

**T.C**  
**ISTANBUL AYDIN UNIVERSITY**  
**INSTITUTE OF GRADUATE STUDIES**



**PERFORMANCE ANALYSIS OF MULTIPLEXING TECHNIQUES FOR PASSIVE  
OPTICAL NETWORK**

**MASTER'S THESIS**

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**Department of Electrical and Electronics Engineering**  
**Electrical and Electronics Engineering Program**

**Aug, 2021**



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**Aug,2021**



## **DECLARATION**

I hereby declare that all information in this thesis document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this thesis.



**Abdulkadir Omar Abdullahi**

## **FOREWORD**

First of all, I would like to thank the Almighty ALLAH for his support, help, and generosity to complete this thesis. Second, I would like to thank my family, especially my father and mother for supporting me throughout my life. They pushed me to be the best person that I can be, and I would not be the person I am today without you in my life. I would like to thank my brothers and sisters for all the support and encouragement. I would like to express my special gratitude and thanks to my advisor **Assist.Prof. Dr Necip Gökhan KASAPOĞLU** for his continuous support, patience, motivation, and immense knowledge that helped me successfully carried out this thesis. I would like to give my worm thanks to our honorable Head of Department Dr. Eylem Gülce ÇOKER for his valuable advices from time to time when I needed it which made my thesis work became smoother.

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**May, 2021**

**Abdulkadir Omar Abdullahi**

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## ABBREVIATION

<b>PON</b>	: Passive Optical Network
<b>TDM</b>	: Time Division Multiplexing
<b>WDM</b>	: Wavelength Division Multiplexing
<b>QoF</b>	: Quality of Factor
<b>BER</b>	: Bit Error Rate
<b>FTTH</b>	: Fiber to the Home
<b>CO</b>	: Central Office
<b>AON</b>	: Active Optical Network
<b>RN</b>	: Remote Node
<b>OLT</b>	: Optical Line Terminal
<b>ONU</b>	: Optical Network Unit
<b>ODN</b>	: Optical Distribution Network
<b>OAN</b>	: Optical Access Network
<b>DSL</b>	: Digital Subscriber Line
<b>ADSL</b>	: Asymmetric Digital subscriber line
<b>VDSL</b>	: Digital subscriber line
<b>HFC</b>	: Hybrid Fiber Coaxial
<b>Wi-Fi</b>	: Wireless Fidelity
<b>Wi-MAX</b>	: Worldwide Interoperability for Microwave Access
<b>P2MP</b>	: Point to Multipoint
<b>P2P</b>	: Point to Point
<b>ATM</b>	: Asynchronous Transfer Mode
<b>Mbps</b>	: Megabit Per Second
<b>Gbps</b>	: Gigabit Per Second
<b>MPCP</b>	: Multi-Point Control Protocol
<b>MAC</b>	: Media Access Control
<b>MAN</b>	: Metropolitan Area Network
<b>LAN</b>	: Local Area Network
<b>WAN</b>	: Wide Area Network
<b>AWG</b>	: Arrayed Waveguide Grating
<b>CW</b>	: Continuous Wave
<b>MZM</b>	: Mach Zehnder Modulator
<b>NRZ</b>	: Non-Return to Zero
<b>LED</b>	: Light Emitting Diode
<b>LCD</b>	: Liquid Crystal Display

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# PERFORMANCE ANALYSIS OF MULTIPLEXING TECHNIQUES FOR PASSIVE OPTICAL NETWORK

## ABSTRACT

Recently, fiber optic networks are widely used because it has high data rate, capacity and could life along more than 20 years and it can reach a far distance.

Passive optic networks offered high capacity and better performance according to the data rate and bandwidth and then reduced consumption of fiber optic (i.e., length, cables) and increase the capacity of customers. There are more techniques that expansion the spread spectrum of fiber optic included Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM). This thesis focuses in the comparison between TDM/WDM according to the quality factor and bit error rate with distance (length of fiber optic) by utilizing of the Opti-system software. the WDM outperform than TDM with the fiber length increasing.

**Keywords:** *Optical Fiber, Fiber to the Home, Passive Optical Network, Time Division Multiplexing, Wavelength Division Multiplexing.*

## PASIF OPTİK AĞLARIN ÇOKLAMA TEKNİKLERİ İÇİN PERFORMANS ANALIZI

### ÖZET

Son zamanlarda, Fiber optik ağlar, yüksek veri hızına, kapasitesine sahip olduğu ve 20 yıldan fazla yaşayabildiği ve uzak mesafelere ulaşabildiği için yaygın olarak kullanılmaktadır.

Pasif optik ağlar, veri hızı ve bant genişliğine göre yüksek kapasite ve daha iyi performans sunarken, daha sonra fiber optik (yani uzunluk, kablo) tüketimini azaltarak müşterinin kapasitesini artırdı. Fiber optiğin yayılma spektrumunu genişleten daha fazla teknik vardır (Zaman bölmeli çoğullama ve dalga uzunluğu bölmeli çoğullama) TDM ve WDM. Bu tez, Opti-system yazılım versiyonu7 kullanılarak, kalite faktörü ve mesafe ile bit hata oranına (fiber optik uzunluğu) göre aralarındaki karşılaştırmaya odaklanır, WDM, fiber uzunluğu arttıkça TDM'den daha iyi performans gösterir.

**Anahtar Kelimeler:** *Optik Fiber, Eve Fiber, Pasif Optik Ağ, Zaman Bölmeli Çoklayıcı, Dalgaboyu Bölmeli Çoklayıcı.*

## **1.INTRODUCTION**

### **1.1 Introduction:**

Communication of fiber optic is a means of delivering data from one location to another by transmitting visible light via an optical fiber; the light shapes an electromagnetic carrier wave to carry data is modulated. In a fiber network, there are two common systems available, one of them is passive optical network (PON) which access network architecture of fiber optic that delivers signals to the home via fiber cabling using a point to multipoint scheme that allows a single optical fiber to connect several sites using passive components.

The bandwidth supplies of telecommunication network users have risen rapidly in recent years; access networks for optical must now provide bandwidth associated to each user, as fine as support data rate is high broadband multiple services versatility and communication for numerous end users, division multiplex of time and division multiplex of wavelength that are leased in the PON for upgraded capability efficiency and power. for data applications in TDM/PON has limited accessibility but has much higher bandwidth, WDM/PON on the other hand will resolve TDM problems PON's by allocating an exacting wavelength to every single user (Nour, 2017).

The first PON operation was in the 1980s, to add optical access solutions to their networks the multiple of the world's largest carriers worked together. In any case, due to rising cost and lowly demand at the time, these only survived as trial applications. In 1990 the internet became popular, showing the need for reliable broadband connectivity. A set of seven main network workers known to the access networks of full-service alliance in 1995 to establish a mutual set of specifications for systems of optical access.

This resulted in ITU/T recommendation G-902 in 1998 and in 1999 ITU/T agreed the new specifications as the 155Mbps PON system, this was termed broadband passive optical network B/PON or more normally asynchronous transfer mode created A/PON or ATM/PON,

while the FSN and ITU/T have been dynamically upgrading B/PON, ethernet has become much common (Shaukat, Ibrahim, & Nazir, 2011) (Lallukka & Raatikainen, 2006).

The institute of electrical and electronics engineers (IEEE) proved the first mile of ethernet is a research set, which later became the IEEE 802-3ah task force, this task force had an E/PON sub task force, which strenuous on standardizing the 1Gbps ethernet infrastructure focused on symmetrical PON, the work was completed and in the summer of 2004, the first edition of Standard 1 the ONT is a ONU used for fiber to the home (FTTH) that includes the user port function {G.984.1} was approved (Lallukka & Raatikainen, 2006). The first mile alliance of ethernet is starting to raise ethernet based standards as the first mile technique, the FSN consortium was also involved and launched a new initiative in 2001 to standardize PON networks running at bit rates above 1Gbps work was defined on the first of the B/PON and the recently introduced generic framing procedure (GFP) principles, the analysis was conducted at a quick rate, the ITU/T recommendation {G.984} is the initial documents or the standard of gigabit capable PON were announced in 2003.

### **1.1.1 Description of the problem:**

The use of the TDM technology used in PON was not efficient enough because the Q factor rapidly decreased with increasing the distance and BER, so we move from TDM technologies to WDM in the passive optical network.

### **1.1.2 Objectives:**

There are several specific objectives for completing this research:

- ✓ The method uses Opt-system software.
- ✓ The output parameter is used to test the device in relations of bit error rate (BER) and quality of factor (QoF)
- ✓ One-way 4-User TDM PON WDM PON.
- ✓ To obtain which one is better performance TDM or WDM.
- ✓ Development of the optical network system using PON.

## 1.2 Literature Review:

We found that from previous works studies:

There are many benefits of passive optical network (PON), such as low distortion of signal, efficiency cost, saving energy, in areas where inhabited both customer residential and business over the technologies of first mile and last mile.

for passive optical networks is one of the main elements that the growth networks of fiber to the home (FTTH), the PON is assumed to be one among the most real connectivity architectures can provide long reach and high capacity is noticed that. As increase the length of fiber, the quality factor will reduce and bit error rate increases as the technology progresses from the TDM to the WDM.

The correspondence capacity network transmission for interest is expanding quickly because of the expanding number of brilliant innovation clients for access networks of optical to broadband have been developed to solve two issues:

- ✓ The client to sharing fair channel limits.
- ✓ Adequate allocation of limits on the basis of the required resources.

Wavelength for detached division multiplexing of optical network for passive is a capable key for achieving a high rate of information, great flexibility, great convention, straight forwardness and simple overhaul potential, the predominant optical access network to broadband it arising out of innovative work today is P2MP optical organization identified as passive optical network PON (Shaddad, Mohammad, Al-Hetar, & Al-Gailani, 2013). carbon dioxide associated with clients who utilize one downstream frequency channel and another upstream frequency channel, time division multiplexing innovation is utilized in this PON, so it is frequently alluded to as TDM/PON current PON models give a lot higher information transmission capacity, the application is simply accessible to end clients, TDM/PONs can have an ease for each client as the data transfer capacity is shared between all end clients, so WDM/PON is utilized to tackle this issue, the WDM/PON arrangement gives phenomenal versatility since it can uphold numerous frequencies on a similar fiber foundation and isn't liable to control parcel misfortune WDM PON additionally has great convention straight forwardness and upgradeability WDM

PONs gives a capable optical access solve for significantly increment access network transmission capacity WDM PON is rendered primarily from the OLT optical line terminal in central office (CO), optical fiber, distant hub, and numerous ONU (Shaddad, Mohammad, Al-Hetar, & Al-Gailani, 2013).

In a PON-type WDM framework, each ONU incorporates an optical transmitter fit for sending optical signs of variable frequencies and an optical sign accepting channel that changes the frequency of the beneficiary and the regulator The OLT characterizes the communicating frequency and recipient frequency from the presently free frequencies in light of the solicitation to relegate frequencies from each ONU and designates these frequencies to the ideal ONT. The control unit of the ONU changes the transmission frequency of the optical transmitter and the frequency of the optical transmitter channel to the frequencies defined by the OLT response packet and information correspondence begins.

For time division multiplexed in passive optical network TDM PONs for strands FTTH were concocted into the home in the last part of the 1980s. The serious issues of a minimal effort, multi-access photovoltaic organization geography was explored and settled in the next years, and the main frameworks were created by significant merchants and actualized by driving administrators. Simultaneously, questions were raised about the capacity of PONs TDM tools with shared data transmission to meet the expanding transfer speed necessities. For future PONs, sufficiency development by different frequencies has been proposed, and along these lines frequency division (WDM) PON research has been proposed. Then, practically all monetarily sent PONs were TDM-PON arrangement, were financially understanding and effectively meet limit necessities (Harstead, Veen, Houtsma, & Dom, 2018). Aggregate arrangements started with broadband PON (BPON) 622 Mbps downstream, 155 Mbps upstream in 2003 and ethernet PON (EPON) 1Gbps symmetric in 2004, trailed by gigabit PON G/PON in 2008 2488Mbps transfer and 1248Mbps transfer, during this time, GPON/EPON advancements started to extend to 10Gbps, in 2009 IEEE 10G E/PON 1 and 10Gbps upstream 10Gbps downstream was normalized, In 2010 ITU-T 10 gigabit XG/PON1 2,488Gbps normalized upstream 9,953Gbps downstream afterward ITU-T added a standard 10Gbps symmetric XGS/PON 9,953Gbps upstream and downstream in 2016, following a couple of years, the mass arrangement of 10Gbps class PONs is presently expanding, innovation and tech 2008 ' follows gigabit PON (GPON)

2488 Mbps transfer, 1248 Mbps transfer at that time, GPON/ EPON advances started to grow to 10Gbps afterward ITU/T added a standard 10Gbps symmetric 9,953Gbps upstream and downstream in 2016 (Harstead, Veen, Houtsma, & Dom, 2018). 10G EPON was normalized 10Gbps downstream, 1 and 10Gbps upstream in 2009 ITU-T 10 gigabit XG/PON1 in 2010 9,953Gbps downstream, 2,488Gbps upstream was normalized. Afterward, ITU-T added a standard 10Gb/s symmetric 9,953Gbps upstream and downstream in 2016. Following a couple of years, the mass arrangement of 10Gbps class PONs is currently expanding. 488Gbps upstream innovation normalized in 2010. At that point ITU-T, in 2016, added 10 gigabit symmetric XGS/PON default 9,953Gbps upstream and downstream. (Harstead, Veen, Houtsma, & Dom, 2018).

Deployed the optical access for passive optical networks is regularly the select of technology because of make share by a large number of subscribers for the transmission and the central office devices. (Suzuki, Fukada, Nettet, & Davey, 2007).

An optical line terminal in the central office is related to a number of optical network units via an optical distribution network (ODN) with optical fibers and passive optical dividers, the ODN is clearly passive, which is extremely appealing to the worker It is now possible to operate on a single fiber, by the use of wavelength division multiplexing (WDM) with upstream wavelengths of 1310 nm between those areas (1260 up to 1360nm) and downstream wavelengths of 1490 nm between those areas (1480 up to 1550nm), it is published the capacity with PON customers using a multi access of protocol TDMA that gives transmission time slots to every subscriber, the highest number of PON reaches and splits are defined or calculated by both the PON protocol and the physical layer optical range. (Townsend, et al., 2009).

The existing of passive optical network (PON) should be raised to accommodate higher data rates and greater size since the bandwidth demand is growing more and more quickly, in addition to the present commercial PON based on time division multiplexing (TDM) many alternatives have been suggested including a wavelength division multiplexing PON architecture (WDM PON). (Li, Hu, Ren, Zhu, & Mo, 2015).

As a communication technology grows, the need internet has for high speed that growing time by time due to the requiring a high data rate and a wide bandwidth, future of our technology

is designed to be flexible to provide wide bandwidth and to accommodate a big quantity of new applications, the fiber optic technology that utilizes optical light as a transmitting medium has been developed to solve this problem, optical fiber gives us the right way to solve the issue of an access network and also it gives us a mixture of low probability of error, high bandwidth and high transmission power. (Rani, Sachdeva, Ramandeep, & Goyal).

Fiber to the home system counts the opinion of service sources at the same time FTTH a 100 percent placement of optical fiber, as the signal travels through the fiber and the power decreases due to the presence of different non linearity in the fiber sector. (Rani, Sachdeva, Ramandeep, & Goyal).

For passive optical networks have evolved from conventional time division multiplexing TDM/PON such as ethernet passive optical networks E/PON and gigabit passive optical networks G/PON to wavelength division multiplexing WDM/PON it divides upstream data transmission into various wavelengths and certainly gives better protection and higher average data speeds. (Wang, et al., 2011).

The major groups of standardization for passive optical network systems i.e. the ITU/T and IEEE have worked over the last few years to improve the PON systems formal line rate behind 10Gbps, the task force of IEEE has explained a framework based on a 25Gbps nominal line rate, the ethernet passive optical network (EPON) of (802.3ca) 50G The ITU/T has tracked down a 50Gbps even higher nominal line rate over the past ten years, operators already deploy PON as a nominal 10Gbp line rate for upgrades to passive optical network of GPON and EPON gigabit sensitive networks, the next step in the ITU/T analysis was to show that line prices should at least four times those now posted (Zhang, Liu, Wu, & Nettet, 2020).

This necessity has led to work in ITU/T and this part focuses on the recent development in ITU/T standards the readers will be guided to those interested in reviewing the IEEE PON standardization project while this part concentrates on the ITU/T PON standards, some reference to IEEE PON is still made that is because the IEEE and ITUT are attempting to ensure that the main aspects of their respective PON standards have much commonality as possible so that divergences can be minimized and convergence encouraged especially applies for the physical

layer, for example by taking the same wavelength planes to the extent possible to allow the use of the popular optical element (Zhang, Liu, Wu, & Nettet, 2020).

The restriction bandwidths of access technologies for the last mile and the growing demand for high-speed bandwidth encourage fibers to the home in order to provide new high-speed services, one of the FTTH operations that is a solution for access networks due to the point to multipoint P2MP architecture is passive optical network. (Bindhaiq, et al., 2015).

Currently, gigabit ethernet passive optical network and capable G/PON based on time division multiplexing specifications is overlooking in several countries worldwide nevertheless, since all the users of the device share the entire spectrum of bandwidth, every subscriber becomes access to a small data rate sometimes reduced to Mbps, today request for high bandwidth increases fast as advanced multimedia technologies such as online gaming and video on demand, the new systems also need to be modified and improved by new technologies, next generation PONs is suggested by groups of interest in telecommunications such as access network of full service, IEEE and ITU for next generations of passive optical network (Bindhaiq, et al., 2015).

Two segments for next generation of passive optical network are separated: first segment is next generation of passive optical network1 and second segment is next generation of passive optical network2. NG/PON1 is well defined as the next generation of midterm based on 10Gbps and NG/PON2 celebrated as the next generation in the long term was suggested by FSN as a 40Gbps minimum and has to be retroactive, studies on activating NG/PON2, such as 40G TDMPON have recently been performed. Wavelength division multiplexing of PON WDM/PON, time/wavelength division multiplexing of PON TWDM/PON and orthogonal frequency division multiplexing of PON OFDM/PON (Bindhaiq, et al., 2015).

Optical Network of passive is a cross point high-rate optical data link network, different standards of PONs were established ATM PON in broadband PON, ethernet PON and gigabit PON. PON is considered to be XPON for these different criteria some essential cases will be considered to achieve capable efficiency in the last two PON standards (Kadhim & Rahman, 2013).

