# Investigation of FTTH Architectures Based on Passive Optical Networks

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# CERTIFICATE

I, Deeksha, hereby certify that the work which is being presented in this thesis entitled, **"Investigation of FTTH Architectures Based on Passive Optical Networks"**, by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of **Dr. R. S. Kaler.**

The matter presented in this thesis has not been submitted in any other University / Institute for the award of any other degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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# ABSTRACT

Fiber based access networks can deliver performance that can support the increasing demands for high speed connections. One of the new technologies that have emerged in recent years is Passive Optical Networks. Fiber-to-the-home (FTTH) is experiencing great public acceptance throughout the world. To satisfy future bandwidth demands, existing fiber-to-the-home (FTTH) access networks must be upgraded. Since the lifetime of a passive optical network (PON) is expected to be greater than 25 years, replacing the existing PON infrastructure is not desirable when upgrading the network throughput. In this thesis, we propose inexpensive solutions for next generation PONs using the existing passive splitter-based infrastructure. This master's thesis aims to explain the design and planning of a PON. The main idea of this project is to build a fictitious environment that will allow us to study in depth about FTTH networks and decide which is the most optimal option for this environment.

First of all, a network architecture based on FTTH systems with GEPON (Gigabit Ethernet Passive Optical Networks) access is presented. This architecture is targeted to deliver a very high speed, end to end optical communication between the edge notes connecting the end users. This transmission allows the simultaneous delivery of triple play service (data, voice and video). The comparative investigation and suitability of various data rates is presented. It has been observed that the proposed system is most suitable at data rate of 2 Gbps. It is demonstrated that as we increase the data rate, number of users to be accommodated decreases due to increase in bit error rate. Also it is demonstrated that as we increase the distance of transmission the value of bit error rate increases which is undesirable.

In second case, another network architecture based on FTTH system access with 10 Gbps data rate is presented. This architecture is responsible for end to end simultaneous transmission of voice and data for 56 ONUs. The comparative investigation and suitability of various optical modulation formats for internet and voice over IP transmission is also presented. It has been observed that the most suitable modulator is Optical $\sin^2$ modulation. Also the use of semiconductor optical amplifier helps in increasing the transmission distance up to a larger extent

In last section, we present a bidirectional PON based FTTH architecture. This architecture provides uplink and downlink transmission at different data rates according to various PON standards. The system utilizes a Travelling wave Semiconductor Optical Amplifier (TSOA). It is observed from the BER results that the performance of our scheme is good for 10 Gbps system for downstream transmission as it accommodates 64 ONUs. So this scheme is a practical solution to meet the data rate of the optical links simultaneously in tomorrow's PON access networks.

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| | |
|---|---|
| FTTH | Fiber To The Home |
| FTTN | Fiber To The Node |
| FTTB | Fiber To The Building |
| FTTC | Fiber To The Curb |
| FTTP | Fiber To The Premises |
| PON | Passive Optical Network |
| GEPON | Gigabit Ethernet Passive Optical Network |
| BPON | Broadband Passive Optical Network |
| GPON | Gigabit Passive Optical Network |
| CO | Central Office |
| DSL | Digital Subscriber Line |
| CATV | Cable Television |
| VDSL | Very high bit rate DSL |
| AON | Active Optical Network |
| P2P | Point to Point |
| P2MP | Point to Multi Point |
| OLT | Optical Line Terminal |
| ONU | Optical Network Unit |
| RN | Remote Node |
| ITU | International Telecommunication Union |
| TDM | Time Division Multiplexing |
| WDM | Wavelength Division Multiplexing |
| SCM | Sub Carrier Multiplexing |

| | |
|---|---|
| OCDM | Optical Code division Multiplexing |
| FSAN | Full Service Access Network |
| AES | Advanced Encryption Standard |
| MAC | Media Access Control |
| SOA | Semiconductor Optical Amplifier |
| APD | Avalanche Photo Diode |
| EML | Externally Modulated Laser |
| DML | Direct Modulated Laser |

# CHAPTER 1

# INTRODUCTION

## 1.1 Development of Fiber Optic Systems

With the advancement in the communication systems, there is a need for large bandwidth to send more data at higher speed. Residential subscribers demand high speed network for voice and media-rich services. Similarly, corporate subscribers demand broadband infrastructure so that they can extend their local-area networks to the Internet backbone. This demands the networks of higher capacities at lower costs. Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution [1]. Progressing from the copper wire of a century ago to today's fiber optic cable, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas [2]. Optical communication technology gives the solution for higher bandwidth. By developing the optical networks, larger transmission capacity at longer transmission distance can be achieved. To accomplish higher data rates, these optical networks will be required fast and efficient wavelength conversion, multiplexing, optical splitter, optical combiner, arithmetic processing and add-drop function *etc.*

In fiber optic communication, there is degradation of transmission signal with increased distance [1]. To remove loss limitations, optical amplifiers are used which directly amplify the transmitter optical signal without converting it into electric forms. The optical amplifiers are used in linear mode as repeaters, optical gain blocks and optical pre-amplifiers. The optical amplifiers are also used in nonlinear mode as optical gates, pulse shaper and routing switches. The optical amplifiers are mainly used for amplification of all channels simultaneously in WDM light wave system called as optical in-line amplifiers. The optical amplifiers are also bit rate transparent and can amplify signals at different wavelengths simultaneously. The optical amplifier increases the transmitter power by placing an amplifier just after the transmitter called power booster. The transmission distance can also be increased by putting an amplifier just before the receiver to boost the received power [2]. The optical amplifier magnifies a signal immediately before it reaches the receiver called as optical pre- amplifier.

## 1.2 What is FTTH (Fiber To The Home)?

The access network, also known as the “first-mile network,” connects the service provider central offices (COs) to businesses and residential subscribers. This network is also referred to in the literature as the subscriber access network, or the local loop [3]. The bandwidth demand in the access network has been increasing rapidly over the past several years. Residential subscribers demand first-mile access solutions that have high bandwidth and offer media-rich services. Similarly, corporate users demand broadband infrastructure through which they can connect their local-area networks to the Internet backbone. It is estimated that there would be a bandwidth demand of 1 Gbps or more, around year 2020, and over 10 Gbps in year 2030. The bandwidth need is shown in Figure 1.1.

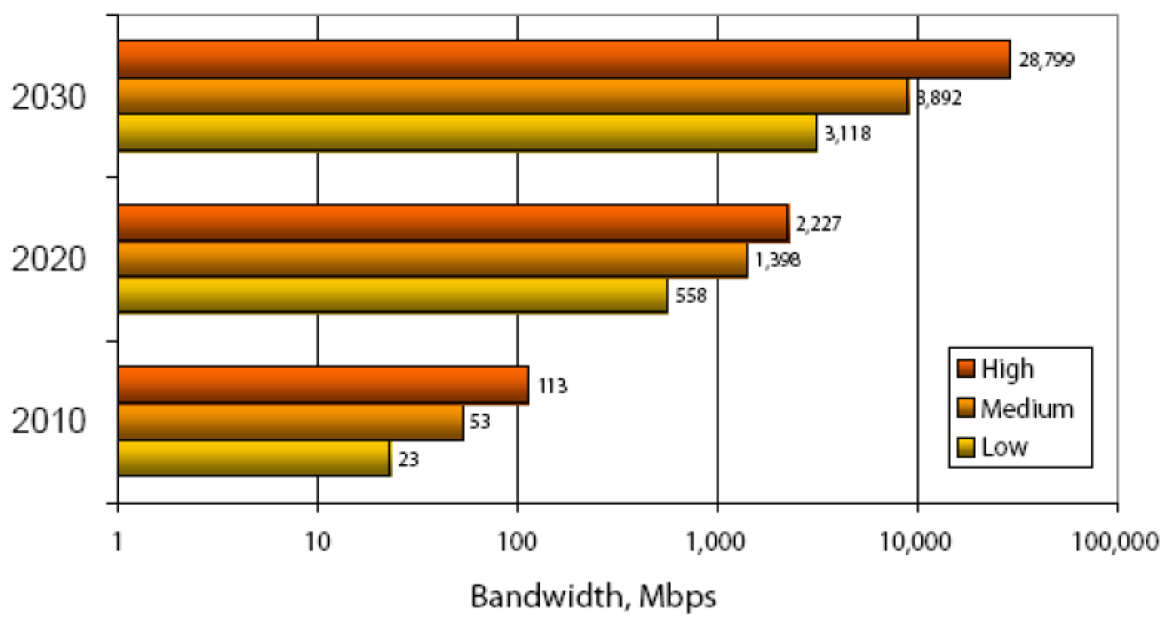


**Figure 1.1: Projections of needed bandwidth in the future [4]**

The predominant broadband access solutions deployed today are the digital subscriber line (DSL) and community antenna television (CATV) (cable TV) based networks. However, both of these technologies have limitations because they are based on infrastructure that was originally built for carrying voice and analog TV signals, respectively; but their retrofitted versions to carry data are not optimal. Currently deployed blends of asymmetric DSL (ADSL) technologies provide 1.5 Mbits/s of downstream bandwidth and 128 Kbits/s of upstream bandwidth at best. Moreover, the distance of any DSL subscriber to a CO must be less than 18000 ft because of signal distortions [5]. Although variations of DSL such as very-high-bit-rate DSL (VDSL), which can support up to 50 Mbits/s of downstream bandwidth, are gradually emerging, these technologies have much more severe distance limitations. For example, the maximum distance over which VDSL can be supported is limited to 1500 ft. CATV networks provide Internet services by dedicating some radio frequency (RF) channels in a coaxial cable for data. However, CATV networks are mainly built for delivering broadcast services, so they don't fit well for the bidirectional communication model of a data network. At high load, the network's performances usually frustrating to end users.

Demand for a new generation of bandwidth-hungry services and triple-play delivery to customers (voice, data, and video) ignited fierce competition among US service providers of all kinds. These developments motivated service providers worldwide to invest in FTTx (Fiber To The x). FTTx is an acronym that embraces a number of optical access technologies, such as Fiber To The Node (FTTN), Fiber To The Curb (FTTC), Fiber To The Business–or Building–(FTTB), Fiber To The Home (FTTH), and Fiber To The Premises (FTTP). Depending on the physical point in the field where fiber terminates and interfaces with copper and/or equipment, FTTH may take any of these flavors and architectures. Different FTTH architectures can be realized using different protocols and technologies. Indeed, FTTH can be classified using a couple of other methods [6].

## 1.3 FTTH Architecture

When building a FTTH network, it would certainly be important to evaluate what FTTH architectures may be appropriate to adopt. This is important even if it is not related to new developments. However, new developments provide a good opportunity to evaluate and implement the optimal system that is cost effective and satisfies future demands from a FTTH network. Here, we focus on different architectures that are adopted by the FTTH Industry [6]. There are mainly two FTTH architectures that are of current interest, which are namely point-to-point architecture (P2P), and the point to multipoint (P2MP) architectures which are further classified as Active Optical Network (AON), and Passive Optical Network (PON).

## 1.4 Point-to-Point (P2P) Architecture

In this architecture, as the name suggests, individual fiber run from the Optical Line Termination (OLT) to each Optical User Unit (ONU). In other words, individual fiber runs to each home (therefore also often just called "home-run fiber") [7]. Figure 1.2 is an illustration of the P2P architecture, where a separate fiber-pair is laid from the OLT to an ONU.

P2P architecture has its advantages as well as certain major drawbacks. One advantage is the opportunity to provide the ultimate capacity, and satisfy each customer's requirements completely. Individual fiber pair also means greater flexibility in providing services to customers [8]. There are however some major drawbacks with the P2P architecture. At the OLT, the need for hub equipment will scale with number of ONUs (i.e. homes or subscribers). Besides the cost of acquisition, these equipments may also cause problems in connection with space and power consumption. P2P solution also requires many fiber pairs, and with these all the installation and maintenance [7].

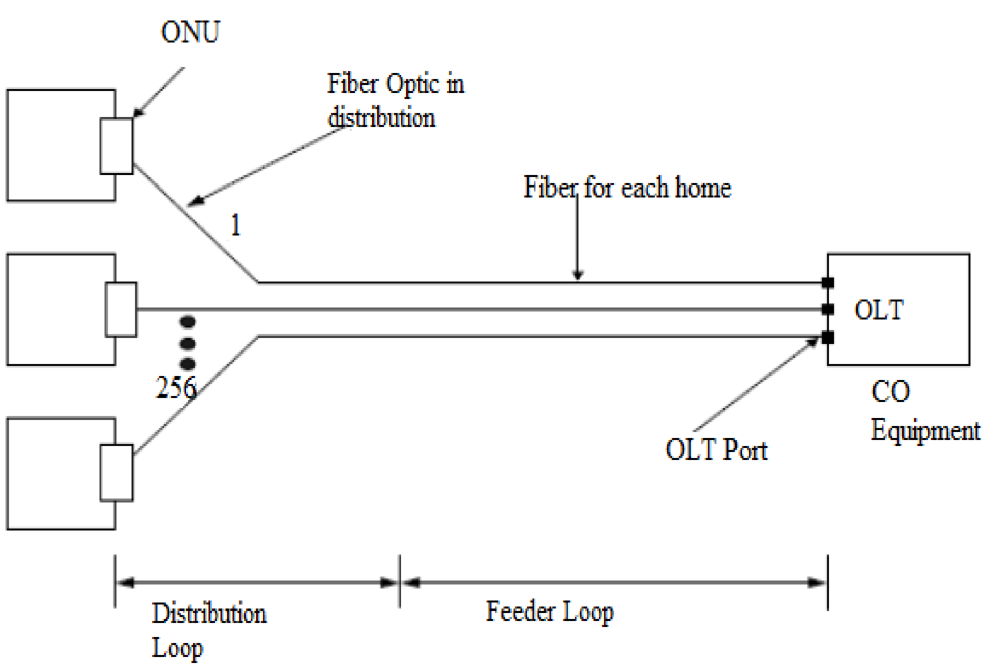


**Figure 1.2: Point-to-point (P2P) architecture [9]**

## 1.5 Active Optical Network (AON)

AON is characterized by a single fiber which carries all traffic to a remote node (RN) close to the end users from the central office [7]. It is also often denoted as Active Ethernet Network, since equipment needed to provide TV, telephony and Internet are connected through the common Ethernet standard.

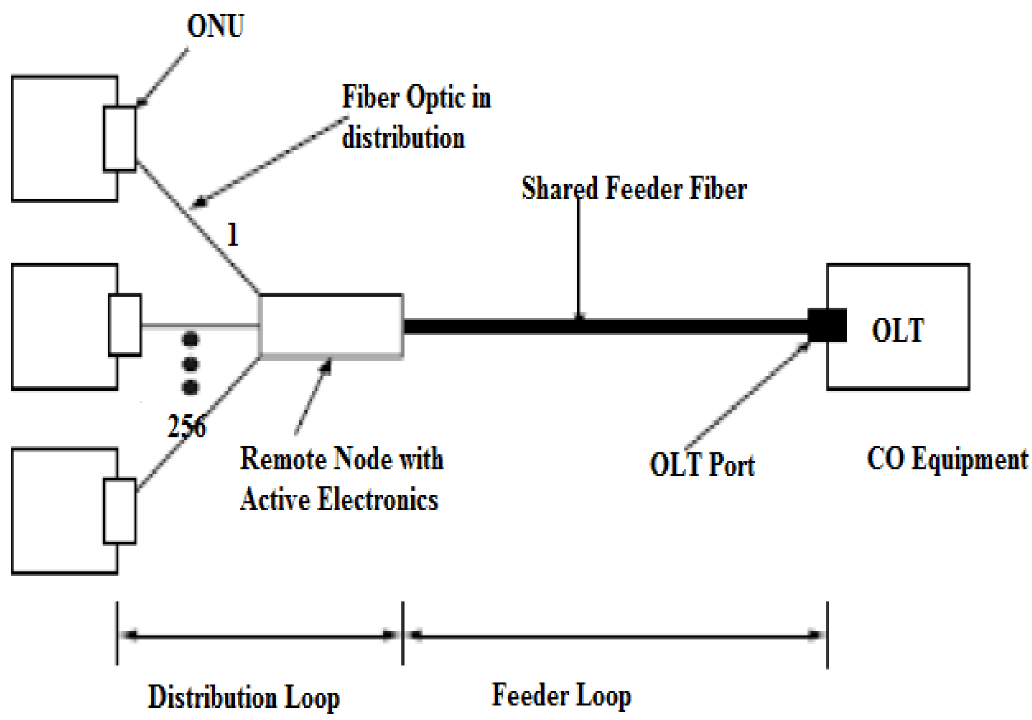


**Figure 1.3: Active Optical Network (AON) [9]**

The remote node contains an active element, which processes the data frames that are sent from the central office (OLT) to the remote node, and forwards only frames to the respective network units (ONUs). From the remote node to network units, individual fibers are run to each cabinet/curb, home, building etc. based on the type of solution that is implemented. Figure 1.3 shows the main components and functions of the AON architecture.

Compared to the P2P architecture, the AON architecture's main advantage is that it is only used a single shared fiber to cover a certain area, thus reducing the fiber cost. It also scales better than the P2P model [7].

### 1.6 Passive Optical Network (PON)

In this architecture, the active node from AON is replaced with a passive optical power splitter/combiner (only noted as splitter from here on); see Figure 1.4. The splitter is denoted as passive since it just broadcasts all the data that it receives. Like the AON, there is a single shared feeder fiber from the OLT to the splitter. The task of sorting out the right packets that belongs to each subscriber lies within the network units (ONTs) in the PON model. OLT is very important segment of PON. It can be said that it acts as a "brain" of a PON network. The most important functions that OLT perform are traffic scheduling, buffer control and bandwidth allocation Because of the additional data processing task, ONUs in a PON model are usually costlier than in AON [10].

