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OPTION: NETWORKS AND TELECOMMUNICATIONS

Theme

Design and Installation of an FTTH Network

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Defended on 18/06/2025, before a jury composed of:

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My gratitude goes to all the professors and teachers who contributed to my education from the beginning to the completion of my studies.

I would also like to extend my gratitude to my parents, all the members of my family, friends. Thank you for your encouragement and support.

Dedication

I dedicate this work to my beloved parents, whose unconditional love, sacrifices, and endless support have been the foundation of my journey. This achievement is a reflection of your love and belief in me.

To my two dear brothers, thank you for your encouragement and unwavering faith in me.

To my precious sisters, your kindness and constant presence have always lifted my spirit.

And to my friends, thank you for your support.

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General Introduction

Since the beginning of the twentieth century, the field of telecommunications has constantly improved, as it has become a point of convergence and interaction between various technologies and scientific, economic, and other disciplines.

Access networks have undergone rapid development, driven by the emergence of new digital services and an growing demand for bandwidth. This transformation has been fueled by the widespread use of multimedia applications, remote work, e-learning, and the Internet of Things (IoT), all of which require fast, stable, and high-performance connections.

To meet these needs, ultra-fast broadband access has become essential. Using fiber optic cables as the primary transmission medium, have proven to be the most efficient technological solution. Among these, Fiber to the Home (FTTH) stands out as a key approach, bringing fiber directly to users homes and offering a reliable and scalable answer to modern connectivity demands.

Algeria aims to achieve a transformation in telecommunications by launching its first industrial project, Opti Connect, which is currently underway and seeks to roll out fiber optic connectivity across the entire national territory.

This thesis is situated within this broader context and aims to explore the design and implementation of a high-speed FTTH network, based on Passive Optical Network (PON) architecture and, more specifically, the Gigabit PON (GPON) technology, that provides a downstream bite rate of 2.5 Gbps and an upstream bite rate of 1.25 Gbps.

The main objective of this work is to design, simulate, and evaluate an FTTH network capable of delivering high-quality service to end users.

We adopted a dual approach: a theoretical study of optical fiber technologies and PON architectures, followed by a practical simulation using the OptiSystem software to assess network performance and validate the feasibility of the proposed GPON model.

The structure of this thesis is organized into three main chapters:

- Chapter 1 presents the fundamentals of optical fiber, covering its components, advantages, and main applications. It also provides an overview of optical networks, including various FTTx architectures.
- Chapter 2 focuses on the design and deployment of an FTTH network based on passive optical architecture, addressing both technical and practical considerations.
- Chapter 3 is devoted to the simulation of a GPON link. The performance analysis is conducted using the OptiSystem software, and the results are interpreted to evaluate the efficiency and viability of the proposed network design.

CHAPTER 1

Fundamentals of optical fiber

1.1 Introduction:

Fiber optics has been playing an increasingly crucial role within the telecommunication revolution. Not only most long-distance links are fiber based, but optical fibers are increasingly approaching the individual end users, providing wide bandwidth links to support all kinds of data-intensive applications such as video, voice, and data services.

1.2 Fiber optic communication system:

A fiber optic communication system, in its simplest form, is composed of three main components that ensure the transmission and reception of information:

An optical transmitter, which converts electrical signals into light signals.

An optical fiber, which serves as the transmission medium, carrying the light over long distances.

An optical receiver, which transforms the received light signal back into an electrical signal.

figure 1.1 clearly illustrates the signal's path from the transmitter to the receiver through the optical fiber.[4]

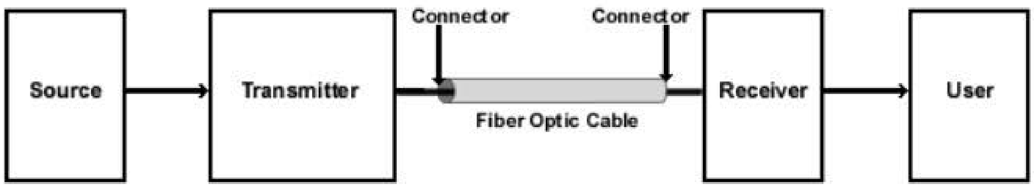


Figure 1.1: Block diagram of fiber optics system.

1.3 Light Source:

The optical source is an active component. Its main function is to convert electrical energy, supplied in the form of current, into optical energy. [4]

1.3.1 Source selection:

In optical transmission system, light must be efficiently injected into the fiber from a light source. All the characteristics of optical fibers directly influence the choice.

The source must:[4]

- Have a small emitting surface, ideally smaller than the fiber's input surface;
- Emit light in directions compatible with the fibers acceptance cone (or numerical aperture);
- Operate at wavelengths where the fiber is most transparent, in order to maximize the amount of light transmitted to the fibers end;
- Have a narrow spectral width to minimize chromatic dispersion;
- Provide high optical intensity;
- Have a fast response time;
- Enable easy modulation;
- Be reliable;
- Be cost-effective.

1.3.2 Light-emitting diode (LED):

Based on spontaneous emission, the LED is an incoherent source, which has a large spectral width. It is generally used with multimode fibers in short-distance transmission systems that require low bandwidth, although coupling LEDs to single-mode fibers has also been successfully pursued, particularly with the use of advanced structures.[5]

1.3.3 Laser diode (LD):

Laser is a device that amplifies light, which is reflected in its name: LASER, an acronym for Light Amplification by Stimulated Emission of Radiation. Its operation is based on the formation of an electromagnetic standing wave within a resonant cavity, resulting in a highly coherent and monochromatic light output. It is characterized by its narrow output spectrum, which significantly reduces chromatic dispersion, making it especially suitable for long-distances transmission systems.[5]

1.4 Optical fiber:

1.4.1 Definition:

Optical fiber is a medium for transmitting information between two distant points (transmitter and receiver) using light signals. It consists of a cylindrical waveguide made of transparent glass or plastic, it supports data transmission over long distances with low attenuation. This technology offers several advantages, including immunity to electromagnetic interference, Very high bandwidth, High flexibility and excellent quality transmission, making it a key component in modern telecommunications infrastructure.[6]

1.4.2 Structure of optical fiber:

Optical fiber consist of three basic concentric elements as illustrated in figure 1.2 :[7]

- **The core:** The core is the central part of an optical fiber that guides the light, typically made of glass (silica) or plastic. It has a slightly higher refractive index (n1) and the diameter may vary from about 5 um to 100 ţm.

- **The cladding:** The optical cladding surrounds the fiber core and has a lower refractive index (n2) than the core. This enables a phenomenon called total internal reflection, which keeps the light inside the core and guides it over long distances with minimal loss.

- **The coating:** The coating acts as a shock absorber to protect the fiber from environmental and mechanical damage, as well as performance degradation and micro cracks. The buffer generally composed of one or more layers of plastic material. Sometimes, extra protection is provided by adding metallic sheaths.

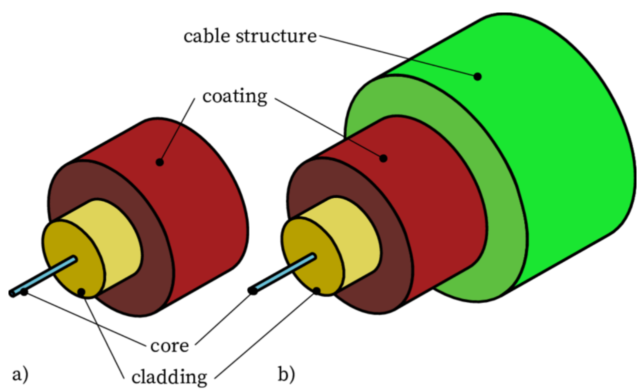


Figure 1.2: structure of an optical fiber.

1.4.3 Classification of optical fibers:

In fiber optic communications, single mode and multimode fiber constructions are used depending on the application:

1.4.3.1 Single-mode fiber:

Single-mode fiber allows light to propagate through its core in one mode, the fundamental mode. Its core has a very small diameter, approximately 9 ţm, which reduces the number of light reflections. This leads to a decrease in attenuation, enabling the signal to propagate at high speed and over long distances. Furthermore, single-mode fiber offers a much wider bandwidth than multimode fiber, making it ideal for very high-speed data transmissions, such as in long-distance networks. [8]

1.4.3.2 Multi-mode fiber:

The core of Multi-mode fiber is relatively large (usually 50 or 62.5 ţm) allows light to travel in several modes. However, this causes modal dispersion: the light rays arrive at different times at the end of the fiber, which distorts the signal. In addition, the signal loses more power (attenuation) compared to single-mode fiber. These effects limit the signal quality and reduce the transmission distance. This is why multimode fiber is mainly used for local networks (LAN) or short-distance connections. [8]

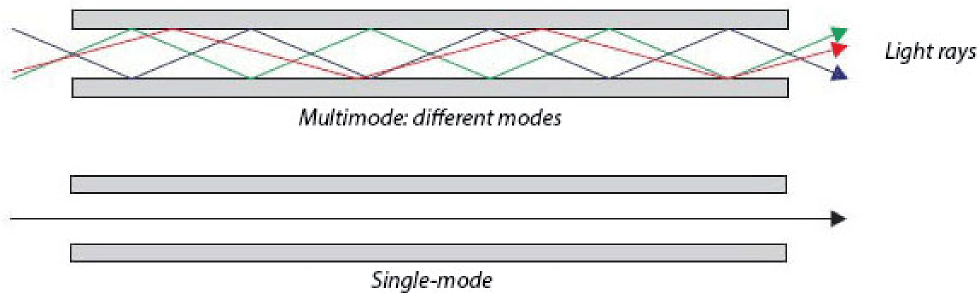


Figure 1.3: single mode and multimode fibers.

- **Multimode step-index fiber:** A constant core refractive index (n1) and a cladding with a slightly lower refractive index (n2) characterize this type of fiber. This sharp contrast between the two indices creates a "step" in the refractive index profile as illustrated in figure 1.4, which gives it the name step-index fiber. This structure causes abrupt reflections of light at the core-cladding interface, allowing the signal to propagate. The core diameter is approximately 50 ţm or more,it is enough to allow the propagation of multiple modes.[5]

- **Multimode Graded index fibers:** The light travels forward in the form of sinusoidal oscillation as illustrated in figure 1.4, it is characterized by a higher refractive index at the center of the core, which gradually decreases toward the core-cladding interface. Consequently, light travels faster near the cores edge, equalizing mode travel times and minimizing modal dispersion.[5]

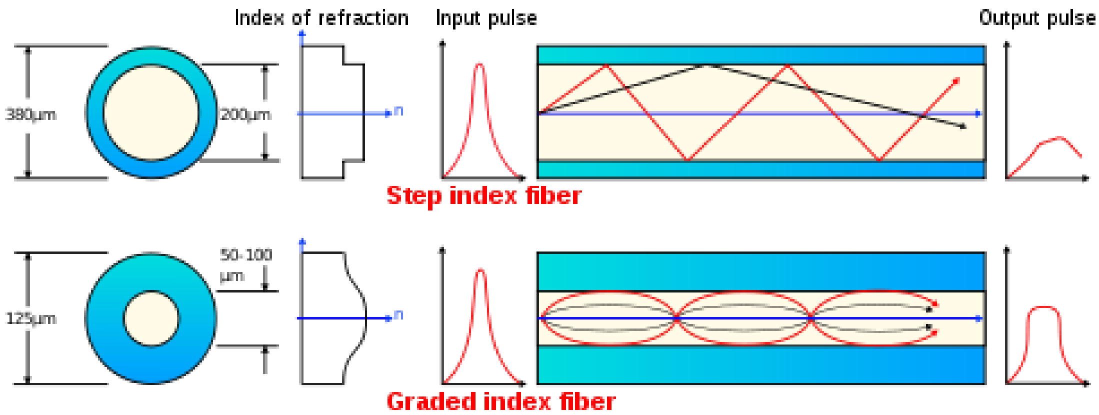


Figure 1.4: Multimode step-index and Graded-index fiber.

1.4.4 Attenuation in optical fiber:

Attenuation is one of the most important characteristics in optical transmissions. It refers to the decrease in power of the light signal as it propagates through the fiber, usually expressed in the logarithmic unit of the decibel.

The total attenuation in decibels (dB) is given by:

$$\text{Attenuation (dB)} = 10 \cdot \log_{10}\left(\frac{P_{\text{in}}}{P_{\text{out}}}\right)$$

Where:

- P_{in} is the input optical power
- P_{out} is the output optical power

In optical ber communications, the attenuation is usually expressed in decibels per unit length following:

$$\alpha = \frac{10 \cdot \log_{10}\left(\frac{P_{\text{in}}}{P_{\text{out}}}\right)}{L}$$

Where:

- α is the attenuation coefficient (in dB/km)
- L is the fiber length (in km)

Optical fiber began to stand out in field of telecommunications when transmission losses were reduced below those of metallic conductors (less than 5 dB/km).[5]

Figure 1.5 expands our view of the low attenuation regions where fiber transmission is most practical.

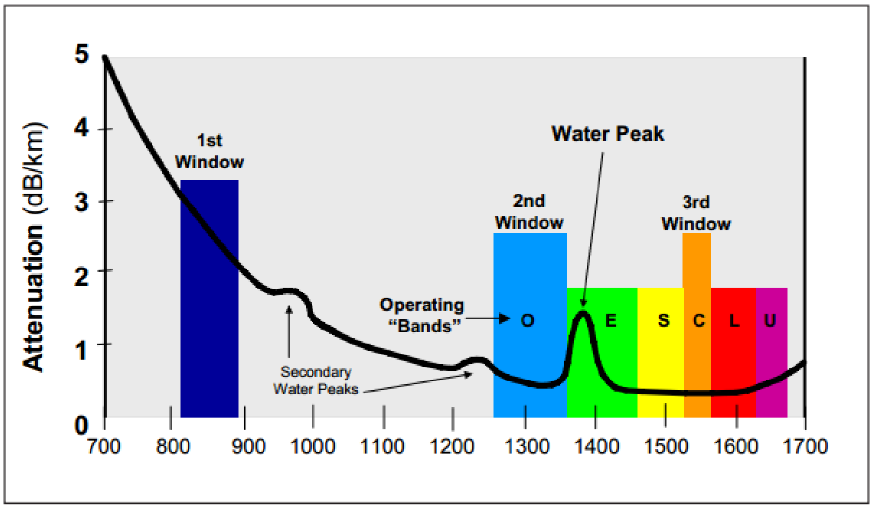


Figure 1.5: Attenuation of silica glass fiber showing the three major wavelength regions at which the systems are most practical.

- The 1st window (820880 nm): High attenuation (3 dB/km), used only in Multi-Mode fibers with LEDs, and is less common today.
- The 2nd window (12601360 nm): Moderate attenuation (0.33 dB/km), chromatic dispersion is zero, widely used, especially in Single-Mode fibers.
- The 3rd window (15301625 nm): Split into C-band and L-band, this is the most widely used window today, thanks to its low attenuation and compatibility with optical amplifiers, making it ideal for long-distance transmission.

Several factors can cause signal loss in an optical fiber. These include absorption, scattering due to variations in the refractive index within the core (notably Rayleigh scattering), irregularities at the core-cladding interface, and losses related to fiber bending. Additional losses may also occur at junctions (splices, connectors) and at the fiber ends (input and output).[9] These different loss mechanisms are illustrated in Figure 1.6.

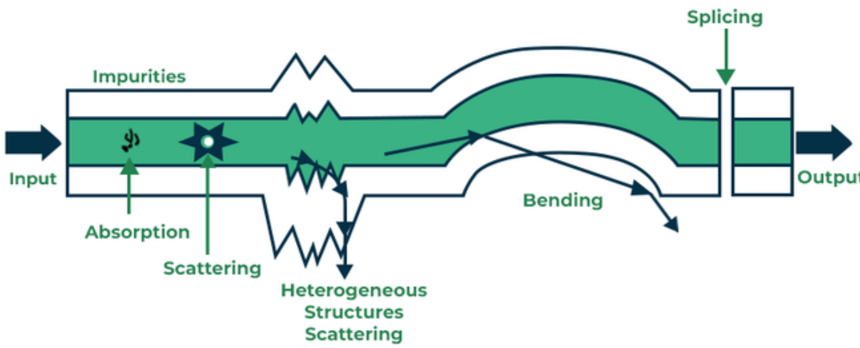


Figure 1.6: Attenuation process in an optical fiber.

1.4.4.1 Material absorption losses in silica glass fibers:

When a photon has sufficient energy, it can excite an electron, causing it to transition to a higher energy level from its initial state. This process results in the absorption of part of the incident light by the material. As illustrated in Figure 1.7[5]

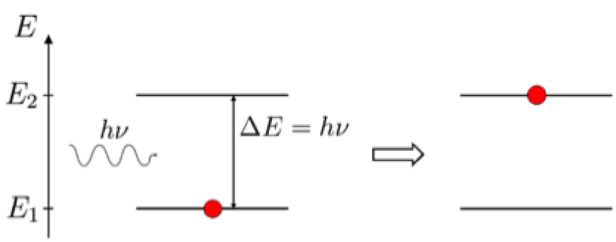


Figure 1.7: Absorption Phenomenon.

- **Intrinsic absorption:** The absorption of light can be intrinsic, resulting from the interaction with one or more of the major components of the glass. It is mainly divided into two categories: due to electronic transitions within the silica structure (UV absorption) or due to molecular vibrations (Infrared absorption).

