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Design and Performance Evaluation of WDM-PON using FTTx Architecture

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Design and Performance Evaluation of WDM-PON using FTTx Architecture

Presented by:
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Favorable opinion of the Jury President

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Stamp and signature

Dedication

I dedicate this work to my precious parents whom I owe everything in my life, to the light of my life my lovely mother who showed me with the indefatigable care, sincere prayers, endless love and unparalleled tenderness who that was pushing further to complete this research.

To my father who helped me to chase my dreams and taught me that in life “There is no gain without pain”.

To all those who struggled, suffered and challenged circumstances in order to pursue the realization of their dreams and their works, to all those who believe that there is nothing that comes easily in life, that after determination and commitment there Will be the pursuit which followed by a received patient.

Acknowledgement

First of all, I should be so grateful and thankful to Allah, the Most Gracious and the Most Merciful for giving me the patience, power, and will to complete this work.

I wish to extend my deep gratefulness to my supervisor **Dr.Abdesselam Salim** for his inestimable guidance, insightful suggestions, continuous support, and patience throughout the preparation of this work. He always giving me the invaluable piece of advice and comments and provided me with useful ideas. Having worked with him was a fruitful experience. My sincere thanks should go to the honorable members of the jury; **Pr. Benakcha Abdelhamid**, **Dr. Guesbaya Tahar**, for their collaboration in analyzing this work. To all the people who have supported me to complete the research work directly or indirectly. Especially my close friend Toumi Asma for her assistance.

Finally, I thank all my family and especially my parents, their support, their prayers to me, To my beloved sisters "Amel, Amina, Asma, Hana" who were around any time I need To all my friends whom I shared the unforgettable moments, Bouthaina, Asma, Chiva, Sofia and Amina.

Abstract

Optical access networks are currently undergoing a very rapid evolution that accompanies the development of the Internet and telecommunication services around the world. FTTx has different types of technologies and architectures, they are adopted according to applications and services. Among its different implementations there is the Passive Optical Network (PON), considered as a standard for access to high-speed networks.

The main idea of this project is to create a fictional environment that will allow us to study FTTx networks in depth and to choose the most optimal option for this environment. Simulation software meeting the design requirements will be chosen, the design of the passive optical network will be realized and the results of the simulation will confirm that the network is applicable and can be implemented in a real environment. We will work on the determination of transmission quality taking into account certain parameters of the link, such as the bit rates used, the length of the fiber and the type of modulation.

الملخص

تشهد شبكات الوصول البصرية حاليًا تطورًا سريعًا يصاحبها تطور خدمات الإنترنت والاتصالات في جميع أنحاء العالم. تمتلك FTTx أنواعًا مختلفة من التقنيات والمعماريات ، ويتم اعتمادها وفقًا للتطبيقات والخدمات. من بين تطبيقاتها المختلفة ، الشبكة البصرية السلبية (PON) ، والتي تعتبر معيارًا للوصول إلى الشبكات عالية السرعة.

الفكرة الرئيسية لهذا المشروع هي خلق بيئة خيالية تسمح لنا بدراسة شبكات FTTx بتعمق واختيار الخيار الأمثل لهذه البيئة. سيتم اختيار برنامج محاكاة يفي بمتطلبات التصميم ، و تحقيق تصميم الشبكة البصرية السلبية وستؤكد نتائج المحاكاة أن الشبكة قابلة للتطبيق ويمكن تنفيذها في بيئة حقيقية. سنعمل على تحديد جودة الإرسال مع مراعاة معلمات معينة للارتباط ، مثل معدلات البتات المستخدمة وطول الألياف ونوع التشكيل.

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ADSL	Asymmetric Digital Subscriber Line
AES	Advanced Encryption Standard
AON	Active Optical Network
APD	Avalanche Photodiode
APON	ATM (Asynchronous Transfer Mode) Passive Optical Network
BER	Bit Error Rate
BPON	Broadband Passive Optical Network
BW	Bandwidth
CO	Central Office
CWDM	Coarse Wavelength Division Multiplexing.
CATV	Cable Television
DSL	Digital Subscriber Line
DWDM	Dense Wavelength Division Multiplexing
DS	Downstream
EDFA	Erbium Doped Fiber.
EPON	Ethernet Passive Optical Network.
FSAN	Full Service Access Network
FTTB	Fiber To The Building
FTTC	Fiber To The Curb
FTTH	Fiber To The Home
FTTN	Fiber To The Neighborhood
FTTO	Fiber To The Office
FTTP	Fiber To The Premises

FTTU	Fiber To The User
FTTx	Fiber To The x
GEM	GPON Encapsulation Mode
GEPON	Gigabit Ethernet Passive Optical Network
GPON	Gigabit Passive Optical Network
GTC	GPON Transmission Convergence
HDTV	High-Definition TV
IEEE	Institute of Electrical and Electronics Engineers
IPTV	Internet Protocol TV
ISP	Internet Service Provider
IP	Internet Protocol
IDSL	Integrated Services Digital Network Digital Subscriber Line
ITU-T	International Telecommunications Union
LED	Light Emitting Diode
LD	Laser Diode
LAN	Local Area Network
LASER	Light Amplification by Stimulated Emission of Radiation
LC	Little Connector
LED	Light-Emitting Diode
LPBF	Low Pass Bessel Filter
MAC	Media Access Control
MAN	Metropolitan Area Network
MZM	Mack Zehnder Modulator

MUX	Multiplexer
NRZ	No Return to Zero
NGPON	Next-generation Passive Optical Network
NRZ	Non-Return to Zero
ODN	Optical Distribution Network
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical Line Terminal
ONT	Optical Network Termination
ONU	Optical Network Unit
PON	Passive Optical Network
POTS	Plain Old Telephone Service
P2P	Peer-to-Peer
P2MP	Point to Multipoint
PtP	Point-to-Point
PD	Photo- Diode
PIN	P-type Intrinsic N-type
PLOu	Physical Layer Overhead
PLSu	Power Leveling Sequence upstream
Q Factor	Quality Factor
RZ	Return To Zero
RF	Radio Frequency
Rx	Receiver
SNR	Signal-to-Noise Ratios

SMF	Single Mode Fiber
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing PON
VoIP	Voice over Internet Protocol
VOLT	Video Optical Line Termination
VDSL	Very high-bit-rate DSL
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network
WDM PON	Wavelength Division Multiplexing Passive Optical Network
xPON	x Passive Optical Network
XG-PON	10 Gigabit Passive Optical Network
10G-EPON	10 Gigabit Ethernet Passive Optical Network

General Introduction

In recent decades, access networks have been developing very fast, whether in fixed and wireless access or in mobile networks. Fiber optic networks have been evolving with a significant impact on a large number of applications. Indeed, optical fibers are very interesting for their bandwidth and their rate, much higher than those offered by other technologies.

This evolution has a profound impact on content providers and network operators. Indeed, copper access networks around the world are largely replaced by a fiber access network. The most important catalyst for this change is the growing perception that the copper access network is no longer able to meet the increasing bandwidth demand and the immediacy required for the fluidity of use.

The optical fiber can provide higher bandwidth over a longer distance. In order to partially fulfill the aforementioned requirement, telecommunication companies have been already deploying Fiber-To-The-x (FTTx) networks in various parts of the world. The concept of the different variations of the FTTx technology, namely FTTH (Home), FTTC (Curb) and FTTB (Building) are the provision of fast fiber connections in high proximity to the end user’s premises. FTTx networks primarily constitute Passive Optical Networks (PONs) that are considered as one of the most promising.

Most optical access systems deployed today are based on Gigabit PON (Passive Optical Network) technologies. These are passive optical networks based on a point-to-multipoint architecture operating at a rate of 1.25 or 2.5 Gbps. For the future bandwidth demand for which a bit rate of the order of Gbits / s per user would be required, the TDM time division multiplexing PON technology seems to be insufficient or less economical because the bit rate is too high for a large number of users.

So, the use of wavelength division multiplexing (WDM) wavelength division multiplexing technology in the optical access network is a very promising solution for mounting at a very high rate. The high throughput capacity of the WDM-PON is explained by the fact that the communication with each user is dedicated to a wavelength. For this reason, WDM-PON technology is emerging as one of the most potential candidates for future PON generation.

The aim of this final project is to study and simulate the passive optical network (PON). In this context, we are interested in a PON-WDM architecture (PON with wavelength division multiplexing).Our work is organized into 3 chapters:

The first chapter describes in a general way the principle of a digital connection by the optical fiber. We quote the characteristics of the components which intervene in this type of connection, the advantages and disadvantages of the optical fiber. Additionally, we study the components of the transmission part of the optical link, namely the optical sources, such as the LED diodes and the LASER diodes, as well as the components of the reception part such as PIN optical receivers. We will also define the complementary elements of an optical link such as the erbium doped fiber amplifier (EDFA), as well as the types of modulation and applications.

The second chapter will be devoted to optical access networks with the different FTTx architectures that exist, as well as the operation of a passive optical network (PON) with its various elements such as OLT (Optical Line Termination), ONU (Optical Network Unit), and splitter. Moreover, we deal with a presentation that is about the different categories of the PON network such as the APON, the BPON, the EPON, the GPON, the PON-WDM system and by mentioning the speeds offered by the PON networks as well as network security and reliability.

The third chapter aims to present the OptiSystem simulation software version 16.0 that was used to study the bidirectional WDM-PON system and the various elements of the link (bidirectional optical fiber, optical circulator). The last section focuses on the final design of the network and the results that show that the network works. The figure shows what the design has been, an explanation of all the important elements (OLT, ONT, and Splitter) and the parameters that have taken into account to make it works. The scheme is divided into five areas that define the entire design. Our work is mainly about knowing the PON network performance by changing the fiber, length bite rate and showing the results in each area of ONT for the five areas, also having the results by BER and Q-factor.

1 Chapter 1 Fundamentals of optical fibers and communucation

1.1 Introduction

Fiber optics is a major building block in the telecommunication infrastructure. Its high bandwidth capabilities and low attenuation characteristics make it ideal for gigabit transmission and beyond. First, developed in the mid-1970s, fiber optics played a major role in the advent of the information age by making a revolution in the telecommunications industry. With the explosion of information traffic due to the Internet, electronical commerce, computer networks, multimedia, voice, data, and video, the need for a transmission medium with the bandwidth capabilities for handling such vast amounts of information is paramount.

Optical fiber communication is a method for carrying information at a distance in the form of light. The light forms an electromagnetic carrier wave that is modulated to carry information. A standard modern fiber-optic communication system consists of a transmitting device to convert the electrical signal into an optical signal to send into the optical fiber, an optical fiber cable carrying the light, multiple kinds of amplifiers, and an optical receiver to recover the signal and convert it back into an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.

In this chapter, we will first discuss the evolution of the transmission and the different elements of an optical fiber link.We will describe the optical transmission system, the composition of the optical fiber and its characteristics, its advantages as well as its disadvantages.

1.2 How a fiber optic communication works?

Unlike copper wire-based transmission where the transmission entirely depends on electrical signals passing through the cable, the fiber optics transmission involves the transmission of signals in the form of light from one point to the other. Furthermore, a fiber optic communication network consists of transmitting and receiving circuitry, a light source and detector devices like the ones shown in the figure 1.1.

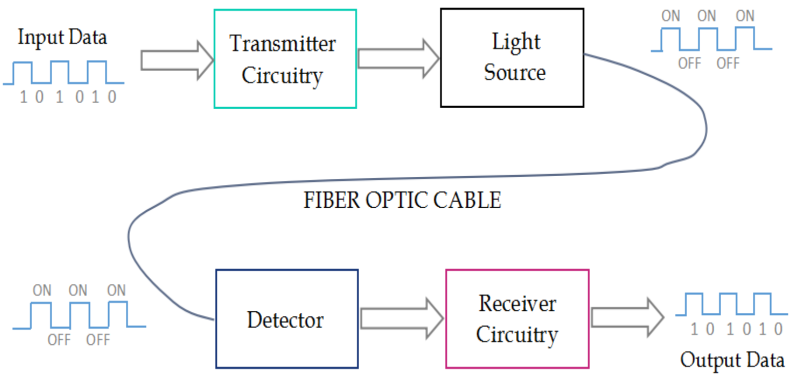

Figure 1.1: *Basic fiber optical communication system [1]*

When the input data, in the form of electrical signals, is given to the transmitter circuitry, it converts them into a light signal with the help of a light source. This source is of LED (light emitting diodes) whose amplitude, frequency and phases must remain stable and free from fluctuation in order to have efficient transmission. The light beam from the source is carried by a fiber optic cable to the destination circuitry wherein the information is transmitted back to the electrical signal by a receiver circuit.

The receiver circuit consists of a photodetector along with an appropriate electronic circuit, which is capable of measuring the magnitude, frequency, and phase of the optic field. This type of communication uses the wavelengths near the infrared band that is just above the visible range. Both LED and Laser can be used as light sources based on the application. [1]

1.3 Fiber Optic Link Components

In order to comprehend how fiber optic applications work, it is important to understand the components of a fiber optic link. Simplistically, there are main components in a fiber optic link. [3]

1.3.1 Optical Transmitter

There are two main types of fibre optic transmitter that are in use today. Both of them are based around semiconductor technology :

1.3.1.1 Light Emitting Diodes (LEDs)

LEDs emit light through, and light is created by a method known as spontaneous emission typical emit incoherent light with a relatively wide spectrum in fiber optic communication systems. This is due to their small size, long lifetime and low cost. Usually, be light output in the range 30 – 60 nm in LED this leads to poor beam focus and incoherent radiation that can limit the distances over which data can be transmitted. [4]

1.3.1.2 Laser diodes

Lasers emit light through amplification of radiation by stimulated emission “Light Amplification by Stimulated Emission”. Often Lasers have a higher output power than LEDs the light output from a laser diode can be in the region of 100 mW and so they are capable of transmitting information over long distances. Also, lasers have a much narrower spectral width and carry the most bandwidth, thus are an excellent light source for long haul fiber optics links. [5-8]

1.3.2 Modulation

Lasers and LEDs used in telecommunication applications are modulated using one of two methods: ***direct modulation*** or ***external modulation***.

1.3.2.1 Direct modulation

The figure 1.4 depicts laser diode used as direct modulation. In this modulation type, the output power of the device depends directly on the input drive current. This means light is emitted from the device when "1 (binary one)" is being transmitted and no light is emitted when "0 (binary zero) " is being transmitted. [6]

Advantages: This optical modulation is simple. It is cheaper as no complex circuitry is involved during the modulation process.

Disadvantages: This method is slower compared to indirect or external modulation type. It can be used below 3 GHz.

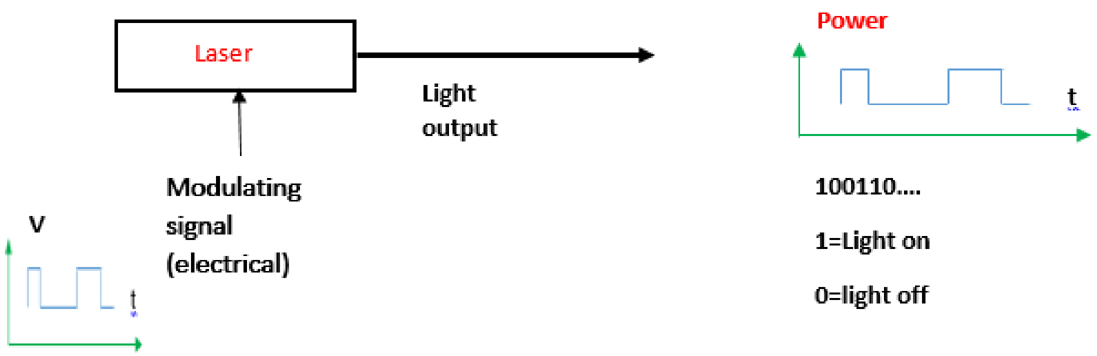

***Figure 1.2**: Laser diode used as optical direct modulation*

1.3.2.2 External modulation

In external modulation (Figure 1.3), an external device is used to modulate the intensity or phase of the light source. The light source remains on while the external modulator acts like a “shutter” controlled by the information being transmitted. External modulation is typically used in high-speed applications such as long-haul telecommunication or cable TV headends. The benefits of external modulation are that it is much faster and can be used with higher-power laser sources. The disadvantage is that it is more expensive and requires complex circuitry to handle the high-frequency RF modulation signal. [1]

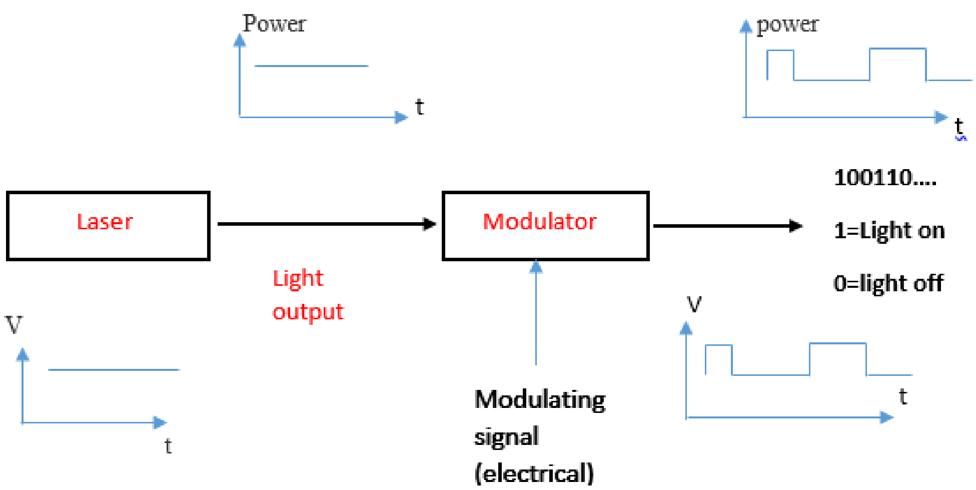

***Figure 1.3**: Laser diode used as optical external modulation*

1.3.3 Optical Reciever

The last component of the fiber optic link is the optical receiver, which uses a photodiode to convert the optical signals into electrical. The two types of photodiodes used are: Positive Intrinsic Negative (PIN) and the Avalanche Photo Diode (APD). [3]

1.3.3.1 Positive Intrinsic Negative (PIN)

In order to allow operation at longer wavelength where the light penetrates more deeply into the semiconductor material, a wider depletion region is necessary. To achieve this, the ***n type*** material is doped so lightly that it can be considered intrinsic, and to make low resistance contact a highly doped ***n type (n+)*** layer is added. This creates a PIN structure, as may be seen in Figure.1.4 where all absorption takes place in the depletion region. [7]

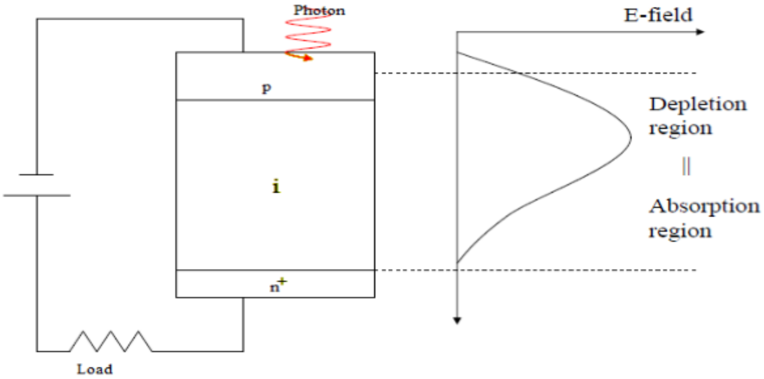

Figure 1.4*: PIN photodiode showing combined absorption and depletion [7]*

1.3.3.2 Avalanche Photo Diode (APD)

The second major type of optical communications detector is the avalanche photodiode (APD). This has a more sophisticated structure than the PIN photodiode, in order to create an extremely high electric field region as may be seen in Figure 1.7. Therefore, as well as the depletion region where most of the photons are absorbed, and the primary carrier pairs generated, there is high field region in which holes and electrons can acquire sufficient energy to excite new electron-hole pairs. This process is known *as impact ionization* and is the phenomenon that leads to avalanche breakdown in ordinary reverse biased diodes. It often requires high reverse bias voltages (50 to 400 V). [7]

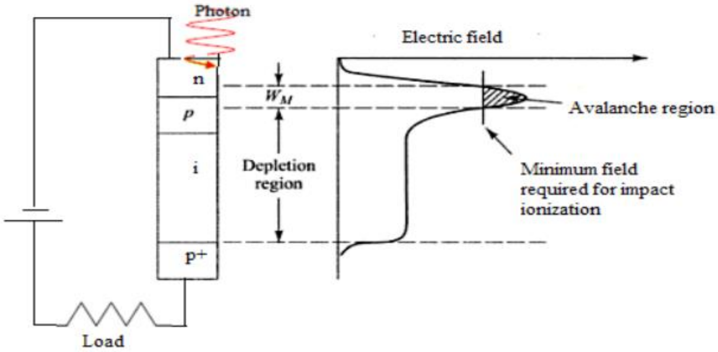

Figure 1.5*: Avalanche photodiode showing high electric field region [7]*

1.4 The optical amplifier

Optical amplifier is a device that amplifies an optical signal directly, without first converting it to electrical form. Optical amplifiers are important in optical communication. There are several different physical mechanisms that can be used to amplify a light signal, which corresponds to the major types of optical amplifiers.

An example of this type is the erbium doped fiber amplifier (EDFA).It is one of the most widely used optical amplifiers. EDFAs contain a length of fiber working as an active region that is heavily doped with erbium ions and is pumped optically at 980 nm, 1480 nm or both using a semiconductor laser in the 10 to 100 milliwatt output range.

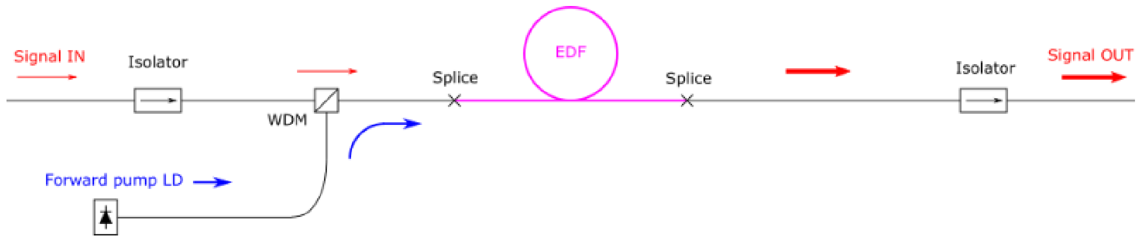

***Figure 1.6**: EDFA block diagrme*

Figure 1.6 shows one common configuration of EDFA. The input signal is combined with the pump light by a WDM coupler and launched to the EDF. The pump light launched to the EDF creates population inversion and the input signal is amplified by stimulated emission.

Isolators are placed both at the input and output, in order to stabilize signal amplification by eliminating unwanted back reflection from the output port. In this common configuration, the wavelength of the pump LD is locked close to the peak absorption wavelength of erbium (by an external fiber Bragg grating); the wavelength range is normally between 974 nm to 980 nm. [5-8]

1.5 The optical fiber

Optical fiber is a medium in which communication signals are transmitted from one location to another in the form of light through thin fibers of glass or plastic. These signals are digital pulses or continuously modulated analog streams of light representing information. These can be voice, data, computer, video or any other type of information.It is the same type of information that can be sent on metallic wires such as twisted pair, coax (coaxial cables) and through the air on microwave frequencies. [9]

1.5.1 Definition of optical fiber

An optical fiber is a thin, flexible, transparent fiber that acts as a waveguide, or "light pipe" to transmit light between the two ends of the fiber. Optical fibers are widely used infiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. [3]

1.5.2 Structure of the optical fiber

The optical fibers used in communications have a very simple structure. It is composed of the glass core, the cladding layer and the coating, strengthening fibers, Jacket.

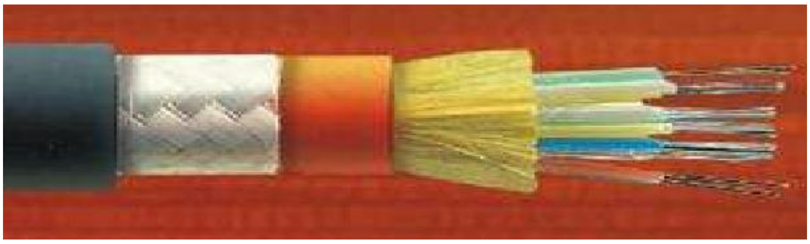

***Figure 1.7**: Structure of the optical fiber cable [10]*

Core: The core of a conventional optical fiber is a cylinder of glass or plastic that runs along the fiber's length. The core is surrounded by a medium with a lower index of refraction, typically a cladding of a different glass, or plastic. The three most common core sizes are :

- 9 µm diameter (single-mode)
- 50 µm diameter (multi-mode)
- 62.5 µm diameter (multi-mode)

Cladding: The fibers are coated with a glass of slightly lower refractive index. This is known as *cladding*. The cladding increases the critical angle within the core fiber and also prevents adjacent fibers from touching each other. At every point of contact, the light would escape into another fiber.

