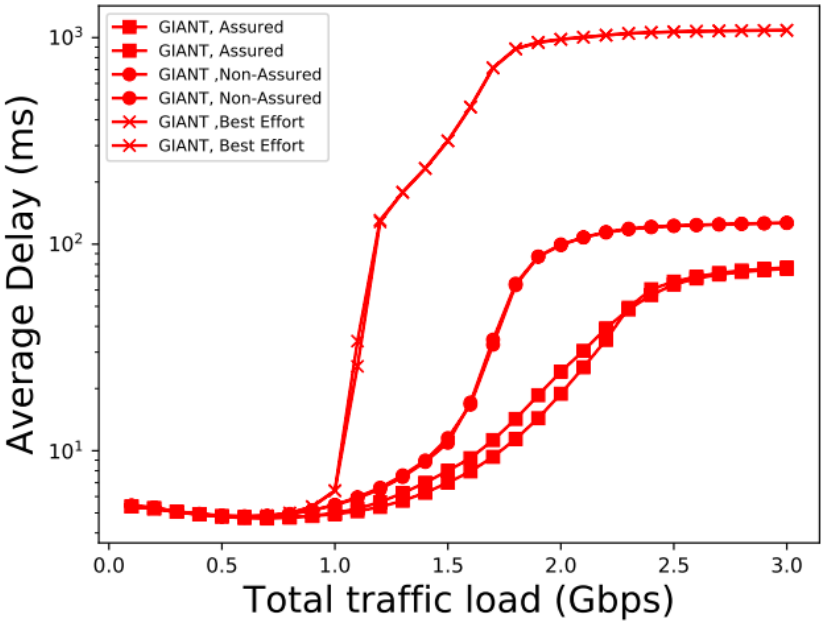


Figure 16: Average Delay for GIANT-GIANT

When the total amount of traffic on the network hits 2.15 Gbps, which is the maximum capacity of the upstream connection, the best-effort traffic starts to experience congestion. Due to the fact that it receives a smaller allocation after the maximum load, its latency rises. GIANT has the disadvantage of having a longer waiting time for newly arrived frames; as a result, it exhibits a high frame loss when the total traffic load is greater than the upstream bandwidth. This is due to the fact that it does not make use of the surplus bandwidth and has a low polling frequency. The decrease in the ratio of unallocated bandwidth is caused by the growth in the volume of traffic.

In addition to this, it experiences a significant amount of frame loss, as can be seen in Figure 17. Because the max load is constantly less than the upstream amount, no DBA suffers any loss of packets until the max value of load. As a result, no packets are lost until 1 Gbps because there is no DBA suffering any loss of packets until the max value of load. Once the max connection capacity has been achieved, BestEffort will be punished before any other strategy. After that, it enters the situation of overloaded traffic, in which Non-Assured traffic suffers the penalties first, followed by Assured traffic.

