Mohamed Khider University of Biskra
Faculty of Science and Technology
Department of Electrical Engineering

MASTER THESIS

Electrical Engineering
Telecommunication
Networks and Telecommunication

Réf. : Entrez la référence du document

Submitted and Defended by:
Rezgui nedjm eddine & bourezg zaineb bouthina

On: Sunday, June 26, 2022

Planning FTTH Network using QGIS

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University year: 2021 - 2022

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In:…………………………………

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Acknowledgement

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

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Abstract

In recent years, the demand for broadband telecommunications networks has increased. One of the strategies used by telecommunication companies to increase bandwidth applies the FTTH (Fiber to the Home) approach and uses the PON (Passive Optical Network) topology.

This thesis aims to answer several questions, such as what are PON networks, and what are their advantages? What steps should be taken to plan an FTTH network?

During the planning phase, we will make sure that the FTTH planning meets the specifications and that all users are taken into consideration. We hope the network will continue to work for at least 30 or 40 years.

Keywords: PON, FTTH, K-means, QGIS, Optical fiber, access techniques, optical GPON

Résumé

Ces dernières années, la demande de réseaux de télécommunications à large bande a augmenté. L'une des stratégies utilisées par les sociétés de télécommunications pour augmenter la bande passante applique l'approche FTTH (fibre à la maison) et utilise la topologie PON (réseau optique passive).

Cette thèse vise à répondre à plusieurs questions, telles que sont les réseaux PON, et quels sont leurs avantages? Quelles mesures doivent être prises pour planifier un réseau FTTH?

Pendant la phase de planification, nous nous assurerons que la planification FTTH répond aux spécifications et que tous les utilisateurs sont pris en considération. Nous espérons que le réseau continuera de travailler pendant au moins 30 ou 40 ans.

ملخص

في السنوات الأخيرة ازداد الطلب على شبكات الاتصالات ذات النطاق العريض ، إحدى الاستراتيجيات التي تستخدمها شركات الاتصالات لزيادة عرض النطاق الترددي هي شبكات الألياف البصرية إلى المنازل (FTTH) واستخدام طبولوجيا الشبكة الضوئية السلبية (PON).

تهدف هذه الأطروحة إلى الإجابة على العديد من الأسئلة مثل: ما هي شبكات PON وما هي مزاياها؟ ما هي الخطوات التي يجب اتخاذها للتخطيط لشبكة FTTH؟

خلال مرحلة التخطيط ، سوف نتأكد من أن تخطيط شبكة FTTH يفي بالمواصفات وأن جميع المستخدمين تم أخذهم في الإعتبار .و نأمل أن تستمر الشبكة في العمل لمدة 30 أو 40 عامًا على الأقل.

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Glossary

LEDs	Light Emitting Diodes
GaAsP	Gallium Arsenide Phosphide
Gap	Gallium Phosphide
FWHM	Full Width at Half Maximum
DWDM	Dense Wavelength Division Multiplexing
Mw	Milliwatt
MMF	Multimode optical fibers
LANs	Local Area Networks
RF	Radio Frequency
SI	Step Index
dB/km	decibels per kilometer
SMF	Single-mode fibers
EDFA	Erbium Doped Fiber Amplifier
WDM	wavelength division multiplexing
LD	Laser Diode
PIN	Positive Intrinsic Negative
APD	Avalanche Photo Diode
InGaAs	Indium gallium arsenide
PON	Passive Optical Network
FTTA	Fiber To The Antenna
FTTB	Fiber To The Building
FTTH	Fiber To The Home
FTTN	Fiber To The Neighborhood
FTTC	Fiber To The Curb

ONT	Optical Network Termination
OLT	Optical Line Terminal
ADSL	Asymmetric Digital Subscriber Line
POTS	Plain Old Telephone Service
NGA	Next-Generation Access
BBU	Baseband Unit
RRH	Remote Radio Head
MIMO	Multiple-Input and Multiple-Output
DSL	Digital Subscriber Line
ISP	Internet Service Provider
P2P	Point-To-Point
P2MP	point-to-Multipoint
CO's	Central Offices
TDM	Time Division Multiplexing
ONUs	Optical Network Units
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
GPON	Gigabit Passive Optical Network
MDU	Multi-Dwelling Unit
MTU	Multi-Tenant Units
FSAN	Full Service Access Network
ATM	Asynchronous Transfer Mode
ITU-T	International Telecommunication Union
APON	ATM Passive Optical Network
BPON	Broadband Passive Optical Network

EPON	Ethernet Passive Optical Network
GFP	Generic Framing Procedure
OFDM-PON	Orthogonal Frequency Division Multiplexing Passive Optical Network
FDMA	Frequency Division Multiplexing Access
TDMA	Time Division Multiplexing Access
CDMA	Code Division Multiplexing Access
GIS	Geographic Information System
DBMS	Database Management System
GUI	Graphical User Interface
GICC	Geographic Information Coordination Commission
CRS	Coordinate Reference System
OSP	Outside Planning
FATs	Fiber Access Terminals
QuickOSM	Quick Open street map

General introduction

General introduction

Over the past 30 years, there has been a rapid growth in media streaming services such as video on demand (VOD), online games and high definition television over the Internet, which has necessitated new communication networks; Broadband access.

To deal with this situation, the traditional copper access networks, extremely widespread in many countries, were quickly replaced by fiber-optic access networks.

Most optical access systems deployed today uses Gigabit PON (Passive Optical Network) technologies as their foundation. These are passive optical networks based on a point-to-multipoint architecture operating at speeds of 2.488 Gbit/s (downlink) and 1.244 Gbit/s (uplink).

The aim of this final project is to study and plan the Fiber To The Home network, our work is organized into 4 chapters:

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

The second chapter will be devoted to optical access networks with the different FTTx architectures that exist, as well as the operation of a passive optical network (PON) with its various elements such as OLT (Optical Line Termination) we will see ZTE c300 and c320 OLT, ONU (Optical Network Unit), and splitter. Moreover, we deal with a presentation that is about the different categories of the PON network such as the APON, the BPON, the EPON, the GPON, and the types of multiplexing techniques used in FTTH-PON networks such as FDMA and TDMA, and WDM, finally CDMA.

The third chapter aims to present the QGIS software version 3.16 that was used in the planning of FTTH networks, this chapter is split into parts; the first part discusses the steps of how to design an FTTH network, and the second part discusses the planning on QGIS. Moreover, we will see how to plan two types of neighborhoods in Zeribet El Oued: urban and suburban.

Our last chapter will illustrate how to implement and automate FTTH planning using QGIS built-in functions and the K-means algorithm, as well as how to apply those implementations in a real-life scenario, along with the advantages and disadvantages of both automated and manual planning.

Chapter 1

Introduction to the optical fiber transmission support

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Chapter 1

Introduction to the optical fiber transmission support

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1.1. Introduction

Optical fibers are flexible transparent fibers made of pure glass (silica) or plastic, with a diameter slightly thicker than that of a human hair, and used in optical-optical communications, due to their ability to transmit farther and with higher wavelengths (data transfer rate) and less exposure to interference than conventional wired cables.

These fibers are manufactured through a technique called chemical vapor-modified deposition technology, which is the most common in the world.

Telecom companies are replacing traditional phone lines that use copper wires to transfer data across with these cables. One day, all telecom companies will use fiber optics. Design considerations for these cables mainly include appearance, stiffness, durability, tensile strength, flammability, size, temperature range, and flexibility.

1.2. Optical communication system

In order to comprehend how fiber-optic applications work, it is important to understand the optical communication system. In a nutshell, there are specific main components that construct a fiber optic communication system.
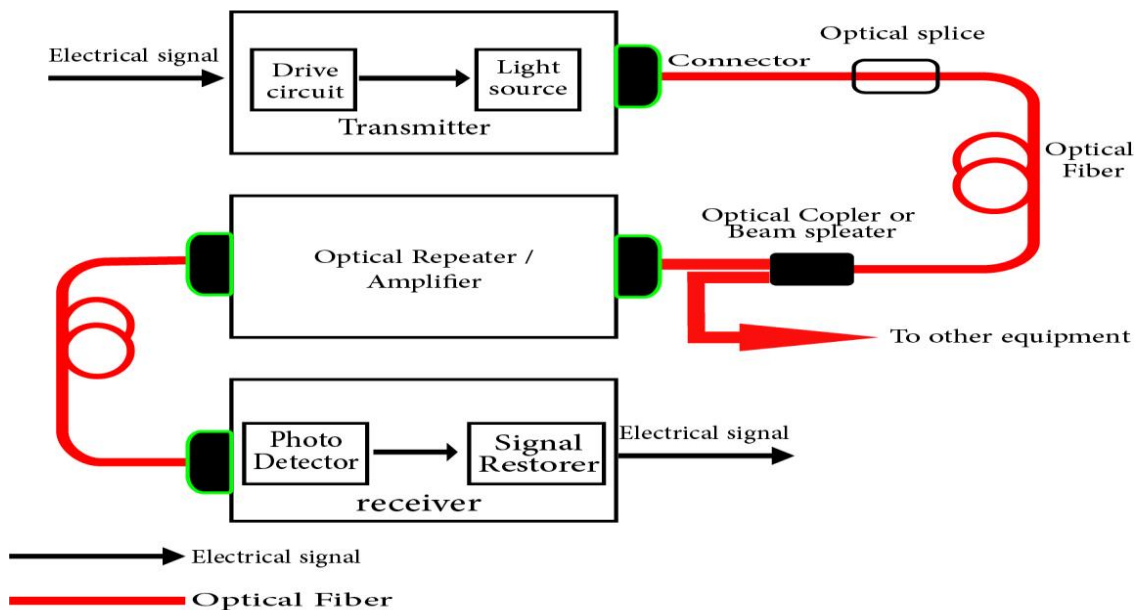
Figure 1.1: Optical communication system.

In (figure 1.1) above shows the optical communication system and demonstrates its main components are:

- Transmitter;
- Fiber optic cable;
- Optical repeater / amplifier;
- Receiver.

1.2.1. Optical Transmitter

Optical transmitters are critical components in any fiber optic system. This assembly converts electrical signals into corresponding optical signals that can be coupled into an optical fiber. The light emitter is an important element; Because, it is often the most expensive element in the system, and its properties often greatly affect the ultimate performance limit of a given compound. [1]
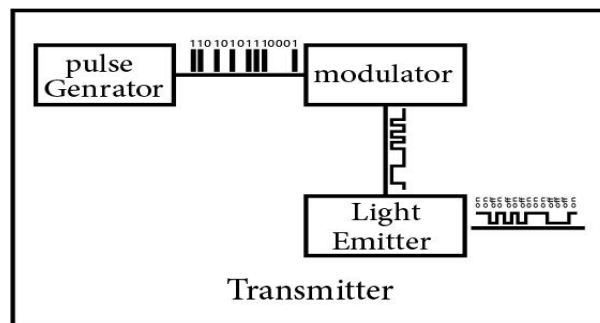
Figure 1.2: Diagram of the optical transmitter.

As we can see in (figure 1.2), there are three main components which are the pulse generator, the drive circuit (modulator), and the light emitter. Both the drive circuit and the light emitter are based on semiconductor technology.

1.2.1.1. Light Emitting Diodes (LEDs)

LEDs emit light as the consequence of charge carrier's recombination across the P-N Junction. The conversion process is fairly efficient in that it generates little heat compared to incandescent lights. LEDs are of interest for fiber optics because of five inherent characteristics:

- They are small;
- They possess high radiance (i.e., they emit lots of light in a small area);
- The emitting area is small, comparable to the dimensions of optical fibers;
- They have a very long life, offering high reliability;
- They can be modulated (turned off and on) at high speeds. [2]

Semiconductors such as Germanium and Silicon emit energy in the form of heat while semiconductors such as GaAsP (Gallium Arsenide Phosphide) and GaP (Gallium Phosphide) emit energy in the form of light. Thus, this type of semiconductor is used in the manufacturing of LEDs. [3]

1.2.1.2.   Laser diodes

LASER emits light as a result of photons striking the atom and compels them to release a similar photon. A laser works on the principle of stimulated emission. Often Lasers have a higher output power than LEDs the light output from a laser diode can be in the region of 100 mW (Milliwatt); therefore, they are capable of transmitting information over long distances. Also, lasers have a narrower spectral width and carry the most bandwidth, thus they are optimal light sources for long-haul fiber optics links. [4]

Table 1.1: Comparison of LEDs and Lasers. [2]

Characteristics	LEDs	Lasers
Output Power	Linearly proportional to drive current	Proportional to current above the threshold
Current	Drive Current: 50 to 100 mA Peak	Threshold Current: 5 to 40 mA
Coupled Power	Moderate	High
Speed	Slower	Faster
Output Pattern	Higher	Lower
Bandwidth	Moderate	High
Wavelengths Available	0.66 to 1.65 µm	0.78 to 1.65 µm
Spectral Width	Wider (40-190 nm FWHM)	Narrower (0.00001 nm to 10 nm FWHM)
Fiber Type	Multimode Only	SM, MM
Ease of Use	Easier	Harder
Lifetime	Longer	Long
Cost	Low ($5-$300)	High ($100-$10,000)

FWHM: full width at half maximum

As we can see in (table 1.1) there are differences between lasers and LEDs, the difference decides what we will need to your application.

As an example, if we need to send signals over DWDM (Dense wavelength-division multiplexing) technology we need to use lasers because it has a Narrower Spectral Width and a long range of more than 50 Km.

1.2.1.3.   Optical Modulators

The simplest optical modulator we could think of is the switch of a flash light. Suppose we turn on a flashlight for 1 second and turn it off for 1 second. We generate digital data '1' and '0', respectively, as shown in (figure 1.3). In this example, the bit rate of the optical data generated from the flashlight is 1 bit/s. Optical modulation techniques can be divided into two types: (i) direct modulation of lasers and (ii) external modulation of lasers.
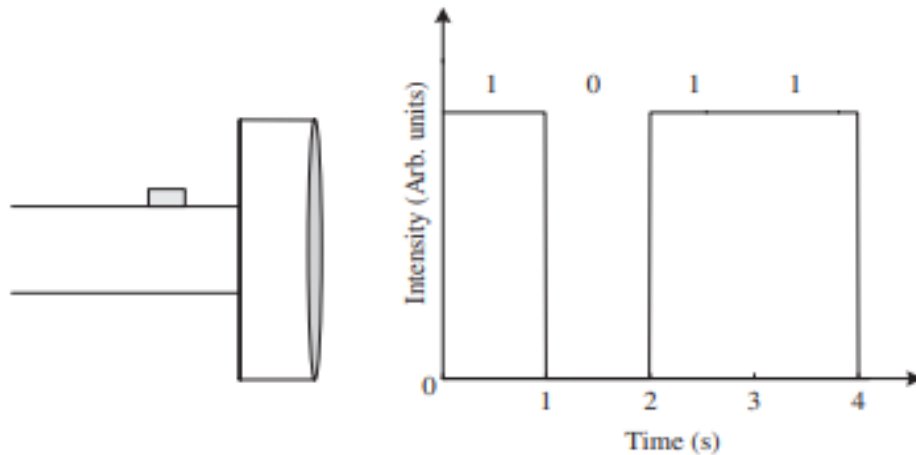
Figure 1.3: A simple optical modulator: the switch of a flash light. [5]

1.2.1.3.1. *Direct Modulation*

The laser drive current can be modulated by a message signal, as shown in (figure 1.4). For example, when the message signal is bit '0' (bit '1'), the laser is turned off (on) and, therefore, the information in the electrical domain is encoded onto the optical domain.
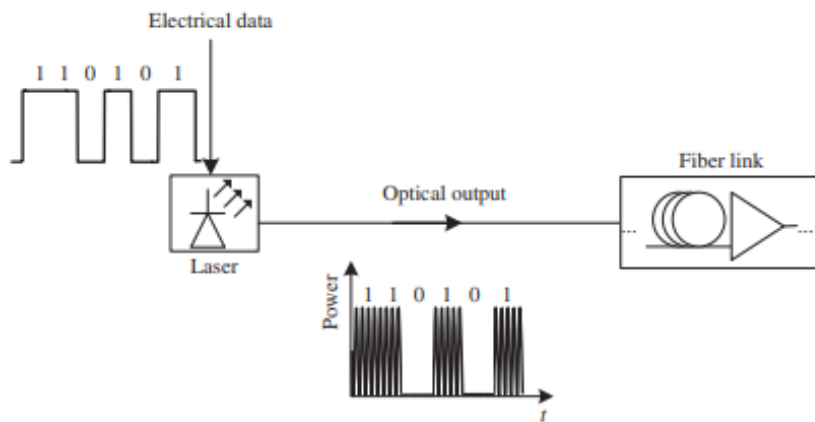
Figure 1.4: Direct modulation of a laser. [5]

Directly modulated lasers are usually used for transmission systems operating at low bit rates (≤ 10 GB/s) and for short-haul application (<100 Km). The pulse distortion and frequency chirp prevent the use of directly modulated lasers for high-bit-rate applications.

1.2.1.3.2. *External modulation*

In external modulation (figure 1.5), an external device is used to modulate the intensity or phase of the light source. The light source remains on while the external modulator acts like a "shutter" controlled by the information being transmitted. External modulation is typically used in high-speed applications such as long-haul telecommunication or cable TV head ends. The benefits

of external modulation are that it is much faster and can be used with higher-power laser sources. However, it is more expensive and requires complex circuitry to handle the high-frequency RF modulation signal. [6]
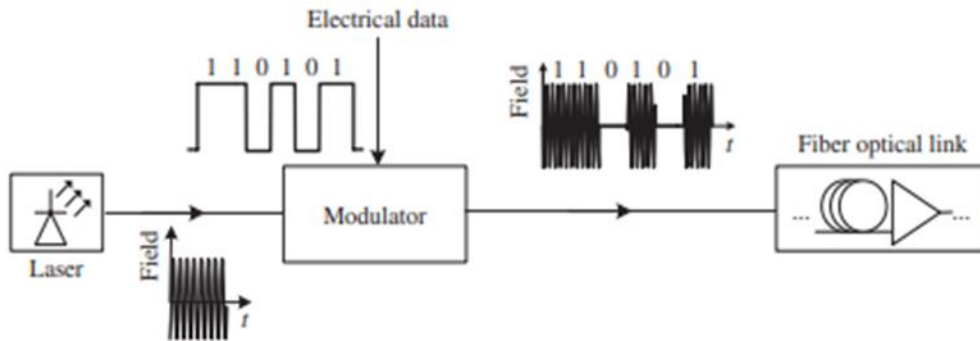
Figure 1.5: A transmitter using an external modulator. [5]

1.2.2. Optical fiber

Optical fiber is a flexible, transparent fiber made by drawing glass (silicon dioxide) or plastic to a diameter slightly thicker than a human hair. Optical fibers are most commonly used as a way to transmit light between the two ends of an optical fiber and are widely used in fiber optic communications, where they enable longer distances and higher bandwidths than cables.