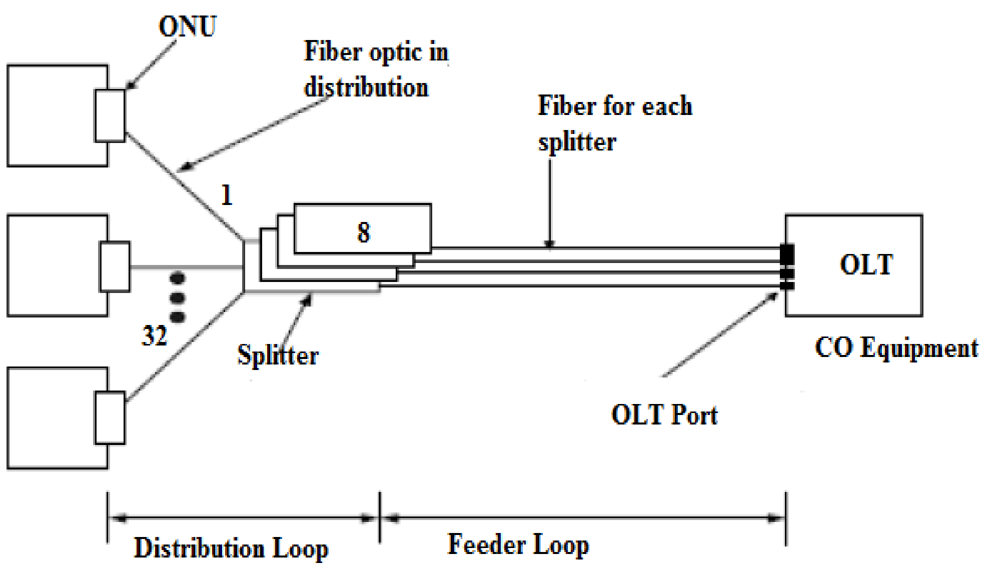


**Figure 1.4: Passive Optical Network (PON) [9]**

Today there are two primary types of standardized passive optical network technologies, Ethernet Passive Optical Networks (EPONs), and Gigabit-capable Passive Optical Networks (GPONs). EPON is standardized by IEEE, and is a category of networks based on the Ethernet technique [11]. An EPON combines the low-cost Ethernet equipment and fiber infrastructure, and transmits Ethernet data frames directly. It can provide 1 Gbps capacity in both upstream and downstream directions, and cover a distance of up to 20 km and support 20 km maximal differential distance [12]. These features enable EPONs to transmit data, voice and video traffic efficiently in an integrated network. In contrast, GPON evolves from the ATM PON (APON/BPON) technique, and is standardized by

ITU-T under work of the Full-Service Access Network (FSAN) group. Compared to EPONs, a GPON can support higher data rate, up to 2.488 Gbps for both downstream and upstream. It can cover a longer distance, up to 60 km, and support a differential distance of up to 20 km [13].

Upstream from the different users to the OLT must be allocated by some kind of multiple access technique to avoid collision between the different streams. All the PON standards mentioned above use Time Division Multiplexing (TDM) techniques, which means that the upstream packets are interleaved on a time basis, through the shared fiber.

In addition to TDM, there are three major multiplexing techniques for fiber access networks [12]: Wavelength Division Multiplexing (WDM), Sub Carrier Multiplexing (SCM) and Optical Code Division Multiplexing (OCDM). In WDM-PONs, each ONU uses a different wavelength channel to send its packets to the OLT. The same wavelength channel can be used for both upstream and downstream communication. In a SCM-based PON, each ONU modulates its packet stream on a different electrical carrier frequency, which subsequently modulates the light intensity of the ONU's laser diode. This means that the packet streams are placed into different frequency bands. In an OCDM-based PON each ONU uses a different signal sequence of optical pulses. This signal sequence is on-off modulated with the data to be transmitted [12].

TDM is currently the most popular multiplexing method for building a PON infrastructure. This is associated with the fact that the TDM technology has a moderate technical complexity, and costs less to implement than the other techniques [11]. On the other hand, while TMD-based PONs at present moment appear to be satisfactory for current bandwidth demands, future bandwidth projections and other trends in the broadband domain shows that other multiplexing techniques could be more favorable for a more future proof fiber based access network.

## 1.7 The PON Standards Overview

The existing PON standards are the results of efforts of two different groups of network providers and equipment vendors. The standards represent the different views and attitudes of these groups towards the problem and the possible future of the telecommunication market.

### 1.7.1 Broadband PON Standard

The Broadband Passive Optical Network (BPON) [14] standard was introduced first in 1999; it was accepted by the International Telecommunications Union (ITU). The standard was endorsed by a number of network providers and equipment vendors which cooperated together in the Full Service Access Network (FSAN) 1 group. The FSAN group proposed that the ATM protocol should be used to carry user data; hence sometimes access networks based on this standard are referred to as APONs [15, 16].

The architecture of the BPON is very flexible and adapts well to different scenarios. The underlying ATM protocol provides support for different types of service by means of adaptation layers [17]. The small size of ATM cells and the use of virtual channels and links allow the allocation of available bandwidth to end users with a fine granularity. Moreover, the deployment of ATM in a backbone of metropolitan networks and easy mapping into SDH/SONET containers allow the use of only one protocol from one end user to another.

Yet, the advantages of ATM proved to be the main obstacle in deployment of BPON and despite many field trails [18] BPON did not gain much popularity. The complexity of the ATM protocol made it difficult to implement and in many cases superfluous. The much simpler, data only oriented Ethernet protocol found a widespread use in local area networks and started to replace ATM in many metropolitan area and backbone networks [19].

### 1.7.2 Gigabit PON Standard

Progress in the technology, need for larger bandwidths and the unquestionable complexity of ATM forced the FSAN group to revise their approach. As a result a new standard called Gigabit Passive Optical Network (GPON) [20] was released and adopted by the ITU in 2003. The GPON’s functionality was heavily based on its predecessor, although it is no longer reliant on ATM as an underlying protocol. Instead a much simpler Generic Framing Procedure (GFP) is used to provide support for both voice and data oriented services. A big advantage of the GPON over other schemes is that interfaces to all main services are provided. Employing GFP guaranteed that packets belonging to different protocols could be transmitted in their native formats.

Functionality was also provided which allowed seamless interoperability with other GPONs or BPONs. As in modern networks the security of transmitted data is a key issue. A sophisticated mechanism based on the Advanced Encryption Standard (AES) and a complex exchange of unique keys was built into the GPON architecture.

In comparison with the BPON standard much higher transmission rates are specified, the GPON being capable of supporting transfer rates of up to 2.48 Gbps in the downstream as well as the upstream direction.

### 1.7.3 Ethernet PON Standard

The EPON standard is the result of work in the vendor driven cooperation, the Ethernet in the First Mile Alliance (EFMA). Noticing that the majority of traffic in the network is data oriented and that efficient mechanisms enabling support for real time services were in place, the group decided that the sophisticated functionality of the BPON and GPON protocols was no longer needed. Instead, as the Ethernet protocol had became widespread and had a dominant role in the data oriented local and metropolitan networks [21], the EFMA decided to promote its functionality in PONs. The final version of the new protocol and necessary amendments to the existing ones were accepted by the standards body and released as IEEE 802.3ah in September 2004 [20]. The main goal was to achieve a full compatibility with other Ethernet based networks. Hence, the functionality of Ethernet's Media Access Control (MAC) layer is maintained and extensions are provided to encompass the features of PONs. The achieved solution is simple and straightforward, and allows legacy equipment and technologies to be reused.

## 1.8 OptSim

The core version of OptSim was first developed in 1983 by the Optical Communication Group of Politecnico di Torino [22]. The optical simulation software was originally known as TopSim, a transmission system simulation package, which was developed for mobile and satellite communication. TopSim was furthered improved with the addition of a library for optical systems and after continuous refinement efforts by the simulation specialists of Politecnico di Torino, the simulation software was later known as OptSim. OptSim is an advanced vectorial fiber simulator tool that takes into account all important phenomena including fiber loss, chromatic dispersion, birefringence, polarization mode dispersion (PMD), Kerr non-linearity and amplified spontaneous emission accumulation. OptSim is a simulator that is capable of calculating more than 15,000 km of non-linear fiber with high precision in a reasonable time. The fiber is simulated by solving the nonlinear Schrodinger equation using a modified version of the standard Split-Step Fourier (SSF) method, which solve the problems related to the cyclical numerical convolution effects intrinsic to the standard SSF method by implementing a true linear numerical convolution by means of component processing techniques (overlap-and-add algorithm) [23]. This method has allowed extremely long fiber links to be simulated on a large window (thousand of bits at standard bit rates) with excellent accuracy. OptSim is actually the fastest simulator because all the simulation components are based on a time domain computation [22]. With OptSim, it is possible to model very closely a "real" ultra-long haul system and achieve realistic results. In addition, continuous refinement of the design parameters can be performed to achieve optimal results, which is difficult to perform in the hardware implementation environment because it can be costly, time consuming and relatively inflexible.

### 1.8.1 System Requirements for OptSim:

The Windows versions require for OptSim Windows 2000/XP. OptSim is not guaranteed to work under Windows 95/98/NT. OptSim will also run under Linux and various UNIX using X Windows or XFree86 and Motif. Hardware requirements areas follow [24]:

• Pentium II 400 MHz

• Minimum of 64 Mbytes of RAM for data processing. 128 Mbytes of RAM for faster processing time.

• 100 Mbytes of free space for complete OptSim installation.

• A PostScript compatible printer to print the schematics or graphs created with OptSim.

• A Color graphic display with resolution of 1024x768 pixels or higher.

# CHAPTER 2

# LITERATURE REVIEW

Important decisive factors are cost, satisfaction of future bandwidth demands and scalable architecture. The adopted technology should also allow for improvements and replacements with future network components. Hence, it is advisable for one to concentrate on the P2MP architectures. Therefore, the main focus of our literature review is on PON (Passive Optical Networks).

## 2.1 Literature Survey

P. Chanclou *et al.* [25] reported broadband optical access network evolution including high speed interfaces for fixed and mobile services. The impact of network access evolution on network architecture and transmission equipment localization on the metropolitan network was also mentioned. Some technical challenges were also discussed, namely concerning the optical extended budget, as well as the impact of access evolution on the metropolitan network. They have described a possible evolution of the optical access networks using optical budget extension in order to optimize the number of optical central offices. The issues of central office location were presented in function of customer eligibility. Convergence of radio and fiber technologies was also discussed, as possible topics of network development.

Josep Prat [26] investigated a feasible evolutionary path for FTTH passive access networks (PON), proposing a set of technical solutions that could potentially and remarkably reduce the individual cost, per user and per Mbps. Advanced FTTH access networks, based on new transmission concepts and advanced subsystems, were proposed and analyzed, being characterized by a higher density of users served per feeder fiber, extended distance reach to the metropolitan area, bidirectional single fiber, centralized control, guaranteed bandwidth per user of tens/hundreds of Mbps, passive protection and, above all, low cost potentiality. With this aim, some novel devices like remote optical amplification in the passive network, hybrid WDM-TDM multiplexing, reflective ONU, bidirectional single fiber transmission, direct FSK/IM laser modulation and fast widely tunable lasers among others, were also implemented.

Frank Effenberger *et al.* [27] reviewed that Passive optical networks are the most important class of fiber access systems in the world. They outlined in some depth the technologies used to implement this architecture, including the G-PON and E-PON systems being deployed, and the advanced PON systems that provide the evolution path to ever higher bandwidths. This article has outlined the current and next generations of PON technologies. While there were considerable differences between these systems, there were also striking similarities. This should be no surprise, as they share the same fiber medium and physical topology. Fundamentally, the differences amount to an issue of design style and base technology choice, rather than anything profound. As the deployment of PONs grows into the many millions of homes served, it can be seen that a new era of access networks is upon us. The 100-year history of the copper network is finally coming to an end, and the age of the PON has begun.

U. Ibrahim *et al.* [13] evaluated WDM-PON access network architecture accommodating 32 users successfully. Results affirmed that network performance degrades more linearly over increasing secondary SMF lengths when APDs are used compared to exponential decay in signal quality which was found to be the case using PIN photo receivers. Simulation work revealed that performance gains of around 15km in terms of system reach and up to 5 Gbps in terms of data carrying capacity per user can be attained if APDs are used at the receiver side in downstream direction.

Rajneesh Kaler *et al.* [28] simulated an optimized GE-PON based FTTH access network to provide residential subscribers with full services. They described the requirements of GE-PON access network with considerations of services and PON specific layered functions. To satisfy those requirements, they simulated an optimized architecture and describe the detailed functions of major elements. Finally, they consider the major technical issues i.e. BER to realize the GEPON based FTTH access network. Considering the future prospect of FTTH access network, the FTTH would be motivated by the following factors. There would be no need for outdoor cabinet sites, resulting in simpler network configuration and operation. No change of intermediate ONU would be required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services. Maintenance would be easy, because it requires maintenance only for fiber systems, and fiber systems are regarded more reliable than hybrid fiber-metal ones. FTTH is a driver for the development of advances optoelectronics technologies, and the great volume in production of optical modules will also accelerate the reduction in cost.

Erik Weisa *et al.* [29] reviewed on a FTTH field trial with GPON (Gigabit-capable passive optical network) technology in the network of Deutsche Telekom in the region of the cities of Berlin and Potsdam. Focus of this trial was to gain practical experience regarding GPON technology, fiber installation in existing ducts with micro duct technology, fiber cabling in customer buildings and impact on operational processes. Furthermore it was reported on an initial Deutsche Telekom FTTB deployment based on GPON technology in the city of Dresden with the main targets to obtain practical deployment and operation experiences with fiber-based access networks and to provide broadband access to a part of the city formerly not servable by DSL (digital subscriber line) technology.

Ali Nouroozifar *et al.* [30] demonstrated an upstream bandwidth allocation algorithm for QoS provisioning in the newly emerged EPON. Based on the agreed guaranteed delay for various traffic types, traffic had been categorized into three profiles with different delays. They showed that various customer applications requirements can be satisfied and services can be prioritized and granted to the customers. Through simulation results, it had been shown that various triple-play traffic can be categorized into three different profiles and with fulfilling the delay requirement of these services they achieved an efficient bandwidth allocation. EPON is being considered as one of the best catalyst for the famous “Last Mile” problem. Ethernet Passive Optical Networks (EPON) is leveraging the access networks by using the mass available Ethernet technology in the LANs and hence lower cost and the already deployed fiber infrastructure. EPON scalability provides both service providers and customers to scale from Mbps rates up to Gbps rates.

M. Massoud Karbassian *et al.* [31] proposed a novel architecture for coherent optical code-division multiple-access passive optical networks (OCDMA-PON). As optical spreading sequences, a recently introduced prime code family hereby referred to as double-padded modified prime code (DPMPC) had been employed and analyzed. The transceivers operate under homodyne dual-balanced detection scheme. For coherent modulation, binary phase-shift keying was employed where the phase is modulated by Mach–Zehnder external phase-modulator. The proposed architecture for optical network units and line terminals were also presented and analyzed. The network scalability of fiber link distances as well as bit-error rate, considering 1) fiber link noise e.g., amplifier spontaneous emission noise; 2) thermal noise; 3) photo-detectors' shot-noise; 4) relative intensity noise; and 5) mainly multiple-access interference, had been investigated. The results had indicated that this architecture can improve the network scalability, capacity and transmission performance, leading to the promising scheme for optical transport networks.

Bernhard Schrenk *et al.* [32] investigated Optical Network Units for Next-Generation Passive Optical Networks with wavelength reuse for asymmetrical 2.5G/1.25G and symmetrical 10G/10G down- and upstream data rates. The transmission performance was enhanced by a feed-forward cancellation circuitry adapted to an RSOA and an REAM used as remodulator. The range of downstream extinction ratios for error-free upstream transmission at BER of 10-10 was extended from 3 to 4 dB for the RSOA-based ONU and from 1.5 to 3 dB for the REAM-based ONU.

Liu Yang *et al.* [33] reported that with a good DBA algorithm, the GPON upstream channel can be oversubscribed, thus increasing the number of ONUs/ONTs that can connect to the network as well, the data rates to subscribers can be supported and the service provider can charge for the full bandwidth service to multiple users. In this investigation a new algorithm was proposed to allocate the bandwidth of the upstream channel for the GPON. The improved DBA algorithm based on the all the T-CONT, and using the polling algorithm to solution the increase the channel utilization. Finally, simulation results showed that the average delay can satisfy the full service QoS requirements of GPON.

Sebastia Sallent *et al.* [34] studied the upgrading problem of existing Passive Optical Networks (PONs) that need to increase their capacity at different points in time. Their method upgraded line rates and migrated network services over new wavelength channels based on increasing traffic demand and cost constraints. Method minimized capital expenses and system disruptions, while ensuring effective resource usage. Their multistep model used Mixed Integer Linear Program (MILP) formulations whose cost parameters are set by a pricing policy. They evaluated the PON upgrade through installation of single-wavelength transceivers or multiple-wavelength arrays of transceivers.

Navid Ghazisaidi *et al.* [11] reviewed that Passive optical networks (PONs) are currently evolving into next-generation PONs (NG-PONs) which aim at achieving higher data rates, wavelength channel counts, number of optical network units (ONUs), and extended coverage compared to their conventional counterparts. Due to the increased number of stages and ONUs, NG-PONs face significant challenges to provide the same level of survivability like conventional PONs without exceeding the budget constraints of cost-sensitive access networks. Toward this end, partial optical protection, in combination with interconnecting a subset of ONUs through a wireless mesh network (WMN) front-end, are promising solutions to render NG-PONs survivable in a cost-effective manner. In this analysis, they reported a probabilistic analysis of the survivability of NG-PONs and hybrid fiber-wireless (FiWi) access networks, taking both optical and wireless protection into account. In addition, they proposed different selection schemes to wirelessly upgrade a subset of ONUs, and investigate their performance for a wide range of fiber link failure scenarios and different NG-PON topologies.