- **Extrinsic absorption:** Extrinsic absorption is caused by impurities, particularly transition metal elements such as chromium and copper. This type of absorption can degrade fiber performance. However, it can be reduced to acceptable levels through advanced glass refining techniques.

1.4.4.2 Rayleigh scattering:

Rayleigh scattering is a physical phenomenon that occurs due to the non-homogeneity of the material. Part of the light is scattered out of the fiber core resulting in a loss of power. This attenuation is wavelength dependent and decreases rapidly as the wavelength increases. [10]

1.4.4.3 Splicing:

There are two methods of splicing, mechanical or fusion. In both cases, these situations lead to optical losses, which can be caused by:[11]

- Lateral misalignment.
- Longitudinal misalignment.
- Angular misalignment.

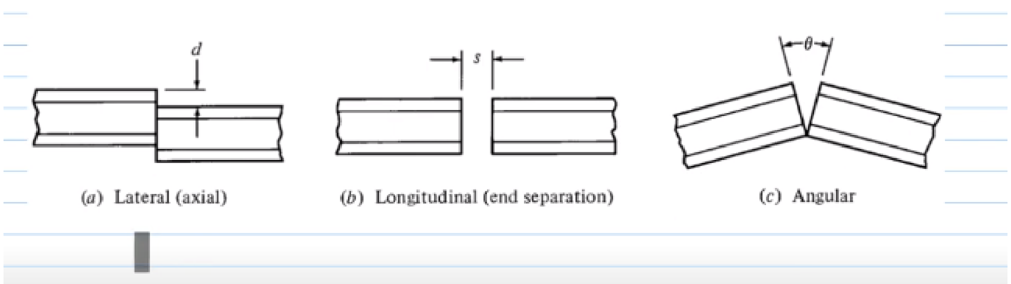


Figure 1.8: The different misalignment in fiber splicing.

1.4.4.4 Macro-bend and micro-bend:

Bending is a common issue leading to optical fiber losses, when a fiber is bent beyond its critical radius; light rays over the acceptance angle escape the core due to failed total internal reflection. There are two main types:[12]

- Micro bending: is the small-scale localized deformation.
- Macro bending: is the large radius bends, typically over 2 mm.

Theses deformation can negatively affect signal performance. Therefore, it is important to minimize them during fiber installation and maintenance.

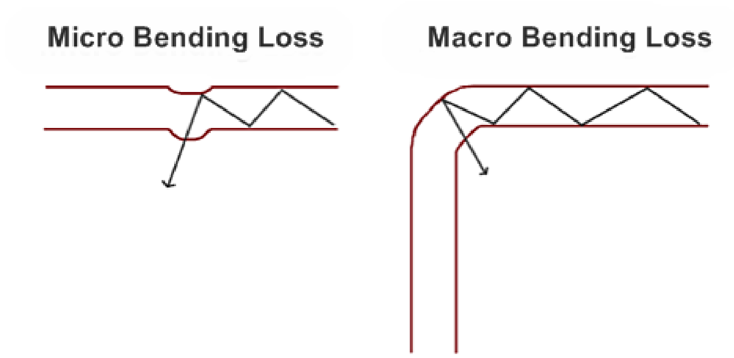


Figure 1.9: Losses due to micro bending and macro bending.

1.4.5 Dispersion in optical fiber:

1.4.5.1 Definition:

Dispersion is a physical phenomenon that occurs during the transmission of light pulses through an optical fiber. It results in a temporal broadening of the pulses, caused by the fact that different components of the signal travel at slightly different speeds. This broadening can lead to overlapping between bits, which reduces the signal quality and limits the amount of data that can be transmitted over long distances.[4]

1.4.5.2 Modal dispersion:

Pulse broadening caused by modal dispersion occurs because different propagation modes In multimode fiber travel along optical paths of varying lengths, resulting in distinct times. As a result, some modes arrive before others, causing the pulse to spread out. This phenomenon, occurs only in multi-mode fibers. [5]

In step index multi-mode fiber, modal dispersion primarily results from differences in path lengths between modes, as their propagation speed is considered identical. The total pulse broadening in graded index multimode fibers is less than that observed in step index multimode fibers. Consequently, graded index fibers offer a significant advantage in terms of bandwidth compared to step index multimode fibers.

Single mode fiber does not exhibit modal dispersion because only one propagation mode is allowed (a straight line). Unlike multimode fibers, there is no dispersion caused by multiple optical paths. As illustrated in Fig 1.10. [11]

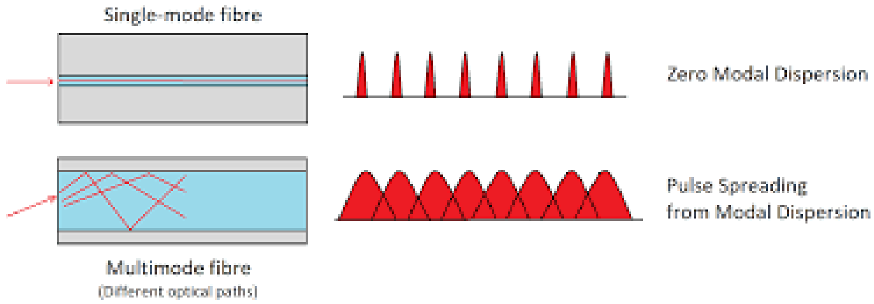


Figure 1.10: Modal dispersion.

1.4.5.3 Chromatic dispersion:

Chromatic dispersion occur in all types optical ber, refers to the difference in propagation speed between the various wavelengths that make up a light source. Since each pulse consists of multiple wavelength, and each one travels at a different speed through the optical fiber, they reach the destination at different times that result the pulse spreading, as illustrated in the fig 1.11.

The delay differences may result from dispersive properties of the waveguide material (material dispersion) and guidance effects within the ber structure (waveguide dispersion). [5]

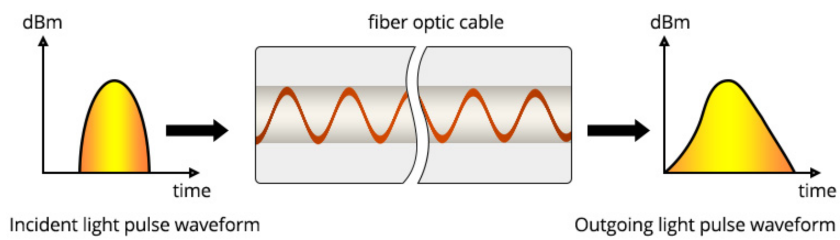


Figure 1.11: Chromatic dispersion.

- **Material dispersion:**

The pulse broadening due to material dispersion is caused by the different propagation speeds of the various wavelength emitted by the optical source, whether it is a LED or laser. [5]

- **Waveguide dispersion:**

  This is because light is not completely confined within the core of the fiber. In reality, the electric and magnetic fields that make up the light pulse extend slightly beyond the core, into the cladding. This ”spillover” of the electromagnetic field into the cladding becomes more significant as the wavelength increases.

  Thus, the light wave experiences an average refractive index between that of the core and the cladding. Shorter wavelengths, being more confined within the core, propagate more slowly than longer wavelengths, leading to the spreading of the light pulse during transmission. This effect is nearly negligible in multimode fibers, where the core is relatively large, but becomes significant in single-mode fibers, where the core diameter is approximately the wavelength.[11]

1.4.6 Non-Linear effects:

Three broad categories of nonlinear effects that can be separated based on their characteristics: Kerr effects, Brillouin scattering and Raman scattering.

- **Kerr effect:**

  The optical Kerr effect occurs when an intense light wave causes a change in the optical properties of a so-called nonlinear medium. Specifically, the refractive index of this material is modulated as a function of the power of the light passing through it. [13]

- **Brillouin scattering:**

  Stimulated Brillouin Scattering (SBS) occurs when an intense light wave interacts with acoustic vibrations in the fiber, provided the optical power exceeds a critical threshold (PsB). This phenomenon generates a backscattered wave whose frequency is slightly shifted from the original signal, with a specific offset determined by the fiber’s properties. Unlike other nonlinear effects, SBS in optical fibers is unidirectional: the generated wave propagates exclusively in the opposite direction to the incident wave.[14]

- **Raman scattering:**

Stimulated Raman Scattering (SRS) is a phenomenon where the interaction between a high-power optical wave (called the pump wave) and the fiber material leads to the generation of a new, lower-frequency wave, along with a vibrational excitation in the glass structure.

This mechanism involves three coupled components: the pump wave, the Stokes wave, and an internal vibration of the medium.

This effect becomes significant only when the pump power exceeds a critical threshold, denoted. Unlike Brillouin scattering, which mainly occurs in the backward direction, stimulated Raman scattering can take place in both forward and backward directions along the fiber.

1.5 Detectors for optical fiber receivers:

In optical transmission systems, semi-conductor detectors (APD photodiodes and PIN Photodiodes) are commonly used to converts the received optical signal into an Electrical signal.

1.5.1 Avalanche photodiodes (APD):

Avalanche photodiodes (APDs) play a critical role in high data rate optical fiber communication systems due to their ability to detect weak infrared signals with high sensitivity. Their performance, particularly in the infrared region up to 3.5 ţm, makes them a preferred choice over standard photodiodes. APDs operate under high reverse-bias voltage, allowing avalanche multiplication, which amplifies the photocurrent generated by incident light. This internal gain enhances the detection of low-power signals, crucial for long-distance or low-intensity optical links.[15]

1.5.2 PIN photodiodes:

The PIN diode is a semiconductor component used as a photo detector, particularly in fiber optic communication systems. It consists of three layers: a positively doped P-layer, an undoped intrinsic layer, and a negatively doped N-layer. When an optical signal transmitted through a fiber reaches the intrinsic layer, the energy from the photons generates electron-hole pairs.

These charges are then separated by the internal electric field of the diode: electrons are attracted to the N-layer and holes to the P-layer, creating a photocurrent proportional to the received light intensity. Thanks to its structure, the PIN diode offers good sensitivity and fast response time, making it a preferred choice for detecting optical signals in high-speed transmission systems.[16]

1.6 Advantages and Applications of optical fiber:

1.6.1 Advantages:

Optical fiber transmission offers several important advantages Compared to traditional communication systems:[4]

- **Low Attenuation:** Modern optical fibers exhibit very low signal loss, allowing for longer distances between repeaters or even their complete removal, which enhances system reliability.
- **Electrical Isolation:** Made from insulating materials (glass or plastic), optical fibers are immune to electromagnetic interference. This ensures high-quality transmission without the need for additional shielding, even in electrically noisy industrial environments.
- **Lightweight and Compact:** Optical fiber cables are at least five times lighter and more compact than traditional coaxial cables. This makes them easier to transport and install, especially in confined spaces like airplanes, ships, or satellites.
- **High Bandwidth:** Due to their large bandwidth capacity, optical fibers can carry multiple channels of data, replacing several conventional transmission paths and offering a major economic advantage.
- **No Crosstalk:** Since optical fibers do not emit or pick up external radiation, they are free from crosstalk, ensuring very high-quality data transmission.

1.6.2 applications:

Thanks to its characteristics, optical fibers are used in a wide range of applications.[9]

- Cable television (CATV).
- Data transmission for control and monitoring in airplanes, ships, cars, trains, measuring systems, industrial facilities, and power networks.
- Interconnection between computers.
- Communication and control in hazardous environments, such as fuel tanks, where the absence of sparks is essential.
- In-building communications, such as between offices.
- Public communication networks:

  a) Between a local exchange and homes (less than 56 km),

  b) Between exchanges within a city (less than 89 km),

  c) Between interurban exchanges (1030 km).

- Submarine and international telecommunications, with repeater spacing ranging from 10 to 100 km, and a total distance of around 10,000 km for an intercontinental connection.

  The use of optical fiber is not limited to the field of telecommunications but also extends to the following fields:

- Industrial applications: require fast and reliable communication and resist extreme conditions (heat, interference, power cuts).
- Medicine in surgery: used in endoscopy, diagnostics, surgery, laboratories.
- Sensors: it can measure deformation, temperature, vibrations, and movement by detecting changes in light.
- Use in other work environments: applied in automotive, plumbing, electrical work, construction, decoration, etc.

1.7 Optical networks:

Optical networks can be classified into two categories based on how optical signal is handled and processed:

1.7.1 All-optical network (or transparent network):

In this type of network, data transmission and exchange occur entirely in the optical domain, from the source node to the end-user node, without any conversion to electrical signals at any Point during the transmission. [5]

1.7.2 Opaque network:

This type of optical network requires optoelectronic conversion at each node. This conversion prevents a purely optical connection, as the signal must be converted at each step of the transmission path.

This architecture leads to additional delays, increased complexity in routing information, and higher energy consumption due to the repeated conversion between the optical and electrical signal.[17]

1.8 Architecture of optical networks:

1.8.1 Backbone networks:

The backbone is the core of a high-speed network. Whether national, or even intercontinental, connect multiple collection networks through access points called ”Operator Points of Presence” (POP). To ensure this interconnection, various technologies are used, such as:Microwave links, Optical links, whether terrestrial or submarine, Satellite links, based on telecommunication satellite.[18]

1.8.2 Collection Networks:

Collection networks form the backbone of regional, departmental, or local loops. Their main function is to provide the connection between long-distance transport networks and access networks, which link end-users through access nodes.

These networks are primarily based on loop architectures and fiber optic technologies. Additionally, the transmission capacity of each fiber is significantly enhanced using wavelength division multiplexing (WDM) techniques. While collection networks are mainly based on optical fibers often referred to as ”optical loops” in certain specific cases. [18]

1.8.3 Access networks:

The access networks, also known as the distribution networks, refers to the entire infrastructure used to connect the end users.[5]

This network enables users to access a variety of telecommunication services through the deployed techniques, including the FTTx (Fiber To The x) technologies, which aim to bring the optical fiber as close as possible to the end user. This helps improve the quality of service, particularly in terms of bandwidth. The most common configuration vary depending on the location of the optical network termination.[2]

1.8.3.1 Optical access networks up to the distribution point:

Fiber optics is deployed up to a distribution point (located, for example, in the center of a residential area).

From there, the final distribution to end users is carried out using another technology such as cables, ADSL, wireless networks, etc...[19]

FTTN (Fiber To The Node):

Fiber to the node is a hybrid network architecture that uses optical fiber and copper. Fiber is used for the transport segment up to the node, while the final distribution to the users is carried out via copper pairs. To improve data rates and reduce signal attenuation, the length of the copper segment is minimized, which also reduces the need for repeaters.

FTTC (Fiber To The Curb):

Fiber to the Curb (FTTC) follows a similar approach to FTTN but brings the optical fiber even closer to end users, typically up to a street cabinet (distribution point) located within 300 meters of the building. This hybrid architecture uses fiber for the main network segment, while the final connection to homes or offices is made using coaxial cables or twisted pairs. These short copper or coaxial links carry the signal from the curb directly into the premises over a minimal distance.

1.8.3.2 Optical access networks to the end-user:

FTTB (Fiber to the Building):

The optical fiber is deployed up to the base of a building, such as a basement or technical room. From that point, the final connection to each user is carried out (100m) using another medium, typically copper or coaxial cables. This technique allows an increase in bandwidth, providing access to ultra-high-speed internet.[19]

FTTH (Fiber to the Home):

This network is a type of telecommunication infrastructure in which optical fiber is extended directly to the subscribers residence. Unlike traditional access networks based on copper cables, such as those used for ADSL connections, FTTH uses optical fiber to deliver significantly higher data rates. This technology can provide up to 2 Gbit/s in both downstream and upstream directions.

Although the installation of FTTH is similar to that of coaxial cable networks requiring the deployment of fiber all the way to the users premises it is mainly implemented in urban areas, where the high deployment cost is more easily justified. However, FTTH remains a relevant solution even in rural environments, as optical fiber can transmit data over long distances without signal degradation, unlike copper cables.[2]

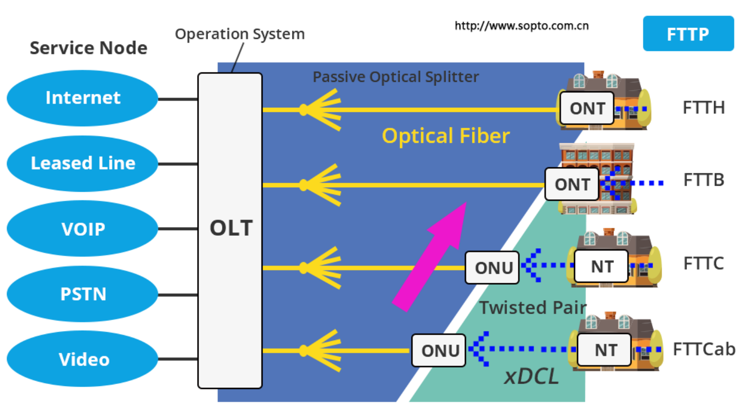


Figure 1.12: FTTx technologies.

1.8.3.3 Access network Layers:

The different components that make up a high-speed network are organized into three distinct layers:[3]

- **Infrastructure layer:**

  The physical infrastructure layer includes, among other components: ducts, technical conduits pulling chambers street cabinets, and technical facilities.

- **Passive layer:**

  The passive optical infrastructure layer primarily includes fiber optic cables, splicing enclosures, patch panels, building distribution frames, distribution splitters, termination blocks, and various connection accessories, connection points, and other passive components that ensure the optical signal reaches the end-user.