1.2.2.1. *Structure of the optical fiber*

The optical fibers used in communications have a very simple structure. It is composed of the glass core, the cladding layer, the coating, strengthening fibers, and a jacket (figure 1.6).
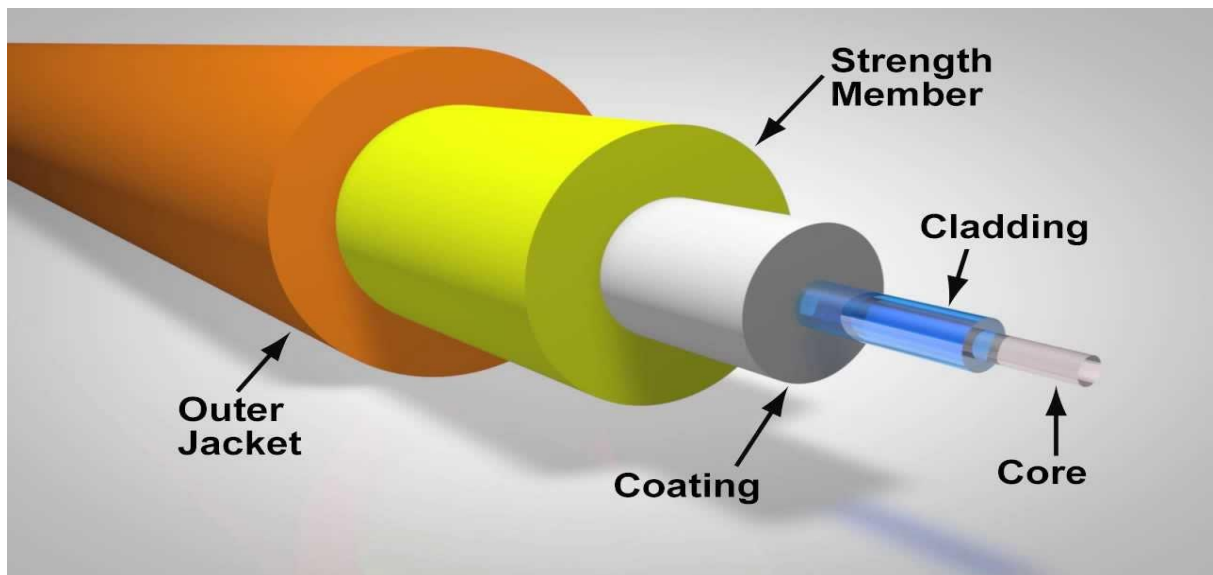
Figure 1.6: Structure of optical fiber

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

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

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

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

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

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

1.2.2.2. *Types of optical fiber*

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

1.2.2.2.1. *Multimode optical fibers (MMF)*

Multimode fiber optic cable has a large diametric core that allows multiple modes of light to propagate. As a result, the number of light reflections created as the light passes through the core increases, creating the ability for more data to pass through at a given time. Because of the high dispersion and attenuation rate with this type of fiber, the quality of the signal is reduced over long distances. This application is typically used for a short distance, data and audio/video applications in LANs (local area networks). RF (radio frequency) broadband signals, such as what cable companies commonly use, cannot be transmitted over multimode fiber. [8]

a) Multimode Graded index

Graded-index fibers bend the rays inward and also allows them to travel faster in the lower index of refraction region, it is a type of fiber where the refractive index of the core is lower toward the outside of the fiber. This type of fiber provides high bandwidth capabilities. Thus, graded-index fibers have bandwidths which are significantly greater than step-index fibers, but still much lower than single-mode fibers. Typical core diameters of graded-index fibers are 50, 62.5 and 100 µm. The main application for graded-index fibers is in medium range communications, such as local area networks (figure 1.7). [4]
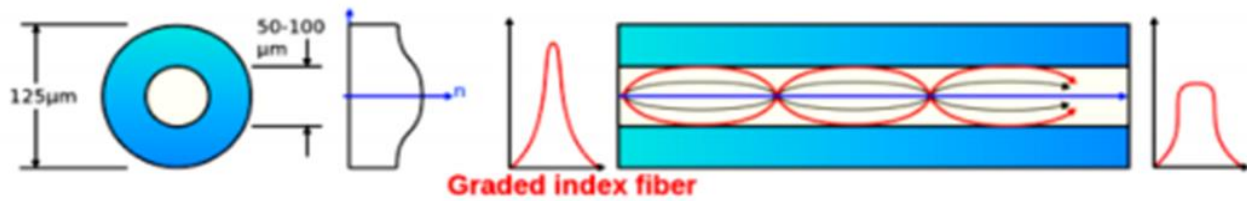
Figure 1.7: Graded-index Multimode fiber [4]

b) Multimode step index fibers

In a multimode SI (step index) fiber, the core is significantly bigger when compared to a single mode fiber by approximately 100 microns. Therefore, more modes are allowed to propagate inside the fiber. The total reflection is ensured by the values of the refractive indices n1 (core) and n2 (cladding) with always n1> n2 the multimode step-index fibers are intended for short distance transmissions, they use the wavelengths 850nm and 1300nm (figure 1.8). [4]
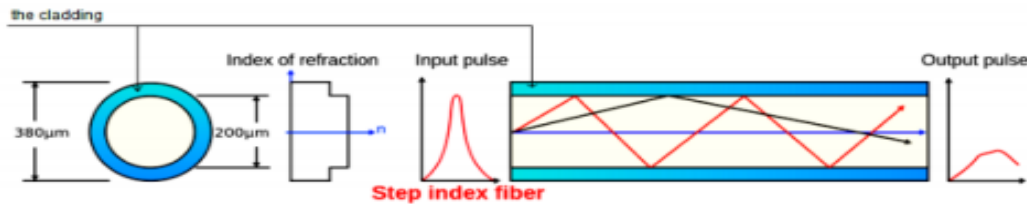
Figure 1.8: Step-Index Multimode fiber. [4]

1.2.2.2.2. *Single-mode fibers (SMF)*

Single-mode fibers (also called Mono-mode Fibers) are optical fibers which are specifically designed to support only a single propagation mode per polarization direction for a given wavelength. Single-mode fibers usually have a relatively small core (range from 8.3 to 10 µm) and a small refractive index difference between core and cladding; the mode radius is typically a few microns (figure 1.9). [7]
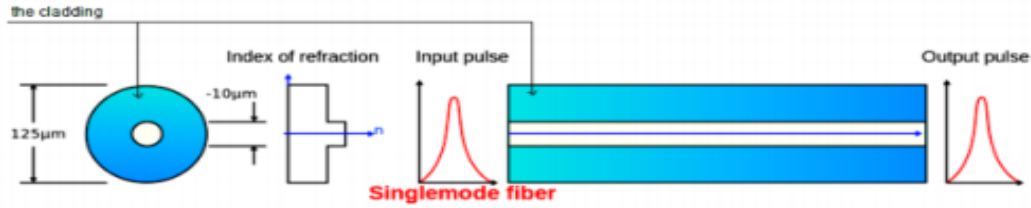
Figure 1.9: Single-mode fibers (SMF). [4]

1.2.2.2.3. *Multimode and single mode types and speed*

Multimode fiber has been classified and each category has different performance, but in single-mode fiber, there are two standardized categories (Table 1.2).

Table 1.2: Types and speeds of multimode and single mode fiber.

	OS1/OS2	OM1	OM2	OM3	OM4	OM5
Core/cladding(µm)	9/125	62.5/125	50/125	50/125	50/125	50/125
Fast Ethernet 100 Mb	40 Km	2 Km	2 Km	2 Km	2 Km	2 Km
1GbE	100 Km	275 m	550 m	800 m	1100 m	1100 m
10GbE	40 Km	33 m	82 m	300 m	400 m	400 m
40GbE	40 Km	-	-	100 m	150 m	150 m
100GbE	40 Km	-	-	100 m	150 m	150 m
Jacket color						

1.2.2.3. *Characteristics of an optical fiber*

After tackling both the definitions and nature of optical fibers above, the following section is dedicated to highlighting its main properties.

1.2.2.3.1. *Attenuation*

The attenuation of an optical fiber measures the amount of light lost between input and output. Total attenuation is the sum of all losses. [9]

Optical losses of a fiber are usually expressed in decibels per kilometer (*dB/km*). The expression is called the fiber's attenuation coefficient α and the expression is.

$$\alpha = 10 * \log_{10}\left(\frac{p_i}{p_o}\right) \quad [\text{dB/km}] \qquad (1.1)$$

Where:

p_i: input power

p_o: output power

α : is attenuation constant

The typical fused silica glass fibers we use today has a minimum loss at 1550nm.
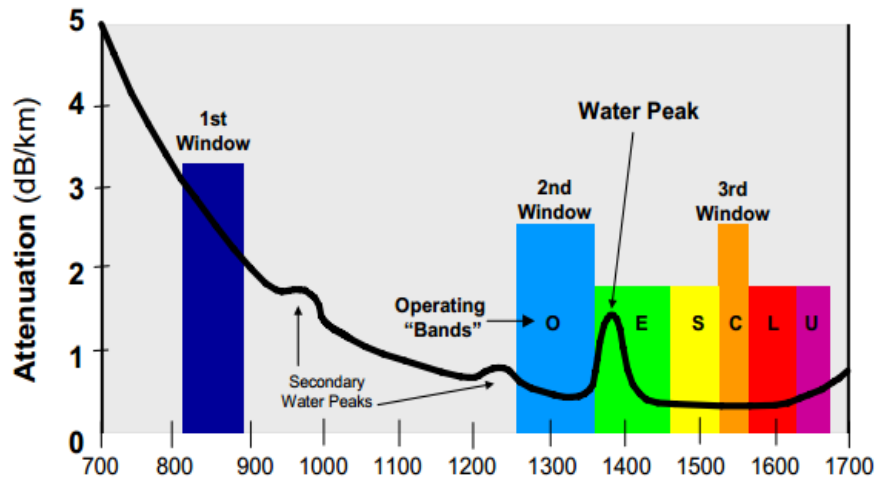
Figure 1.10: Attenuation spectrum of optical fiber. [10]

As we can see in (figure 1.10) there are three transmission windows:

- The first window from 820 to 880 nm

   For this window, the attenuation is very high, close to 3dB/ km (LED diode). This window is only used in Multi-Mode.

- The second window extends from 1260 to 1360nm

   For this window the attenuation is reasonable and in the order of 0.33dB/km. Chromatic dispersion is zero. This window is widely used.

   • The third window from 1530 to 1625nm:

It consists of two sub-bands:

   • C-band from 1530 to 1565nm
   • L-band from 1565 to 1625nm

This is the window of choice for almost all modern applications.

All fibers have the same windows, but the attenuation values may be different for different manufacturers.

The various losses in the cable are due to**:**

a) Absorption

Absorption is uniform. The same amount of the same material always absorbs the same fraction of light at the same wavelength. If you have three blocks of the same type of glass, each 1-centimeter thick, all three will absorb the same fraction of the light passing through them.

b) Scattering

Scattering losses occur when a wave interacts with a particle in a way that removes energy in the directional propagating wave and transfers it to other directions. The light is not absorbed, just sent in another direction. However, the distinction between scattering and absorption does not matter much because the light is lost from the fiber in both cases.

c) Macrobending Loss

Macrobending happens when the fiber is bent into a large radius of curvature relative to the fiber diameter (large bends). These bends become a great source of power loss when the radius of curvature is less than several centimeters. [9]

1.2.2.3.2. *Dispersion*

Dispersion is the dependence of light's phase velocity or phase delay as it transmits through an optical medium on another parameter, such as optical frequency, or wavelength. Several types of dispersion can occur inside an optic's substrate: chromatic, intermodal, and polarization mode dispersion.

a) *Chromatic Dispersion*

The refractive index is the ratio between the speed of light in a vacuum and a light wave's phase velocity while traveling through a medium, such as air or glass. In pulsed laser applications, light is commonly described using frequency because time is generally more critical and the frequency of light is a fixed value, while its wavelength is dependent on the refractive index it is traveling within.

b) *Intermodal Dispersion*

Intermodal dispersion is a dependence of the group velocity of light in a waveguide, such as multimode fiber, on the optical frequency and the propagation mode. in multimode optical fiber communication systems, this severely limits the achievable data transmission rate, or bit rate. Intermodal dispersion could be prevented by using single-mode fibers or multimode fibers with a parabolic refractive index profile.

c) *Polarization Mode Dispersion*

Polarization mode dispersion is the dependence of light's propagation characteristics in a medium on polarization state, which can be relevant in high data rate single-mode fiber systems. All three types of dispersion may cause temporal broadening or compression of ultrashort pulses in free space or optical fibers, potentially causing separate pulses blend together and become unrecognizable. [11]

1.2.3. Optical amplifier

An optical amplifier is a device that receives some input signal and generates an output signal with higher optical power. Typically, inputs and outputs are laser beams, either propagating as Gaussian beams in free space or in a fiber. The amplification occurs in a so-called gain medium, which has to be "pumped" from an external source. Most optical amplifiers are either optically or electrically pumped.

Semiconductor optical amplifiers can be electrically or optically pumped. In most cases, electrical pumping is used, which is highly convenient and allows for very compact amplifiers. While ordinary semiconductor optical amplifiers are quite limited in output power, substantially higher pulse (up to several watts) can be obtained from tapered amplifiers. [12]

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

Figure 1.11: EDFA block diagram [4]

Figure 1.11 shows one common configuration of EDFA. The input signal is combined with the pump light by a WDM (wavelength division multiplexing) coupler and launched to the EDF (erbium doped fiber). The pump light launched to the EDF creates population inversion and the input signal is amplified by stimulated emission.

Isolators are placed both at the input and output, in order to stabilize signal amplification by eliminating unwanted back reflection from the output port. In this common configuration, the wavelength of the pump LD (Laser Diode) is locked close to the peak absorption wavelength of

erbium (by an external fiber Bragg grating); the wavelength range is normally between 974 nm to 980 nm. [4]

1.2.4. Optical regenerator

An important application of optical signal processing is for regenerating optical signals degraded during transmission through fibers and amplifiers. An ideal optical regenerator transforms the degraded bitstream into its original form by performing three functions: reamplification, reshaping, and retiming. Such devices are referred to as 3R regenerators to emphasize that they perform all three functions. According to this terminology, optical amplifiers can be classified as 1R regenerators because they only reamplify the bitstream. Devices that perform the first two functions are called 2R regenerators. Since 2R and 3R regenerators have to work at time scales shorter than the bit slot in order to carry out pulse reshaping and retiming, they must operate at time scales of 10 ps or less, depending on the bit rate of the optical signal. As nonlinear effects in optical fibers respond at femtosecond time scales, highly nonlinear fibers are often employed for such devices. However, the use of SOAs is also being pursued in view of their low-power requirements. [13]
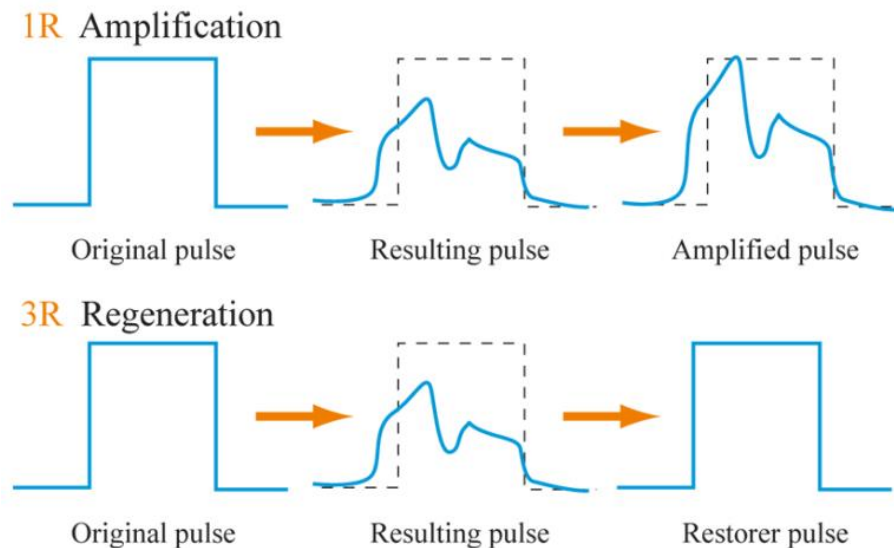
Figure 1.12: Amplification and regeneration of optical pulses. [14]

In (figure 1.12) shows the principle work of 1R and 3R regenerators.

1.2.5. Optical Receiver

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

1.2.5.1. PIN Photodetector (pin-PD)

The pin photodetector is one of the popular types used in fiber-optic. The performance of pin-PDs surpasses that of pn photodiodes because they can easily be tailored for optimum quantum efficiency and bandwidth. The basic pin-PD consists of three regions: heavily doped p+ and n+ layers and an intrinsic i-layer that is typically a much lower-doped semiconductor. The i-layer sandwiched between the p+ and n+ layers is shown in figure 1.13. [5]
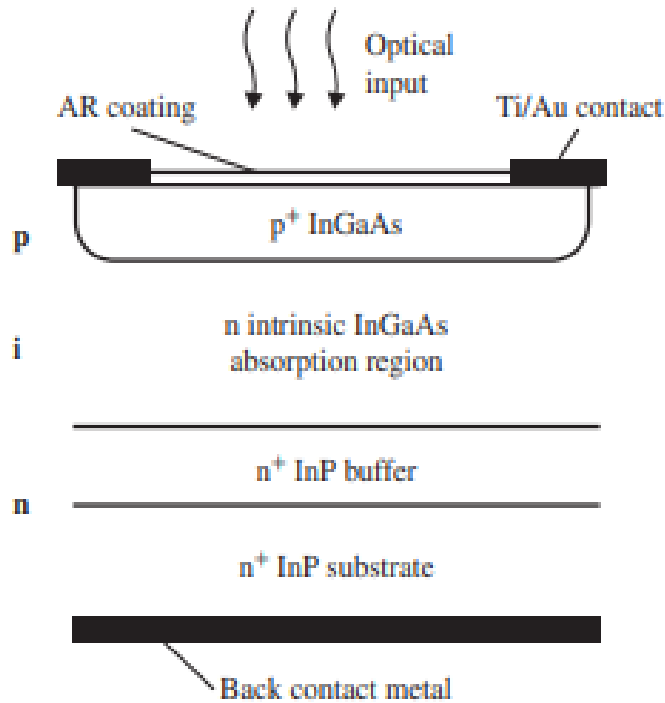
Figure 1.13: Schematic structure of a front-side-illuminated InGaAs (Indium gallium arsenide)–InP pin photodiode. [5]

1.2.5.2. Avalanche Photo Diode (APD)

The second major type of optical communications detector is the avalanche photodiode (APD), which has a more sophisticated structure than the PIN photodiode, in order to create an extremely high electric field region as shown in figure 1.14. Therefore, the depletion region where most of the photons are absorbed, and the primary carrier pairs generated, there is high field region in which holes and electrons can acquire sufficient energy to excite new electron-hole pairs. This process is known as *Impact Ionization* and is the phenomenon that leads to avalanche breakdown in ordinary reverse biased diodes. It often requires high reverse bias voltages (50 to 400 V). [4]
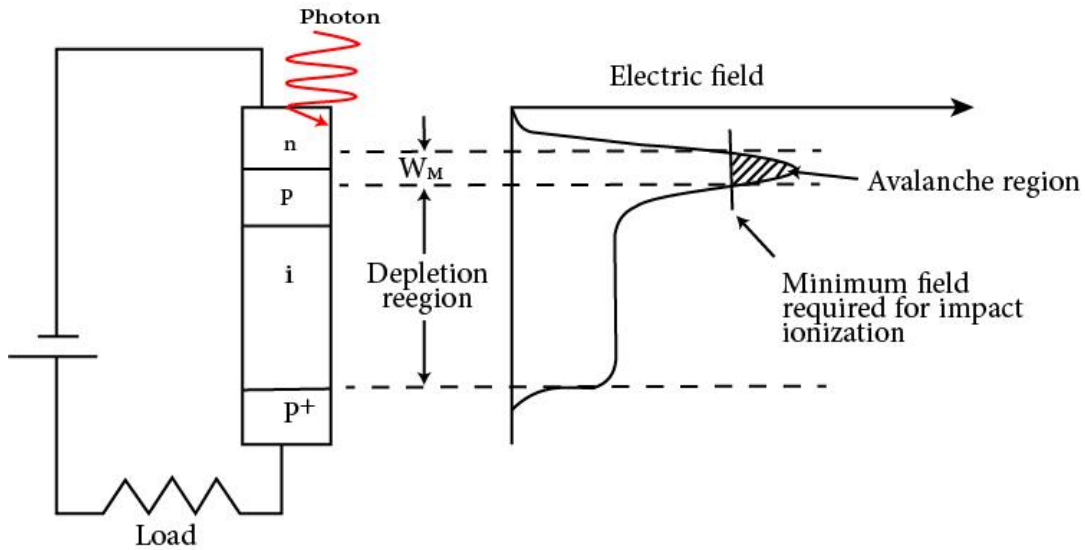
Figure 1.14: Avalanche photodiode showing high electric field region. [4]

1.3. Advantages and Disadvantages of optical fiber

The advantages of optical fiber include the following:

- Bandwidth is higher than copper cables;
- Less power loss and allows data transmission for longer distances;
- The optical cable is resistance for electromagnetic interference;
- The size of the fiber cable is 4.5 times better than copper wires and;
- These cables are lighter, thinner, and occupy less area compare with metal wires;
- Installation is very easy due to less weight;
- The optical fiber cable is very hard to tap because they don't produce electromagnetic energy. These cables are very secure while carrying or transmitting data;
- A fiber optic cable is very flexible, easily bends, and opposes most acidic elements that hit the copper wire

The disadvantages of optical fiber include the following

- The optical fiber cables are very difficult to merge and there will be a loss of the beam within the cable while scattering;
- The Installation of these cables is cost-effective. They are not as robust as the wires Special test equipment is often required to the optical fiber;
- Fiber optic cables are compact and highly vulnerable while fitting;
- These cables are more delicate than copper wires;
- Special devices are needed to check the transmission of fiber cable.[15]

1.4. Applications of optical fibers

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

- Medical: Used as light guides, imaging tools and also as lasers for surgeries;
- Defense/Government: Used as hydrophones for seismic and SONAR uses, as wiring in Aircraft, submarines and other vehicles and also for field networking;
- Data Storage: Used for data transmission;
- Telecommunications: Fiber is laid and used for transmitting and receiving purposes;
- Networking: Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission;
- Industrial/Commercial: Used for imaging in hard to reach areas;
- Broadcast/CATV: Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications. [4]

1.5. Conclusion

In this chapter, we have cited different types and speeds of optical fiber cable, the both components of an optical communication system such as transmitter and receiver, the main characteristics of the optical fiber, and the advantages/disadvantages of the optical fiber and its applications. To conclude, we are able to say that optical fiber is an optimum solution to exceptionally tall information rates, and desires in this region are likely to extend sharply within the near future. Modern structures are executed such as inactive optical engineering PON (Passive Optical Network) which can be considered within the following chapter.