Claudio Rodrigues *et al.* [35] reviewed and compared the current gigabit passive optical networks (GPON) fiber to the home (FTTH) based solution, and discussed an evolution scenario to future next generation PONs (XGPONs) and wavelength division multiplexing PONs (WDM-PONs) from an operator point-of-view, i.e., taking into account standardization, wavelength planning, optical line terminal as well as optical network terminal equipment and transmission convergence layer. They also compared solutions for the provision of quintuple play services over orthogonal frequency division multiplexing (OFDM) in several aspects such as equipment requirements, capacity to the end user and limitations. It was shown that GPON based networks cannot provide the long-term bit-rate requirements of users in the future and that a pure WDM-PON network (that is, not coexisting with GPON/XGPON) is the solution that best meets these requirements.

Anis Ouali *et al.* [36] reported a mixed integer linear programming (MILP) approach to demonstrate how this technique can be applied to automate the FTTH designs, hence reducing the capital expenditure (CAPEX) of telecoms companies. Different network examples illustrating optimal or near optimal placement of network elements such as splitters and distribution points and cable assignments for different network elements were provided. They demonstrated the feasibility of FTTH network designs using the mixed integer linear programming approach. Results showed that the generated locations of cable distribution points and splitter nodes were well ordered with a satisfactory degree of symmetry. In addition, the short computational time to solve the given networks reported the advantage of applying MILP to automate the FTTH network problem.

Kaharudin Dimyatt *et al.* [37] investigated the performance of a novel 2.5 Gbps FTTH-PON Network architecture which employed a passive optical booster configuration for future user scaling. The passive booster configuration used an NxN AWG and exploits its cyclical routing table which was made possible by the device's Free Spectral Range (FSR) property configuration for future user and services scaling. The new configuration was compared with a conventional access network configuration which is based on the FTTH-EPON standard.

Jun-ichi Kani *et al.* [38] proposed a novel and simply configured broad-band optical access network that uses coherence multiplexing (CM) and half-duplex bidirectional transmission. It allowed the on-demand use of broad bandwidth on existing fiber-to-the-home (FTTH) access lines. The design of the proposed CM network considered degradation factors in CM systems. The first analysis was a numerical simulation to optimize the tradeoff between available user number and fiber dispersion degradation, and the second estimated acceptable access-line loss in the network. This study proved that the capacity of existing FTTH access lines that employ star couplers can be significantly enhanced.

Sandeep Singh *et al.* [39] demonstrated a transmission system for triple play (voice, video, and data) with centralized orthogonal frequency division multiplexing-fiber to the home broadband passive optical network (OFDM-FTTH-BPON) based on an external modulator. At the one of two arms of system, voice and internet data were transmitted using Pseudo random binary sequence (PRBS) generator at bit rate of 1.25 Gbps. In another arm of system, video was transmitted with the help of 4 QAM modulated OFDM signal. The 1.25 Gbps voice signal, 1.25 Gbps data signal and 10 Gbps video signal had been transmitted over 20km single mode fiber (SMF) successfully.

Sandis Spolitis *et al.* [40] reported that the maximum reach of the Dense Wavelength-Division-Multiplexed Passive Optical Network (DWDM-PON) system can be severely limited by chromatic dispersion (CD). Their research contained the investigation of long-reach high speed 16-channel DWDM-PON system with efficient CD compensation methods. It was shown that chromatic dispersion compensation has a crucial role for guaranteed downstream optical link performance and maximum link length of high speed long-reach DWDM-PON system. The results showed that usage of additional 7 km long dispersion compensating fiber (DCF) placed in central office improves the DWDM-PON network reach by 19.3% (from 57 km up to 68 km) but usage of fiber Bragg grating (FBG) improves network reach up to 26.3% (from 57 km up to 72 km). As a result, authors recommend the use of FBG for chromatic dispersion compensation to increase the maximum transmission distance of high speed DWDM-PON system.

Juhee Park *et al.* [41] proposed and demonstrated a new in-service fault-localization method for a wavelength division multiplexing passive optical network (WDM-PON). This scheme used a tunable OTDR (optical time domain reflectometry) realized by a wavelength locked Fabry-Perot laser diode. They successfully detected the faults both at the feeder fiber and the drop fibers. The resolution and the dynamic range were 100 m and 12 dB, respectively. In addition, the crosstalk induced by the OTDR signal to the transmission data was negligible. The proposed fault-localization scheme can be realized cost effectively and would be useful to monitor the status of the outside plant of a WDM-PON in-service condition.

Patryk J. *et al.* [42] reported that Reflection and Rayleigh backscattering-induced interferometric crosstalk in a link employing a reflective semiconductor optical amplifier (RSOA) may cause significant power penalty and, thus, limit the performance of the system. They investigated interferometric crosstalk suppression in a centralized light generation wavelength division multiplexing-passive optical network (WDM-PON) by single-tone phase modulation either by utilizing the nonlinear behavior of the RSOA at the optical network unit (ONU) or by applying an external phase modulator at the source side. 6- and 7-dB reduction in power penalty for reflection-induced crosstalk was achieved, respectively. For Rayleigh backscattering-induced crosstalk power penalty was improved with 3 and 4.5 dB, respectively. The results showed that an RSOA is very sensitive to reflections and backscattering and the tolerance to these impairments can be significantly improved by appropriate phase modulation.

Andres Sierra *et al.* [43] presented an overview of TDM and WDM EPON technologies, summarizing their most important merits and differences. Through the use of simulation methods a comparison of both technologies in terms of bandwidth capacity, distance reach ability and scalability was presented. As presented in the simulation results, the differences on the physical layer between the two methods were not significant in terms of performance or reachable distances. Nonetheless, the architectural distinction between the two creates a variance in their capacity, costs and therefore the possible applications. Greater benefit for networks requiring high bandwidth and privacy was obtained when WDM EPON was used. On the other hand, the use of TDM EPON sacrifices bandwidth and privacy but resulted in a more cost-efficient use of network resources.

S.F. Shaukat *et al.* [44] explained that one of their aims was to provide highly scalable solutions to service providers to make fiber reach the end user. An extensive research had been carried out to evaluate a Broadband Passive Optical Network (BPON) for both downstream and upstream traffic to achieve the desired targets. The system was analyzed on the basis of Data Rate, Fiber length, Coding technique, number of users, wavelengths and their effects on Bit Error rate (BER) as the key performance parameter using

Optisystem Simulator version 7. Remarkable results have been achieved and a novel relation had been developed between the data rate and accommodated users. It had been revealed that, in downstream direction, doubling the number of users only requires switching to the lower data rate in order to maintain identical BER effects over the same fiber length. Additionally, the relation had also been tested on Return-to-Zero (RZ) and Non-Return-to-zero (NRZ) coding and was found to be unaffected by coding formats used.

John D. Downie *et al.* [45] demonstrated purely passive long reach (100 km) 10 Gb/s TDM-PON and WDM/TDM-PON systems enabled by the use of ultra-low-loss optical fiber with attenuation 0.17 dB/km and downstream duo binary signal transmission. No in-field optical amplification was required. In both cases, a TDM split ratio up to 1:128 was supported, providing a downstream bandwidth per subscriber of almost 80 Mb/s. Downstream transmission using chirp-managed laser technology was also shown to be feasible for the application, demonstrated in the TDMPON system. Upstream bit rates demonstrated were 1.25 Gb/s and 2.5 Gb/s using a directly modulated laser at the customer site. For the TDM-PON configuration, no FEC was required. For the WDM/TDM-PON configuration, standard FEC may be used for downstream signals with a channel spacing of either 100 GHz or 200 GHz. For the alternative WDM/TDM-PON configuration proposed, no FEC was required as each wavelength is transmitted over a separate fiber, eliminating cross-channel nonlinear effects, but using a high-power amplifier to amplify all channels together before transmission.

Craig Michie, *et al.* [46] summarized a general analysis of the optical link budget for an amplified passive optical network. The analysis extended over other analysis in that it accounts for the fact that significant power is transmitted during a zero, arising from the finite extinction ratio of the source and the fact that the amplifier contributes significant levels of amplified spontaneous emission which is only loosely filtered. It was demonstrated analytically and experimentally that this produces a significant effect. The results revealed that the extinction ratio of the received signal was degraded which is a key performance factor. The general analysis was applied to the case of a PON with splitting ratio before amplification which exceeds the currently deployed PON capability.

## 2.2 Motivation

The steady increase in the demand for broadband services and the consequent increase in the volume of generated traffic in our communication networks have motivated the need to implement next generation networks. Fiber-to-the-home (FTTH) is the end game for many service providers. As compared to other broadband access technologies such as digital subscriber line (DSL), and cable/modem, passive optical network (PON) technology seems to be the best solution to alleviate the bandwidth bottleneck in the access network. From a historical perspective, the first bandwidth breakthrough in the access network was the arrival of DSL and cable based solutions. They provided nearly a 1000-fold increase in data rates over traditional 'dial-up' modems. It is clear that because of the limited bandwidth of a coaxial cable, the complexity of the cable systems is expected to be higher than that of PONs.

We have seen in the review of FTTH networks, a lot of work can be done in better deployment of FTTH architectures in order to achieve large distance of transmission at high bit rates. More users can be accommodated by applying different transmission techniques in the FTTH architecture.

For deployment of access networks, operators are encouraged to invest on a PON infrastructure. Incorporating passive optical networks (PON) offers a good solution to increase the capacity of standard FTTH architectures. Although PON technology is mature for backbone networks, its user handling capacity and longer transmission distance is still considered for access networks. Therefore, there is still a need to solutions for PON in FTTH access networks.

## 2.3 Thesis Objectives

In this thesis the research is carried out keeping in view the following objectives:

1. To investigate Fiber To The Home triple play services at 2 Gbps using GE-PON architecture for 56 ONUs.
2. To investigate GPON based Fiber To The Home architecture at 10Gbps using SOAs and APDs.
3. Investigation on 50km bidirectional FTTH transmission comparing different PON standards.

## 2.4 Thesis Organization

This thesis is composed of six chapters and structure of thesis is as follows:

**Chapter 1** presents the brief overview of FTTH optical access network, passive optical networks and various PON standards.

**Chapter 2** reviews the history of various PON based FTTH standards and provides a literature review related to the FTTH architecture in order to achieve optimized number of users and other factors.

**Chapter 3** provides the investigation of Fiber To The Home at 2Gbps data rate using GE-PON architecture for 56 users. The performance is based on BER characteristics.

**Chapter 4** includes the performance analysis of GPON based Fiber To The Home architecture using SOAs and APDs at 10Gbps.

**Chapter 5** is based on the investigation of 50km bidirectional fiber to the home transmission comparing different PON standards.

**Chapter 6** concludes the work carried out in this thesis with the future prospective of FTTH access networks based on PON standards.

# CHAPTER 3

# Simulation of Fiber to the Home Triple Play Services at 2 Gbit/s using GE-PON architecture for 56 ONUs

In this implementation, we proposed FTTH (Fiber To The Home) GEPON (Gigabit Ethernet Passive Optical Network) link design for 56 subscribers at 20 km reach at 2 Gbps bit rate. A 1:56 splitter is used as a PON (Passive Optical Network) element which creates communication between a Central Office to different users and also a boosting amplifier is employed before fiber length which decreases BER and allows more users to accommodate. This architecture is investigated for different number of users from a CO (Central Office) to the PON in terms of BER (Bit Error Rate). The results at 2 Gbit/s system between the BER and different number of users illustrate that as the number of users increases beyond 56 users the BER comes to unacceptable level and if further increase data rate of system say 5Gbps, then we observe a sharp increase in BER.

## 3.1 Introduction

The next generation technology needs to be compatible with today's bandwidth needs and to also offer bandwidth elasticity to support future growth based on network expansion and new application development. Since optical technology has proven to have large bandwidth capacity, it appears to be the proper choice to solve the bottleneck between backbone and access networks [47]. Thus, several fiber-to-the-home (FTTH) or fiber-to-the-premises (FTTP) networks have been proposed to provide broadband services to the end user. FTTH is simply the 100% deployment of optical fiber in the access network [28]. However, access networks have three great requirements; they must meet high reliability, performance, and be cost efficient. Therefore, it is important to understand which of the proposed FTTH networks meet these requirements better.

To meet the low cost and reliability requirement, FTTH/FTTP networks have employed passive optical components at the customer premises and therefore they are known with a generic term, Passive Optical Networks (PON) [48]. PONs have a tree topology in order to maximize their coverage with minimum network splits, thus reducing optical power

Several architectures have been proposed of Time Division Multiplexing PON (TDM-PON) provides Broadband PON (BPON) with downstream of 622 Mbps [44], Ethernet PON with 1.25 Gbps downstream, & Gigabit PON (GPON) with 2.5 Gbps downstream. Gigabit-capable passive optical network (GPON) is the basic technology to support the structure of the next-generation fiber to the home (FTTH) system and supports multi-speed rates, full services, robust network, high efficiency and other advantages, and considers the suggestions of service providers at the same time [49]. GPON is regarded as one of the best choices for broadband access network in the future.

The cost benefits have enabled increasing deployment of passive optical network delivering fiber to the home. However, in many cases, extended reach requires some form of amplification to overcome the additional losses [46]. In order to increase transmission distance of a system, an amplifier is introduced somewhere between the transmitter and the splitter. Analysis of the effectiveness of the amplifier can be determined by evaluating the Q factor or BER of the system.

Erik Weis et al. [29] reported a FTTH field trial with GPON (Gigabit-capable passive optical network) technology in the network of Deutsche Telekom in the region of the cities of Berlin and Potsdam. Focus of this trial was to gain practical experience regarding GPON technology, fiber installation in existing ducts with micro duct technology, fiber cabling in customer buildings and impact on operational processes. Their main target was to obtain practical deployment and operation experiences with fiber-based access networks and to provide broadband access to a part of the city formerly not servable by DSL (digital subscriber line) technology.

Bernard HL Lee et al. [37] investigated the performance of a novel 2.5Gbps FTTH-PON Network architecture which employs a passive optical booster configuration for future user scaling. The passive booster configuration uses an NxN AWG and exploits its cyclical routing table which is made possible by the device's Free Spectral Range (FSR) property configuration for future user and services scaling. The new configuration is compared with a conventional access network.

Junichi Kani et al. [38] proposed a novel and simply configured broad-band optical access network that uses coherence multiplexing (CM) and half-duplex bidirectional transmission. It allows the on-demand use of broad bandwidth on existing fiber-to-the-home (FTTH) access lines. The study shows that the capacity of existing FTTH access lines that employ star couplers can be significantly enhanced.

Till now we observe that the number of users used in FTTH simulations are maximum 32. Considering [29], we see that 1 OLT is connected to a maximum of 10 users. Similarly in [37] and [38] an error free transmission over a 25km link with 32 optical splitting and with a 7-km 9-dB standard access line, 12 users at rate of 155 Mb/s was found to be acceptable.

In this implementation we simulated the FTTH with GEPON architecture for a bit rate of 2 Gbit/s using booster amplifier for 56 users and correspondingly BER is determined for different number of users like 48, 32, 64 etc. It is seen that up to 56 users, an optimized value of BER is obtained.

## 3.2 Simulation Setup

To optimize the BER in PON, the transmission through the optical fiber path employs the CWDM (Coarse Wavelength Division Multiplexing) technique with data/voice component transmitted at wavelengths in the range of 1480-1500 nm, and video within the 1550-1560 nm range.

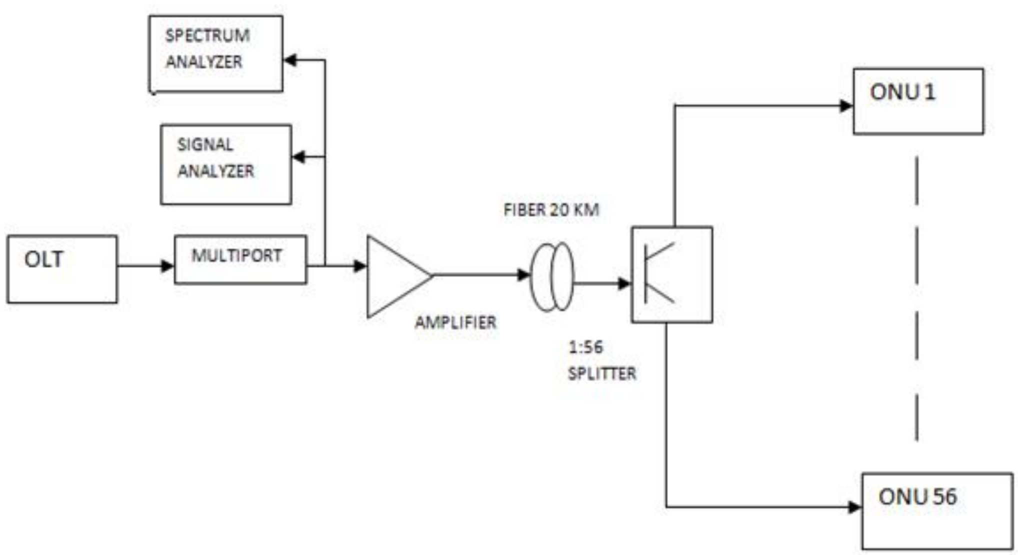


**Figure 3.1: Block diagram for simulation setup for 56 users GEPON based FTTH architecture**

Figure 3.1 depicts the block diagram for simulation setup for GEPON architecture and figure 3.2 shows the simulation setup.