Coating: The coating is the first non-optical layer around the cladding. The coating typically consists of one or more layers of polymer that protect the silica structure against physical or environmental damage. The coating is stripped off when the fiber is connectorized or fusion spliced.

Strengthening fibers: These components help protect the core against crushing forces and excessive tension during installation.

Jacket: The jacket is an important feature of the fiber. It is 900 microns and helps protect the fiber from breaking during installation and termination and is located outside of the coating. [3]

1.5.3 The types of optical fiber

Optical fibers can be classified into two categories according to their diameters and the propagation of the wavelength.

1.5.3.1 Single-mode fibers (SMF)

In single-mode, only one light is transmitted in the fiber which diameter's ranges from 8.3 to 10 microns, see Figure (1.8). Since there is only one light, the problem associated with the multimode fiber does not exist and by this, we can have a higher transmission rate and also it can be used for long distance. [9]

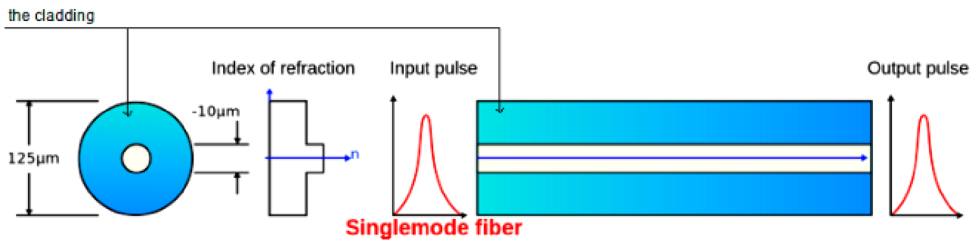

***Figure 1.8**: Single-mode fibers (SMF) [4]*

1.5.3.2 Multimode optical fibers (MMF)

Multimode fiber was the first type of fiber to be commercialized. It has a much larger core than single-mode fiber, allowing hundreds of modes of light to propagate through the fiber simultaneously. Additionally, the larger core diameter of multimode fiber facilitates the use of lower-cost optical transmitters such as LEDs or vertical cavity surface emitting lasers (VCSELs) and connectors. There are two types of multimode fiber. [11]

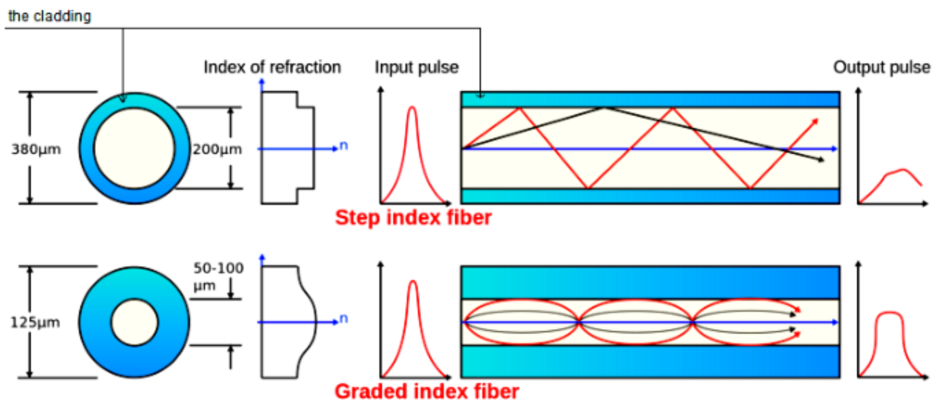

Figure 1.9*: Multimode optical fibers (MMF) [4]*

a) Multimode step index fibers

In a multimode SI (step index) fiber, the core is significantly bigger when compared to a single mode fiber, about 100 microns. And therefore more modes are allowed to propagate inside the fiber. The total reflection is ensured by the values of the refractive indices n1 (core) and n2 (cladding) with always n1> n2 the multimode step-index fibers are intended for short distance transmissions, they use the wavelengths 850nm and 1300nm.

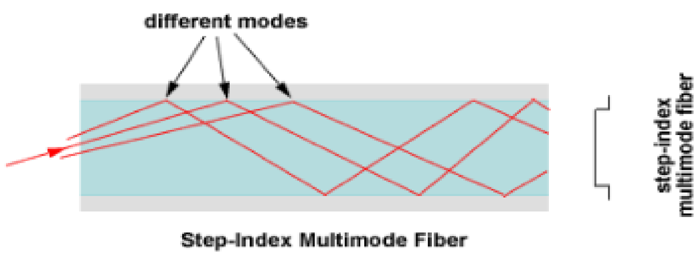

Figure 1.10*: Step-Index Multimode fiber [10]*

b) Multimode Graded index fibers

Graded-index fibers bend the rays inward and also allows them to travel faster in the lower index of refraction region, is a type of fiber where the refractive index of the core is lower toward the outside of the fiber. This type of fiber provides high bandwidth capabilities. As a result, graded-index fibers have bandwidths which are significantly greater than step-index fibers, but still much lower than single-mode fibers. Typical core diameters of graded-index fibers are 50, 62.5 and 100 µm. The main application for graded-index fibers is in medium-range communications, such as local area networks. [12]

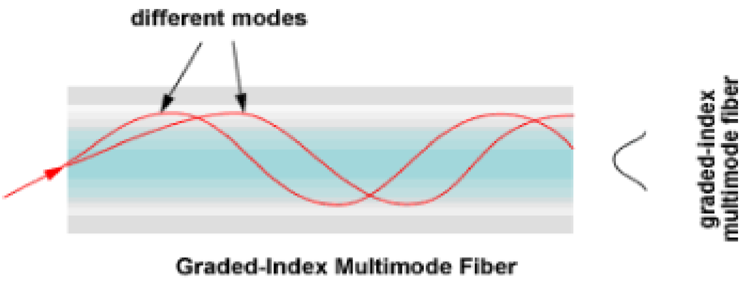

Figure 1.11*: Graded-Index Multimode fiber [10]*

1.5.4 Characteristics of an optical fiber

After dealing with the definition, the nature and the role of optical fiber previousely, the next step that will be dealt with is showing its two main caracteristics as follows:

1.5.4.1 Attenuation

Attenuation means loss of light energy as the light pulse travels from one end of the cable to the other. It is also called as *signal loss* or *fiber loss.* It also decides the number of repeaters required between transmitter and receiver. Attenuation is directly proportional to the length of the cable. Attenuation is defined as the ratio of optical output power to the input power in the fiber of length L. [13]

$$\alpha = 10 * \log 10 \frac{pi}{po} \quad [\, dB \,/\, km \,] \qquad (1.1)$$

Where:

Pi : Input Power

Po: Output Power, α is attenuation constant

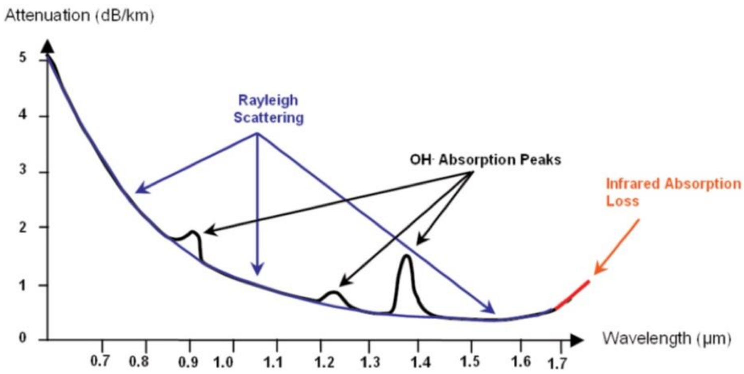

Figure 1.12*: Typical Attenuation vs.Wavelength [14]*

The various losses in the cable are due to

- Absorption
- Bending Loss
- Scattering

1.5.4.2 The dispersion

It is defined as pulse spreading in an optical fiber. As a pulse of light propagates through a fiber, elements such as numerical aperture, core diameter, refractive index profile, wavelength, and laser line-width cause the pulse to broaden. Dispersion increases along the fiber length. The overall effect of dispersion on the performance of a fiber optic system is known as *Inter symbol Interference* (ISI). Inter symbol interference occurs when the pulse spreading caused by dispersion causes the output pulses of a system to overlap. [4]

There are many kinds of dispersion, each of which works in a different way, but the most important three are discussed below:

a) Material dispersion (chromatic dispersion)

Chromatic Dispersion (CD) is pulse spreading due to the fact that different wavelengths of light propagate at slightly different velocities through the fiber because the index of refraction of glass fiber is a wavelength-dependent quantity; different wavelengths propagate at different velocities. [4]

b) Waveguide dispersion

Waveguide dispersion is a very complex effect and is caused by the shape and index profile of the fiber core. However, this can be controlled by a careful design and a waveguide dispersion can be used to counteract material dispersion. [13]

c) Intermodal dispersion (Modal Dispersion)

Modal dispersion is a distortion mechanism occurring in multimode fibers and other waveguides, in which the signal is spread in time because the propagation velocity of the optical signal is not the same for all modes. [13]

1.6 Advantages and disadvantages of optical fibers

Given the speed and bandwidth advantages optical fiber, it also contains some drawbacks. Here are advantages and disadvantages of optical fiber cable:

1.6.1 The advantages

Here are the main advantages of fiber optic transmission.

- ✓ *Cost*: Less maintenance costs due to fewer amplifiers required and less electricity is consumed.
- ✓ *Reliability:* Reliable, immune to noise and almost non-existent attenuation (distortion).
- ✓ *Bandwidth:* High bandwidth capabilities, increased from traditional CATV (cable television) network (up to 330MHz or 450MHz).
- ✓ *Flexibility* : Has ability to adapt to new services such as voice, data or video
- ✓ *Size* : Lighter weight and thinner than copper cables with the same bandwidth, much less space is required in underground cabling ducts and easier for installation engineers to handle
- ✓ *Security*: Much more difficult to tap information, a great advantage for banks and security installations. Immune to Electromagnetic interference from radio signals,
- ✓ *Longer Distance*: in fiber optic transmission, optical cables are capable of providing low power loss, which enables signals can be transmitted to a longer distance than copper cables.
- ✓ *Technology Support:* Can support cable telephones, increased number of CATV channels (to over 200), a direct infrastructure to new Digital TV standards. [15]

Though fiber optic transmission brings lots of convenience, its disadvantages also cannot be ignored.

1.6.2 The disadvantage

- ✓ Cables are expensive to install but last longer than copper cables.
- ✓ Optical fiber are fragile and can be broken or have transmission loses when wrapped around curves of only a few centimetres radius. However, by encasing fibres in a plastic sheath, it is difficult to bend the cable into a small enough radius to break the fibre.
- ✓ Very expensive receivers and transmitters are required.
- ✓ Transmission on optical fibre requires repeating at distance intervals.
- ✓ Optical fibres require more protection around the cable compared to copper. [4]

1.7 Applications of optical fibres

Fiber optic cables find many uses in a wide variety of industries and applications. Some uses include:

- ➢ *Medical:* Used as light guides, imaging tools and also as lasers for surgeries.

- *Defence/Government:* Used as hydrophones for seismic and SONAR uses, as wiring in aircraft, submarines and other vehicles and also for field networking.
- *Data Storage:* Used for data transmission.
- *Telecommunications:* Fiber is laid and used for transmitting and receiving purposes.
- *Networking:* Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission.
- *Industrial/Commercial*: Used for imaging in hard to reach areas.
- *Broadcast/CATV:* Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications. [3]

1.8 Conclusions

In this chapter, we have seen a description of an optical fiber link, the components of a transmitter, a receiver and its characteristics, advantages, and disadvantages of the optical fiber and its applications. To conclude, we can say that optical fiber is certainly the best way to transport very high data rates, and the needs in this area are likely to increase sharply in the near future. New architectures are implemented such as passive optical architecture PON (Passive Optical Network) that will be studied in the next chapter.

2 Chapter 2

Introduction to FTTx system and network PON

2.1 Introduction

Optical networks have grown rapidly in recent years. This evolution is due to the growing demand for high-speed downloads: videos, images and video conferencing. All of these applications require a lot of bandwidth to access Internet information as quickly as possible.

The demand for higher bandwidth has led to the establishment of broadband-based FTTH (Fiber to The Home) type access networks. Among the different FTTH implementations the Passive Optical Network (PON) can provide a very high data rates to customers, an extended coverage area, reduced fiber deployment thanks to its point-to-multipoint architecture and reduced the cost of maintenance through the use of passive components in the network. The integration of Wavelength Division Multiplexing (WDM) into a PON network is the answer to the increasing in bit rates and rate sharing in the access network. Each client is assigning a specific wavelength.

The objective of this chapter is to present the networks on fiber optic, in the first part we describe the different architectures FTTx (Fiber to the) such as FTTH (Fiber to the Home) and FTTB (Fiber to the Building).

Then, we address the part of the passive optical network according to its architecture (unidirectional or bidirectional), its operating principle and its various elements such as the ONT (Optical Network Termination), the OLT (Optical Line Terminal) and the separator. We also present some advantages and disadvantages of the network and technologies PON (Passive Optical Network), then a disscussion of the PON WDM (wavelength multiplexing).

2.2 Access network

An access network is the part of a telecommunications network which connects subscribers to their immediate service provider (Central Office). It is contrasted with the core network and is traditionally called *last-mile* networks.

The access network may be further divided between *feeder plant* or distribution network, and drop plant or edge network. Traditionally, optical fibers have been widely used in backbone networks because of their huge available bandwidth and their low loss. [16]

- Technologies for access network Wired :
  - Plain Old Telephone Service (POTS).
  - A symmetric Digital Subscriber Loop (ADSL).
  - Cable-modems using cable-TV (CATV).
  - Optical Access Network FTTx.
- Technologies for access network Wireless :
  - Satellite Systems: For Direct broadcast by satellite (DBS).
  - Cellular networks.
  - Fixed wireless access :
    - Local Multipoint Distribution System (LMDS).
    - Multichannel Multipoint Distribution System(MMDS).
    - WiFi/WiMax.
    - Free space optic FSO (optical wireless).

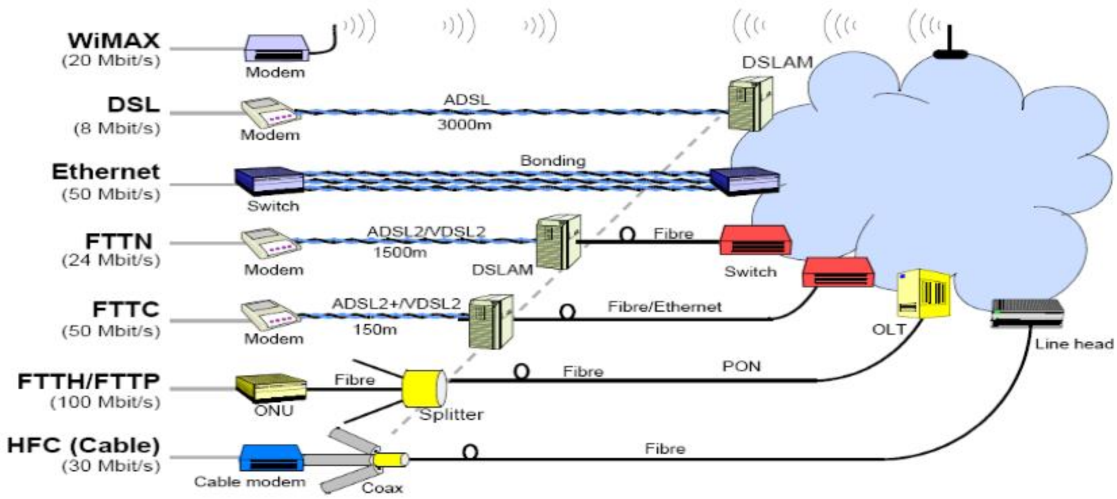

***Figure 2.1**: Access Network (Air, Copper, and Fibre access) [16]*

2.3 FTTx Networks

FTTH networks belong to the family of FTTx transmission systems within the world of telecommunications. These networks, which are considered broadband, have the ability to transport a large amounts of data and information at very high bit rates up to a point close to the end user.

The FTTx family comprises a set of technologies based on transport of digital signals through optical fiber as transmission medium. The different levels of scope depending on the degree of optical fiber closer to the end user, which arise as a result of a greater or lesser price reduction of these systems. All FTTx networks support a logical network configuration of a tree, a star, a bus and a ring, as seen in figure (2.2) and all with the ever present possibility of using active components depending on the location of users or end customers. [17]

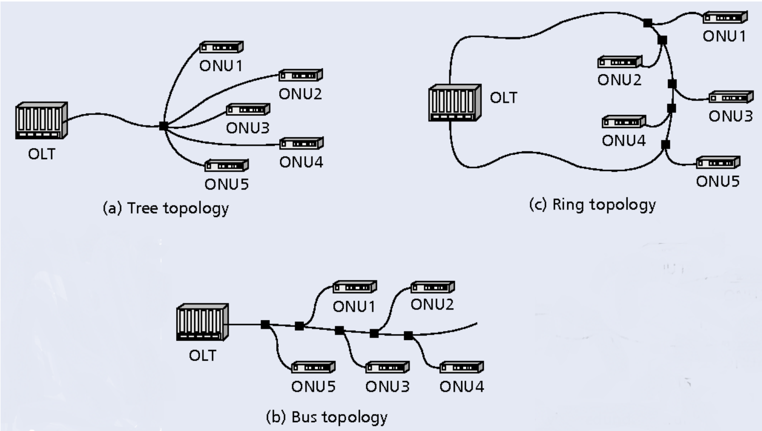

Figure 2.2: *FTTx topology*

Depending on the degree of penetration of FTTx, these networks can be classified into the following: [18]

- *FTTB*, *fiber-to-the-business*: refers to the deployment of optical fiber from a central office switch directly into an enterprise.
- *FTTC, fiber-to-the-curb:* describes running optical fiber cables from central office equipment to a communication switch located within 300m of a home or an enterprise coaxial cable, twisted-pair copper wires (e.g., for DSL).
- *FTTH*, *fiber-to-the-home*: refers to the deployment of optical fiber from a central office switch directly into a home. The difference between FTTB and FTTH is that typically businesses demand larger bandwidths over a greater part of the day than do home users.
- *FTTN, fiber-to-the-neighborhood*: refers to a PON architecture in which opti-cal fiber cables run to within 1km of homes and businesses being served by the network.
- *FTTP*, *fiber-to-the-premises*: has become the prevailing term that encompasses the various FTTx concepts. Thus FTTP architectures include FTTB and FTTH implementations. An FTTP network can use BPON, EPON or GPON technology.

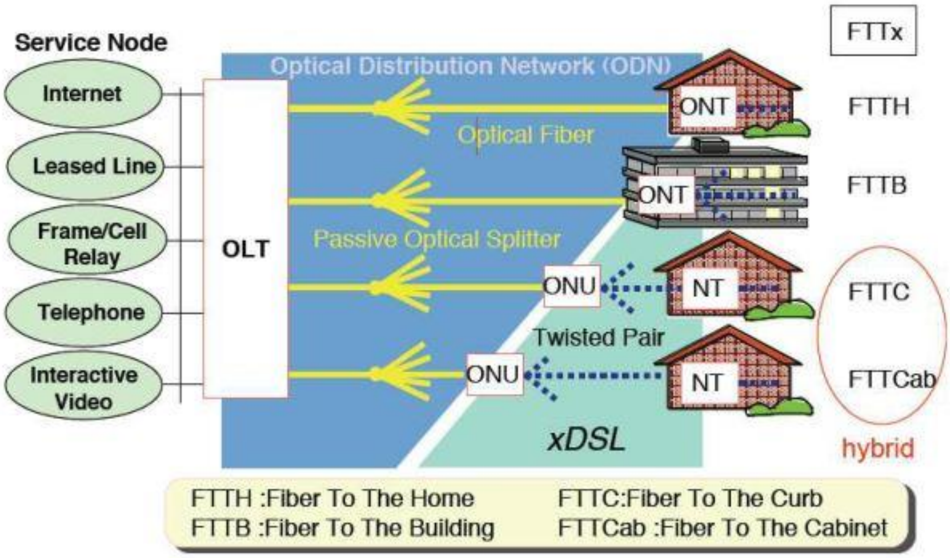

***Figure 2.3**: Some FTTx scenarios [17]*

Among all of these acronyms, the prevailing terms FTTH and FTTP As described in figure 2.3.

2.4 FTTH network

FTTH networks belong to the family of FTTx transmission systems within the world of telecommunications.These networks, which are considered broadband, have the ability to transport a large amounts of data and information at very high bit rates up to a point close to the last user. Figure (2.3) explains the idea of FTTH solutions. [17]

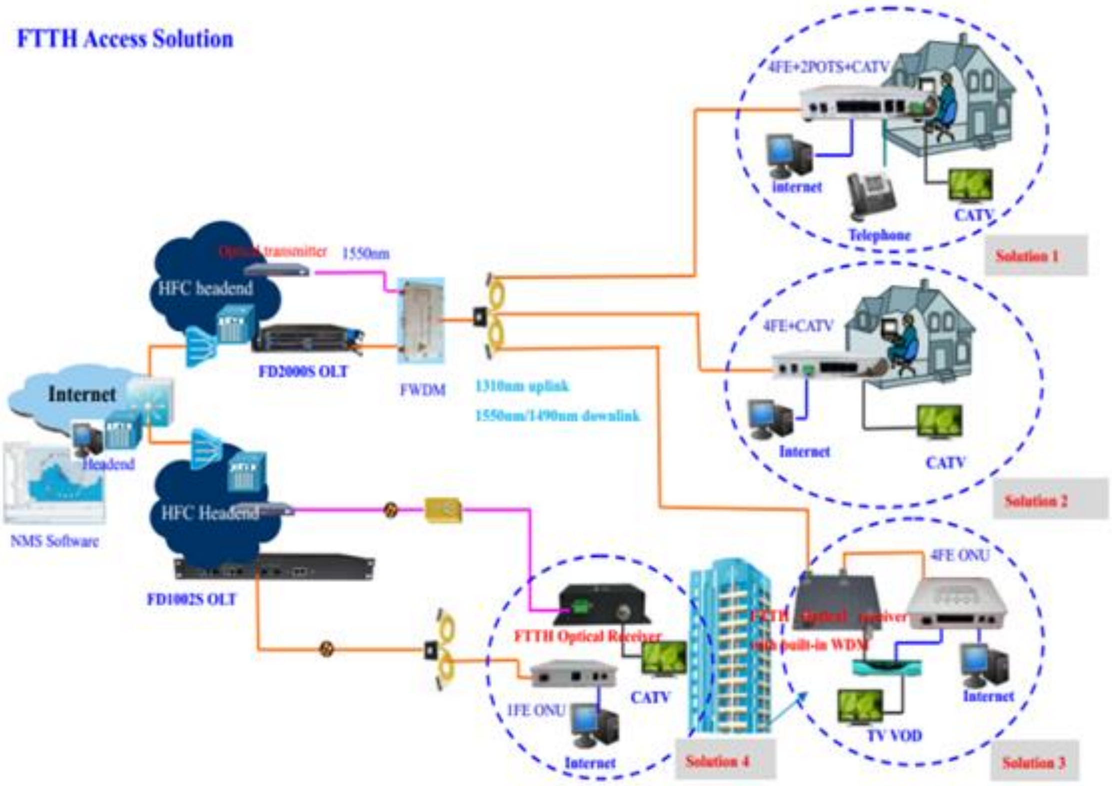

Figure 2.4: FTTH solution [17]

Fiber-to-the-home (FTTH) networks are being installed in point-to-point (P2P) and point-to-multipoint (P2MP) time-multiplexed passive optical network (PON) architectures.