The necessity to reduce complicated and costly time-sharing of available bandwidth in TDM-based PONs has led to the creation of new forms of access networks that improve network operation while managing ever-increasing bandwidth demands. These access networks are known as WDM-PONs, and they use many separate wavelengths to transport data at speeds up to electronic processing limitations of a few Gbps. Three major devices are included in the PON architectural system: optical line terminals (OLT), optical network units/optical network terminals (ONU/ONT) and optical distribution network (ODN) so in the transmitters at the OLT side create a single wavelength carrying the information destined for a specific ONU. The RF signal in OLT is created by a user bit sequence generator and coupled with a CW laser at wavelengths ranging from 1490nm to 1493nm. The frequency spacing specifies the sort of network elements used and the costs associated with them, therefore these wavelengths are then combined onto a single fiber using a WDM multiplexer with particular insertion loss installed inside the CO. The multiplexed output is attached to a single mode fiber (SMF) of varying length (km) that ends on a WDM demultiplexer. (Aldhaibani, et al., 2012)

The success of time division multiplexing (TDM) in optical access is built on two pillars: its ease of use and the maturity of the electro-optical devices used. The photonic integration of laser diodes with external modulators provides a cost-effective user equipment does not need for cooling or wavelength stability. In contrast to wavelength division multiplexing (WDM), TDM has achieved high market infiltration via the ethernet and gigabit passive optical network (E/GPON) standards and is currently arranged as a 10Gbps solution via 10G-EPON and XGPON; TDM is also being considered for NG-PON2 and has heavily partial new research effort, particularly in reach-extended hybrid WDM/TDM PONs. (Verbrugge, Bakopoulos, Lazaro, & Yin, 2012) The high peak data rate necessary to provide an averaged low sustainable data rate comes TDM for high bit-rate PONs into question. Beyond 10Gbps migration to enable business-class fiber to the house or other bandwidth-demanding services is essentially constrained by the electrical capacity of the driving circuitry in the transmitter and receiving subsystems.

Because of the growth of internet and multimedia services, technologies such as passive optical network (PON) have risen to the top of the research field. Because it is more cost efficient, network service providers typically implement time division multiplexing (TDM)-

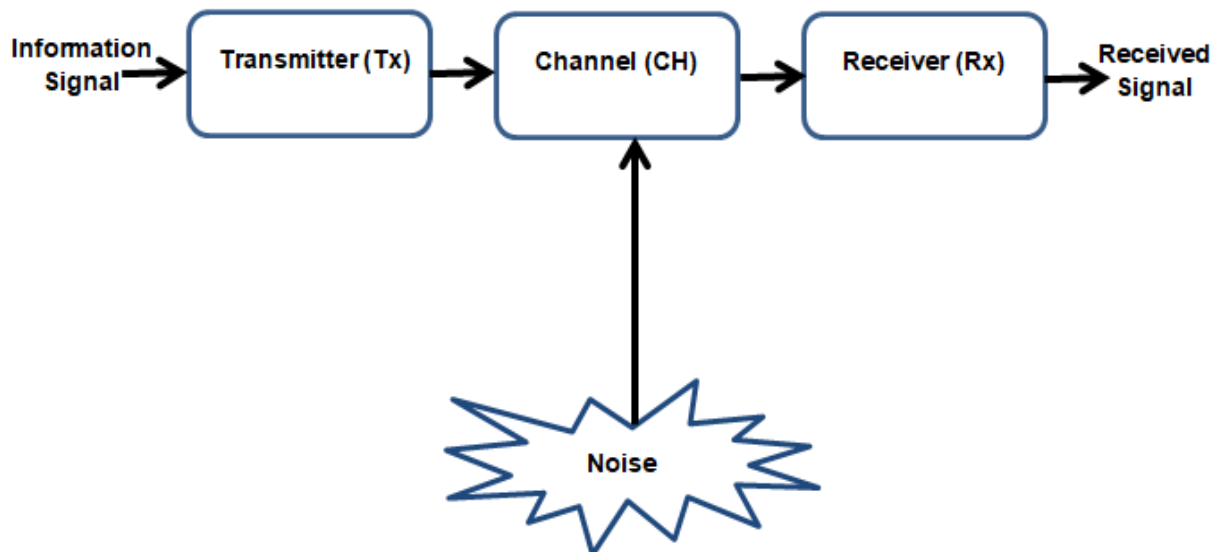
based PON. The fundamental constraint of TDM-PON is its restricted bandwidth, hence wavelength division multiplexing (WDM) based PON is employed to give higher bandwidth. However, the fundamental constraint of WDM-PON is its high cost. As a result, the advantages of TDM-PON and WDM-PON balance each other out, and a hybrid WDM/TDM PON design is proposed. (Lohani & R.S.Prasad, 2015)



## 2.PASSIVE OPTICAL NETWORK

### 2.1 A General Communication System:

Communication meaning as a general method of exchanging data, to transfer their opinions, thoughts, and feelings to others the people they must make communicate, the methods of communication is essential to all human life and includes oral and body language, print, and electronic procedures. In system of communication have a transmitter, communication channel or medium, and a receiver these basic components are shown in Fig 2.1 the communication process starts when made human being some kind of message or information that must be received by others a message may also be made by a computer or electronic current, In electronic communication systems, the message is named to as data, the message shape is an electronic signal it fed to the transmitter which then sends over the communication channel, the message is picked up by the receiver and reached to another human, during the signal pass in the communication channel the signal may add noise or makes interference and in the receiver, Noise is the universal period applied to any phenomenon that disgrace or interferes with the transmitted information (Jr., 2016).



**Figure 2. 1:** General Communication System

### **2.1.1 Transmitter:**

The initial point in sending a message is to translate it into an electronic format that can be submitted, a microphone is utilized to convert sound into an electronic audio signal for voice messages and camera transforms the light data in a scene into a video signal for television, the message is captured on a keyboard and changed to binary codes that can be kept in memory or transmitted serially in computer systems physical properties are converted into electrical signals by transducers (Ramaswami, Sivarajan, & Sasaki, 2009). The transmitter is a series of electronic components and circuits that transform an electrical signal into a signal that can be transmitted over a specified communication medium.

Amplifiers, filters, modulators, voltage, oscillators, and other circuits make up transmitters the creative intelligence signal modulates a higher frequency bearer sine wave produced by the transmitter, and power amplifiers boost the combined signal's amplitude (Jr., 2016), with selected transmission medium the resulting in a signal that is compatible.

### **2.1.2 Channel Communication:**

The channel of communication is the medium by transmit from one place to other place which the electronic signal, many various types of media including wire conductors, fiber optic cable, and free space are utilized in communication systems, (Jr., 2016).

### **2.1.3 Noise:**

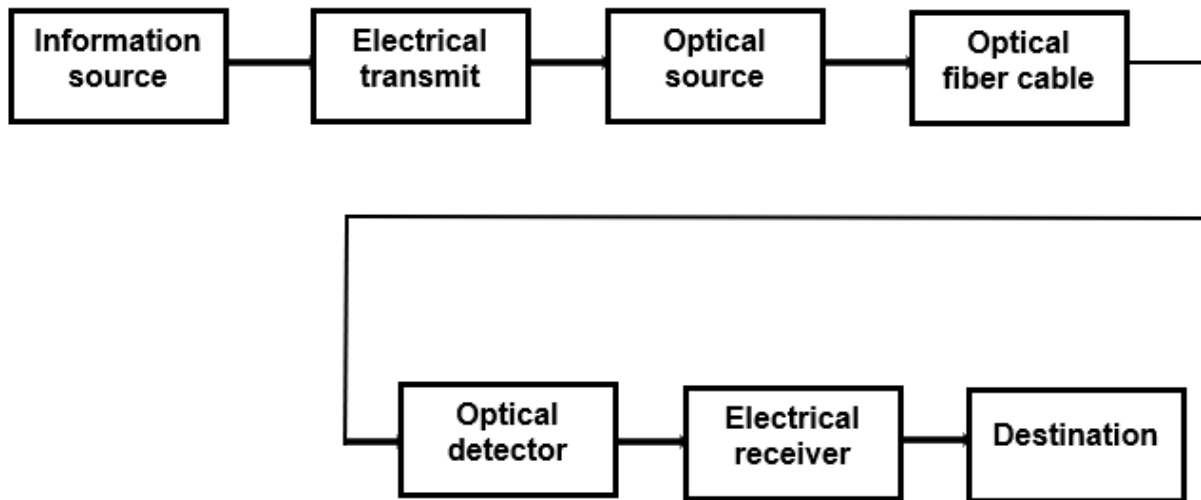
Is included for the reason that it is an insufficiency in all electronic communications; its effect is especially heavy on the receiving section of every communication device, even though some noise can be extracted out, the overall approach of noise reduction is to use factors which donate to less noise and lesser temperatures. A common form is the signal noise ratio (SNR), which is the signal strength, divided by the noise power and can be expressed mathematically or in decibels. A high S/N ratio is clearly chosen for good noise estimation results. (Ramaswami, Sivarajan, & Sasaki, 2009).

#### **2.1.4 Receivers:**

Is a blend of electronic elements and circuits which accept the message sent from the channel and revert back it to a humanistic form; receivers consist of amplifiers, oscillators, mixers, filters and detectors which receive the original signal from the modulated carrier. It can be a voice signal and video signal fed into a liquid crystal display (LCD) screen or binary data obtained by a device, which is then seen on a video monitor. (Hanane, 2019) (Jr., 2016).

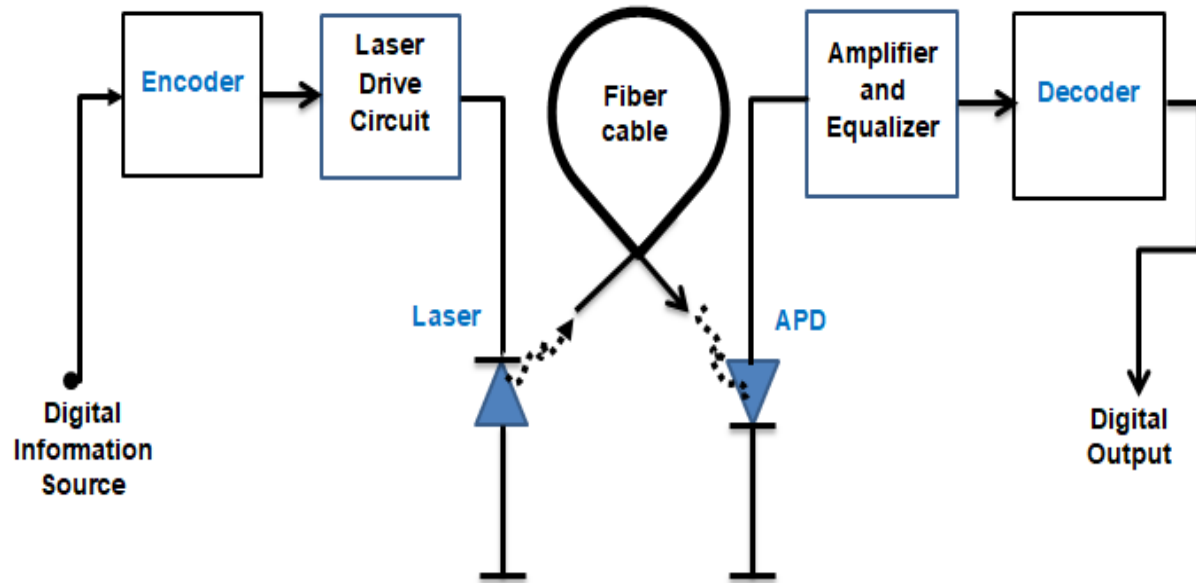
#### **2.2 A Digital of Fiber Communication System:**

The information source sends an electrical signal to an electrical phase emitter, which drives the light source to modulate the light wave carrier. The optical source, which converts electricity to optics, may be a semiconductor laser or a light emitting diode, the propagation medium is fiber optic cable, and the receiver includes a light detector that regulates a second electrical level. Resulting in demodulation of the optical carrier photodiodes p/n, p/i/n or avalanche and since phototransistors and photoconductors are used for the detection of the optical signal and the optical–electrical transition in some cases, electrical interfacing is needed at both ends of the optical connection, and signal processing is currently done electrically. Analog or digital information signals may be used to modulate the optical carrier In the system shown in Figure2.2 analog modulation is the process of continuously changing the light emitted from an optical source regardless, distinct variations in light intensity are obtained on/off pulses with digital modulation, which is also easier to implement, for an optical fiber communication system, analog modulation is less effective and requires a much higher signal to noise ratio at the receiver than digital modulation furthermore. Semiconductor of optical sources do not always provide the linearity needed for analog modulation, particularly at high frequencies modulation, optical fiber communication links for Analog are typically restricted to shorter distances and lower bandwidth service than digital links for these reasons (Senior & Senior, 2009).



**Figure 2. 2:** Fiber Optic of Communication System

Figure 2.3 represents a block of a typical digital fiber optic link; the information source's digital signal is first appropriately encoded for optical transmission, with the encoded digital signal, the drive circuit of laser modulates the power of a straight-line semiconductor laser after passing a digital optical signal via an optical fiber cable, the avalanche photodiode APD detector is used to amplifier and equalizer or filter to offer gain, linear signal processing, and noise bandwidth reduction. Finally, the signal is cracked to regain the original digital data; the numerous components of this system, as well as alternative optical fiber system configurations, in any case it given the benefits of integrating optical waves with optical fibers over the line and other forms of radio communication, these systems are gaining momentum in many parts of the globe. (Senior & Senior, 2009).

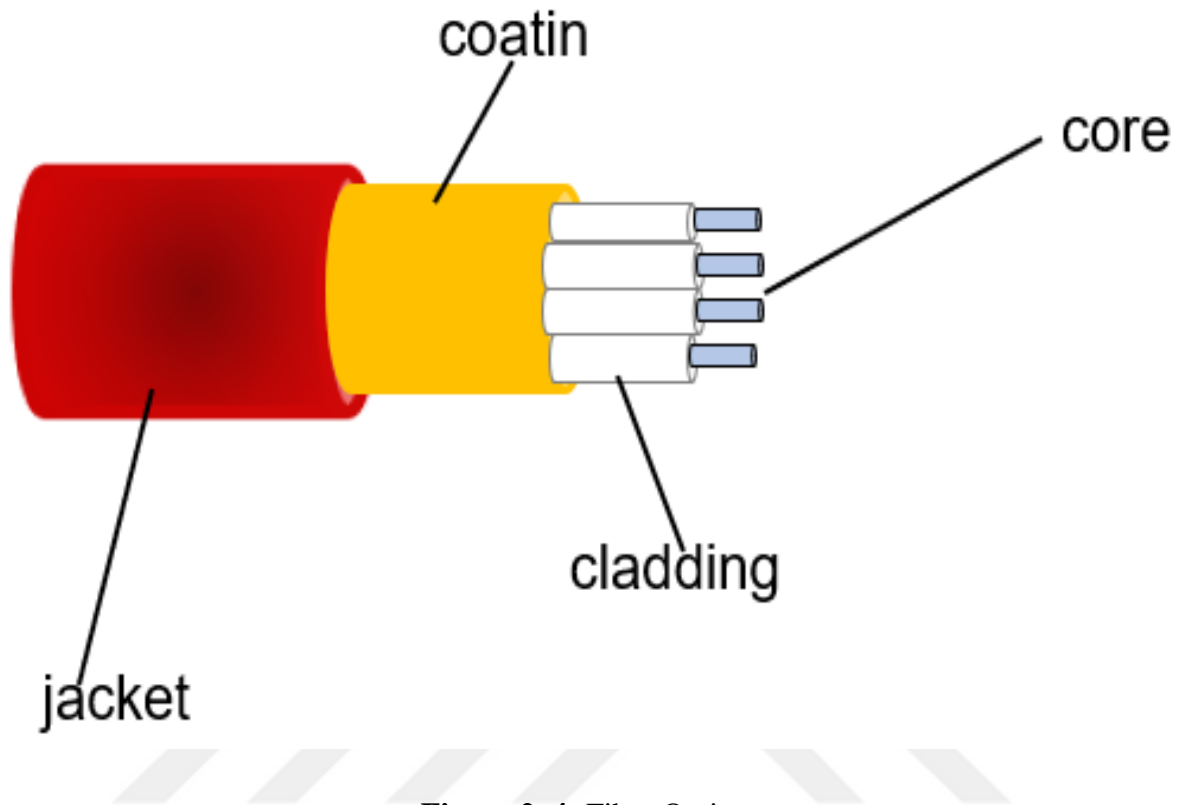


**Figure 2. 3:** Digital of Fiber Optic Communication System

### 2.3 Fiber Optic:

The introduction of optical fiber into the telecommunications industry was revolutionized in the early 1980s by providing an optimal transmission medium with unparalleled ultrawide bandwidth and extraordinarily low penetration loss., at the middle core of fiber optic has of  $9\mu\text{m}$  with a diameter for single mode fiber and  $50\mu\text{m}$  a diameter for multimode fiber, For both SM-fiber and MM-fiber, there is a  $125\mu\text{m}$  diameter cladding layer on the external core as shown in Fig 2.4.

The core and cladding are both made of  $\text{SiO}_2$  however, the core has the refractive index slightly greater than the cladding due to doping, thereby adding an elastic layer of acrylate coating to the core in which the visual field of signals is found mainly within the core, external cover to protect the fibers primarily and the fiber is generally swollen by the secondary layer of jacket. Because the fiber diameter including jacket and coating, is less than 1 mm in diameter and no material is used, the weight of the fiber per unit length is much less than that of the coaxial cable (Hui, 2019).



**Figure 2. 4:** Fiber Optic

Two concentric dielectric cylinders make up a fiber optic, the core/internal cylinder has an index refractive of  $n_1(r)$  and a radius of  $n_1(r) > n_2$  (2) the cladding/external cylinder has a refractive index of  $n_2$  and a radius of  $n_1(r) > n_2$ . A core diameter is 4 up to  $9\mu\text{m}$  and a cladding diameter of  $125\mu\text{m}$  is common values for silica/based fiber optic for single mode.

The refractive index  $n$  of waveguide optical is usually transformed with radius  $r$  from the fiber axis and is expressed by

$$n^2(r) = n_2^2 + NA^2 s\left(\frac{r}{a}\right) \quad (2.1)$$

The numerical aperture at the core axis  $NA$  is the ration of the facility of fiber optic to gather or restrain the episode light ray inside it, and the profile function  $s(r/a)$  characterizes any profile with a scaling parameter, normally the core radius, from  $s=1$  at maximum (Senior & Senior, 2009).

Advantage of optical fibers: -

- ✓ Large bandwidth.
- ✓ They allow higher throughput.
- ✓ They are absolutely unaffected by electromagnetic interference.
- ✓ The electrical cables have higher environmental resistance and corrosive liquid resistance.
- ✓ Easy availability and low cost.