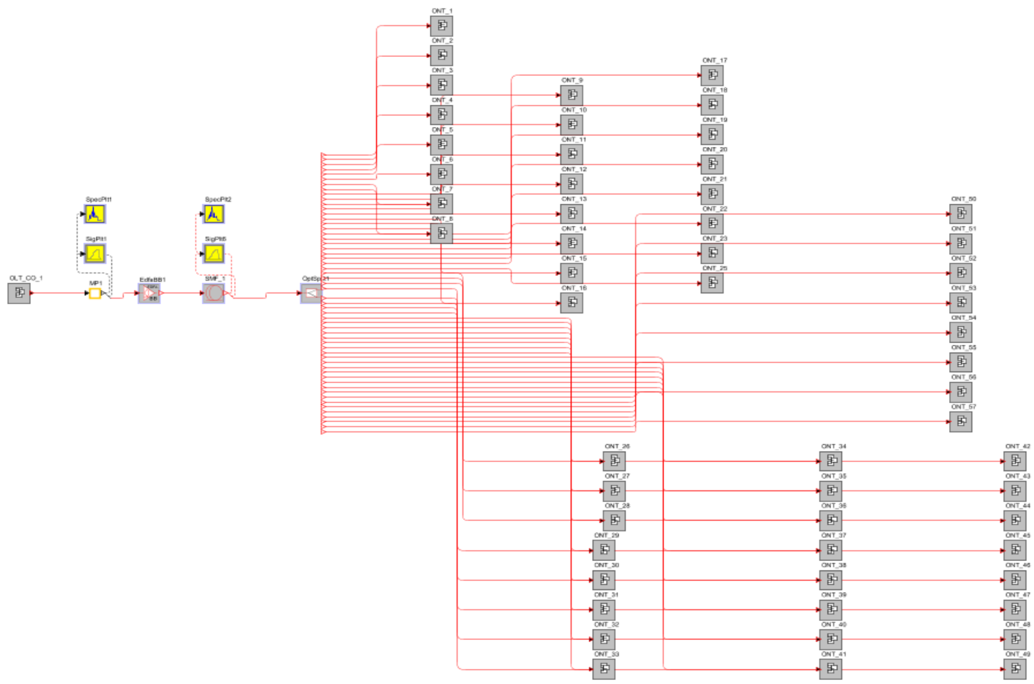

**Figure 3.2: Simulation Setup for 56 users GEPON based FTTH architecture**

CO OLT (Optical Line Terminal) block which is the transmitter block consists of Data/VOIP and Video components as shown in Figure 3.3. The Data/VOIP transmitter modeled with pseudo-random data generator (PRBS), NRZ modulator driver, direct-modulated laser, and booster amplifier.

The video component modeled as RF SCM (sub-currier multiplexed) link with only two tones (channels) for simplicity. RF video transmitter consists of two Electrical Signal Generators, summer, direct-modulated laser, and pre-amplifier. Next, Data/Voice and Video signals are multiplexed at Multiplexer and launched into 20-km fiber span. Before travelling over fiber, a booster amplifier is used to boost the incoming signal which improves BER. Amplifier is having a constant gain of 30dB. Output from the fiber trunk goes through the 1:56 splitter and then to individual users. User’s ONT consists of splitter and data and video receivers. Data receiver configured with optical filter, PIN receiver, and BER Tester. The video signal receiver consists of optical filter, PIN receiver and electrical filters. Yellow-colored blocks on schematic correspond to measurement instruments – to visualize to link's optical spectrum, waveforms, eye diagrams, etc. as shown in Figure 3.4.

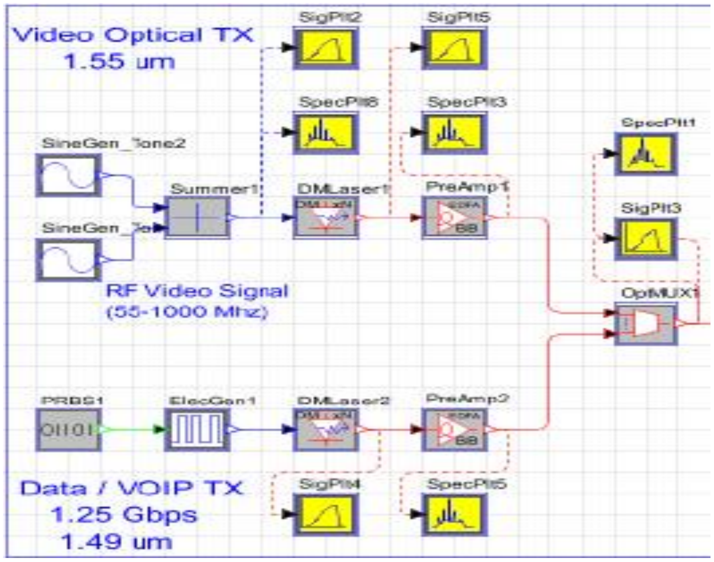


**Figure 3.3: OLT components for GEPON based architecture**

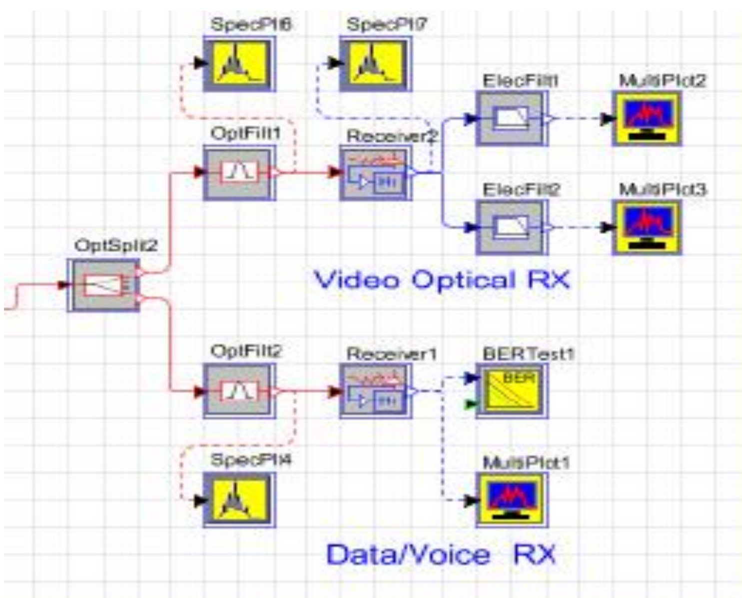


**Figure 3.4: ONT components for GEPON based architecture**

To convert the data and video again in the original form, we use a high sensitivity receiver or detector which performs both the function, the first one is to detect whether data or voice is and again converted in the form of the electrical signal. The same phenomena is repeated or done simultaneously for different users at the same time. To measure the spectrum of the voice and data at the user's end we use spectrum analyzer. But as we know that data is transmitted in the digital domain or also in the light pulses so in transmission on the fiber such type of noise also produced *e.g.* inter symbol interference, noise so in the effect of such things error should be occurred. So to measure the error we applied an instrument called BER Tester, as we know some standard also made to accept that type of error by ITU-T standard. Now at the end of the receiver side every ONT has a particular receiver for both the reception of the voice and the data. Before the reception a splitter is used to differentiate the particular user.

Optical splitter component simulates an "Ideal" optical splitter. It works as a balanced splitter with the same attenuation on each output. Attenuation is set to a default value of 0 dB, so this component implements an ideal splitter without any insertion loss, *i.e.* a component that perfectly splits the input signals.

Photodiode considered as a PIN photodiode. The output current generated by the photo detection process depends on the input optical power and on the dark current. Its parameters are 193.42 THz/1590 nm/1650 nm reference freq/wavelength, 0.80 quantum efficiency, 0.99 A/W responsively and zero dark current.

## 3.3 Results and Discussions

As we know that we use optical splitter as a passive device, so on the basis of these factors some experimental results have been obtained. Data is transmitted at the wavelength of 1490 nm and the video is transmitted at the wavelength of 1550 nm. Both the wavelengths are selected because these wavelengths window has certain advantage i.e. it is low attenuation window. So each user has separate or slightly different wavelength spectra for video and the data. As number of ONUs increases some errors have also occurred so BER is calculated, a graph is showing the effect the number of users on the BER.

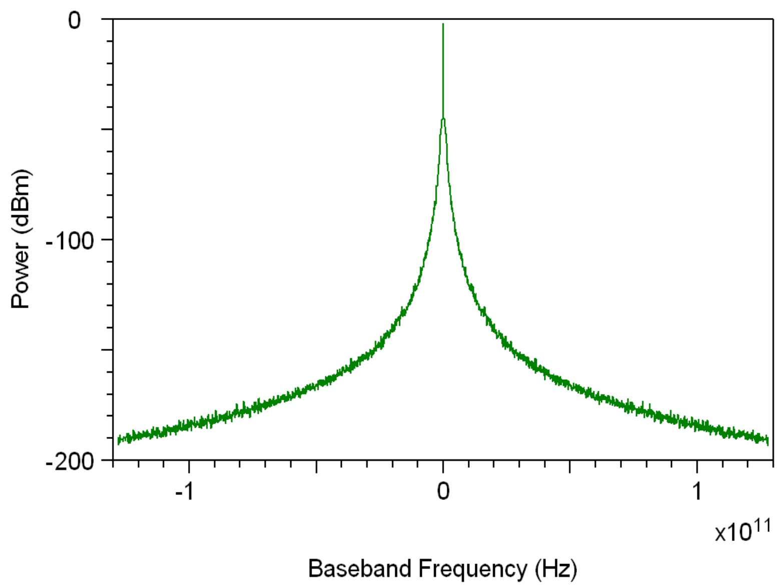


**Figure 3.5: Received voice and data signal frequency spectrum at 20km**

Figure 3.5 represents the frequency spectrum of received voice and data signal for user 1. These spectra are observed at the receiver side as data and video are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise.

Table 3.1 shows the values of BER for different number of users in this architecture when boosting amplifier is installed in path and it is shown that for 16 users with data rate of 2Gbps we obtained BER of 6.1073e-009 without amplifier and with amplifier the same BER decreases to 4.1443e-013 for same specifications.

**Table 3.1: BER for various users**

| No. of Users | BER |
|---|---|
| 16 | 4.1443e-013[a.u] |
| 24 | 2.7566e-012[a.u] |
| 32 | 1.5977e-011[a.u] |
| 40 | 1.0658e-010[a.u] |
| 48 | 7.2043e-010[a.u] |
| 56 | 4.5246e-009[a.u] |
| 64 | 2.5065e-008[a.u] |

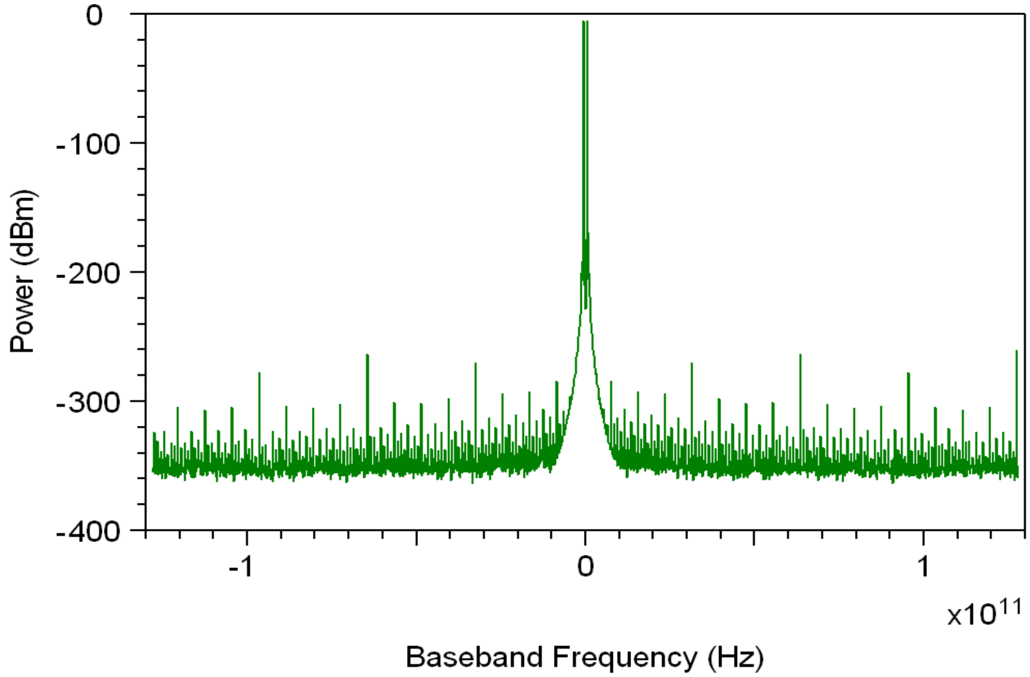


**Figure 3.6: Received frequency spectrum of video signal at 20 km**

Similar to Figure 3.5, we obtain received frequency spectrum of video signal for user1 as shown in figure 3.6 and Figure 3.7 shows the OLT output optical waveforms for data and video signal.

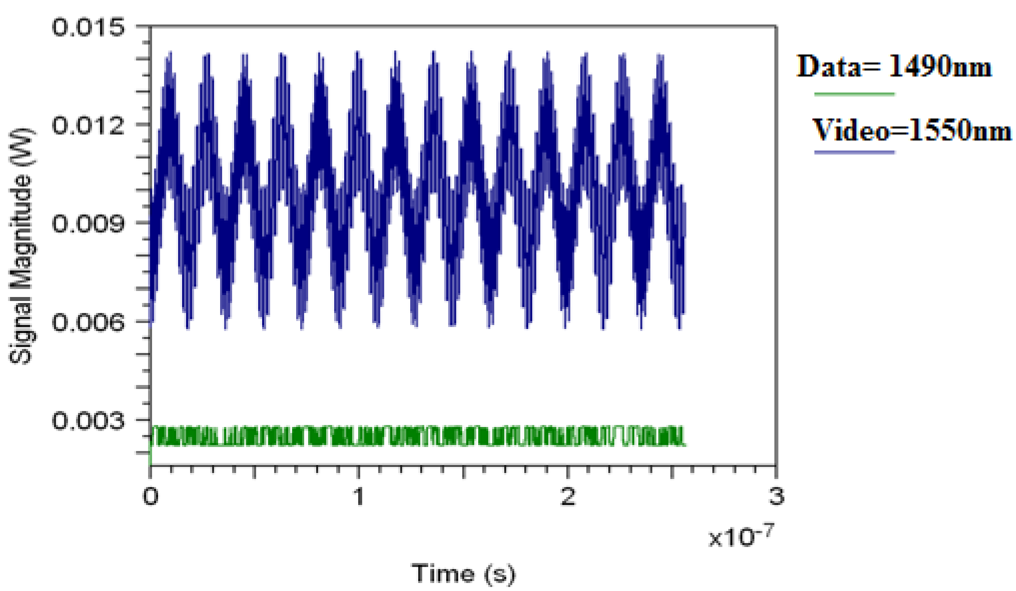


**Figure 3.7: OLT output optical waveforms for data and video signal**

Figure 3.8 depicts the eye diagram for data and voice in case of 56 users.

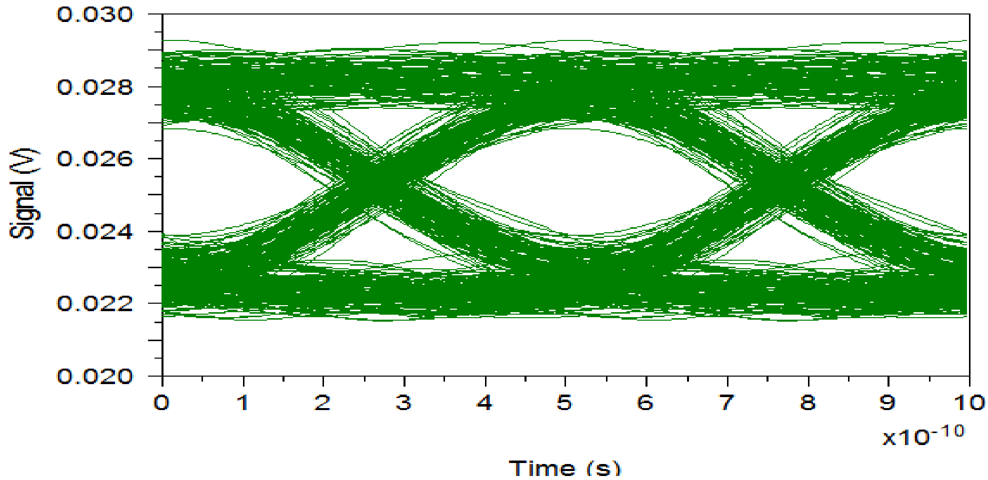


**Figure 3.8: Data and voice signal output eye diagram for 56 users at 20 km**

Basically, we extended or increased the number of users using a passive device named as optical splitter. This simulation describes the relation between the users and BER, if we increase the number of users then our data and voice distorted and become error full. Figure 3.9 represents the BER versus the users.