2.4.1 Point to Point Architectures (P2P)

A point-to-point (P2P) is an Active Optical Network (AON) and referred to the network when a direct fiber connection exists between the central office (CO) and the Optical Network Termination (ONT) located at the subscriber's home as shown in figure (2.3). Fiber is dedicated to each user, so optical power experiences small loss and the power budget allows the distance between the CO and user's home to be as long as 10 km. There is no need for network addressing in P2P network because every user is connected by a dedicated fiber to the CO. [19]

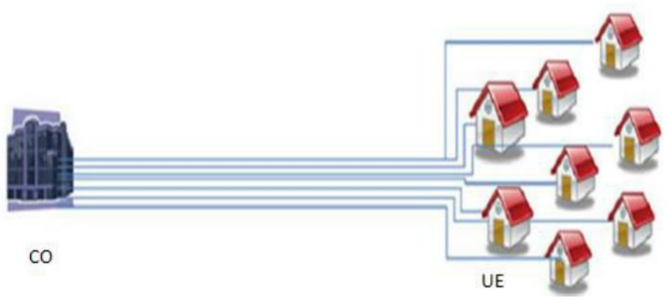

Figure 2.5: Point to point access topology [19]

2.4.2 Point to Multi Point architectures (P2MP)

Any network user does not use the network resources by the same manner. The high speed link from CO can be shared between groups of users. This topology is suitable for home users and small offices .The shared fiber can carry TDM data or WDM data or hybrid directed to multiple users. Point-to-multipoint costs of implementation and operation less than Point-to-point because the shared portion cost is shared between all the users that are served by the same fiber. [20]

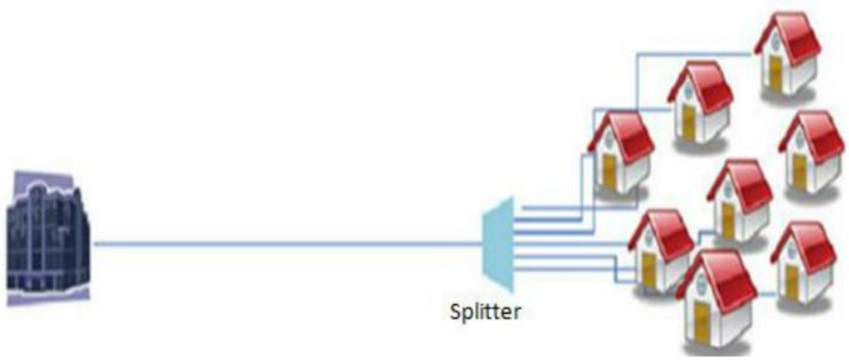

***Figure 2.6**: Point to Multipoint topology [19]*

2.5 Passive Optical network (PON)

Passive Optical Network (PON) is a set of technologies standardized by ITU-T and IEEE, although it is originally created by the Full Service Access Network (FSAN) working group. PON is a converged infrastructure that can carry multiple services such *as plain old telephony service* (POTS), *voice over IP* (VoIP), *data,video, and/or telemetry*, in that all of these services are converted and encapsulated in a single packet type for transmission over the PON fiber. [21]

PON is a telecommunications technology that implements a point-to-multipoint architecture, in which unpowered fiber Optic Splitters are used to enable a single optical fiber to serve multiple end-points such as customers without having to provision individual fibers between the hub and customer. [4] Passive Optical Network (PON) has no active components between Central Office and customer. Passive equipment has no electrical power needs, it guides the traffic signals contained within specific optical wavelengths. Voice, video and data traffic flows (triple play) can be easily implemented using different wavelengths. [22] It consists of three main parts:

The Optical Line Terminal (OLT) resides in the CO, connecting the optical access network to the metro backbone. and the Optical Distribution Network (ODN) between OLT and ONU while the optical network units (ONUs) are located close to the end users and provide customer service interfaces to the end users, converting optical signals to electrical ones.

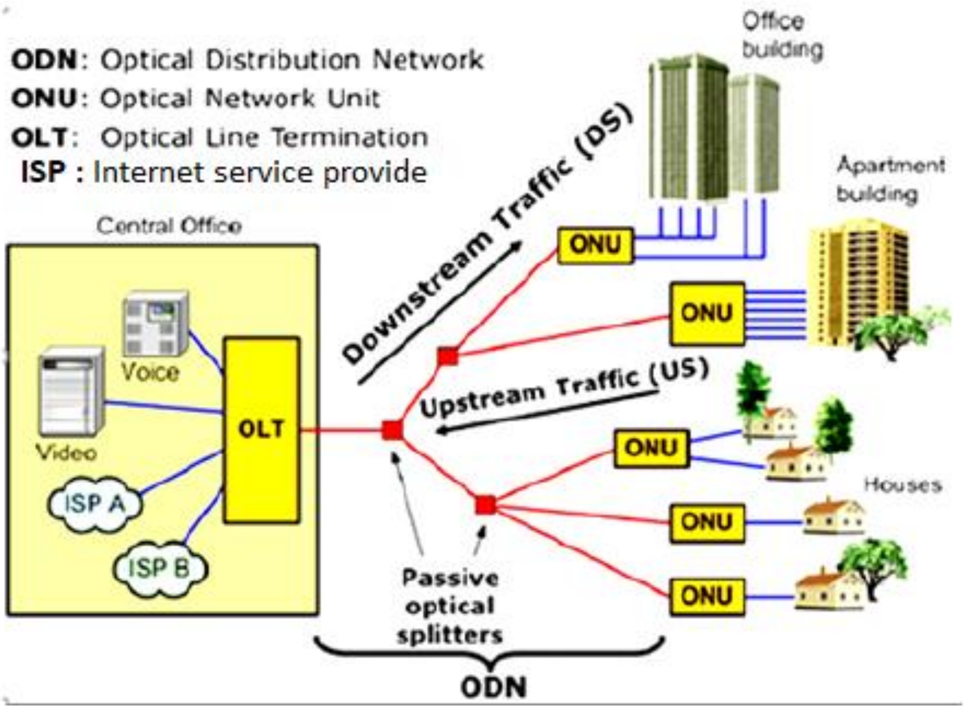

***Figure 2.7**: Passive Optical Network architecture [22]*

2.5.1 The optical line terminal (OLT)

The OLT is located in a central office and controls the bidirectional flow of information across the ODN. An OLT must be able to support transmission distances across the ODN of up to 20 km (currently could be more with EDFA). In the downstream direction, the function of an OLT is to take in voice, data, and video traffic from a long-haul network and broadcast it to all the ONT modules on the ODN. In the reverse direction (upstream), OLT accepts and distributes all the traffic from the network users. Simultaneous transmission of separate service types on the same fiber in the ODN is enabled by using different wavelengths for each direction. For downstream transmissions, a PON uses a 1490 nm wavelength for combined voice and data traffic and a 1550 nm wavelength for video distribution. Upstream voice and data traffic use a 1310 nm wavelength using TDM, WDM or both. [18]

Figure 2.8*: The optical line terminal (OLT): (a) 8 PON Port (b) 128 PON Port*

2.5.2 Optical Distribution Network (ODN)

The Optical Distribution Network is an integral part of the PON system, provides the optical transmission medium for the physical connection of the ONUs to the OLTs. It reachs 20 km or farther. The ODN specifically has five segments which are: *feeder fiber*, *optical distribution point*, *distribution fiber*, *optical access point, and drop fiber*. The *feeder fiber* starts from the optical distribution frame (ODF) in the central office (CO) telecommunications room and ends at the *optical distribution point* for long-distance coverage. The *distribution fiber* from the optical distribution point to the *optical access point* distributes optical fibers for areas along side it. The *drop fiber* connects the optical access point to terminals (ONTs). The ODN is the most essential path to PON data transmission and its quality directly affects the performance, reliability, and scalability of the PON system. [16]

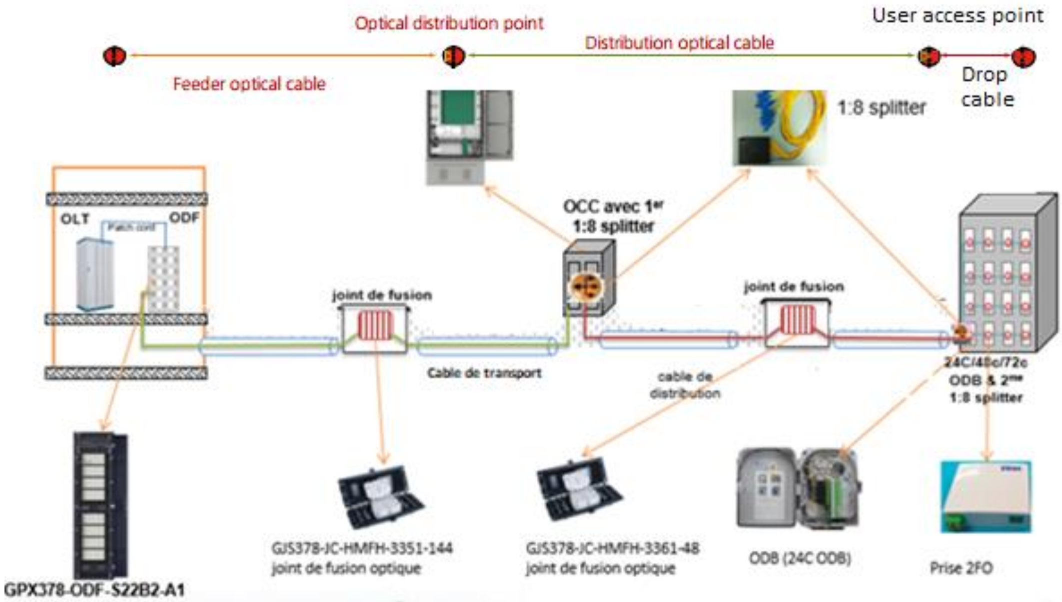

Figure 2.9 *: Optical Distribution Network (ODN)*

2.5.2.1 Optical Distribution Frame (ODF)

- ODF is a passive component, and a very important component for organizing the fiber optic cable connections.
- ODF is usually used indoor and could have a very big size frame or smaller similar to patch panel boxes depending on the network design requirements.

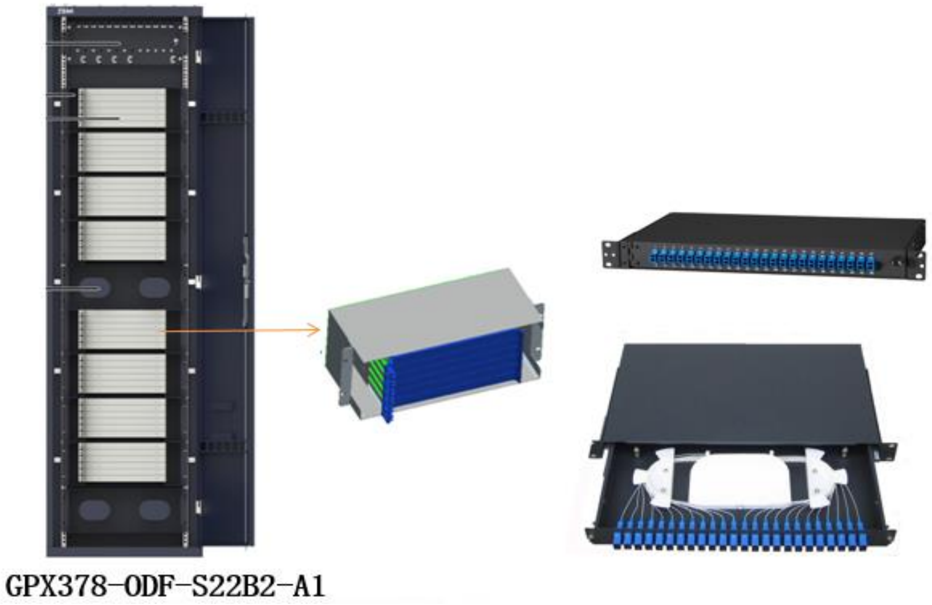

Figure 2.10: *Optical distribution frame (ODF)*

2.5.2.2 Optical Splitter

Splitter is the main element in PON since it is passive power divider that gives Passive Optical Network its name. It is known as splitter but it is bidirectional device that divide the power downstream optical signal from OLT to all splitter outputs connected to ONTs, it also combines the incoming upstream signals from ONTs to one fiber connecting to OLT. The losses due to power division limits the number of outputs ***N*** connecting to ONTs or split ratio [20]

$$Attenuation\ Splitter = 10\ log\ \frac{1}{N} \qquad (2.1)$$

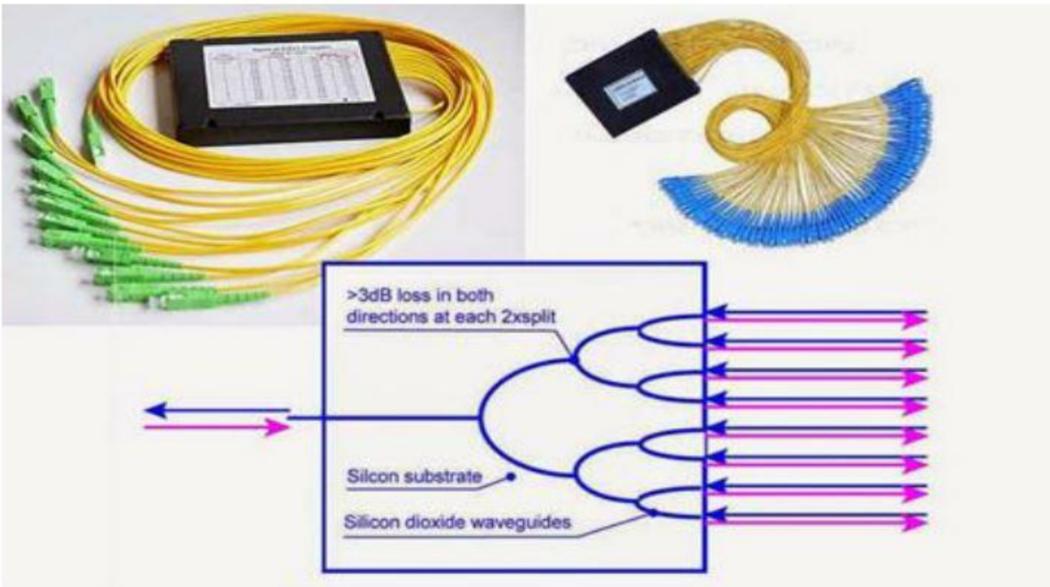

Figure 2.11*: Schematic drawing for PLC Splitter [20]*

The ONT or ONU terminates the PON and presents the native service interfaces to the user. These services can include voice (plain old telephone service "POTS" or voice over IP "VoIP"), data (typically Ethernet or V.35) and video.

2.5.3 Optical Network Unit (ONU)

Figure 2.12*: Optical Network Unit [16]*

The ONU converts optical signals transmitted via fiber to electrical signals. These electrical signals are then sent to individual subscribers. In general, there is a distance or other access network between ONU and end user's premises. Furthermore, ONU can send, aggregate and groom different types of data coming from customer and send it upstream to the OLT. ONU could be connected by various methods and cable types, like *twisted-pair copper wire, coaxial cable*, *optical fiber or Wi-Fi.* [23]

2.5.4 Optical Network Terminal (ONT)

Actually, ONT is the same as ONU in essence. ONT is an ITU-T term, whereas ONU is an IEEE term. They both refer to the user side equipment in GEPON system. But in practice, there is a little difference between ONT and ONU according to their location. ONT is generally on customer premises. [23]

Figure 2.13: *Optical Network Terminal (ONT) [16]*

2.6 Description of Passive Optical Network's operation

Once detailed all the elements that build a PON, it is necessary to know how the global system works and the behavior of the network with all the interconnected elements, from the head OLT towards ONT users, and vice versa.

The most important thing to note in the generic operation of the network is the existence of two channels, one ascending and one descending. However, both generally work through the same physical cable, so different wavelengths are assigned to each transmission channel and depending on traffic, coexisting in the same fiber at least 3 different wavelengths: one for video flow in the upstream channel and two for data flow of uplink and downlink respectively. [18]

Below both transmission channels will be analyzed in more details:

2.6.1 Downstream channel

The downstream channel is the direction of information from the OLT operator to the ONU located on the end user. In this network, the PON behaves like a point multipoint network. The OLT includes plenty of added voice and data frames that go towards PON, through the Packet Optical Line Terminal (POLT) and the Video Optical Line Terminal (VOLT). Frames collected by these teams are transformed to signals which inject in the different branches of the users. These branches are formed by one or two fibers that carry signals bi or unidirectional, passively coupled by optical splitters that allow the union of all the ONT in the network and without intermediate regeneration of signals (avoiding active elements). [5]

2.6.2 Upstream channel

The upstream channel is the direction of information from the ONU end user to the OLT operator. In this network, the PON behaves like a point to point. Each ONU includes the added frames of voice and data (from each user) that are directed toward the OLT. At this point, the ONU performs the same operation as the OLT in the downstream channel, turn the frames into injecting signals through on optical fiber that have been dedicated to the user. [5]

The splitters of each stage are in charge of collecting information from all corresponding ONTs and multiplex it in a single output fiber towards the operator OLT.

In order to transmit information from different ONT on the same channel, is necessary (as in the downstream channel) the use of TDMA, so that each ONT sends the information in different time intervals controlled by the OLT unit. [17]

2.7 PON technologies

There are three main types of PONs depending on the data multiplexing scheme. The currently deployed PON technology is time division multiplexing (TDM) PON, where traffic to multiple ONUs are TDM multiplexed into the upstream/downstream wavelength. The main TDM PONs are: BPON, EPON and GPON.

Wavelength division multiplexing (WDM) PON and Orthogonal Frequency Division Multiplexing (OFDM) PON constitute another two types of PON technologies. WDM PON uses multiple wavelengths to provise bandwidth to ONUs, while OFDM PON employs a number of orthogonal subcarriers to transmit traffic to ONUs. With the WDM or OFDM technology, these PONs are potentially able to provide higher than 40 Gbps data rate and even Tera bps data rate.

Figure 2.14 shows the evolution of PONs systems. TDM is the multiplexing scheme for all PONs which have been standardized until now. Numerous research articles in tackling challenges in WDM PON have been published since WDM PON was first proposed in 1986. However, it has not been included in the standard yet mainly.

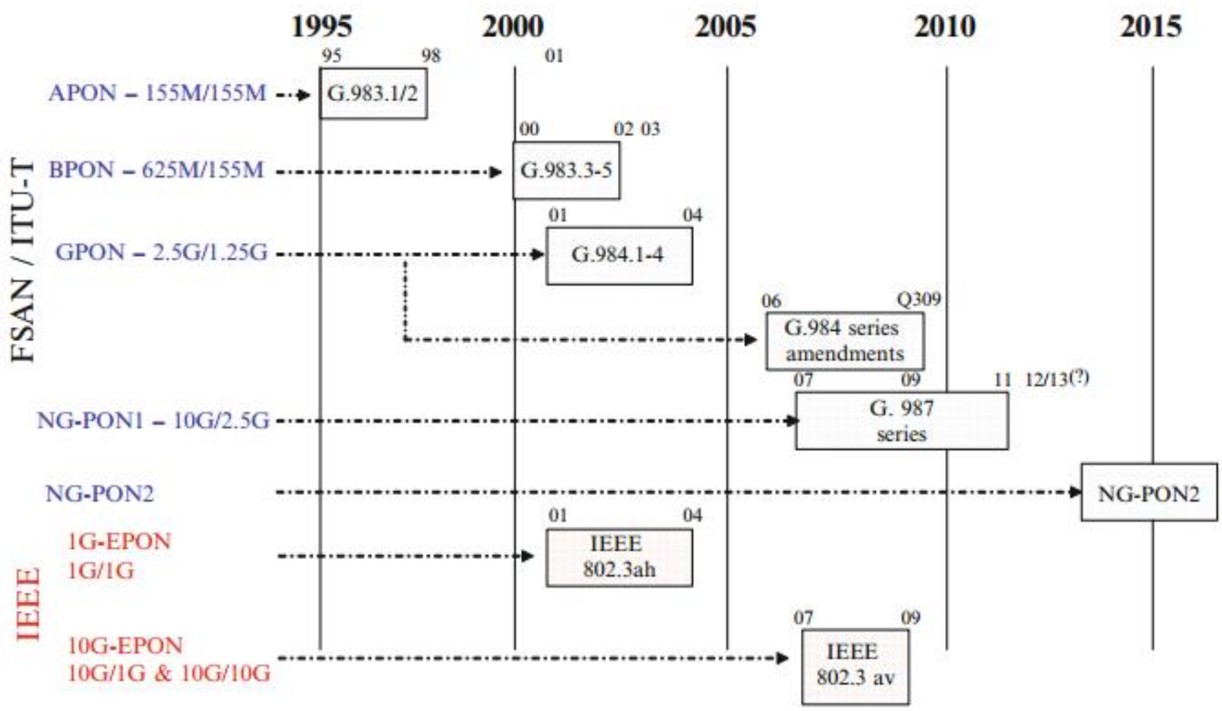

Figure 2.14: *Evolution of PON [21]*

Due to the high system cost, OFDM PON has received intensive research attention in recent years owing to its high bandwidth provisioning. Both WDM PON and OFDM PON are considered as future PON technologies. [21]

2.7.1 Time division multiplexing (TDM) PON

The currently deployed PON systems are TDM PON systems, which include ATM-PON (APON), Broadband PON (BPON), Ethernet PON (EPON), Gigabit PON (GPON), 10G EPON, and Next-generation PON (NG-PON) to provide different data rates. APON/BPON, GPON, and NG-PON architectures were standardized by the Full Service Access Network (FSAN), which is an affiliation of network operators and telecom vendors.

Since most telecommunications operators have heavily invested in providing legacy TDM services, these PON architectures are optimized for TDM traffic and rely on framing structures with very strict timing and synchronization requirements. [21]

TDM PON is the application of time-division multiplexing in Passive Optical Networks (PON). The two key network functions of an OLT are to control user traffic and to assign bandwidth dynamically to the ONT modules. Since up to 32 ONTs use the same wavelength and share a common optical fiber transmission line, some type of transmission synchronization must be used to avoid collisions between traffic coming from different ONTs.

The simplest method is to use Time-Division Multiple Access (TDMA), where in each user transmits information within a specifically assigned time slot at a prearranged data rate. The multiplexed downstream signal is broadcast to all the ONTs. Each ONT discards or accepts the incoming information packets, depending on the packet header addressing. Sending traffic in the upstream direction is more complicated since all users have to time share the same wavelength. To avoid collisions between the transmissions of different users, the system uses a TDMA protocol.