In the 1980s, FITL research began fiber access systems are also known fiber to the X system where X can be defined {home, curb, premises, neighbor, etc.} as to how depth fiber is deployed on the field or how near it is to the user, in FTTH device fiber is connected to household users from the service provider. In a FTTC system fiber is fitted to a community curb in which the optic signal becomes electricity and is distributed through twisted couples to end users (LAM, 2007).

An FTTC system can also be seen as a hybrid fiber-twisted pair system. Most of us currently believe the fibers to x as the P2MP power splitting PON, current fiber access systems could be point to point.

#### **2.4 Fiber to the Home (FTTH):**

is a future-proof access technology that combines voice, data, and video in one link in order to provide multi-player facilities other futuristic services include voice/video/data and so on. Fiber in the local loop requires a large and growing multiplayer user market that includes both households and businesses. Businesses want more bandwidth, and many of the advanced services that only fiber can deliver to FTTH customers can reach more than 1Gbps of bandwidth, which is virtually infinite in today's scenario of developing internet usage by businesses and households in recent years, coupled with increased capacity demands, has increased the need for optical fiber cable of the last mile, the provider's primary concern is whether a fiber network for an active point-to-point or installation point-to-multipoint fiber network for a passive.

The rapidly expanding demand for internet applications and high bandwidth has brought huge entry into optical access networks. There is a good tournament between various types of

technologies to provide bandwidth and broadband services to end users. Digital subscriber loop (DSL) is the control access technology that can be grouped into 2 standard, asymmetric digital subscriber loops (ADSL) and very high-speed digital subscriber loops (VDSL) hybrid coax fiber (HFC) is believed to be the existing access technology used for the distribution of video and the Internet. Wireless fidelity (Wi/Fi) network is standing on IEEE 802.11 standards. Worldwide interoperability for microwave access (Wi/MAX) networks is standing on IEEE 802.16 standards. The fiber to the home is a strong competitor for all access technologies used, since it provides a cheap element. FTTX provides different innovations in the PON standard. In the 1990s, work on the passive optical networks was quickly undertaken and the FSAN Group outlined the initial PON requirements, using the asynchronous transfer mode as their layer 2 reporting protocol defined as asynchronous (A/PON) (ITU-T G.983.1). Orderly to support a full group of telecommunication services, FSAN make the first recommendations for Broadband (B/PON) (ITU-T G.983.x) in 1998. In 2001, the IEEE 802.3 working set took creativity in organizing Ethernet in the first mile (EFM), where the surviving ethernet devices were applied to PONs with little adaptations defined as ethernet (E/PON) (IEEE 802.3 ah). In 2003, the FSAN propounded the first recommendation for (G/PON) (ITU-T G.984.x). In the last mile of broadband access network, the explosive development of bandwidth-intensive applications has laid down a challenge, which requires lower cost, better ability and more flexibility. DSL, HFC and Wireless of the present access technologies have been upgraded a little by their capacity for bandwidth. However, they do have physical limitations to unlock the capability bottleneck that exists for subscriber access networks. As internet traffic grows rapidly and new app deployment is required, service providers need to search for new technology to install the new application. The necessary new technologies have an acceptable property to provide voice, data and video service to remote users throughout a single network, which will be easy, scalable and fast, so that users are able to collect attention and guarantee their competitive advantages for the near future. Moreover, new services represent a realistic challenge and placed growing pressure on telecommunications operators because of the spectral bandwidth shortage. Therefore, service providers want to use open access networks to meet the ever-increasing demand for bandwidth. Thus, fiber to the home (FTTH) is being used in huge numbers to prepare for the explosive demand for bandwidth driven by the excessive growth of Internet services. As an outcome,

FTTH is predicted to be the best supplier of broadband technology by 2035 because it can easily scale due to its extensive fiber networks. (Bindhaiq, et al., 2015).

## **2.5 Passive Optical Network (PON):**

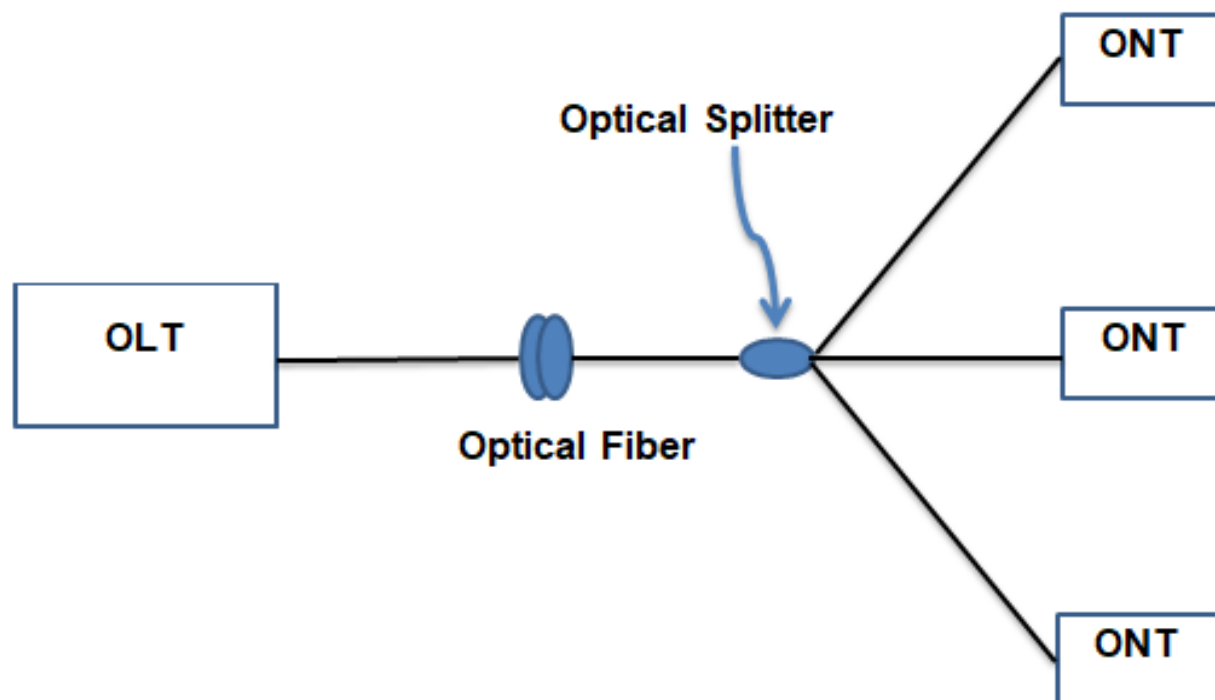
The optical fiber is the most advanced communication medium and the only one capable of helping the next generation of services, the key advantage of providing a last mile of optical fiber is higher bandwidth, longer distances from the middle to the user, increased resistance to electromagnetic interference, increased protection and decrease signal degradation moreover, using PON technology means eliminating repeaters and optical amplifiers and therefore reducing initial expenditure, lower power consumption, less space and less failure points (Nour, 2017).

Passive of optical network is a network that transmits data in the optical domain between the optical line terminal (OLT) and the optical network unit (ONU) or optical network terminal (ONT) and the transmission of the optical signal is passive, this means that the devices of optical network between the transmitter and the receiver are passive, no electrical devices are used, the PON theory is summarized in the following sentence. The attitude of PON is to share the central optical line termination and the feeder fiber over as many optical network units as is practical provided cost-effective optics (TJacob & Raj, 2015) (Lallukka & Raatikainen, 2006).

Passive optical network (PON) have recognized a momentous quantity of attraction about their potential for giving connectivity of broadband to almost every subscriber, principally in remote areas can attract costumer by fiber optics to populate regions that have been abandoned, connectivity without dropouts of error free can give new opportunities to make a communication, earn money and enjoy cultural events, speeds of transmission are multi gigabit with distances of a few tens of kilometers; these qualifications were previously kept for high speed and long haul backbone networks. PON can support a new period of applications, convert fiber sensing like correct time and monitor new trends in open (Horvath, Munster, Oujezsky, & Bao, 2020).

Passive optical network (PON) study and technology have progressive over the last three periods, establishing PONs as a foundation of today's deep fiber connectivity solutions. It is widely observed as the favorite technology for applying fiber to the home solutions that offer high bandwidth to subscribers at low cost. Passive optical network (PON) is a fiber optic network of point to multi-point that has passive components in the signal direction which

connects OLT to multiple ONU's at customer sites via 1: N optical splitters it employs a passive fiber tree topology to extend coverage, provide flexibility, reduce the number of network breaks, decreasing power loss of optical and increasing physical scope. PON's performance is based on its high bandwidth, cost-effective physical structure, ease of maintenance and service. Due to the lack of electronic active elements in the connecting connection between the optical line terminal and the optical network unit. Furthermore, the use of passive optical network in access networks provides end to end transparency, reduces processing and eliminates the impact of electrical noise sources. Figure represents the architecture of PON of point to multi-point estate in PON, and multiplexing techniques are needed to aid the abilities of multiple access standpoints. Asynchronous time module, broadband, gigabit, and ethernet are four major types of passive optical network for low-cost access network services (Bindhaiq, et al., 2015).



**Figure 2. 5:** Passive Optical Network

### **Optical Line Terminal (OLT):**

It organizes multiplexing on the other end of the ONT/ONU to execute renovation between the electrical signal utilized by service provider's apparatus and the fiber optic signal utilized by PON between the renovation units (Praveena, Vennila, & Vaishnavi, 2017) (Nour, 2017).

## **Optical Network Unit/Terminal (ONU/ONT):**

Individual users who finish all of the ODN distributed endpoints adapt PON to subscriber service interface. ONTs are a subset of ONUs. The ONT converts light signals from fiber optics into electrical signals. The ONU has a large number of subscribers, while the ONT has only one subscriber (Praveena, Vennila, & Vaishnavi, 2017).

## **Splitters:**

Are passive power distributors that assist the OLT and ONT to communicate each other, in addition to the multiplexer and de-multiplexer. The splitter is a two-way optical distribution system with a single input and several outputs. (Praveena, Vennila, & Vaishnavi, 2017)

In P2MP architectures, optical splitters are used to separate light in the optical fiber and send it to various destinations. Optical splitters are critical in the implementation of FTTH, since one optical connection can be separated to support multiple users (Hamza & Bugaje, 2018). The ratio of optical split may consist of (1:2 1:4 1:8 1:16 1:32 1:64 and 1:128).

### **2.5.1 Types of Passive Optical Network:**

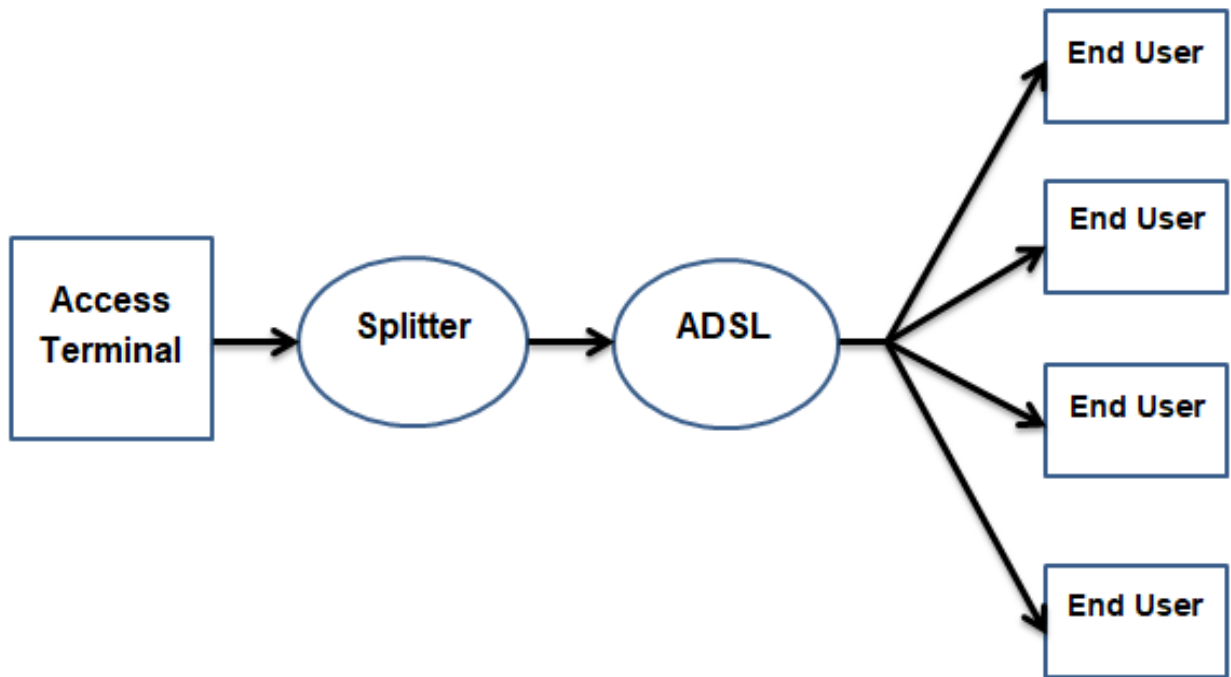
#### **2.5.1.1 Asynchronous Time Module/Broadband of Passive Optical Network:**

Up to 32 users can connect to an ATM PON or BPON, which offers high speeds of 622Mbps downstream and 155Mbps upstream. In the downstream, cell-based ATM multiplexing is used. In the upstream, a TDMA is used. ATM cells, also known as APON packets, are sent in both directions. For synchronization purposes, each ATM cell is added with a small packet overhead to support the payload power, with particular attention paid to reducing the size of the APON packet overhead. In the APON, burst mode synchronization is used to leave a sentry time between consecutive bursts; it gives the receiver enough time to quickly recover the correct clock for each burst coming from various nodes. APON/BPON can be successfully applied if these technical problems are fixed (Sharma & Sharma, 2018). The major characteristics of the APON as shown

Standard: It follows the ITUG.983. this is the international standard provided by the government body or international organization.

Data packet size: APON uses the 53 bytes of the data packets for the data transmission purpose.

- ✓ Bandwidth: bandwidth allocation for the APON is lies in between the 155Mbps to 622Mbps.
- ✓ Traffic modes: it shows the transfer of the signal in the ATM mode.
- ✓ Distance: up to 20km and splits the PON up to 32.
- ✓ Average bandwidth per user: 20mbps is usually given to the individual user in the APON.



**Figure 2. 6:** Broadband Optical Network for Passive

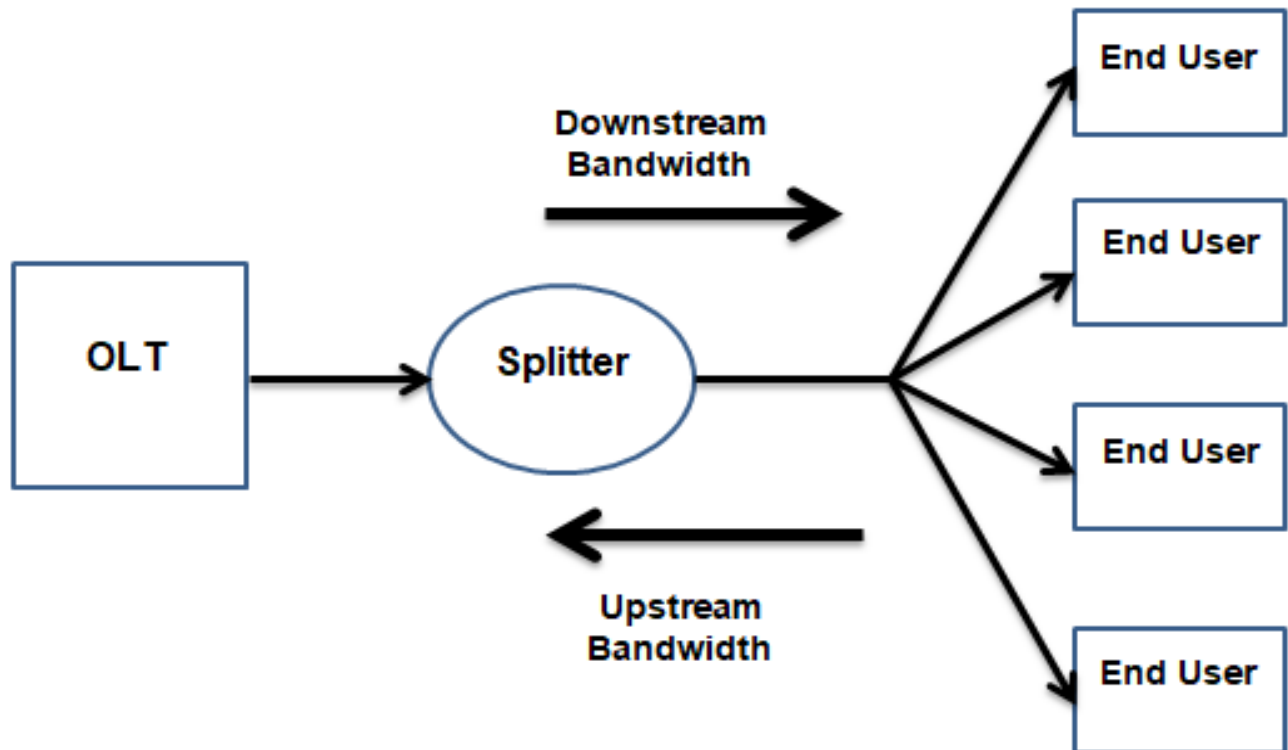
### 2.5.1.2 Gigabit Passive Optical Network:

In contrast to APON and EPON, gigabit PON has a higher bandwidth so the GPON specification specifies various downstream and upstream transmission speeds however most vendors offer 1.2Gbps upstream and 2.4Gbps downstream. Upstream operating wavelengths are 1330-1390, while downstream operating wavelengths are 1450-1500 For video distribution, the wavelength range 1530-1550nm can be used. Transmission containers transmit upstream bandwidth in GPON so GPON are used to transport data from ONU while maintaining service quality and increasing bandwidth. For the upstream service, OLT allocated bandwidth to ONUs.

In many areas, such as facilities, line rate offerings, and safety, GPON has defeated EPON. It has great support from all PONs for different networks however, due to the complex physical specifications, it cannot be more cost effective than EPON (Sharma & Sharma, 2018).

Standard: It follows the ITUG.984. This is the international standard provided by the government body or international organization.

- ✓ Bandwidth: bandwidth allocation for the GPON is lies in between the 1.2 to 2.4Gbps.
- ✓ Traffic Modes: it shows the transfer of the signal in the ATM/TDM, Ethernet mode.
- ✓ Distance: it covers 20km and splits the PON up to 64.
- ✓ Average Bandwidth per User: 40mbps is usually given to the individual user in the APON.