- **Active layer:**

  The network architecture layer consists of the electronic network equipment. At this level, the fiber is activated to deliver bandwidth to operators. The performance of different general communication technologies must be evaluated from the perspective of the system architecture layer.

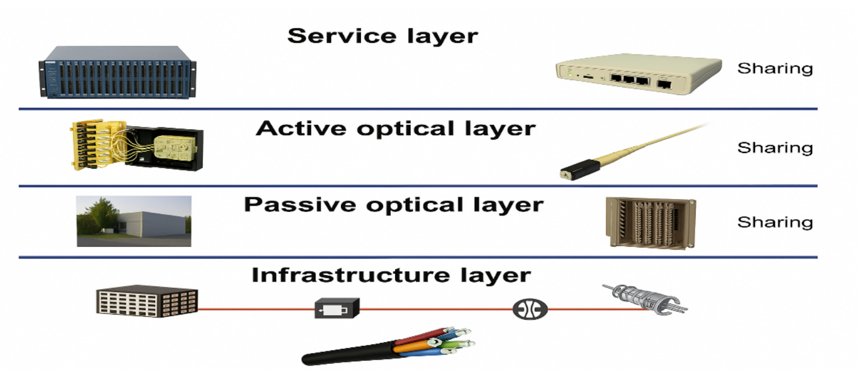


Figure 1.13: Access network Layers.

1.9 Conclusion:

In this chapter, we explored the fundamental elements of an optical fiber link as well as the different types of networks in which this technology is implemented.

First, we presented the essential components of an optical link (LED and laser), the optical fibers themselves, their structure, classification and characteristics, as well as optical receivers (APD and PIN photodiodes). Then, we highlighted the various application domains of optical fiber, which go far beyond traditional telecommunications and now extend to various sectors.

Finally, an introduction to optical networks allowed us to distinguish the different access networks.

In the next chapter, we will address the concrete design and implementation of FTTh network.

CHAPTER 2

Deployment of an FTTh passive network

2.1 Introduction

In response to the growing demand for high-speed internet, FTTx technologies have become a major focus in the development of modern communication infrastructures. This chapter focuses on the study and installation of a passif FTTH network,which represents the best solution due to its reliability and many advantages.

2.2 FTTH architectures:

2.2.1 Passive Point-to-point (P2P) architecture:

In a P2P topology, each subscriber is connected through their own dedicated fiber that runs directly from their home to the Access Node As illustrated in Figure 2.1. The path between the distribution node and the end user may include several segments of fiber joined by splices or connectors, but it always provides a continuous optical path. [2]

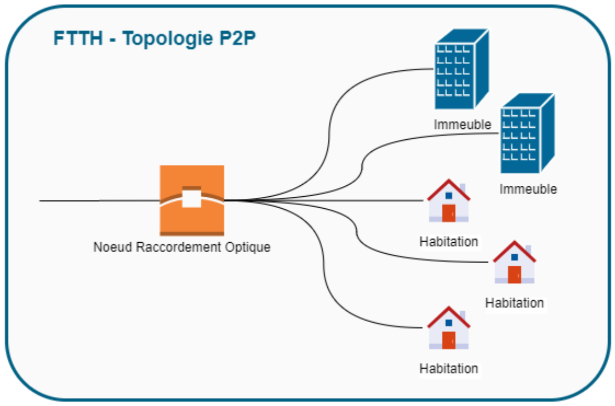


Figure 2.1: Point-to-point architecture.

2.2.1.1 Advantages:

- Dedicated bandwidth for each user, allowing high speeds (over 1 Gbps if needed).
- Symmetric bandwidth, ideal for HD video conferencing and file sharing.
- Easy to test and maintain, offering flexibility in varied environments.
- Scalable and durable architecture, suited for future bandwidth needs.[20]

2.2.1.2 Disadvantages:

- Higher cost due to the larger number of components.
- Longer deployment time, with more cabinets and distribution points needed.[20]

2.2.2 Passive Point-to-multipoint (PON) architecture:

PON use a single "feeder" fiber from the OLT to the branching point, from which individual dedicated fibers are deployed to each user. A passive optical network technology like GPON uses passive optical splitters at the branching points, and the data is encoded so that each user only receives data intended for them.[2]

This work will primarily focus on this type of architecture, chosen for the design of our FTTH network.

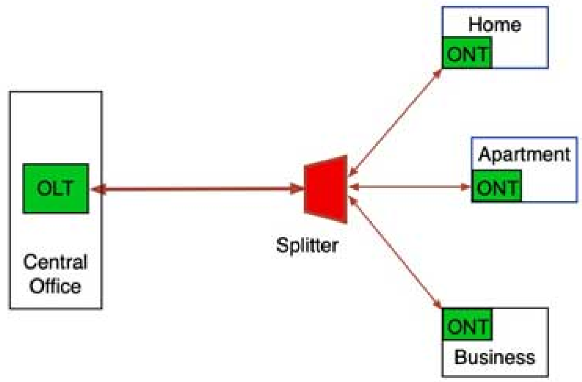


Figure 2.2: Point-to-multipoint architecture [1].

2.2.2.1 Transmission directions:

- **Downstream (OLT to ONT):** In the downstream direction, the data sent by the OLT is labeled according to its intended recipient. As a result, all ONTs receive the data, but only the targeted ONT forwards it to the subscriber's local network.[21]
- **Upstream (ONT to OLT):** In the upstream direction, since the optical splitter is a passive component, it's necessary to clearly identify which ONT is transmitting. Two methods can be used for this purpose:

  The first, is based on time division,the second method involves using a different transmission wavelength for each ONT.

  However, the second method is more expensive to implement, which is why it is rarely used for upstream transmission. Nonetheless, it is already applied to achieve full-duplex communication on the fiber, with each direction using a different wavelength.[21]

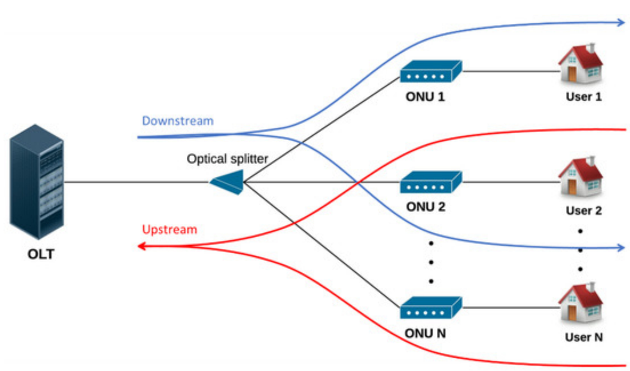


Figure 2.3: Transmission directions, downstream and upstream.

2.2.2.2 PON standards:

- **ATM PON (APON):** It is based on PON technologies combined with ATM. It offers a downstream speed of 155 or 622 Mbit/s and an upstream speed of 155 Mbit/s, shared among 32 users. However, the APON solution is expensive and complex to implement. It does not support video services, has limited bandwidth, and clock recovery can be challenging it is standardized by ITU-T G.983.[22]

- **Broadband PON (BPON):** it is an evolution of the APON standard, adapted to support video transmission. It uses Wavelength Division Multiplexing (WDM) technology and provides dynamic bandwidth allocation. This system allows voice and data to be transmitted over the same fiber, while reserving specific wavelengths (overlay wavelengths) for digital and analog television.

  BPON supports downstream speeds of up to 1 Gb/s and upstream speeds of up to 622 Mb/s, although in practice, the upstream rate is often limited to 155 Mb/s, it is standardized by ITU-T G.983.[22]

- **Ethernet PON (EPON):** This standard uses the Ethernet protocol for data transmission. It supports a symmetrical data rate of up to 1.25 GB/s per port, shared among up to 64 users. The maximum reach is approximately 20 km, depending on the number of connected subscribers; it is standardized by IEEE 802.3ah.[23]

- **Gigabit PON (GPON):** A more recent standard that uses either ATM or Ethernet as transport protocols. It provides a maximum downstream rate of 2.5 Gb/s and an upstream rate of 1.25 Gb/s per port, shared among up to 64 users. The reach can extend to about 60 km, depending on the number of users connected per port; it is standardized by ITU-T G.984.[23]

- **XG-PON:** offers improved performance with 10 Gbit/s downstream and 2.5 Gbit/s upstream, also over a shared fiber. It is defined in the ITU-T G.987.x standard. [24]

- **XGS-PON:** goes even further by delivering 10 Gbit/s both downstream and upstream (symmetric), although some implementations may still use 2.5 Gbit/s upstream. It is standardized under ITU-T G.9807.1. [24]

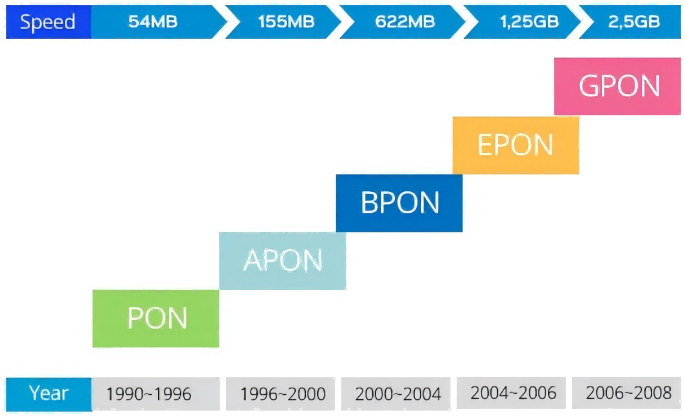


Figure 2.4: evolution of PON technology.

2.2.2.3 Advantages:

- Cost Reduction: Fewer optical ports and cables required, leading to lower installation and maintenance costs.
- Passive Infrastructure: Optical splitters do not need power, allowing flexible installation locations.
- Simplified Deployment: Fewer active components and faster implementation compared to P2P networks.[20]

2.2.2.4 Disadvantages:

- Shared Bandwidth: Bandwidth is divided among multiple users, leading to lower performance during high usage.
- Asymmetric Bandwidth: Download speeds are higher than upload speeds, limiting applications that need high upload.
- Performance Limits: Splitters cause signal loss and may not suit high capacity or long-term networks.[20]

2.2.3 Comparative study of PON and P2P deployment:

In a PON, fiber deployment is divided into three main parts:[25]

- Horizontal cabling: this involves laying fiber in the streets. A single fiber is deployed by the operator to serve subscribers, using passive splitters to distribute the signal.

- Vertical cabling: this refers to the fiber installed inside buildings. Typically, one fiber is laid to each apartment, starting from a mutual connection point located at the base of the building.

- Transition zone: this zone links the fibers of the infrastructure operator with the subscribers' fibers. This transition is achieved using passive optical splitters, which divide the optical signal among users.

In contrast, an FTTH P2P network connects each subscriber directly to the optical distribution node (ODN) using a dedicated and bidirectional fiber. This means the fiber is not shared each user has their own private connection. For both horizontal and vertical cabling, one fiber per household is required. While this approach demands a more extensive infrastructure, it offers higher performance and greater scalability.[6]

2.2.4 Selection criteria:

Several criteria are taken into account when choosing the network architecture:[6]

- **User density:** In high-density residential areas, PON architecture is recommended, as one fiber can serve multiple users through optical splitters, but in low-density areas, P2P architecture is more suitable, since each user requires a dedicated fiber.

- **Distance:** In terms of reach, Point-to-Point networks typically cover up to 10 km, although longer distances are possible depending on the optical transceivers used. On the other hand, PON standards such as GPON and XGS-PON support distances of 10 to 20 km, with the actual limit depending on the optical power budget and the number of splitters in the network.

- **Cost:** The overall infrastructure cost depends on several factors, including material prices, conduit availability, site topography, and local labor costs.

- **Bandwidth:** Today access networks need to provide data rates of up to 300 Mbit/s per user in order to meet the growing demand for high-definition television (HDTV), smooth internet browsing, and high-quality video calls. Current FTTH architectures, including both PON and P2P, are fully capable of delivering such bandwidth, thanks to advancements in optical technologies and improved network configurations.

- **Security:** In PON architecture, the shared medium requires encryption to secure the user data, but in P2P, each user has a dedicated fiber, which ensure better isolation and privacy.

2.3 Design and dimensioning of the FTTH passive network:

To ensure an optimal FTTH network installation, it is crucial to follow a structured methodology that guarantees network performance, long-term reliability, and cost control. The key steps are as follows:

2.3.1 Study of the Existing Situation and Needs Definition:

This initial phase aims to analyze the geographical area concerned by the FTTH network deployment. It begins with the collection of administrative and technical data, including:

- The location map of the area,
- The subdivision plan,
- Architectural plans,
- The type and number of dwellings (urban, suburban, or rural),
- The type of area (single-family housing, collective housing, or mixed),
- Population density,
- The possible installation methods (aerial, underground, façade, etc.).

In a second step, the study involves identifying and marking the needs on the plans, and, if necessary, conducting field surveys. These surveys help assess the nature of the dwellings, identify existing infrastructure (such as manholes, ducts, or poles), and gather any other relevant information to better define the needs of the area under study.[3]

This approach is essential to ensure the technical and economic feasibility of the FTTH project.

2.3.2 architecture and topology selection:

passive optical network provides three architectures:[23]

- **Star architecture:** in this configuration, each PON port of the OLT is connected to a unique splitter. This splitter directly serves multiple ONTs.

- **Tree architecture:** This is the most commonly used architecture in PON networks. It consists of cascading multiple optical splitters to form a tree-like structure as illustrated in figure 2.5. The first splitter is often located at the Optical Distribution Frame (ODF) or in a secondary optical distribution point; the second splitter is placed closer to the subscribers, for example, inside buildings.

  This architecture allows efficient sharing of the OLT port capacity across multiple levels.

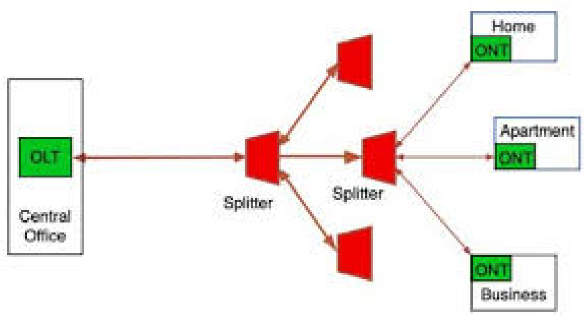


Figure 2.5: PON tree architecture [1].

- **Bus architecture:** This architecture consists of the serialization of the optical splitters.

2.3.2.1 Split ratio selection:

In the case of a PON network, the infrastructure is shared among subscribers with optical splitters. These passive components distribute the downstream optical signal to multiple users and combine the upstream optical signals into a single stream without the need for electrical power.

In FTTH networks, they are widely used to distribute the signal from the OLT (Optical Line Terminal) to several ONTs (Optical Network Terminals) located at subscribers' premises. [3]

A large part of the design time is generally spent deciding on the optimal placement of splitters to optimize the cable network. In dense urban areas, the high subscriber density may justify using a single 32 port splitter. In less dense areas, it is often more efficient to cascade splitters to achieve the 32 way split or 64. Splitters are available in binary ratios (2, 4, 8, 16, 32) and can be cascaded in any order.

2.3.2.2 Types of splitters:

PLC optical splitters is the most commonly used in optical networks, it can be classified according to the type of chip they use, which defines their configuration as 1ŒN or 2ŒN (for example: 1Œ4, 1Œ8, 1Œ16, 2Œ32, 2Œ64, etc.).

The choice of the number of input and output ports depends on the installation conditions, such as cable length or network requirements.[26]

Figure 2.6: PLC optical splitter.

2.3.2.3 WDM Components:

Wavelength Division optical multiplexers are used in FTTH networks to:[27]

- Monitor the network (optical budget),
- Transmit signals at specific wavelengths (such as 1550 nm, 1625 nm, 1650 nm),
- Allow the coexistence of multiple PON technologies (G-PON, XG-PON, NG-PON2...).

These components, similar in appearance to optical splitters, act as filters by isolating specific wavelengths. When used; they are typically installed at the level of the Central Office.

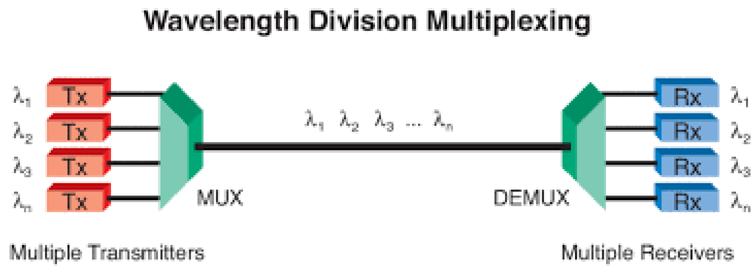


Figure 2.7: wavelength division multiplexing.

2.3.3 Fiber Optic Cables:

This step defines the number and type of fibers required in each segment of the network. Transport and distribution sections.

In FTTH networks, G.652.D fiber is generally used outdoors in transport and distribution part, while G.657.A fiber is used inside buildings in the connection part of the network:[2]

G.652.D:

The main characteristics of G.652.D optical fiber are as follows:

- Attenuation of approximately 0.35 dB/km at wavelengths of 1310 nm and;
- Lower attenuation around 0.23 dB/km at 1550 nm;
- Polarization Mode Dispersion (PMD) 0.2 ps/km;
- Chromatic dispersion of about 18 ps/nmkm at 1550 nm;
- Zero chromatic dispersion around 1310 nm.