The OLT controls and coordinates the traffic from each ONT by sending permissions to them to transmit during a specific time slot. The time slots are synchronized so that transmission bursts from different users do not collide. Since each end terminal is located at different distances from the central office, the OLT uses a ranging technique to measure the logical distance between the users and the OLT. This enables each ONT to adjust its transmission timing properly to avoid traffic collisions. [24]

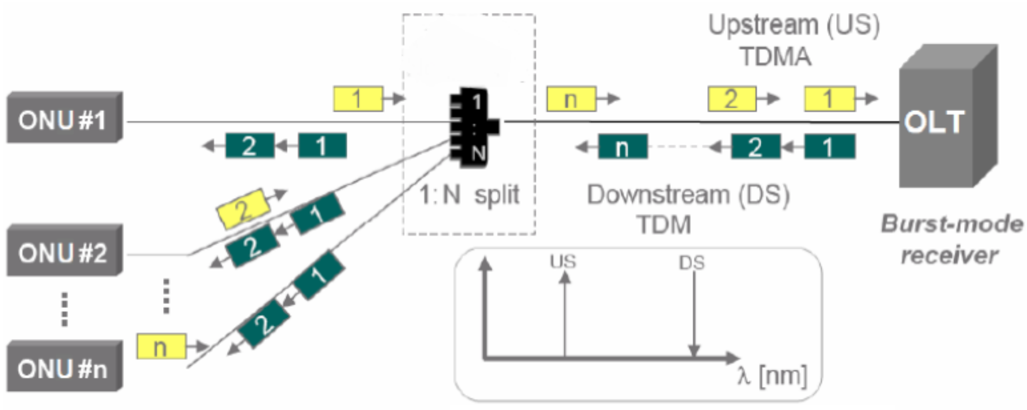

Figure 2.15: *PON architecture based on time division multiplexing (TDM) [25]*

a) ATM PON (APON)

The first generation of the PON series was standardized by the ITU-T full-service access network (FSAN) group in the mid-1990s. This was to explore the end-to-end ATM connection based on a point-to-multipoint tree configuration. Using ATM protocol at first was accepted, as ATM Protocol is the main protocol for telephone networks and also used for data transfer. APON networks support 32 subscribers with a single upstream data rate of 155 Mbps and downstream data rate of 622 or 155 Mbps (Asymmetric). As defined in the IEEE 802.3 family, the maximum data rate in APON was 622 Mbps to 1.244 Gbps. [26]

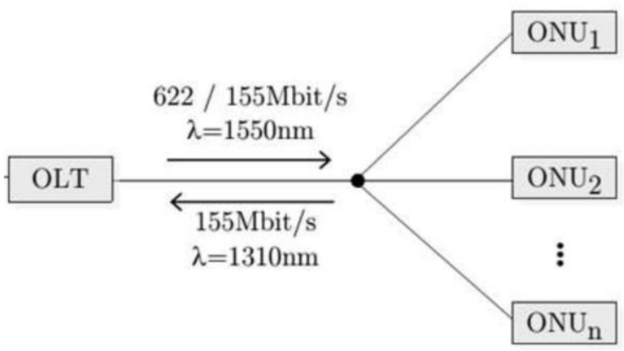

Figure 2.16: *Typical APON network according to ITU-T G.983 [20]*

Figure 2.16 describes the structure of a typical APON network according to ITU-T G.983 standard, where the downstream wavelength is at 1550nm and upstream wavelength at 1310nm.

b) Broadband PON (BPON)

Broadband PON (BPON) as defined in ITU-T G.983 series, was a further improvement of the APON. The objective of BPON was to achieve cost-effective deployment of broadband optical access systems. BPON offers numerous broadband services including ATM, Ethernet access, and video distribution. BPON uses ATM as the same signaling and transport protocol. However, BPON also provides enhanced security. Another significant difference between APON and BPON is that BPON allowed video distribution while APON did not focus on video. BPON made more sophisticated use of WDM by adding additional wavelengths for video distribution. BPON digital signals operate at ATM rates of 155, 622 and 1244 Mbps (see figure 2.17). [27]

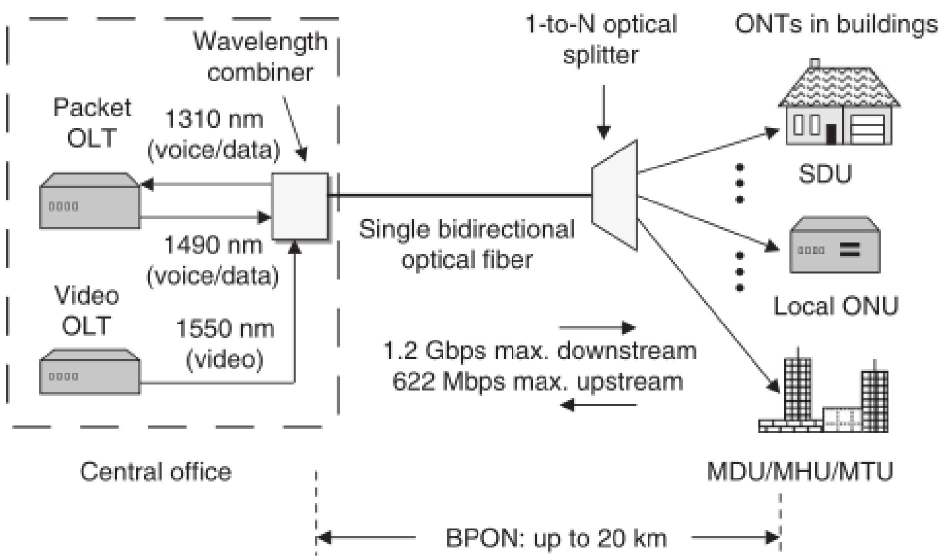

Figure 2.17*: Basic BPON architecture and operational concept [18]*

c) Ethernet PON (EPON)

Ethernet-based PON is known as Ethernet PON (EPON) but is sometimes also referred to as Gigabit EPON (GEPON). EPON is now a part of the IEEE 802.3 standard. It supports the speed of 1.25 Gbit/s in both the downstream and upstream directions. EPON is based on Ethernet, unlike other passive optical network technologies which are based on ATM. It provides simple, easy to manage connectivity to Ethernet-based IP equipment both at the customer premises and at the central office (CO). EPON is well suited to carry packetized traffic as well as time-sensitive voice and video traffic. [26]

d) Gigabit PON (GPON)

GPON is defined in International Telecommunication Union Telecommunication Standardization Sector (ITU-T) G.984 recommendation. GPON is a point-to-multipoint architecture, where a single fiber connects to a passive optical splitter that distributes fibers to multiple subscribers, up to 64 subscribers per GPON interfaces. The optical splitter has variously different split configurations, such as 1:2, 1:4, 1:32, etc. Downstream data transmitted on a wavelength of 1490 nm. Upstream data transmits on a wavelength of 1310 nm. GPON providing asymmetrical data rates at 2.488 Gbps downstream and 1.244 Gbps upstream. A GPON system consists of mainly active equipment; the first one is optical line terminal (OLT) and second is optical network terminals (ONTs). OLT, that connects several ONT by using a passive optical splitter as shown in figure 2.18. [28]

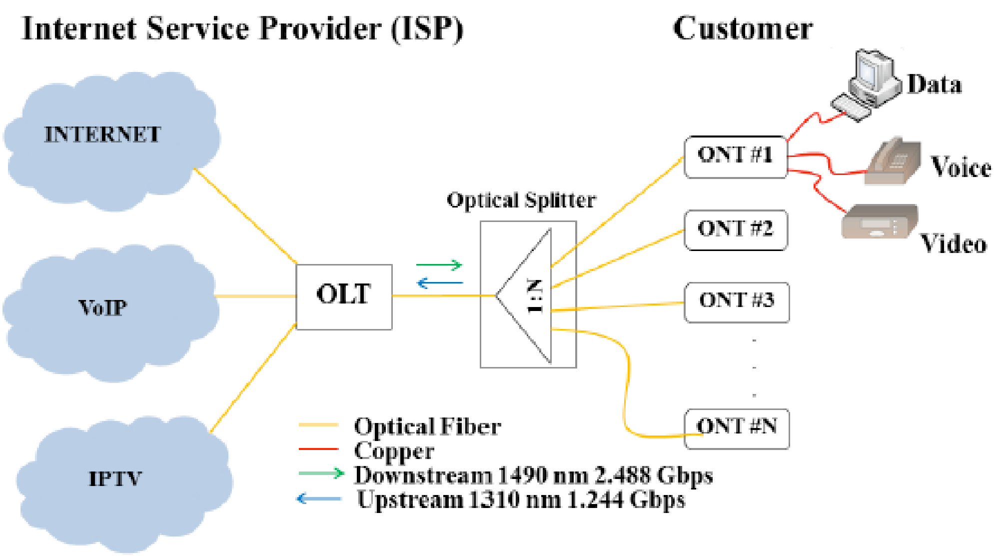

***Figure 2.18** : GPON architecture [28]*

To separate upstream/downstream signals of multiple users over a single fiber, GPON adopts two multiplexing mechanism [19]:

- ✓ Downstream traffic is broadcasted by the OLT to all ONUs. Each of these processes the traffic which is assigned to it through an address contained in the header of the Protocol Data Unit (PDU).
- ✓ Upstream traffic uses Time Division Multiple Access (TDMA) mechanism under control of the OLT located at the CO which assigns time slots to each ONU for synchronized transmission of its data bursts.

The bandwidth assigned to each user may be static or dynamically variable, for support of voice, data and video applications. Figure 2.19 and figure 2.20 illustrate broadcast and TDMA modes.

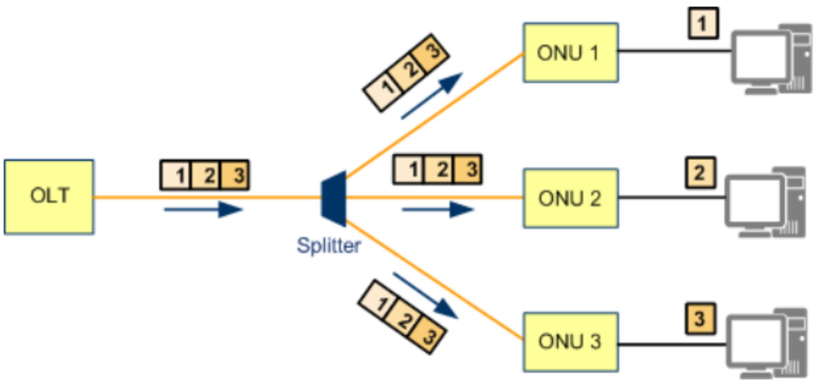

***Figure 2.19**: GPON Broadcasting to Downstream [29]*

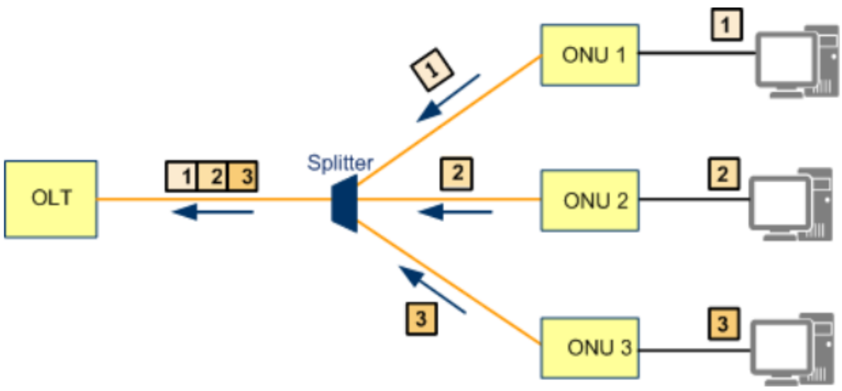

***Figure 2.20**: GPON TDMA to Upstream [29]*

d.1) GPON Transmission

Media access control (MAC) layer control protocol is needed to coordinate the traffic transmission such as the collision between traffic from different ONUs can be avoided GPON Encapsulation Method (GEM) is a method which encapsulates data over GPON.

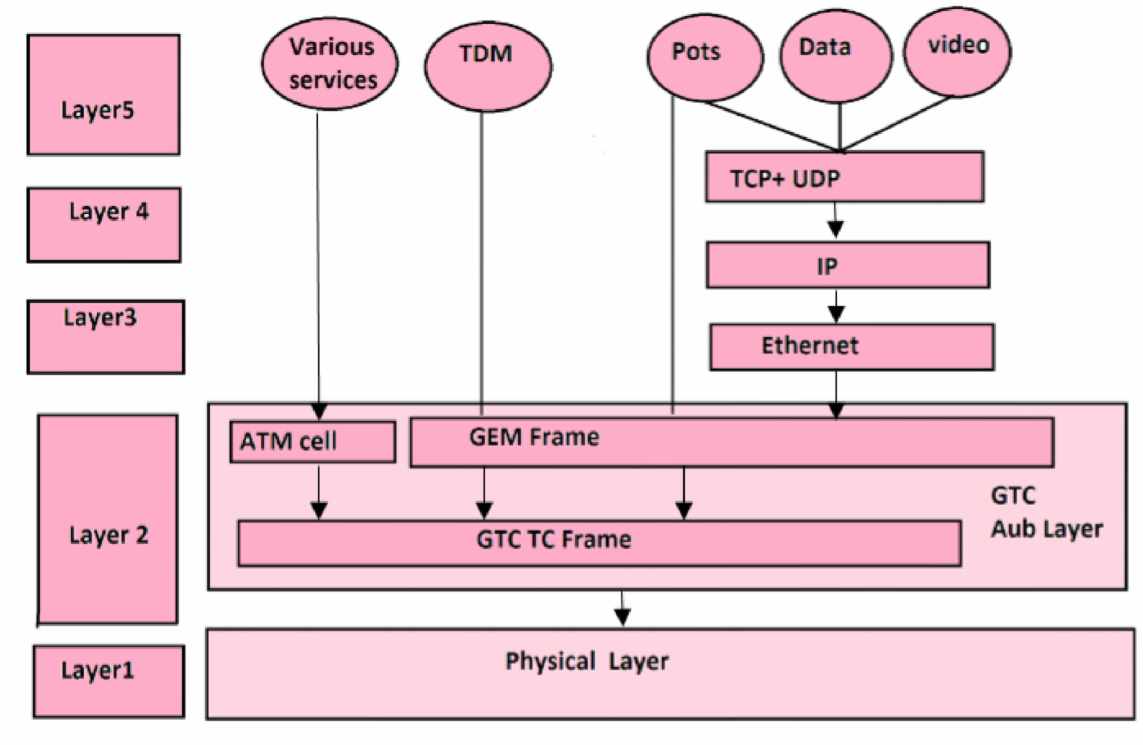

Figure 2.21: *GPON layer structure [30]*

Figure 2.20, shows the frame structure of GPON. It supports a frame of 125 µs long that uses TDM to divide the available bandwidth among the users, whilst the upstream MAC layer is based on TDMA. GPON supports two layers of encapsulation where the Ethernet frame is encapsulated into a GEM frame which is encapsulated again into a GPON Transmission Convergence (GTC) frame. The GTC frame also includes pure ATM cells and TDM traffic (see figure 2.21). [30]

d.2) Security in GPON

Downstream data are broadcasted to all ONUs in which each one of them receives data in a specific time. Because of that, some malicious user can reprogram its own ONU and capture all downstream data belonging to all ONUs connected to that OLT. In the upstream direction, GPON uses point-to-point connection so that all traffic is secured from eavesdropping. Therefore, each of confidential upstream information (such as security key) can be sent in clear text. The GPON recommendation G.984.3 describes the use of information security mechanism to ensure that users are allowed to access only the data intended for them. The encryption algorithm to be used is the Advanced Encryption Standard (AES). It accepts 128, 192, and 256-byte key which makes encryption extremely difficult to compromise. A key can be changed periodically without disturbing the information flow to enhance security. [31]

ITU-T FSAN has identified 2 major migration steps to replace G-PON [25]:

- A first step: called **"NG-PON1"** requiring compatibility with an existing Class B infrastructure.

The NG-PON1 is characterized by its ability to reuse the deployed infrastructure for the GPON. It can also be superimposed on a G-PON system running on the same infrastructure, thus allowing the gradual migration of clients to NG-PON1 without disrupting the clients remaining on the G-PON. There are two variants of NG-PON1: XG-PON1 and XGPON2. These new PON standards will constitute the G.987.x series of recommendations.

- A second step: called **"NG-PON2"** in allows major rework of its infrastructure.

Always with the aim of increasing the bandwidth offered to the end user, the NGPON2 takes into account long-term solutions and should succeed NG-PON1 but this time without constraint of mandatory coexistence with the previously deployed architecture. Thus, it redefines network architectures that will or will not use the existing infrastructures. Thus, the NG-PON2 focuses on low-cost and scalable technologies, such as very high bit rate (40 Gbit / s) TDM PONs, WDM PONs, hybrid PON WDM-TDM solutions, and multiplexing solutions. Orthogonal Frequency Division Multiplexing (OFDM), etc. The NG-PON2 must be capable of offering much more capacity per client than current G-PON systems and NG-PON1 systems.

Table 1 lists PON technologies with comparison of data backet size. Maximum and minimum upstream and downstream data rates split ratio and distance.

***Table 1**: PON Technologies [20]*

	A/BPON	EPON (GEPON)	GPON	10 GPON	WDM PON
Standard	ITUG.983	IEEE802ah	ITUG984	IEEEP802.3av	ITU G983
Data Packet Cell Size	53 bytes	1518 bytes	53 to 1518 bytes	1518 bytes	Independent
Maximum Downstream Line Rate	622 Mbps	1.2 Gbps	2.4 Gbps	IP; 2.4 Gbps, Broadcast; 5 Gbps On demand	1-10 Gbit/s per channel
Maximum Uptream Line Rate	155/622 Mbps	1.2 Gbps	1.2 Gbps	2.5Gbps	1-10 Gbit/s per channel
Dwonstearm wavelength	1490 and 1550 nm	1550 nm	1490 and 1550 nm	1550 nm	Individual wavelength/channel
Upstream wavelength	1310nm	1310nm	1310nm	1310nm	Individual wavelength/channel
Traffic Modes	ATM	Ethernet	ATM Ethernet or TDM	Ethernet	Protocol Independant
Voice	ATM	VoIP	TDM	VoIP	Independant
Video	1550nm overlay	1550 nm overlay/IP	1550 nm overlay/IP	IP	1550 nm overlay/IP
Max PON spllits	32	32	64	128	16/100's
Max Distence	20 km	20 km	60 km	10 km	20 km
Avareg Bandwidth per User	20 Mbits/s	60 Mbits/s	40 Mbits/s	20 Mbits/s	Up to 10 Gbits/s

2.7.2 Wavelength division multiplexing (WDM) PON

WDM is an abbreviation for "Wavelength-Division Multiplexing" and now it is one of the most widely used technology for high-capacity optical communication systems. Figure (2.22) schematically shows a typical WDM transmission system. At the transmitter side, multiple optical transmitters each emitting at a different wavelength individually send signals and these signals are multiplexed by a wavelength multiplexer (MUX). The multiplexed signals are then transmitted over one main transmission line (optical fiber cable). At the receiver side, the signals are de-multiplexed by a wavelength de-multiplexer (DEMUX) and sent to multiple receivers.

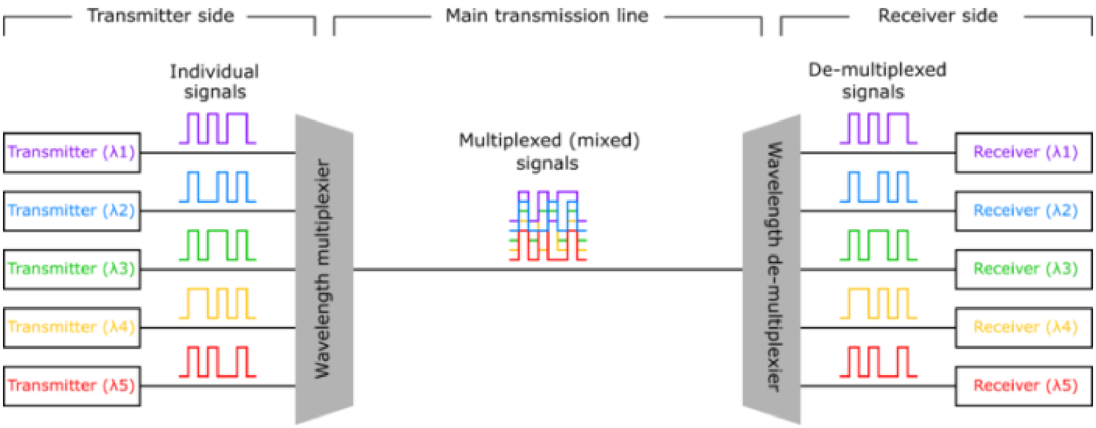

***Figure 2.22**: Schematic of WDM transmission system [32]*

WDM-PON is the passive optical network (PON) based on wavelength division multiplexing (WDM) technology, which delivers higher network security. This system allows ONUs to have light sources at different tuned wavelengths coexisting in the same fiber, increasing the total network bandwidth and the number of users served in the optical access network. Wavelength Division Multiplexing PON, or WDM-PON, is a type of passive optical networking, being pioneered by several companies. This technology looks forward to a day when optical technology is cheaper and easier to deploy and end users demands higher bandwidth. WDM-PON can provide more bandwidth over longer distances by devoting optical bandwidth to each user. By increasing the link loss budget of each wavelength, making it less sensitive to the optical losses incurred at each optical splitter. [33]

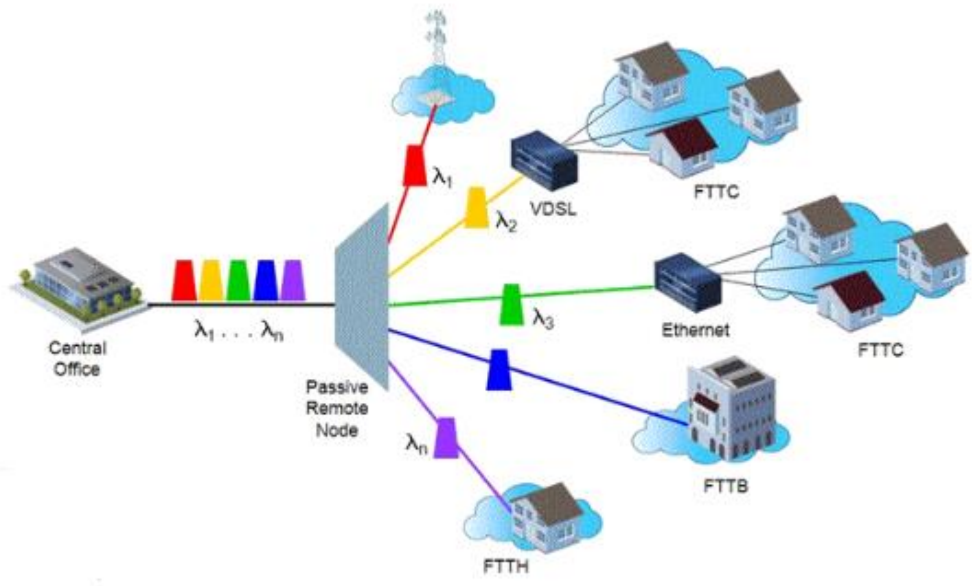

Figure 2.23*: PON based on wavelength division multiplexing (WDM) [33]*

❖ **Why Apply WDM-PON in FTTx Networks?**

We have known that WDM-PON supplies each subscriber with a wavelength instead of sharing wavelength among 32 or even more subscribers in TDM PON, thus providing higher bandwidth provisioning. WDM-PON is regarded as a candidate solution for next-generation PON systems in competition with TDM PON for possessing the following advantages. [33]:

- ✓ WDM-PON allows each user being dedicated with one or more wavelengths, thus allowing each subscriber to access the full bandwidth accommodated by the wavelengths.
- ✓ WDM-PON networks typically provide better security and scalability because each home only receives its own wavelength.
- ✓ The MAC layer control in WDM-PON is more simplified as compared to TDM PON because WDM-PON provides P2P connections between the OLT and the ONU and does not require the point-to-multipoint (P2MP) media access controllers found in other PON networks.
- ✓ Wavelength in a WDM-PON network is effectively a P2P link, thus allowing each link to run at a different speed and with a different protocol for maximum flexibility.

There are two variants of WDM: CWDM (Coarse Wave Division Multiplexing) and DWDM (Dense Wave Division Multiplexing). The only difference between them is the band in which they operate, and the spacing of the wavelengths and thus the number of wavelength or channels that can be used.