**Figure 2. 7:** Gigabit Passive Optical Network

Gigabit PON systems, downstream data is broadcasted at about 2.4Gbps while upstream data is transmitted at about 1.2Gbps. Anyway, the bandwidth capability of the PON systems is anticipated to enhance as the demands for services increase (MAI-Quzwini, 2014).

Gigabit Passive Optical Networks are Optical Systems for access networks, stated on the ITU - T specifications G.984 series. A GPON can give services at high bandwidth (high data rate) to long reach more than 50km. consist of optical line termination (OLT), optical network units (ONU) and a passive 1: N optical splitter with fibers connecting the OLT and ONUs make up a typical GPON specified network topology so in other scenarios, the OLT serves as a connection between a PON and the core network of a service provider. The ONUS on the other hand terminates the PON and provides service interfaces to the end subscriber through a variety of ports. GPON is a technology established by the (ITU/T G.984). The transmitting medium is optical fiber. It employs time division multiple access in the upstream multiple access technique by a rate of 1.2Gbps and broadcast in the downstream multiple access technique with a rate of 2.4Gbps (Ubaidillah, Alfita, & Toyyibah, 2017). The following are some of GPON's best levels:

- ✓ It may be able to support FT Tx service in three directions (data, voice, and video) over a single optical fiber core.
- ✓ It has the ability to divide bandwidth into 32 ONTs.
- ✓ It can transmit data at various bit rates, giving it versatility.
- ✓ Cable installation is easier than P2P architecture
- ✓ Controlling bandwidth allocation.

Although there are some constraints to GPON, they include:

- ✓ Layering model complexity.
- ✓ High cost.

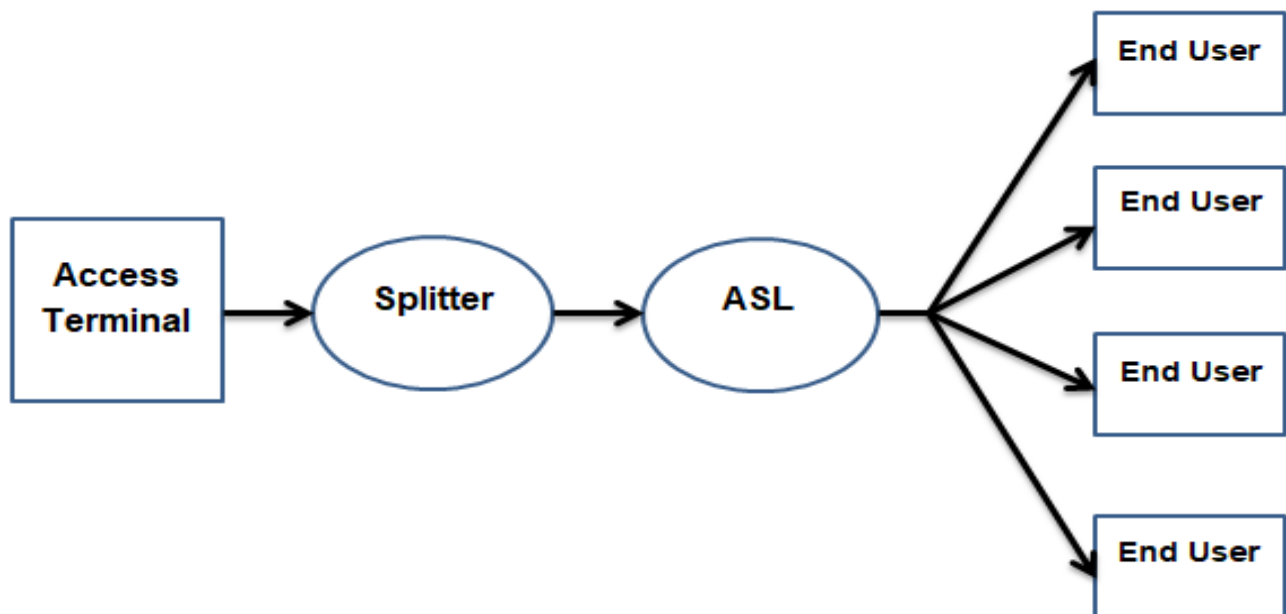
### **2.5.1.3 Ethernet/Passive Optical Network:**

Users can see traffic from the CO or OLT, but not from other users, since ethernet PON operates on a point-to-multipoint (P2PMP) topology. CO and OLT use TDMA to allow only one user to attach at a time. The P2MP fiber network is regulated using the multipoint control protocol (MPCP), which establishes a peer-to-peer link between the CO and the subscriber. The

MAC layer implements this protocol, which manages bandwidth assignment, polling, auto-discovery, and ranging. ONUs undertake auto discovery and synchronize to OLT timing; the OLT generates the global time signal for network reference; the 802.3 frames are transmitted downstream and extracted by the logical connection ONUs. Upstream control uses time slots that can hold numerous 802.3 frames, and 64B messages are sent downstream to assign upstream bandwidth. In their respective time period, the ONU sends ONU based information to the OLT in a 64B report message (Sharma & Sharma, 2018). EPON is a cost-effective access solution for audio, video, and data applications in the home, building, and business.

Standard: It follows the IEEE802ah.

- ✓ Size of data packet: utilize 1518 bytes of the data packets for the data transmission purpose.
- ✓ Bandwidth: bandwidth allocation for the EPON is lies in between the 1.2Gbps to 1.25Gbps.
- ✓ Traffic modes: it shows the transfer of the signal in the ethernet mode.
- ✓ Distance: up to 20km and splits the PON up to 32.
- ✓ Average bandwidth per user: 20mbps is usually given to the individual user in the APON.



**Figure 2. 8:** Ethernet of Passive Optical Network

Ethernet frames sent via OLT are passed through a 1: N passive split on the downstream to respectively ONU. Splitting ratios usually range from 4 to 64. Meanwhile ethernet beginning from the network to the subscribers is announced by default downstream, it matches the EPON architecture: packets are transferred through the OLT taken from their destination by ONU based on a media access control address (MAC). Because of the directional riches of an upstream optical splitter or passive combiner and data frames from any ONU can spread the OLT there are no other ONUs. In this way, the work done upstream of EPON is alike to P2P technology. Regardless, unlike an actual P2P network, EPON frames will still be combined from various ONUs sent sequentially; in the upstream direction it means that from the user to the network the ONUs must divide the primary fiber optic channel's bandwidth and properties. Ethernet with over 320 million ports globally, has become a widely recognized standard that gives significant economies of scale. Ethernet which is similar in terms of scalability and administration, is gaining traction in MAN's and WAN's, given that Ethernet is used in 95% of LAN's (Kramer & Pesavento, 2002).

### **3.MULTIPLEXING TECHNIQUES OF PASSIVE OPTICAL NETWORK**

#### **3.1 Time Division Multiplexing Technique of Passive Optical Network:**

TDM PON is a point to (point or multi-point) shape. The downstream of OLT announced the packages. It is extracted from the ONU designated optical network unit after going through a 1: N optical splitter. Data is sent in packets, and each subscriber is sent after a certain amount of time has passed. The goal ONU uses the same time delay to differentiate packets aimed at it (Mohammed, 2013).

TDM is technique used to rise the capacity of the spread spectrum. TDM PON is the application of time-division multiplexing in passive optical networks (PON). An OLT's two primary network functions are subscriber traffic management and dynamic bandwidth allocation to ONT component. Up to 32 ONTs utilize the same wavelength and having a similar fiber optic transmission line, to prevent traffic from multiple ONT, some procedure of transmission timing must be applied. The most basic approach is to utilize multiple time division access, in which every subscriber sends data at a fixed data rate within a specific allocated time period. All ONTs broadcast the multiplexed downstream signal. Depending on the packet header addressing, each ONT received the incoming information packets. Upstream traffic is more difficult to send since all users must use the same wavelength over time (Jacob & Raj, 2015)

The TDMA protocol is used by the system to prevent conflicts between transmissions from different subscribers. The OLT manages and coordinates traffic for each ONT by sending transmission permissions within a given time frame. Slots are synchronized so that transmission bursts for multiple subscribers do not dispute. Since every station is at a various distance from the CO, OLT employs range technology to determine the logical distance between subscribers and OLT (Hanane, 2019). In the time division bidirectional method, this helps every ONT to correctly time its transmission to avert traffic collision, and the OLT and ONU alternately timing using fiber for upstream and downstream transport operations. Path combiners, like the dual full

wavelength fiber solution are used in OLT and ONU to differentiate between upstream and downstream optical signals. The following effect is prevented by distinguishing between rise and fall signals in the time domain, at the expense of a 50% reduction in overall system output. The OLT schedules time slots for both upstream and downstream transmissions. Burst mode receivers are needed in both the OLT as a remote terminal, TDM-PON employs a passive power divider via the power divider, the same OLT signal is sent to multiple ONUs, signals of ONUs performing multiple multithreading in time domain. The address labels on the label help ONUs identify their data (Hanane, 2019).

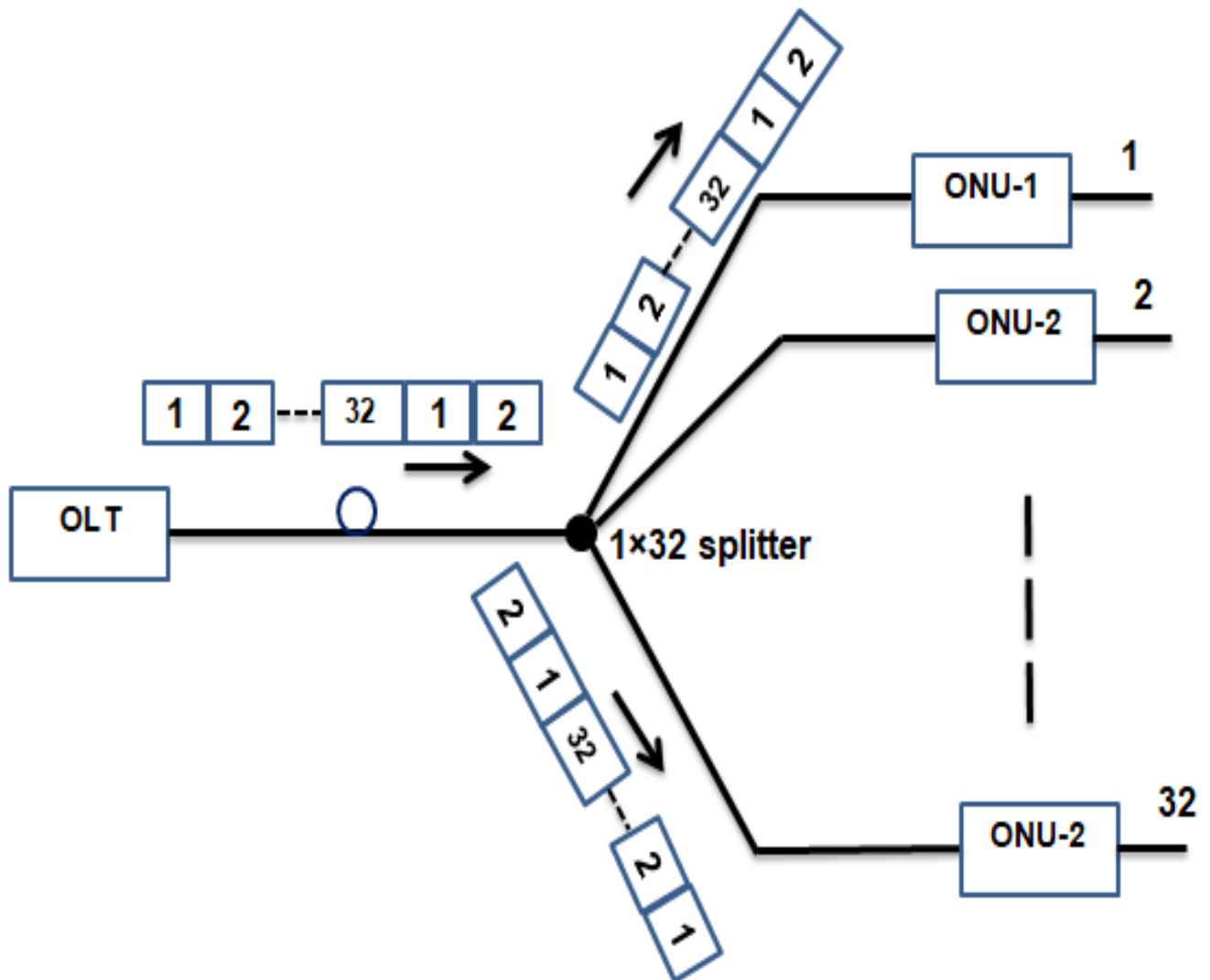


Figure 3. 1: TDM PON

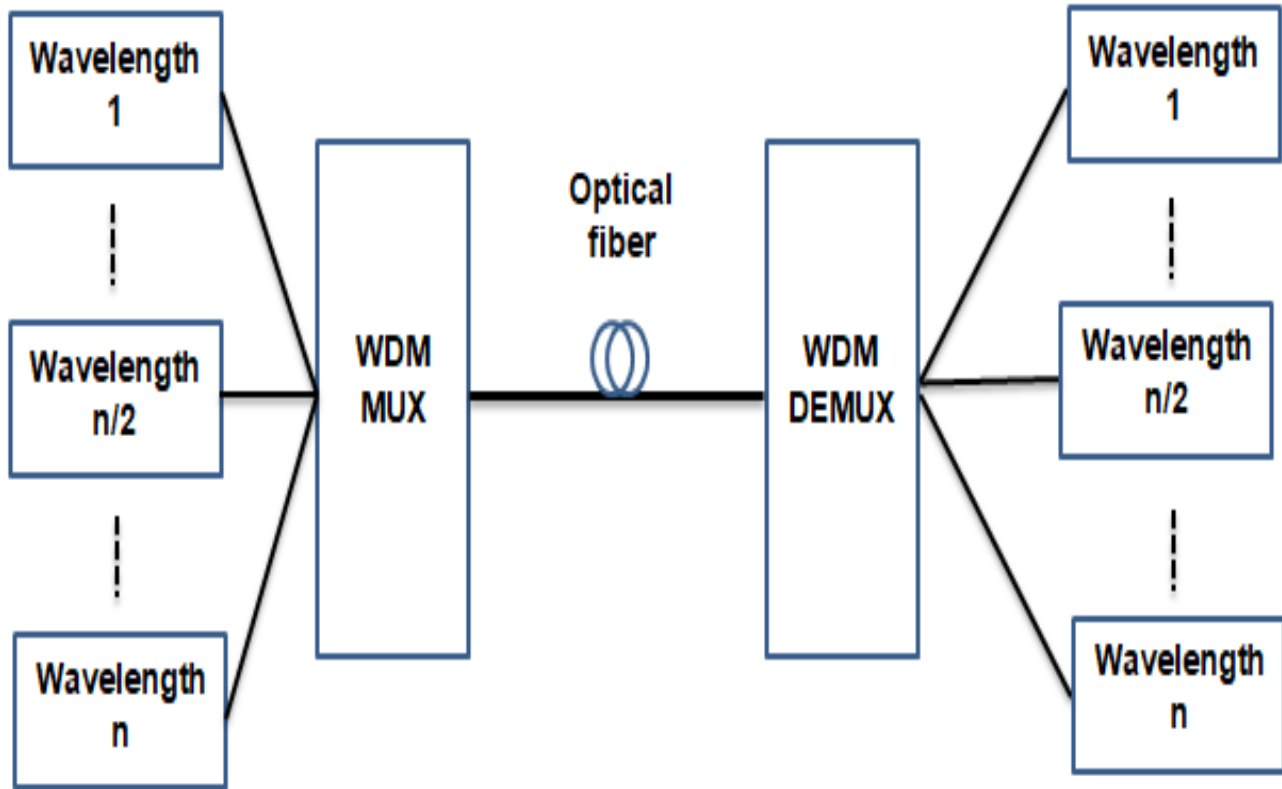
The most basic approach is to use time division multiple access, in which every subscriber conveys information within a given period of time at a predetermined data rate, as shown in the figure 3.1, and the multicast signal is broadcast throughout the ONT depending on the package header address, each ONT accepts incoming data packets. Since all subscribers must use the same wavelength over time, primary traffic is more complicated. Each ONT's traffic grants it transmission permissions for a set period of time. A method for calculating the rational distance among users and the e OLT, allowing every ONT to change transmission time to avoid traffic conflicts.

### **3.2 Wavelength Division Multiplexing Technique of Passive Optical Network:**

Wavelength division multiplexing (WDM) allows greater use of optical fiber's broad bandwidth and can improve cable network power. Signals from two or more-line systems are sent over the same fiber via WDM. Signals from various sources are mixed via a multiplexer and fed into an optical fiber, where they are distinguished by a de-multiplexer and detected by the photo detector. WDM devices in the drive unit are essentially a power combination known as a multiplexer. The system in the receiving unit is known as a de-multiplexer, and it should be able to separate between the several channels with minimum signal loss and distortion. With angularly distributed multiplexing components, multiple channels can be multiplexed and resolved. These light beams become co-linear at the multiplexer's output and can simply be shot into an optical fiber simultaneously. A WDM operates the other way around in the receiver, directing light beams of various wavelengths from a fiber into their channels. The figure 3.2 depicts a WDM system's block diagram. Any communication system's primary aim is to increase transmission distance as high capacitance grows, the main component or feature that causes signal distortion and affects fiber optic communication is loss and scattering. Knowing that as bit rate increases, dispersion contributes in restricting long-distance fiber optic transfers (Mohammed, 2013).

WDM PONs is created as a potential technology. To optimize performance without increasing data rate, this PON uses several wavelengths in a single fiber. Despite the fact that TDM PON is only allocated one wavelength. A TDM PON has a medium bandwidth but many more channels. A single-mode fiber links a central office (CO) to a network distribution unit

made up of passive optical distributors or multiplexers and de-multiplexer in the PON architecture. The OLT in the CO is made up of a group of tonnage laser sources or fixed wavelength laser sources that are used to send traffic to the ONU optical network unit. The laser works at a fixed frequency that is assigned to each client.



**Figure 3. 2:** WDM PON

Frequency allocation may be permanent or dependent on bandwidth needs. The data is then fed into a multiplexer combines it all and spreads it around the optical fiber for 50 to 100 kilometers. The optical fiber from the hubs is wired directly to the inactive WDM de-multiplexer (Mohammed, 2013). Its task that isolates the light based on wavelength and send it to the appropriate ONU. The ONU then employs an optoelectronic portion to change the light signal to an electrical signal and obtain the data (Mohammed, 2013).

WDM-PON has many benefits over TDM-PON due to its virtual P2MP structure:

- ✓ Broadband: each ONU is allocated a specific wavelength (every user should run at a rate equal to or greater than the full bit rate of a wavelength channel).