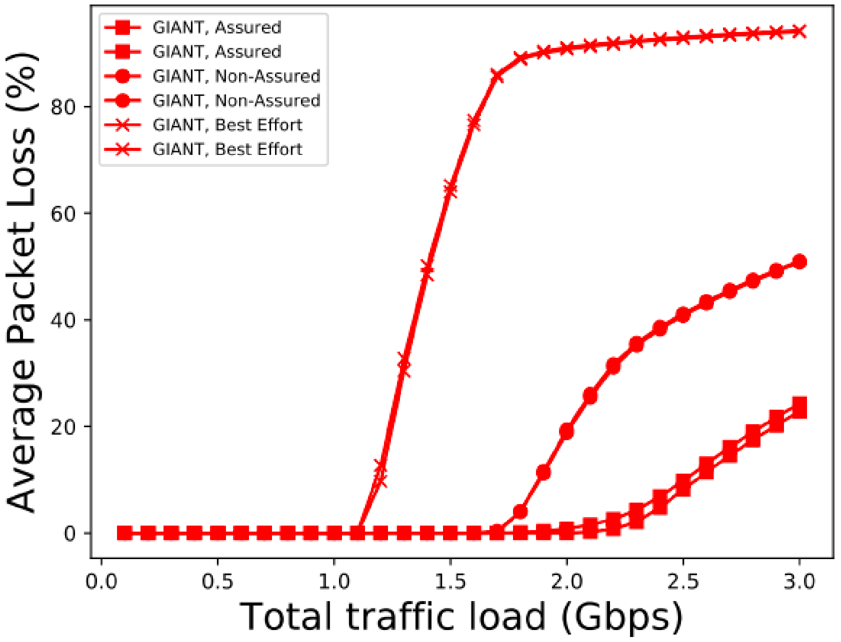


Figure 17: Frame Loss for GIANT-GIANT

5.2 VNO1 = GIANT, VNO2 = XGIANT

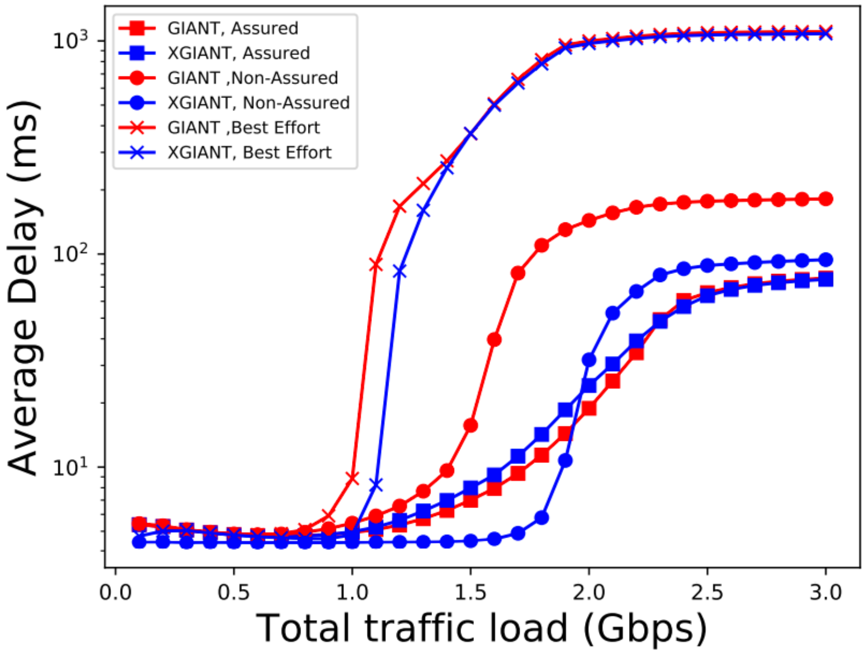


Figure 18: Average Delay for GIANT and XGIANT

The results of the two VNOs operating GIANT and XGIANT DBA for the upstream transmission are displayed in Fig.18. These results demonstrate the merging of several DBAs at OLT. GIANT must wait for a certain length of time before it can allocate the grant to TCONT. During this time, the channel remains idle, which causes it to experience delay. Since GIANT must wait for the buffer occupancy report from the ONU before allocating the grant, the delay is caused. GIANT has a higher average packet delay compared to XGIANT, particularly for Best-Effort traffic. This is because, when using X-GIANT, the Tx. slots are given to the containers together with their own elapsed timer SI values. This eliminates the need for any waiting time, unlike when using GIANT, which waits for its counter value to become invalid before allocating grants to the TCONTs. As shown in Figure 18, TCONTs with lower priority, such as TCONTs 3 and 4, are subject to longer delays in the event of an overcrowded state because they do not make advantage of the available excess bandwidth. Therefore, GIANT's delay performance is impaired since it is unable to issue the bandwidth request until the down counter SI has run its course for it. TCONT-3 exhibits a greater delay for GIANT compared to TCONT-2 due to the fact that it delivers the allocations just once as specified by the SI. Because of this, the vast bulk of the bandwidth is allocated to TCONT-2, whereas TCONT-3 and TCONT-4 have their allocations restricted and, as a result, their quality is reduced.

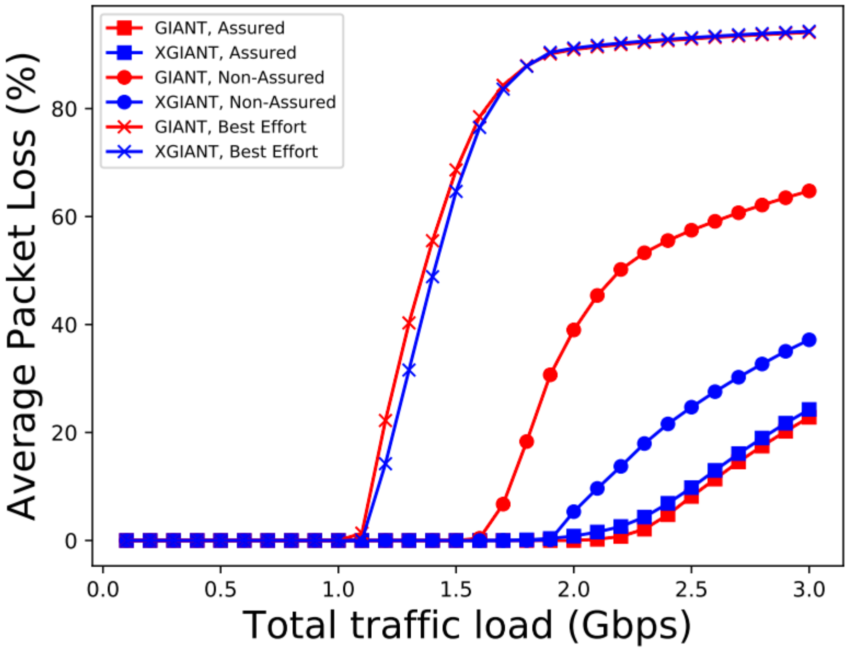


Figure 19: Frame Loss for GIANT and XGIANT

In a similar fashion, the frame loss that occurs between the two VNOs that are operating GIANT and XGIANT DBA at the OLT can be shown in Fig.19. Up until the maximum connection capacity is achieved, no packets are ever lost; however, after this point, each traffic type experiences a proportionate amount of frame loss. The GIANT network is the first to experience packet loss, followed by the XGIANT network. Because it does not employ unused bandwidth, GIANT causes a significant increase in the frame loss rate for low priority traffic classes. As the traffic reached 2 gigabits per second (Gbps), frame loss for TCONT-2 was also detected. In a manner analogous, XGIANT suffers from packet loss as well if the traffic load is raised. After the threshold for the maximum amount of traffic has been achieved, the first device to experience packet loss is TCONT-4. Subsequently, TCONT-3 and TCONT-2 are also affected by the loss of packets.

5.3 VNO1 = GIANT, VNO2 = XGIANT-D

The operators that ran GIANT and XGIANT-D are depicted in Figure 20 along with their average delay findings. The XGIANT-D is a better and enhanced variant of the XGIANT DBA, which is founded on the principles of fairness and rigorous priority. The amount of delay experienced by their guaranteed and non-guaranteed traffic is almost equivalent. It ensures that the strictness policy is adhered to by allocating the unused bandwidth to TCONT-2 and TCONT-3 in order to provide high priority TCONT with the lowest possible latency. The BestEffort provides bursty traffic, and XGIANT-D ensures that TCONT-4 receives more unused bandwidth grant than non-bursty traffic classes by introducing a threshold value that ensures provision of bandwidth to each BestEffort TCONT. This allows XGIANT-D to make sure that TCONT-4 receives more unused bandwidth grant than non-bursty traffic classes.