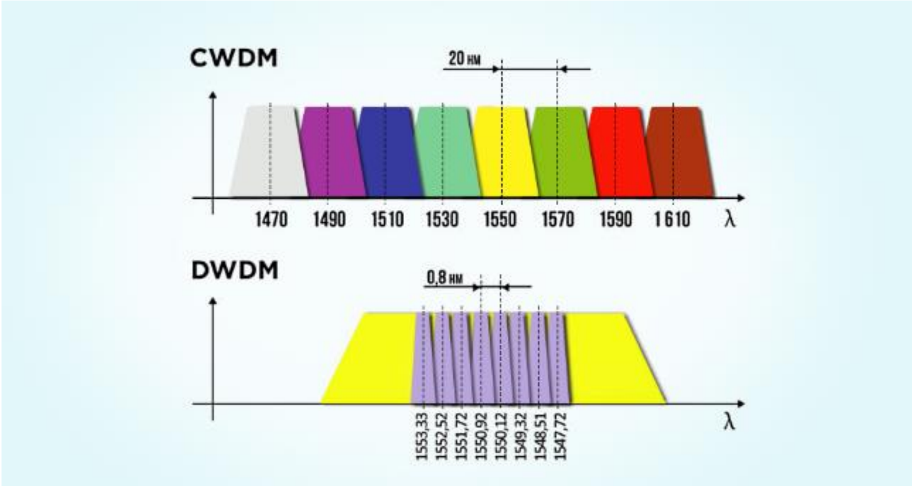

Figure 2.24: *Wavelengths bands CWDM and DWDM [34]*

2.7.2.1 Coarse Wavelength Division Multiplexing (CWDM)

Coarse WDM is a relatively new standard set by ITU in 2002 (G.694.2). CWDM is an economical technique to save fiber resources by transmitting multiple wavelengths on one optical fiber and it is a multiplexing technology for city and access network. Transmission is realized using of 18 wavelengths between 1270nm and 1610nm with a 20nm interval. It has attracted a lot of attention, particularly in the metro and access networks. There are still limited varieties for CWDM components at this stage, but there are certainly a lot of potential applications, especially in transmission systems up to the 50 km distance. [35]

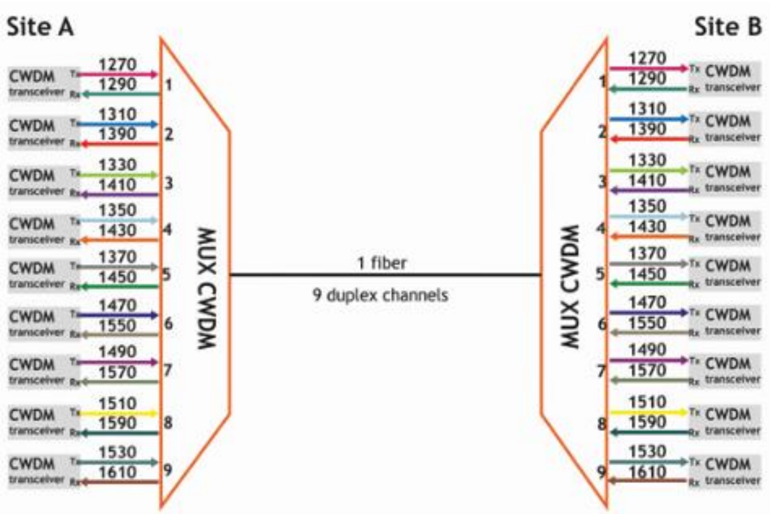

Figure 2.25: *Transmission CWDM mux/demux [33]*

2.7.2.2 DWDM (dense wave-division multiplexing)

In a DWDM, the channel spacing of the WDM channels is usually very condensed, DWDM can carry 40, 80 or up to 160 wavelengths with a narrower spacing of 0.8/0.4nm (100 GHz/50 GHz). Its wavelengths are from 1525nm to 1565nm (C band) and 1570nm to 1610nm (L band). As a result of the dense allocation of channels, a DWDM system requires high precision in different components, such as lasers, filters and multiplexers/demultiplexers. Many need temperature control in order to stabilize the wavelength, according to the ITU grid (G694.1). It has the advantage of high channel count within a single band (C, S or L) which, in turn, leads to higher channel efficiency. On the downside, it is more expensive and some crosstalk issues may arise. [35]

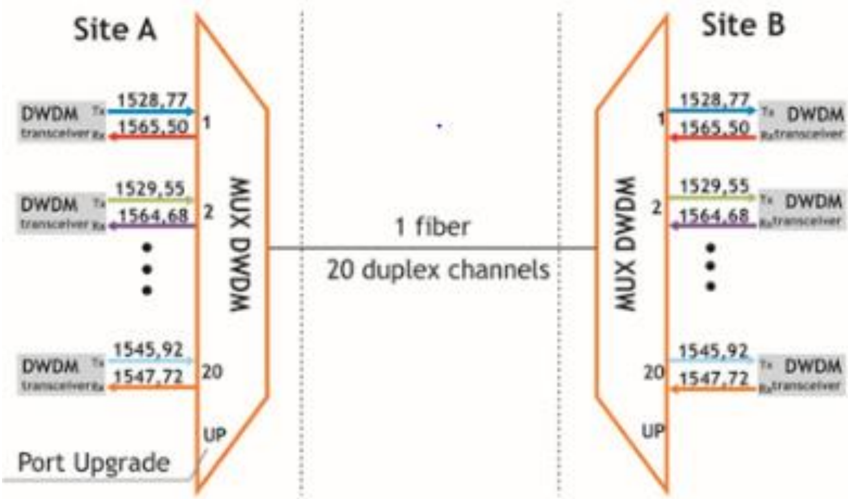

Figure 2.26: *Transmission DWDM mux/demux [33]*

2.8 The security of PON

In PON technology it is difficult for an attacker to try to capture data that is not intended for him. The PON network has implemented mechanisms so that the subscriber can read only the data that is addressed to him. The security mechanism employed is the following. [36]

- Downstream traffic is encrypted. It uses the standardized 128-bit AES algorithm: each client device has its own private encryption/decryption key, new keys are automatically exchanged by the OLT and the OUN at regular time intervals.
- The upstream traffic is transmitted using an optical color of 1310 nm. The client modems have no way to detect this optical signal and therefore to read the traffic coming from other clients.

- Interception of the data causes the temporary interruption of all optical flows, which would be immediately detected by the OLT and generate a major alert.

2.9 Advantages and Disadvantages of PON

a) Advantages of PON

There are a lot of benefits of using broadband PON local access networks such as [37]:

- A PON allows for longer distances between central offices and customer premises. While with the Digital Subscriber Line (DSL) the maximum distance between the central office and the customer is only approximately 5.5 km, a PON local loop can operate at distances of over 20 km
- PON minimizes fiber deployment in both the local exchange and local loop.
- PON provides higher bandwidth due to deeper fiber penetration. While the fiber-to-the-building (FTTB), fiber-to-the-home (FTTH), or even fiber-to-the-PC (FTTPC) solutions have the ultimate goal of fiber reaching all the way to customer premises, fiber-to-the-curb (FTTC) may be the most economical deployment today.
- As a point-to-multipoint network, PON allows for downstream video broadcasting. Multiple wavelength overlay channels can be added to PON without any modifications to the terminating electronics.
- PON allows easy upgrades to higher bit rates or additional wavelengths. Passive splitters and combiners provide complete path transparency.

b) Disadvantages of PON

Despite the many advantages that have the PON to own intrinsic configuration, there are some disadvantages connected with it [38-39]

- One of the first disadvantages is the distribution of information from the OLT to the different ONTs. The fact that a divisor distributes information from the OLT to all ONTs that are connected to the same stage or distribution tree, it causes a drop in network efficiency.
- They have less range than an active optical network, meaning subscribers must be geographically closer to the central source of the data.
- The bandwidth in a PON is not dedicated to individual subscribers meaning data transmission speed may slow down during peak usage times in an effect known as

latency. Latency quickly degrades services such as audio and video, which need a smooth rate to maintain quality.

- Moreover, the fact that all information flow through the same physical channel increases the likelihood of sniffing on the network, losing security, and forcing to establish a high level of encryption.
- Regarding security, PON architecture is sensitive to external sabotage. This problem is produced by the nature of the transmission medium itself.
- Another important aspect is the fact that a stage or distribution tree, depend exclusively on a single OLT. A fault in the OLT header produces a high effect on the network since all the ONT and splitters connected to it are affected. However, the installation of a few OLT provides a cost reduction of network deployment enough considerable

2.10 Conclusion

This chapter has given us an idea about optical networks; due to these networks the transmission of information has become faster, easier and more reliable. The chapter consists of an extensive collection of FTTx optical transmission systems and specifically the FTTH system by which the design and deployment of the proposed network in this project are based. Additionally, this chapter highlights the interest of Passive Optical Networks (PONs), the bit rates, the security and the confidentiality that such networks can offer, we have also seen that the PON technology is economical with respect to investment and maintenance as the minimization of infrastructure. In the next chapter, there will be a simulation of the passive optical network that is based on wavelength division multiplexing, in order to test its performance.

3 Chapter 3

Design of a WDM-GPON System

3.1 Introduction

This chapter is aimed to implement that all methods of designing and planning of an FTTx system that have been detailed in previous chapters, it may be applied to a fictitious environment but could be perfectly real.We are going to study a bidirectional WDM-GPON link using the "OPTISYSTEM." software; this software makes it possible to simulate such a link and to optimize the quality of transmission. At first, we will present this software, as well as the different components and elements used in our connection. Then we will present the results obtained, and this by varying the parameters of the link such as the bit rate, the type of modulation (NRZ, RZ), and the length fiber.

3.2 Presentation of the optisystem software

Optical communication systems are increasing in complexity very quickly. The design and analysis of these systems which typically include nonlinear devices are extremely complex and time-intensive, and therefore, these tasks can only be done efficiently with the help of new advanced software instruments.

Optisystem is a stand-alone product that does not rely on other simulation frameworks. It is a system level simulator based on the realistic modeling of fiber-optic communication systems. This tool has an interactive interface combining digital tools with graphical features and a user interface, it has a new powerful environment simulation and a hierarchical definition of components and systems.

3.2.1 OptiSystem interface

It contains the main window divided into several parts:

❖ **Main parts of the Graphical User Interface (GUI)**

The OptiSystem GUI contains the following main windows: [40]

•Project layout

•Dockers

- **Project layout**

The main working area where you insert components into the layout, edit components and create connections between components see (figure 3.1).

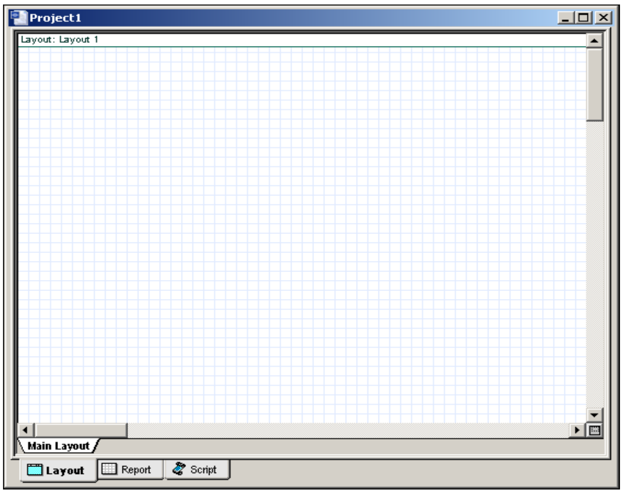

Figure 3.1: *Project layout window*

- **Dockers**

Use dockers, located in the main layout, to display information about the active (current) project:

- *Component Library*: Access components to create the system design.
- *Project Browser:* Organize the project to achieve results more efficiently, and navigate through the current project.

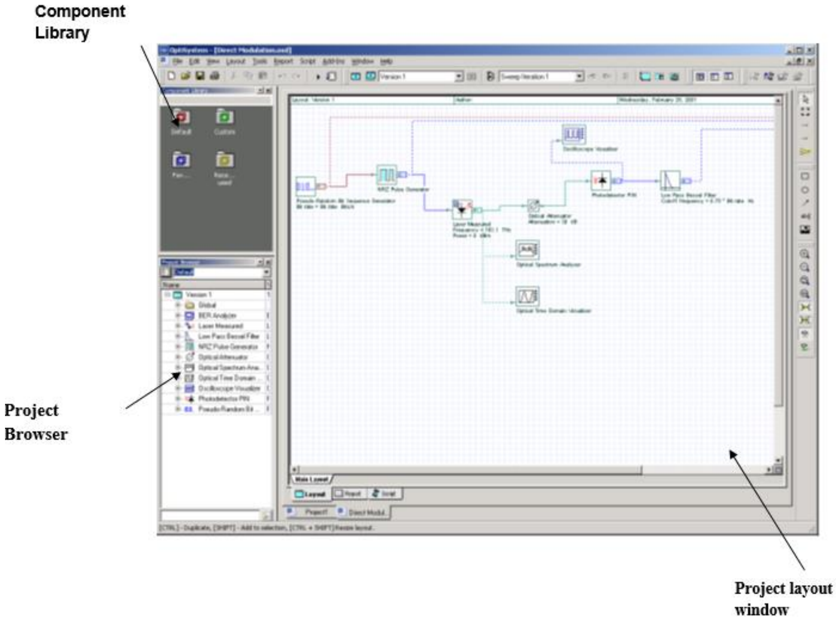

Figure 3.2: *OptiSystem graphical user interface (GUI) [40]*

3.2.2 Applications

OptiSystem's wide range of applications includes:

- Optical communication system design from component to system level at the physical layer;
- CATV or TDM/WDM network design;
- Passive Optical Networks (PON) based FTTx;
- Free Space Optic (FSO) systems;
- Radio Over Fiber (RoF) systems;
- SONET/SDH ring design;
- Transmitter, channel, amplifier, and receiver design;
- Dispersion map design;
- Estimation of BER and system penalties with different receiver models;
- Amplified system BER and link budget calculations;

3.3 Layers of an FTTx Network

An FTTx network can be considered to have different layers: the passive infrastructure comprising the ducts, fiber, enclosures and other outside plant. The active network comprising the electrical equipment and retail services which provide internet connectivity, managed services like IPTV and of course the end users. [41]

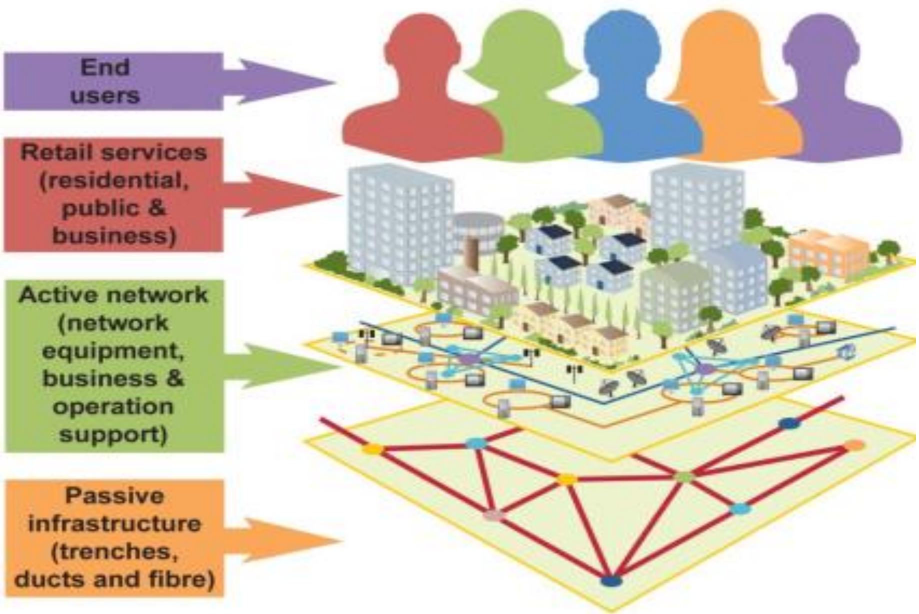

Figure 3.3: *FTTx Network layers [41]*

3.4 Access network design

It is essential to perform an optical infrastructure deployment in the best possible way in order to know the scenario of deployment. The area under deployment is an imaginary environment as an expansion of a city, but it could easily belong to a real environment. Here we can clearly see five distinct areas (figure 3.4) that will need a new generation network to meet their needs.

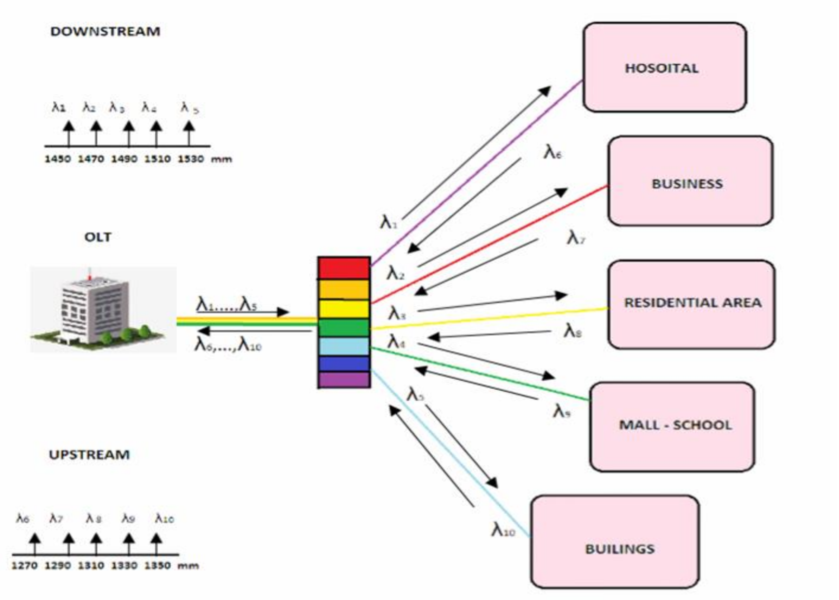

Figure 3.4: *The recomanded scenarios*

- ***Hospital area***: in this area a huge hospital can be existed that covers the whole region and have all the latest technological advances.

The area where it will place the hospital is located 3 km away from the *splitter* and therefore a total of 8 km from the central office. It will arrive at this area a link that would support GPON up to ***1,244 Gbps*** symmetric and will provide LAN and Wi-Fi access in all major points of the hospital. This will cover the required services such as the broadband Internet, HDTV, VoIP, telemedicine and diverse applications for real-time control.

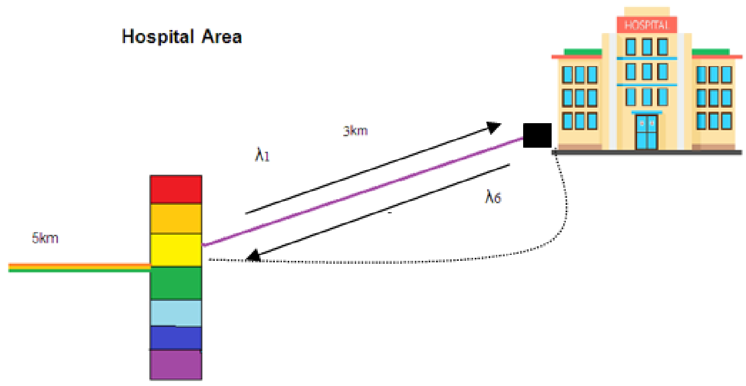

Figure 3.5: *Hospital area*

- ***Business offices area***: we will find 2 buildings with a total of 30 offices that gives service to several companies.

This is an extension of the business area, where it will build two office buildings, in which each one has 15 offices from the total of 30. Each of these offices will require services such as broadband internet, HD video conference, FTP and VoIP. So an FTTB design with a ***2.5 Gbps*** symmetrical GPON link would be sufficient to cover all user's needs.

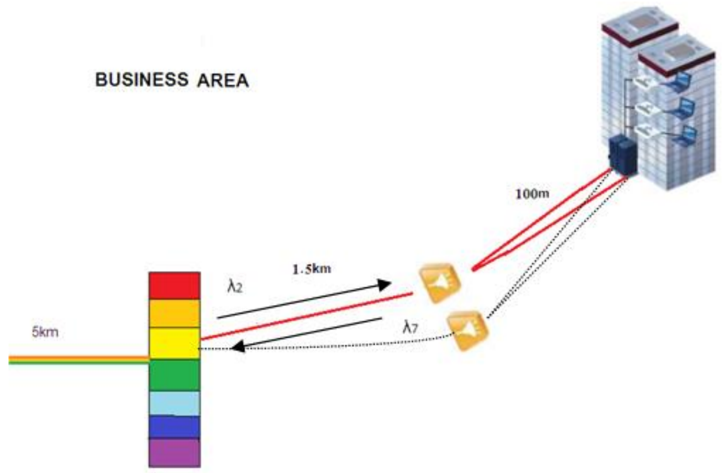

Figure 3.6: *Business area*

- ***Residential area***: it is a distribution of 20 single family homes that will require a full suite of triple play service.

The residential area will have 20 single-family houses that are located 1 km from the optical splitter and 6 km from the OLT.The residential area will demand last generation triple play services that may include: Broadcast (HDTV, 3D channel) ,real time applications (HD video conference, Online games, VoIP) and Broadband internet(Web, mail).

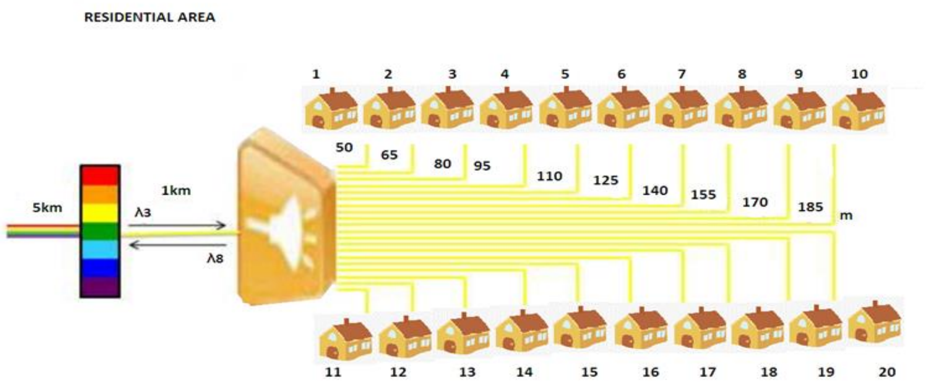

***Figure 3.7**: Residential area*

- ❖ ***Mall and school area***: next to the residential area it will be located a school and a shopping center that at least will enjoy the access to broadband internet and HDTV.

This area is also 1 km from the optical splitter and therefore 6 km from the central office. Speaking about services, it will be required broadband internet access from a local area network (LAN) in different classrooms of the school and broadband Internet with Wi-Fi service that will be given to the various shops and restaurants in the mall, apart from VoIP and HDTV, Will distribute the traffic to the two buildings, which will be equipped with LAN access at school, other LAN and Wi-Fi in the mall by splitter. This can be seen in the following scheme:

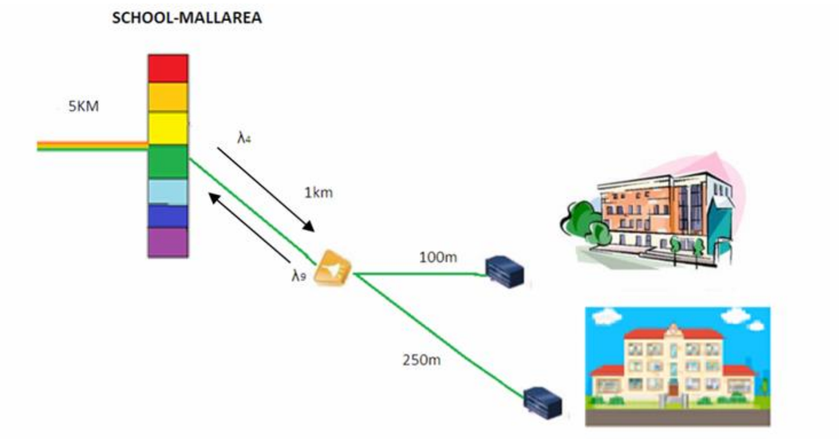

***Figure 3.8**: School-Mall area*

- ❖ ***Buildings area***: this last area represents the apartment buildings which are composed of two buildings and both of them have 22 apartments.

The following figure represents an extension of buildings area in which the first building has 5 floors that are devided into 10 appartments, the second has 6 floors and 12 apartments.

Talking about the services that building's users require, there will be the same as in the residential users such as next generation triple play service.

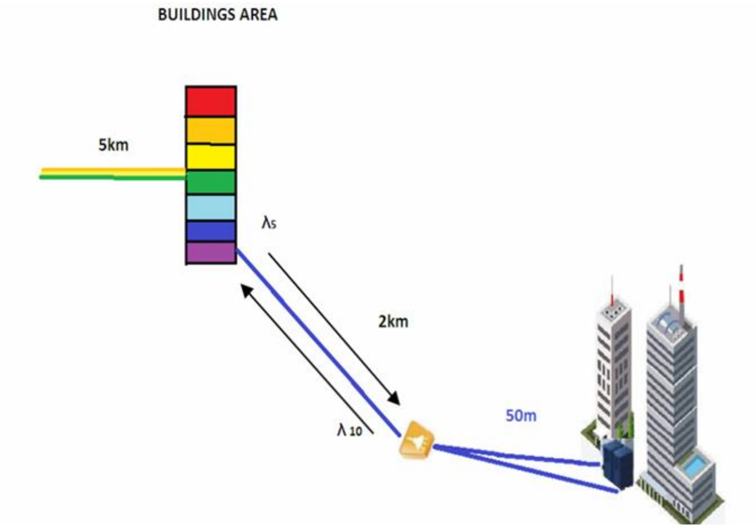

***Figure 3.9**: Buildings area*

3.5 Performance parameters in PON network

To evaluate such quality for PON-WDM systems, there are 2 main criteria: the bit error rate (BER), the quality factor (Q), interpreted as:

3.5.1 Error Rates

Error rates describe the number of bit errors in the number of received bits of the data in communication system due to noise, interference or distortion. In telecommunication transmission, the Bit Error Rate (BER) is the percentage of bits that have errors relative to the total a number of bits received in a transmission. For example, a BER of 10^{-6}, meaning that one bit was in error out of 1,000,000 bits transmitted.

$$BER = \frac{E}{N} \tag{3.1}$$

Where E is the Errors and N is the Total Number of Bits transmitted.

Too high BER may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data, so the BER indicates how often data has to be retransmitted because of an error. BER can be applied to characterize the performance of the communication system, for optical communication systems typically range from 10^{-9} to 10^{-12}depending on the service types. [21]

3.5.2 The Q factor

The Q factor or quality factor represents the loss in energy of the signal. Maximum Q factor has less loss of energy. The quality or performance of a digital communication system is specified by its BER or Q value. The BER is specified as the average probability of incorrect bit identification. In general, the higher the received Q-value, the lower the BER probability will be. Mathematically, equation (3.1) gives the Q-factor of an optical signal. [42]

$$Q = \frac{I_1 - I_0}{\delta_1 - \delta_2} \tag{3.2}$$

Where I_1 is the value of the 1-bit current, I_0 *is* the value of the 0-bit current, δ_1 is the standard deviation of the 1-bit current, and δ_0 is the standard deviation of the 0-bit current. The relationship of Q-factor to BER is defined as:

$$BRE = \frac{1}{2}\, erfc\,(\frac{Q}{\sqrt{2}}) \tag{3.3}$$

3.6 Design of the WDM-GPON and Results

The following figure (3.10) shows the complete design of our WDM-GPON. As explained in the previous sections, the simulation has also been divided into five areas.The design starts from the OLT which transmits information to the users of those five areas, this last will be transmitted with different wavelengths via a single optical fiber that is received by the ONTs. Then it will be demultiplexed and spreaded on the areas in downstream and multiplexed in upstream.