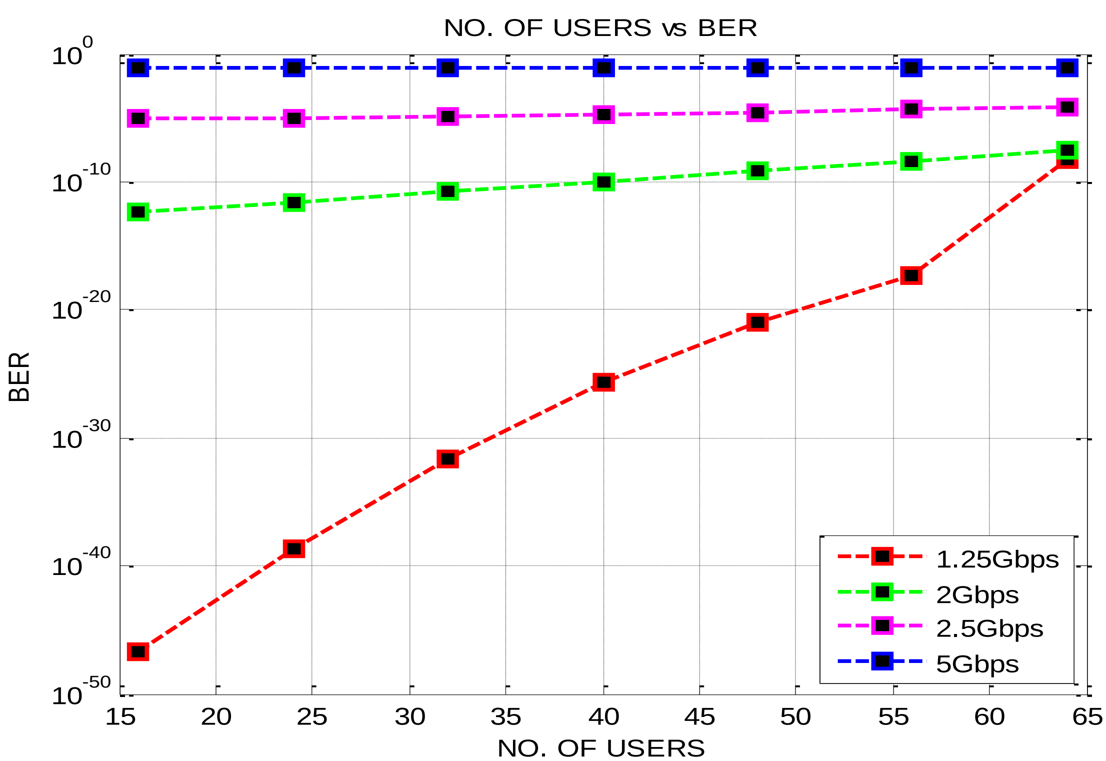


**Figure 3.9: Comparison of system BER at various data rates**

Here we see that if we increase data rate, BER increases sharply but it accommodates less users and if we decrease the data rate, BER decreases and more number of users get accommodated. For example for data rate of 1.25 Gbps at 56 users we have BER value 4.7992e-018, for 2 Gbps system BER of 4.5246e-009 for same users and then we observe a sudden increase in BER of 4.5046e-005 and 8.8212e-002 at data rate of 2.5 Gbps and 5 Gbps respectively. So there is a trade-off between bit error rate and data rate of system.

Figure 3.10 shows the variation of distance and BER for various users. It is seen that if we increase distance, Bit Error Rate increases very sharply.

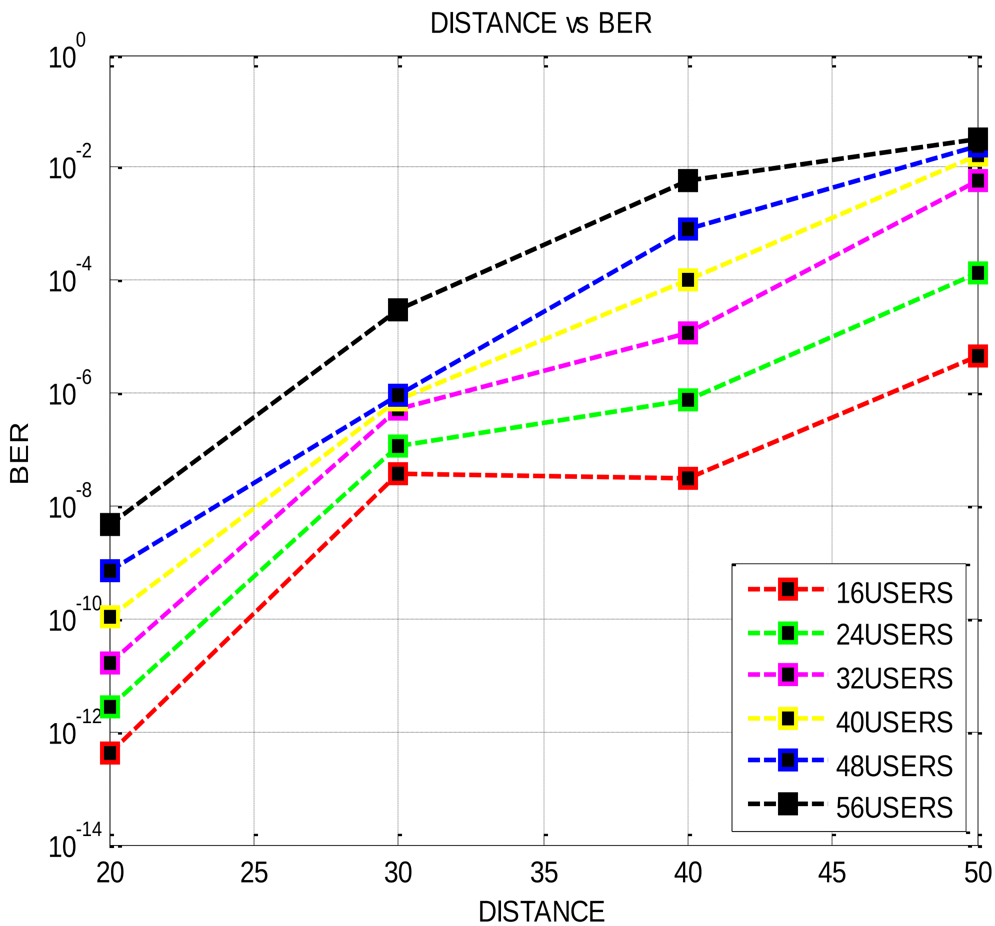


**Figure 3.10: Distance Vs BER**

For example, for 16 users at 20km we receive BER value of 4.1443e-013 and then for same users at distance of 50km, BER of 4.7512e-006. Similarly for 56 users, we obtain BER of 4.5246e-009 and 3.1128e-002 at distance of 20km and 50km respectively. This proves that there is a tradeoff between number of users, distance and BER.

### 3.4 Conclusion

This implementation simulated an optimized GE-PON based FTTH access network to provide residential subscribers with triple play services. We described the requirements of GE-PON access network with considerations of services and PON specific layered functions. To satisfy those requirements, we simulated an optimized architecture and describe the detailed functions of major elements. Finally, we consider the major technical issues i.e. BER to realize the GEPON based FTTH access network. The results at 2 Gbit/s system between the BER and different number of users illustrate that as the number of users increases beyond 56 users the BER comes to unacceptable level and if further increase data rate of system say 5Gbps, then we observe a sharp increase in BER.

FTTH is a driver for the development of advances optoelectronics technologies, and the great volume in production of optical modules will also accelerate the reduction in cost. We described that by using a boosting amplifier can decrease BER up to a certain extent and hence more users can be accommodated.

# CHAPTER 4

# Implementation of GPON Based Fiber to the Home Architecture using SOAs and APD at 10Gbps

In this implementation, we proposed FTTH (Fiber To The Home) GPON (Gigabit Passive Optical Network) link design for 56 subscribers at 140 km reach at 10 Gbps bit rate. One splitter of 1:7 is used as a PON element that provides communication between a central office (CO) to different users at receiver end. Then further each output of this splitter is connected to 1: 8 splitter, in turn serves a total of 56 users. It is seen that by using Semiconductor Optical Amplifiers (SOAs) and Avalanche Photodiode (APD) in architecture increases the transmission distance. The architecture is being investigated for various optical modulation techniques and also for different lengths from a central office to the PON in terms of Q-Factor. The results at 10 Gbps system between the Q-Factor and transmission distance illustrate that as the distance increases beyond 140km the Q-Factor comes to unacceptable level. So we observe a tradeoff between Q-Factor and transmission distance of the system. For 10 Gbps data signal have been transmitted over 140 km single mode fiber (SMF) successfully.

## 4.1 Introduction

The BW requirement in the access networks has been increasing very rapidly over past few years. It is impossible to achieve this requirement using copper based infrastructure due to signal distortion and various other issues [13]. Research in the access networks introduced the concept of Fiber-to-the-x, where x can be Home (H), Curb (C) and Building (B) etc. Fiber to the Home is defined as fiber optic cable that replaces the standard copper wire of the local Telecom. FTTH is desirable because it is capable of carrying high-speed broadband services and runs directly to the home or building [28]. FTTH is simply the 100 percent deployment of optical fiber in the access network.

Gigabit-capable passive optical network (GPON) is the basic technology to support the structure of the next-generation fiber to the home (FTTH) system and supports multi-speed rates, full services, robust network, high efficiency and other advantages, and considers the suggestions of service providers at the same time [49]. GPON is regarded as one of the best choices for broadband access network in the future.

The cost benefits have enabled increasing deployment of passive optical network delivering fiber to the home. However, in many cases, extended reach requires some form of amplification to overcome the additional losses [46]. Semiconductor based amplifiers offer a cost effective solution with a migration path. Given that the standard uses 1490nm downstream and 1310nm upstream wavelengths, wavelengths which are outside the erbium window, semiconductor optical amplifiers (SOAs) play a clear role in this context. In order to increase transmission distance an amplifier is introduced somewhere between the transmitter and the splitter. Analysis of the effectiveness of the amplifier can be determined by evaluating the Q factor of the system.

Traditionally, PIN photodiodes have been employed widely due to their ease of use and low cost [13]. Although, more recently the deployment of several PON architectures have raised feasibility of using APDs due to potential improvements in the data carrying capability and system reach. APDs obviously are expensive compared to their counterparts, yet they are believed to be the ultimate choice in a long reach, highly scalable PON architecture with Gbps of data carrying capabilities.

Erik Weis et al. [29] reported a FTTH field trial with GPON (Gigabit-capable passive optical network) technology in the network of Deutsche Telekom in the region of the cities of Berlin and Potsdam. Focus of this trial was to gain practical experience regarding GPON technology, fiber installation in existing ducts with micro duct technology, fiber cabling in customer buildings and impact on operational processes. Their main target was to obtain practical deployment and operation experiences with fiber-based access networks and to provide broadband access to a part of the city formerly not servable by DSL (digital subscriber line) technology.

Bernard HL Lee et al. [37] investigated the performance of a novel 2.5Gbps FTTH-PON Network architecture which employs a passive optical booster configuration for future user scaling. The passive booster configuration uses an NxN AWG and exploits its cyclical routing table which is made possible by the device's Free Spectral Range (FSR) property configuration for future user and services scaling. The new configuration is compared with a conventional access network.

Sandeep Singh et al. [39] have demonstrated a transmission system for triple play (voice, video, and data) with centralized orthogonal frequency division multiplexing-fiber to the home broadband passive optical network (OFDM-FTTH-BPON) based on an external modulator. At the one of two arms of system, voice and internet data are transmitted using Pseudo random binary sequence (PRBS) generator at bit rate of 1.25Gbps .In another arm of system, video is transmitted with the help of 4 QAM modulated OFDM signal.

Till now we have observed that the results on a FTTH trial with GPON technology in the network of Deutsche Telecom was providing broadband access up to 32km [29]. Similarly in [37] we noticed that that this architecture was able to deliver an error free transmission over a 25km link. Also in [39], we found that, 1.25Gbps voice signal, 1.25Gbps data signal over 20km single mode fiber (SMF) were transmitted successfully.

In this investigation we simulated the FTTH with GPON architecture for a bit rate of 10Gbit/s using SOAs and APDs and then the data as user are separated by splitter and Q-factor is determined for different values of distance. It is seen that up to distance of 140km, an optimized value of Q-factor is obtained.

## 4.2Simulation Setup for FTTH using GPON Architecture

To optimize the bandwidth in GPON the transmission through the optical fiber path employs the CWDM technique with data and voice component transmitted at wavelengths in the range of 1480-1500 nm range. The high-speed internet component is represented by a data link with 10 Gb/s downstream bandwidth. The voice component can be represented as VOIP service (voice over IP, packet-switched protocol), which is gaining popularity as an alternative to traditional PSTN (public switched telephone network) with POTS (plain old telephone service) at the customer end. The schematic diagram consists of an optical line termination (OLT) device is installed in the central office (CO), and an optical network termination (ONT) device is installed on the other end, in or near each home or business site. Fiber distribution is done using a tree-and-branch architecture. A single fiber connected to the OLT can be split up to 32 times and connected to multiple ONTs. Current simulation models a typical GPON FTTH design with 56 subscribers and 140km reach as shown in Figure 4.1.

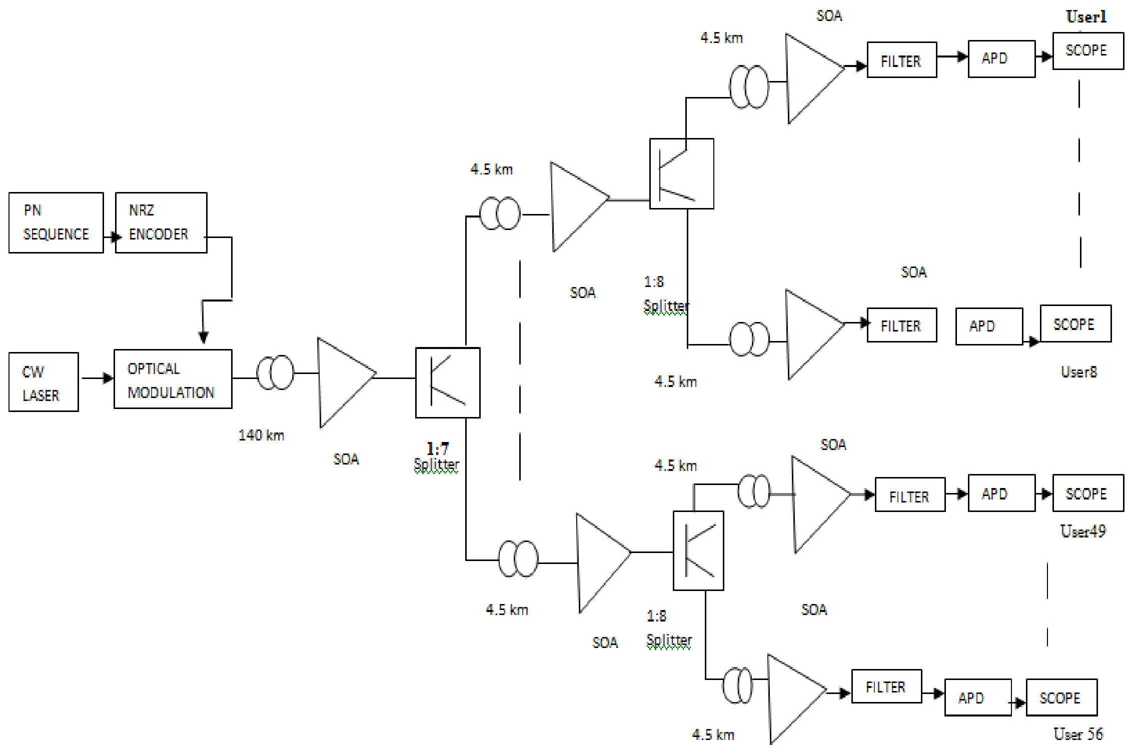


**Figure 4.1: Block diagram of simulation setup**

The Central Office is connected through a 140km standard single mode fiber to the first Remote node with a 1:7 splitter. Each of the seven outputs goes through another 4.5km fiber and then enters the Remote Node with a 1:8 splitter. Outputs from the 1:8 splitters are connected to eight end-users at the ONT. The data is generated from pseudo noise sequence generator which is producing the 10 Gbits/s and is directly fed to the NRZ electrical driver, now the output of the electrical driver and an optical signal generated from CW Laser are fed into different types of optical modulators ($sin^2$, linear and Phase) and data transfers on optical fiber over a length of 100-150 km. Now the output of the optical fiber which is a single mode fiber is then fed to the input of the semiconductor optical amplifier. In order to increase transmission distance of a system, an amplifier is introduced somewhere between the transmitter and the splitter.