Chapter 2

Introduction to FTTx System and network PON

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Chapter 2
Introduction to FTTx System
and network PON

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2.1. Introduction

The recent outbreak of the COVID-19 (Corona Virus) has had challenging implications for communities and organizations around the globe. Many governments asked individuals to work from home, when possible, in an attempt to reduce the spread of the virus. Also, in light of the fact that a huge number of individuals work and utilize the internet, that creates a new challenge as for how we will get required developing of high-speed downloads: videos, images, and video conferencing and transmission capacity to get to Web data as fast as possible.

In Algeria, the impact of COVID-19 was very severe on the network; slow internet speeds, high latency in video conferencing and gaming which exceeded 500 ms in some games and other applications. Consequently, the Algerian government established broadband-based Fiber to The Home (FTTH) type of network access. Among the different FTTH implementations, the Passive Optical Network (PON) can provide very high data rates to customers, and extend coverage area reduced fiber deployment thanks to its point-to-multipoint architecture and reduced the cost of maintenance through the use of passive components in the network

In this chapter, we will present the networks on fiber optic. In the first part we describe the different architectures of FTTx (Fiber to the) such as FTTH (Fiber to the Home) and FTTB (Fiber to the Building). Then, we address the part of the passive optical network according to its architecture (unidirectional or bidirectional), its operating principle, and its various elements such as the ONT (Optical Network Termination), the OLT (Optical Line Terminal), and the separator. We also present some advantages and disadvantages of the network and technologies PON.

2.2. Access network

An access network is a network that physically connects an end system to a direct router (also called an "edge router") on the route from the end system to any other remote end system. Examples of access networks are Internet Service Provider (ISP), home network, corporate network, Asymmetric Digital Subscriber Loop (ADSL), cellular, FTTH …etc.

❖ Technologies for access network Wired:
- Plain Old Telephone Service (POTS);
- Asymmetric Digital Subscriber Loop (ADSL);
- Cable-modems using cable-TV (CATV);
- Optical Access Network FTTx.

❖ Technologies for access network Wireless:
- Satellite Systems: For Direct broadcast by satellite (DBS);
- Cellular networks;
- Fixed wireless access:
  - ➤ Local Multipoint Distribution System (LMDS).
  - ➤ Multichannel Multipoint Distribution System (MMDS).
  - ➤ Wi-Fi/WiMAX.
  - ➤ Free space optic FSO (optical wireless).

Different types of access networks are presented in the following figure (2.1):
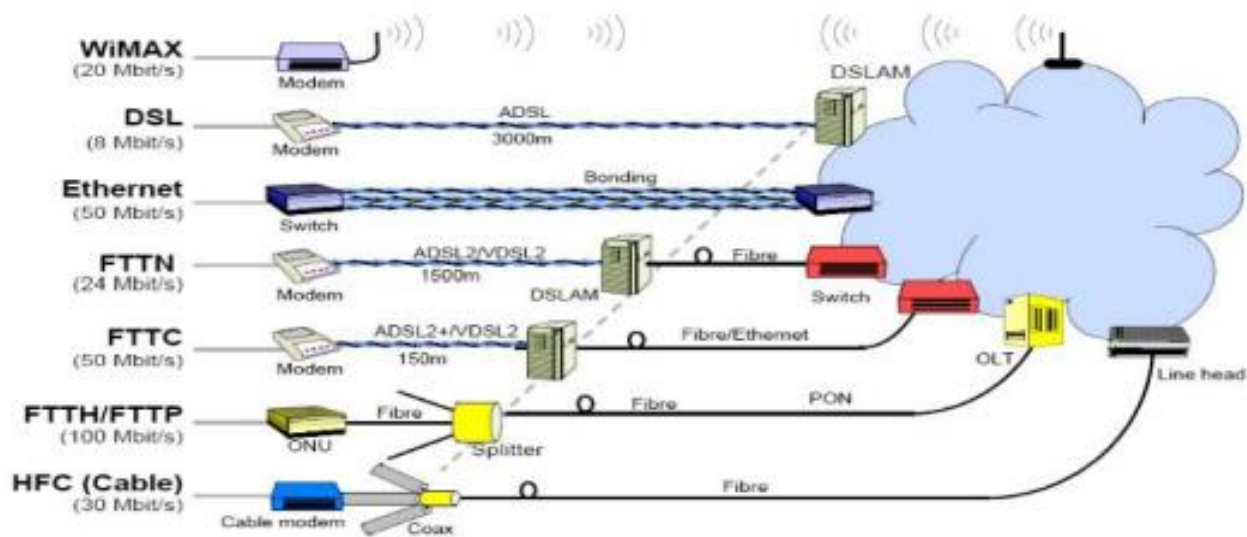
Figure 2.1: Access Network (Air, Copper, and Fiber access). [4]

2.3. FTTx Network

FTTx, or fiber to the "x", is a collective term describing a wide range of broadband network architecture options. Those architectures utilize optical fiber for some or all of their last-mile connectivity. The FTTx is a key method used to drive Next-Generation Access (NGA), describing a significant upgrade to the broadband available by making a step-change in the speed and quality of the service. FTTx networks bring the combined advantages of higher transmission rates and lower energy consumption. The "x" stands for the fiber termination point, such as home, antenna, building, …etc. Therefore, an FTTx network moves optical fiber closer to the user, which allows the latest construction, connection, and transmission techniques to be leveraged fully and diminishes the bottleneck of conventional coax (figure 2.2).
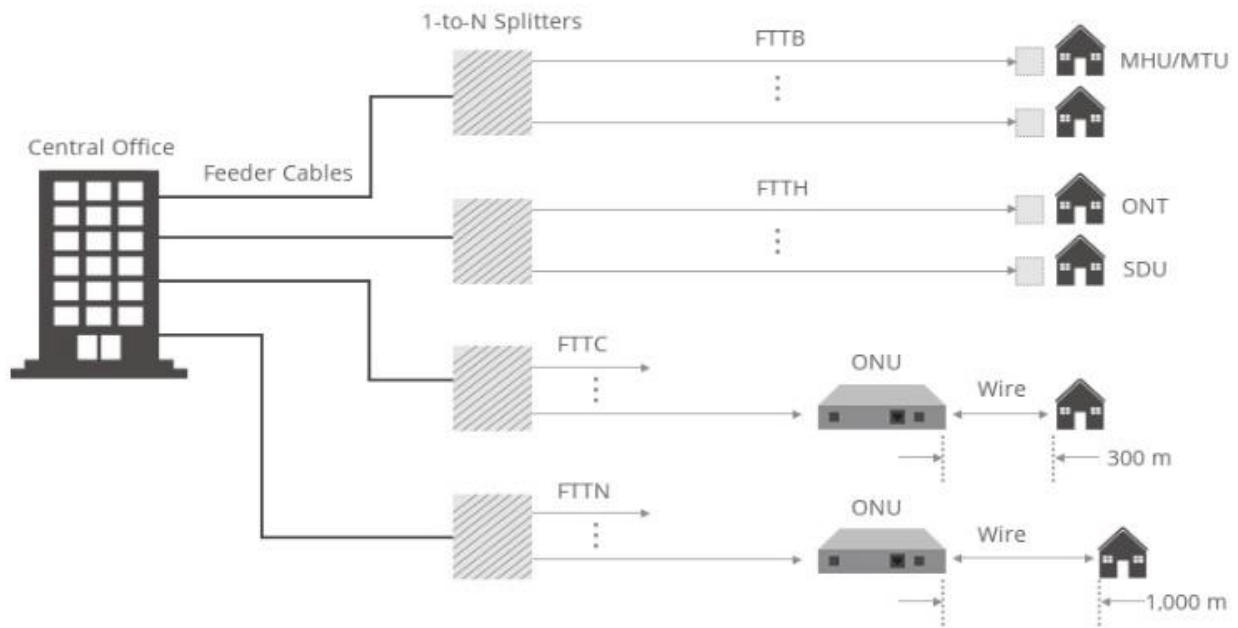
Figure 2.2: FTTx network. [17]

According to different termination places, the FTTx network architectures or FTTx network types include FTTH, FTTA, FTTB & FTTP, FTTN, FTTC, etc. Listed below are the most common ones.

2.3.1. FTTH

FTTH, or Fiber To The Home, is certainly one of the fastest growing applications worldwide. In an FTTH deployment, optical cabling terminates at the boundary of the living space so as to reach the individual home and business office where families and workers can both utilize the network in an easier way. [17]

2.3.2. FTTA

FTTA, or Fiber To The Antenna, is a network architecture utilizing fiber optics to distribute the signals from a Baseband Unit (BBU) to a Remote Radio Head (RRH) near the top of a cell tower, which is referred to as "front-haul" in 5G. FTTA technology is an essential element of 5G, since massive MIMO (multiple-input and multiple-output) translates to more antennas and more cabling. [17]

2.3.3. FTTN

FTTN stands for Fiber To The Neighborhood or Node. It is a network where the optical fiber ends at a street cabinet that serves a few hundred customers within a radius of about a 1 kilometer. The connection between the node and subscribers uses a Digital Subscriber Line (DSL) connection.

2.3.4. FTTC

As a type of FTTN, FTTC means Fiber to the Curb. It is a topology in which the fiber runs from a central office to a curb-side distribution point, such as in a pole or an enclosure, in the vicinity of customer premises. A FTTC network consists of fiber optic cabling ending within a short distance to the end user (usually around 300 meters). [17]

2.3.5. FTTB

FTTB refers to Fiber To The Building. In an FTTB network, optical cabling ends directly at the building. Yet, it is different from the typical Fiber to the Home scenario in that FTTB connects apartment blocks using copper wire.

In this scenario the Internet Service Provider (ISP) use equipment located at basement connected with central office with fiber, and then connects every apartment with DSL connection.

For example, let's suppose a building had a 100 apartment or had 50 offices, connecting every apartment or office with fiber is expensive so ISP uses DSL technology as a cost-efficient alternative.

Note: Fiber to the premises (FTTP) is a blanket designation including FTTH and FTTB.

2.4. FTTH network

The FTTH is a technology that connects subscribers with internet and telephone services, this connection is made out of the Optical Line Terminal (OLT) that is located in the central office of the Internet services provider, and the Optical Network Terminal (ONT), which is the device that we place in our house.

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

2.4.1. Point-To-Point links

As shown in figure 2.3, one option for a point-to-point Ethernet optical access network is to have dedicated fibers running between a metro Ethernet switch at central office of Internet Service Provider and Ethernet switches or a device designated for individual subscribers.
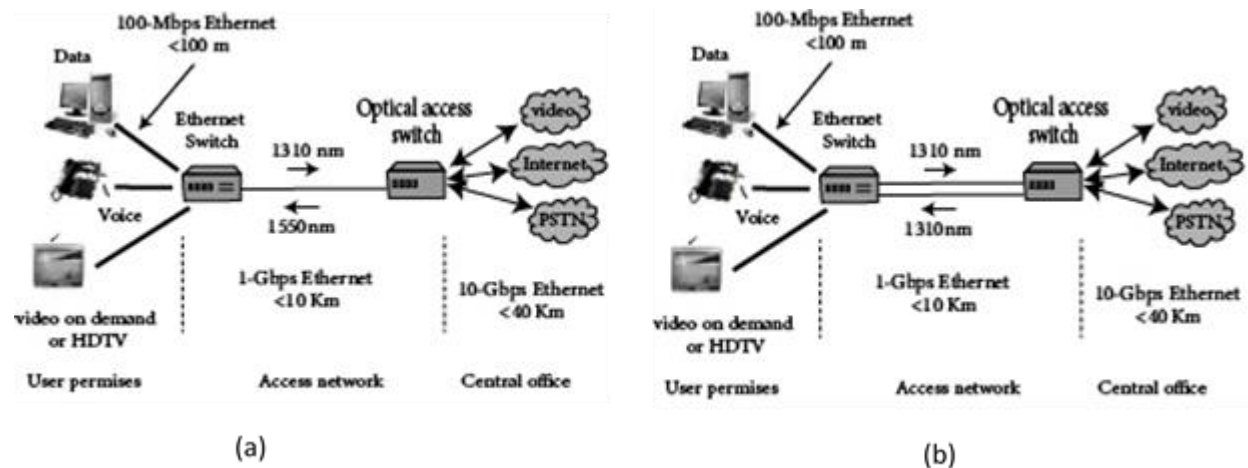
Figure 2.3: Point-to-point Ethernet optical access network
(a): Bidirectional connection, (b) Unidirectional connection

If the connection is bidirectional (Fig.2.3.a), here downstream voice, data, and video services are combined onto a 1550-nm wavelength, and upstream services back to the central office are sent over the same fiber by means of a 1310-nm wavelength.

And if the connection is unidirectional (Fig.2.3.b), the services are combined into 1310 nm wavelength upstream and downstream because the transmitter and receiver are separate. The links can operate at 10 Gbps over distances up to 10 km. Such a scenario requires a large number of optical fiber lines, with each line having its own optical transceivers.

For example, suppose that the network serves 20 subscribers. If the optical link running to an individual subscriber is bidirectional, 20 fibers are required. In case the links are unidirectional, a total of 40 optical fibers are needed. Since each subscriber link needs transmitters and receivers at each end, the system needs a total of 40 optical transceivers. Therefore, this type of network is useful only if each subscriber requires close to the full capacity offered by a gigabit Ethernet line.

2.4.2. Point to Multi Point architectures (P2MP)

No network user uses network resources in the same way. Central offices (CO's) high-speed connections can be shared among groups of users. This topology is suitable for home users and small offices. Shared fibers can carry TDM data, WDM data, or a mix of multiple users. Point-to-multipoint implementation and operating costs are lower than point-to-point costs; Because, the cost of the shared portion is shared by all users served by the same fiber.

And there are two options for P2MP architectures

> ➢ The centralized approach uses single-stage splitters located in a central hub in a star topology which mean each network component (ONT) is physically connected to a central node (OLT) via optical spliter (figure 2.4).
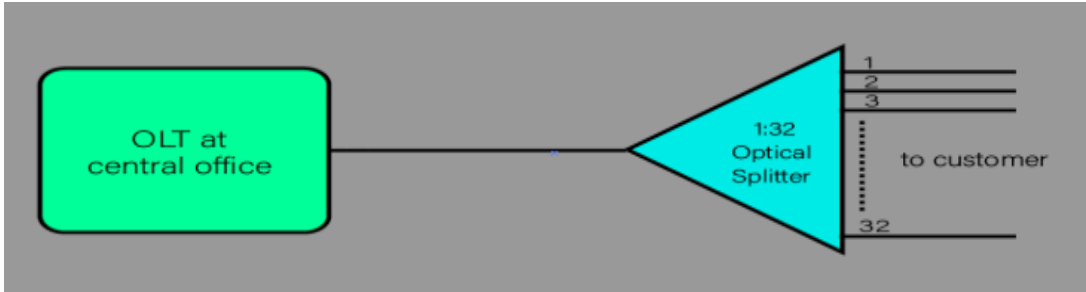

Figure 2.4: Centralized diagram

> ➢ The cascaded approach uses multi-stage splitters in a tree-and-branch topology (figure 2.5).
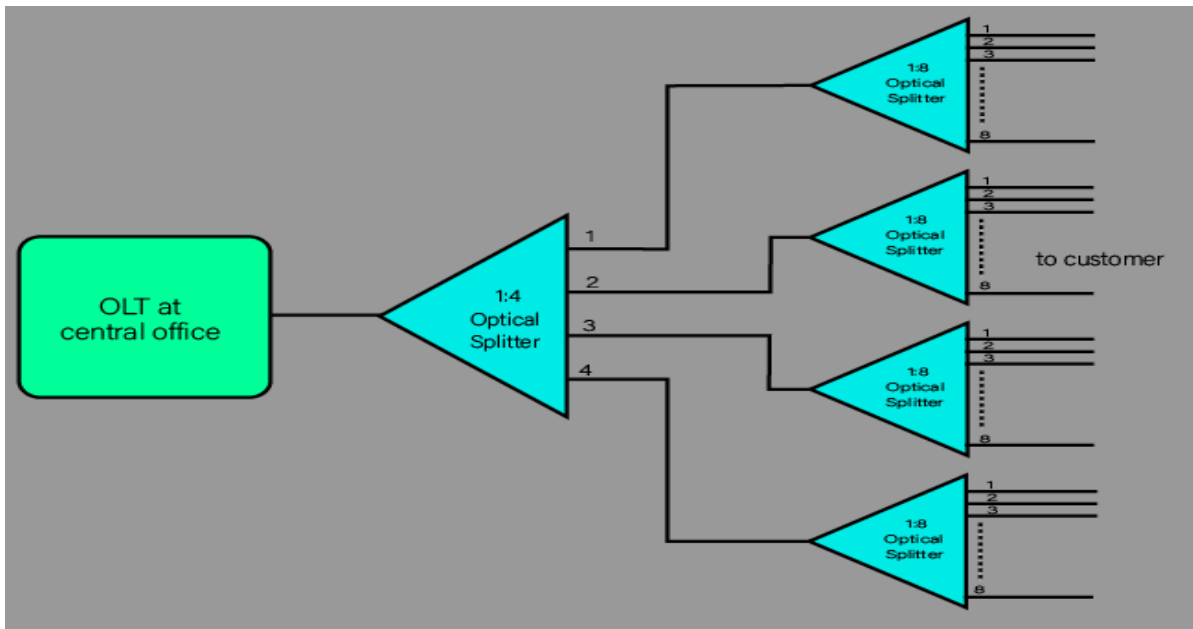
Figure 2.5: Cascaded diagram.