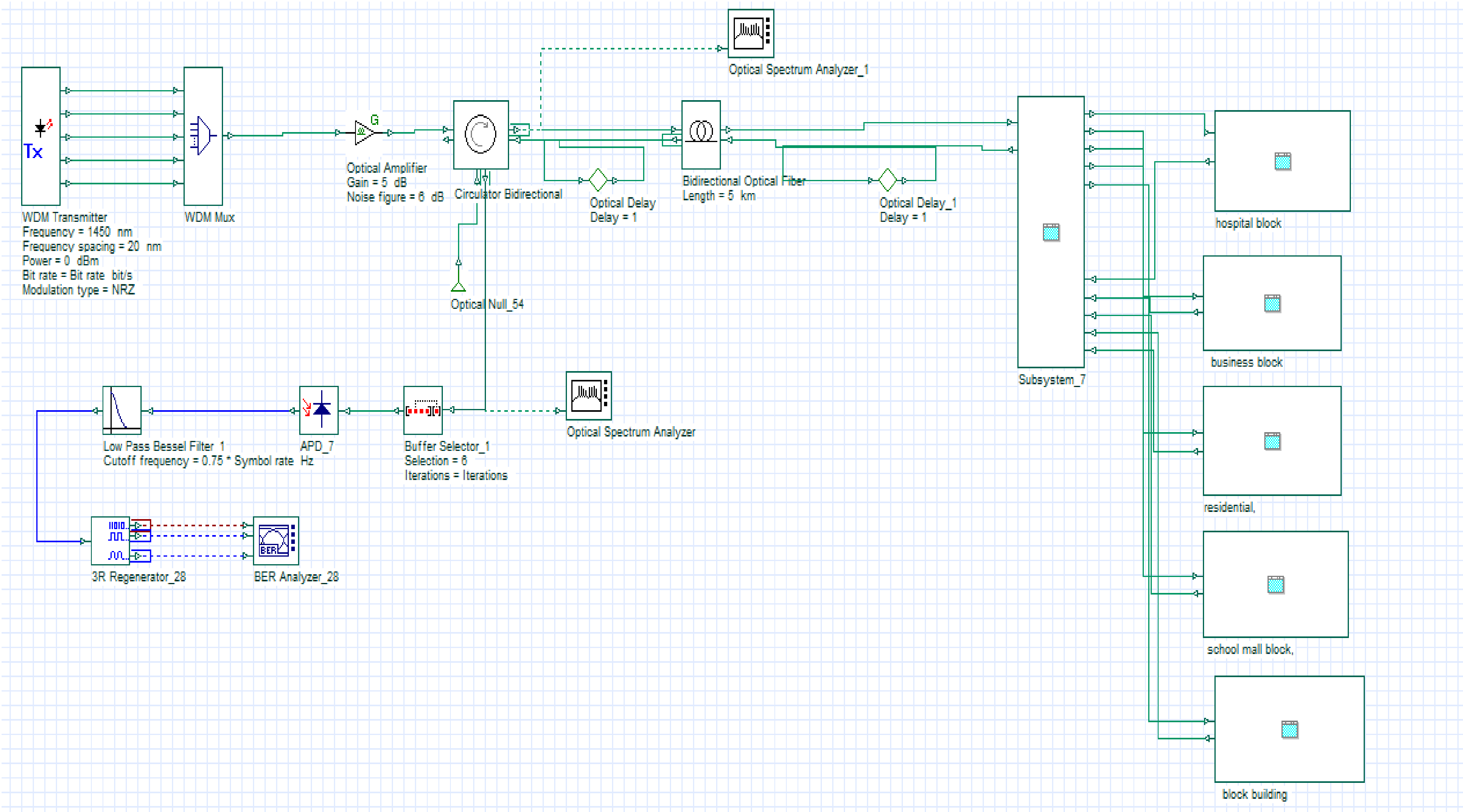

***Figure 3.10**: WDM GPON – Complete design*

The most important global parameters of the network can be seen in the figure 3.11:

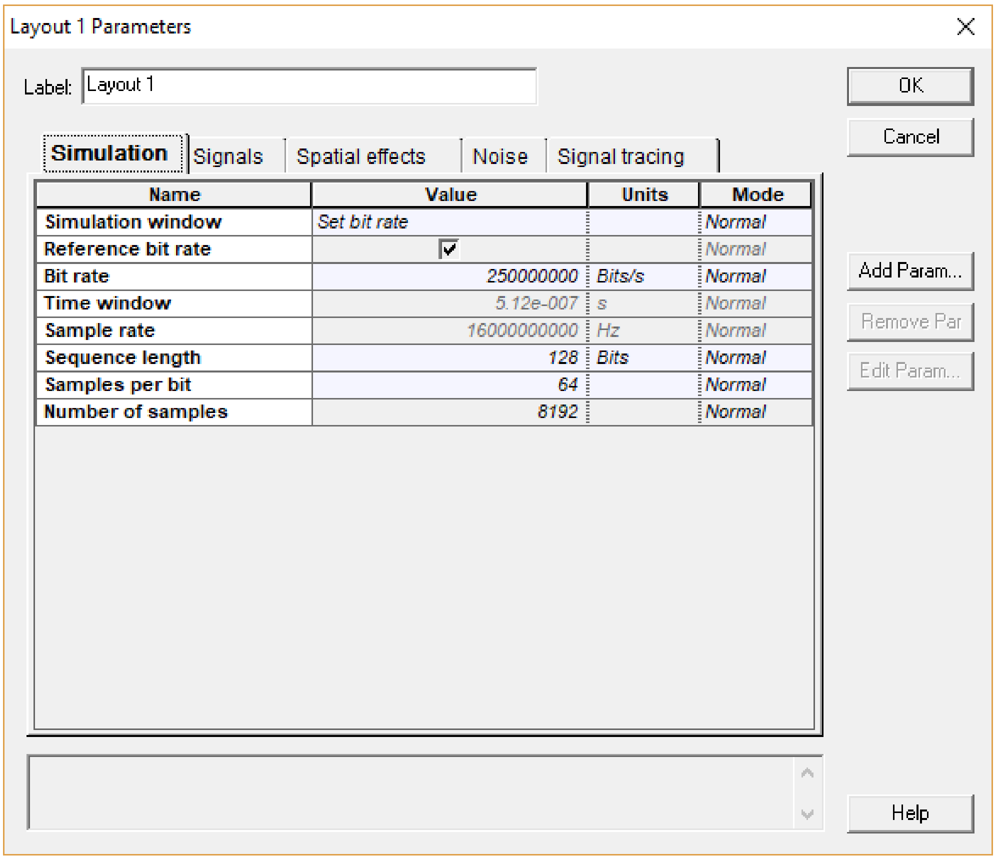

***Figure 3.11**: WDM GPON – Global parameters*

The global bit rate used for the design will be 2.5 Gbps. Other important parameters are the sequence length (128 bits) and the samples per bit (64). This will make a total of 8192 samples and are important because it needs large enough sequences for simulating the network at these high bit rates.

***Table 2**: Layout parameters*

Layout Parameter	
Bit rate (downstream)	2.5 Gbps
Sequence length	128 bits
Samples per bit	64
Number of Samples	8192

3.7 WDM PON in downstream

In downstream, the optical signal will direct from the OLT to the end users (ONT's). The first network element is the optical transmitter located at the OLT. This laser will broadcast five different wavelengths from (1450 nm, 1470 nm, 1490 nm, 1510 nm and 1530 nm) with a frequency spacing of 20 nm. The transmission power will be 0 dBm and it will use NRZ modulation. The next element is an optical multiplexer, which multiplexes these five wavelengths to transmit on a single fiber; this multiplexer 1:5 has an insertion loss of 2 dB.

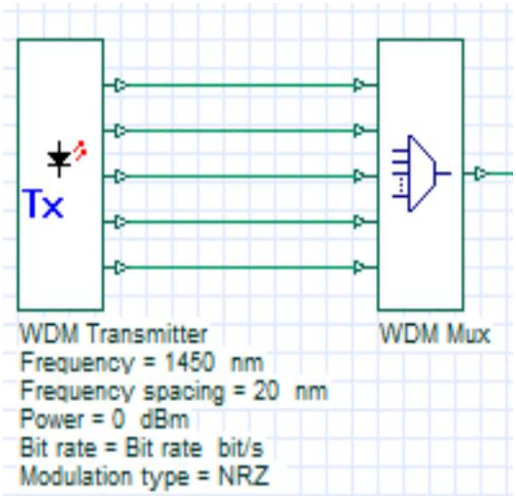

***Figure 3.12**: OLT and multiplexer*

To ensure good quality signal in the case of major losses so EDFA amplifier of about 10 dB of gain is placed in front of OLT; an optical circulator with insertion losses of 3 dB and return losses of 65 dB has been inserted and the optical signal will be inserted in the optical fiber at 5 km from the central office. The important parameters of this fiber, which will carry information in both directions, are 0.2 dB/km of attenuation, 16.75 ps/nm/km of dispersion and 0.075 ps/nm2/km of dispersion slope.

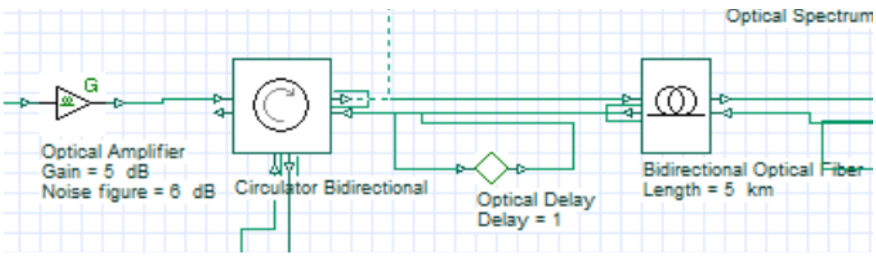

***Figure 2.13**: Bidirectional optical Fiber*

This next figure (3.14) shows the spectrum of the signal that has been inserted into the optical fiber:

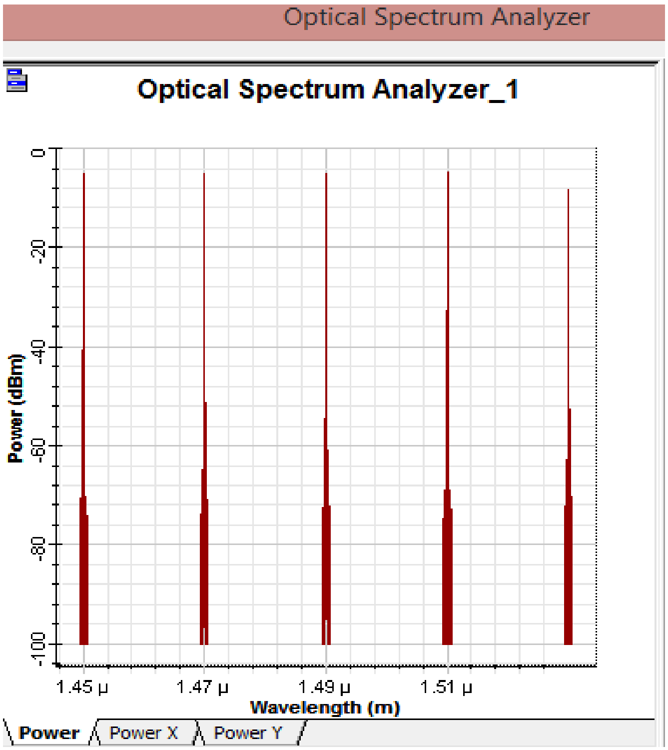

***Figure 3.14**: Downstream spectrum*

The *splitter* contains a multiplexer and demultiplexer (splitters). Each is used in one direction of traffic. For downstream traffic, the signal from the optical fiber is demultiplexed into 5 different branches with each of them carries a different wavelength. This 1:5 splitter has a starting frequency of 1450 nm and a frequency spacing of 20 nm.Concerning this multiplexer the value of insertion losses of 2 dB and a starting frequency of 1270 nm with a frequency spacing of 20 nm.

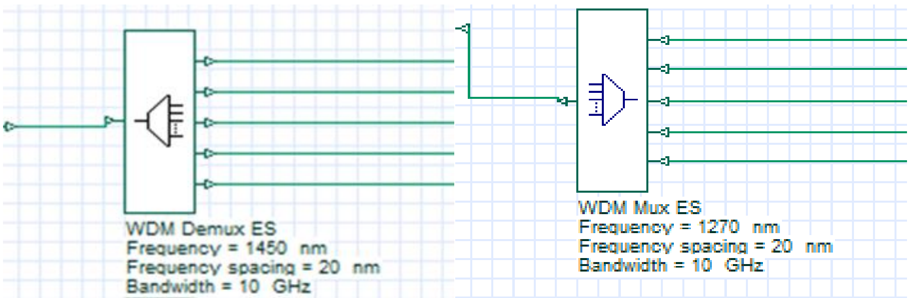

***Figure 3.15**: Splitters Block*

Wavelengths are directed to the five areas respectively: The hospital, business, residential, school-mall, and the building. Then, there will be a simulation for each area with its own explanation.

❖ *The hospital block*

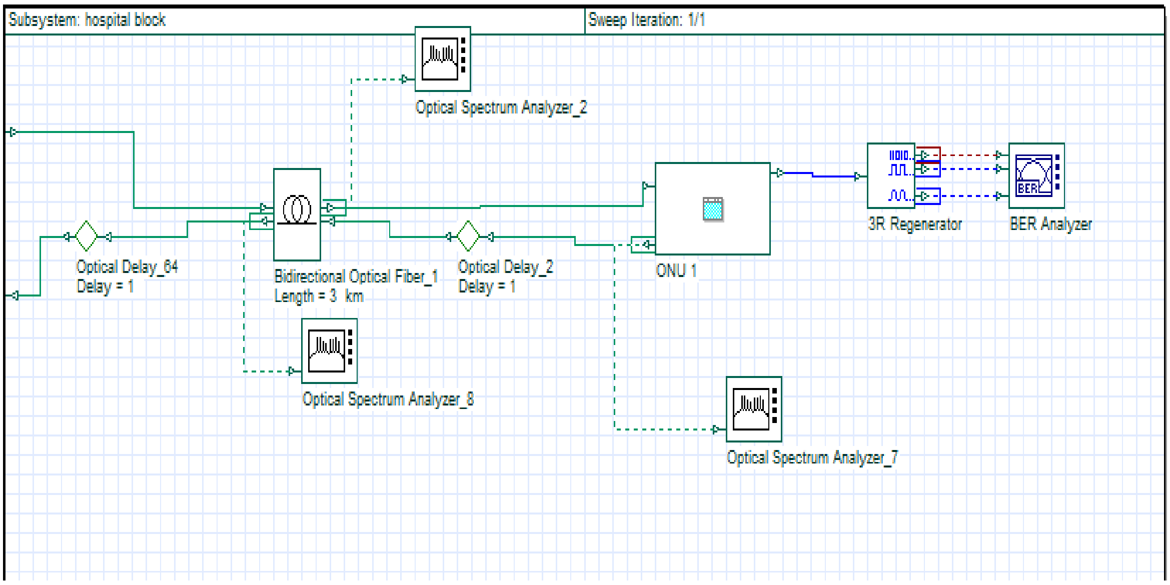

Figure 3.16: *The HOSPITAL Block*

The simulation begins with the hospital area in which we find: bidirectional optical fiber of the length by 3km that carries the information in both directions the downstream and the upstream which has the same parameters as the ones stated before, there will be the same as in the next areas. The optical delays that occur around the optical fiber are required and recommended to perform the simulation. With the "Optical Spectrum Analyzer" that is connected to the bidirectional optical fiber, it can be seen in figure (3.17) that the spectrum of the signal will reach the ONU in 1450 nm.

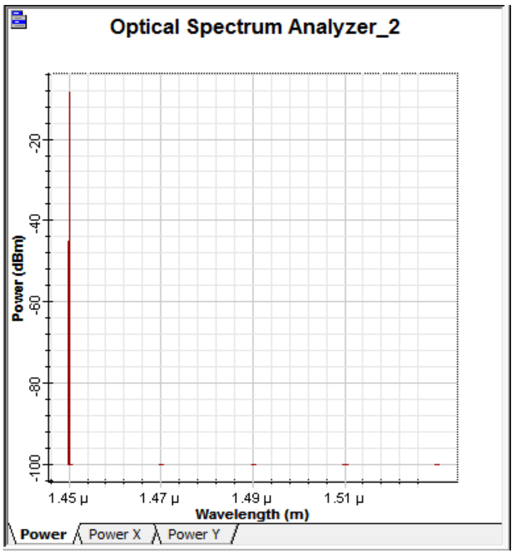

Figure 3.17: *Downstream spectrum into HOSPITAL Block*

The last element of this block is the Optical Network Unit (ONU) where the signal is received and transformed into electrical form to visualize it in the BER Analyzer. It consists of a photodetector APD which transforms the optical signal to an electrical signal.The optical signal is filtered by a low pass Bessel filter with a cutoff frequency of 0.75*Bit rate.

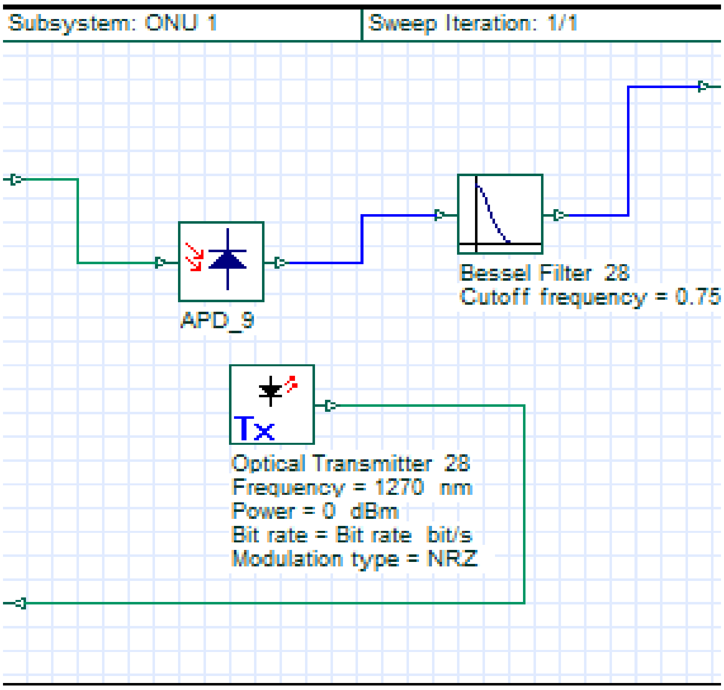

Figure 3.18: *ONU Block*

❖ the *business block*

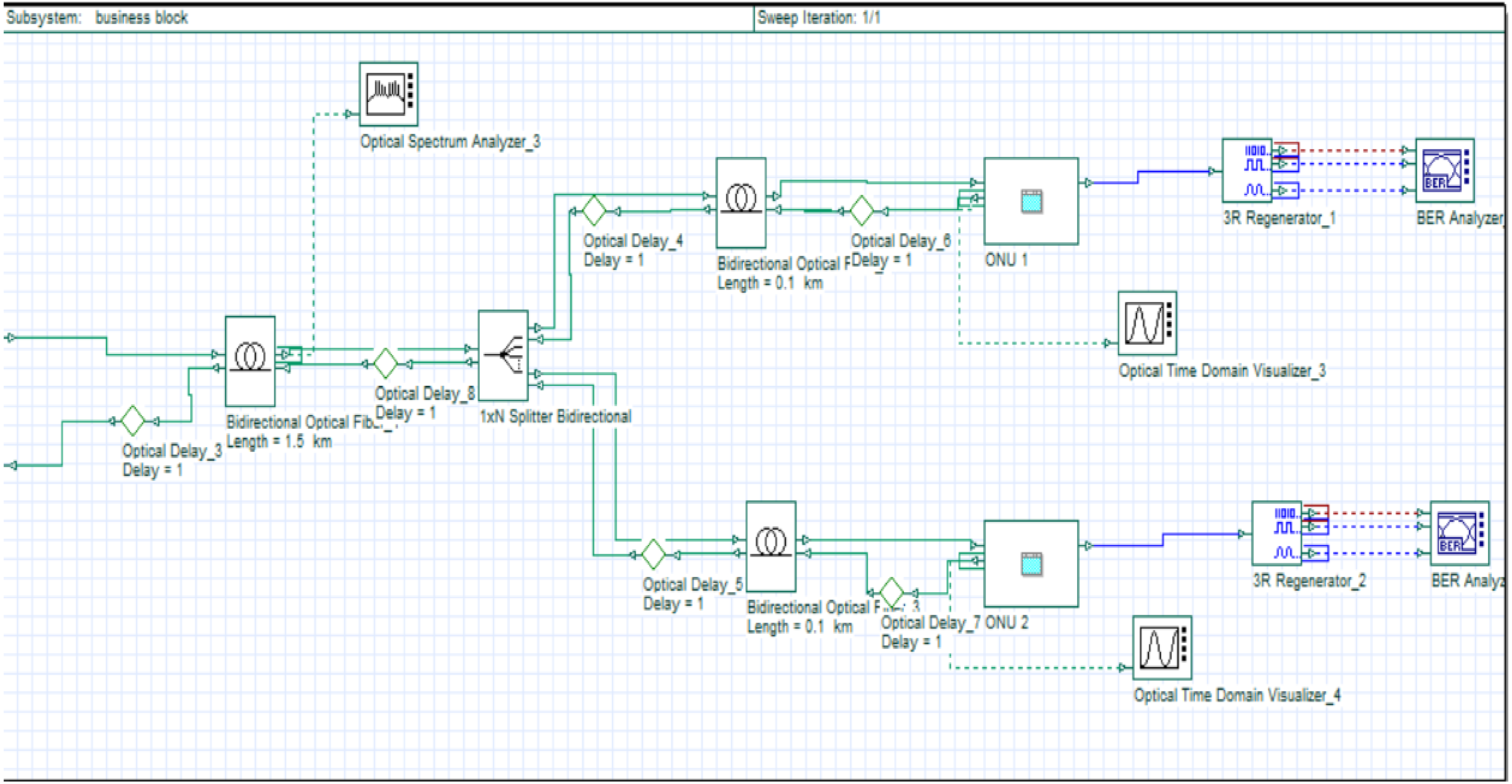

Figure 3.19: *BUSINESS Block*

In this block, the first element that will be to find is the bidirectional optical fiber of 1.5km. Immediately, we find a 1:2 splitter which divides the signal into two needed branches to reach the two buildings.