This fiber optic cable consists of:[28]

-Optical fiber (strand)

-Tube (loose tube) containing 12 optical fibers (strands)

-Dielectric central strength member

-Water-blocking tape

-Inner sheath ripcord

-Inner sheath

-Water-blocking yarn

-Outer sheath ripcord

-Outer sheath.

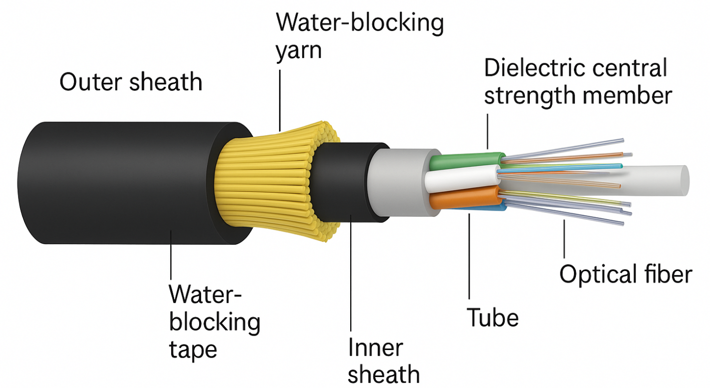


Figure 2.8: G.652.D cable.

There are several types of fiber optic cables, classified according to the number of loose tubes (tubes) and fiber strands they contain:

FO 72: 6 loose tubes / 72 fibers

FO 48: 4 loose tubes / 48 fibers

FO 36: 3 loose tubes / 36 fibers

FO 24: 2 loose tubes / 24 fibers

FO 12: 1 loose tube / 12 fibers

In practice, especially in Algeria, the most commonly used fiber optic cables are the FO72 and FO36 types.

G.657:

The G.657 fiber designed to support very small bending radii, there are several types of this fiber (A1,A2,B2,B3),but G.652A2 is currently the most used in FTTH access networks due to its higher bend tolerance and compatibility with G.252D fiber.

G.657.A2:

This optical fiber plays a key role in FTTH network deployments due to its advanced technical characteristics:

- Designed to withstand very small bending radii;

- it is particularly well suited for confined environments such as inside buildings where space is limited;

- Its high flexibility allows for optimized installation in splice boxes and handholes, while ensuring low attenuation levels.

These features make it a valuable tool for network operators, enabling easier integration of future active transmission equipment upgrades.

2.3.3.1 Aerial cables:

This type of fiber optic cables is usually used for outside installation on poles. Due to its installation environment, the design of aerial fiber optic cable must consider to protect it from the destruction of the nature and manufactured damage or theft. Aerial cable's laying method is not hard to implement as it can utilize the existing overhead pole line.

They are easily affected by the natural disasters, as well as the influence of an outside force and the mechanical strength weakening in themselves. Therefore, the failure rate of aerial fiber optic cables are higher than the pipeline or directly buried fiber optic cables.[29]

2.3.3.2 Underground cables:

Underground cables are fiber optic cables specifically designed for installation in ducts or for direct burial. Their robust construction ensures the durability and reliability of the network, both at the backbone level and in the access network up to the subscriber.

These cables are available in uni-tube or multi-tube versions, depending on the requirements of the network architecture.[30]

2.3.3.3 Façade cables:

- **Façade cables with permanent accessibility:**

  Designed for discreet deployment along building facades, including sharp bends and cornices, these cables are flexible and compact (12 mm in diameter). Their UV-resistant polyethylene sheath ensures high durability against impacts and compression. Each cable can carry up to 72 fibers.[27]

- **Outdoor drop façade cables:**

These cables are used for subscriber connections they contain 1 to 4 optical fibers. Flexible and easy to install, they feature a UV-resistant, halogen-free sheath.[27]

- **in-building cables(Patch cord):**

  An optical fiber patch cord is a fiber optic cable terminated with connectors on both ends, designed to connect equipment to a fiber optic cabling system.[31]

  In FTTH SC-APC to SC-APC is the most commonly used.

Figure 2.9: SC-APC to SC-APC Patch cord.

2.3.4 Optical budget calculation:

2.3.4.1 PON Loss Budget:

In a PON, the system must respect specific power levels at the receiver to work properly. For example, in a GPON network, the optical loss budget must be between -13 dBm and -28 dBm. This means that the total losses in the link should not be lower than 13 dB (to avoid too much power at the ONT) and must not exceed 28 dB (to stay above the receiver sensitivity).

When designing the network, we need to calculate all losses in the optical path, including:

- Fiber attenuation (dB/km).
- Splice losses.
- Connector losses.
- Splitter losses.

- And an engineering margin.

Table 2.1: Optical fiber cable attenuation.

Name	Type	Attenuation (dB)
Optical fiber (G.652D)	1310 nm per 1 km	< 0.35
	1550 nm per 1 km	< 0.22
	1490 nm per 1 km	< 0.23

2.3.4.2 Example of GPON budget calculation:

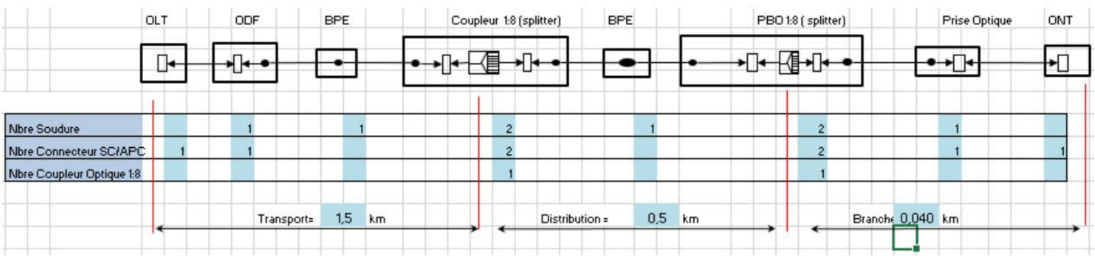


Figure 2.10: FTTH link.

Table 2.2: Total Attenuation of a FTTH Link

Designation	**Attenuation (dB)**	**Quantity**	**Unit**	**Losses (dB)**
Fiber Optic Cable at 1550 nm	0.35	2.04	km	0.47
Connector	0.3	8	unit	2.4
Splice	0.1	7	unit	0.7
Optical Splitter	10.6	2	unit	21.2
Total				**25.014**

So, a typical PON budget calculation looks like this:

$$Att_{\text{total}}[dB] = \alpha_{\text{lin}}[\text{dB/km}] \times L[\text{km}] + \sum Att_{\text{spli}}[dB] + \sum Att_{\text{conn}}[dB] + \sum Att_{\text{splitter}}[dB] \quad (2.1)$$

- Att_{total} : Total attenuation of the optical link (in dB).

- α_{lin} : Linear attenuation coefficient of the fiber (in dB/km).
- L : Length of the fiber optic link (in km).
- $\sum Att_{\text{Spli}}$: Sum of attenuation due to splices (in dB).
- $\sum Att_{\text{conn}}$: Sum of attenuation caused by connectors (in dB).
- $\sum Att_{\text{splitter}}$: Sum of attenuation due to optical splitters (in dB).

Fiber: 1.34 km Œ 0.35 dB/km = 3.5 dB
Splices: 7 Œ 0.1 dB = 1 dB
Connectors: 8 Œ 0.5 dB = 0.6 dB
Splitters (1Œ8): 10.6 Œ 2 dB= 21.2 dB
Total = 25.014 dB

$$M\ [dB] = (P_{\text{Tx}}\ [dBm] - S\ [dBm]) - (Att_{\text{total}}\ [dB])$$

- M : Power margin (also called safety margin), in dB.
- P_{Tx} : Transmitter output power, in dBm.
- S : Receiver sensitivity, in dBm.
- Att_{total} : Total attenuation of the link, in dB.

margin is : [dB] = 7.9 dB.

2.3.5 Civil work planning:

During the deployment of an FTTH network, civil engineering works are essential for installation of underground and aerial cables. Below are some of the components used in :[27]

2.3.5.1 Ducts:

Ducts are conduits installed underground to allow the routing and protection of fiber optic cables. They can be used in existing infrastructure or in newly built networks. Ducts make it easier to install cables using methods such as pulling, air blowing, or water floating.

There are mainly two types of ducts:

- PVC (Polyvinyl Chloride): affordable and easy to handle, mostly used over short distances, but not very pressure-resistant.

- HDPE (High-Density Polyethylene): more durable and suitable for modern installation techniques, making it ideal for new networks.

Figure 2.11: Underground ducts of FTTh deployment.

2.3.5.2 Micro-ducts:

Micro ducts are small HDPE conduits used for blowing optical fiber cables, especially in FTTH networks. They can be installed inside larger ducts or directly in the ground. Thanks to their pressure resistance, they enable long-distance deployment. Available in various diameters, they can be used individually or bundled to serve multiple endpoints. Their installation is simple, fast, and suited to various environments (residential buildings, multi-dwelling units, industrial zones).

2.3.5.3 Ducts chambers:

Duct chambers are made of reinforced concrete and may include a riser. They are equipped with a grill, a steel frame, access covers, and entry masks for duct passage, as well as access accessories (hooks, rungs) and cable management components.

2.3.5.4 Aerial poles:

There are mainly three types of poles used: wooden poles, galvanized steel poles, and, experimentally, poles made of fiberglass-reinforced resin. Most of them are simple in structure.

The average distance between two poles is around 35 meters, but depending on the network layout or the terrain conditions, this distance might need to be reduced and reinforced in certain cases.[27]

2.4 Implementation of an FTTH network:

The deployment of an FTTH network is a costly task that requires proper planning of point of presence, as well as prior knowledge of roads, rivers, and other public infrastructure in the area covered by the network.

2.4.1 Fiber path in the FTTH access network:

The Fiber to the Home network is made up of three main parts: Transport, Distribution and Connection.

- **Transport:** This is the connection between the Optical Distribution Frame (ODN) and the Mutualization point (MP).
- **Distribution:** This links the MP to the Optical Branching Point (OBP).
- **Connection:** This final part connects the OBP to the Optical Terminal Outlet (OTO) inside the users premises.

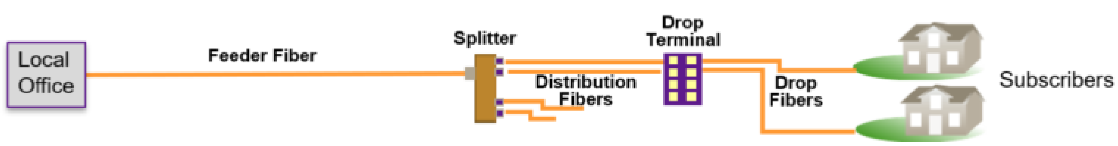


Figure 2.12: fiber optic path.

2.4.2 Optical distribution node (ODN):

The Optical Distribution Node is a technical facility that serves as the starting point of the fiber network towards end users. It houses active and passive equipment for operators as well as:

- an access control and intrusion detection system
- a fire safety system

- a 48V power workshop

- an inverter and batteries

- air conditioning

- optical line termination (OLT) .

- Optical distribution frame (ODF):

Its capacity can reach up to 50,000 fiber lines (FO), depending on the area served as illustrated in table 2.3. The technical room size depends on the technology used, with a recommended design for PON deployment. [3]

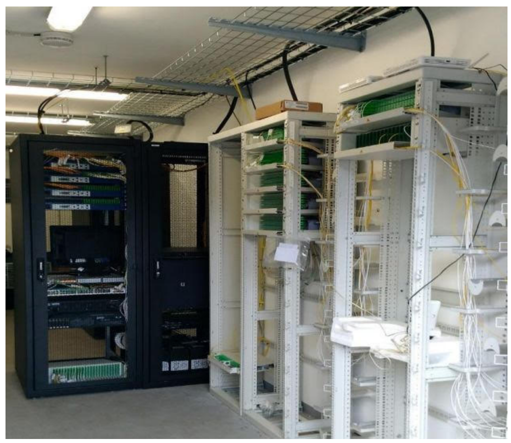


Figure 2.13: The Optical Distribution Node.

Table 2.3: fiber count and distance by area type[2].

Type of area	**OF number**	**Distance between user and ODN(km)**.
Very dense urban area	4000 to 30 000	1 to 2.
Urban area	5000 to 50 000	1 to 5.
Rural area	2000 to 10 000	3 to 10.
Economic area	2000 to 10 000	1 to 3 .

2.4.2.1 Optical line termination :

It is an active component located in the ODN that comes in the form of racks containing several cards with ports. Each port can serve up to 64 users. With 16 cards in a single OLT, it can support around 16,000 users.

Its main role is to convert electrical signals into optical signals for transmission via fiber cables and manages data traffic and assigns communication channels to users.[3]

Figure 2.14: Optical line termination.

2.4.2.2 Optical distribution frame :

An Optical Distribution Frame is a device used to manage fiber optic cable connections in FTTH network installations. It combines fiber splicing, termination, connectors, and adapters in one unit.

The ODF also protects fiber connections from physical damage. There are three main types: wall-mounted, floor-mounted, and rack-mounted.[3]

Figure 2.15: wall-mounted Optical distribution frame.

2.4.3 The Mutualization point:

The Mutualization Point is an optical cabinet, usually located outdoors, which serves as the junction point between the transport network and the distribution network in an FTTH architecture.

It enables the connection between the fibers coming from the OLT and the distribution fibers going toward the users. This point typically contains passive optical splitters (1:N), which allow a single fiber from the ODN to be shared among multiple end users.[27]

2.4.4 The Splice Protection Point:

The Splice Protection Point (SPP) plays a key role in optimizing and adding flexibility to FTTh networks. It is installed in a manhole and allows a transport cable to be split into several secondary cables, which then supply multiple ODFs in the distribution part or optical branching points (OBPs).[27]

Enclosure Type	**Fiber Capacity**	**Number of Cassettes**
Type 1	24FO	2
Type 2	48FO	4
Type 3	72FO	6

Table 2.4: Different types of Splice Protection Point.

2.4.5 Fiber distribution terminal (FDT):

The fiber distribution terminal is an outdoor cabinet that is usually installed on the street.It serves as the connection point between the transport network and the distribution network.

Figure 2.16: Fiber distribution terminal.

In FTTH architecture, the FDT is placed between the ODF and OBP.

From ODF to FDT, fiber deployment follows several technical steps:[32]

a) Using existing infrastructure: Fiber optic cables are mainly routed through existing civil engineering infrastructure, specifically the underground ducts of the installed copper telephone network.

b) Accessing manholes (pulling chambers): Approximately every 1 to 2 kilometers, a manhole must be opened to guide and pull cables through, which is a critical step in ensuring network continuity.

c) Performing fiber splicing: At specific locations, fiber splicing is carried out to connect cable sections, ensuring seamless transmission of optical signals without loss.

2.4.6 Fiber distribution closure:

2.4.6.1 Building entry point:

It is a box installed in the basement of the building, where the optical fiber cable from the Infrastructure Operator arrives. It is the same type of box that is used in manholes to ensure optical continuity in both transport and distribution networks.[33]

2.4.6.2 Optical branching point (OBP):

is a box installed at the end of the final customer cabling. It is the point where the optical outlets of customers are connected to the vertical fiber optic network.

It is located just downstream of the Mutualization Point (MP) and just before the start of the final customer cabling, which connects the OBP to the Optical Terminal Outlet (OTO) inside the home. There are two types: Indoor and Outdoor. [25]

- **indoor Optical Branching Point:**

  This type of optical connection box is typically found in apartment buildings, where it is installed on each floor or every other floor.

  it is also known as the Floor Distribution Box , connects each apartment to the buildings vertical fiber optic backbone. It serves as an intermediate distribution point, allowing technicians to easily manage, connect, or troubleshoot fiber links to individual units during installation or maintenance operations.[25]

Figure 2.17: indoor Optical Branching Point.

- **outdoor Optical Branching Point:**

  This type of Optical Branching Point (OBP) is usually installed on the façade of individual houses. Typically, one OBP is placed for every three houses. For safety reasons, it is installed at a height between 2 and 4 meters.

In less densely populated areas, the OBP can be installed in various types of infrastructure: underground, on façade, or on poles. The main goal is to make the most of existing infrastructure and use paths already taken by other networks. In such areas, the OBP is generally located: in an underground chamber, on a telecoms or electricity pole,or on the building façade.[3]

Figure 2.18: pole-mounted OBP.

2.4.7 The Optical Termination outlet:

The Optical Termination outlet is the terminal part of the access network it is a white box installed inside the user's home. This box contains an optical socket to which the user connects their modem (ONT) in order to access the services provided by the FTTH network.[34]

Figure 2.19: The Optical Termination outlet.