Because of this, BestEffort traffic for XGIANT-D has less delay than GIANT does. This is because GIANT does not make advantage of the unused bandwidth that is still available, as seen in Fig.20. An increase in traffic up to 3 gigabits per second generates an increase in latency not just for lower priority traffic classes but also for higher priority traffic classes. As a result of the fact that it does not begin allocating bandwidth until the Service Increment (SI) has expired, GIANT encounters delay even before the maximum traffic has been met. Because it has entered the overloaded situation, even the BestEffort of XGIANT-D has a substantial delay at 1.2 Gbps when it reaches 1 Gbps. This DBA has the least average queuing-delay when it comes to TCONT-2 traffic out of the two DBAs, but at the expense of the mean queuing-delay for BestEffort (TCONT-4) traffic. In the case of XGIANT-D, TCONT-4 is allotted a smaller portion of the available bandwidth in comparison to XGIANT-P.

The observed packet loss for the two different Virtual Network Operators (VNOs) that were running GIANT and XGIANT-D (a variation of XGIANT) is presented in Fig.21. Up until a traffic load of 1 Gbps is experienced on either of the DBAs, there is no observable packet loss. When the traffic climbs beyond 1 Gbps, the TCONT-4 protocol for GIANT is the first to experience frame loss, followed by the TCONT-4 protocol for XGIANT-D. Frame loss occurs for the remaining traffic classes if there is an increase in the overall volume of traffic.