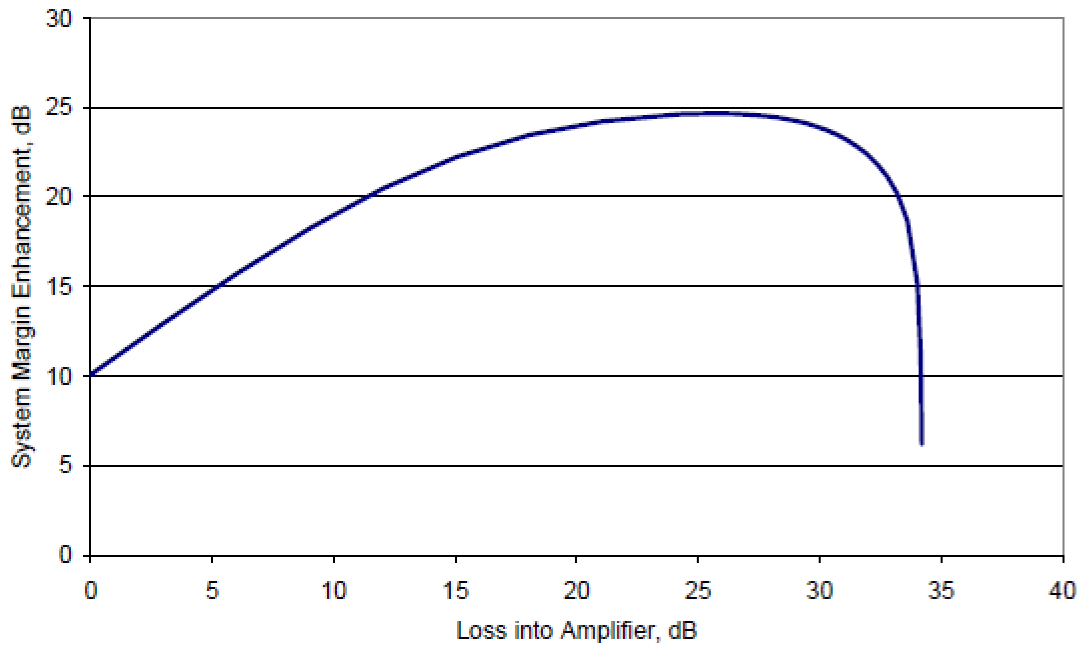


**Figure 4.2: System margin enhancement resulting from amplification [46]**

Figure 4.2 reveals clearly the source of the overall system improvements and thus aids the design process for amplifier based components. When the loss into the amplifier is low, i.e. the amplifier is used as a booster. At the other end of the system, when the amplifier is used as a pre-amplifier, the performance enhancement is limited by the noise figure of the amplifier which dictates the ASE level at the receiver. Mid-span, or post splitter, the system benefits are at their greatest and tend towards the gain of the amplifier.

After amplification signal is fed to input of the optical splitter which splits the input into the 1:7 output now the 7 outputs of the filter is fed to the receiver side of users which are further divided into 1:8 splitters each means a total of 56 users. Light signal received at receiver side is filtered with the help of Gaussian filter and then to convert it back to its original form we use a high sensitivity receiver APD photodiode. The same phenomena is repeated or done simultaneously for different users at the same time.

The data component is transmitted at wavelengths in the range of 1480-1500 nm. Optical splitter component works as a balanced splitter with the same attenuation on each output. Attenuation is set to a default value of 0 dB, a component that perfectly splits the input signals.

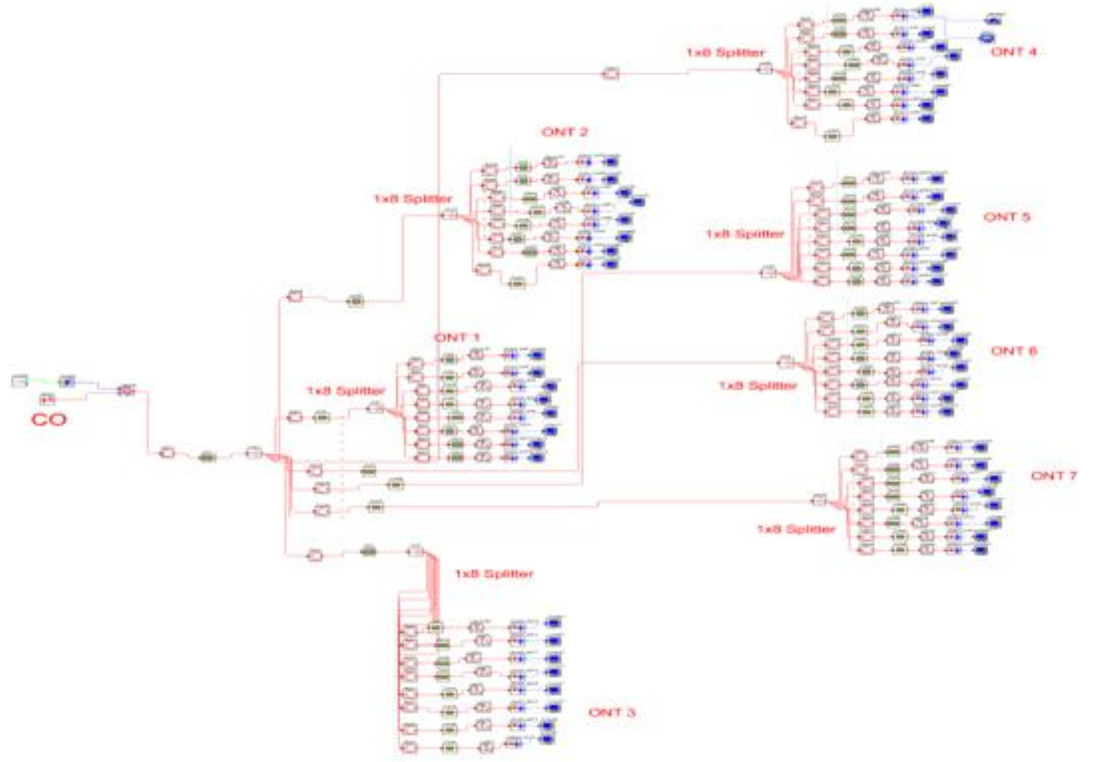


**Figure 4.3: Simulation Setup**

Photodiode is considered as an APD photodiode. The output current generated by the photo detection process depends on the input optical power and on the dark current. Its parameter are 196.66THz/1524 nm, reference freq./wavelength, 0.70 quantum efficiency, 0.86 A/W responsivity and 2.5 nA dark current. The simulation setup is shown in Figure 4.3.

## 4.3 Results and Discussions

Data is transmitted at the wavelength of 1500 nm. This particular wavelength is selected because this wavelength has certain advantage i.e. it is low attenuation window. We have calculated the value of Q-factor at different distances for different types of optical modulators and we see that as we increase the distance value of Q-Factor starts decreasing.

Figure 4.4 shows the signal spectrum output from OLT with data/voice signal at 1500 nm. We have considered various modulation techniques to calculate Q-Factor. First of all, we used optical modulator $\sin^2$ and it gives the optimized value of Q-factor of 16.08 dB at distance of 140km.

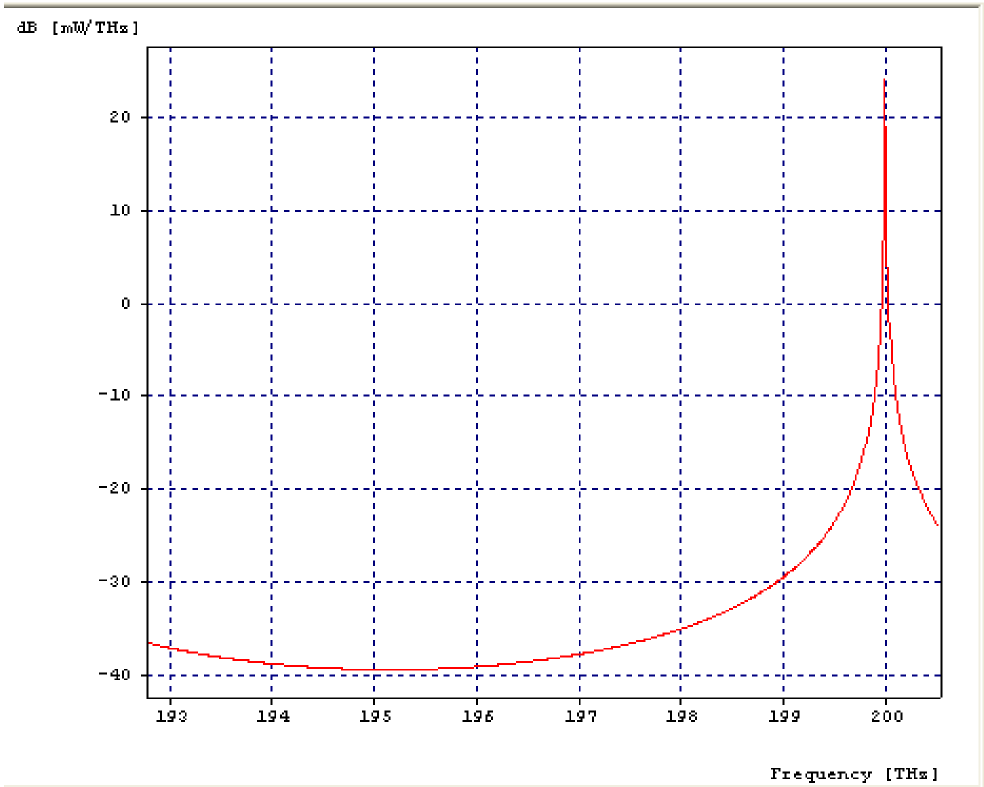


**Figure 4.4: The Signal Spectrum Output from OLT**

Table 4.1, 4.2 and 4.3 below shows the results for the same. From results shown in these tables it is reported that we get optimized value of Q-factor by using $Sin^2$ optical modulation technique. We obtain Q-Factor of 16.08 dB at 140 km for 56 users that's why $sin^2$ is the most suitable technique for the system. Upon the distance some errors has also occurred so how much distance disturb the data and that's why Q-Factor is calculated. The values of eye opening and jitter are also reported but these values keep on swinging and do not lead to any result or parameter.

**Table 4.1: Parameters measured for Optical Modulation $Sin^2$**

| Length(km) | Q-Factor(dB) | Eye Opening | Jitter(ns) |
|---|---|---|---|
| 120 | 28.78 | 2.090e-005[a.u] | 0.154337 |
| 130 | 25.40 | 4.743e-006[a.u] | 0.14803 |
| 135 | 21.48 | 1.895e-009[a.u] | 0.15820 |
| 140 | 16.08 | 6.779e-007[a.u] | 0.15238 |
| 150 | 6.02 | 1.421e-006[a.u] | 0.14968 |

**Table 4.2: Parameters measured for Optical Modulation Linear**

| Length(km) | Q-Factor(dB) | Eye Opening | Jitter(ns) |
|---|---|---|---|
| 120 | 27.92 | 1.914e-005[a.u] | 0.1522 |
| 130 | 24.79 | 4.143e-006[a.u] | 0.1568 |
| 135 | 20.66 | 1.463e-006[a.u] | 0.1492 |
| 140 | 14.59 | 3.404e-006[a.u] | 0.1461 |
| 150 | 6.02 | 1.282e-009[a.u] | 0.1425 |

**Table 4.3: Parameters measured for Optical Phase Modulator**

| Length(km) | Q-Factor(dB) | Eye Opening | Jitter(ns) |
|---|---|---|---|
| 120 | 9.30 | 3.144e-007[a.u] | 0.1522 |
| 130 | 7.57 | 1.099e-007[a.u] | 0.1568 |
| 135 | 7.25 | 2.795e-008[a.u] | 0.1492 |
| 140 | 6.02 | 6.455e-010[a.u] | 0.1625 |
| 150 | 6.02 | 6.982e-010[a.u] | 0.1764 |

The optical spectrum at the input to ONT is shown in Figure 4.5.

Figure 4.6 shows the eye diagram at distance 140km with use of optical modulator $sin^2$ that provide us Q-Factor of 16.08 dB.

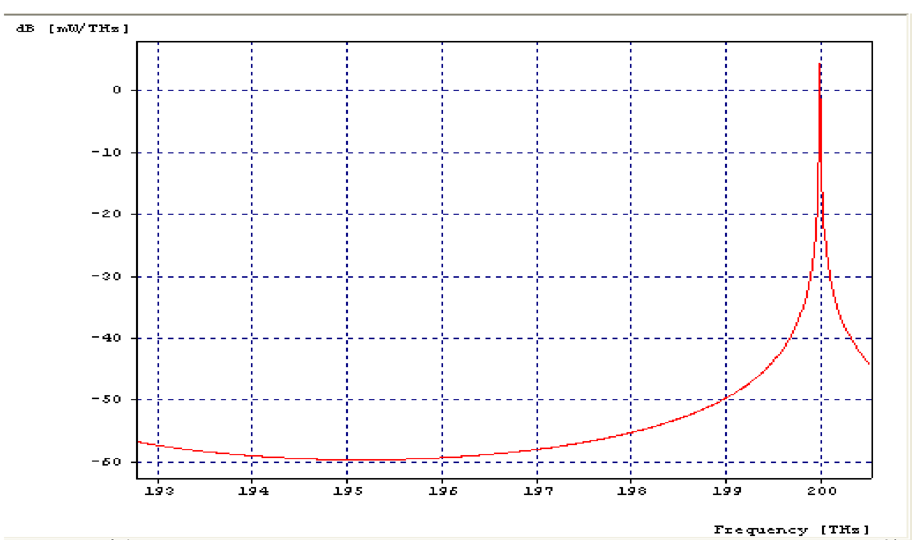


**Figure 4.5: The Optical Spectrum at the input to ONT**

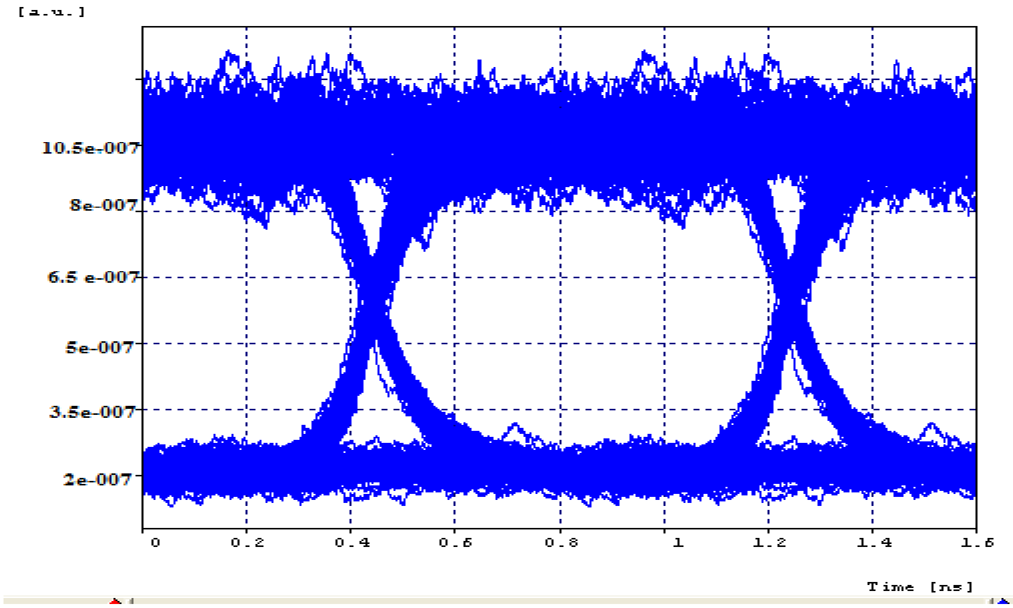


**Figure 4.6: Eye diagram that provides optimized Q-factor at distance 140km using $\sin^2$ optical modulator**

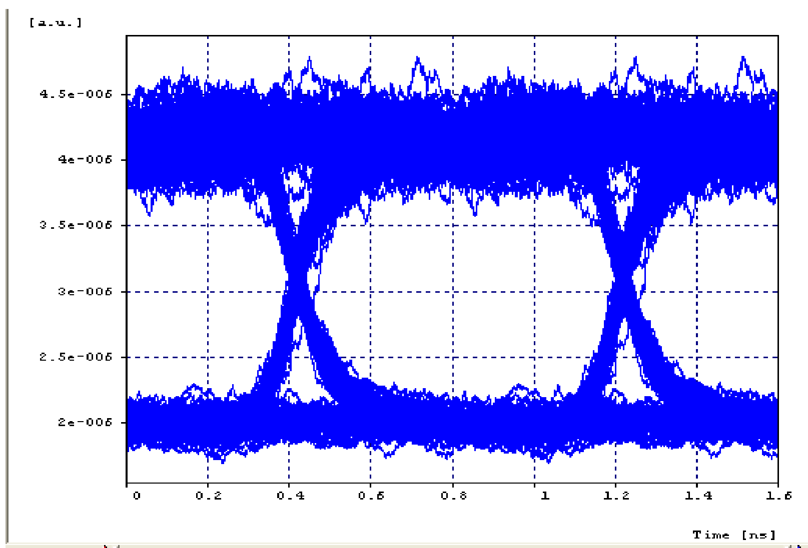


**Figure 4.7: Eye diagram that provides optimized Q-factor at distance 140km using linear amplitude modulator**

Figure 4.7 shows the eye diagram of system using linear modulator. In case of linear modulator the Q-factor corresponds to 14.59dB and for phase modulator its value corresponds to 6.02dB.

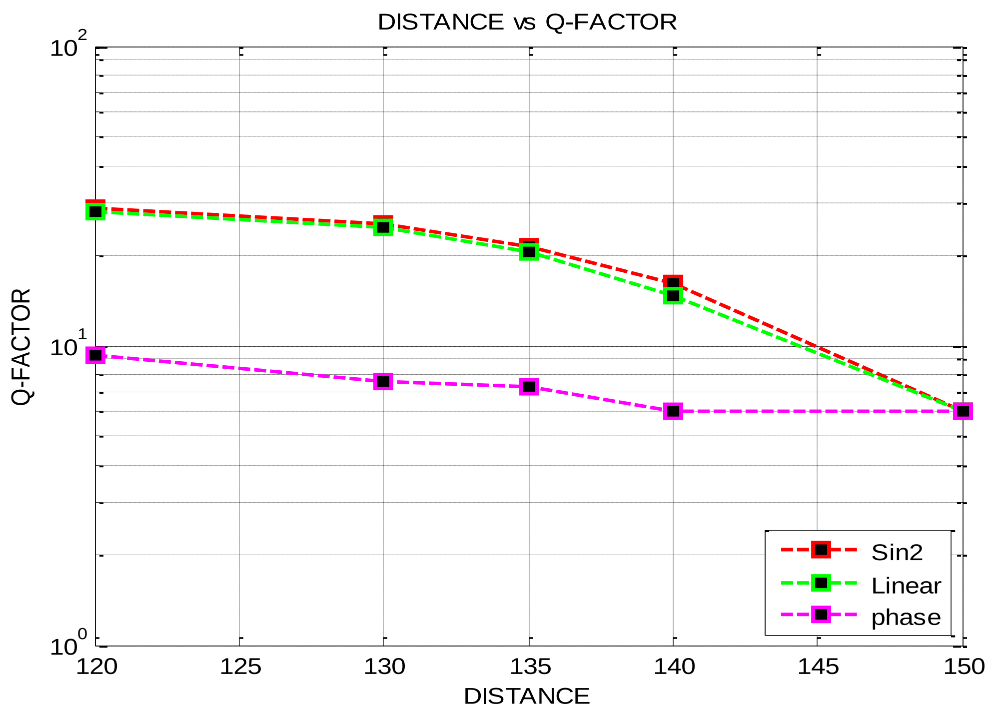


**Figure4.8: Distance Vs Q-Factor**

Figure 4.8 depicts the variation of Q-Factor with respect to transmission distance. The value of Q-Factor decreases as distance of transmission increases. For example for distance of 120 km we have Q-Factor of 28.78 dB, as we increases the distance say up to 140km the Q-Factor comes out to be 15.08 dB. So there is a tradeoff between Q-Factor and transmission distance. We have to make a choice out of the two according to requirements of the system.