2.5. Passive optical network

A passive optical network contains no active optical elements at any intermediate points along the network paths. Figure 2.6 illustrates the basic architecture of a typical PON in which a fiber optic network connects switching equipment in a central office with a number of service subscribers.
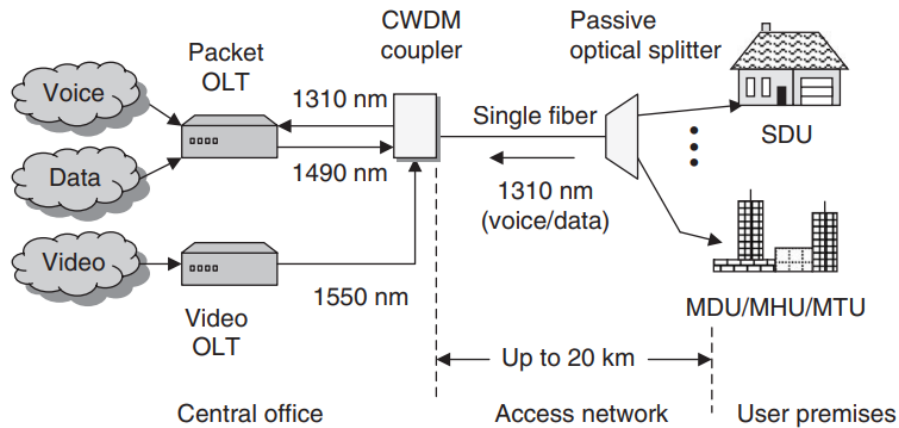
Figure 2.6: Basic architecture of a typical PON [18]

Starting at the central office, one single-mode optical fiber strand runs to a passive optical power splitter near a housing complex, a large apartment or office building, a business park, or some other campus environment. At this point there is a splitting device that simply divides the optical power into N separate paths to the subscribers. If the splitter is designed to divide the incident optical power evenly and if *P* is the optical power entering the splitter, the power level going to each subscriber is *P/N*. Designs of power dividers with other splitting ratios are also possible and there could be more than one splitter in a particular path, depending on the application. The number of splitting paths can vary from 2 to 64, but typically, they are 8, 16, or 32 paths. Hence, from the optical splitter, individual single-mode fibers then run to each building or serving equipment. The optical fiber transmission span from the central office to the user can be up to *20km*. In such a network, active devices exist only in the central office and at the end terminal. [18]

2.5.1. Optical Distribution Network (ODN)

The ODN (an integral part of the PON system) provides the optical transmission medium for the physical connection of the ONUs (Optical Network Units) to the OLTs (Optical Line terminates) with *5km* or farther reach. Within the ODN, fiber optic cables, fiber optic connectors, passive optical splitters, and auxiliary components collaborate with each other. The ODN specifically has five segments which are: feeder fiber, optical distribution point, distribution fiber, optical access point, and drop fiber (figure 2.7). The feeder fiber starts from the optical distribution frame (ODF) in the central office telecommunications room and ends at the optical distribution point for long-distance coverage. The distribution fiber from the optical distribution point to the optical access

point distributes optical fibers for areas alongside it. The drop fiber connects the optical access point to terminals (ONTs), achieving optical fiber drop into user homes. In addition, the ODN is the very path essential to PON data transmission and its quality directly affects the performance, reliability, and scalability of the PON system. [20]
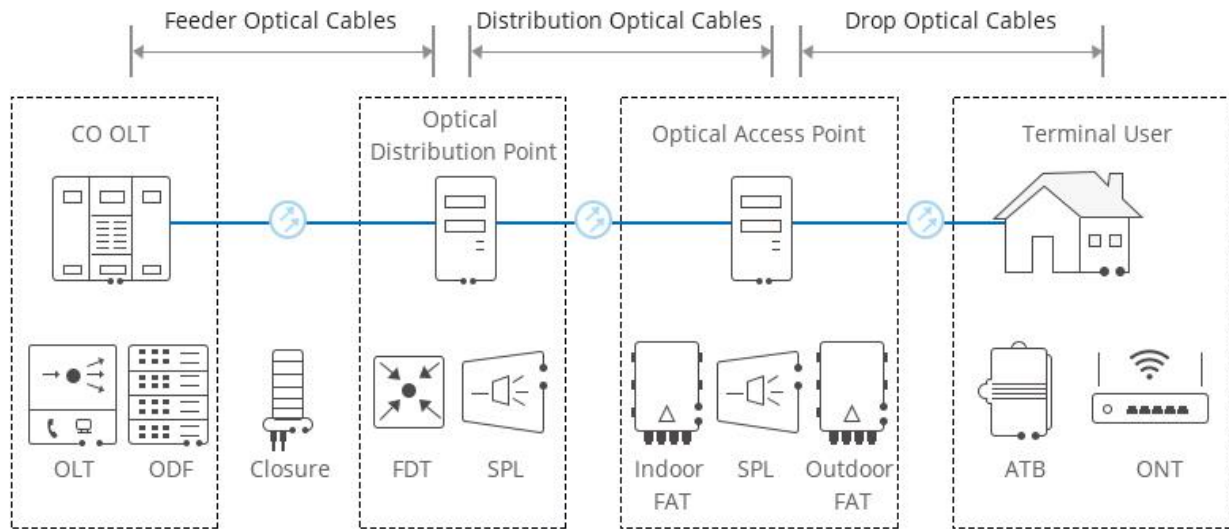
Figure 2.7: Optical Distribution Network (ODN). [20]

2.5.2. Optical Distribution Frame (ODF)

➢ The ODF is a passive component, and a very important component for organizing the fiber optic cable connections.
➢ The ODF is usually used indoor and could have a very big size frame or smaller similar to patch panel boxes depending on the network design requirements.
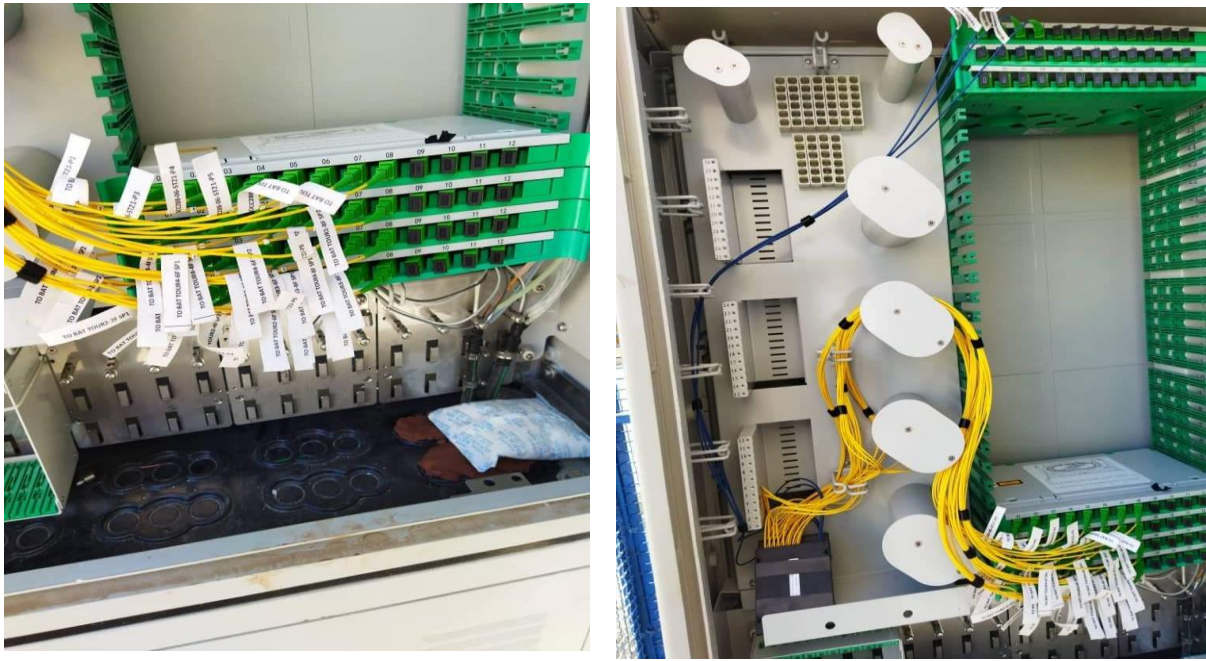
Figure 2.8: Optical distribution frame (ODF).[Algerie telecom]

2.5.3.   Optical Splitter

This device is the key component in PON for distributing optical signals from the same feeder fiber to customers. Where it splits the light beam coming from the input to the several light beams based on the number of output and vice versa, and output power is divided by the number of output.

In an ideal star coupler, the optical power from each input is divided equally among the output ports. The total loss of a device is its split loss plus the extra loss in each path through the star.

$$\text{splitting loss} = 10 \log N \qquad \text{(dB)} \qquad \qquad (2.1)$$

Equation 2.1 explains how to calculate the loss in an optical splitter, where N is the number of the outputs.

The PLC (Planar Lightwave Circuit) based optical splitters are popular for PON applications. These are highly reliable components that exhibit stable operation over wide temperature and wavelength ranges. Standard values of these ranges are -40 to +85ºC and 1280 to 1650 nm, respectively. [18]

Figure 2.9: 1:8 PLC fiber splitter steel tube bare fibers 250μm. [Algerie telecom]

As we can see in table 2.1, there is a slight difference between the Typical loss and actual loss, due to the structure of the material made with.

Table 2.1: Loss ratio of fiber optic splitter. [21]

Parameter		Specification						
Operating wavelength(nm)		1260-1650						
Type	1:N	1:2	1:4	1:8	1:16	1:32	1:64	1:128
Insertion loss(dB)	Typical	3.6	6.8	10.0	13.0	16.0	19.5	23.5
	(P/S)Max	3.8/4.0	7.1/7.3	10.2/10.5	13.5/13.7	16.5/16.8	20.5/21.0	24/24.5

2.5.4. Optical cables for PONs

The optical fiber used predominantly for PONs is the *G.652c* or *G.652d* single-mode type. Enclosing these optical fibers within some type of cabling structure provides physical and environmental protection. Different cable designs are used depending on where in the PON they are deployed. The cable structure will vary greatly depending on whether the cable is to pull or blown into underground or intra building ducts, buried directly in the ground, installed on outdoor poles, or placed underwater. To prevent excessive stretching, the cabling process usually includes the incorporation of strength members into the cable design. This is especially important in the design of aerial cables that can experience severe stresses due to factors such as wind forces or ice loading. Common strength members are strong nylon yarns (e.g., Kevlar), steel wires, and fiberglass rods. [18]

2.5.5. Optical Connectors

Many types of optical fiber connectors are available for a variety of applications. Their uses range from simple single-channel fiber-to-fiber connectors in a benign location to rugged multichannel connectors used under the ocean or for harsh military field environments. Connectors are available in designs that screw on, a twist on, or snap in place. The Snap-On designs are the ones that are widely used for PON applications. The designs include both single- and multichannel assemblies for cable-to-cable and cable-to-circuit card connections (figure 2.10).
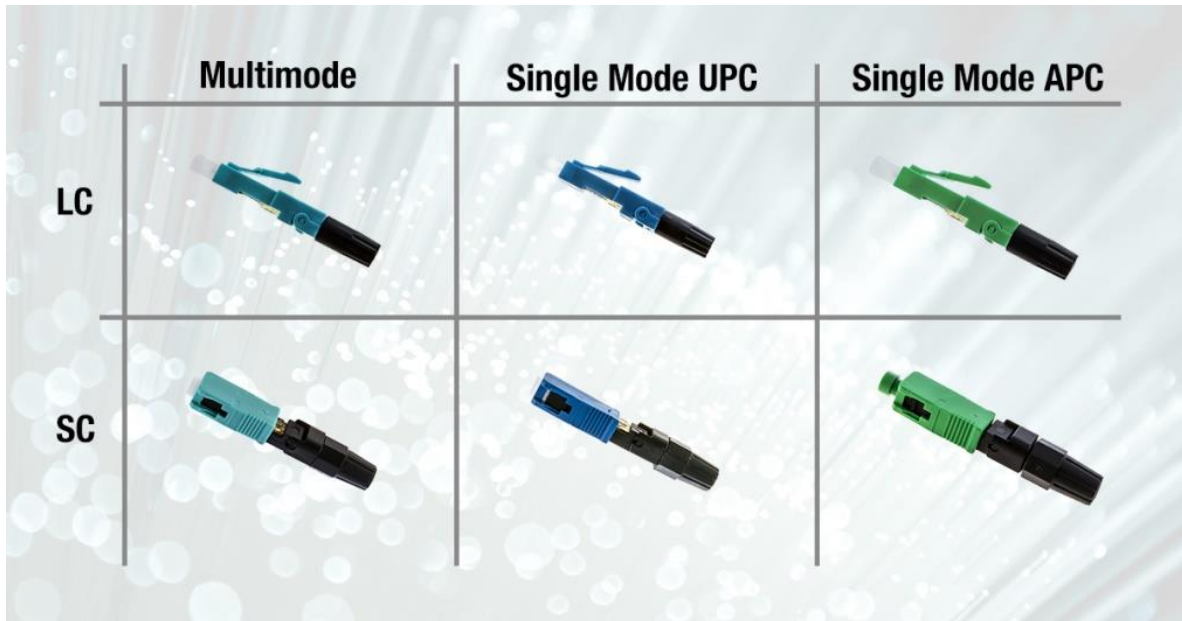
Figure 2.10: Different type of fiber optic connecter. [22]

2.5.6. Optical Splices

A fiber splice is a low-loss bond between two fibers, which can be made using either fusion splicing or mechanical splicing (Figure 2.11). In the making and evaluating process of optical fiber splices, one must take into account the physical differences among the two fibers, fiber misalignments at the joint, and the mechanical strength of the splice.

The total splice loss typically is *0.1dB* to *0.3dB* for fusion splicing and around *0.5dB* for mechanical splices.

(a)   (b)
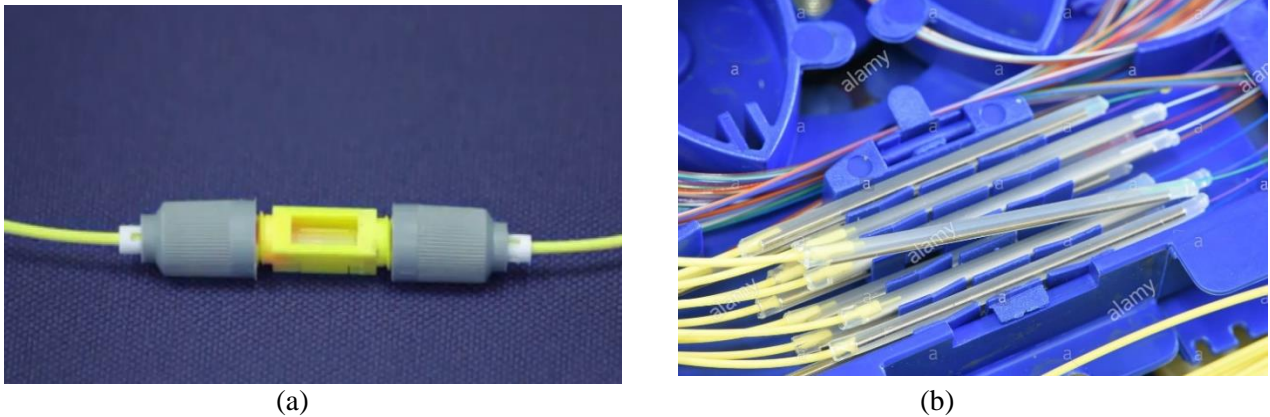
Figure 2.11: Optical splice: (a) Mechanical splice and (b) Fusing splice. [23-24]

2.6.   Active PON modules

In this section we showcase some of the basic functions and compositions of the OLT, ONT equipment.

2.6.1. Optical Line Terminal

The OLT is located in a central office and controls the bidirectional flow of information across the ODN. An OLT must be able to support transmission distances across the ODN of up to *10km*. In the downstream direction the function of an OLT is to take in voice, data, and video traffic from a long-haul or metro network and broadcast it to all the ONT modules on the ODN. In the opposite direction (upstream), an OLT accepts and distributes multiple types of voice and data traffic from the network users. A typical OLT is designed to control more than one PON (Figure 2.12).

(a)

(b)

Figure 2.12: The optical line terminal (OLT): (a) ZTE GPON OLT C300
Port (b) ZTE GPON OLT C320. [25-26]

The OLT C300 Technical Specifications [27]:

- Chassis Configuration (21").
  - Total 23 slots;
  - 16 slots for universal line cards;
  - 2 slots for switch & control cards;
  - 2 slots for power cards;
  - 2 slots for uplink and cascading interfaces;
  - 1 slot for environment detecting card.
- Subscriber Card Density.
  - GPON card: 8/16 ports per card;
  - P2P card: 24/48 ports per card;
  - XG PON1 card: 8 ports per card.
- Uplink interface card.
  - 4*10GE uplink per card;
  - 2*10GE+2*GE uplink per card;
  - 4*GE uplink per card;

- o 1*STM-4/OC12 or 2*STM-1/OC3 TDM uplink per card;
- o 32* E1/T1 uplink card (balanced and unbalanced).

The OLT C320 Technical Specifications [28]:

- • Capacity.
    - o GPON up to 32 ports;
    - o Uplink interfaces up to 4 *GE (Optical)+2*GE(Electronic) or 2*10GE (Optical)+2*GE (Optical)+2*GE(Electronic).
- • Chassis Configuration (19").
    - o Total 5 slots;
    - o   2 slots for universal line cards;
    - o 2 slots for switch& control cards;
    - o 1 slot for fan module.
- • Subscriber Card Density.
    - o GPON card: 8/16 ports per card;
    - o XG-PON1 card: 8 ports per card;
    - o P2Pcard: 24/48 ports per card.
- • Uplink interface card.
    - o 1*10GE Optical port (Configurable 1*GE Optical port);
    - o 1*GE optical port;
    - o 1*10 M/100 M/1000 M electrical Ethernet port.

2.6.2.   Optical Network Terminal

   The ONT is located directly at the customer's premises; and its purpose is to provide an optical connection to the PON on the upstream side and to interface electrically to the customer equipment on the other side. Depending on the communication requirements of the customer or block of users, the ONT typically supports a mix of telecommunication services. The size of an ONT can range from a simple box that may be attached to the outside of a house to a fairly sophisticated unit mounted in a standard indoor electronics rack for use in large multi-dwelling unit (MDU) or multi-tenant units (MTU) applications, such as apartment complexes or office buildings. At the high-performance end, an ONT can aggregate, groom, and transport various types of information traffic coming from the user site and send it upstream over a single-fiber PON infrastructure. The term *grooming* means that the switching equipment looks inside a time-division-multiplexed data stream, identifies the destinations of the individual multiplexed channels, and then reorganizes the channels so that they can be delivered efficiently to their destinations. [18]

Figure 2.13: Optical Network Terminal (ONT) ZTE F660

Figure 2.14: The rear panel of the ZXHN F660. [29]

For example, ZTE f660 up face and rear panel can be seen in figures 2.13 and 2.14 respectively.

Technical Specifications of ZTE F660

- o   Wavelength: Receiving: 1480~1500 nm and Transmitting: 1290~1330 nm;
- o   Receiving Sensitivity: -28dBm;
- o   Transmitting Optical Power: 0.5~5dBm. [29]

2.7. Different standards of PON networks

The PON network is based on several standards, these are classified as follows:

2.7.1.   The APON standard

APON was started by the full service access network (FSAN) consortium and later transferred to International Telecommunication Union (ITU-T) as the G.983 standards. The aim was to explore the end-to-end ATM (asynchronous transfer mode) connection based on a point-to-multipoint tree configuration. Using ATM protocol at first was accepted, as ATM Protocol is the main protocol for telephone networks and also used for data transfer. APON networks support 32 subscribers with a single upstream data rate of 155 Mbps and downstream data rate of 622 or 155 Mbps (Asymmetric) depending on the nominal line rate chosen for the downstream facility**.** As defined in the IEEE 802.3 family, the maximum data rate in APON was 622 Mbps to 1.244 Gbps. [30]

2.7.2. The BPON standard

Broadband Passive Optical Network (BPON) standards are based on the *G.983* series of ITU-T recommendations that specify ATM as the transport and signaling protocol. Downstream transmission uses a 1490-nm wavelength for combined voice and data traffic, which gets encapsulated in ATM cells at the OLT. The BPON *G.983* standard offers a maximum bandwidth of 1.2 Gbps for the downstream traffic. Voice and data traffic is transmitted upstream by the ONT using a 1310-nm wavelength at a data rate of up to 622 Mbps. [18]

Other characteristics of APON / BPON networks are:

- 32 ONUs in a single PON;
- The length of the fiber can be up to 20 km;
- For voice and data, the downlink and uplink wavelengths used are 1490 nm and 1310 nm respectively;
- A third wavelength (1550 nm) can be used to transport digital video in the downstream direction.

2.7.3. The EPON standard

EPON (Ethernet PON) is a network in which point-to-multipoint (P2MP) topology is implemented with passive optical couplers and optical fiber as PMD (Physical Medium Dependent), which is based on a mechanism called the Multi-Point Control Protocol or *MPCP*.

The MPCP defined as a function in the MAC sub-layer; hence, to control access to a P2MP topology, each ONU in the P2MP topology contains an MPCP protocol element, which communicates with another MPCP element in the Optical Line Terminal (OLT). The main difference between EPON and APON is that in EPON architectures the data is transmitted in packets of variable lengths up to 1518 bytes according to the IEEE 802.3 protocol for Ethernet, whereas in an APON the data is transmitted in cells. Fixed length of 53 bytes (48-byte payload and five header bytes), as specified by the ATM protocol. This format means that it is difficult and inefficient for an APON network to carry traffic suitable for the IP protocol. Indeed, in an IP protocol data is segmented into packets of varying lengths up to 65535 bytes. [31].

2.7.4. The GPON standard

The progress of technology, the need for wider bandwidth, in addition to the insufficiency of ATM, pushed to revise the APON standard and to think of another solution called GPON (Gigabit PON) which was standardized by the ITU in 2003.

The GPON architecture no longer relies on ATM framing but on a much simpler protocol called GFP (Generic Framing Procedure: Multiplexing Protocol).