- ✓ The array waveguide grating (AWG) router's architecture broadening the scope and scalability, removes the splitting loss issue.
- ✓ Excellent encryption and protocol accountability: no data is shared between subscribers
- ✓ Less redundancy and faster implementation: no need for complex media access controller algorithms to handle ONU transmission timing.

There are also some problems that necessity to be addressed in WDM-PON, which are as follows:

- ✓ AWGs commonly need thermal regulation to set aside their wavelength channels that are protected to the ITU grid, thermal AWGs have recently become commercially available due to technological advancements.
- ✓ To stabilize their wavelengths, each wavelength main source includes thermo-electric coolers. Wavelength stabilized lasers are usually costly.
- ✓ Each subscriber requires a different or "colored" transceiver under the WDM-PON scheme, resulting in high installation, management, and maintenance costs.

Wavelength division multiplexing increases device efficiency on a single fiber by sending multiple wavelengths. WDM-PON is uses to different wavelength for every PON network. Light bases of various tuned wavelengths exist in the same fiber of the ONUs, growing complete network capacity and the numeral of subscribers aided in the optical access network (Hanane, 2019). In terms of communication mode, the WDM-PON can use point-to-point, point-to-multipoint, or hybrid solutions. There is no need for complex bandwidth allocation schemes in P2P communications.

The P2MP network employs a WDM/TDM, resulting in high resource utilization performance. WDM PON usages in a single fiber with several wavelengths to increase bandwidth without increasing data rate. A TDM PON usually employs a single wavelength, while a WDM PON employs several wavelengths. A TDM PON has more channels but only a limited bandwidth. As a consequence, both solutions have benefits and both approaches need to be tested. PON has been researched for done ten years and numerous architectures have been projected to improve broadband access capacity using WDM PON (Nour, 2017).

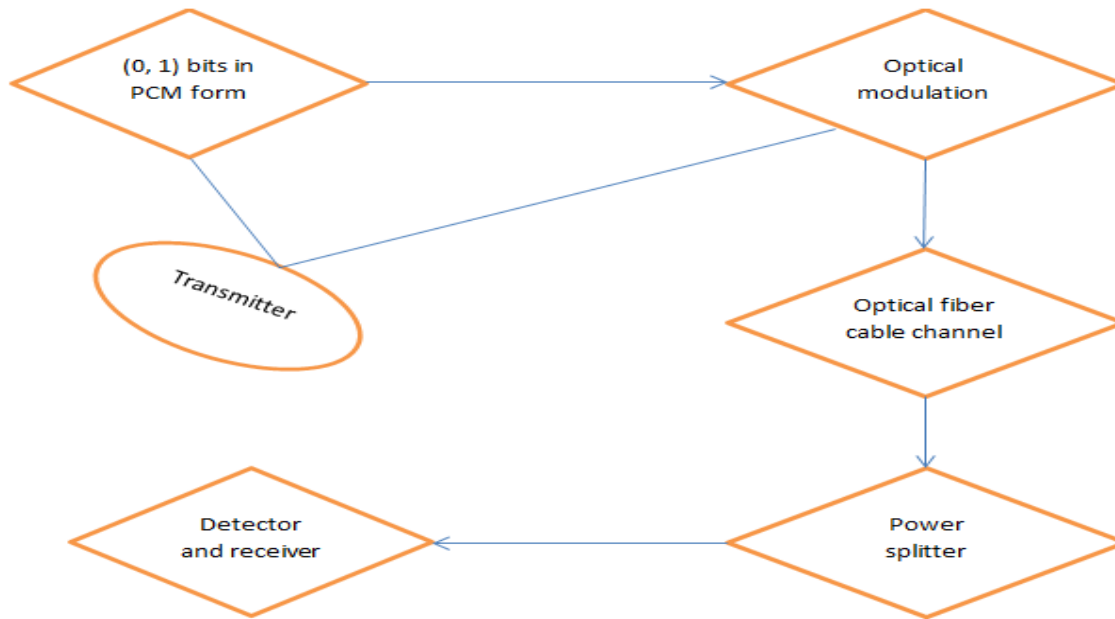
Using different wavelengths, the wavelength division duplex approach distinguishes between upstream and downstream transmission signals. Thus, WDM provides virtual fibers by making a single fiber appear to be multiple fibers, each one carries a single data stream. WDM systems are now commonly used in long distance also marine networks, as well as in metro networks. WDM is an optical multiplexing technique that takes advantage of optical fibers' high bandwidth capability (Rvacca, 2006). In terms of definition the basic concept is to divide an optical fiber's enormous bandwidth into optical channels or an amount of non-overlapping bands and send several optical signals at once and independently in various optical channels over a single fiber, with every virtual signal passed by a single wavelength.

With WDM-technology, the bandwidth is divided or split into different optical channels and each with a speed of a few gigabits per second, which greatly improves the available bandwidth of the optical fiber at a given wavelength, allowing for multiple optical signals to simultaneously and independently be transmitted on various optical channels (Rvacca, 2006).

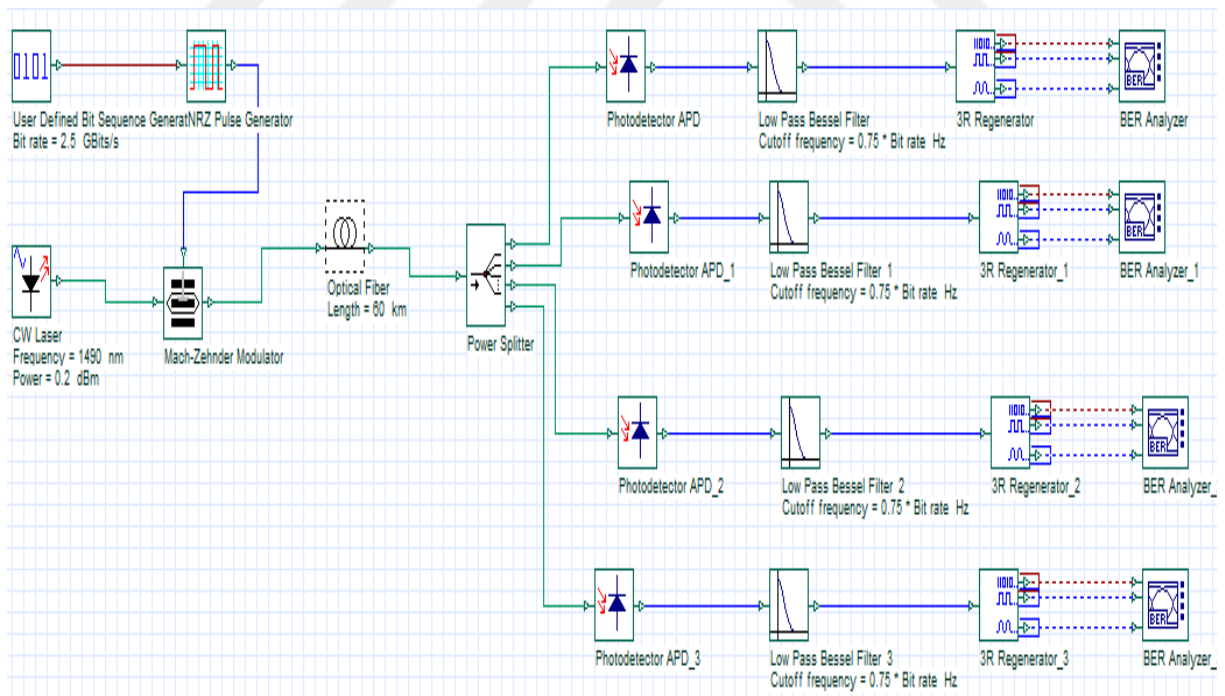
## **4.SIMULATION FOR MULTIPLEXING TECHNIQUES**

### **4.1 Unidirectional of TDM PON:**

Describes the unidirectional TDM PON 4user simulation diagram The OLT contains of a user defined bit sequence generator, non-return to zero pulse generator, a permanent wave laser and a mach-zehnder modulator. The OLT is the transmitter block and the ONU is the receiver block, including a photo detector APD; 3r regenerator, bit error rate and low pass bessel filters. The unidirectional TDM PON was simulated using the 1490 nm wavelength for various fiber lengths. The wavelength and power in the continuous wave (CW) laser source are mounted at 1490 nm with the aid of a 2.5Gbps Data Rate. The module mach-zehnder modulator (MZM) varies the light intensity from the CW laser to the NRZ pulse generator output. In order to receive and separate signals to the users, the output of the mach-zehnder modulator is sent to the ONU over the fiber optics channel connected to the power divider (Jacob & Raj, 2015). The photo detectors corresponding to each ONU are used to detect every of the signals. The APD is the photo detector and output APD is supplied to a bessel low pass filter used for filtering components has advanced frequency. The filtered output is supplied to a 3R regenerator and data is conveyed and the result analysis is carried out with a BER analyzer. So, figure below show the TDM flow chart:



**Figure 4. 1:** Uni-directional TDM PON Flow Chart

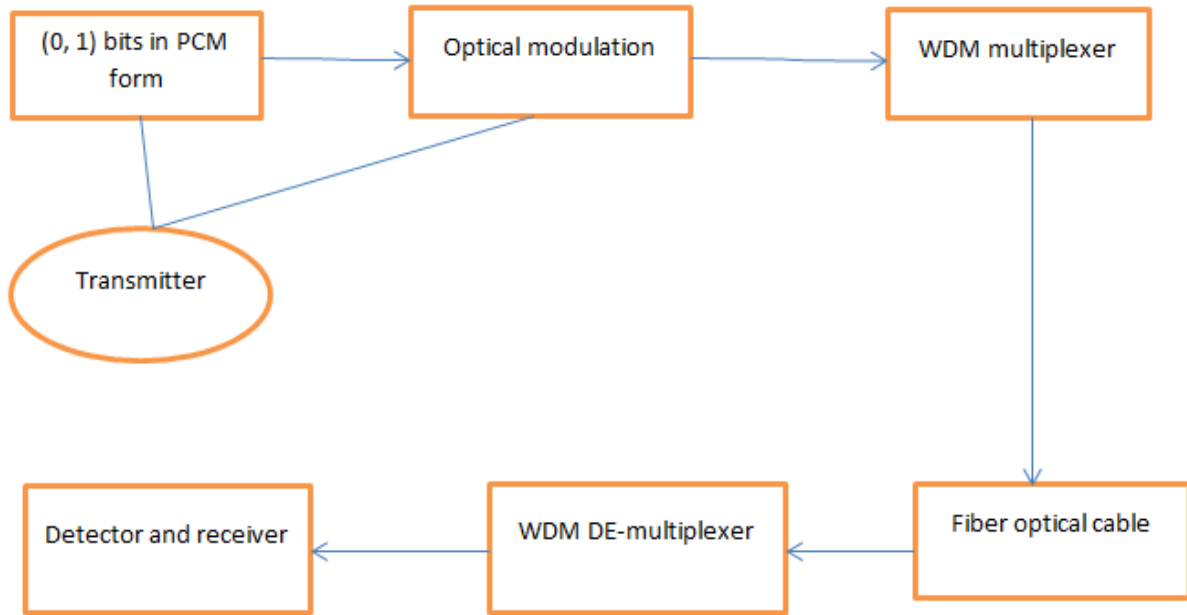


**Figure 4. 2:** Simulation of TDM PON

## 4.2 Unidirectional of WDM PON:

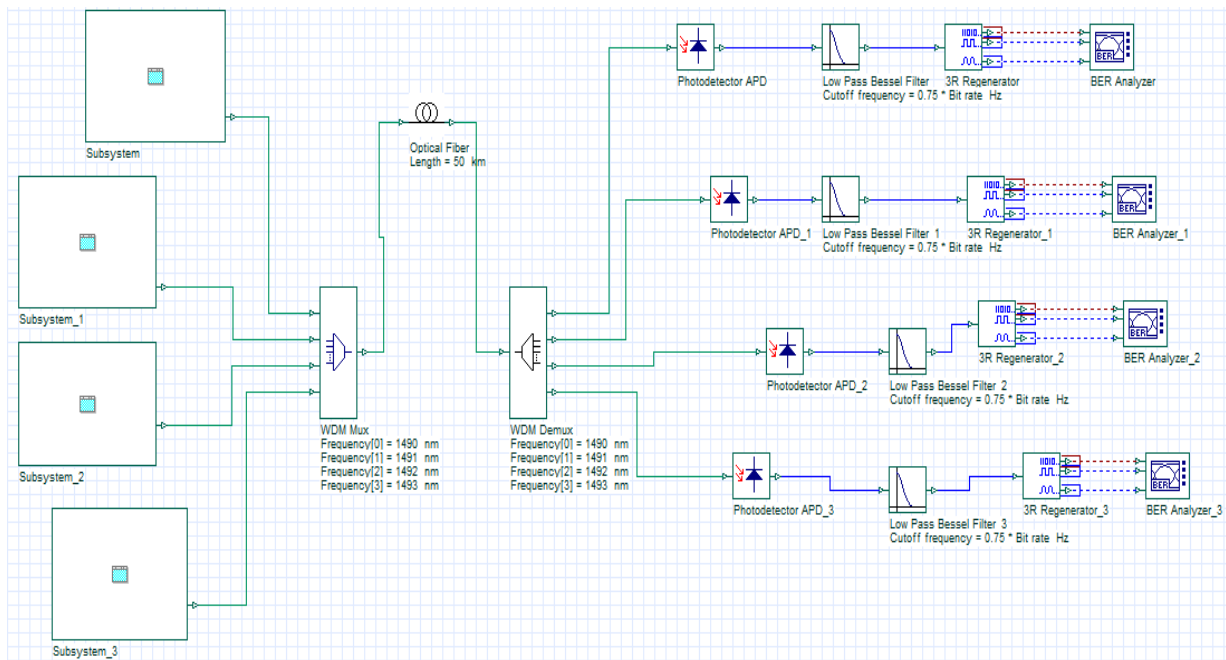
Describe the unidirectional WDM PON 4user simulation diagram. a user defined bit sequence generator, non-return to zero (NRZ) Pulse generator, a permanent wave laser and a mach-zehnder modulator from the transmitter block OLT. A low pass besel filter, APD photo detector, 3r regenerator and BER analyzer form the receiver block ONU. The unidirectional WDM PON was simulated using the various wavelength start 1490 until 1493 for various fiber lengths. The wavelength with 2.5Gbps is applied to the continuous wave (CW) laser source with a power of 0.2dBm. The module mach-zehnder modulator (MZM) varies the light intensity from the CW laser to the NRZ pulse generator output. In order to receive and break signals to the users, the output of the mach-zehnder modulator is sent to the ONU via the fiber optics channel connected to the power divider. The photo detectors corresponding to each ONU are used to detect each of the signals. (MM & Mohammed, 2021) The APD is used here to provide a picture sensor and the APD output is sent to the besel low-pass filter that is used to filter higher frequency components.

The filtered output is supplied to a 3R regenerator and the initially transmitted data are found and the result is analyzed by a BER analyzer. Indicates the simulation set up for unidirectional WDM PON with 4 users has been simulated using the wavelengths 1490 nm and 1491 nm and 1492 nm and 1493 nm for four users with different fiber lengths.

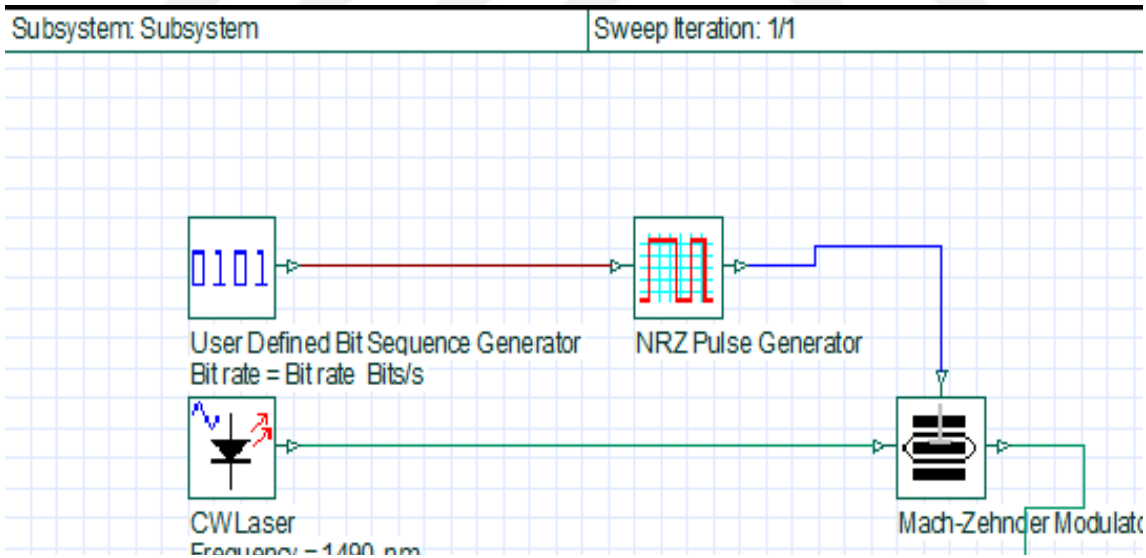


**Figure 4. 3:** Uni-directional WDM PON Flow Chart

The user defined bit sequence generators, NRZ pulse generators, continuous wave laser modulators and mach zehnder modulators consist of each of which corresponds, using the data rate of 2,5Gbps, to the wavelengths 1490 nm and 1491 nm and 1492 nm and 1493 nm. The signal emitted is then encoded with the NRZ pulse generator. The wave lengths of the continuous wave (CW) sources are 1490 nm and 1492 nm and 1493 nm, with a power of 0.2dBm. mach zehnder modulator (MZM) is an optical modulator utilized to adjust the light intensity from the CW laser to the NRZ pulse generator's outputs, the output of the mach zehnder modulator will be transmitted to the optical network device via multiplexer. WDM multiplexer located at the OLT will multiplex these signals and send them as a single signal via the optical fiber (TJacob & Raj, 2015). The WDM de-multiplexer creates the remote node (RN), which separates the signals corresponding to each of the earlier wavelengths and sends them to the ONUs with the corresponding wavelengths. The ONU block, which includes the APD photo detector, low pass bessell filter, and 3r regenerator, as well as the BER analyzer, receives the signals.