## 4.4 Conclusion

We simulated an optimized G-PON based FTTH access network to provide residential subscribers with full services. In this investigation, we simulated an optimized architecture and describe the detailed functions of major elements like SOA and APD. Finally, we consider the major technical issues, i.e. Q-Factor to realize the GPON based FTTH access network. We concluded that by the use of above mentioned factors i.e. SOAs and APDs we can have optimized value of Q-factor for larger transmission distance for extended users.

The results at 10 Gbit/s system between the Q-Factor and transmission distance illustrate that as the distance increases beyond 140km the Q-Factor comes to unacceptable level.

So there is a tradeoff between Q-Factor and transmission distance. For 10Gbps data signal have been transmitted over 140km single mode fiber (SMF) successfully. Considering the future prospect of FTTH access network, the FTTH will be motivated by the following factors. Maintenance is easy, because it requires maintenance only for fiber systems, and fiber systems are regarded more reliable than hybrid fiber-metal ones.

# CHAPTER 5

# 50 km Bidirectional FTTH Transmission comparing different PON standards

In this investigation, a bidirectional Fiber To The Home (FTTH) is proposed where WDM transmitter is used as a seeding source with wavelength of 1550nm. The system utilizes a Travelling wave Semiconductor Optical Amplifier (TSOA) with injection current 0.15A. 50km range FTTH architecture is demonstrated for both downstream and upstream channels. We investigated the impact of different data rates on upstream and downstream data. The BER results show that the performance of our scheme is good for 10Gbps system for downstream transmission as it accommodates 64 ONUs. Simulation results show that BER attains an acceptable value at 15Gbps but only in case of 40 ONUs. Similarly, in case of upstream transmission, Q-Factor of 15.04dB is achieved for 40 ONUs. So this scheme is a practical solution to meet the data rate of the optical links simultaneously in tomorrow's PON access networks.

## 5.1Introduction

For optical access networks, wavelength-division-multiplexing passive optical networks (WDM-PON) are considered as one of the best solution for the next-generation of FTTH because of its almost-unlimited bandwidth [50]. For this reason, an access network architecture utilizing a centralized light source at central office (CO) with wavelength 1550 nm and 1300nm wavelength received at the optical network unit (ONU) is an attractive solution for low-cost implementation of the architecture. Bidirectional single fiber PON can reduce the use of fiber links, as well as the number of network equipments, and hence reduce energy consumption and the cost [51]. Recently, several schemes have been proposed based on SOAs [52], because it can reuse the downstream signal received at the ONU for upstream transmission. Travelling wave SOA (TSOA) is capable to describe the amplification of CW and optical pulse signals. For an optically amplified PON, it is essential for the PON amplifiers to support a wide input dynamic range, which the PON standard calls for to allow the handling of both user distance and user transmitter power variations [53].

Abdel Harkeim *et al.* [54] proposed and demonstrated a bidirectional SCM-WDM PON using a reflective filter and cyclic AWG where up/downlink data could be provided by a single optical source. In the proposed scheme, the signal for downstream was modulated by a single CW laser diode and re-modulated in the optical network unit as an upstream. The results obtained here show that increasing total number of sub-carriers channels has a significant impact on performance of WDM–SCM PON system. These results may be implemented in real system used for broadband and cable TV services.

Oladeji Akanbi *et al.* [55] propose a new bidirectional dense wavelength-division-multiplexing (DWDM)-based passive optical network using optical carrier suppression and separation technique to generate both upstream and downstream wavelength channels from a single laser. They generated 32 DWDM channels and demonstrated error-free symmetric10 Gbps data transmission over 20 km SMF fiber using a wavelength pair.

Lingbin Kong *et al.* [56] proposed a novel DWDM-PON system which provided bidirectional transmission of simultaneous download, upload and video selectcast services using single light source in central office. The experiment results showed that, for 10 Gbps DL, 2.5 Gbps VS and 1.25 Gbps UL services over 20 km transmission, the system had good performance with power penalties less than 0.5 dB. They believed that this proposed scheme would be a promising solution for delivering high-quality multi-services over the future DWDM-PON systems.

Till now, we notice that 1 Gbps signals both for up and downstream were demonstrated in 10 km bidirectional optical fiber link [54]. Also, 32 DWDM channels were demonstrated error-free symmetric 10-Gb/s data transmission over 20-km SMF-28 fiber using a wavelength pair [55]. Similarly the experiment results in [56] show that, for 10 Gbps DL, 2.5 Gbps VS and 1.25 Gbps UL services over 20 km transmission.

We present here in this paper, a bidirectional PON link operating at 1550 nm wavelength as transmitters. Our system operates at 10 Gbit/s in both directions, and transmission is over a single, 50 km standard single mode fiber (SSMF) link. Also the comparison of various PON standards like APON, BPON, GPON and NG-PON is discussed.

## 5.2 Simulation Setup

The architecture of bidirectional PON for 64 ONUs using single fiber based on circulator is shown in Figure 5.1. Circulator is used to isolate optical signals of uplink and downlink, and hence to realize bidirectional transmission in single fiber. Uplinks are allocated to upload burst data from clients and downlinks are used to download multimedia data to clients, such as audio, video and data services.

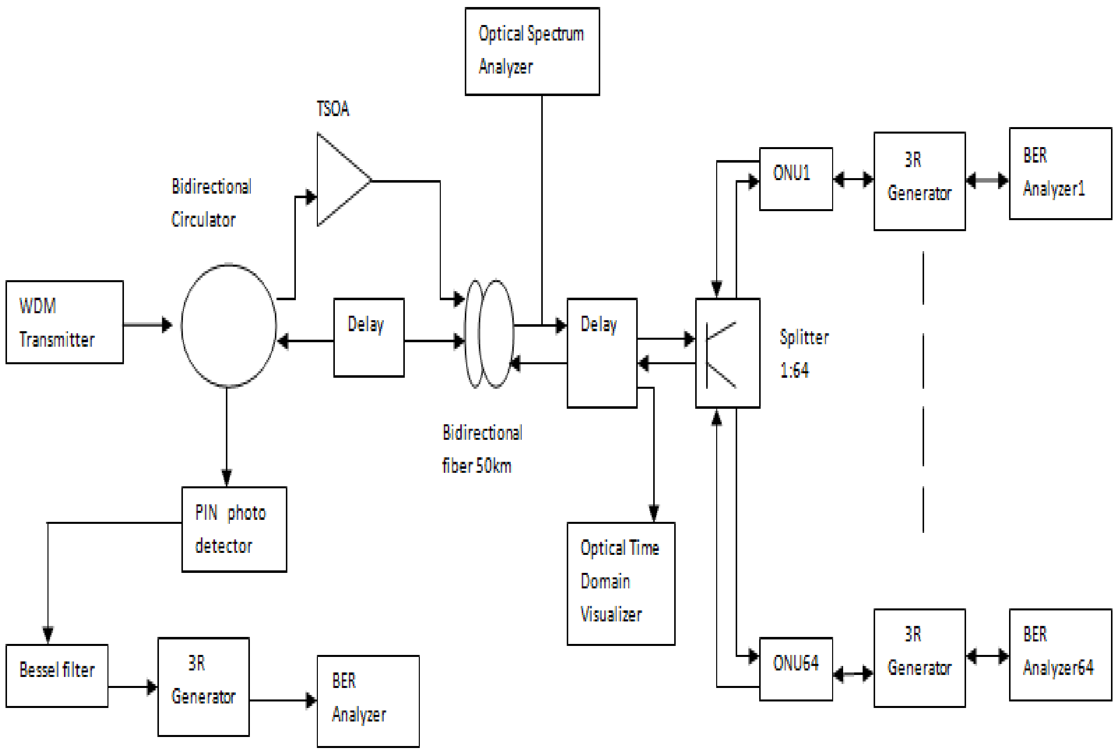


**Figure 5.1: Block diagram for bidirectional FTTH-PON**

In downlink, we place a TSOA in between the transmitter and optical fiber. The circulator used is bidirectional with wavelength dependent isolation, insertion and return losses. Delay element which is used in transmission is used to generate optical signal delay. The delay is added by sending NULL signal to the output port.

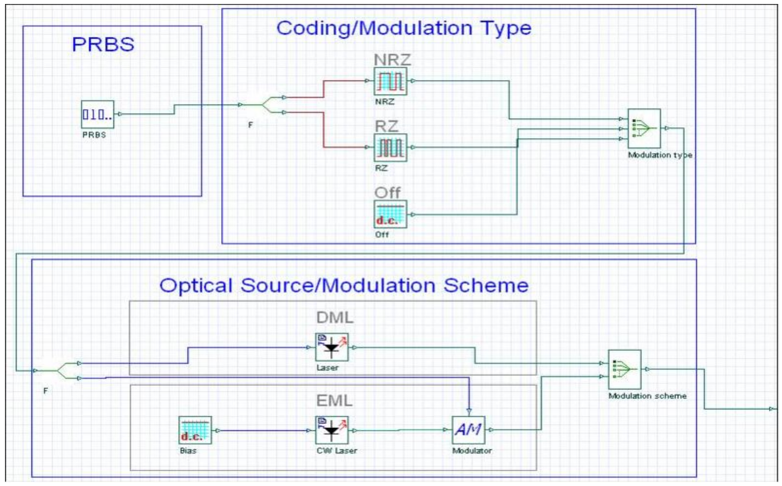


**Figure 5.2: WDM Transmitter Internal Structure**

In WDM transmitter (Figure 5.2), first stage is PRBS (Pseudo Random Bit Sequence) generator. Parameters bit rate, order, number of leading and trailing zeros are used in internal PRBS. The second stage is NRZ coding that generates a NRZ coded signal. The last stage is the optical source and modulation type; by using the parameter Transmitter type, we select between an external modulated laser (EML) and a directly modulated laser (DML). The wavelengths assigned to downlink and uplink signal are 1550nm and 1300nm respectively and the transmission distance that we are considering here is 50km.

Bessel filter is used to filter the signal by using Bessel frequency transfer function. Photoelectric detectors (PIN) are used to convert optical signals into electrical signals, which pass through low-pass Bessel filters and 3R regenerators (Figure5.3).

By using 3R generator, it is possible to recover the original bit sequence and electrical signal. The first output port is the bit sequence, the second one is modulated NRZ signal and last one is copy on input signal. These three signals can be directly connected to BER analyzer, avoiding additional connections between the transmitter and receiver stage.

We choose Optical Spectrum Analyzer (OSA) to track and observe the spectral characteristics of various locations. In order to evaluate the performance of system, BER Analyzers at the terminal are used to observe eye diagram, Q factor and BER value.

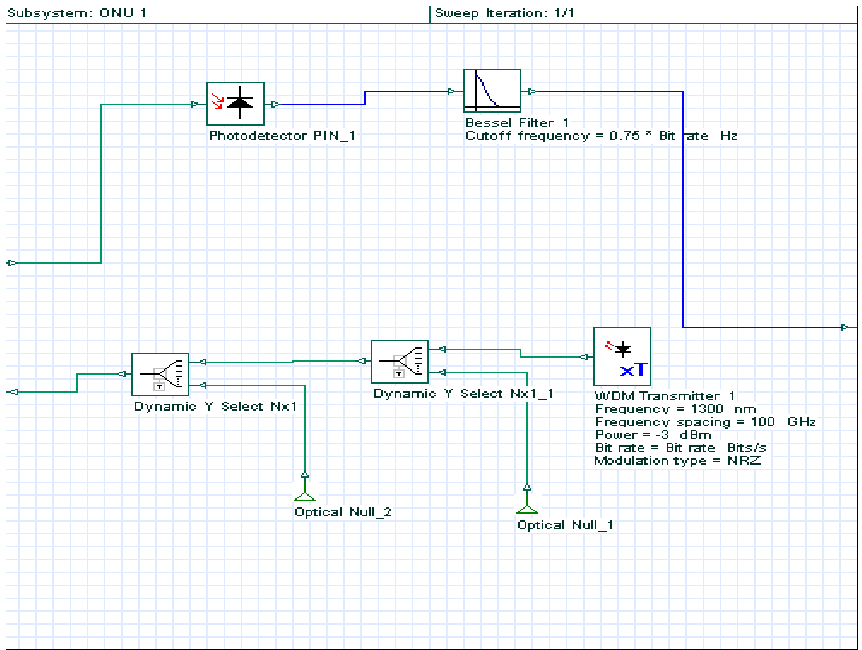


**Figure 5.3: ONUs Components**

## 5.2 Results and Discussions

As we know that we use optical splitter as a passive device, so on the basis of these factors some experimental results have been obtained. Downlink data is transmitted at the wavelength of 1550 nm and the uplink data is transmitted at the wavelength of 1550 nm. Both the wavelengths are selected because these wavelengths window has certain advantage i.e. it is low attenuation window. The performance of bidirectional PON standards in analyzed in detail. In downlink, we placed a TSOA in between the transmitter and optical fiber. The optical spectrum of downlink signal and time domain spectrum is as shown in figure 5.4 and 5.5 respectively. These spectra are observed at transmitter side when downlink signal is passed through TSOA after being generated from WDM transmitter and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise. For the case of 10Gbps we obtain an acceptable value of BER of 1.61e-013 for 64 users in downlink and an acceptable Q-factor of 15.04 dB for 40 users in uplink.

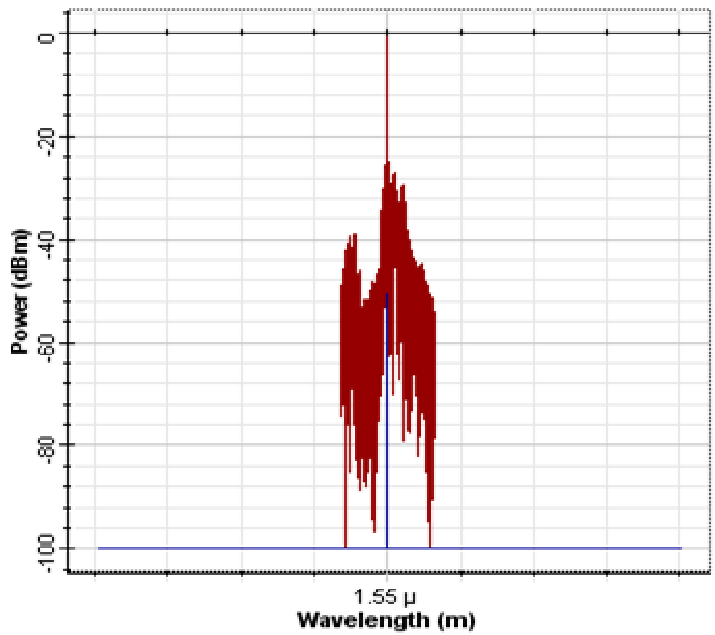


**Figure 5.4: Optical Spectrum Analyzer**

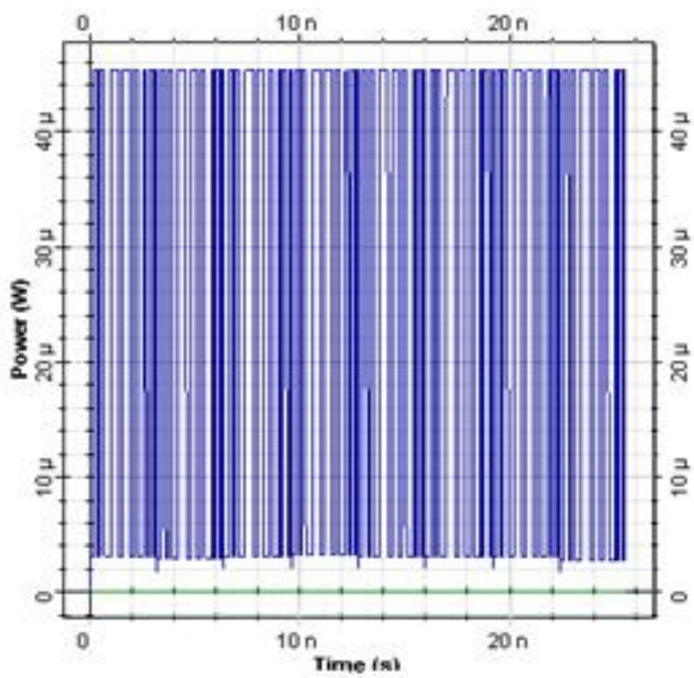


**Figure 5.5: Optical Time Domain Visualizer**

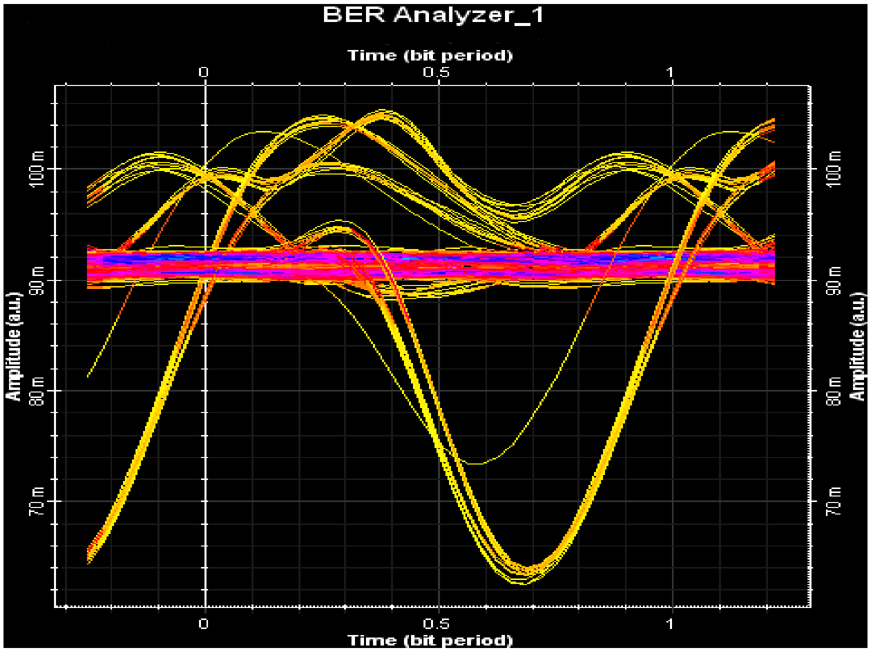


**Figure 5.6: Eye diagram corresponding to 10 Gbps data rate for 64 users**

The eye diagram and BER plot is shown in Figure 5.6 and 5.7 respectively for case when signal is analyzed for 64 users at a distance of 50km.