The most important parameter of this splitter is insertion loss. For a splitter with a division ratio of 1:2, typical losses are about 3.5dB. Since the same division is going to cause a loss of $10 * log\ (2)\ =\ 3dB$, we add an insertion loss of 0.5dB to get 3.5dB of attenuation in each branch. The bidirectional splitter will split the signal into two branches, each one is connected to a bidirectional optical fiber of 0.1 km with the same parameters mentioned above. Finally, each fiber reaches its respective ONU, that in the downstream direction will be identical to the previous one but it will have some changes in upstream that they will see in the next section. The Optical Spectrum Analyzer can see in figure (3.20) the carrier centered in 1470 nm:

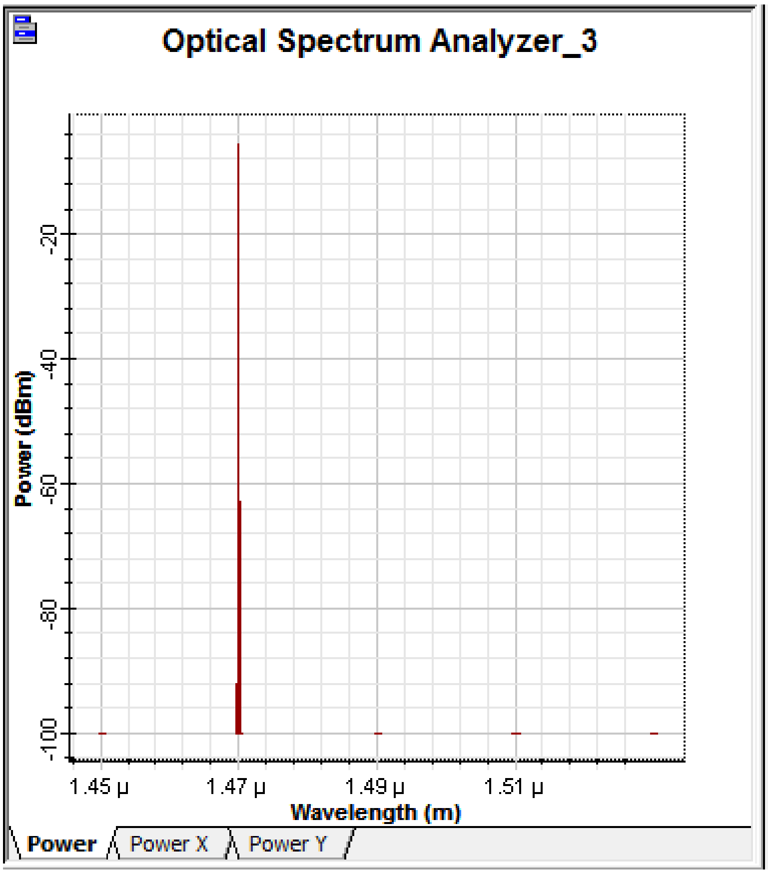

Figure 3.20: *Downstream spectrum into BUSINESS Block*

❖ *The residential block*

The next block that will be found is the residential block, With the Optical Spectrum Analyzer connected to the bidirectional optical fiber, it can see the spectrum of the signal that will reach the ONUs in the residential block.The peak will be centered in 1490 nm.

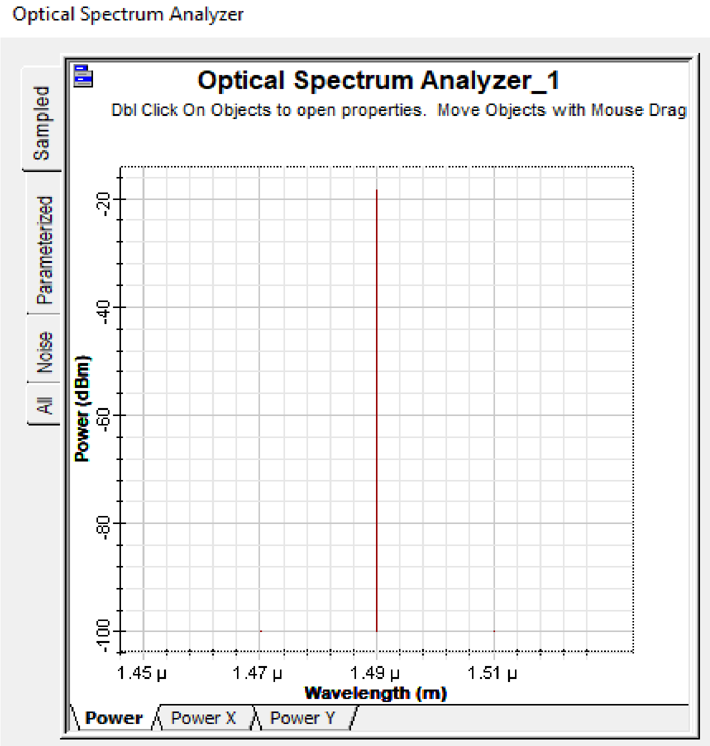

Figure 3.21: *Downstream spectrum into RESIDENTIAL Block*

The first element that we see in this block is the bidirectional optical fiber of 1 km length, which it will come connected from the optical splitter and will reach the splitter 1:20 which will broadcast information to all households. This splitter would correspond in reality to a splitter with a split ratio of 1:32 with a mean insertion loss of 16.5 dB. Since in this case, each branch has a loss of $10 * \log(20) = 13$ dB, it will add an insertion loss of 3.5 dB with a total of 16.5 dB at each branch. Each of the 20 branches that leave the splitter will be connected to a different length optical fiber the nearest ONU at 50 m away and farthest ONU 185 m away.The large losses that the residential area will have due to the great division that the signal will suffer, it should be placed an EDFA amplifier about 10 dB of gain to ensure a good quality signal.

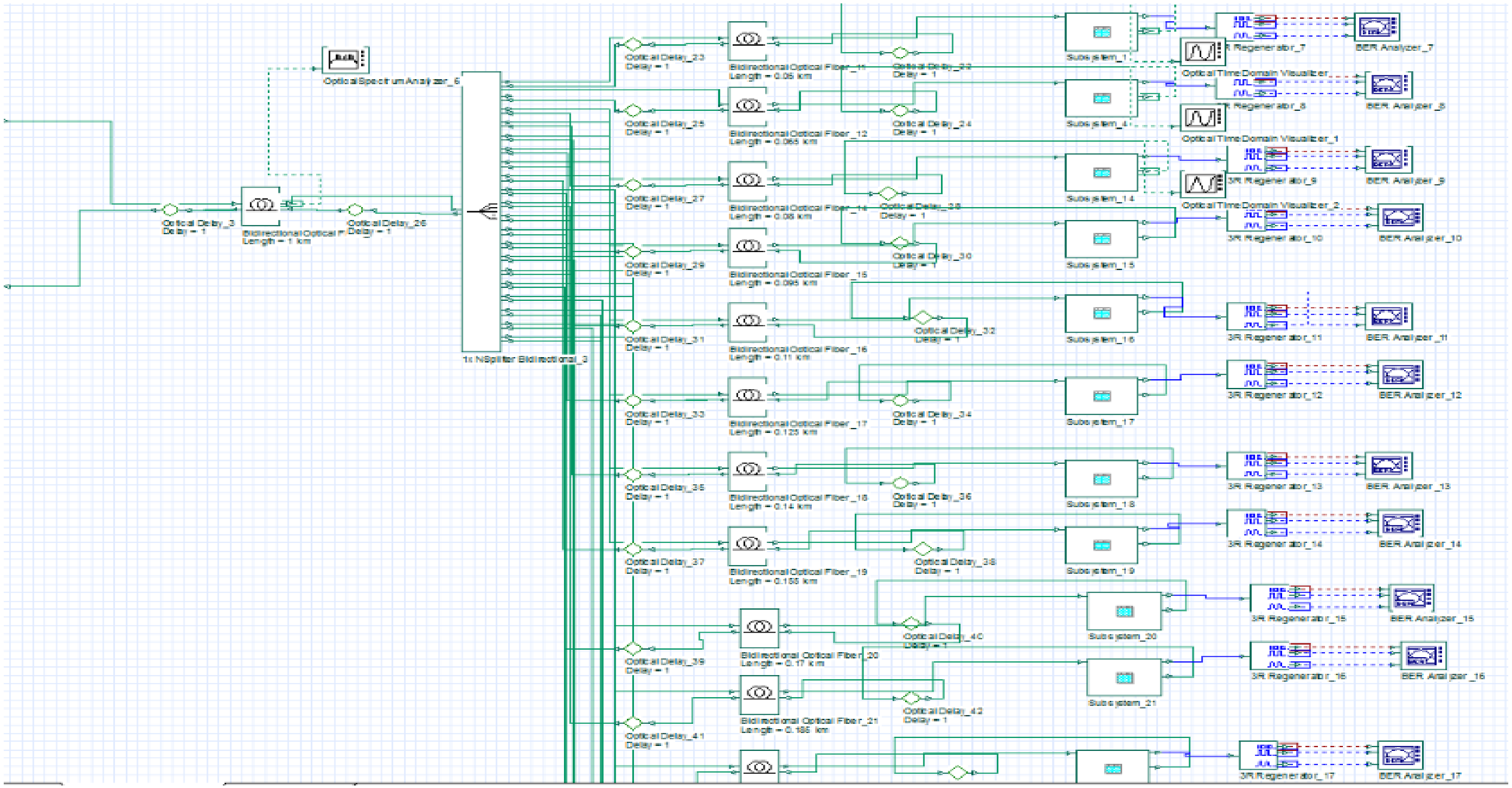

Figure 3.22: *RESIDENTIAL Block*

❖ ***Shool-mall Block***

The distance between splitter and the fourth area that is in the school and the mall is 1km which means far away by 6km from Central Office (CO).The optical splitter has a division ratio of 1:2 and they will be exactly equal to the proposed in the building area ($10 * \log(2) = 3$ dB will add 0.5dB for a total of 3.5dB insertion loss). We need a bidirectional optical fiber of 100 meters to reach the first ONU which will provide service to school and another of 250 meters to arrive at the second ONU which will offer service to the shopping center.The transmited wavelength, to the school and the mall, by 1510 nm that is schown above:

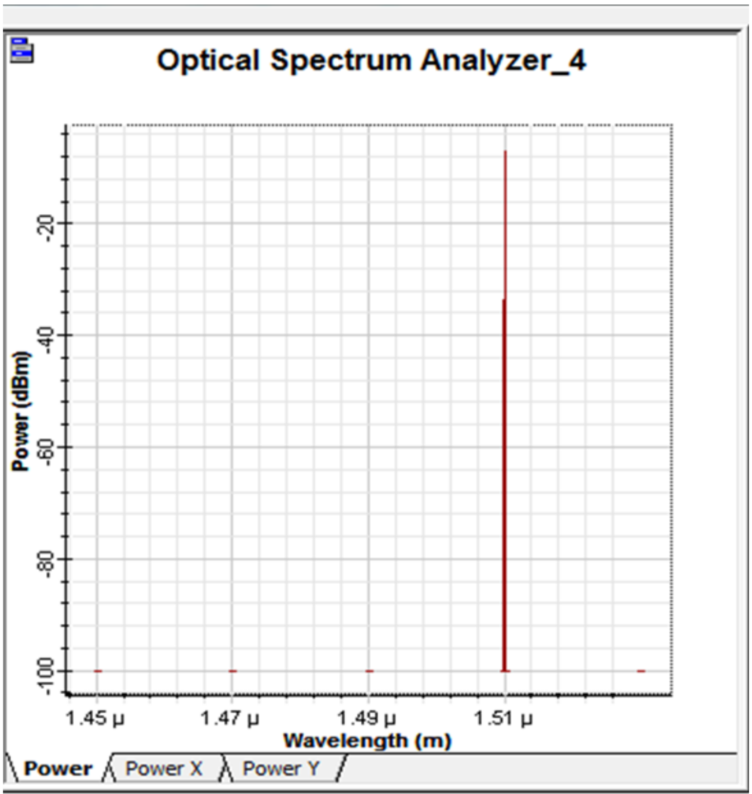

Figure 3.23*: Downstream spectrum into SCHOOL-MALL Block*

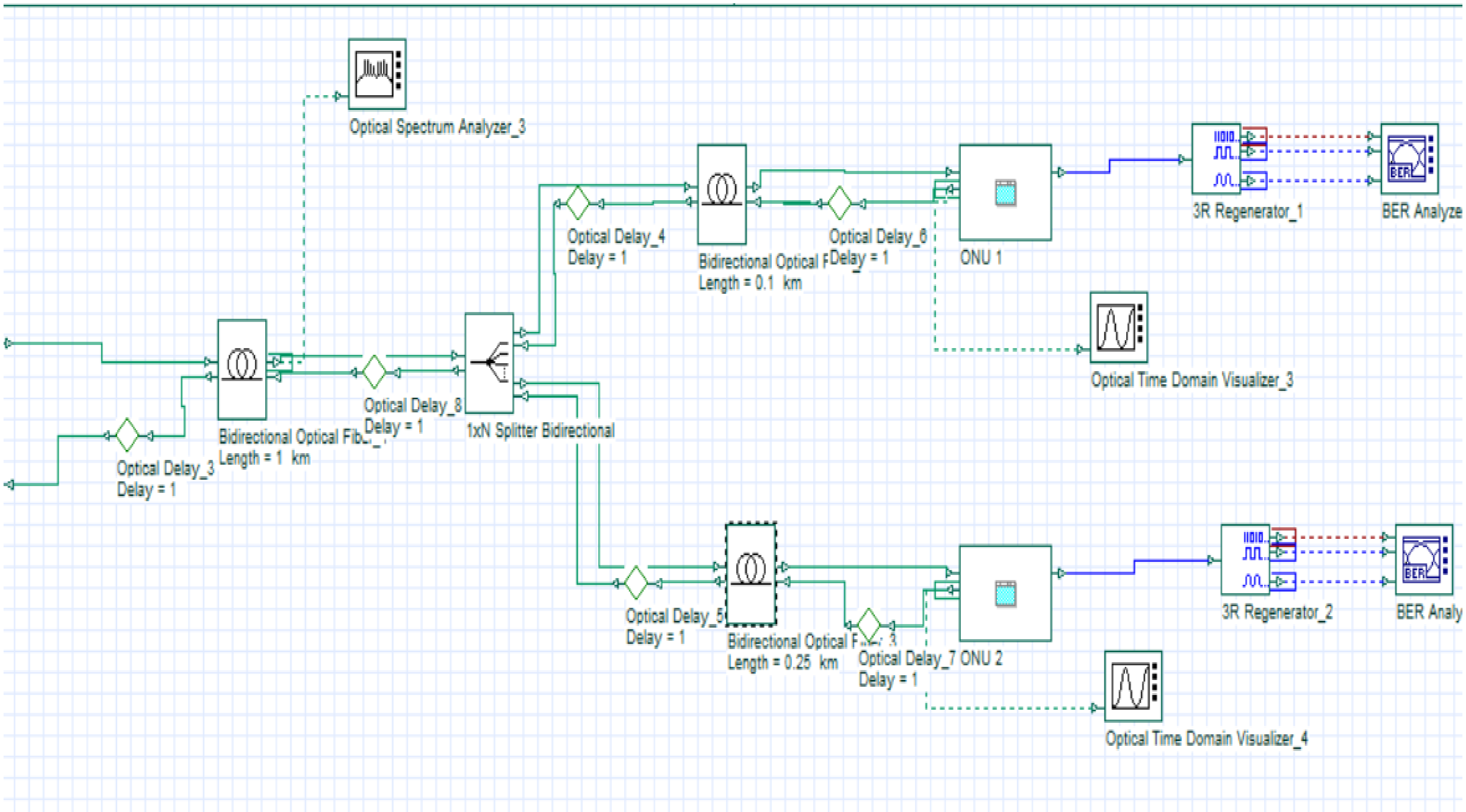

***Figure 3.24**: SHOOL-MALL Block*

❖ ***Buildings Block***

The last block is an area of buildings. The optical carrier is centered on 1530 nm. Using a bidirectional optical fiber of 2 km of length and the same parameters as the previous are connected two fibers of 50 meters long that will connect with the corresponding ONU. Each one will serve a different building.

The optical spectrum Vector of the building is 1530 nm:

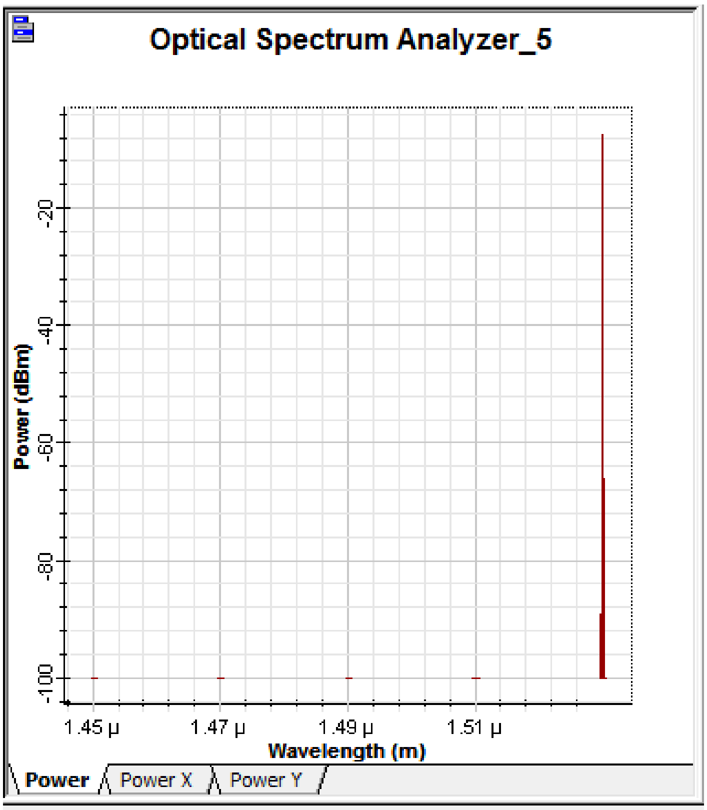

***Figure 3.25**: Downstream spectrum into BUILDINGS Block*

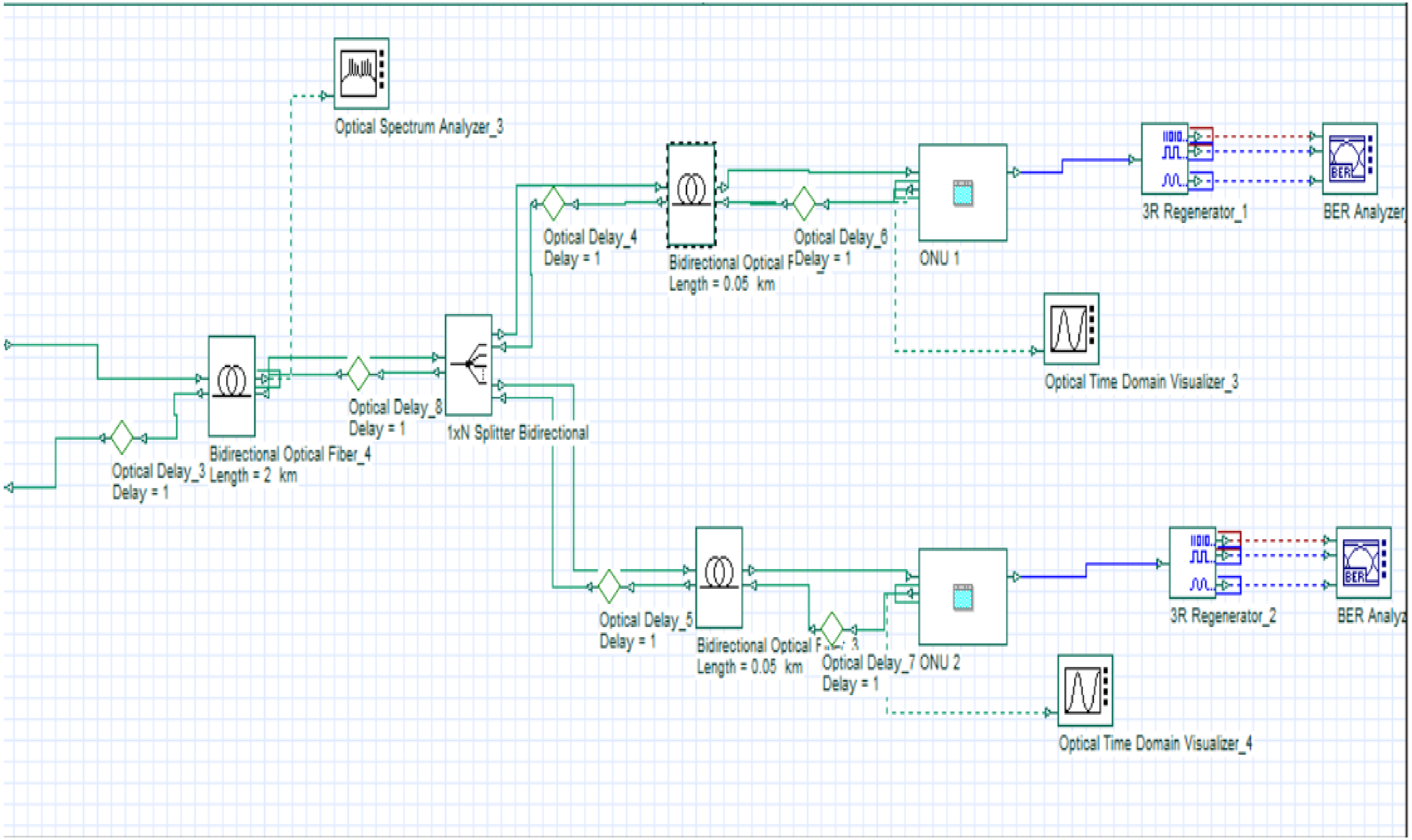

Figure 3.26: *BUILDINGS Bloc*

3.8 WDM PON in upstream

In the upstream, ONUs from each area transmit 1270 nm, 1290 nm, 1310 nm, 1330 nm, and 1350 nm wavelengths respectively, and 0 dBm of optical power, NRZ modulation and bit rate per default. The first block that will be analyzed is the hospital block, the ONU will transmited at 1270 nm, as explained previousely in the page 66.

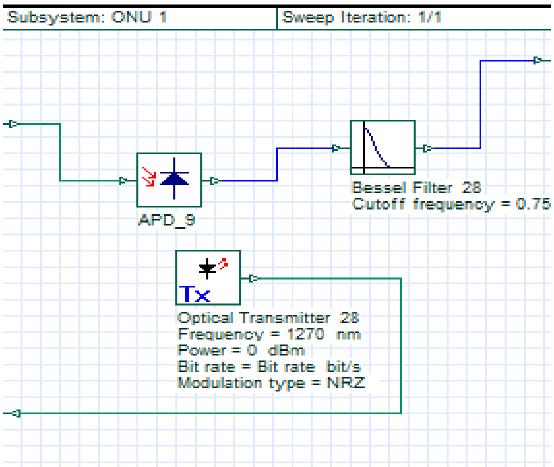

***Figure 3.27**: ONU Block HOSPITAL*

It is also important to note that in each area is going to be transmitted in a different wavelength. Therefore, TDMA will be implemented in each of the areas for each user transmits in a determined instant of time. This will avoid that two users might collide when they wish to transmit information at the same time.