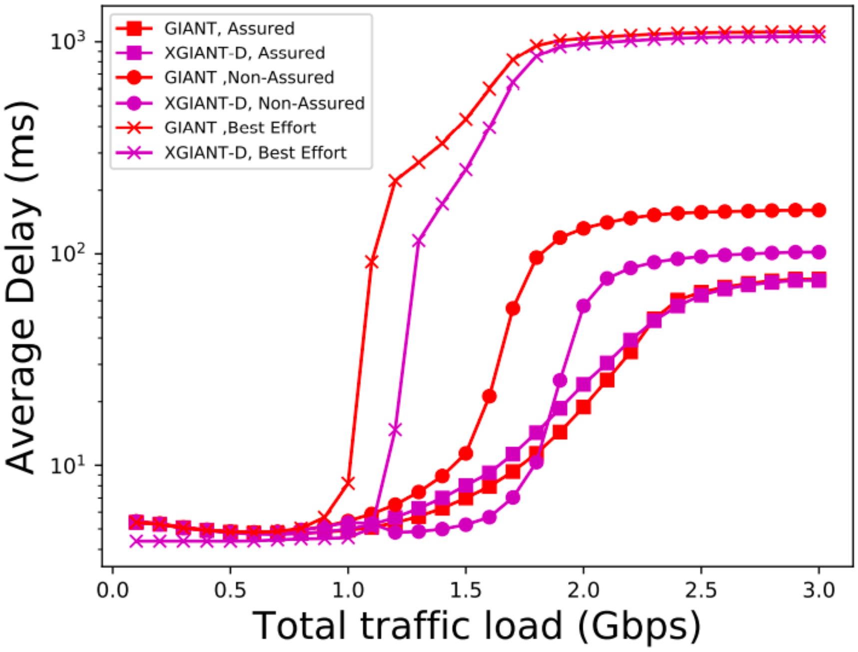


Figure 20: Average Delay for GIANT and XGIANT-D

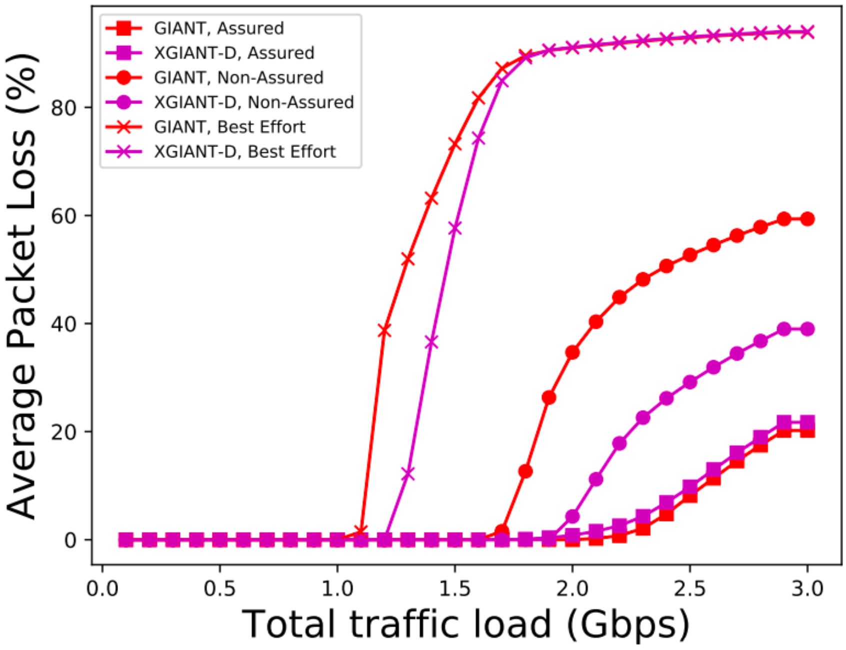


Figure 21: Frame Loss for GIANT and XGIANT-D

5.4 VNO1 = GIANT, VNO2 = XGIANT-P

The results of the two different operators running GIANT and XGIANT-P are displayed in Fig.22. The XGIANT-P is likewise an optimized version of the XGIANT DBA. It adheres to the propagation policy, which guarantees that all the TCONTs are treated fairly and get the same queuing time. Since BF gives the additional grant to TCONT-4, the acquired latency for BestEffort traffic is significantly lower than that of the GIANT. As can be seen in Figure 22, XGIANT-P reduces the queuing delays associated with the Best Effort (TCONT-4) traffic class while maintaining the lowest delay for the TCONT-2 and TCONT-3 traffic classes. It delivers mean-queuing delays that are consistent for all TCONT-2 traffic up to 1 Gbps, and these delays continue to slowly grow as the amount of traffic increases. GIANT has a longer latency overall than XGIANT-P, which has a delay that is visible when it is overloaded.

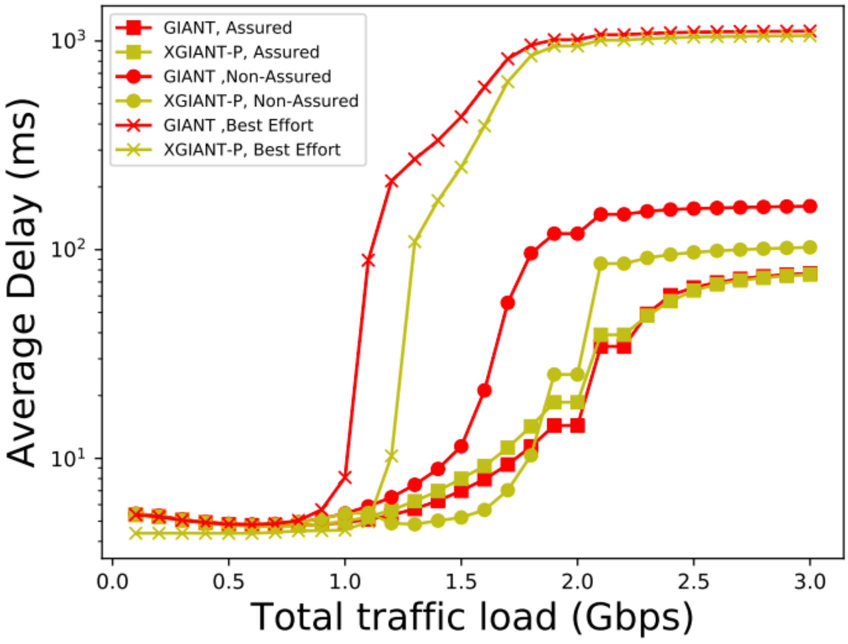


Figure 22: Average Delay for GIANT and XGIANT-P

The queuing time for BestEffort (TCONT-4) in XGIANT-P is lower than in XGIANT-D because XGIANT-TCONT-4 P's receives a greater bandwidth allotment than XGIANT-D does [22]. The regulated over-provision of grant size that XGIANT-P makes to TCONT-4 enables it to deliver greater fairness in mean queuing-delay than XGIANT-D does for each traffic class. This is because XGIANT-P compares favorably to XGIANT-D.

The percentage of lost packets is depicted in Fig.23 for both GIANT and XGIANT-P. GIANT (TCONT-4) experiences a loss of packets as the traffic hits 1.1 Gbps, and this loss of packets continues to rise along with the increase in overall traffic. TCONT-4 of XGIANT-P, which operates at 1.2 Gbps, is likewise subject to packet loss since it only causes minimal delay and packet loss while operating in an underloaded condition. When the storage capacity has been exhausted, there is a reduction in the number of frames stored. After this, TCONT-3 and subsequently TCONT-2 of both DBAs experience the packet loss on their own, respectively.