**Figure 4. 4:** Simulation of WDM PON

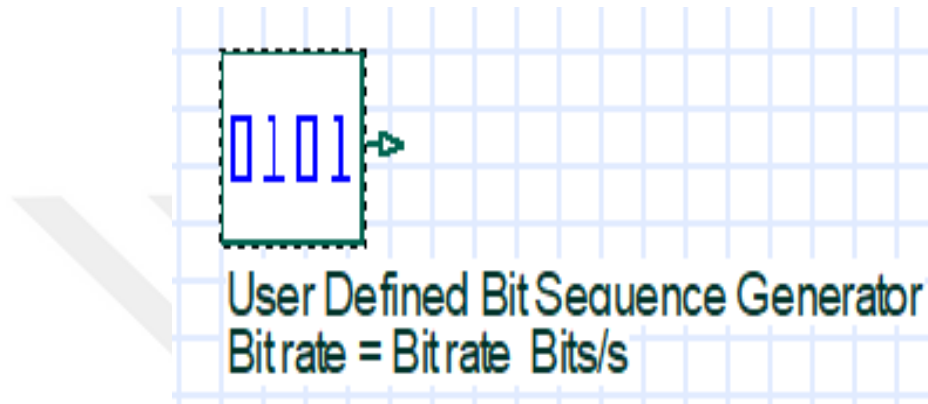


**Figure 4. 6:** Inside of Sub-system

### 4.3 Model Components:

#### 4.3.1 User Defined Bit Sequence Generator:

The bit sequence is designed to estimate the appearances of random data (1, 0) and generates according to different modes of operation.

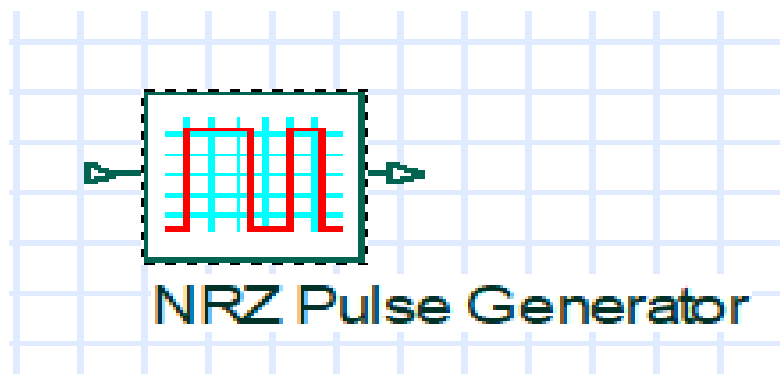


**Figure 4. 7:** User Bit Sequence Generator

#### 4.3.2 NRZ Pulse Generator:

Produces a NRZ coded signal. A range of NRZ codes are commonly utilized and their bandwidths aid as references for all other code sets.

In a sequential data stream, an on-off (or Unipolar) signal denotes a 1 by a pulse of present or light crossing whole bit duration, while a 0 is represented by no pulse at all. These codes are clear to produce and decode. With NRZ coding, the minimum bandwidth is necessary, but in receiver the average power input is important for data source.



**Figure 4. 8:** Non-Returns to Zero Pulse Generators

The way that the electrical signal would be changed in to optical signal bits. NRZ format optical pulse remains through the bit slot and its amplitude does not drop to zero between two or more successive 1bits.

#### 4.3.3 Continuous Wave (CW) laser:

Create an optical signal for a continuous wave (CW). And operate even in these frequencies (Hz, THz and nm), generating electricity (W, mW and dBm).

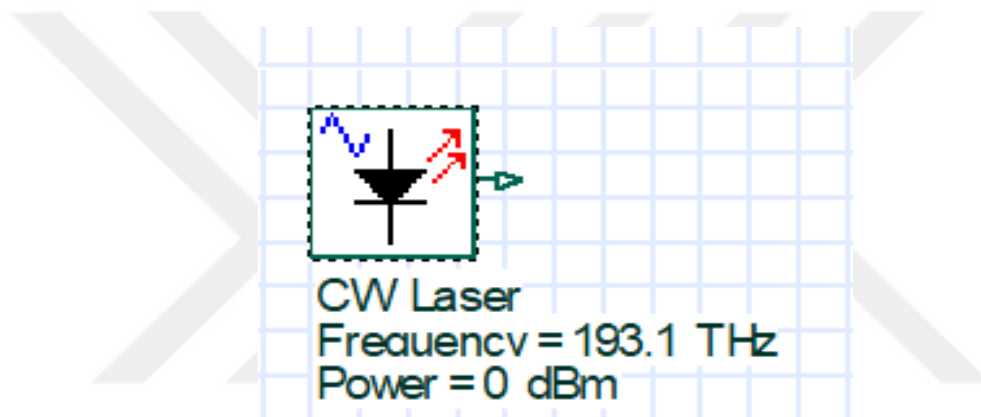


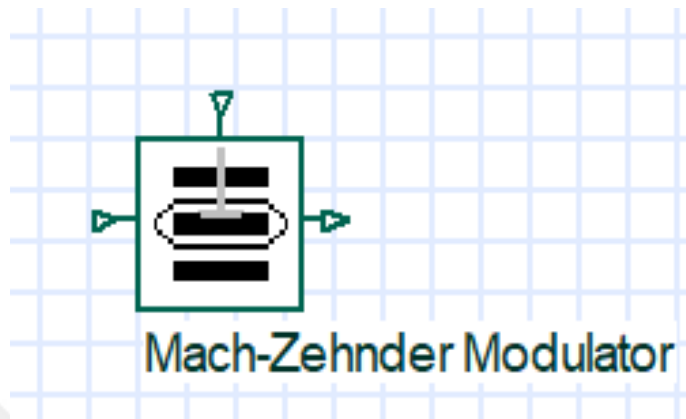
Figure 4. 9: Continuous Wave Laser

#### 4.3.4 Mach-Zehnder Modulator:

Analytical model is used to simulate a mach-zehnder modulator. Depending on the applied voltage, the different paths will cause both constructive and destructive interference at the output. The output strength can then be modified depending on the voltage.

utilized to control the amplitude of optical wave that is given it on side of input waveguide it split in 2 waveguide interferometer arms:

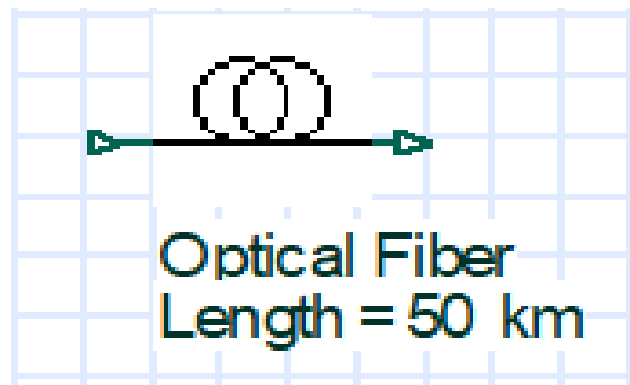
- ✓ If the voltage applied across one of the arms the outcome of phase shift for the wave passing via that arm.
- ✓ When 2arms are recombined the difference phase between the 2 waves is changed to amplitude modulation.



**Figure 4. 10:** Mach Zehnder Modulator

#### 4.3.5 Fiber optic:

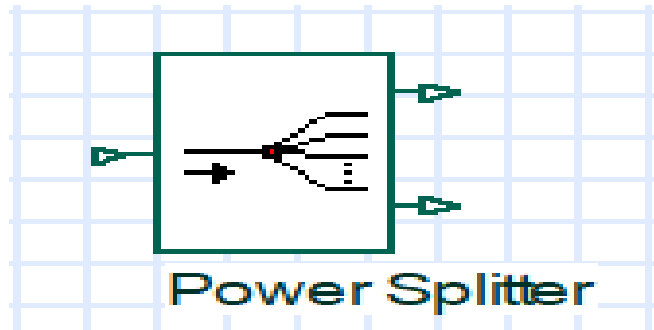
Analytical model is used to simulate a Mach-Zehnder modulator. Depending on the applied the optical fiber module detects the diffusion of an optical field in a single-mode fiber with scattering and nonlinear impact, resulting in optical official stated that are limited to a single frequency band.



**Figure 4. 11:** Fiber Optic

#### 4.3.6 Power Splitter:

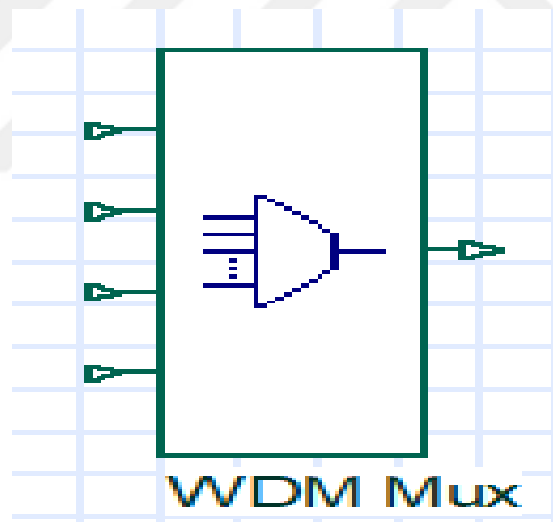
An optical input signal is split into a user-defined number of output signals by an ideal power splitter. optical splitters are used to separate light in the optical fiber and send it to various destinations. Optical splitters are critical in the implementation of FTTH.



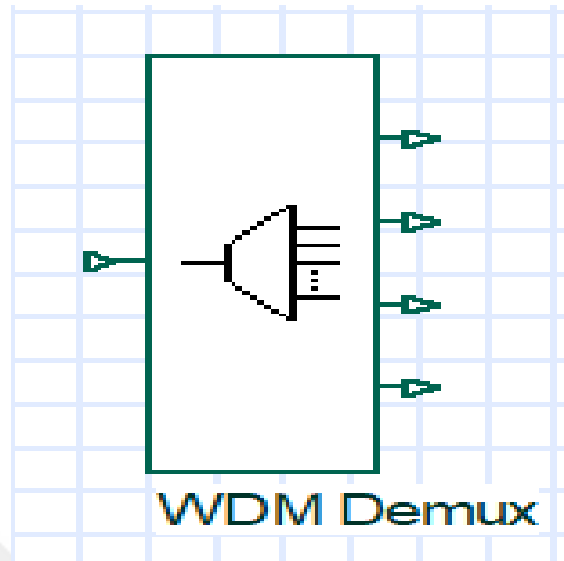
**Figure 4. 12:** Passive of Power Splitter

#### 4.3.7 WDM Mux/De-Mux:

A user-defined number of WDM signal channels are de-multiplexed and Multiplexes a user-specified number of WDM signal input channels.



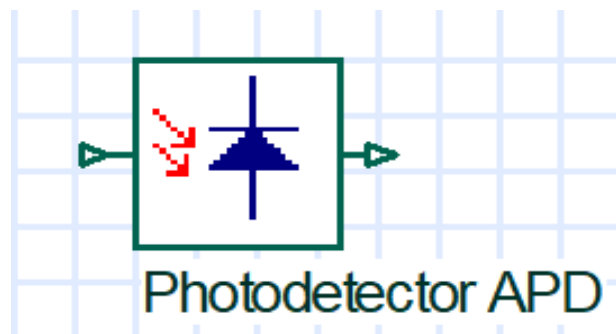
**Figure 4. 13:** WDM Multiplexer



**Figure 4. 14:** WDM De-multiplexer

#### 4.3.8 Photo detector APD:

The frequency transmission feature rolls off a square cosine filter. Changes the signal light in to electrical and has to polarize to inverse shape. Combine optical signal detection with amplification of the current for benefit is high signal noise ration date rate.



**Figure 4. 15:** Photo-detector for Avalanche Photodiode

#### 4.3.10 Low Pass Bessel filters:

Filter with a transfer function of Bessel frequency. Is need to have a sharp slope to prevent interference and want to have a linear phase response to preserve the received signal form so

Bessel filter is kind of linear phase response because of it gives maximally flat group delay or propagation delay across the frequency spectrum.

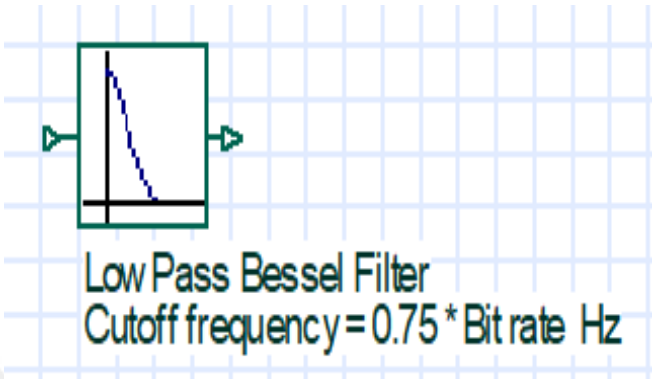


Figure 4. 16: Low Pass Bessel Filter

**4.3.11 3R Regenerator:**

The electrical signal regenerates a part. It means that 3r regenerator is a set based on recovery data elements and pulse generator and can be utilized to recover the bit sequence, modulated electrical signal to be utilized for BER analysis

This element eliminates the requirement to make several branches and connections from the input sometimes it can fail for very noisy systems or in some other cases where the global bit rate does not match the received bit rate. In these cases, generally utilize the input signals for the Eye Diagram Visualizer.

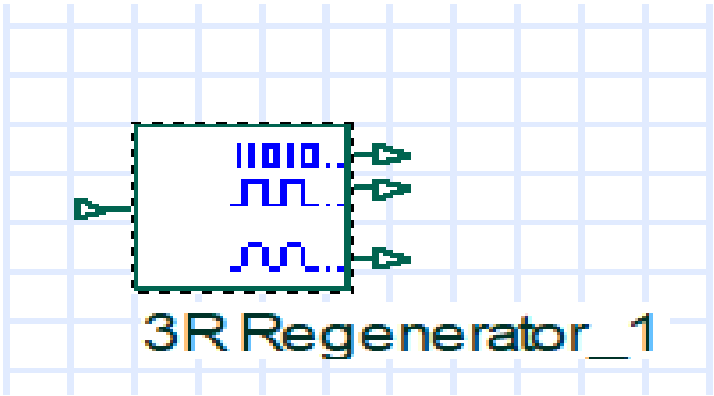
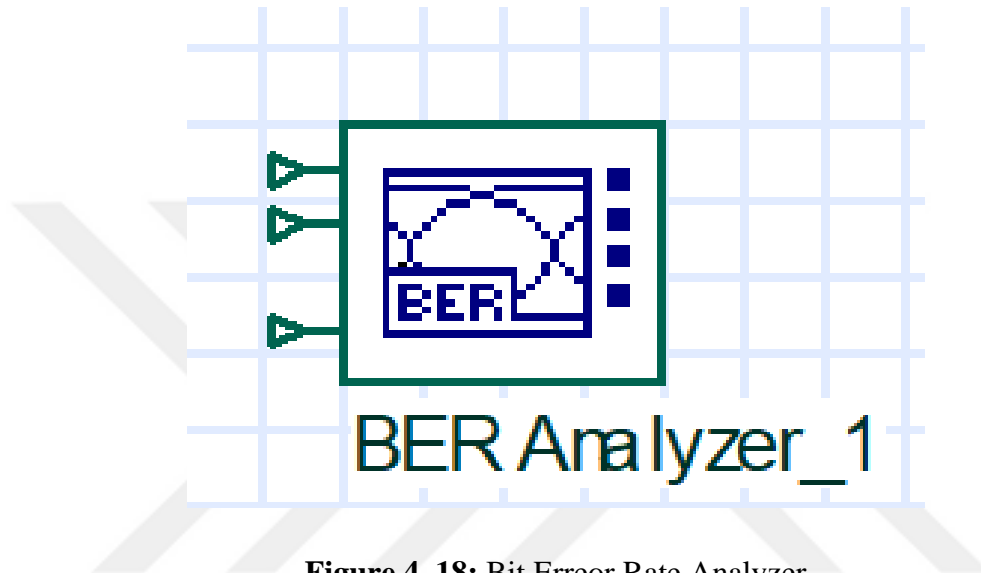


Figure 4. 17: 3R Regenerator

#### 4.3.12 BER Analyzer:

This visualizer helps the user to automatically measure and visualize an electrical signal's Bit Error Rate (BER). Multiple measures, such as quality of factor, eye opening, eye closing and eye height, can be derived from the eye diagram. It can also draw patterns from BER.



**Figure 4. 18:** Bit Error Rate Analyzer

## 5.EXPRIMENTAL RESULT

### 5.1 Experiments and Result:

In this chapter we make discussed the simulation results of TDM and WDM PON according to the Q-factor and BER with varying in fiber length.

#### 5.1.1 Unidirectional TDM PON:

##### 5.1.1.1 Relation Between Q-Factor and Distance:

According to these value parameters CW laser which is utilized by gives the frequency and power depending on what we need to simulate for this simulation we utilized for wavelength of 1490 and power of 0.2dbm, data rate gives 2.5Gbps, with in a lot of various fiber length after that it fed in to the MZM which modulated the signal that received from the CW laser and run the program. After we run our simulation, we found different parameter that we began to design in a graph explains for us the way it makes different compared between distance and Q-factor.