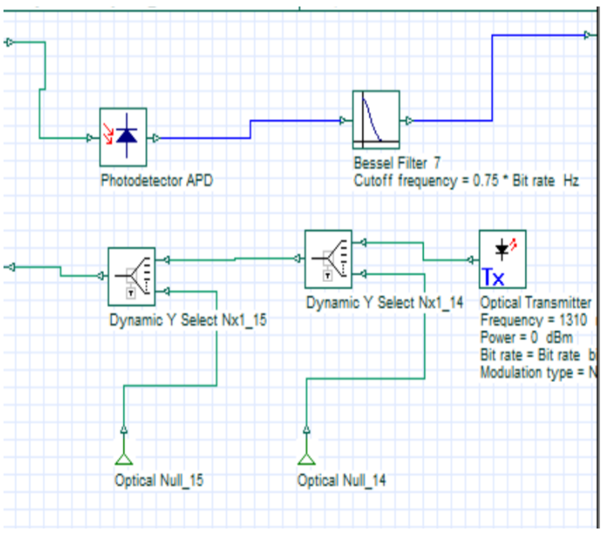

***Figure 3.28**: Business, Residential, School-Mall and Buildings ONU Block*

In this case, as it has more than one transmitter operating on the same wavelength, it must take into account the time division multiple access (TDMA). Therefore it will use a Dynamic Select Y which it will allow to pass the signal only at a determined time instant and the rest will be zero. Since we have only two ONU's, we will use the following formula to define the time interval of each one:

$$Timeslot * (1/Bit\ rate) * Sequence\ length \,/\, 2 + Time\ window \,/\, 2$$

TS = Timeslot, BR = Bit rate, SL = Sequence length, TW = Time window.Where Timeslot is set to 0 in the first ONU and 1 in the second. Fig. 2 shows the signal transmitted by the two ONU’s in the time domain and therefore it proves that the signals transmitted by the various ONU’s do not overlap in time and the ONU that in this case will transmit at 1290 nm in block *business*

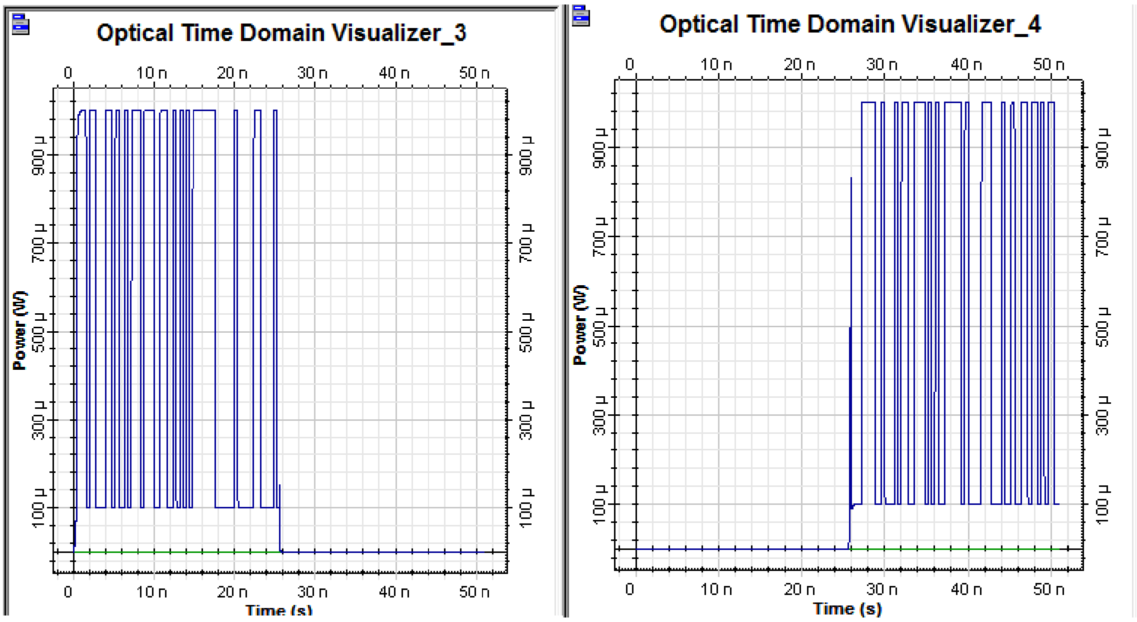

***Figure 3.29**: Optical time domain visualizer in BUSINESS block*

The following figure shows the first three time intervals for the first three ONU's in block *residential.*

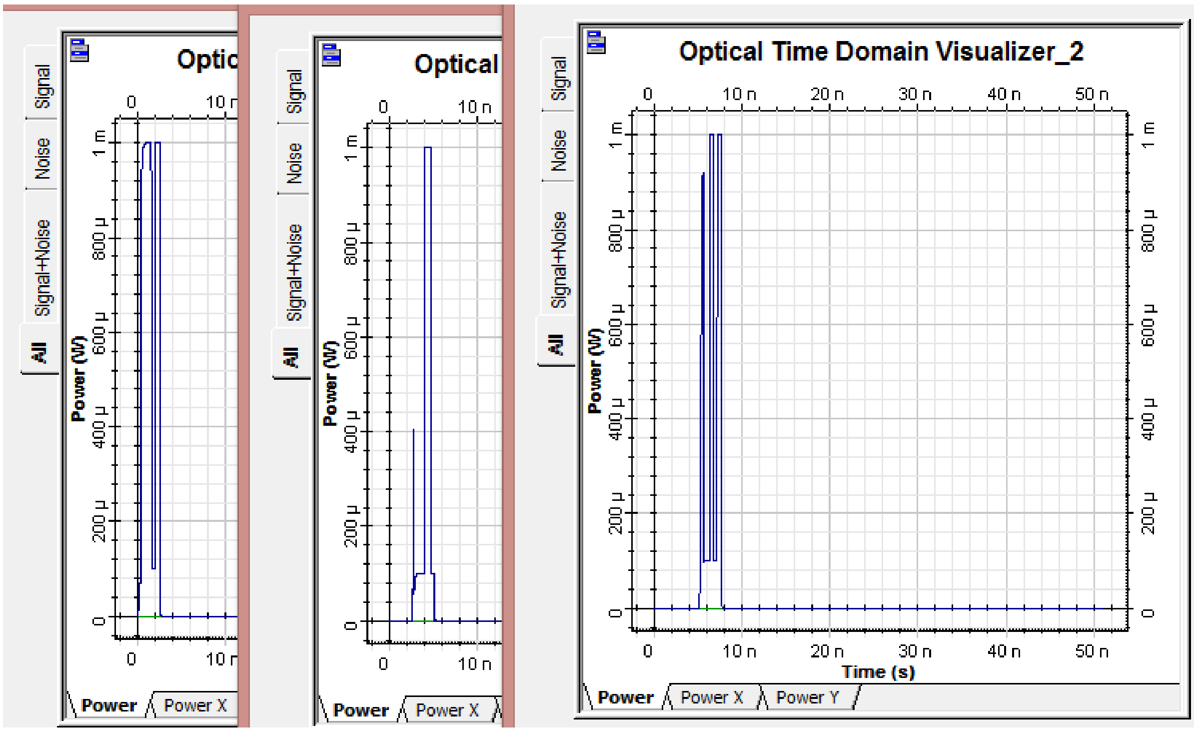

***Figure 3.30**: Optical time domain visualizer in RESIDENTIAL block*

The block for the school and the mall the ONUs will broadcast at a wavelength of 1330 nm. Respect to TDMA, we will use other time the described formula in the business block. Figure is shown a representation of the signal in the time domain for the two ONU's:

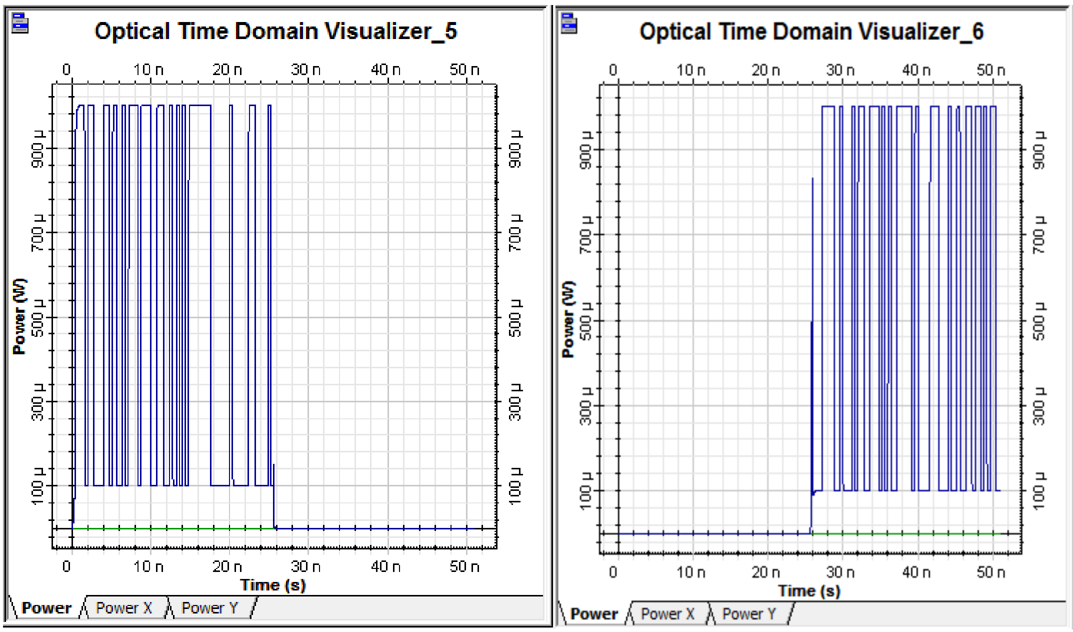

***Figure 3.31**: Optical time domain visualizer in SCHOOL-MALL block*

And the last block design is the BUILDINGS that they will send information in a wavelength of 1350 nm. In addition, the same formula is used to get that the information transmitted by users do not overlap, they also will use TDMA.

The following figure shows the optical signal of the transmitters of each ONU:

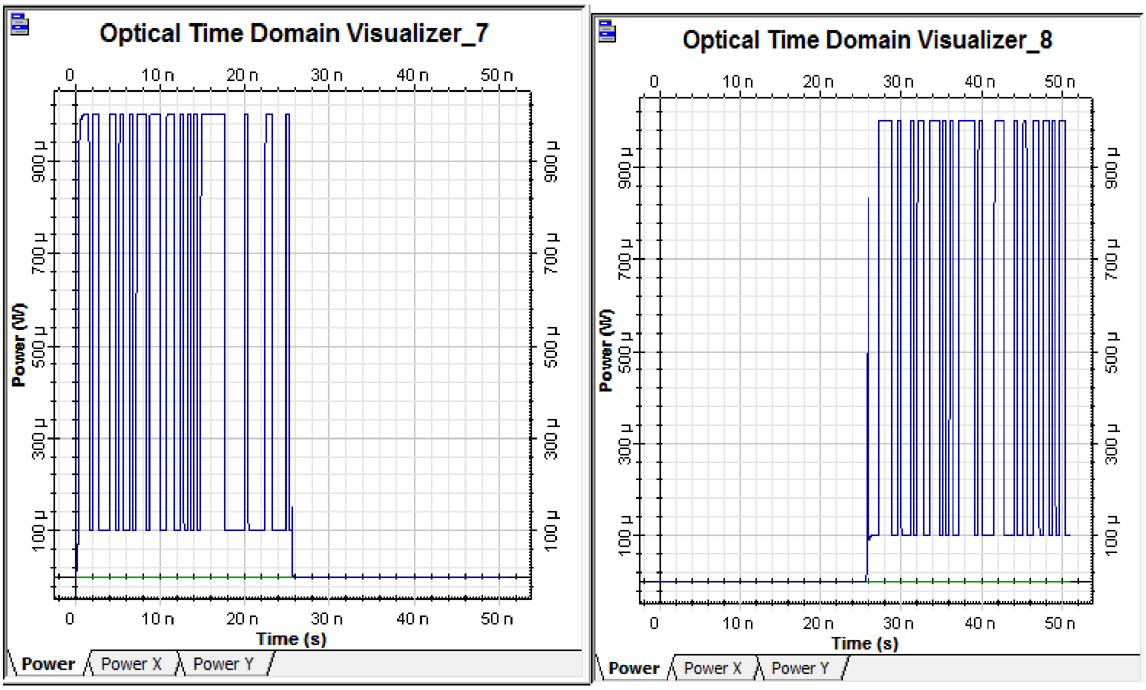

Figure 3.32*: Optical time domain visualizer in BUILDINGS block*

The first element of the receiver will be the Buffer Selector, which will be used to select only the latest iteration of the simulation, After this element, the signal will pass through the ADP Photodetector where it will be converted to electrical domain and as in other cases will be filtered through a Low Pass Bessel Filter with a cutoff frequency of 0.75 * Bit Rate. To end, this signal will be regenerated in order to be displayed on the BER Analyzer.

3.9 Simulation's results

In this section, we will deal with the effect of optical fiber length, bit rate variation and also the effect of coding.

3.9.1 Effect of optical fiber length variation

In this part, we varied the length of the fiber from 5km to 140km and we note each time the BER and the Q-factor for the 5 areas.

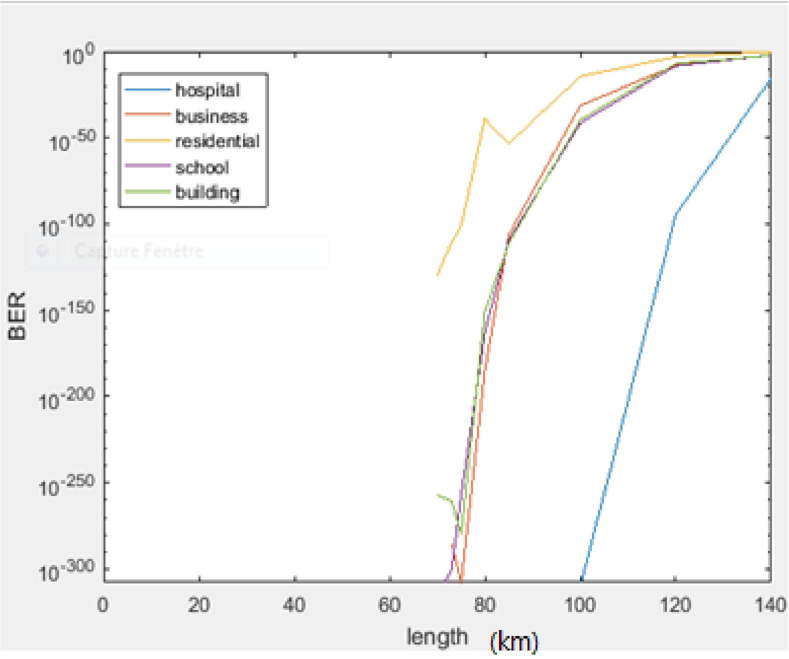

***Figure 3.33**: Variation of the BER according to the length of the fiber*

The figures (3.33-34) illustrates respectively the BER and the Q factor by taking random distance values. At the beginning BER values are found not to be affected by distance, then they started to increase when the distance is increased. In general we consider that optical telecommunications have a good transmission quality for a BER less than 10^{-10}, we obtain this result for a distance of up to 140 km. On the other hand, Q factor values are found to be affected by length values, they are decreased when the distance is increased due to losses. It is found to be better at 40 km than at 100 km.The value of 40 km in the hospital of the area is equal < 150 and the value of 100 km is equal to 50.

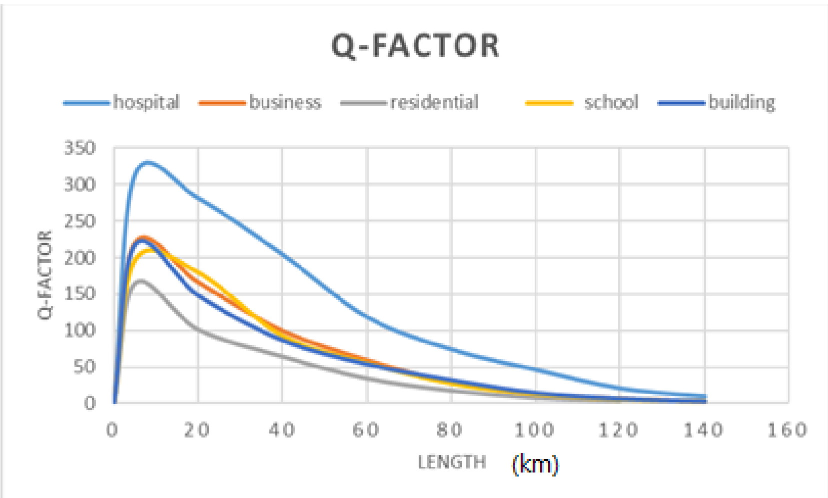

***Figure 3.34**: Variation of the Q-factor according to the length of the fiber*

3.9.2 Effect of bit rate variation

We will proceed in the same manner as before, but by varying the bit rate from 2.5Gbps to 20Gbps and note the BER and the quality factor in transmission, the results are presented in the figures below.

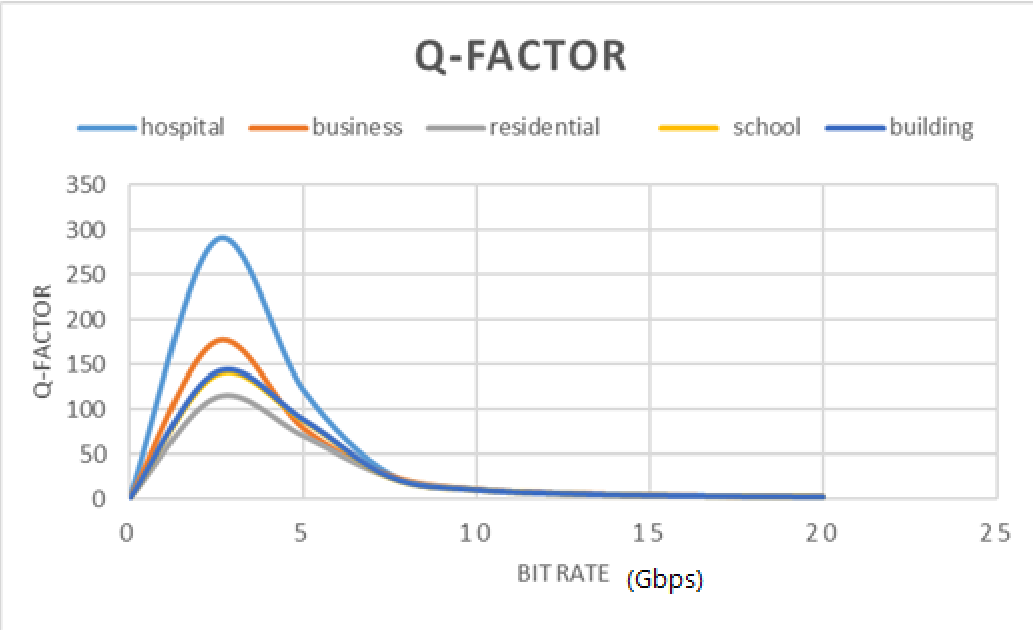

Figure 3.35*: Variation of the Q-factor according to the bit rate*

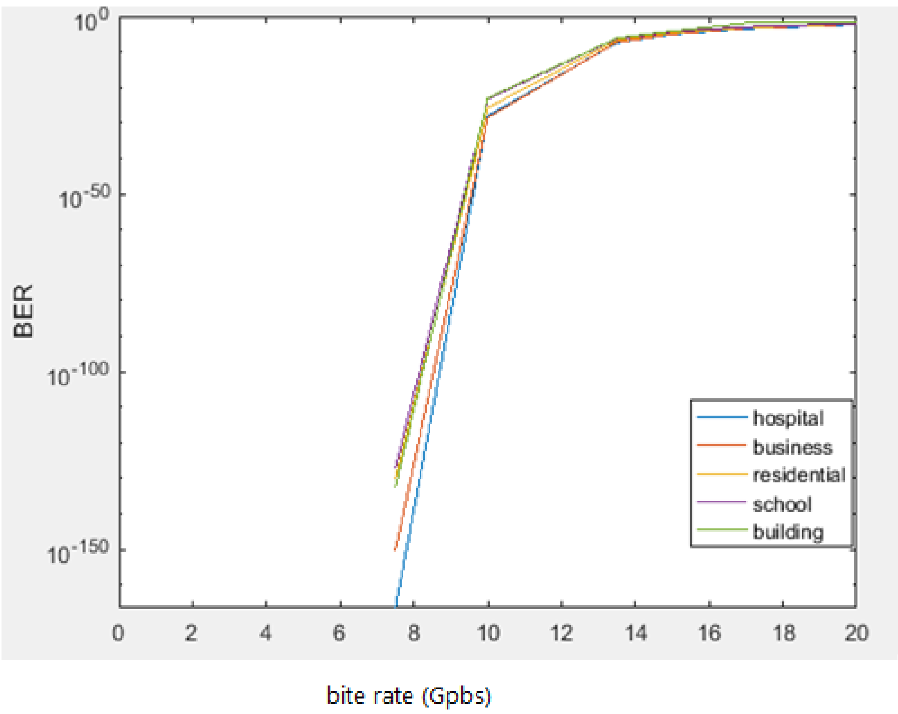

Figure 3.36*: Variation of the BER according to the bit rate*

The remark that can be made from the results obtained in Figures (3.36-37) is an increase in the bit error rate up to 10 Gbit/s, then it becomes stable up to 20Gbit/s. At the same time, the quality factor decreases to become stable at 10Gbps. We have a quality factor greater than 27.5 for a bit rate below 7.5Gbps.

3.9.3 Effect of coding variation

❖ **Non Return-to-zero (NRZ)**

The binary "1" is associated with an optical pulse of duration equal to the symbol time, the data "0" corresponds to the absence of the signal. The NRZ format is used for the bit rates below 10Gbit / s, it is used extensively in Wavelength Division Multiplexing (WDM) systems.Figure 3.36 shows the coding of a data (1001) in NRZ format. [36]

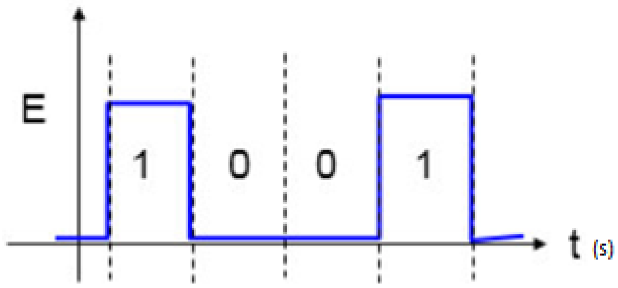

***Figure 3.37**: NRZ Format [36]*

❖ **Return-to-zero (RZ)**

In this format, the pulse associated with the data "1" is of less duration than the symbol time, the data "0" corresponds to the absence of signal.

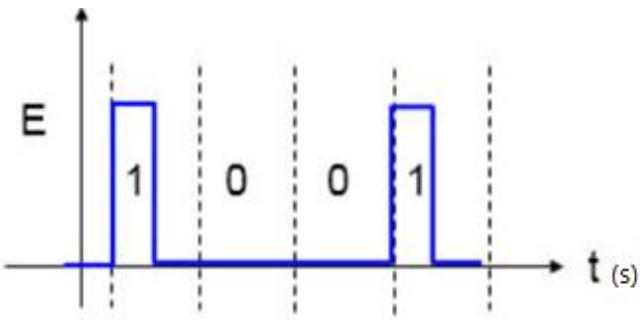

***Figure 3.38**: RZ Format [36]*

Accordingly a use of the two codes RZ, NRZ and a performance comparaison between them will be conducted.

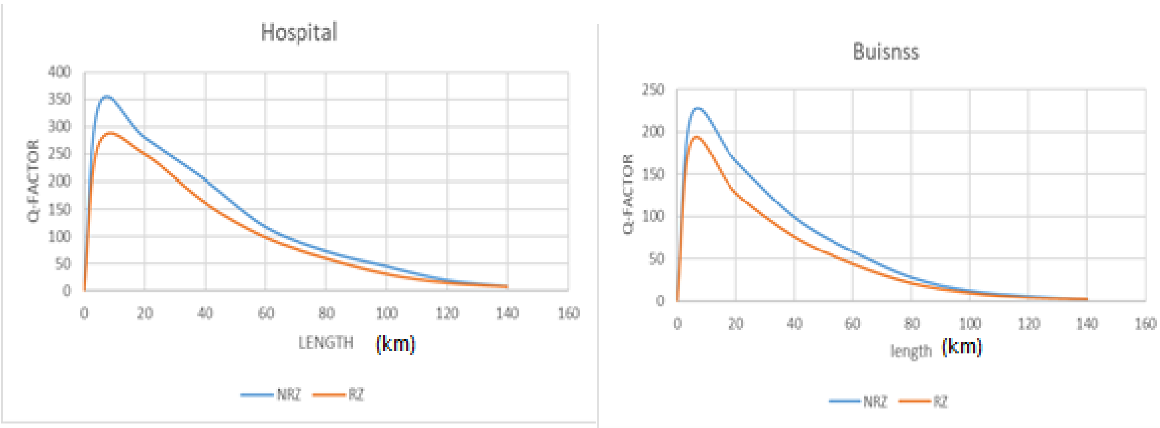

***Figure3.39**: Comparison of the Q-factor RZ / NRZ as a function of distance*

From Figure (3.39), it can be seen that the Q-Factor for the NRZ type is better than that of RZ, for the comparison to the distance of 80km, the Q-Factor of the NRZ type is equal to 28.19, whereas for RZ it is from 21.58. We note a degradation of transmission's quality according to the distance in which one obtains a maximum distance of 120 km for RZ and 140 km for NRZ.

3.10 Conclusions

In our study of the PON link, we carried out our research on transmission performance based on WDM (wavelength division multiplexing) by acting on different parameters such as fiber length and bit rate. For this, we used different criteria to study the quality of transmission. We have done a complete study of the WDM-PON link by establishing the optimal distances and throughput the different quality criteria for the 5 area.

General Conclusion

The objectives of the project have been successfully achieved which carry out broadband and scalable wavelength division multiplexing of the passive optical network. The optical fiber has many applications, one of these applications is the one that it used in optical networking.

We carried out a study of a PON system with Wavelength Division Multiplexing (WDM), acting on the parameters of the connection as the length of the fiber and the flow. This allowed us to highlight the importance of each parameter of the link. We concluded that Passive Optical Networks (PON) can achieve high speeds with good transmission quality, and it is the best architecture for delivering broadband services. WDM-PON with FTTx provides huge bandwidth, greater speed and reach to a number of users. It also improves Q-factor, bit error rate and transmits huge data capacity that increases the overall performance of the optical fiber network. The quality factor and the bit error rate (BER) show that the performance of the network is high. The results have shown a BER of about 0. This shows the high reliability in each of its points of the implemention of this network. WDM-PON technology lowers network costs, energy consumption and lower maintenance requirements.

Future Work

- This Project performance can be studied from a different perspective like system dispersion and operating wavelengths in order to give better performance of the WDM-PON.
- The system efficiency can be developed by increasing the number of areas of the optical network from 5 areas to the whole city.
- This system improves the performance of optical fiber and provide the best possible performance.
- Having the ability to integrate multiple systems and services ,the possibility of interconnecting these networks with other wide area networks and adding local networks by creating LAN

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