The major advantage of GPON is that it can support several services at the same time and allows the transmission of packets based on different protocols (ATM, IP). In addition, compared to

the BPON standard, GPON allows transmission up to 2.48 Gbps in the downstream direction and 1.244 Gbps in the upstream direction although it uses only one wavelength in this direction. [32]

For power-budget calculations, GPON uses the same classes of optics as specified for BPON systems. These optical power budgets are:

- Class A optics: 5 to 20 dB;
- Class B optics: 10 to 25 dB;
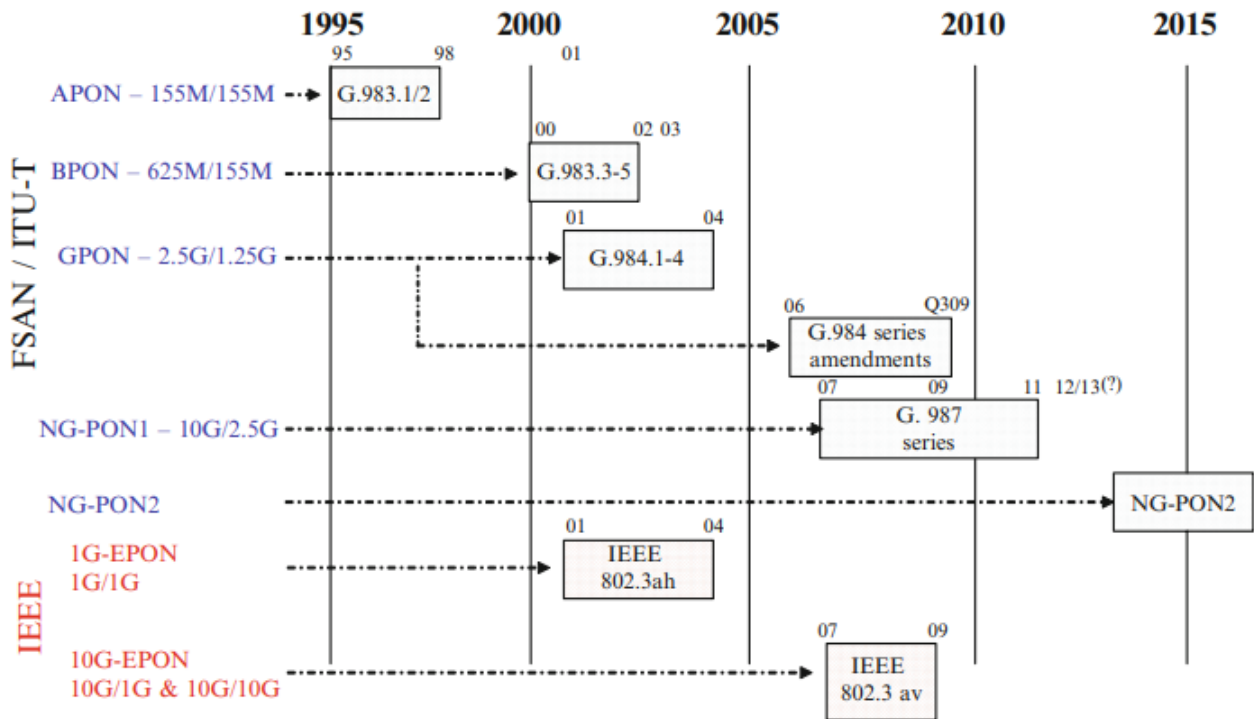- Class C optics: 15 to 30 dB.[17]

Figure 2.15: Evolution of PON. [31]

In figure 2.15 shows the evolution of PONs. TDM is the multiplexing scheme for all PONs which have been standardized until 2013. Numerous research articles in tackling challenges in WDM-PON have been published since WDM-PON was first proposed in 1986. However, it has not been included in the standard yet mainly due to the high system cost. OFDM-PON has received intensive research attention in recent years owing to its high bandwidth provisioning. Both WDM-PON and OFDM-PON are considered as future PON technologies. [31]

2.8.   Multiplexing techniques in FTTH-PON networks

Multiplexing is a technique that consists of passing several information through a single transmission medium. It allows sharing the same resource between multiple users.

The bandwidth of a communication channel (fiber optic) is often much larger than the necessary signal bandwidth. To use more effectively the bandwidth of the chosen channel and

therefore reduce its cost, it is intended to be able to transmit several signals at the same time (Frequency Division Multiplexing, or FDM) or to group the slow transmission channels to transmit them successively on the same channel at high speed (Time-Division Multiplexing, or TDM).

2.8.1. Frequency Division Multiplexing Access (FDMA)

This was the only and earliest technique which was used when the telephone was purely analog. Each interlocutor, or each message, is allocated a frequency band. This technique consists of dividing the bandwidth of a channel into several sub-bands; each sub-band is assigned to a transmission channel (figure 2.16).
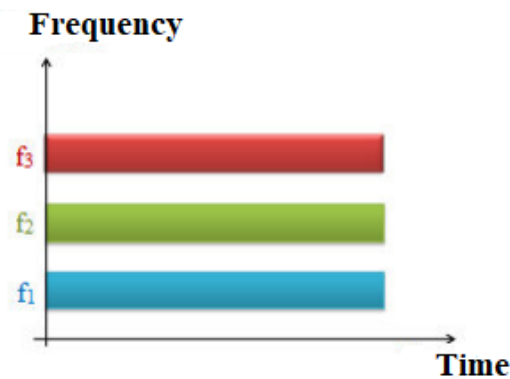
Figure 2.16: Frequency Division Multiplexing Access (FDMA) technique.

2.8.2. Time Division Multiple Access (TDMA)

TDMA time-division multiplexing consists of distributing the transmission of a carrier over separate time intervals (figure 2.17), the carrier is transmitted on time intervals, called time slots, of duration T_S, each of these durations corresponding at a time during which a user can transmit his data. [33]

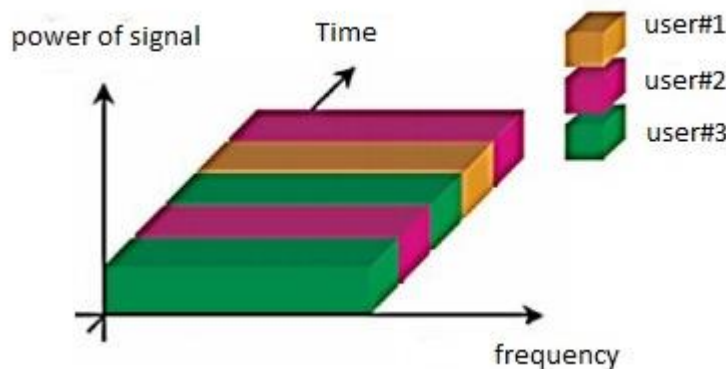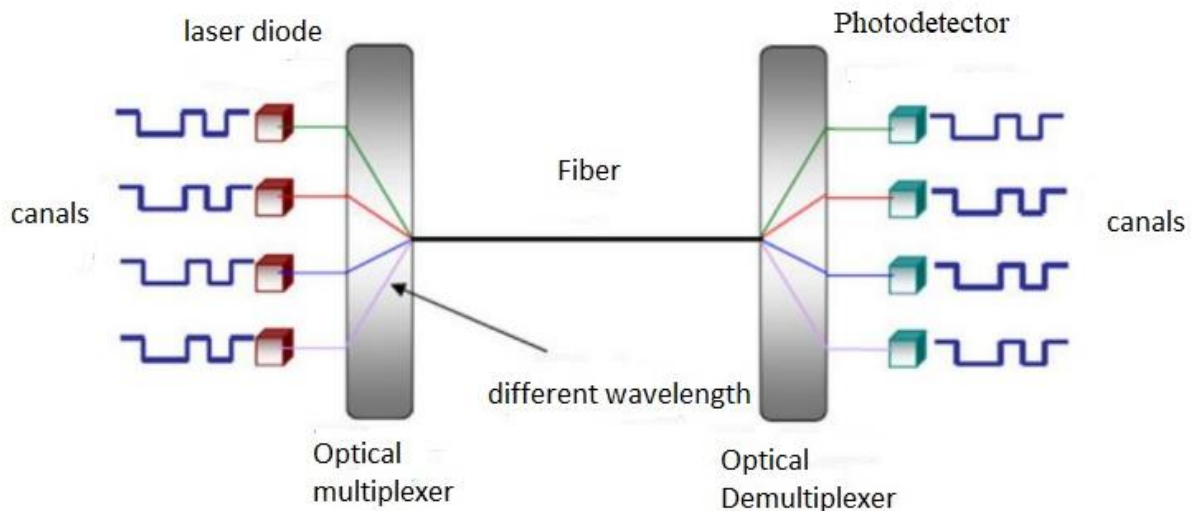**Figure 2.17:** Time-Division Multiple Access (TDMA) technique.

2.8.3. Wavelength Division Multiplexing (WDM)

The WDM technique consists of simultaneously injecting several channels information of N optical carriers, at different wavelengths each transmitting a rate D, in the same optical fiber on the principle that the different lengths wave of a pulse of light propagate on the optical fiber at different speeds. Indeed, the optical fiber has a very low attenuation (*0.2dB/km*) in the transmission window *1.5-1.6µm*, which represents more available bandwidth *15 THz*, i.e. a digital transmission potential of at least *5 Tbit/s* per fiber, the equivalent of 80 million telephone channels.

The use of WDM multiplexing requires a set of laser diodes emitting at different but fairly close wavelengths (around 1550 nm). To the reception, an optical demultiplexer combines/separates the different wavelengths which are then converted to the electron domain only by means of photodiodes. The figure 2.18 represents an example of a link using WDM multiplexing.

Figure 2.18: Block diagram of wavelength division multiplexing [34].

2.8.4. Code Division Multiple Access (CDMA)

CDMA technology is the user differentiation technique by the attribution of a signature or code to each user. In this access technique multiple, the users share the same frequency space and transmit at the same time intervals.

In this case, it is a question of assigning a code to each transmitter, also called a *sequence of code*, which allows it to transmit information without interfering with messages from other users. The reduction of MAI (Multiple Access Interference) is only obtained in the case of the use of strictly orthogonal code sequences.

The multiplexing capacity of CDMA is not limited by physical parameters (time slots available, usable frequencies or wavelengths, etc.), but by the ability to generate a maximum number of code sequences, these being chosen ways to minimize MAI. Figure 2.19 schematizes the distribution of users over the frequency band and over time according to the distribution of code sequences.
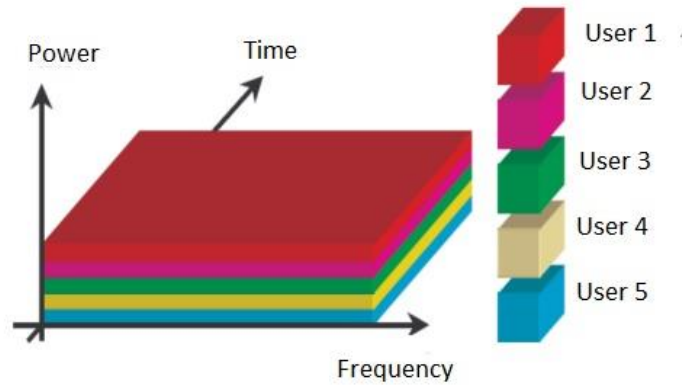
Figure 2.19: Code Division Multiple Access (CDMA) technique [34].

2.9.   Conclusion

In this chapter, we showcased the different optical fiber networks such as FTTB and FTTC, and we have focused on FTTH we have also mentioned its different components. Furthermore, we have highlighted the passive and active optical network components. Finally, we have shown that PON technology is economical in terms of investment and maintenance as it reduces infrastructure.

In the next chapter, we will see how FTTH planning is done using QGIS.

Chapter 3

Planning FTTH network in QGIS case urban and suburban neighborhoods in Zeribet El Oued city

Chapter 3
Planning FTTH network in QGIS case urban and suburban neighborhoods in Zeribet El Oued city

3.1. Introduction

In this chapter, we will study how to deploy an FTTH network in two types of neighborhoods: urban and suburban areas, we choose Zeribet El Oued city as it has the two types of construction mentioned above.

3.2. Geographic information system

A geographic information system (GIS) is an information system capable of providing information, organizing and presenting spatially referenced alphanumeric data using satellites, as well as allows users to produce maps and geographical plans adapted according to their needs.

The term "geographic information system" refers to software tools, but the use of this software encompasses data, know-how, and much more powerful hardware.

GIS provides several types of information related to geography and urbanization such as statistics, queries, etc. For this, GIS is used in all areas of local authorities, public sector, business, schools, administrations, and especially in the field of research and development since any study is directly linked to geography, population growth, and population dispersion. GIS is able to provide information on all of this in terms of timeliness and speed. Nowadays GIS occupies a very large market all over the world and offers jobs all over the world.[35]

3.2.1. Components of a GIS

A working GIS integrates five key components: hardware, software, data, people, and methods.[35]

A. Hardware

Hardware is Computer on which GIS software runs. Nowadays there are a different range of computer, it might be Desktop or server based.

B. Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are:

- Tools for the input and manipulation of geographic information;
- A database management system (DBMS);
- Tools that support geographic query, analysis, and visualization;
- A graphical user interface (GUI) for easy access to tools.

C. The data

The essential part of a GIS is the geographic data that can be default by the producer or inserted by the user.

D. Users

GIS have become indispensable. They are used in all fields and all sectors related to geography because of their flexibility and ease of use.

E. Methods

The use of a GIS requires the user to respect the regulations of the organization, which is responsible for copyright.

QGIS is a free software program developed in 2011 by CCIG (geographic information coordination commission). QGIS is one of the most powerful and widely used GIS in the world; it uses the CRS (Coordinate Reference System) to position and locates objects relative to each other.[35]

3.3. Steps to design an FTTH network

The process of designing any FTTH network can be summarized into three or 4 steps, as presented by the algorithm in (figure 3.1).
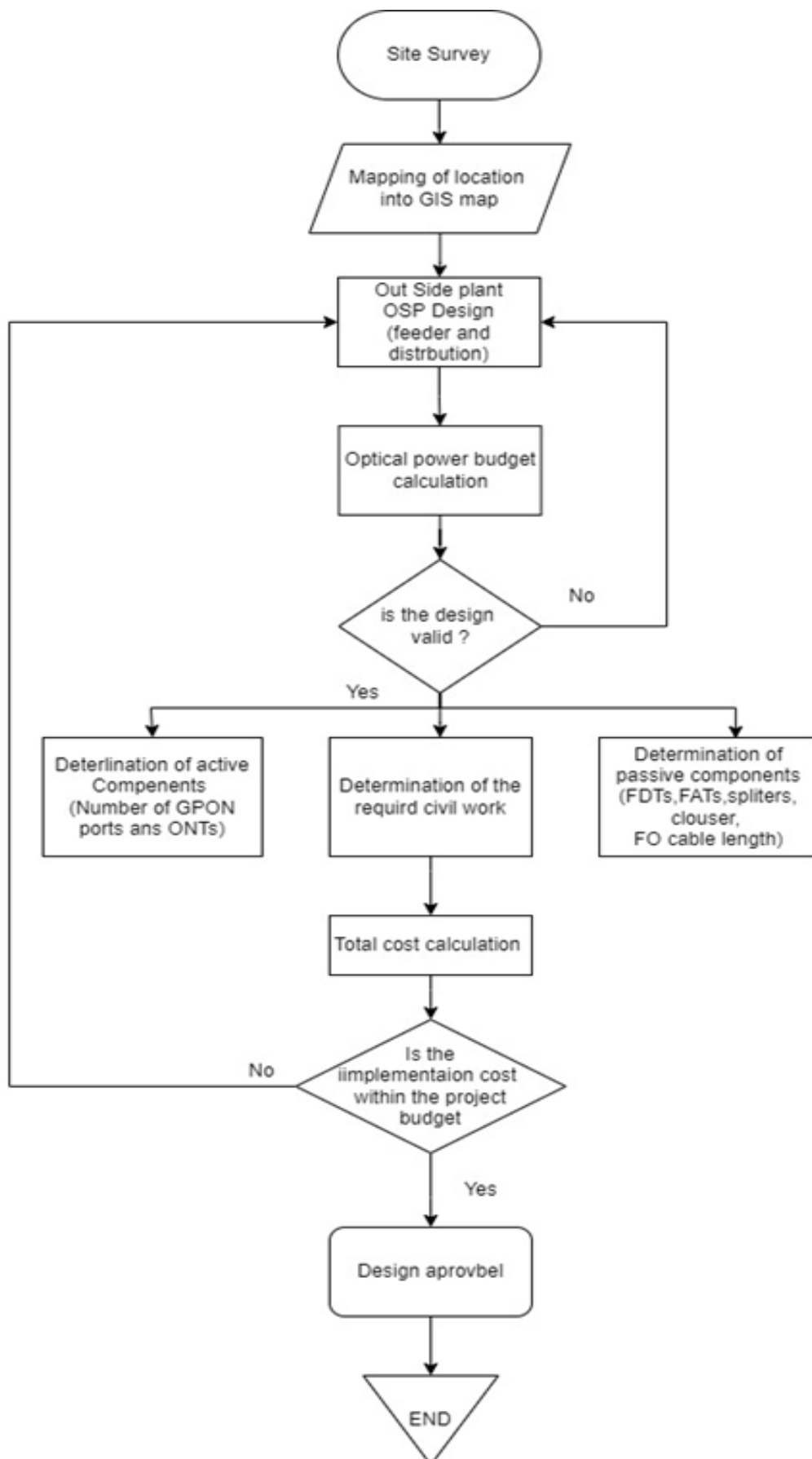
Figure 3.1: GPON FTTH access network design steps diagram.[36]

3.3.1. Site survey (field study)

Site survey is an inspection of the area where the FTTH network will be proposed, to gather information for a design or estimate the initial procedures required for deploying optical fiber, where we take into account:

- The number of potential subscribers for each house because we may find two or more families live in one house and each of them has its own network;
- Number of commercial subscribers (Internet cafes, libraries ... etc.);
- Are there underground trenches to pass fiber?
- Are surrounding homes are complete or still under construction;
- Are there any electric towers if there are no buildings?

3.3.2. GIS mapping

After the site survey, we need to add the field study to GIS MAP to select the number of potential subscribers for each home, and the GIS program will calculate the placement of potential FAT locations as well as fiber deployment locations and finally calculate power budget. In addition, we check if the design is valid, we proceed to step 3, if not we redesign.

3.3.3. Calculate the passive and active PONs

In this step, we calculate how much FAT is needed and how many splitters, FDH size, and cable type (12 or 24...or 144 fibers). As well as GPON, ports and OLT types will serve the area for at least 10 or 20 years.

3.3.4. Cost calculation

We calculate the cost without required civil work because our focus in FTTH planning is not on FTTH construction, if the cost was in the project budget design is valid, if it is not then we go back to Outside Planning (OSP) and redesign.

3.4. First case urban areas

In this section, we will apply the steps discussed above to the urban area in Zeribet El Oued.

3.4.1. Field study

We are going to do a field study of the western city of Zeribet El Oued (figure 3.2).

Figure 3.2: Topological area that will be covered by the fiber infrastructure in the city of Zeribet el Oued.

Because the zone has different buildings, structures we need to divide it into 3 small sectors for better calculations and more accurate design.

Figure 3.3: Different types of building.

As we can see in figure 3.3 there are three different types of sectors are yellow zone and blue, red zone. The type of the building decides how many apartment or potential subscribers.

- The yellow sector has buildings that had 6 or 8 potential subscribers. (figure 3.4)
- The blue sector has buildings that had 4 potential subscribers. (figure 3.5)
- The red sector has buildings that had 1 potential subscriber. (figure 3.6)

Figure 3.4: Two building has 6 potential subscribers in different locations.

Figure 3.5: Building has 4 potential subscribers.

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Figure 3.6: Building has 1 potential subscriber

In addition, there are 10 stores and they are in the same place and this gives us less concern. (Figure 3.7)

Figure 3.7: The highlighted area is the place of stores.

For deploying the fiber cable, there are two types of deployment.

- Feeder optical cable must be deployed underground because it is so sensitive every fiber feed more than 24 Fiber Access Terminals (FATs).
- Distribution optical cables are deployed on walls or along with the electric towers because we cannot dig in all neighborhoods.

Figure 3.8: Manhole to pass optical fiber.

As we can see in the figure, 3.8 there is an old manhole and will use it for deploying the feeder cable.

Now that we have completed the site survey, it is time to organize the survey before map it in QGIS (table 3.1).

Table 3.1: An overview of site statistics.

Sector	Type of building	Number of building	Potential subscribers	Total potential subscribers
A	Residential has 6 homes	76	6	456
	Regular homes	4	2	8
	Commercial	2	5	10
B	Residential has 8 homes	32	8	256
C	Regular homes	103	2	206
D	Residential has 4 homes	62	4	248
E	Regular homes	3	3	9
	Commercial	5	3	15

3.4.2. GIS Mapping

After we finish the site survey, now we move to add the site survey to the QGIS program.

a. Create a new points temporary layer, name it "users" and add a geometric point on every building in site work (figure 3.9).
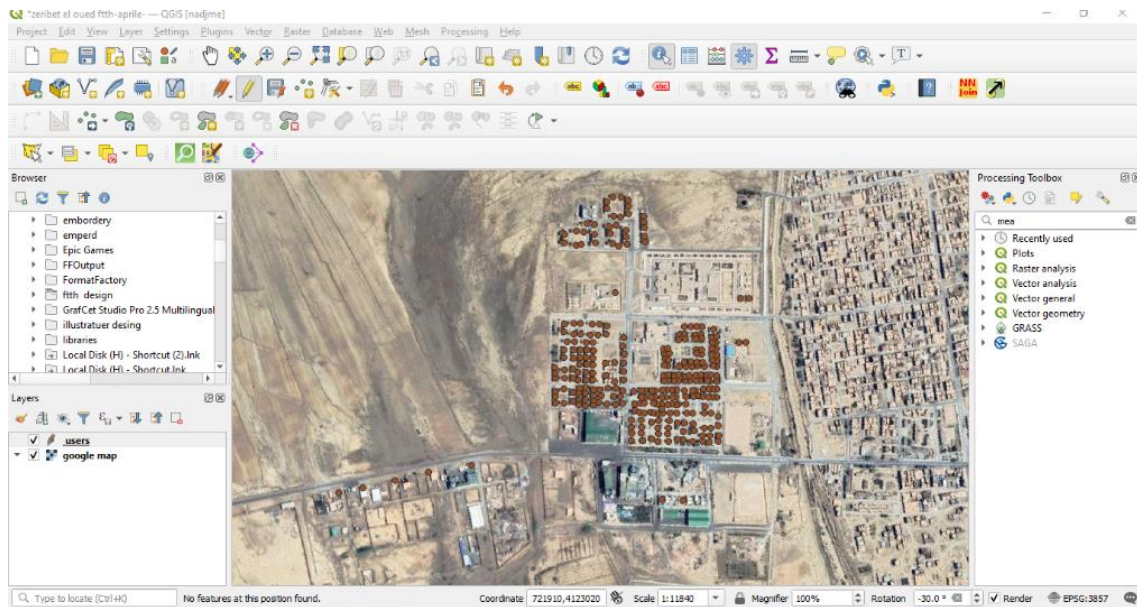
Figure 3.9: Geometric point on every building.