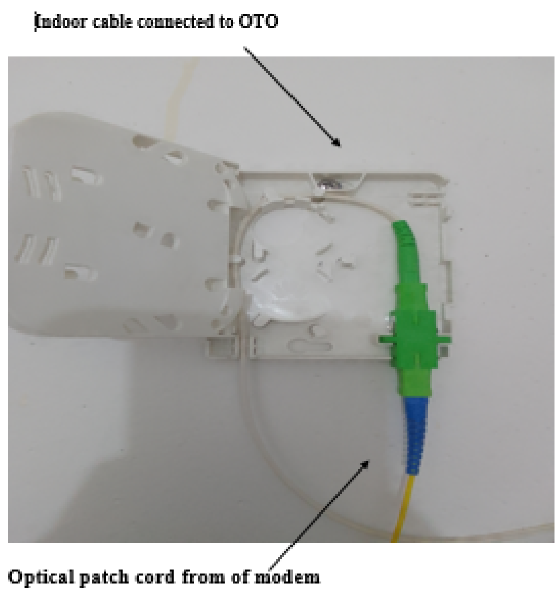


Figure 2.20: The Optical outlet with indoor cable connected to the modem's patch cord.

2.4.8 Optical network terminal (ONT):

The ONT is a key component in fiber optic networks, especially in FTTH or PON architectures. Main functions of the ONT:

- Converts optical signals received via fiber into electrical signals.
- Transforms light pulses into usable digital data for the clients equipment.

- Performs error correction on received data.

- Filters both incoming and outgoing data flows.

- Sends data to the local network through Ethernet ports.

- Converts user-generated data into optical signals for upstream transmission.

- Provides the transition between the FTTH/PON (optical) and Ethernet/IP (client-side) protocols.

- Encapsulates Ethernet frames for transport over the shared GPON network[6][35]

Figure 2.21: Optical network terminal front view.

Figure 2.22: Optical network terminal rear view.

2.4.9 Optical splicing and connectorization techniques:

2.4.9.1 Fiber optic Splicing:

Splices are a methods used permanently to connect two optical fibers. Once done, they cannot be taken apart. They ensure good signal continuity with very low optical loss, low reflectance (signal return), and strong resistance to pulling.

They are mainly used during the network installation phase to connect fibers along the infrastructure, from the Optical Connection Node to the Branching Point. Splices are also used in the final subscriber connection between the Optical Branching Point and the Optical Terminal Device inside the home.

Two technologies are common for splicing fiber to fiber:

- **Fusion splicing:** Fusion splicing involves the generation of an electric arc between two electrodes to join two optical fibers. After cleavage, the fibers are carefully aligned and grouped in the arc zone, allowing their ends to melt and fuse. Virtually all single-mode splices are fusion.

  The optical loss of the splice depends on the technology of the splicing machine, especially its alignment system. High-precision splicers use core alignment, which means that they align the fiber cores directly (9 ţm), resulting in high-quality splices with typical losses of 0.1 dB.[36]

- **Mechanical splicing:** Mechanical splicing involves aligning the ends of two properly cleaved optical fibers to allow light to pass through efficiently.

  This method is also used when connecting fibers to connectors. An index-matching gel is commonly applied. Different manufacturers use various techniques to achieve this type of splice.

  There are two types of cleaves used in mechanical splicing: angled and straight. Angled cleaves generally provide better return loss performance, although they can be more complex to handle. Typically, the loss of insertion of a mechanical splice is 0.1 dB. [36]

The table below show the technical specifications of a mechanical splice:

Table 2.5: Technical specifications of a mechanical splice[3].

Fiber	125 ţm, 250 ţm
Insertion loss	< 0.1 dB (typical), < 0.3 dB (max)
Reflection	< -40 dB
Wavelength	1310 nm, 1490 nm, 1550 nm, 1625 nm
Temperature	-40řC to +75řC

2.4.9.2 Connectors:

Connectors allow two optical fibers to be linked in a removable way, making connection and disconnection operations easier. They are mainly used at network operation points and at the end of the network, on the subscribers side.

There are different types of connectors used in FTTH networks:

- **Fiber connector (FC):** This is a first-generation of single mode connectors, known for its durability and proven reliability, its threaded coupling mechanism makes it less suitable for confined spaces. As a result, it is rarely found in modern racks where high connection density is required.[19]

- **Straight tip (ST):** BNC-type bayonet connector without a positioning key.Designed for multimode fiber; the lack of axial precision leads to poor reproducibility with single-mode fiber.[37]

- **Lucent connector (LC):** This connector, similar to an RJ45 with its push/pull mechanism, features a more compact body than the SC connector. It is especially suited for increasing the density of front panel connections, making it a preferred choice in FTTH deployments. Optically, it is designed for single-mode applications, with an average insertion loss of about 0.1 dB. It uses a 1.25 mm diameter ferrule.[37]

- **Subscriber Connector (SC):** This type of connector is widely used in single mode systems, featuring a square design and a push/pull connection system, is particularly recommended for new installations. The SC allows for high integration density and used in duplex or multiplex configurations. Although it is one of the oldest connectors, it remains widely used today due to its excellent optical performance.[2]

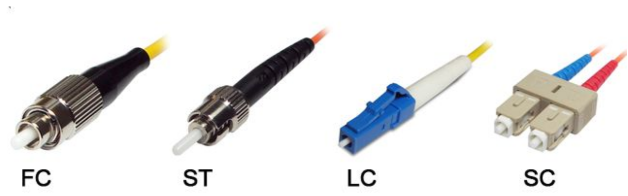


Figure 2.23: FC, LC, SC and ST Connectors.

PC (Physical Contact): PC fiber connector is a polishing type designed to reduce the air gap between two fibers, improving return loss around -40 db compared to -14 db for flat-polished connectors.it was commonly used with OM1 and OM2 multimode fibers but is now considered replaced by UPC polishing.[38]

UPC (Ultra Physical Contact): UPC is an improved version of the PC polish, with a smoother end-face achieved through extended polishing. It offers better performance, with return loss around -50 dB. However, it is less durable frequent plugging and unplugging can wear down the surface and reduce performance.[38]

APC (Angled Physical Contact): APC connectors were developed to achieve even lower return loss. They have an end-face polished at an 8ř angle, which deflects reflected light into the cladding instead of back into the fiber core. This design greatly reduces signal reflection, with a typical return loss of -60 dB or better.[38]

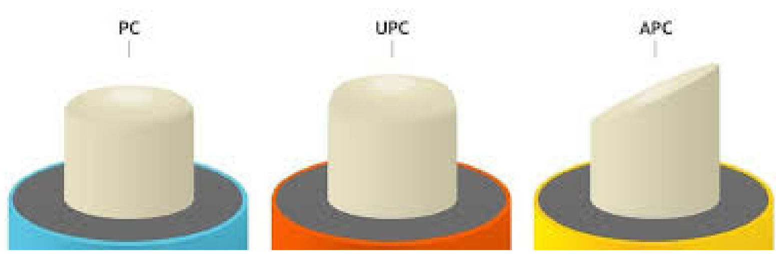


Figure 2.24: PC, UPC and APC connectors.

2.5 Testing and validation procedures:

2.5.1 Optical time Domain reflectometer (OTDR):

An OTDR, is a device used to test optical fibers. It works based on the principle of reflectometry and helps analyze the characteristics of the fiber, such as its length, signal loss, and the location of any faults. This tool is widely used in telecommunications to detect problems that could affect the quality of the optical signal.[39]

Figure 2.25: Optical time Domain reflectometer (OTDR).

2.5.1.1 Principle of operation:

The OTDR sends strong light pulses into the fiber using a laser. As the light travels through the fiber, it hits different things like connectors, splices, breaks, or the end of the fiber. These points cause changes in the fibers refractive index, which creates reflections (called Fresnel reflections) that bounce back to the OTDR. By measuring how long the reflections take to return, the OTDR can figure out exactly where these events are happening.

In addition, because the fiber is not perfect and has tiny flaws, a small part of the light gets scattered in all directions. This is called backscattering.

The OTDR analyzes both the backscattered light and the reflections to give detailed information about the fibers condition like signal loss and any possible issues. [40]

2.5.1.2 Understanding OTDR trace result:

An OTDR provides a visual representation of signal loss along a fiber. Each change in the trace indicates a specific event, helping to identify and diagnose issues within the link.

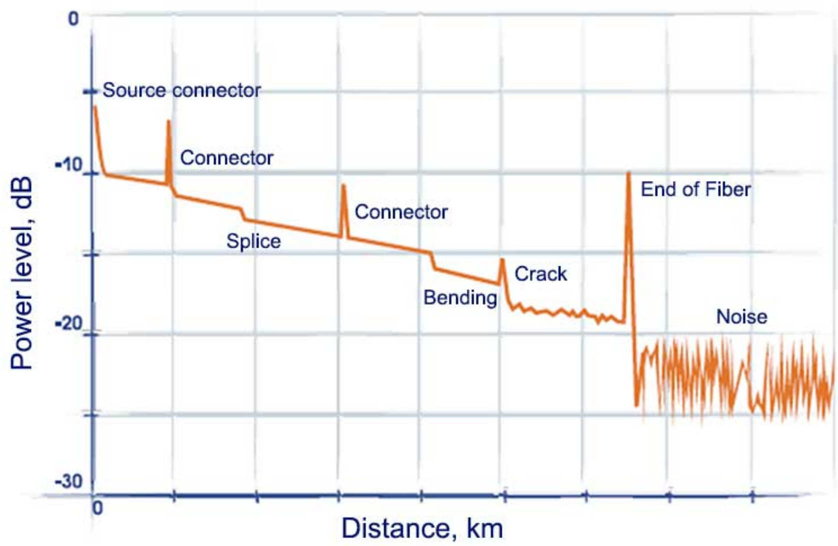


Figure 2.26: OTDR trace of the optical link.

- **Launch:** the beginning of the measurement where the signal is injected into the fiber.

- **Reflective event:** Reflective events typically occur when there is a significant change in the refractive index, resulting in signal attenuation with light reflection back to the OTDR. These events are usually associated with:[1]

  -Connectors: Often identified by a sharp peak on the OTDR trace, connectors can cause reflections due to the air-gap interface.

  - Mechanical Splices: These splices are less precise than fusion splices and may not be perfectly aligned, causing a reflective event, although they sometimes do not have as large a reflection as a connector does.

  - Fiber Breaks:A fiber break can appear as a reflective or a non-reflective event, depending on factors associated with the specific break.

- **Non-reflective event:** Non-reflective events on an OTDR trace show signal loss without any reflection peak. They usually appear as small drops and are caused by stress on the fiber. Common examples include fusion splices, which cause minimal signal loss, and macro bends, which create higher loss without reflection due to light escaping.[41]

- **Fiber end:** The end of the fiber is a crucial event that marks the physical end of the fiber under test. A sudden drop in the OTDR trace, indicating no further reflections or scatterings, identifies it.[41]

- **Gain event:** is an apparent increase in signal on an OTDR trace, caused by a splice between fibers with different characteristics, such as mode field diameter. [41]

2.5.2 Optical power meter:

optical power meter, is a device used to measure the intensity of optical signals in fiber optic networks, which is essential to ensure good transmission quality.

It can handle a wide range of wavelengths, with 1310 nm and 1550 nm being the most commonly used in telecommunications.

In Passive Optical Networks (PON), a specialized version called a PON photometer is employed to simultaneously measure downstream (1490/1550 nm) and upstream (1310 nm) signals. It supports burst mode for detecting intermittent upstream transmissions without interrupting the data flow. These instruments are useful during both installation and maintenance.

The results can be displayed in three formats: linear mode (milliwatt, mW), logarithmic mode (decibel-milliwatt, dBm), or relative mode (dB). [42]

Figure 2.27: Optical power meter.

2.5.3 The Visual Fault Locator (VFL)

The Visual Fault Locator, commonly known as a red light pen, is a handheld device used to check the optical continuity of a fiber link. It emits a visible red laser light that helps detect fiber breaks, sharp bends (macro-bending), faulty connectors, or poor splices. The light can usually travel up to 7 km through the fiber, making it suitable for short-distance tests, especially in FTTH networks using G.657A2 fiber. They verifying optical continuity during installation or troubleshooting. However, since they use laser light, it is important to check the output power before use (should not exceed 1 mW) to avoid eye injuries.[43]

Figure 2.28: The Visual Fault Locator.

2.6 Conclusion:

The deployment of an FTTH network requires careful planning, from selecting the right architecture to field implementation. This chapter focuses on the FTTH solution, presenting its main network architectures (P2P and P2MP) and standards.

It covers the key steps of designing and installation of passive network from transport to subscriber connection, splicing methods, and the measurement instruments used to ensure optimal network performance.

CHAPTER 3

Simulation of GPON FTTH link

3.1 Introduction

As part of this project, we will carry out a simulation of a FTTH (Fiber To The Home) network based on the GPON standard. The objective is to design and evaluate the performance of an optical access network capable of providing high-speed service to multiple users.

GPON technology, defined by the ITU-T G.984 standard, is widely used for its advantages in terms of high-speed connectivity, reliability, stability, security, and energy efficiency.

The simulation will be carried out using the OptiSystem 7.0 software.

3.2 OptiSystem 7.0 software presentation:

OptiSystem is a software developed by the Canadian company Optiwave, mainly used by engineers and researchers to design, simulate, and analyze optical transmission systems. It offers great flexibility, as users can add custom-built functions to expand the range of possible simulations.

With OptiSystem, it is possible to test and optimize almost any type of optical link. The software is based on accurate and realistic modeling of fiber optic communication systems, making it a powerful tool for studying and developing optical technologies.[44]

3.2.1 OptiSystem 7.0 interface:

This software is mainly consisting of a main window divided into several sections:[6]

Library: A database that contains all types of models used to create various block diagrams, such as inputs, encoders, modulators, filters, etc.

Layout Editor: Allows the design of block diagrams using different components from the library, which can be configured by modifying their parameters.

Current Project: Displays the various files and components related to the current project.

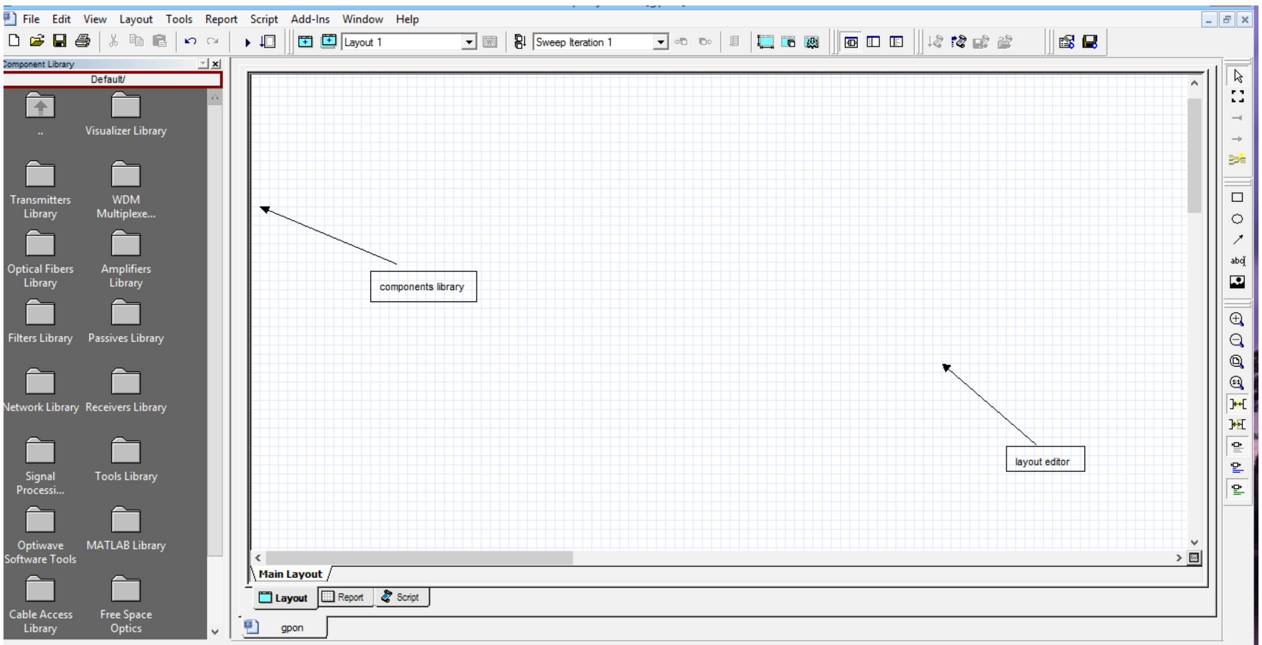


Figure 3.1: Graphical interface of OptiSystem 7.0.

3.2.2 Application of OptiSystem software:

Among the various applications of OptiSystem, the most commonly used are:[44]

-Design of optical communication systems.

-Calculation of Bit Error Rate (BER) and link budget.

-Design of TDM/WDM networks and Passive Optical Networks (PON).

-Design of Free Space Optical (FSO) systems.

-Design of transmitter, channel, amplifier, and receiver.

3.3 Quality metrics of an optical transmission :

3.3.1 Bit Error Rate (BER):

Bit Error Rate (BER) is a key indicator of signal quality in telecommunications. It represents the proportion of bits received incorrectly out of the total number of bits transmitted, reflecting the overall end-to-end system performance including the transmitter, receiver, and transmission medium.

BER is calculated by dividing the number of erroneous bits by the total transmitted bits. A BER of 10 is typically acceptable for telecommunications, while a BER of 10źş is preferred for data transmission.[45]

$$\text{BER} = \frac{\text{Number of bits received incorrectly}}{\text{Total number of bits transmitted}}$$

3.3.2 Q-factor:

The quality factor, is a measure of the quality of an optical signal. It is derived from the noise statistics of the signal levels (1) and (0) to be detected, and is given by:

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0}$$

where the values represent the mean levels of the useful signal, and the standard deviations correspond to the probability density distributions of symbols 1 and 0.