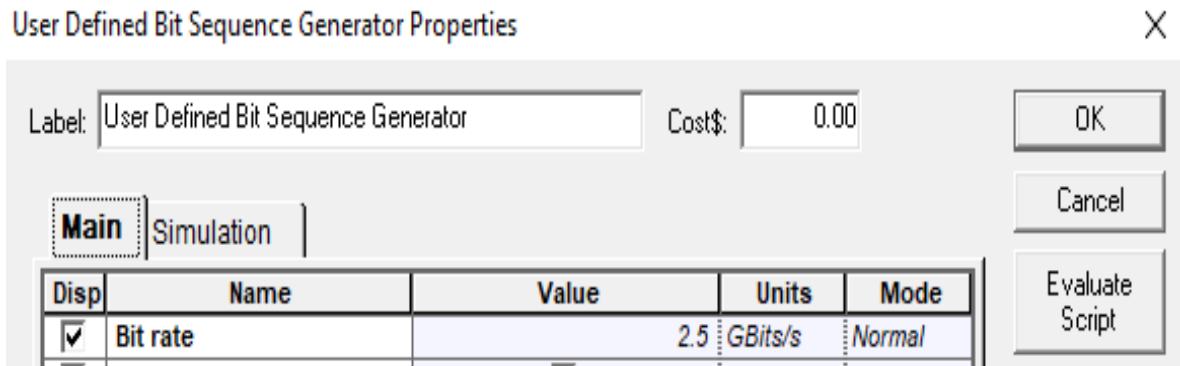


Figure 5. 1: Bit Rate

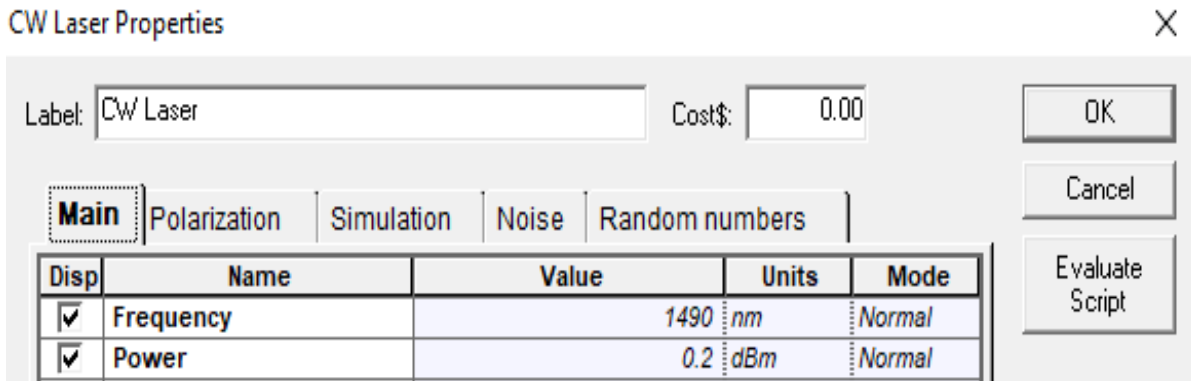


Figure 5. 2: Continuous Wave Laser

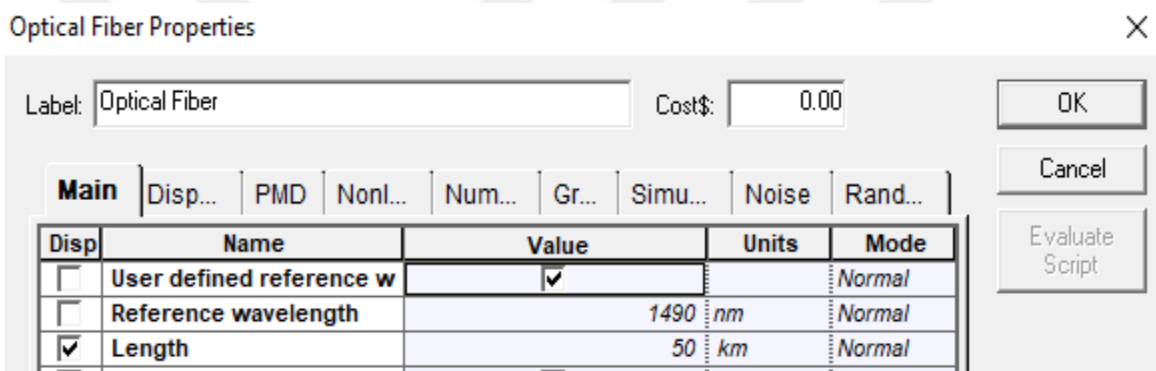


Figure 5. 3: Wavelength and Length

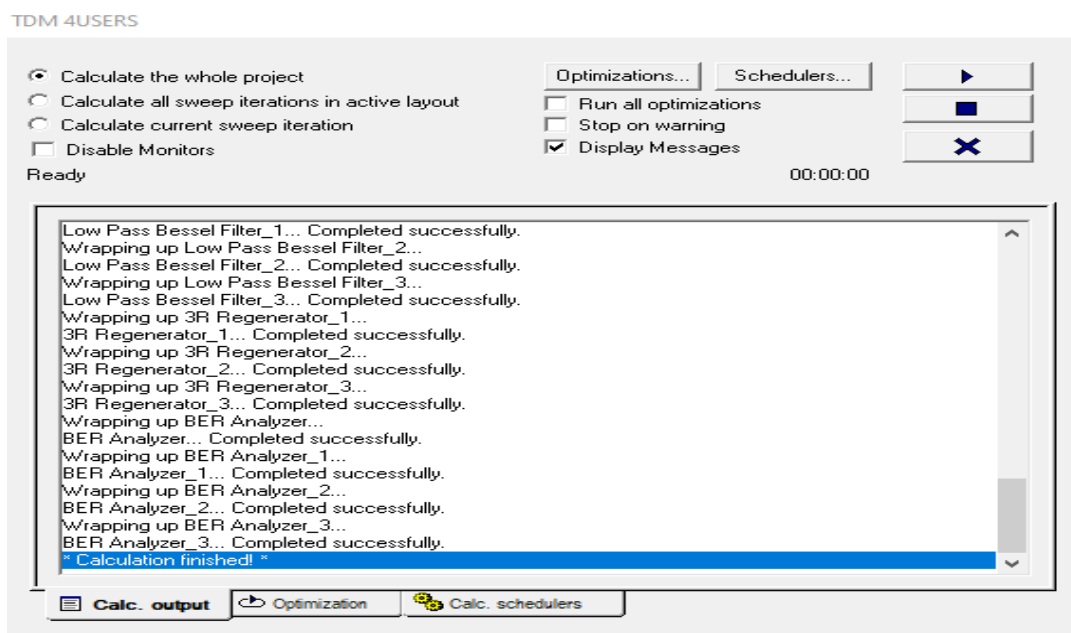


Figure 5. 4 Run Program TDM 4User

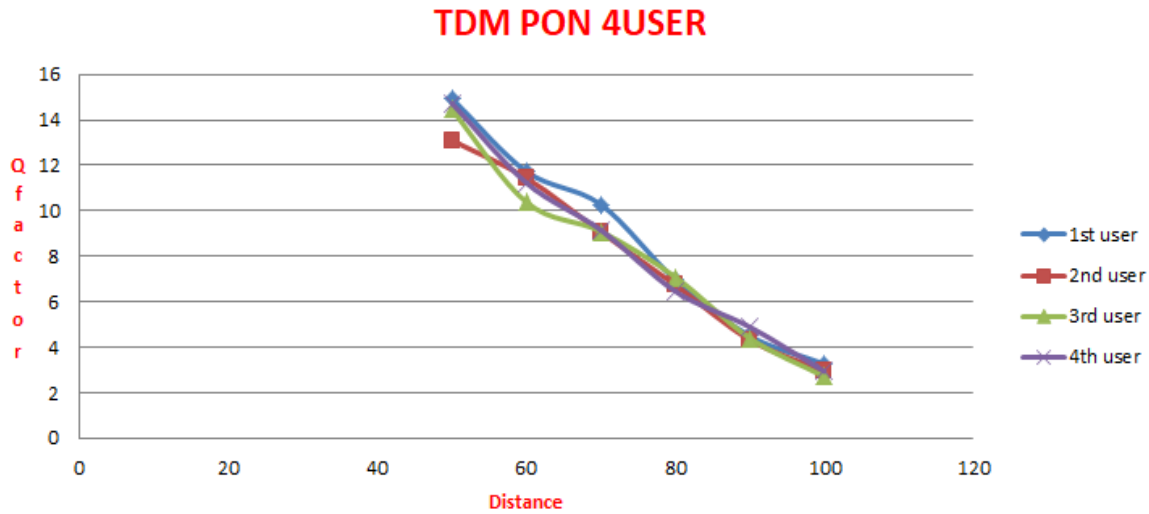
After running the program and have a look the BER analyzer for each user we get parameters that indicate in the following table.

**Table 5. 1:** Performance Analysis of TDM-PON Based on Distance and Q-factor

Distance	1 <sup>st</sup> user of max Q factor	2 <sup>nd</sup> user max Q factor	3 <sup>rd</sup> user max Q factor	4 <sup>th</sup> user max Q factor
50	14.9422	13.095	14.453	14.7263
60	11.7261	11.4363	10.3733	11.2303
70	10.2714	9.0625	9.08977	9.15252
80	6.95803	6.73559	7.08407	6.45508
90	4.49769	4.33027	4.39758	4.89127
100	3.265	2.94186	2.71189	2.9346

The performance of a unidirectional TDM PON system with 4 users is evaluated the factor of quality with respect to the distance.

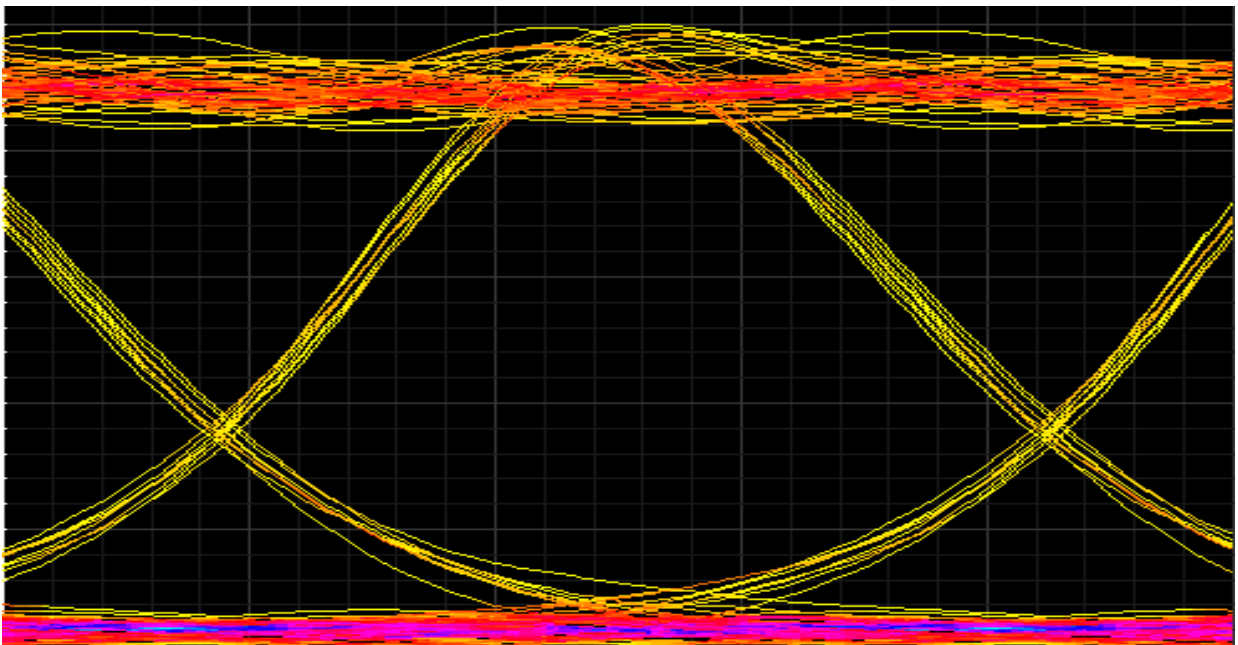
Figure below shows the variation of Q-factor with distance for the unidirectional TDM PON system, the graph shows how the Q-factor value varies with distance from 50 to 100 km at power of 0.2dBm, when the distance increases, the Q-factor decreases.



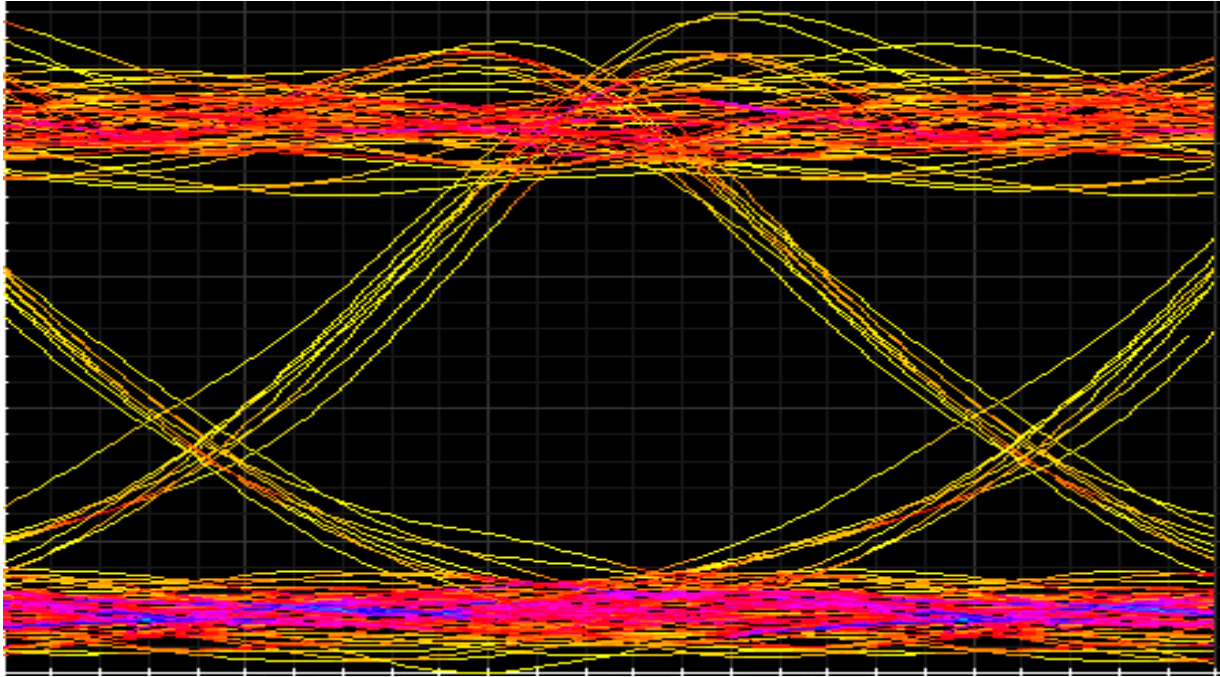
**Figure 5. 5:** Graph Result of TDM PON for 4User

#### 5.1.1.2 BER and Distance in Eye Diagram:

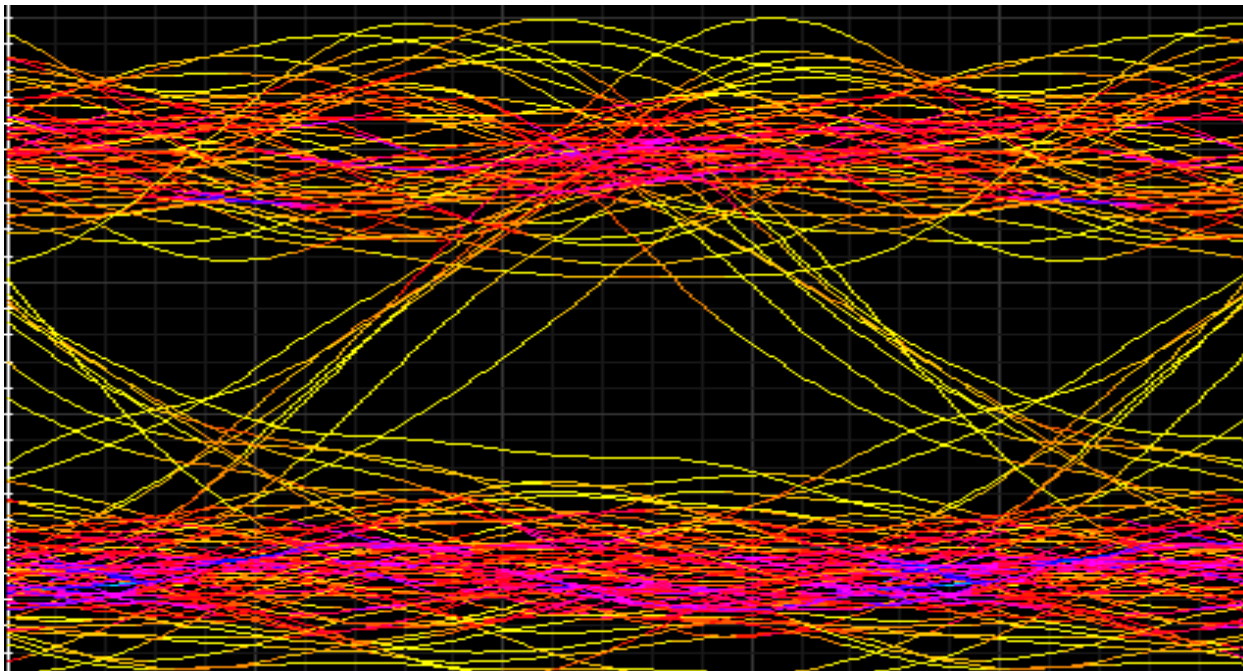
After run the program according to pervious parameter's we find at the receiver system ONU we get the following shapes that describes how to increase ISI in three different fiber length 50, 70 and 90km.



**Figure 5. 6:** BER for Length 50km



**Figure 5.7:** BER for Lengths 70km



**Figure 5.8:** BER for Lengths 90km

Figure above shows the variation of ISI with distance for the unidirectional TDM PON system, an input power of 0.2dBm, when the distance increases, BER increase quickly as we shown from the eye diagram.

### 5.1.2 Unidirectional WDM PON:

#### 5.1.2.1 Relation between Q-Factor and Distance:

In WDM model we use for transmitters as same the TDM components except frequencies because in WDM PON each user needs to have special wavelength that is way we separate the users.