In figure 3.10 we can see the attribute table of the "users" layer, the layer it have two attributes sector and subscribers.

Figure 3.10: Attribution table of "users" layer.

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b. Now let us organize our work we need to categorize the points by sector (figure 3.11).
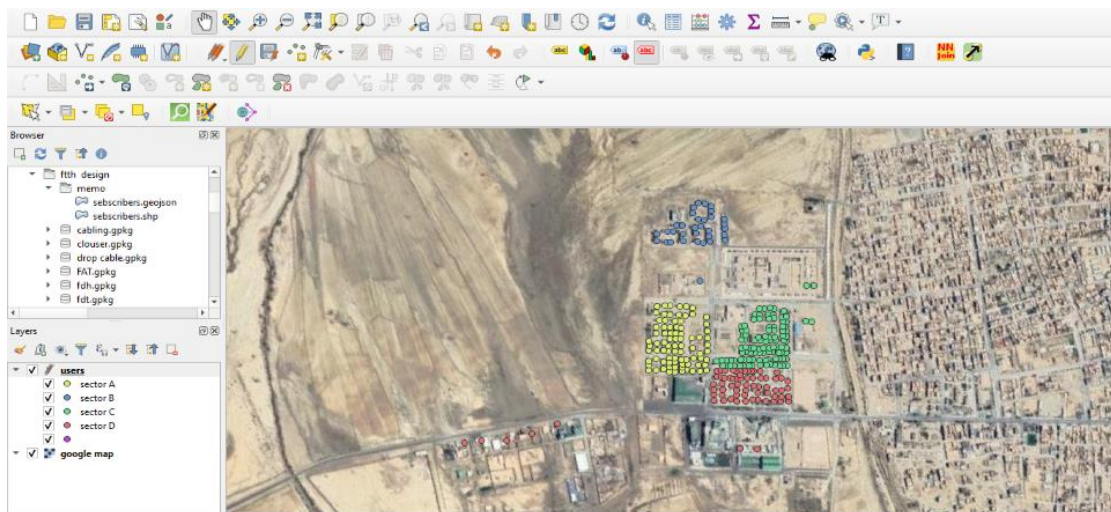

Figure 3.11: Geometric points categorized by sectors.

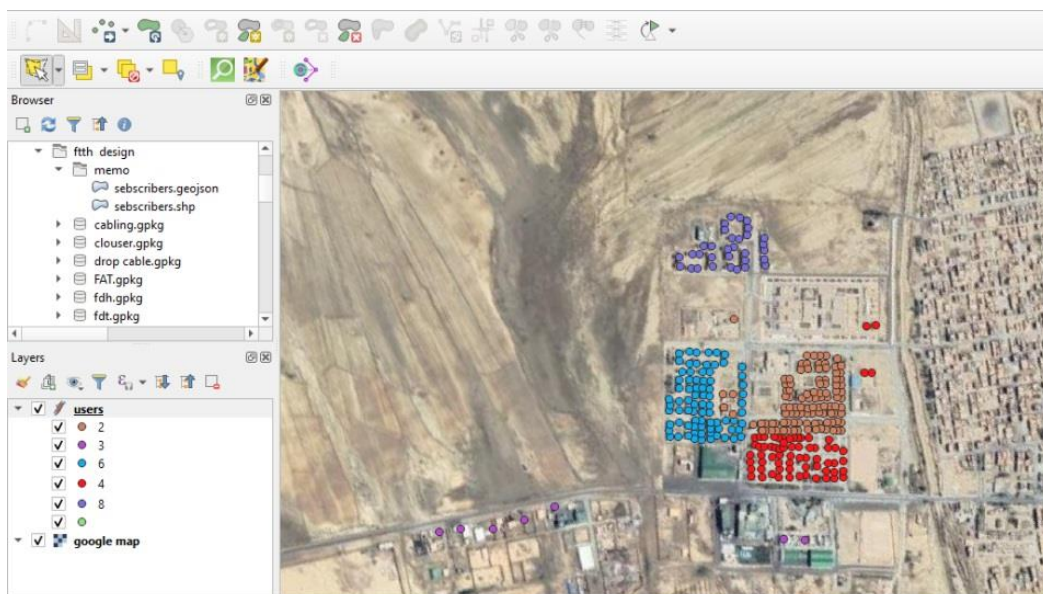c. Now add the number of potential subscribed for each building in different sectors (figure 3.12).

Figure 3.12: Geometric points categorized by the number of potential subscribers.

d. Now let us calculate the potentials FATs subscribers, to do so we have this algorithm, which will calculate the potential FAT based on the number of potentials subscribers on every building (figure 3.13).
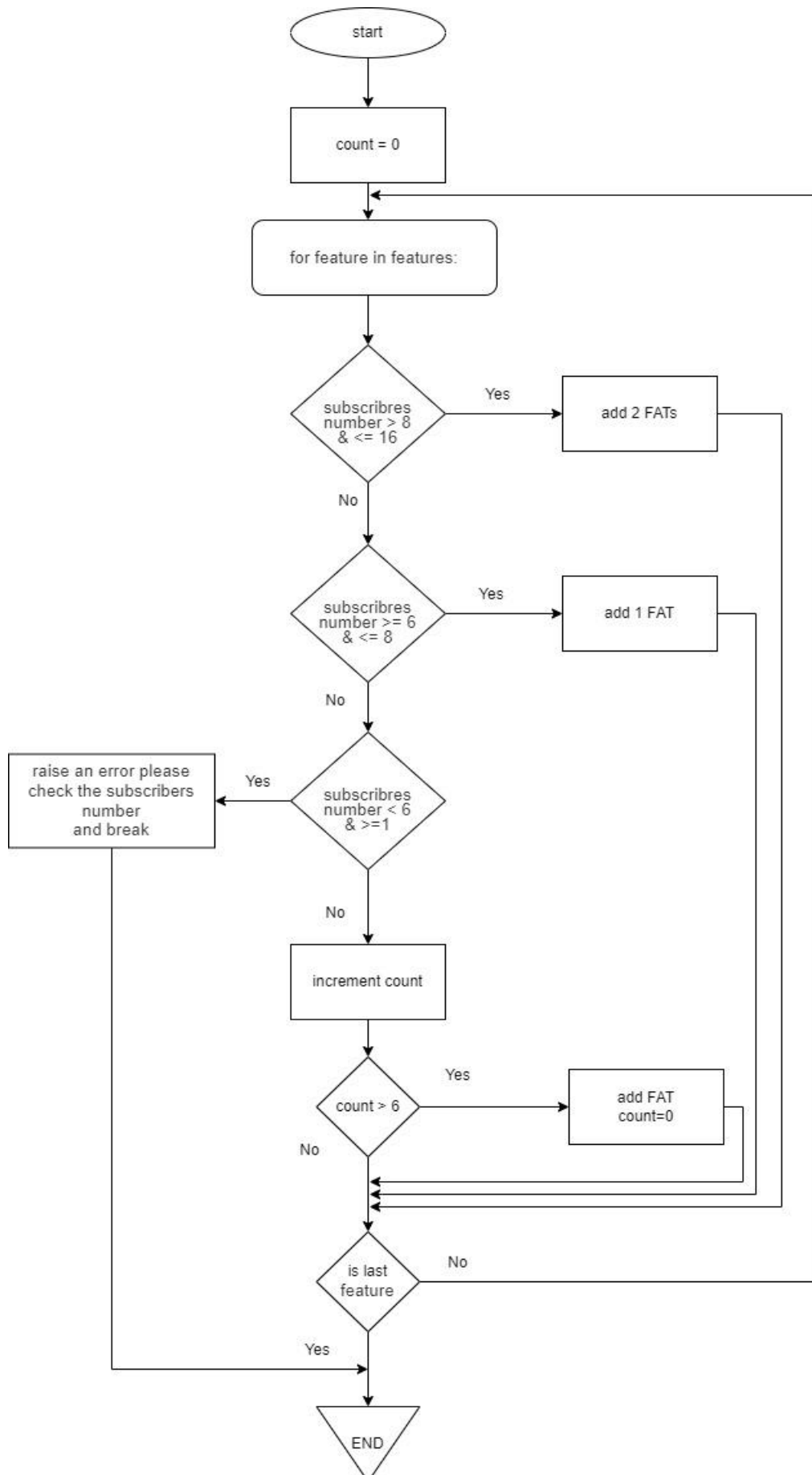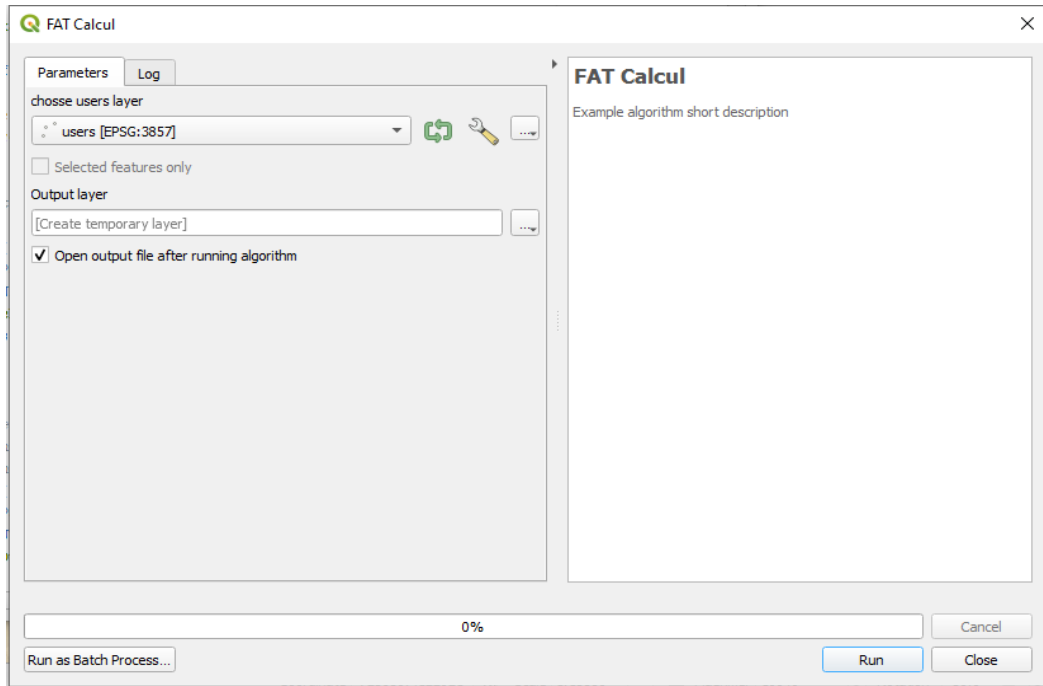
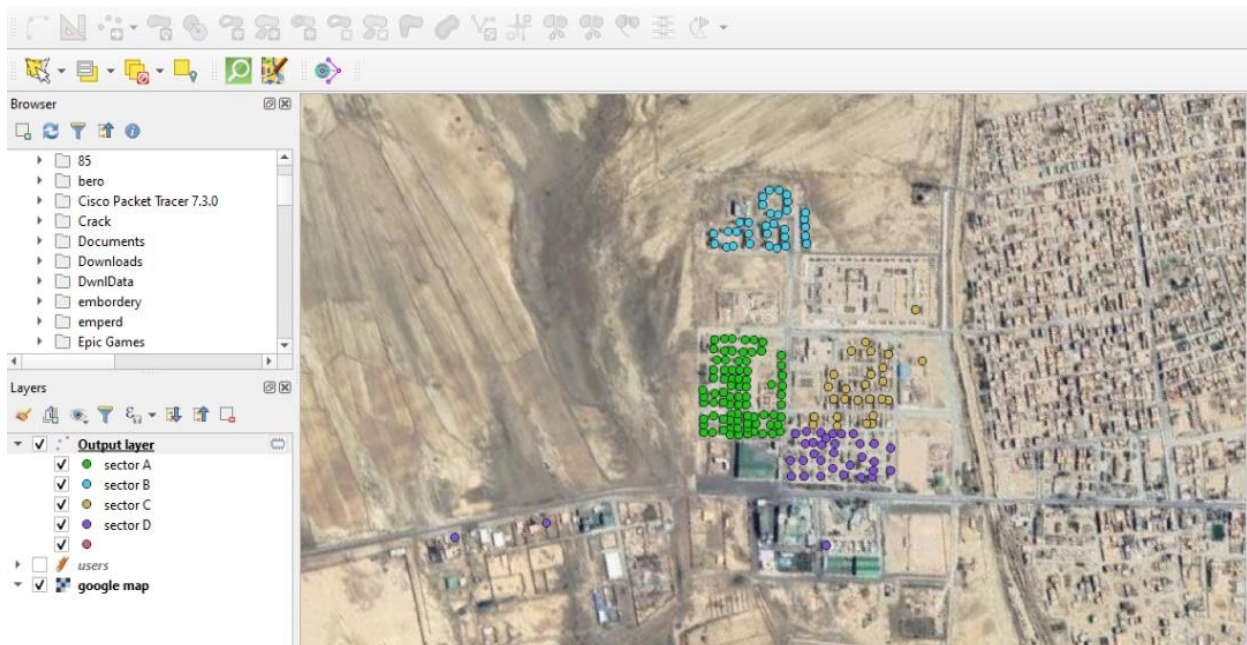**Figure 3.13:** FATs calculation organigram.

**Figure 3.14:** Graphical user interface of the FAT calculation algorithm.

In figure 3.14 we can see the graphical user interface of the FATs calculation algorithm.

In figure 3.15 shows possible placement of fiber access terminals, the layer is categorized by sector to see each sector and FAT that belongs to it.

Figure 3.15: FAT potential placement.

e. After we calculate FATs and determine the place of each one, now it is time to choose the place of FDH and OLT and how to deploy fiber cable (feeder and distribution) in figure 3.16.
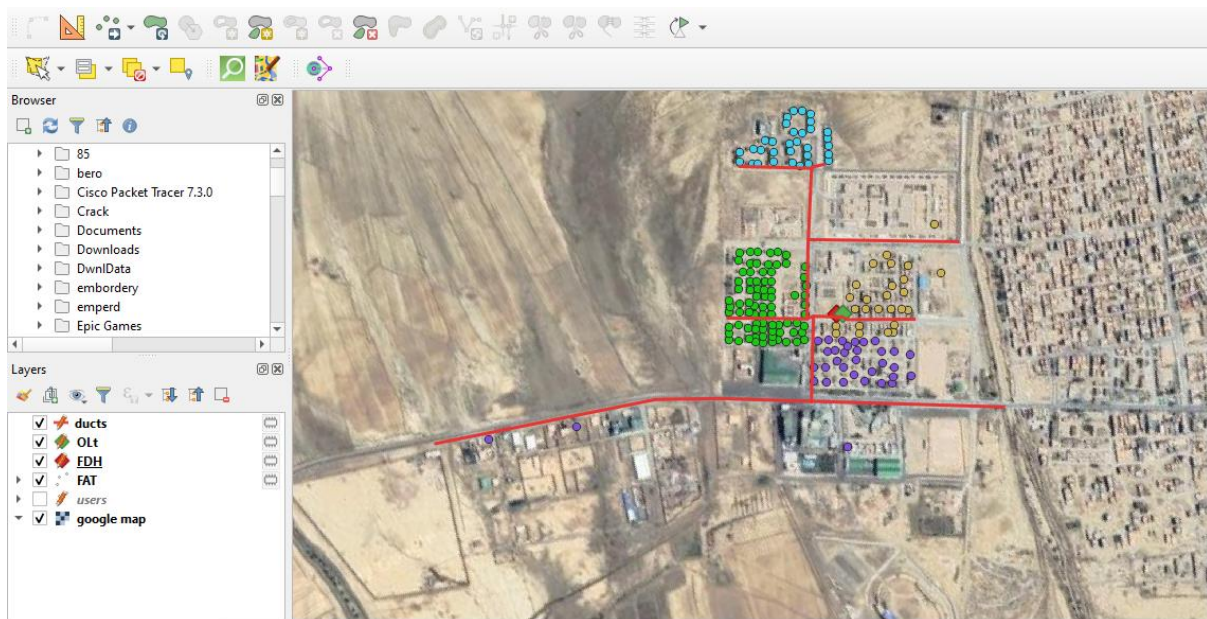
Figure 3.16: Assign ducts and FDH, OLT placement.

After we calculate FATs potential placement it is time to connect them with FDH to do that we need to divide the connection into two-part.

a. The first part is the feeder optical cable; this cable is deployed under-ground across all sectors to feed a group of FATs depending on the number of those FATs, typically the number of fibers cable is 36 OF or 72 OF or more.

b. The second part is the distribution optical cable, this cable deploys on the face of a building or on an electric tower based on the type of the building.

Feeder optical cable depends on the number of FATs as an example in sector A there are 81 FATs so we can use 144 fiber or divide it into two feeder cables 72 fiber and 24 fibers, the second scenario is the most commonly used approach, because if any things happen to feeder cable at least, not all the FATs get effected.

All-optical cables used in distribution are 36 optical fibers, and can serve up to 10 FATs.
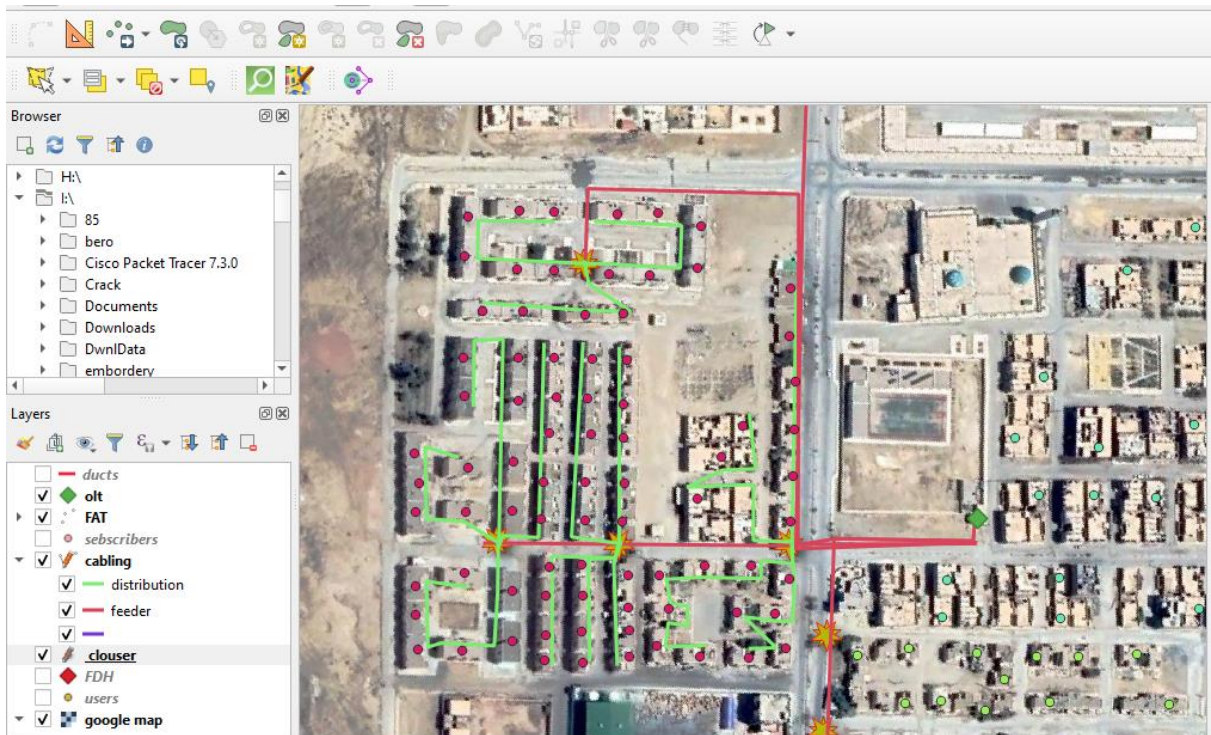

Figure 3.17: Outside planning for sector A.