3.3.3 Eye diagram:

The eye diagram is a basic tool used to check the quality of a channel in a digital system. It is created by overlaying the rising and falling edges of a binary signal over a specific time window.[46]

The general principle is that the smaller core area,the lower the quality of the received signal,the lower the quality factor,and consequently,the more difficult it is to detect the signal without errors.

The eye diagram is characterized by phenomena that allow the evaluation of the transmitted signal quality:

-Timing jitter is caused by dispersion and the coupling between signal pulses and amplified spontaneous emission (ASE) noise.

-Amplitude noise in the link results from the accumulation of amplified spontaneous emission along the signals propagation path.

-Temporal broadening of signal pulses is due to chromatic dispersion, leading to inter-symbol interference (ISI).

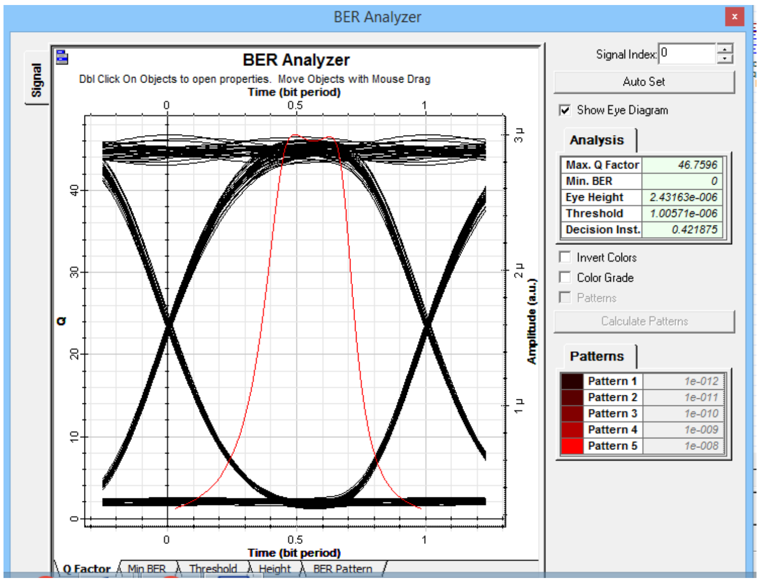


Figure 3.2: Eye diagram.

3.4 Reminder on GPON technology:

Before starting the simulation of the FTTH network based on GPON technology,it is important to recall some fundamental principles in order to better understand the technical choices made during the simulation.

Table 3.1 presents an overview of the main characteristics of this technology:

Table 3.1: Summary of GPON Technology Characteristics

Element	**Description**
Technology Name	GPON (Gigabit Passive Optical Network)
Architecture	Point-to-multipoint
Central Equipment	OLT (Optical Line Terminal)
User Equipment	ONT (Optical Network Terminal)
Passive Component	Optical splitter (1:8, 1:16, 1:32, up to 1:64 .)
Wavelengths Used	1490 nm (downstream), 1310 nm (upstream), 1550 nm (video)
Downstream Bit rate	Up to 2.5 Gbit/s
Upstream Bit rate	Up to 1.25 Gbit/s
Maximum Distance	Around 20 km .

3.4.1 GPON architecture advantages in FTTH networks:

- **Fiber Sharing:** In a GPON architecture, a single optical fiber is shared among multiple homes, which optimizes the use of the network infrastructure.
- **High Performance and Reliability:** GPON offers a high level of performance and reliability, thanks to dynamic bandwidth allocation among subscribers.
- **High Shared Bandwidth:** This technology can provide up to 2.5 Gbps of shared bandwidth, which is more than sufficient to meet the needs of households (Internet, streaming, etc.).
- **Fewer Cables Required:** Compared to a Point-to-Point architecture, GPON requires fewer fiber cables to be installed, reducing deployment costs.
- **Ideal for High-Density Areas:** GPON is particularly suitable for urban areas, where fiber sharing is advantageous.

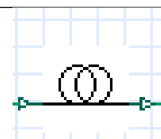
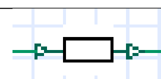
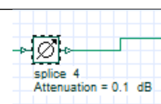
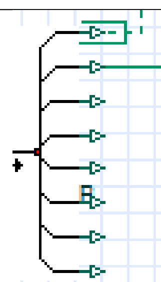
3.5 Experimental part: GPON link simulation

3.5.1 Description of the architecture:

The simulated system includes an Optical Line Terminal (OLT) and an Optical Distribution Frame (ODF) located at Optical distribution node (ODN). From there, the signal is distributed through an Intermediate Optical Distribution Point (ODP) and then further branched using optical splitters.

The design follows a tree topology, using two successive 1:8 splitters, the first positioned at the FDT and the second at the Optical Branching Point (OBP). This configuration allows the network to serve up to 64 end-users, each connected via an ONT, while maintaining a total optical loss below the critical threshold of 28 dB (class B+), ensuring compliance with GPON power budget requirements.

Table 3.2: Optical Network Components, Attenuation.

Component	**Figure**	**Unit Attenuation**
Optical Fiber Cable (1490 nm)		0.23 dB/km
Connector		0.3 dB
Splice		0.1 dB
Splitter 1:8		10.6 dB

In the following, we will simulate a bidirectional FTTH-GPON link, covering both downstream and upstream transmissions. The downstream transmission.

3.5.1.1 Simulation Parameters

The simulation parameters are aligned with those used in the practical setup, as detailed below:

Table 3.3: Simulation Parameters.

Parameter	**Value**
Nominal downstream data rate (OLT ONT)	2.5 Gbit/s
Downstream wavelength	1490 nm
Nominal upstream data rate (ONT OLT)	1.25 Gbit/s
Upstream wavelength	1310 nm
Average launched optical power	5 dBm
Encoding type (downstream and upstream)	NRZ (Non-Return-to-Zero)
Receiver sensitivity	-28 dBm

This configuration ensures the simulation closely replicates real-world conditions.

- **Downstream Transmission configuration(64 user):**

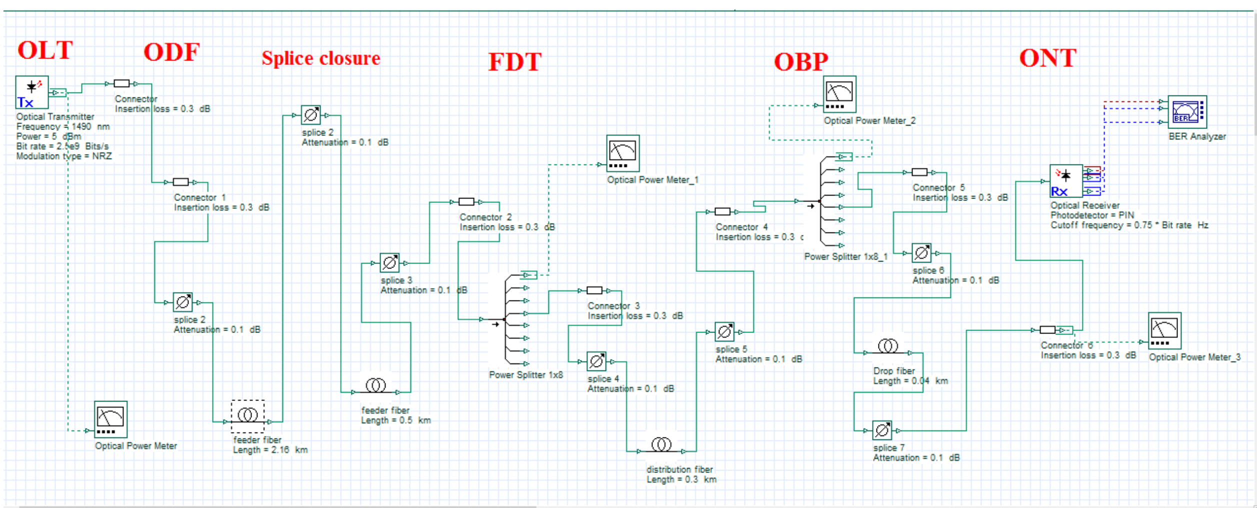


Figure 3.3: Downstream Transmission configuration.

- **Upstream transmission configuration (64 user):**

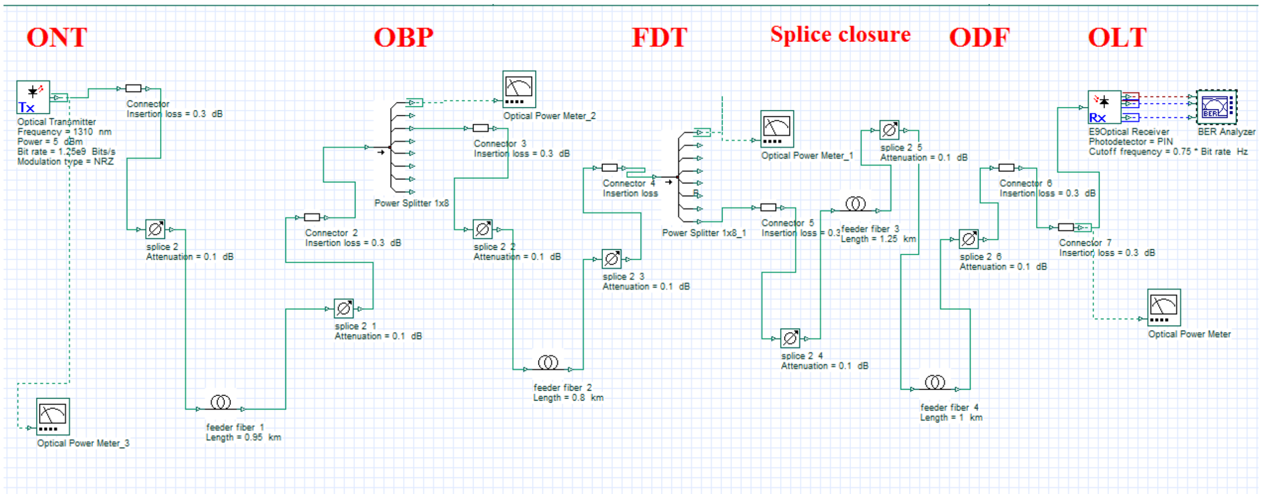


Figure 3.4: Upstream transmission configuration.

3.5.2 Impact of the distance:

To analyze the impact of distance on transmission quality, we performed simulations on both downstream and upstream links by varying the optical fiber length from 3 km to 22 km.

- **Impact of the distance on down stream transmission:**

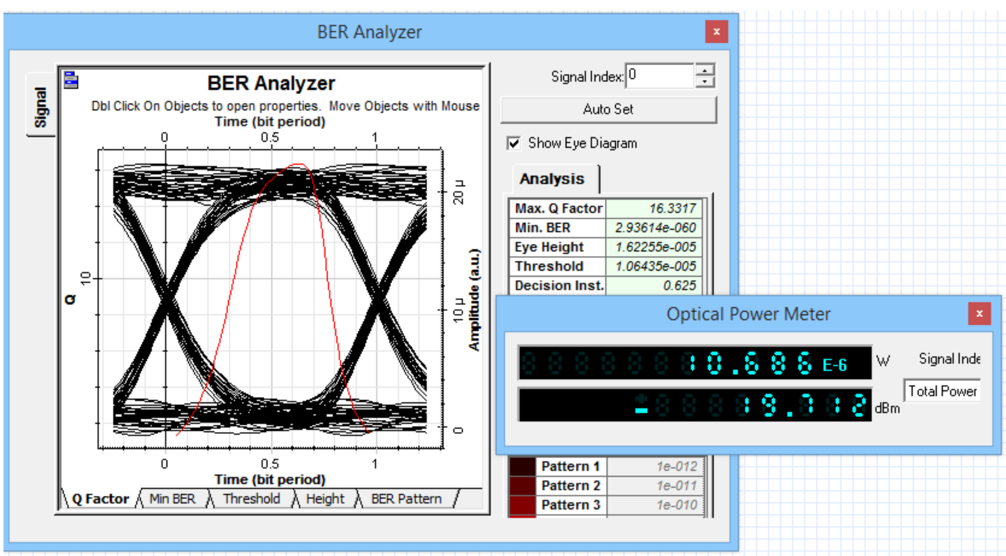


Figure 3.5: Eye diagram at 3 km downstream.

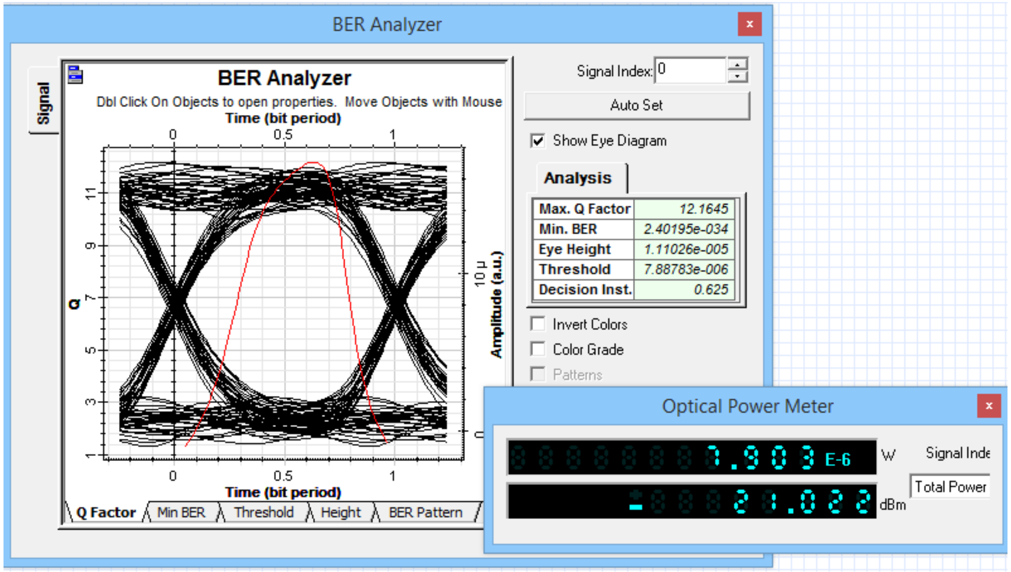


Figure 3.6: Eye diagram at 10 km downstream.

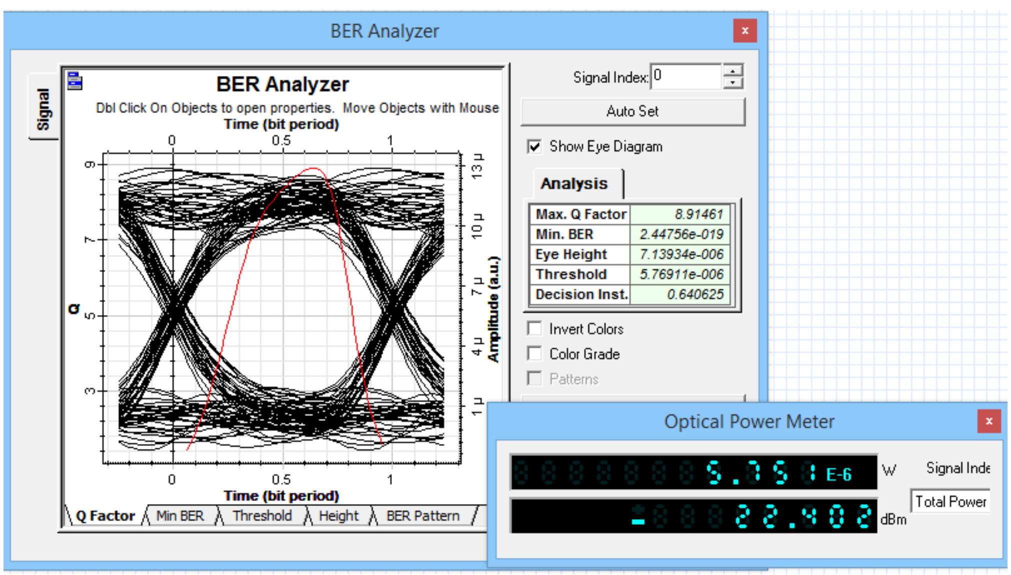


Figure 3.7: Eye diagram at 16 km downstream.