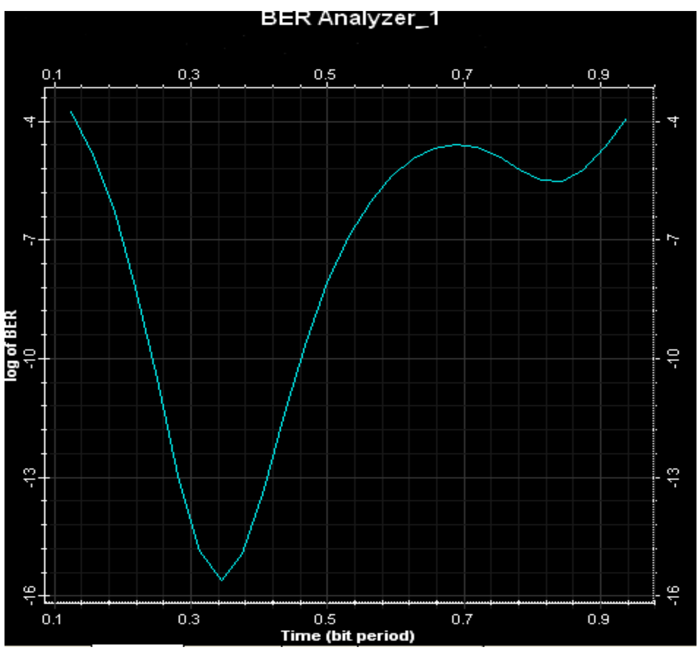


**Figure 5.7: BER analyzer downlink**

Basically we extend or increase the number of users using a passive device named as optical splitter. But optical splitter has also some limitations. So this paper describes the relation between the users and BER, so if we increase the number of users and distance then signal gets distorted and become error full.

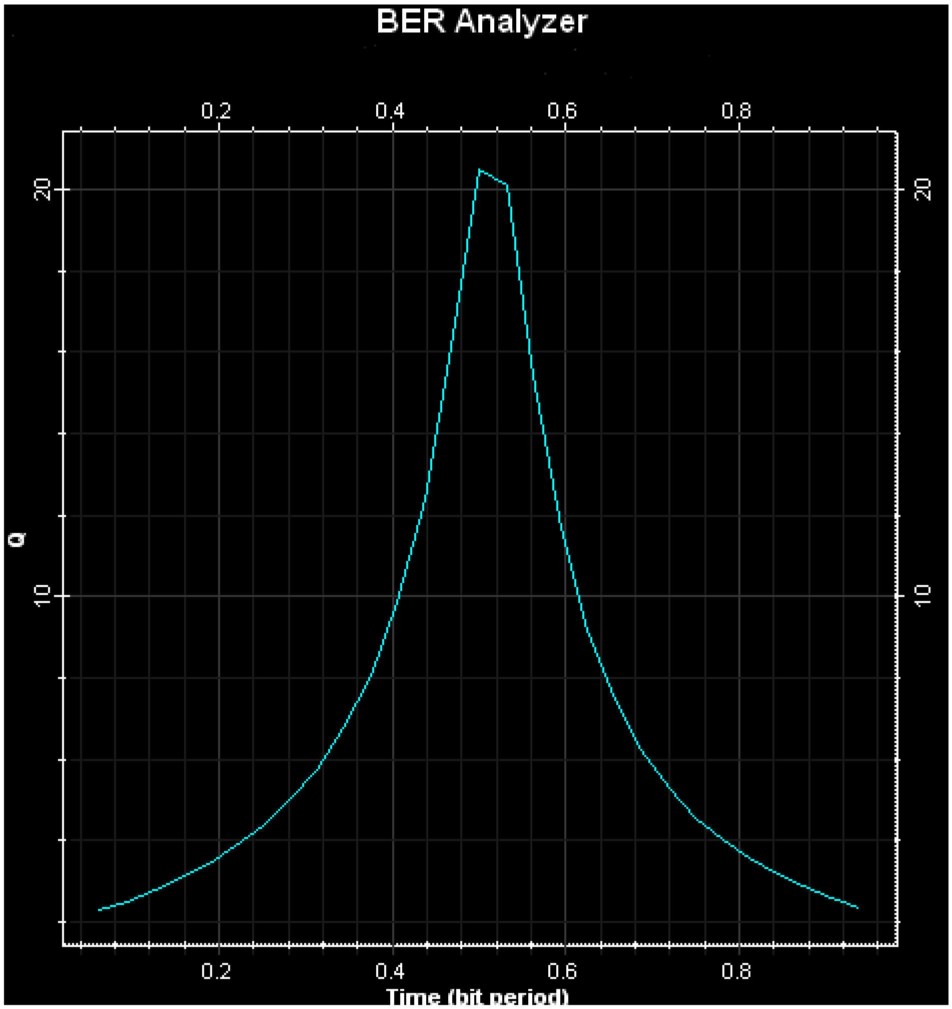


**Figure 5.8: Q-Factor analyzer uplink**

Figure 5.8 corresponds to Q- Factor of the uplink signal with 40 users at 10Gbps data rate. In figure 5.9 we see that if we increase data rate, Q-Factor decreases sharply or it accommodates less users and if we decrease the data rate, Q-Factor decreases as well as more number of users get accommodated.

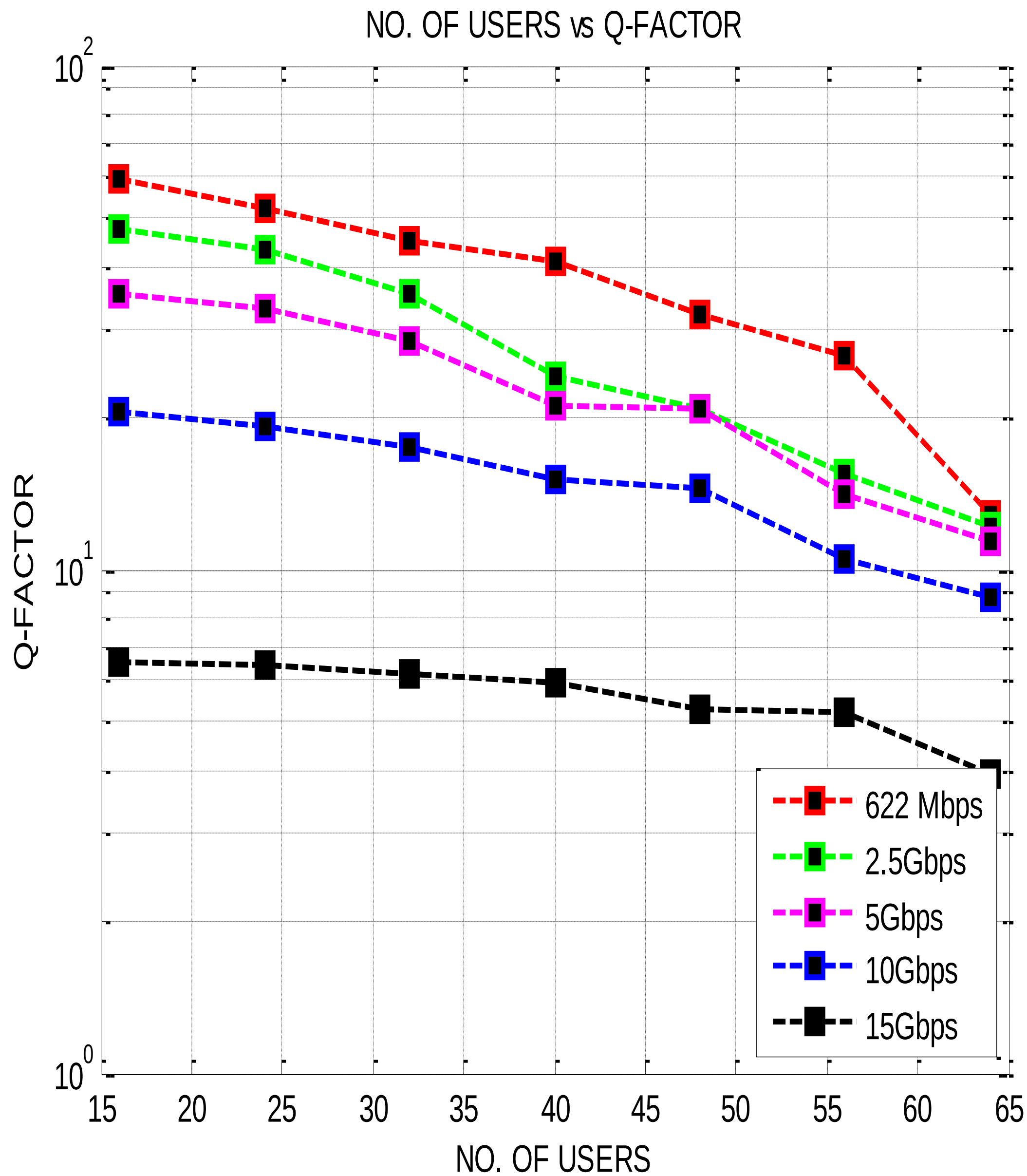


**Figure 5.9: Q-Factor Vs Users Plot**

Similarly in figure 5.10, we see that on increasing data rate, BER increases very fast and it increases more and more as we increase number of user. If we want to accommodate more users, we have to decrease data rate. So there lies a trade-off between BER, Q-Factor and data rate.

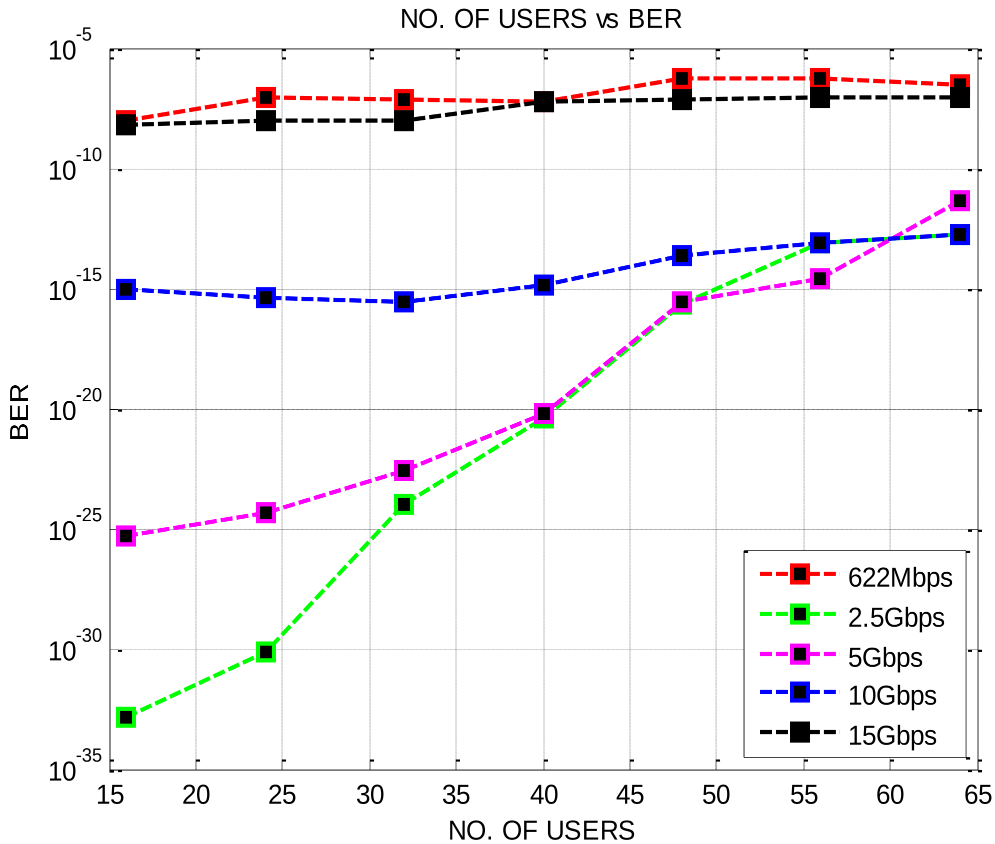


**Figure 5.10: BER Vs Users Plot**

## 5.4 Conclusion

PON provides an efficient solution for the future access networks due to its huge bandwidth and energy-saving. In this paper, we designed a bidirectional high speed PON using single fiber. We successfully demonstrated a proof of concept experiment at 10Gbps, and received optimized results at downlink and uplink both. We showed that with only 10GBps of data rate, error-free performance can be achieved for a symmetrical PON over a bidirectional 50 km feeder using 64 users. These performance and reliability results are sufficient for high data rate PON applications.

# CHAPTER 6

# CONCLUSION & FUTURE SCOPE

## 6.1 Conclusion

This Chapter Provides the summary of the research work done in this thesis. In this thesis work, the comparison of the different FTTH architectures has been presented. Throughout this thesis, we have discussed a series of important optimization problems for the design, planning, and deployment of FTTH networks and passive optical networks. The common features as well as the differences between three main architectures were outlined. We showed that the use of passive optical networks is very advantageous in designing FTTH architectures. First the conclusions have been made from this work done and then its future scope is being discussed. The major results are summarized as below

Firstly we demonstrated FTTH (Fiber To The Home) GEPON (Gigabit Ethernet Passive Optical Network) link design for 56 subscribers at 20 km reach at 2 Gbps bit rate. A 1:56 splitter is used as a PON (Passive Optical Network) element. The results at 2 Gbit/s system between the BER and different number of users illustrate that as the number of users increases beyond 56 users the BER comes to unacceptable level and if further increase data rate of system say 5Gbps, then we observe a sharp increase in BER.

In second case, we investigated FTTH (Fiber To The Home) GPON (Gigabit Passive Optical Network) link design for 56 subscribers at 140 km reach at 10Gbps bit rate. It is seen that by using Semiconductor Optical Amplifiers (SOAs) and Avalanche Photodiode (APD) in architecture increases the transmission distance. The results at 10 Gbit/s system between the Q-Factor and transmission distance illustrate that as the distance increases beyond 140km the Q-Factor comes to unacceptable level. So there is a tradeoff between Q-Factor and transmission distance. For 10Gbps data signal have been transmitted over 140km single mode fiber (SMF) successfully.

Lastly, we designed a bidirectional high speed PON using single fiber. An access network architecture is utilized using a centralized light source at central office (CO) with wavelength 1550 nm and 1300nm wavelength received at the optical network unit (ONU). The BER results show that the performance of our scheme is good for 10Gbps system for downstream transmission as it accommodates 64 ONUs. BER attains an acceptable value at 15Gbps also but for limited ONUs. In case of upstream transmission, Q-Factor of 15.04dB is achieved for 40 ONUs was obtained successfully.

## 6.2 Future Scope

It is envisaged that, in the coming future, access based on the PONs will be dominant. Primarily because this technology is maturing fast, it allows the total cost to be shared amongst a larger number of customers. It is certain that as a number of available HDTV channels grow even more bandwidth will be required. This could provide an incentive to quicken the development of FTTH networks based on WDMA mode and significantly reduce their time to market. Despite being in the laboratory phase, this technology might become available on the market in the next couple of years. In comparison with other access technologies such as DSL or Cable, FTTH offers much bigger bandwidth. Although the objectives of this research have been achieved, there are still other research opportunities to be investigated.

The introduction of PONs with WDM access is a huge area for research. In such a network, the OLT will have to make decisions not only about allocating time slots to ONUs but also about choosing an appropriate wavelength to carry the signal. As the complexity of such a system is much higher, the problems faced by the bandwidth allocation algorithm are harder to solve.

Using different simulation tools for the proposed FTTH architectures could help to estimate the performance for larger systems under different conditions and network parameters.