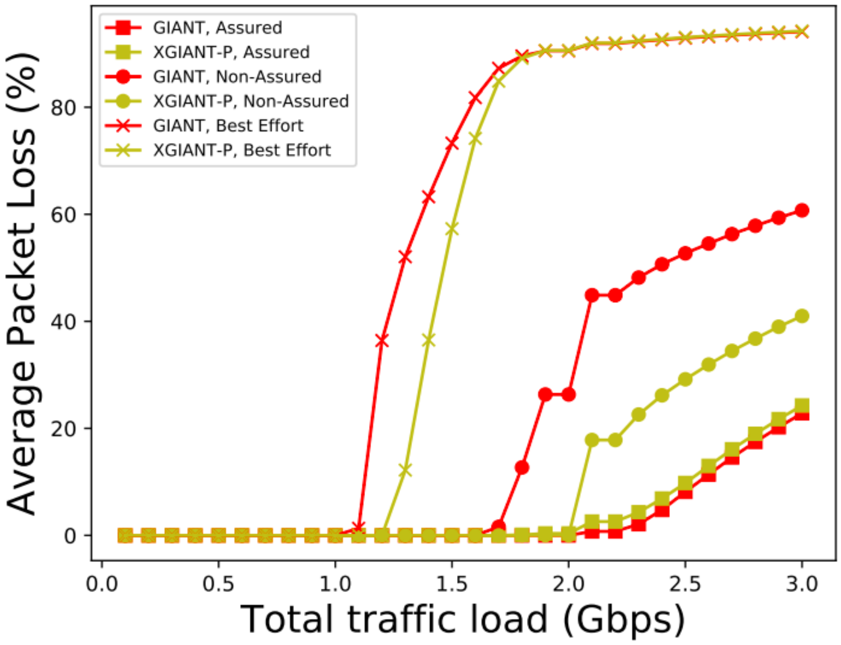


Figure 23: Frame Loss for GIANT and XGIANT-P

5.5 VNO1 = GIANT, VNO2 = EBU

The results of the two VNOs running GIANT and EBU simultaneously are depicted in figure 24. A counter for bytes & a SI, which is a down counter, are included in each queue that the EBU maintains. Only when the SI timer value has expired can EBU make use of the remaining utilized b/w, which is then included to the byte counters of the other traffic containers. Since the IBR issue prevents the utilization of unused bandwidth [9] very significant latency and frame loss for TCONT-4 are informed, as can be seen in Fig.24 and Fig.25; this is the system's primary area of deficiency. However, in the cases of TCONT-2 and TCONT-3, EBU demonstrates strong performance. This results in a less amount of bandwidth being allocated to TCONT-3 and TCONT-4, since the additional bandwidth that is not being used is "borrowed" from one TCONT and then "refunded" in the subsequent frame cycle.

If there is more traffic on TCONT-2 than expected, the grant that was allotted to it might not be distributed to TCONT-4. This would cause significant delays since EBU would consider TCONT-4 to be idle. As a result of the overloaded condition, EBU approaches a state of continual delay and packet loss. Because the EBU offers more grant to TCONT-3 than it does to TCONT-2, TCONT-3 has an initial delay that is less than TCONT-2. The trend of GIANT demonstrates that it behaves in a manner consistent with its history. Because the extra bandwidth is not being utilized, GIANT displays longer delay times for TCONT-3 when the demand on the system is lower.

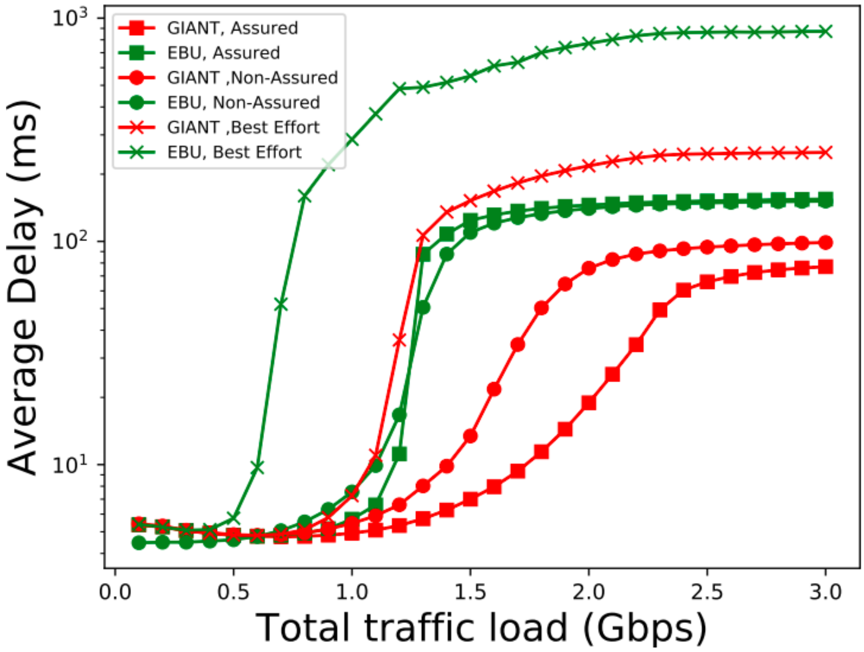


Figure 24: Average Delay for GIANT and EBU

Fig.25 depicts the percentage of lost frames experienced by both the GIANT and EBU algorithms. Because of the issue with its IBR that was discussed before, it is abundantly evident that EBU experiences frame loss at an early stage as a result of the issue. When the threshold for the maximum amount of traffic is achieved, BestEffort of GIANT begins to experience frame loss, which is then followed by packet loss for all other types of traffic. Due to the fact that it does not make use of the available bandwidth, BestEffort for EBU has the reputation for having the lowest performance in terms of both mean delay and frame loss.

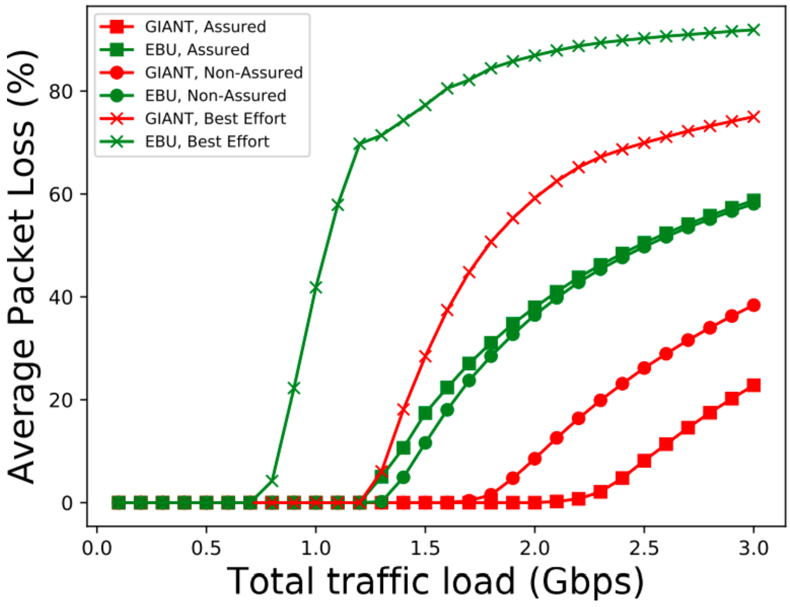


Figure 25: Frame Loss for GIANT and EBU

5.6 VNO1 = XGIANT, VNO2 = EBU

The following table displays the findings for the scenario in which one operator is in charge of XGIANT and the other is in charge of EBU. Figure 26 illustrates the average amount of delay that occurs when a packet is being sent. Traffic container 2s' mean delay stays low and steady for the case of X-GIANT when raised from 0 Gbps to 1 Gbps in Fig.26; however, a sharp hike is noted for TCONT-2 of EBU at the traffic load 1 Gbps because the buffer is completely occupied. After then, the delay carries on becoming longer, and when the traffic load reaches 1.3 Gbps, an unanticipated increase occurs. After that, the delay keeps getting longer, but at a slower rate of increase.