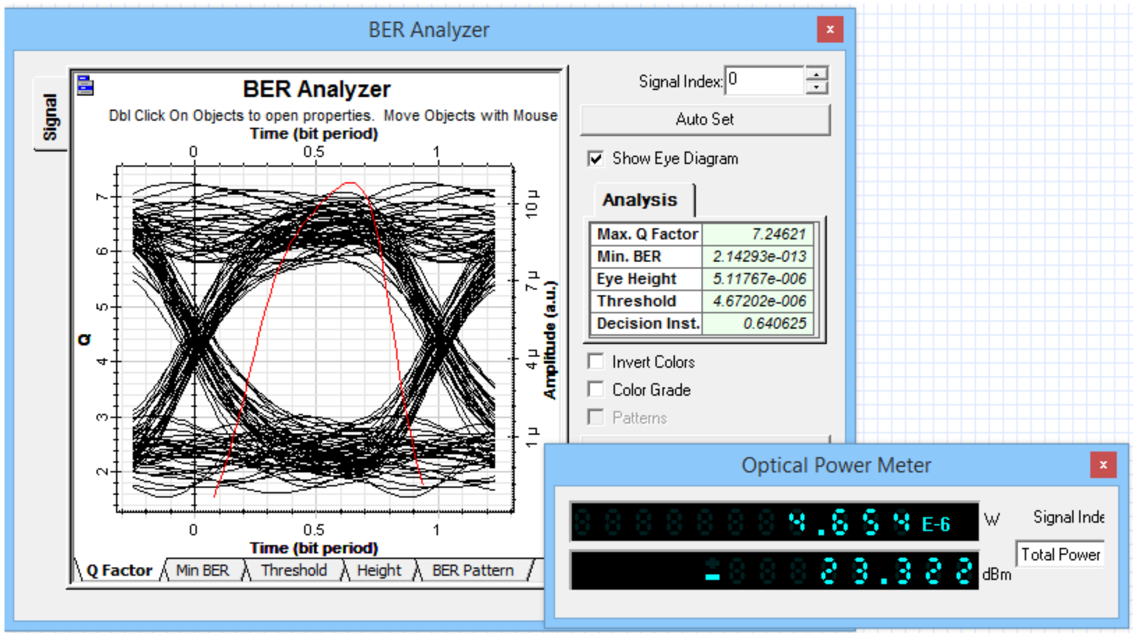


Figure 3.8: Eye diagram at 20 km downstream.

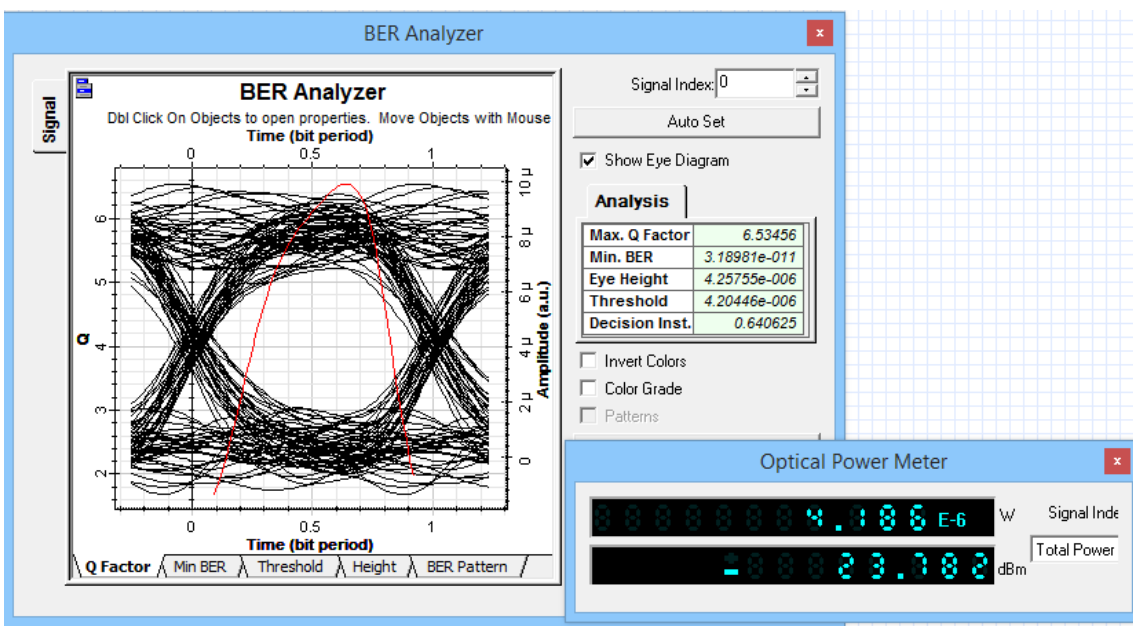


Figure 3.9: Eye diagram at 22 km downstream.

The feeder cable length is varied from 3 km to 22 km (noting that the maximum allowable length for a feeder cable is 20 km) in order to observe the impact of distance on the FTTH network.

The following table summarizes the BER and Q-factor results for the simulated link.

Table 3.4: Effect of Distance on Downstream Transmission.

Distance (km)	BER	Q Factor	Attenuation (dB)
3	2.9361e-060	16.3317	-19.712
5	8.69008e-054	15.3961	-19.975
8	8.70016e-042	13.4921	-20.562
10	2.40195e-034	112.1645	-21.022
12	2.78306e-28	10.966	-21.482
14	2.38414e-023	9.8864	-21.942
15	3.05442e-021	9.3881	-22.172
16	2.44756e-19	8.91461	-22.402
17	1.29015e-017	8.46414	-22.632
18	4.60906e-016	8.03684	-22.862
19	1.16532e-014	7.63093	-23.092
20	2.14293e-013	7.24621	-23.322
22	3.18981e-011	6.53456	-23.782

- **Impact of the distance on upstream transmission:**

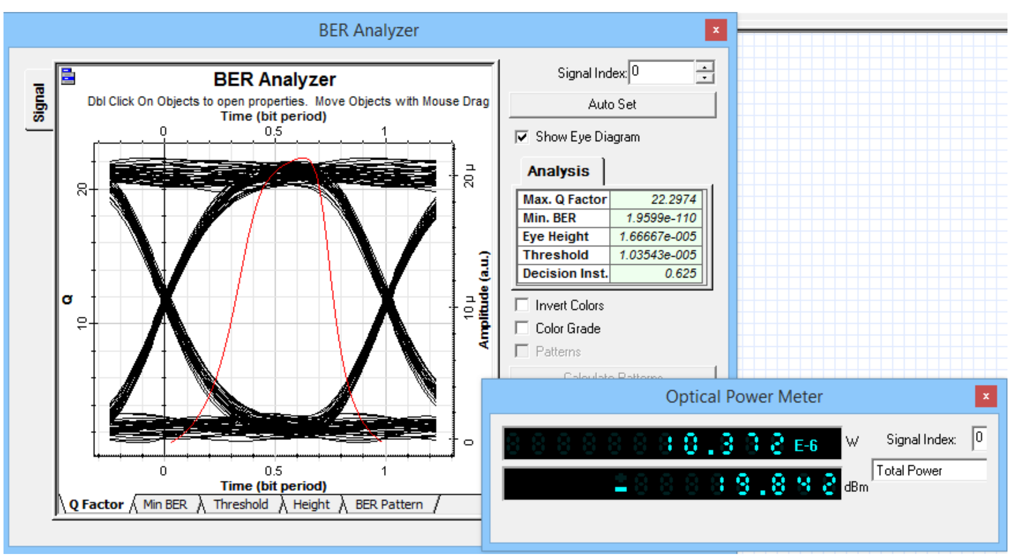


Figure 3.10: Eye diagram at 3 km upstream.

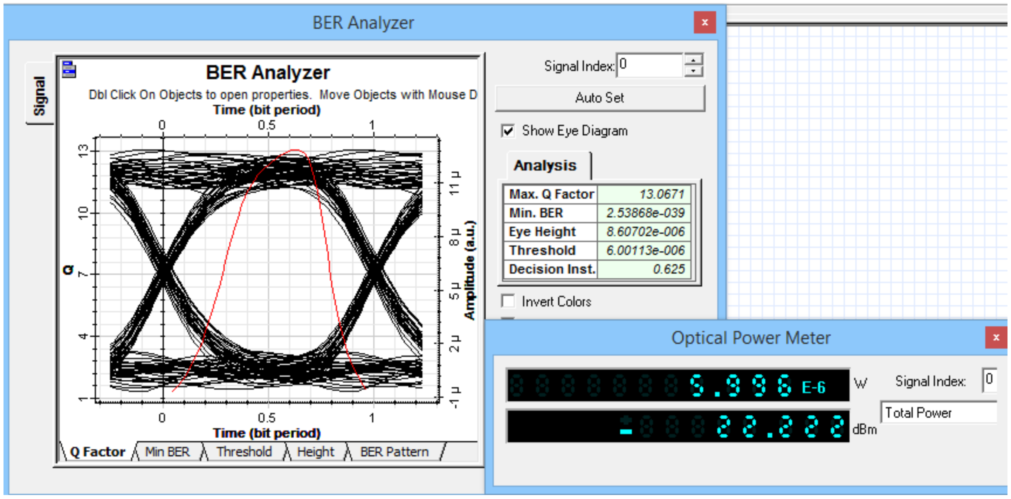


Figure 3.11: Eye diagram at 10 km upstream.

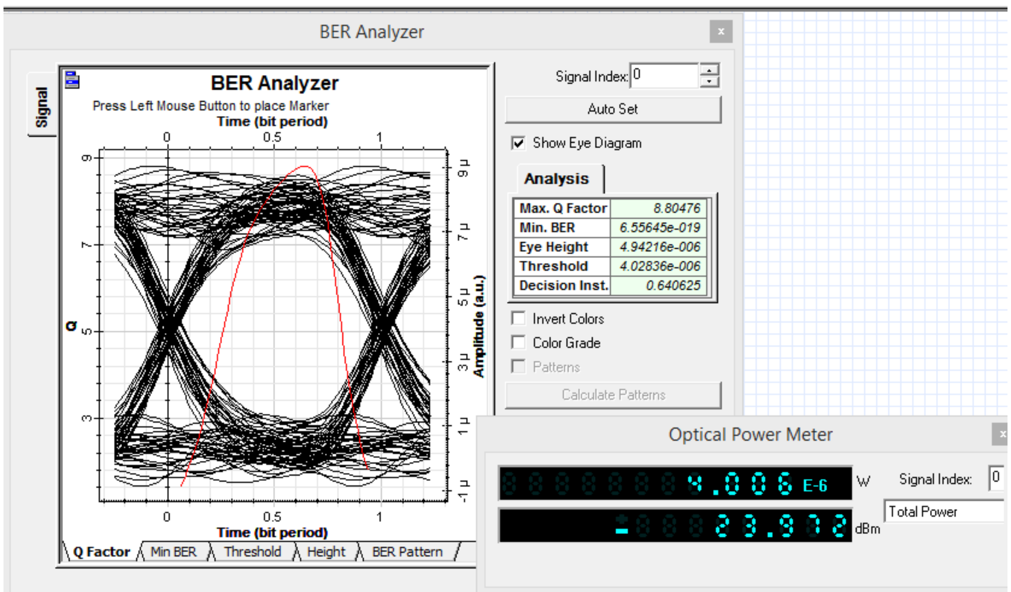


Figure 3.12: Eye diagram at 15 km upstream.

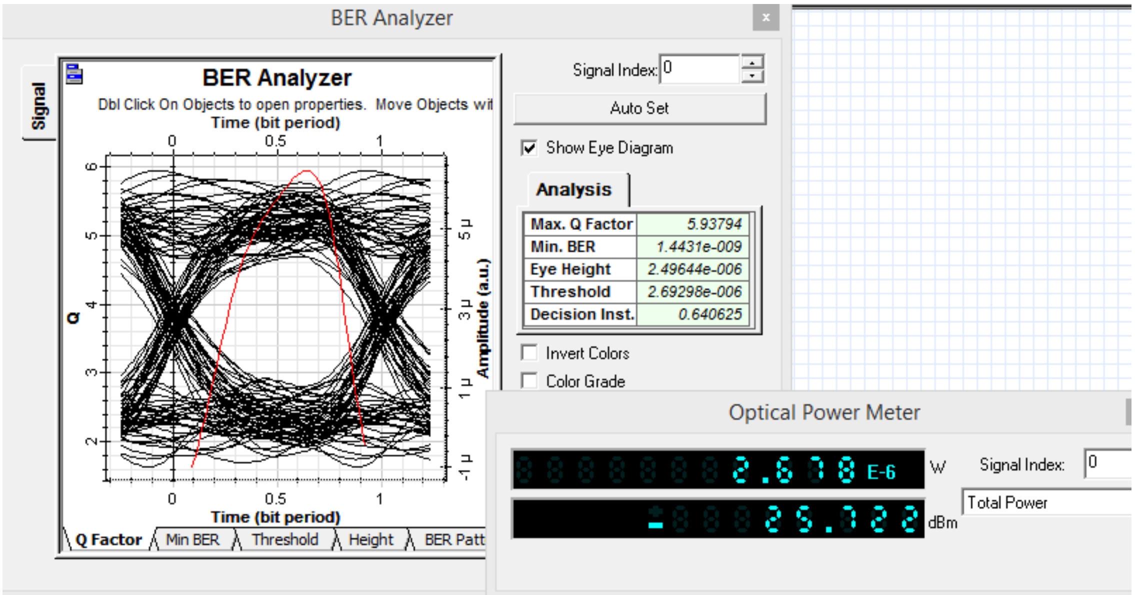


Figure 3.13: Eye diagram at 20 km upstream.

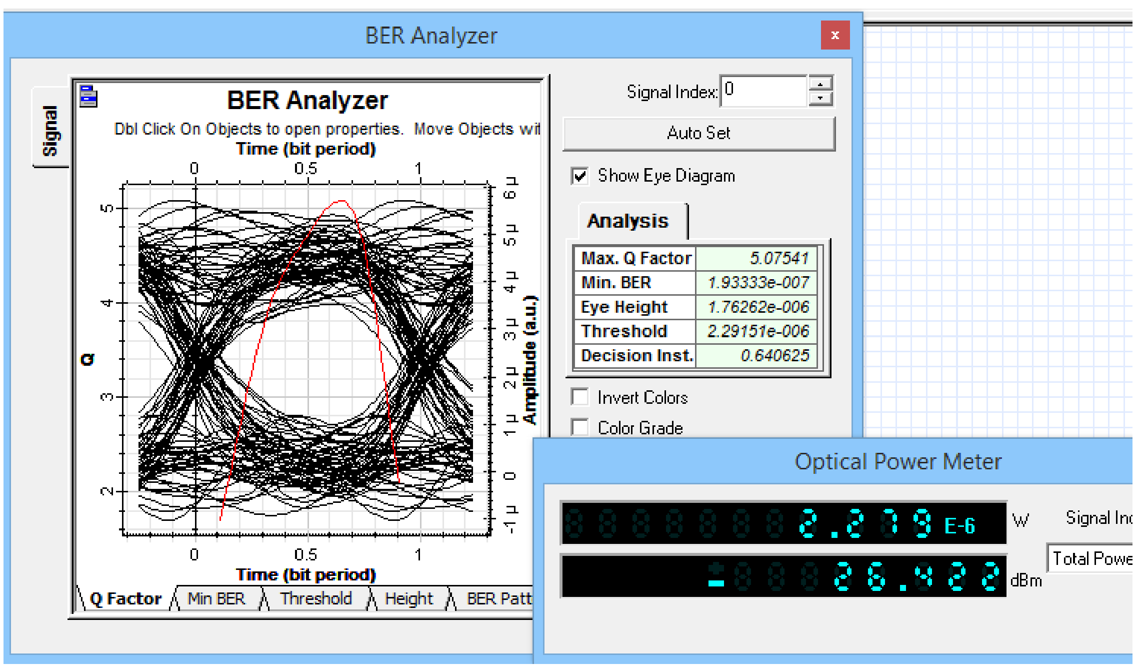


Figure 3.14: Eye diagram at 22 km upstream.

The following table summarizes the results obtained for the simulated link:

Table 3.5: Effect of Distance on upstream Transmission.

Distance (km)	BER	Q Factor	Attenuation (dB)
3	1.9599e-110	22.2974	-19.842
5	1.9599e-110	22.2974	-19.842
8	3.69364e-053	15.3022	.21.522
10	2.53868e-039	13.0671	-22.222
12	3.29069e-029	11.1515	-22.922
14	8.02407e-022	9.52791	-23.622
15	6.55645e-019	8.80476	-23.972
16	2.03033e-016	8.13674	-24.322
17	2.74446e-014	7.51973	-24.672
18	1.82749e-012	6.99924	-25.022
19	6.64776e-011	6.42375	-25.372
20	1.4431e-009	5.93794	-25.722
22	1.9333e-007	5.07541	-26.422

3.5.2.1 Analysis of the simulation results:

- As the distance between the ONT and the OLT increases, we observe a significant degradation in signal quality. This is clearly demonstrated by a consistent trend: the BER rises, while Q-factor decreases.

- The Quality Factor and BER show better performance for transmission distances under 20 km.

- At a distance of 15 km, the eye diagram remains open, and the BER is on the order of 10šź. However, this BER is even lower than the minimum recommended for fiber optic communication systems, which is generally around 10š, according to ITU-T G.984 standards for GPON networks.

- At a distance of 20 km, the results remain acceptable, ensuring a successful transmission.

- Beyond 20 km, the eye diagram becomes distorted, indicating a significant degradation in optical signal quality due to increased dispersion and attenuation ,two phenomena that naturally intensify with distance in optical fibers.

- The received power in the downstream path varied from -19.712 dBm at a distance of 3 km to -23.322 dBm at 20 km, and from -19.842 to -25.722 dBm in the upstream path. These values remain within acceptable limits, since the minimum tolerated power level in the upstream direction is typically -28 dBm as per GPON specifications.

- The performance results in both the downstream and upstream directions are nearly identical, indicating a balanced and symmetrical optical link.

3.5.3 Impact of splitting ratio:

In this part, we study the impact of the splitting ratio on the performance of a GPON network. This parameter determines the number of users that can be served by a single fiber from the OLT output, and it directly affects optical losses and transmission quality.