Figure 3.17 illustrates the two feeder cables that will be spliced into 16 distribution cables, while figure 3.18 explains how OSP looks.
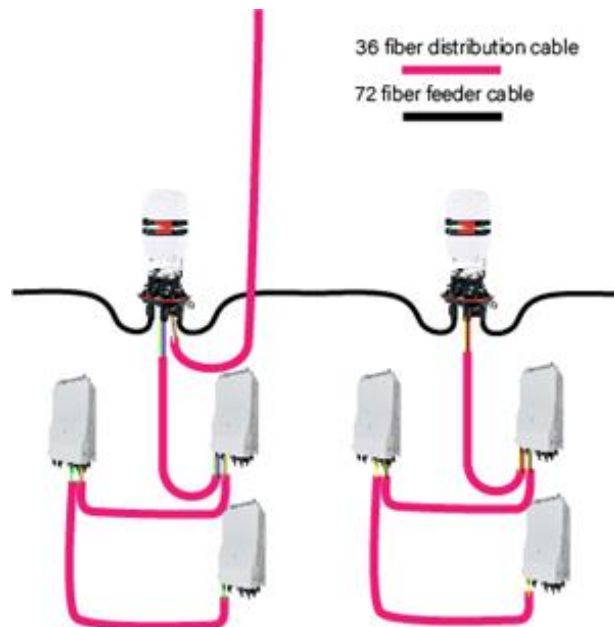

Figure 3.18: Example of OSP.

In figure 3.18 we can see an example of OSP where the 72-feeder cable enters the first closure and goes to the second closure, in the first closure there are two distribution cables are spliced with the feeder cable. In addition, the second closure there is one distribution cable spliced with the feeder cable and figure 3.19 will explain how the fiber will be spliced.
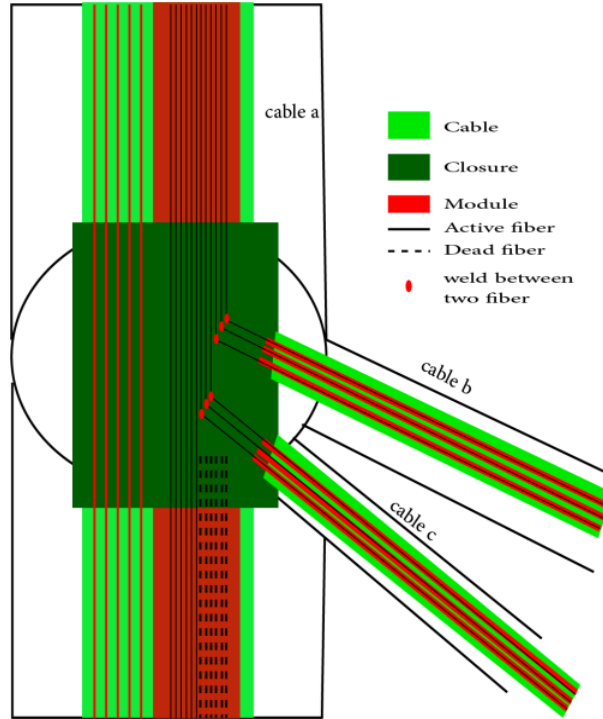
Figure 3.19: Splice fiber at manhole.

Figure 3.19 shows that cable "b" is welded with the first three fibers of cable "a" in a color-coded order. The blue fiber of the first module in cable "a" is welded with the blue fiber of the first Module in the cable "b", the orange fiber of the first module in cable "a" is welded with the orange fiber of the second module of cable "b", the green fiber of the first module in cable "a" is welded with the green fiber of the third module of cable "b" and the same thing for cable "c".

3.4.2.1. Theoretical optical power budget

The optical power budget is the amount of light required to transmit signals successfully over distance through a fiber-optic connection, to design a good FTTH network the theoretical power budget must be in the range of 20 to 24 dB.

To calculate the total power we use equitation 3.1 and the description of the symbols is explained in (table 3.2).

$$\propto_{\text{theoretical}} = \propto_L \times L + \propto_e \times N_e + \propto_c \times (N_{c-1}) + \propto_s * N_s \qquad (3.1)$$

Table 3.2: Theoretical value of optical power budget at 1310-1550nm with G952d Standard.

Symbol	description	Theoretical value at 1310nm	Theoretical value at 1550nm
$\propto_L$	linear attenuation in dB/km	0.35	0.21
L	length of fiber cable to be measured in km	/	/
$\propto_e$	maximum loss of a splice in dB	0.1	0.1
N_E	total number of splices in the section	/	/
$\propto_c$	maximum attenuation of a connector in dB	0.5	0.5
N_c	total number of connectors	/	/
$\propto_s$	splitter attenuation 1:8 in dB	10.3	10.3
N_s	total number of splitter	/	/
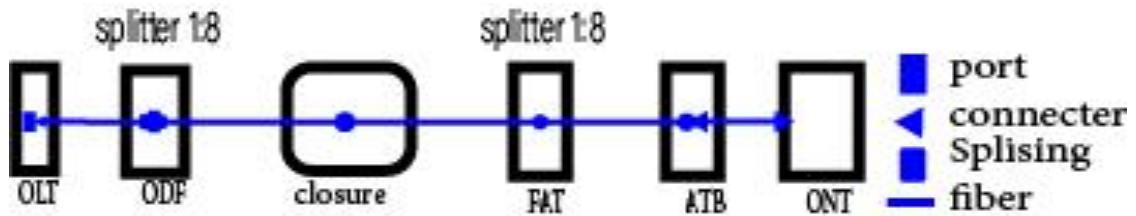
Figure 3.20: Optical budget for an OLT/ONT link.

Table 3.3: The power budgets of some FATs across different sectors.

Sector	FATs number	Cable length	number of splice	Connecter	Splitter loss	Total power budget
A	1	0.128	6	3	20.6	22.74224
	2	0.155	7	3	20.6	22.85115
	6	0.26	7	3	20.6	22.8858
	48	0.3	6	3	20.6	22.799
	49	0.33	7	3	20.6	22.9089
	53	0.446	7	3	20.6	22.94718
B	1	0.532	6	3	20.6	22.87556
	16	0.842	7	3	20.6	23.07786
C	1	0.42	6	3	20.6	22.8386
	7	0.44	8	3	20.6	23.0452
	25	0.68	8	3	20.6	23.1244
D	1	0.8	6	3	20.6	22.964
	14	0.48	8	3	20.6	23.0584
	25	0.8	7	3	20.6	23.064
E	1	0.55	6	3	20.6	22.8815
	3	1.26	7	3	20.6	23.2158

Table 3.3 shows the power budget of some fiber access terminal in different sectors.

Because all buildings are close to OLT and FDH, the power budget is in range of 22 to 23 dB, for that we can say the outside planning is valid.

3.4.3. Calculate the passive and active PONs

Table 3.4: The number of FATs and the total subscribers for every sector.

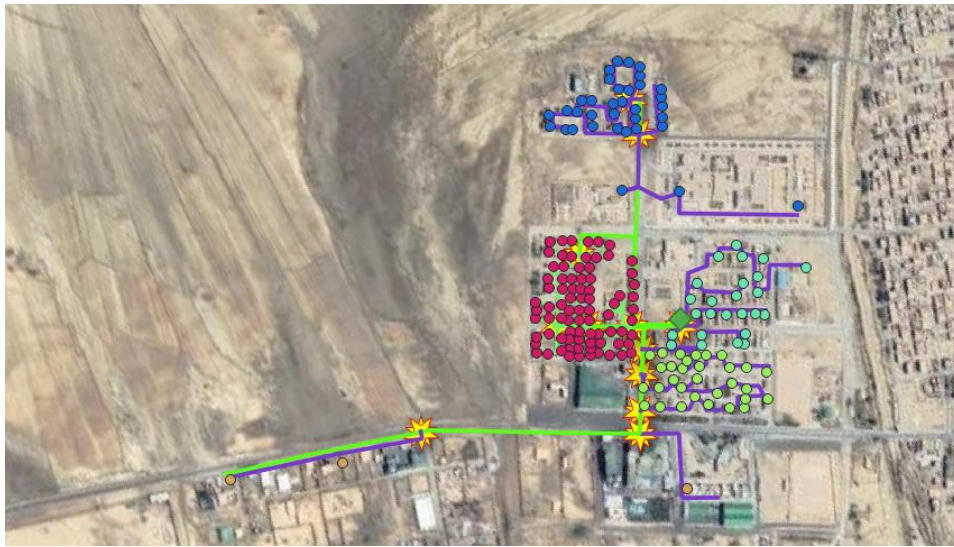| Sector	FATs number	Total subscribers coverage
A	81	648
B	32	256
D	31	248
C	26	208
D	3	24

Figure 3.21: Final outside Planning.

The table 3.4 shows the final subscribers coverage in every sector.

In figure 3.21, we can see that the OSP (Outside Planning) is complete and all active and passive components have been placed.

Table 3.5: Determine active and passive devices.

	Sector A	Sector B	Sector C	Sector D	Sector E	Total
FATs number	81	34	25	31	3	175
Cable length 36 fiber	1638	1525	1370	1638	1997	8168
Cable length 72 fiber	275	601	0	0	0	876
Splitter 1:8	11	5	4	4	1	25
GPON PORTs	11	5	4	4	1	25
closure 72	4	2	1	3	2	11

In table 3.5, we can see there are 175 FATs in total, and to determine how many splitters we need, we have to divide the number of FATs in every sector by 8 (since we are using a 1:8 splitter in FATs) and round to the nearest 8. Our design has 81 FATs in sector "A." We divided

that by 8 (because we used a 1:8 splitter in ODF) and got 11 splitters. For ODF, we need 288 ports because we have 175 FATs.

The reason we choose the 1:8 splitters is that the GPON port can serve 64 users only and the splitter on FAT is 1:8 so every splitter on FDH can serve 8 FATs.

After we calculate the necessary splitters, the next step is to choose the OLT type for all sectors we need 25 splitters, which means we need 25 GPON ports, ZTE OLT C320 can server 32 ports using two cards of 16 ports. So it is suitable for our design.

3.5. Second case suburban areas

After we saw how to design an FTTH network in an urban area, now we will see designing in a suburban area.

3.5.1. Field study

Next, we are going to do a field study of the south city of Zeribet El Oued (Figure 3.22).

Figure 3.22: Topological area that will be covered by the fiber infrastructure in the city of Zeribet el Oued.

The zone we want to deploy an FTTH network has one type of building. Therefore, we will consider every building as 1 potential subscriber.

In addition, all buildings along the national street 82 will consider 3 to 5 commercial stores beside the original building potential subscribers.

3.5.2. GIS Mapping

After we finish the site survey, now we move to add the site survey to the QGIS program.

a. Create a new temporary layer and name it "users_new", then select points for the geometry type of the layer, and then add geometric point to every building (figure 3.23).
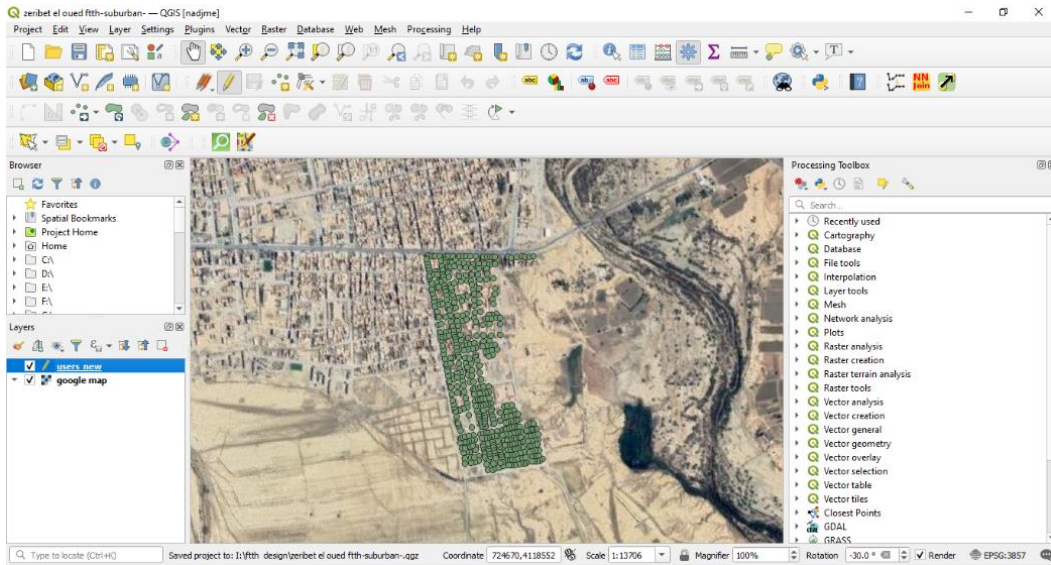

Figure 3.23: Geometric point on every building.

b. Now we add the number of potential subscribers for each building, but since it is a suburban area, there are only two options: one potential subscriber's per building or 1+N potential based on the number of commercial stores in that building.

In figure 3.24 we can see "users_new" layer are categorized based on number of potential subscribers.
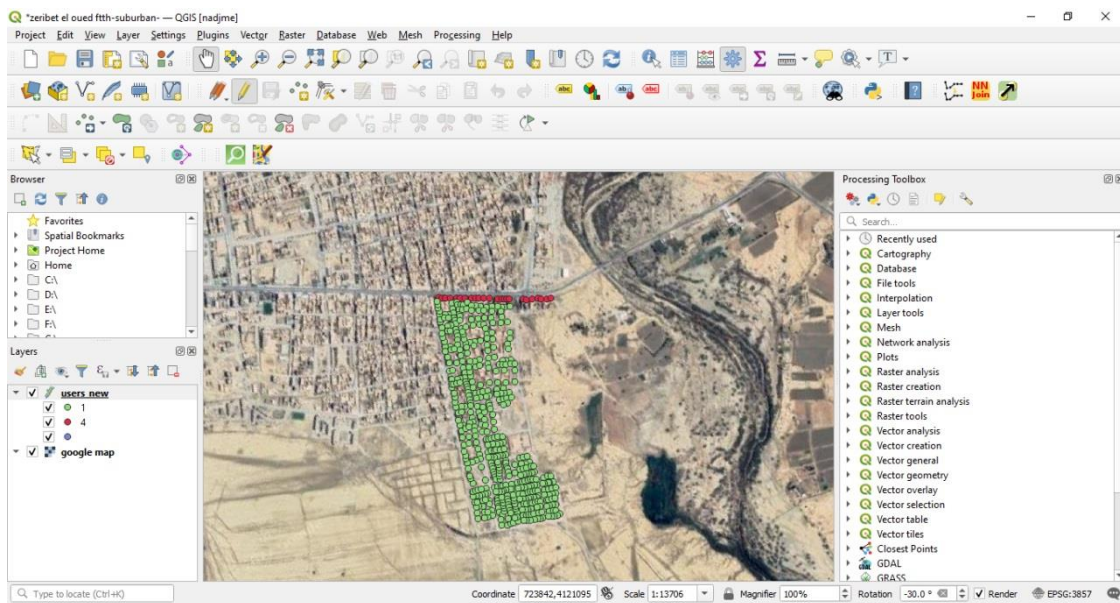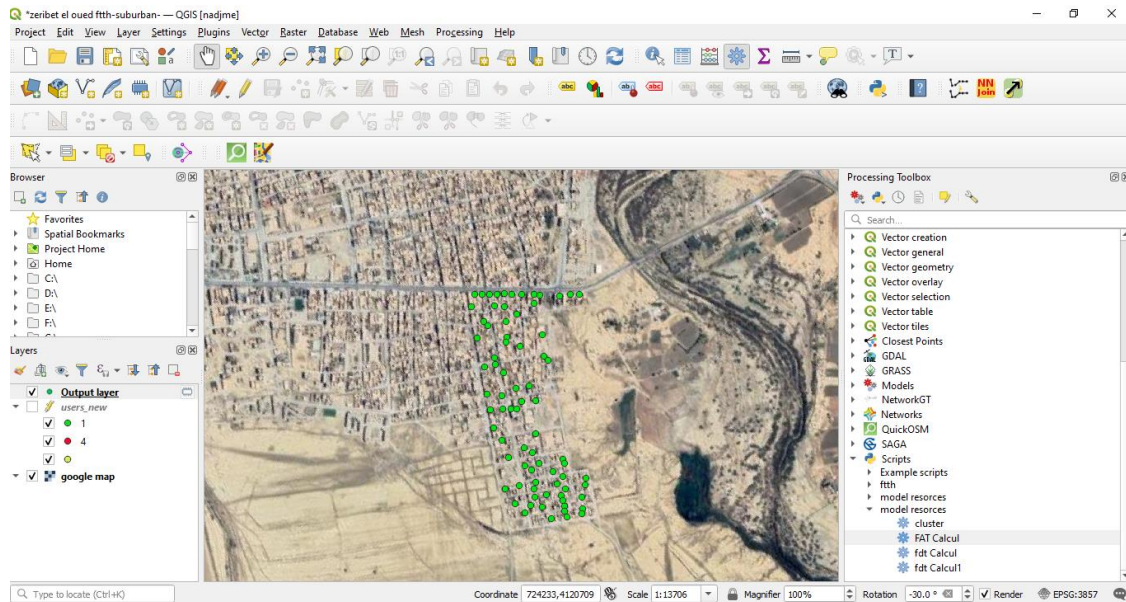

Figure 3.24: The geometric points are categorized based on number of potential subscribers.

c. Now let us calculate the potentials FATs subscribers, we will use the same algorithm we used before in section 3.4.2.d.

Figure 3.25: Potential placement of FATs.

Figure 3.25 shows possible placement of fiber access terminals, if we want to change the placement of one FAT or more, click on toggle editor icon in vector toolbar after that click on vertex tool and move the point to any place you want, after editing save your work.

d. After we calculate FATs and determine their final location, it is time to determine where the FDH and OLT will be located, and how fiber cable will be deployed (feeder and distribution).

It is impossible to put FDH on the site because it must be far away from children and the street. Therefore, we will put it in the central office with OLT.
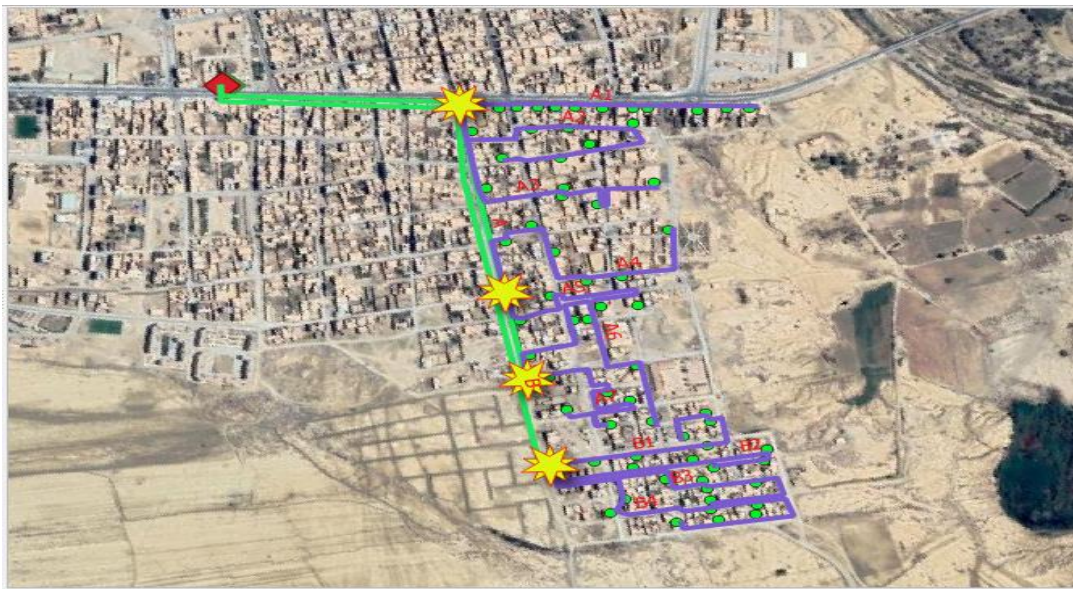
Figure 3.26: Outside planning.

Figure 3.27: Attribute table of cable layer.

As we can see in figures 3.26 and 3.27, there are two feeder cables A and B.

Cable A serves 45 FATs so we will choose 72-fiber cable the remaining fiber will be stumped for future use if needed.

Cable B serves 24 FATs so we will choose 36-fiber cable the remaining fiber will be stumped for future use if needed also.

e.   After we deploy the fiber cable now it is time to calculate the power budget. Table 3.6 shows the power budget of some FATs.