According to the value parameters CW laser which is utilized by gives the frequency and power depending on what we need to simulate for this simulation we utilized for wavelength of 1490, 1491,1492, 1493 and power of 0.2dbm, data rate gives 2.5Gbps, with in a lot of various fiber length after that it fed in to the MZM which modulated the signal that received from the CW laser and run the program. After we run our simulation, we found different parameter that we began to design in a graph explains for us the way it makes different compared between distance and Q-factor

Parameter Groups - Layout 1 X

Parameter group: Frequency Units: nm

Component	Parameter	Value	Mode
CW Laser	Frequency (nm)	1490	Normal
CW Laser_1	Frequency (nm)	1491	Normal
CW Laser_2	Frequency (nm)	1492	Normal
CW Laser_3	Frequency (nm)	1493	Normal

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Spread...  
Load File...  
Assign Values...  
Filter...  
Help

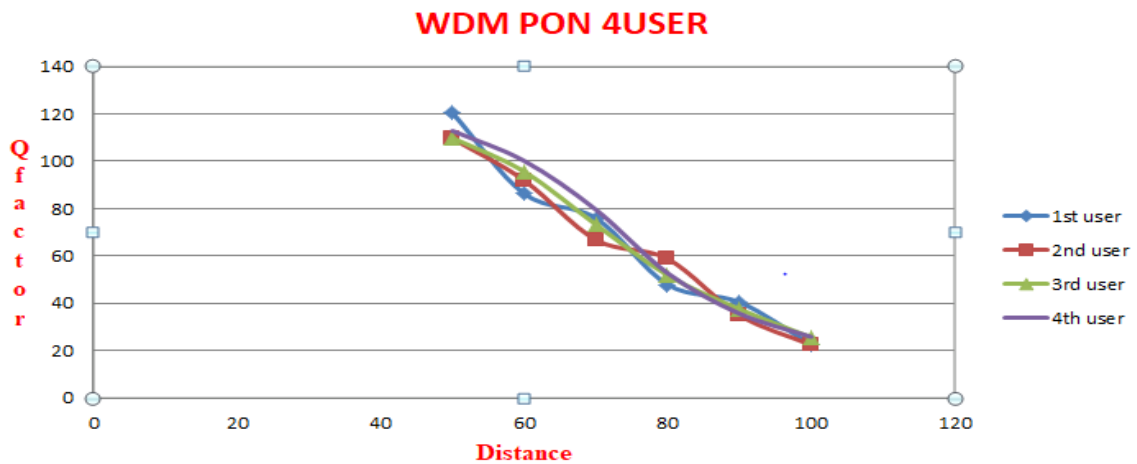
**Figure 5. 9:** Frequencies of WDM PON

And then have a look one by one for these four wavelengths we run the program of WDM model to get the following table:

**Table 5. 2:** Performance Analysis of WDM-PON Based on Distance and Q-factor

Distance	1 <sup>st</sup> user Max Q factor	2 <sup>nd</sup> user Max Q factor	3 <sup>rd</sup> user Max Q factor	4 <sup>th</sup> user Max Q factor
50	120.529	109.74	109.916	112.936
60	86.4017	92.0031	95.7301	100.219
70	76.02	66.8546	73.2913	79.6181
80	47.9328	54.8221	51.8988	52.791
90	40.5079	35.0614	37.6123	35.7323
100	22.6806	22.4704	25.716	25.8817

Figure 5.10 shows the relationship of Q-factor with distance for the unidirectional WDM PON system, putting them in curve for discuss:

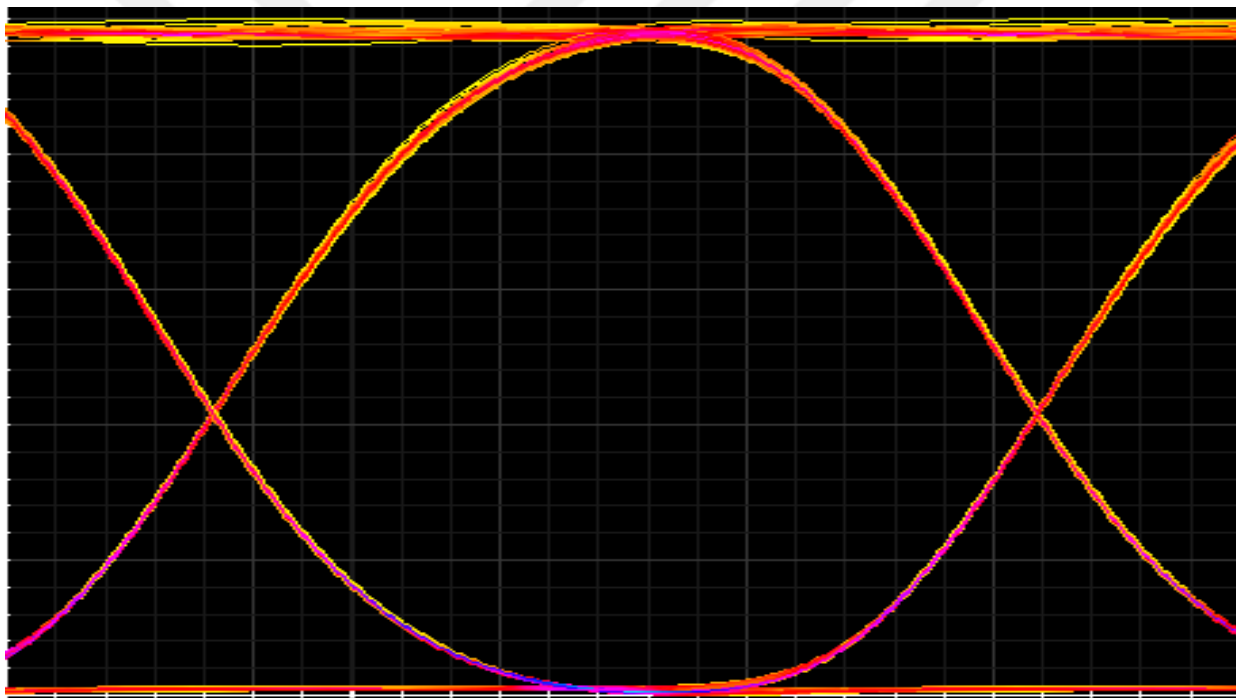


**Figure 5. 10:** Result of WDM PON for 4User

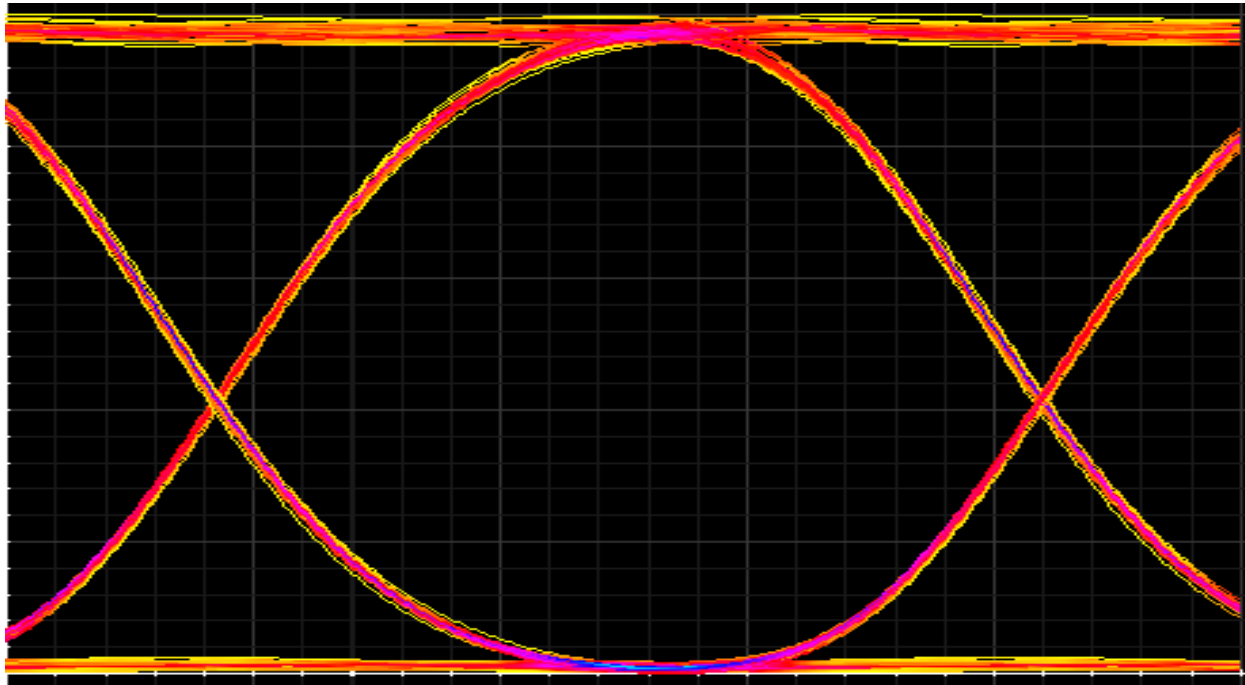
For the graph describe that the value of Q-factor is difference for a distance from 50 to 100 km at power of 0.2dBm, when the distance increases, the Q-factor decreases. It can be seen that by using WDM PON, the quality of the received signal and the distance covered by the transmitted signal has been increased when compared with the TDM PON system.

#### 5.1.2.2 BER and Distance in Eye Diagram:

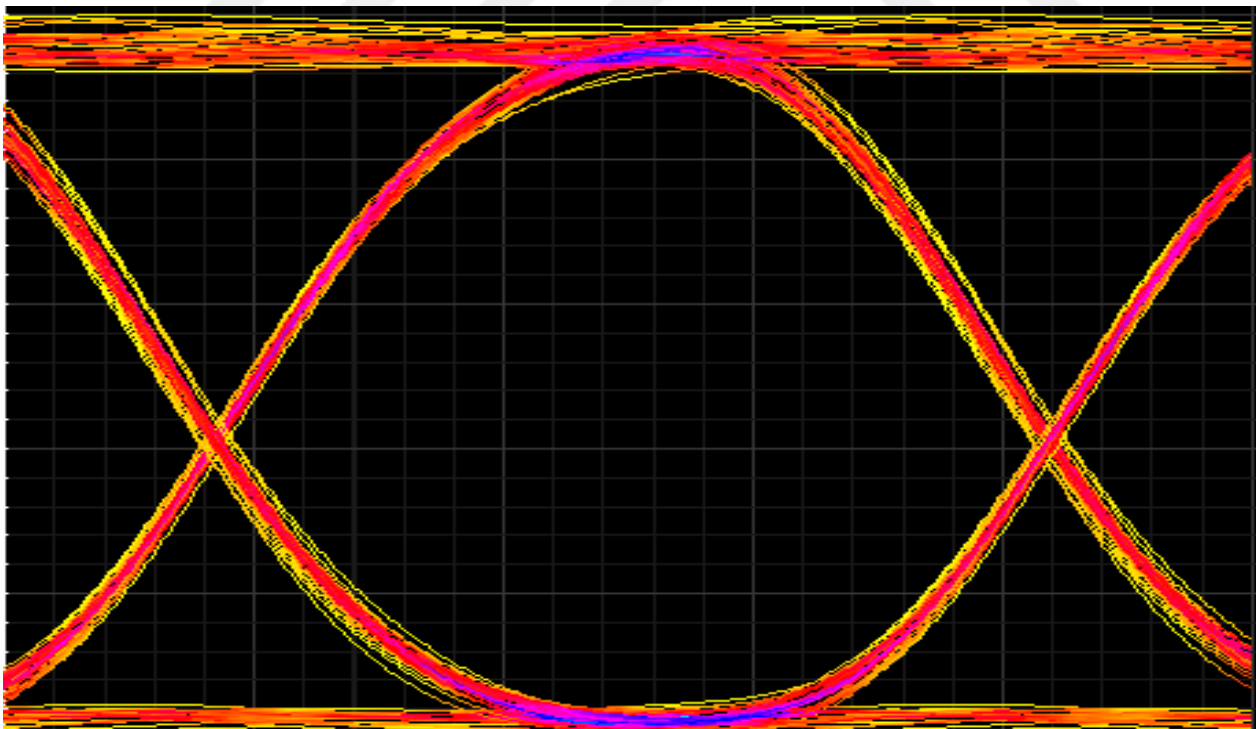
At the receiver system ONU we get the following shapes that describes how to increase ISI in three different fiber length 50, 70 and 90km.



**Figure 5. 11:** BER for Length 50km



**Figure 5. 12:** BER for Length 70km

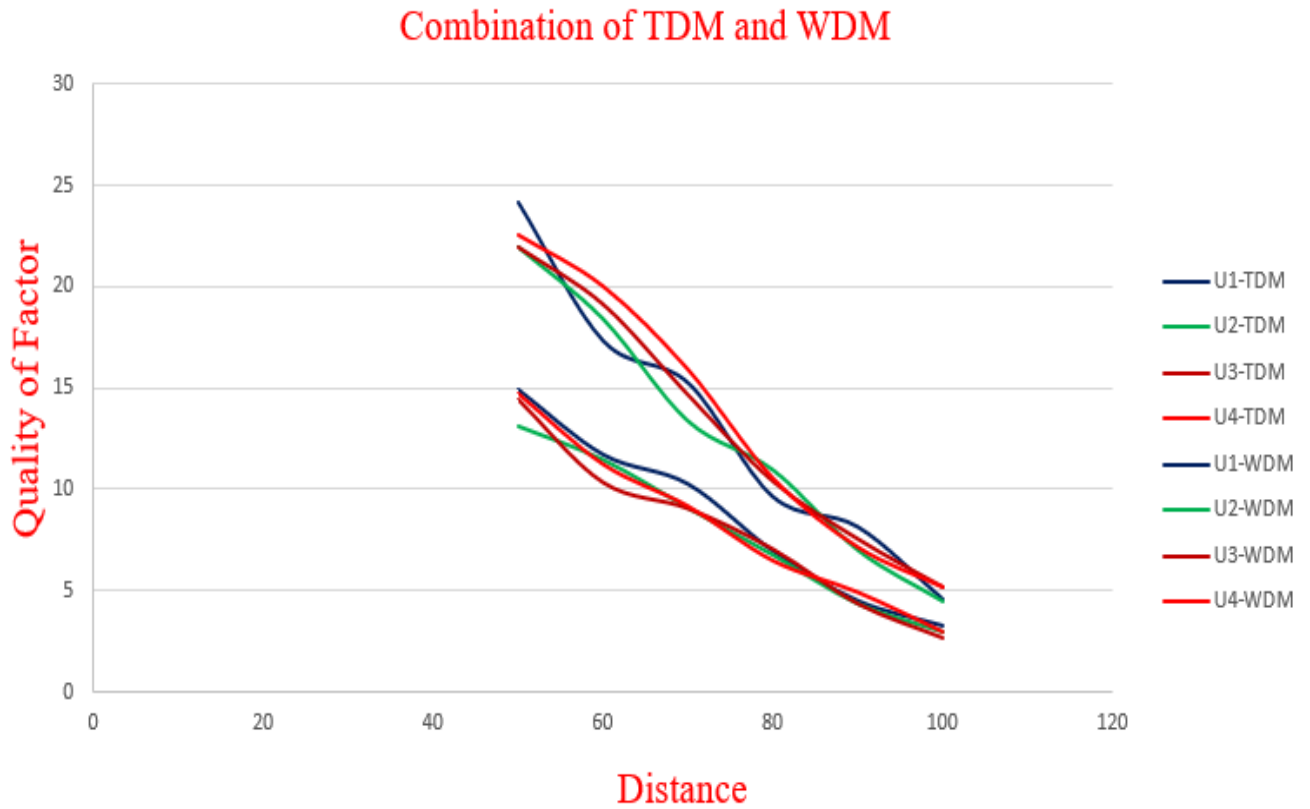


**Figure 5. 13:** BER for Length 90km

Figure above shows the variation of ISI with distance for the unidirectional WDM PON system, an input power of 0.2dBm, when the distance increases, BER increase slowly.

### 5.1.3 Combine of TDM and WDM:

Now we are collecting the two above graphs that we design based on TDM and WDM in one graph in order to make accurate comparison to clarify the difference between these two multiplexing on PON.



**Figure 5. 14:** Combining of TDM and WDM in a Graph

After we design the graph, we knew that the WDM is better than other TDM because the quality of factor it gradually increases as we increase the number of subscribers and the value of TDM is smaller than WDM.

## **6.FUTURE WORK and CONCLUSION**

### **6.1 Conclusion:**

PON plays a critical part in the construction of FTT-Home networks for the purposes of analysis, the PON is one of the greatest effective access architectures that can offer high capacity and long reach, it can be found that for the same data rates, after we run the program and get the result that indicate in the graph it gives us that the unidirectional WDM PON with 4Useris better than the unidirectional TDM PON with 4User that we compare from the Q/factor and BER.

As a result, a good Q-factor, bit error rate, or eye closure is achieved when compared to other current PON, guiding us to a lower cost and greater bandwidth when compared to TDM and WDM PON. Long-distance communication is another area where work may be done.

From the graphs; it has been discovered that increases length of fiber, the factor of quality and the BER will change, implying that the Q/factor will decrease and will increase the BER. As technology has improved from the TDM to WDM, in the WDM PON, in the received signal the quality and distance covered by the signal that already sent has been increased and the number of errors in the received signal has reduced when compared with the TDM PON system. Therefore, PON for WDM it seems that the promising solves for the next generation PON.

passive optical network (PON) derives to the lead of the research field and network service provider regularly organize time division multiplexing (TDM) based PON because it is cost effective, in TDM-PON but the key restriction is its limited bandwidth, so in demand to give much bandwidth that is way wavelength division multiplexing (WDM) is utilized. Nevertheless, the most problem we get in WDM-PON is its high cost because of we give every subscriber has certain wavelength (Lohani & R.S.Prasad, 2015). Therefore, the advantages of TDM-PON and WDM-PON moderate to each other and offer the architecture of hybrid WDM/TDM PON.

## 6.2 Future Work:

For future work, as an outcome, FTTH/B is predicted to be the best supplier of broadband technology by 2035 because it can easily scale due to its extensive fiber networks especially in improving high bandwidth fiber optics and long distances at low and cheapest cost, connections to passive optical networks are one of the alternatives that can cover all of those criteria in order to bring the Internet to your homes as quickly, the PO-Network has a lot of advantages compared to other networks of the first/last mill, such as financial efficiency, energy saving, stability in operation and signal strength.



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## RESUME

### PERSONAL INFORMATION

**Name Surname:** ABDULKADIR OMAR ABDULLAHI

### EDUCATION

**Masters of Science in Electrical and Electronics Eng.**– *Istanbul Aydin University, Istanbul – Turkey*

Graduated -Aug 2021.

**Bachelors of Electronics and Communication Eng.**– *University of Blue Nile, Al-Damazin*

Graduated – Oct 2017.

**High School Diploma** – *Mogadishu, Somalia*

Graduated - Jun 2011.

### WORK EXPERIENCE

**Khalid bin Al-Walid**

*2008-2010*

**Telecommunication Technical Engineer**

Responsible of Telecommunication Equipment Operation and Maintenance.

- Installations, Commissioning and Maintenance of Ericsson RBS 6000 Family (3G – Family).
- Installations, Commissioning and Maintenance of Ericsson RBS (2206, 2216, 2101, 2106).
- Installations and Commissioning of Huawei Radio Sys. such as (OptiX RTN 950).

**Hormuud Telcom Company**

*Feb 2018 – Oct 2018*

### CERTIFICATIONS

**Sudatel Telecom Academy - Diploma** - *Khartoum, Sudan*

*2017*

**New Horizon Training Center** Khartoum, Sudan

2018 Mobile Communication (2G and 3G)

2018 Drive Test and Post Processing

## **PUBLICATIONS**

- A Wireless Weather Monitoring System Using Arduino DUE and GSM Technology  
2018 **IRJET - journal**, “<https://www.irjet.net/archives/V5/i4/IRJET-V5I4165.pdf>”

## **LANGUAGE COMPETENCIES**

- Somali: native language
- Arabic: native language.
- English: fluent (speaking, reading, writing).
- Turkish: Basic (speaking, reading); intermediate (writing).

## **PROFESSIONAL SKILLS**

- Professional of Opti-system Software.
- Good knowledge of PYTHON and C++ in real world applications.
- Excellent Command over MATLAB, Multisim, PORTEUS and HFSS.
- Mastery of Microsoft Office programs (Word, Excel, PowerPoint).
- Excellent communication skills with a focus on team-building.
- Outstanding organizational, multitasking, Fast learner and problem-solving abilities