In the following, we will vary the splitting ratio in the downstream direction in order to analyze its impact on transmission quality.

To ensure a fair comparison, a fixed distance of 10 km will be used in all three scenarios.

- **Case of 1:4 ratio split:**

  Two 1:2 splitters were used, resulting in a splitting ratio of 1:4, which allows serving 4 users from a single input fiber.

  We obtain the following results:

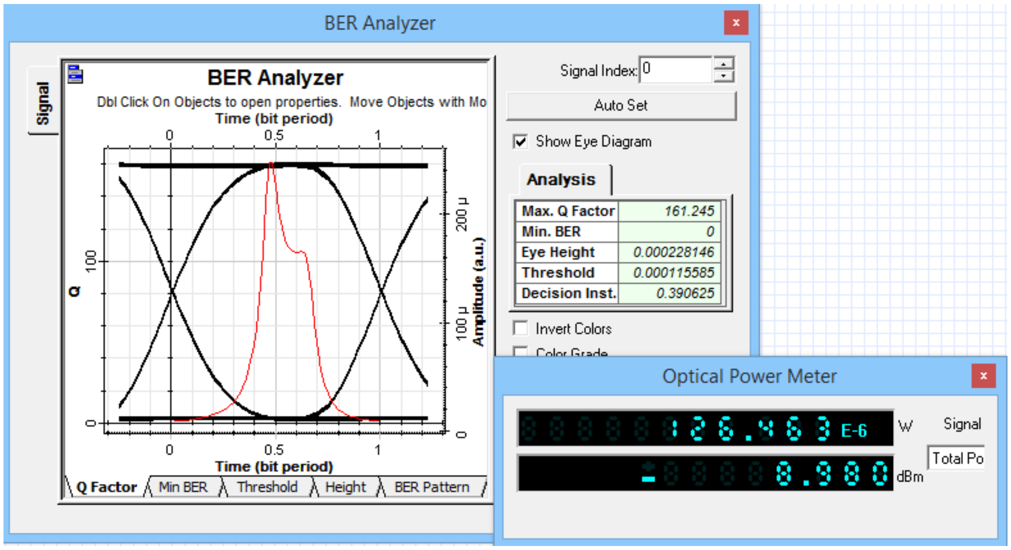


Figure 3.15: Eye diagram at 10 km with 1:4 ratio split.

In this architecture, the Q Factor value is very high (161.245) and the BER is zero, with a received power level sufficient to ensure proper functioning of the link.

- **case of 1:16 ratio split:**

  Two 1:4 splitters were used, resulting in a splitting ratio of 1:16, allowing 16 users to be served from a single input fiber.

  We obtain the following results:

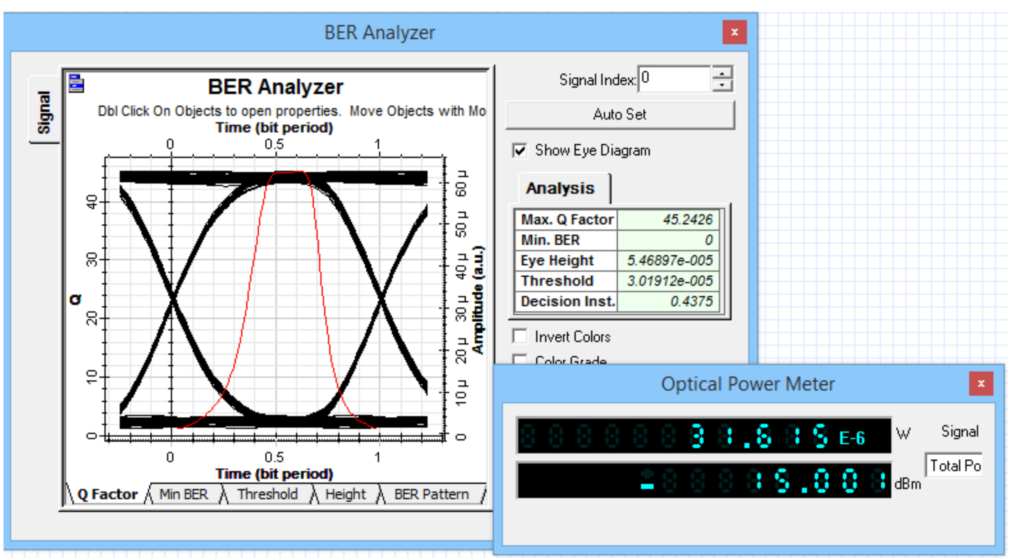


Figure 3.16: Eye diagram at 10 km with 1:16 ratio split.

In this architecture, the Q Factor is also very high (45.2426), and the BER is zero. The received optical power of -15 dBm is still sufficient to ensure proper link operation.

- **case of 1:64 ratio split:**

  Two 1:8 splitters were used, resulting in a splitting ratio of 1:64, allowing 64 users to be served from a single input fiber.

  We obtain the following results:

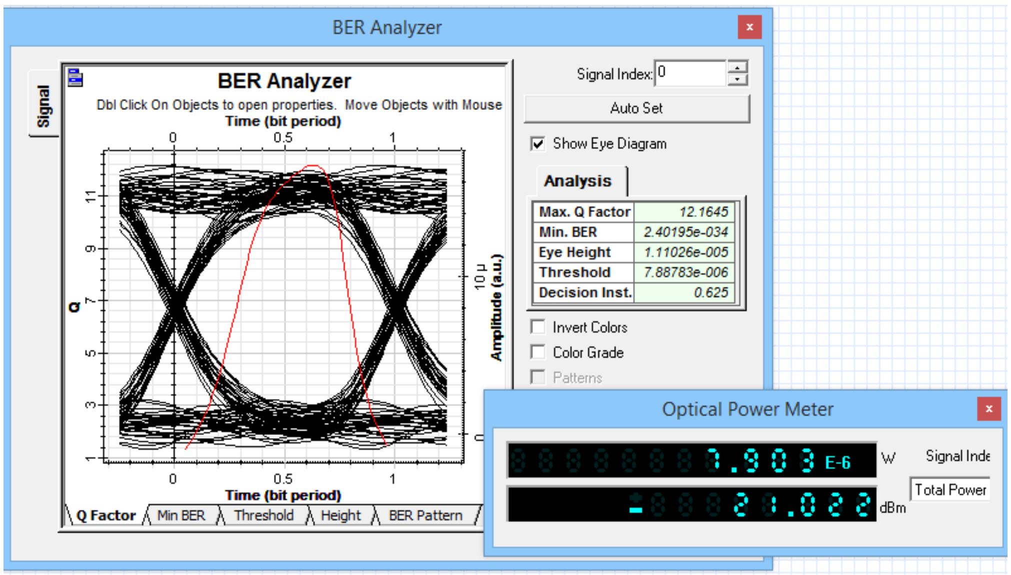


Figure 3.17: Eye diagram at 10 km with 1:64 ratio split.

With the use of two 1:8 splitters, the Q Factor decreases (12.1645) but still very good, and the BER is 2.40195 e-034.The received optical power of -21 dBm is still sufficient for good quality of transmission.

3.5.3.1 Analysis of the simulation results:

- The results obtained from the three simulated architectures indicate that increasing the splitting ratio leads to a degradation in system performance. Specifically, a higher splitting ratio results in a decrease in the Q-factor, an increase in BER, and a reduction in the received optical power at the end-user.

- Reducing the splitting ratio improves transmission quality but limits the number of end-users, thereby increasing deployment costs.

- This cascaded architecture, using two 1:8 splitters to serve up to 64 users, remains compliant with the GPON standard (ITU-T G.984), which allows a maximum split ratio of 1:64, although it exceeds the typical recommendation of 1:32 set by the same standard; however, it requires a reduction in transmission distance in order to stay within the optical budget and limit losses, thereby ensuring proper network performance.

- The simulation results in both downstream and upstream directions are nearly identical.

3.5.3.2 Proposed enhancement based on simulation results:

- 1:2 optical splitters are recommended in rural deployments or in long-distance links, where minimizing optical losses is a priority. They ensure high signal quality and are also suitable for cascading architectures.

- 1:4 optical splitters are recommended to be deployed in semi-urban areas where the distance between the OLT and the subscribers is moderate. They provide a balanced trade-off between splitting capacity and optical power budget.

- In urban areas with high user density and relatively short distances between the OLT and ONT, 1:8 optical splitters are often preferred. They offer a good compromise between the number of subscribers served and the optical power loss, allowing efficient resource sharing while maintaining acceptable signal quality within the GPON power budget.

3.5.4 Optical budget:

3.5.4.1 PON budget calculation :

$$Att_{\text{total}}[dB] = \alpha_{\text{lin}}[\text{dB/km}] \times L[\text{km}] + \sum Att_{\text{spli}}[dB] + \sum Att_{\text{conn}}[dB] + \sum Att_{\text{splitter}}[dB] \quad (3.1)$$

- Att_{total} : Total attenuation of the optical link (in dB).

- α_{lin} : Linear attenuation coefficient of the fiber (in dB/km).

- L : Length of the fiber optic link (in km).

- $\sum Att_{\text{Spli}}$: Sum of attenuation due to splices (in dB).

- $\sum Att_{\text{conn}}$: Sum of attenuation caused by connectors (in dB).
- $\sum Att_{\text{splitter}}$: Sum of attenuation due to optical splitters (in dB).

$$M\ [dB] = (P_{\text{Tx}}\ [dBm] - S\ [dBm]) - (Att_{\text{total}}\ [dB])$$

- M : Power margin (also called safety margin), in dB.
- P_{Tx} : Transmitter output power, in dBm.
- S : Receiver sensitivity, in dBm.
- Att_{total} : Total attenuation of the link, in dB.

In the following example, we will study the optical budget for a case similar to a real scenario.

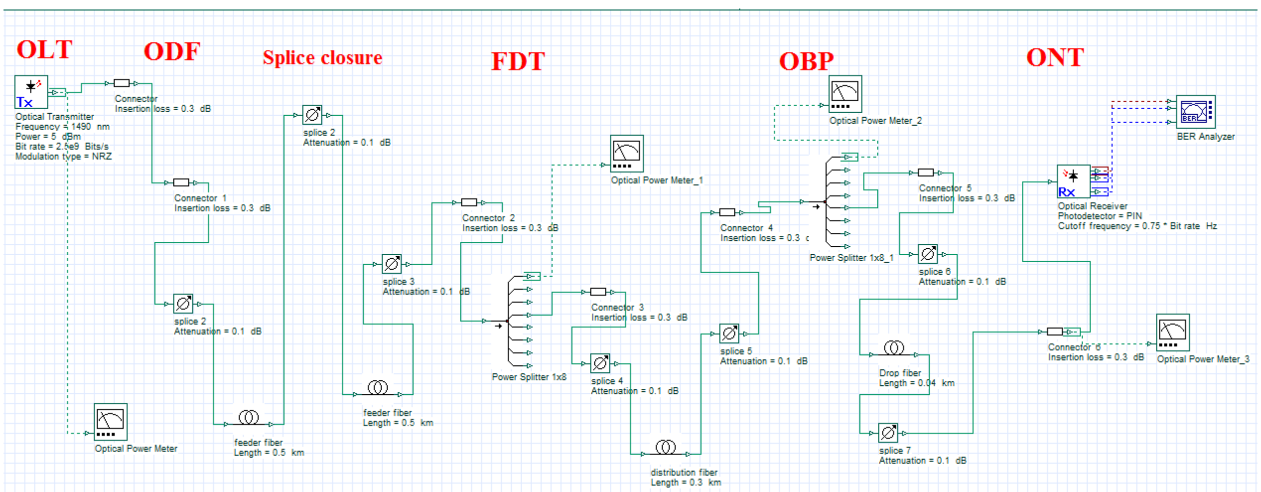


Figure 3.18: exemple of ftth link.

$$Att_{\text{total}}[dB] = (0.23 * 1.34) + (0.1 * 7) + (0.3 * 7) + (10.6 * 2) \tag{3.2}$$

total Attenuation[dB]=24.30[dB]

Margin[dB]=8.7[dB]

result analysis:

- With a total attenuation of 24.30 dB, the optical link complies with the GPON Class B+ standard, which allows a maximum loss of up to 28 dB.

- The margin should be between 5 and 10 dB, and it typically decreases as the number of events increases. In our simulation, the obtained margin is 8.7 dB, which is considered an excellent value.

3.6 conclusion:

In this chapter, we simulated an FTTH link using GPON technology. This allowed us to explore different transmission scenarios and analyze the results obtained.

By examining the BER and the Q-Factor we were able to evaluate the transmission quality in both upstream and downstream directions, across various distances and different member of users. We also calculated the optical budget of the link to assess its performance.

Through these simulations, we observed that certain key parameters must be carefully considered when deploying an FTTH network especially the distance, ratio splitting and the optical budget.

General Conclusion

To meet the growing demand for bandwidth and high-speed broadband services, FTTH technology has become an essential solution due to its many advantages. Designing an FTTH network allows for data rates much higher than those provided by ADSL.

Today, PON technologies are considered a benchmark for high-speed access networks, as they offer high transmission capacity while minimizing the amount of fiber infrastructure required.

The first chapter provides an introductory overview of fiber optic communication. We examined the three main components of an optical link, starting with the light sources which are LEDs and LASERs, followed by the transmission medium which is the optical fiber cable including its various types and characteristics, and finally the last device which is optical receivers, we also discussed the different applications of this technology and its advantages. Finally we studied the optical networks and their architecture, which consists of the backbone, the collection network and the access network.

In the second chapter, we studied the two main architectures for an FTTH network: Point-to-Point (P2P) and Passive Optical Network (PON). We analyzed their advantages and disadvantages, compared their deployment methods, and identified the key criteria for choosing between them. Based on this analysis, we concluded that the PON architecture is more suitable for FTTH, mainly due to its lower deployment cost.

We then conducted a detailed study of the key steps involved in designing a PON-based FTTH network. This began with selecting the coverage area, estimating the number of subscribers, choosing the network architecture, selecting the optical fiber cables, calculating the optical power budget, and addressing the civil engineering aspects.

After completing the design phase, we moved on to the installation of the network, starting from the Optical Distribution Node (ODN) to the ONTs at the subscriber premises. We also covered the techniques used for fiber splicing, as well as the instruments used to test and validate the quality of the optical link.

Finally, the third chapter was dedicated to a realistic simulation of an FTTH network based on the GPON standard. This simulation allowed us to observe the effect of distance and ratio splitting on transmission quality using key performance indicators such as Q-Factor, BER, and the eye diagram.

Perspectives and Recommendations:

These recommendation aim to enhance the quality of service, increase the bandwidth available to end users, and prepare for a potential transition to more advanced technologies:

Preparation for Migration to NGPON Technologies (XG-PON, XGS-PON)

To meet the growing demand for bandwidth, it is advisable to consider the integration of OLT cards compatible with next-generation PON standards, particularly XG-PON (10 Gbps downstream) and XGS-PON (10 Gbps symmetric). These technologies are backward compatible with existing GPON infrastructures through WDM (Wavelength Division Multiplexing), allowing a smooth and gradual migration without requiring a complete overhaul of the network.

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Abstract

Fiber optic is the preferred technology for high-speed broadband access. More specifically, this project focuses on the deployment of Fiber To The Home (FTTH) technology.

The Passive Optical Network (PON) architecture allows a single optical fiber to be shared among several end users through passive optical splitters.

This work involves the study, installation, and simulation of an FTTH network based on the GPON standard. The simulation was conducted using OptiSystem 7.0 software, which enables the modeling of various optical network components.

Link performance was evaluated by analyzing the Bit Error Rate (BER), the Q-Factor, and the eye diagram to assess the quality of the transmitted optical signal.

Résumé

La fibre optique est la technologie privilégiée pour l'accès haut débit à grande vitesse. Ce projet se concentre plus particulièrement sur le déploiement de la technologie FTTH (Fiber To The Home).

L'architecture PON permet de partager une seule fibre optique entre plusieurs utilisateurs finaux grâce à des coupleurs optiques passifs.

Ce travail porte sur l'étude, l'installation et la simulation d'un réseau FTTH basé sur la norme GPON. La simulation a été réalisée à l'aide du logiciel OptiSystem 7.0, qui permet de modéliser les différents composants d'un réseau optique.

Les performances de la liaison ont été évaluées par l'analyse du taux d'erreur binaire (BER), du facteur Q et du diagramme de l'œil, afin d'estimer la qualité du signal optique transmis.

ملخص

تُعتبر الألياف البصرية التكنولوجيا المفضلة للوصول إلى الإنترنت عالي السرعة. ويركز هذا المشروع بشكل خاص على نشر تقنية الألياف البصرية حتى المنزل (FTTH).

تُتيح بنية الشبكة البصرية السلبية (PON) مشاركة ليف بصري واحد بين عدة مستخدمين نهائيين، وذلك باستخدام مقسمات بصرية سلبية.

يركز هذا العمل على دراسة، وتركيب، ومحاكاة شبكة FTTH تعتمد على معيار GPON. وقد تم إجراء المحاكاة باستخدام برنامج OptiSystem 7.0، الذي يساعد على نمذجة مختلف مكونات الشبكة البصرية.

تم تقييم أداء الرابط من خلال تحليل معدل الخطأ في البتات (BER)، ومعامل الجودة (Q-Factor) ومخطط العين، بهدف تقدير جودة الإشارة البصرية المُرسلة.