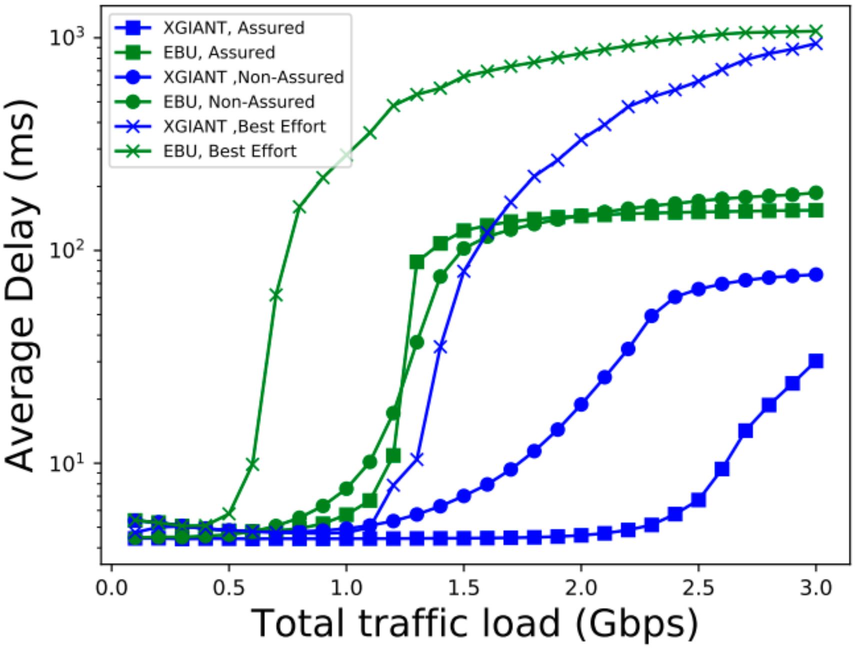


Figure 26: Average Delay for XGIANT and EBU

Due to the fact that XGIANT offers bandwidth grant to TCONT-3 at a greater frequency than TCONT-2 in a single DBA cycle, XGIANT DBA is able to achieve lower mean delay than TCONT-2 in the case of TCONT-3. This allows XGIANT DBA to achieve lower mean delay than TCONT-2. Because of this, the total delay that XGIANT experiences while using TCONT-3 is lower than when using TCONT-2. In the instance of EBU, because it grants greater bandwidth to TCONT-3 than it does to TCONT-2 but keeps the frequency the same, the delays for both TCONTs are approaching each other very closely. The overall average delay for TCONT-4 of XGIANT shows improved results than EBU due to the fact that it utilized the early expiry of its timer value, whereas EBU has minimal impact of clustering of the byte counter, which causes very high delay at an early traffic stage. XGIANT utilized the early expiry of its timer value because EBU has minimal impact of clustering of the byte counter.

In Fig.527, the frame loss ratio that was measured under the situation in which one operator was running GIANT and the other operator was running EBU DBA separately is depicted. Due to an IBR problem, the BestEffort for efficient bandwidth util. suffers high loss of frames early on. This is because the OLT is unaware of the exact values of grant required, and as a result, it over-allocates the bandwidth grants to the respective ONUs. As the traffic reaches its maximum, the BestEffort (TCONT-4) traffic of XGIANT is also penalized. However, as the traffic reaches its maximum, the BestEffort (TCONT- As soon as the maximum link capacity of 2.15 Gbps is achieved, the performance of EBU begins to decline. As a result of the fact that the overall service performance that has been seen for X-GIANT is the most excellent among all, this DBA may be utilized to supply data in situations in which the criteria for latency are quite stringent.

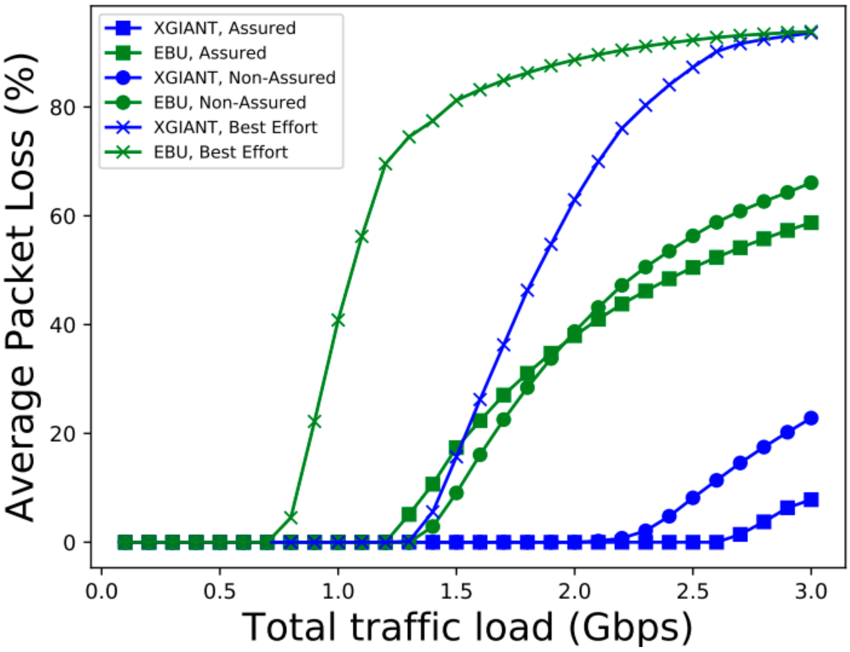


Figure 27: Frame Loss for XGIANT and EBU

The following table presents the findings for the scenario in which there are three operators, each of whom is functioning independently. Figure 28 depicts the amount of traffic that was created for each load. In the scenario when there are three VNOs, this is the amount of traffic that is produced at each traffic load expressed as a percentage of the average transmission rate. The total number of sources is calculated to be 45, which makes sense given that there are 15 ONUs. Because of this, the amount of traffic load created by each source is 47.7 Mbps.

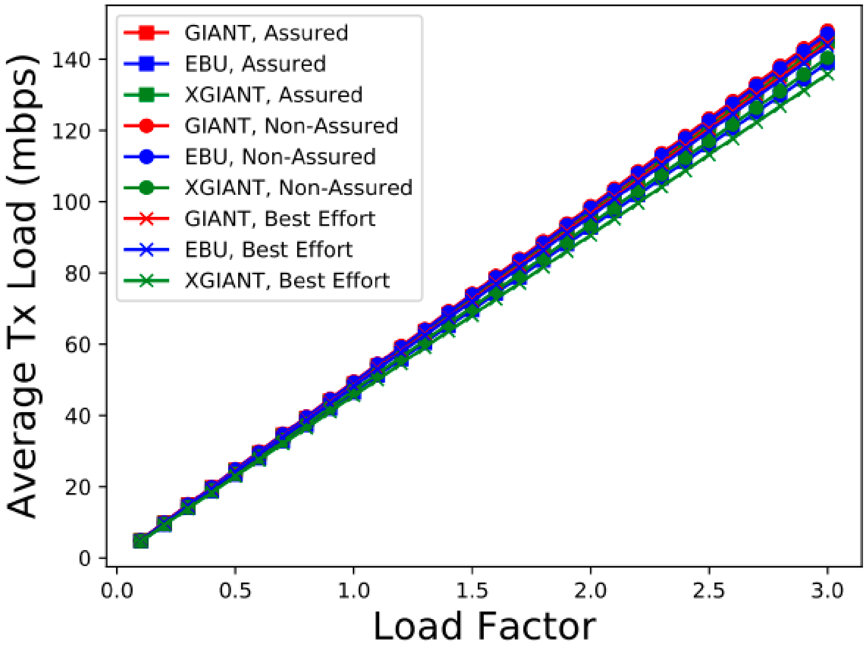


Figure 28: Average Traffic Load

5.7 VNO1 = GIANT, VNO2 = EBU, VNO3 = XGIANT

Figure 29 illustrates the outcomes that take place when there are three VNOs, and each one of them controls the frame-level scheduling in order to enable distinct services [26]. The findings demonstrate the cumulative effect of many VNOs independently operating the GIANT, EBU, and XGIANT programs. Traffic container 2 for X-GIANT displays an abrupt hike at this point, which meant that the buffer is being used to it’s max capacity and keeps increasing at a gentler gradient with rise in total traffic. On the other hand, TCONT-2’s mean delay remains low and almost steady for EBU as it is increased to 1 Gbps. This is in contrast to the behavior of XGIANT, where it remains low and almost constant even as the traffic increases.

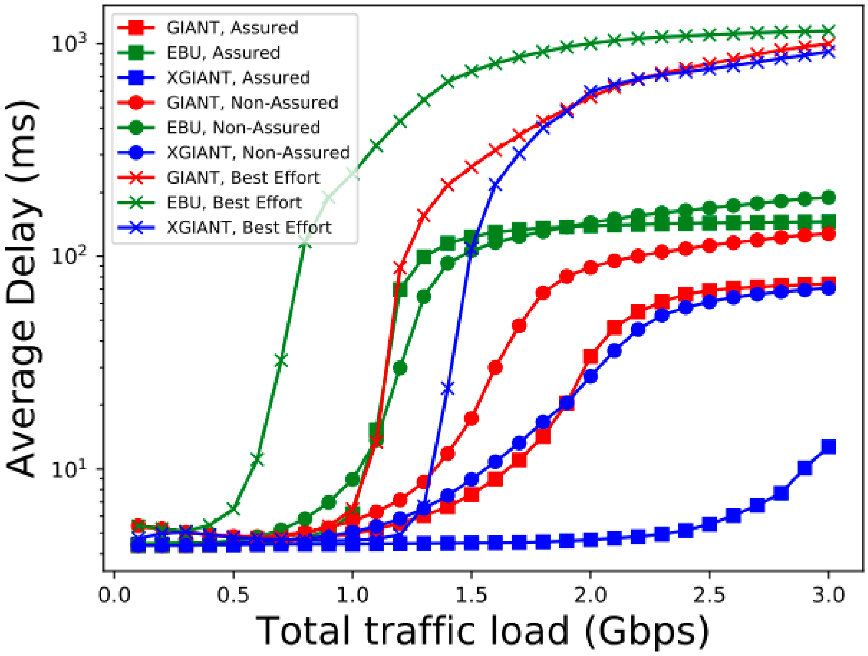


Figure 29: Average Delay for GIANT, EBU and XGIANT

Because it only aggregates the byte counter to a small degree, EBU displays the longest delay for TCONT-4. TCONT-3 has the smallest amount of delay under loaded conditions compared to the other two because it receives a larger proportion of the available bandwidth grant than TCONT-2 [21]. After 1 Gbps, GIANT begins to experience an exponential increase in delay, which ultimately results in the loss of its excess bandwidth allotment. This comparison of three different DBAs, all of which are operating totally independently from one another, gives us a clear image of which one is most suited for which kinds of circumstances. Therefore, the VNO has the ability to select the DBA in accordance with the needs and requirements of its clients, whether those needs and requirements concern near range, long range, lax latency, or vice versa.

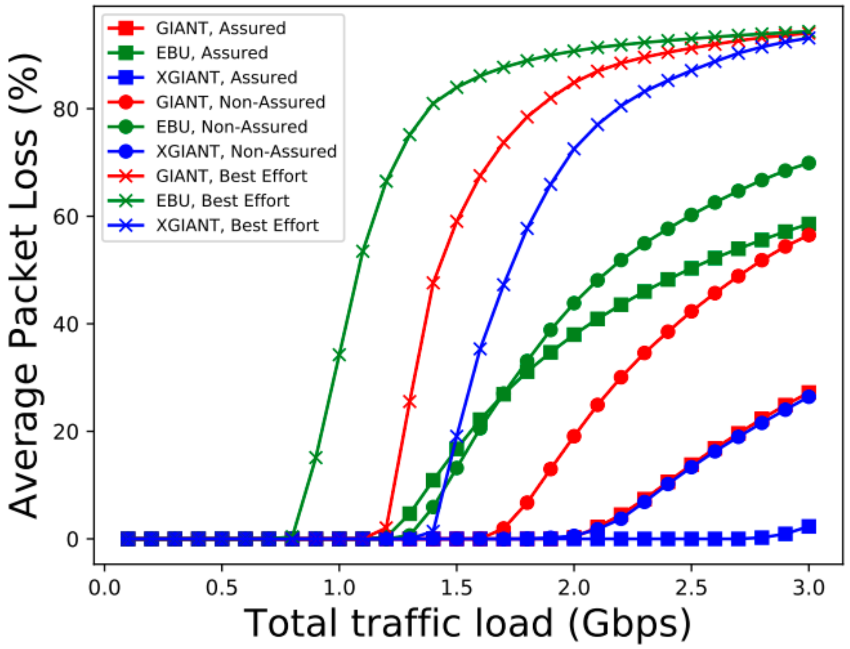


Figure 30: Frame Loss for GIANT, EBU and XGIANT

In Figure 30, you can see the frame loss that occurred when each of the three VNOs ran its DBA algorithms independently. This figure provides a comprehensive analysis of the three DBAs, allowing for the identification of the DBA that is the superior option. Apart from the Best Effort of the EBU, which exhibits frame loss at 0.8 Gbps, all the DBAs show frame loss after 1 Gbps, which indicates that BestEffort is suffering from severe starvation. After that, GIANT and then later XGIANT are both put in a position where they must starve. The fact that XGIANT is seen to have the lowest amount of frame loss in comparison to any of the other DBA makes it abundantly evident that it may be utilized for the consumers' stringent latency needs.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In the course of this research study, we have created fully customized and unconstrained DBAs that are co-existing at the OLT in order to facilitate multi-tenancy and multi-services in access networks. They are able to have complete power over the scheduling of their upstream traffic because the many virtual network operators create individualized frame-level allocations across the shared PON infrastructure.

Each operator executes its own DBA algorithm, and each virtual DBA creates its own virtual BMap. These two sets of data are then merged together at the OLT by the merging engine, and the resulting single physical BMap is used for the entirety of the upstream transmission. Following the slicing of a single frame, each operator is given a distinct section of that frame to use for the transmission of their data.

After that, the users that belong to that operator will transmit in the slots of the frame that were assigned to them by the merging engine. The merging engine is responsible for the difficult task of integrating several virtual BMaps that were sent separately by the DBAs of the VNOs into one final allocation, resolving any conflicts that may arise between the virtual BMaps. Because of this, there is a significant impact not just on the operators but also on the users. Because the resources are shared, there is less investment required, as opposed to the operators having to install the entire fiber infrastructure on their own.

When there are two operators, the findings are evaluated one way, and when there are three operators, the results are studied another way. Due to the fact that each operator is responsible for their own unique DBAs, the findings demonstrate that adding more operators does not significantly impact the overall performance. Up until the maximum connection capacity is achieved, no packets are ever lost; however, after this point, each traffic type experiences a proportionate amount of frame loss. The decision that each operator makes on the DBA to use in relation to the services that are being provided might have an effect on the overall performance measurements. Therefore, depending on the particular DBA and the loads that are delivered, different VNOs experience different amounts of latency and packet loss. As a result, VNOs may make use of it to offer a variety of services that are tailored to the QoS requirements of their customers.

6.2 Future Work

In the future, we want to extend our work to enable 5G FrontHaul networks using network slicing based on TDM-PON. Network slicing is a cost-effective technique that can essentially isolate each subnetwork while still utilizing a single TDM-PON. Network slicing results in the generation of three distinct forms of traffic, which is necessary to satisfy the numerous demands placed on 5G services:

- Improved mobile broadband service (eMBB)
- Connections that are extremely dependable and have a short delay (uRLLC)
- Communications of the massive machine variety (mMTC)

We will also extend this work to include multi wavelength dynamic bandwidth allocation using orthogonal and non-orthogonal multi access in our vPON environment to cater to the requirements of the high-capacity and delay-sensitive applications [35].

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