Table 3.6: Power budget for some FATs in different lines.

Line	FATs number	cable length	number of splice	Connecters	Splitters loss	Total power budget
A1	1	0.385	6	3	20.6	22.82705
	12	0.385	9	3	20.6	23.12705
A2	13	0.53	6	3	20.6	22.8749
	19	0.875	7	3	20.6	23.08875
B1	46	1.11	6	3	20.6	23.0663
	52	1.52	8	3	20.6	23.4016
B2	63	1.27	6	3	20.6	23.1191
	69	1.76	8	3	20.6	23.4808

As we can see in table 3.6, the total power budget is the theoretical range, for that the Outside planning is valid.

3.5.3. Calculate the passive and active PONs

As we can see in table 3.7 there are 69 FATs in total, to determine how many splitters we need. It's simple we just divide the FATs number of every sector by 8 (because we are using 1:8 splitter in FATs) and we round the result. As in our design we have 69 FATs we divided by 8 (because we are using 1:8 splitter in ODF) the result is 9 splitters, and for ODF we choose ODF 144 ports because we have 69 FATs.

Table 3.7: Determine active and passive devices.

	FATs number	Cable length 36 fiber (m)	Cable length 72 fiber (m)	Splitter 1:8	GPON PORTs	closure 72
Total	**69**	**6550**	**900**	**9**	**9**	**4**

After we determine the necessary splitters, then it is time to choose the OLT type for all sectors we need 9 splitters which means we need 9 GPON ports, ZTE OLT C320 can server 32 ports using two cards of 16 ports.so it is suitable for our design.

3.6. Conclusion

This chapter presented a detailed design of the FTTH access network serving two types of construction urban and suburban areas. The design procedure follows a bottom-up approach, in which the number of potential subscribers and the number of passive components is determined after an analysis of the requirements needed, with active components being easy to define.

The next chapter will discuss the implementation and automation of FTTH design.

Chapter 4

Implement and automate FTTH planning using QGIS

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Chapter 4
Implement and automate FTTH planning using QGIS

</div>

4.1. Introduction

This chapter will show how to implement and automate FTTH planning using the K-means clustering algorithm and PyQGIS (python built-in with QGIS software) libraries.

The difficult problems facing FTTH planning engineers are:

- Calculating the right number of FATs;
- Grouping a number of FATs based on geometric distribution;
- Connecting FATs of the same groups between each other.

4.2. What is PYQGIS?

PyQGIS is the Python environment inside QGIS with a set of QGIS libraries plus the Python tools with the potential of running other powerful libraries like Pandas, Numpy, or Scikit-learn.[37]

4.3. Implementation FATs calculation

The problem with FAT calculation is that subscribers' points were distributed geometrically in a random manner. In figure 4.1, we can see 8 points distributed geometrically at random if we calculate based on the order. The result will be wrong because the distance between points is huge see figure 4.2 (the distance between points is in meter), to solve this problem, we will use the K-mean algorithm.
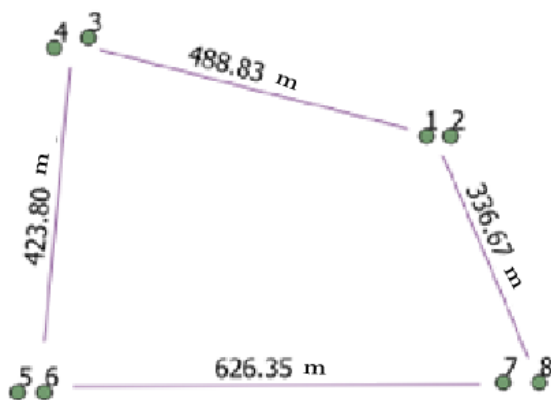
Figure 4.1: Example subscribers' points randomly distributed and the distance between them.
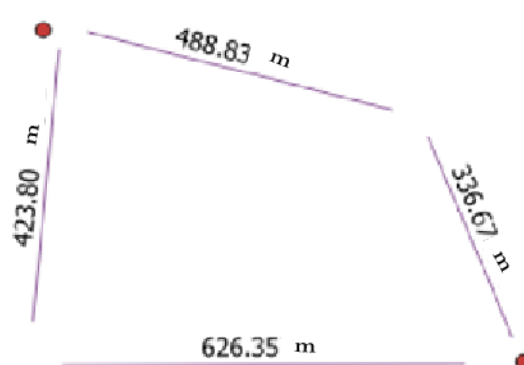
Figure 4.2: Classical FATs calculation example.

4.3.1. Working of K-Means Algorithm

The following stages will help us understand how the K-Means clustering technique works:

- Specify number of clusters K.
- Initialize centroids by first shuffling the dataset and then randomly selecting K data points for the centroids without replacement.
- Keep iterating until there is no change to the centroids. i.e assignment of data points to clusters isn't changing.
    - ✓ Compute the sum of the squared distance between data points and all centroids.
    - ✓ Assign each data point to the closest cluster (centroid).
    - ✓ Compute the centroids for the clusters by taking the average of the all data points that belong to each cluster.[38]

After we saw how the k-means algorithm works, let us use it to solve the problem we discussed above, figure 4.3 explains how to calculate FATs.

As shown in figure 4.3, the organigram starts by assigning the subscribers layer and the number of clusters (based on how subscribers are distributed). After that, the first loop will loop for each cluster in clusters, and the second loop will loop for each point in the cluster.

The second loop will divide the subscriber's number by 8 (because FAT has a splitter of 1:8 which means can serve only 8 subscribers), after that will see if the "rest" value is bigger or equal to 0.75 (0.75 is the threshold, 6/8= 0.75). Then adds 1 FAT if is "rest" is equal to 0.75 else will added based on the value of "rest"; Else if the "rest" value was under 0.75 it will increment the value of the "count" variable. Next, if the value of "count" is bigger than 6, it will add FAT and reset the "count" value to 0; after that will see if it was the last point , and if it is not the last point will back to the loop for the new point else will exit the loop and see if the "count" value is bigger than 1 if it was true will add FA, else will check is it was the last cluster if it was the last cluster the organigram will end else will back to the next cluster.
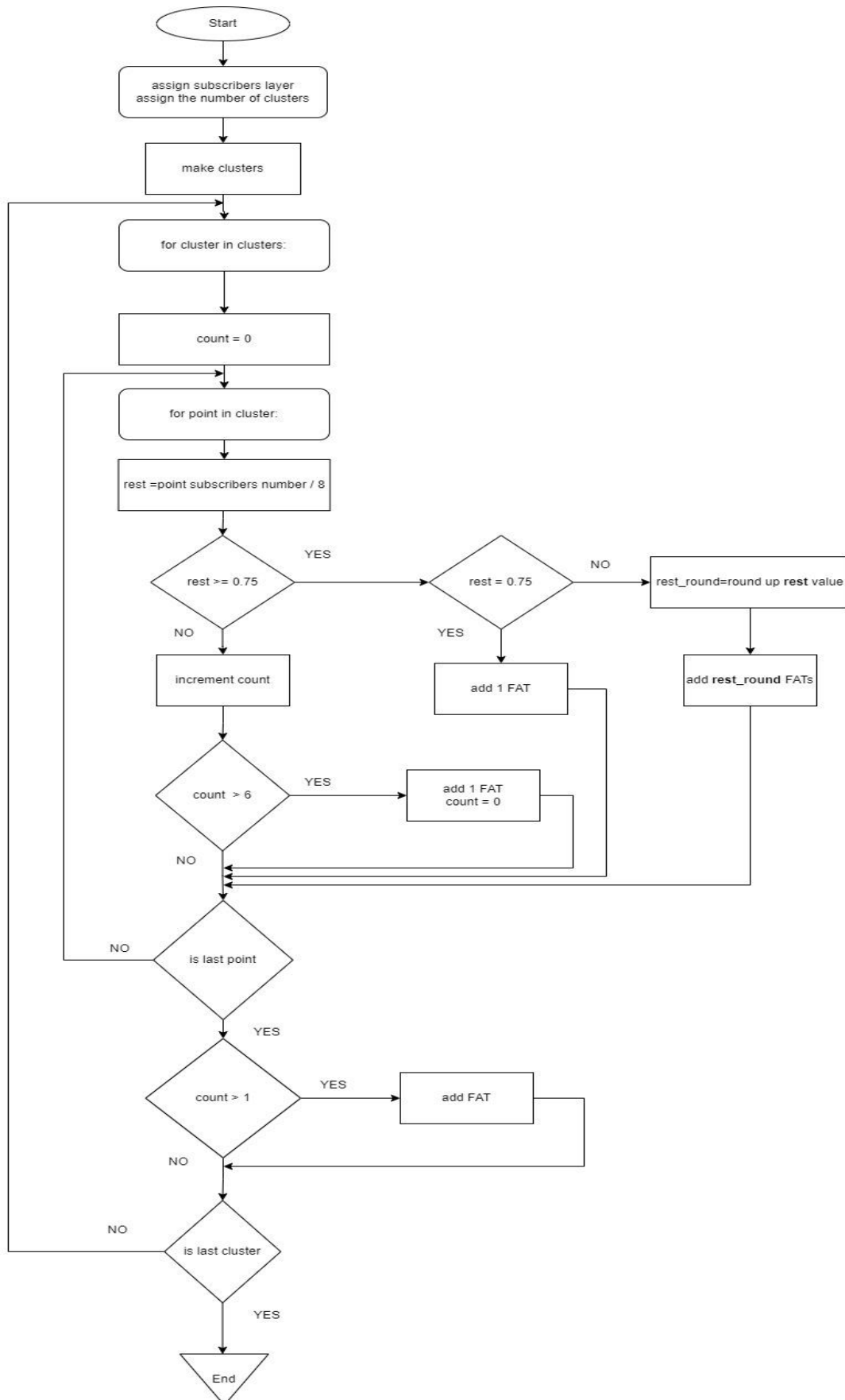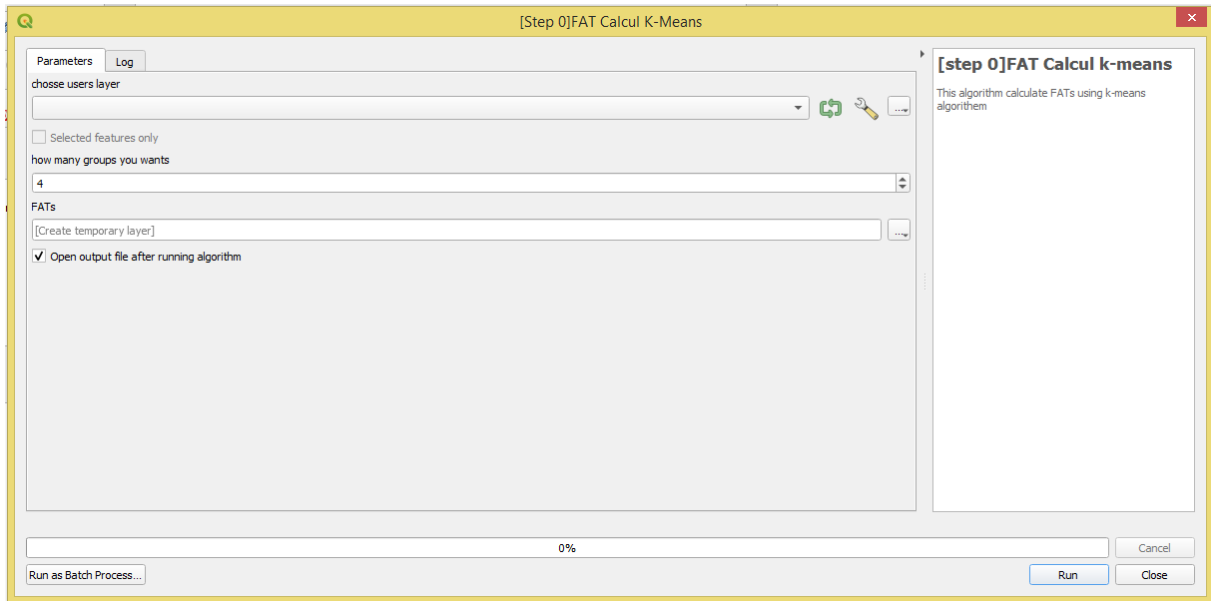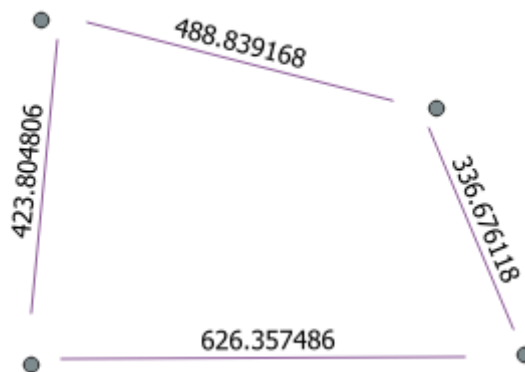
Figure 4.3: FATs calculation organigram using a k-means
clustering algorithm.

Figure 4.4: The graphic user interface of FATs
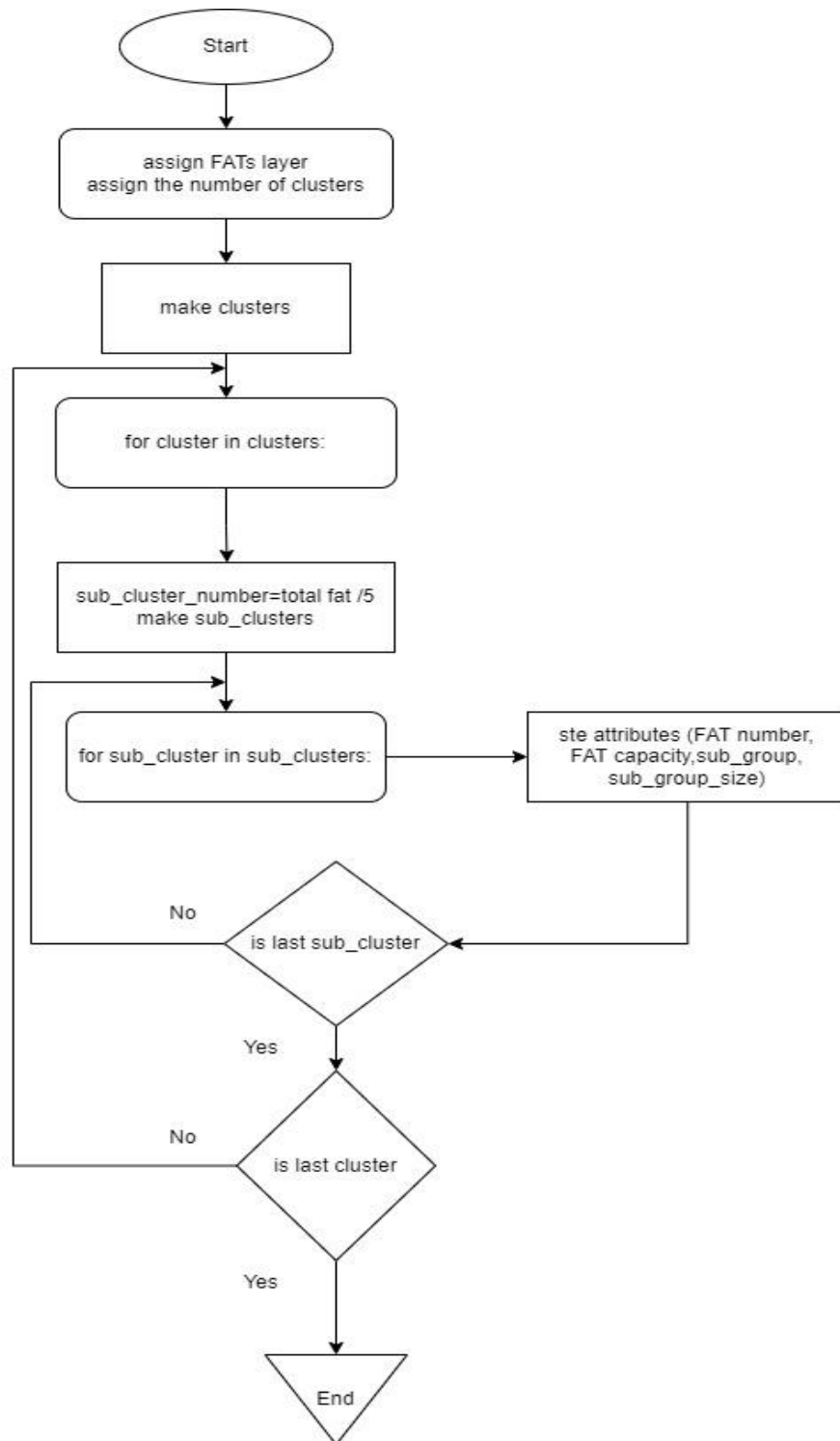calculation using the k-means algorithm.

As shown in figure 4.4, GUI for our algorithm, let us apply it to our example by choosing the subscribers layer and assigning the correct number of clusters. Figure 4.5 shows the results.

Figure 4.5: FATs calculation using k-means
clustering algorithm.

4.4. Implementation of FATs grouping

In the previous chapter, we saw that the key to planning an FTTH network is to group several FATs, and the grouping was done by hand. In this step, we will implement an algorithm that will do an automatic grouping using two-stage of clustering. The first stage is clustering FATs based on the number of clusters that the user will give it, and the second stage is clustering every cluster of the first stage based on the number of FATs of the first cluster divided by 5 (after testing various numbers, number 5 was the best number), figure 4.6 explain the algorithm.

Figure 4.6: FATs grouping organigram.

As shown in figure 4.6, the organigram starts by assigning the FATs layer and the number of clusters after that will make clusters using the K-means algorithm, next the first loop will loop over the cluster, in addition, will divide the total number of FATs in the cluster by 5 and make the sub-clusters using K-means after that the second loop will loop over sub-clusters and setting the attributes (FAT number, FAT capacity, sub-cluster, sub-cluster size) when the first loop is done it goes back to the first loop after the first loop is done it is end of the organigram.
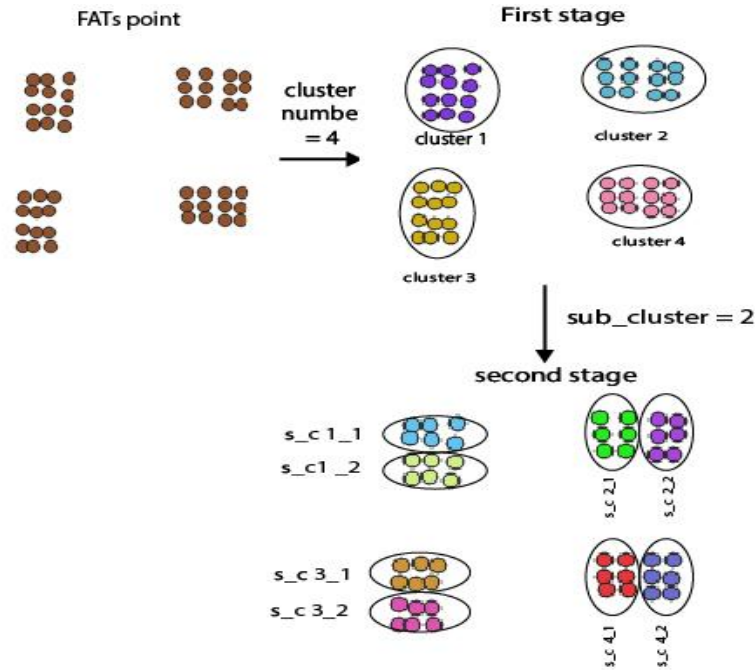
Figure 4.7: Example of FATs grouping algorithm.

s_c: sub_cluster.

As we can see in figure 4.7, There are 48 fats, which are divided into 4 groups of 12 fats each; and the first stage groups all FATs into 4 clusters, and the second stage groups each cluster into two clusters because 12 FATs are divided by 5 is 2 (see the section above to find out why we chose 5).

4.5. Implementation of FATs link

In the previous chapter, We saw that linking a number of FATs takes time and concentration, so to avoid that, we implement an algorithm that connects a number of FATs based on which group they belong to; After connecting FATs, we calculate the distance between the beginning and the end of the lines and see which one is the shortest and connect that to FDH. In this step, we eliminate the feeder section of the ODN; figure 4.8 demonstrates the algorithm steps.

As shown in figure 4.8, the organigram starts by assigning FATs grouped layers and the number of clusters (based on the engineer's desire). Next will order the FATs points based on groups. The next step is to create a line between FAT and the closest line. After that, connecting FATs are in the same group. In addition, it will loop over the connected line and calculate the distance between the start of the line to the FDH and the distance between the end of the line to the FDH, then see which one is the shortest and create a line between the point which has the shortest distances to the FDH; when the loop is complete, the organigram ends.
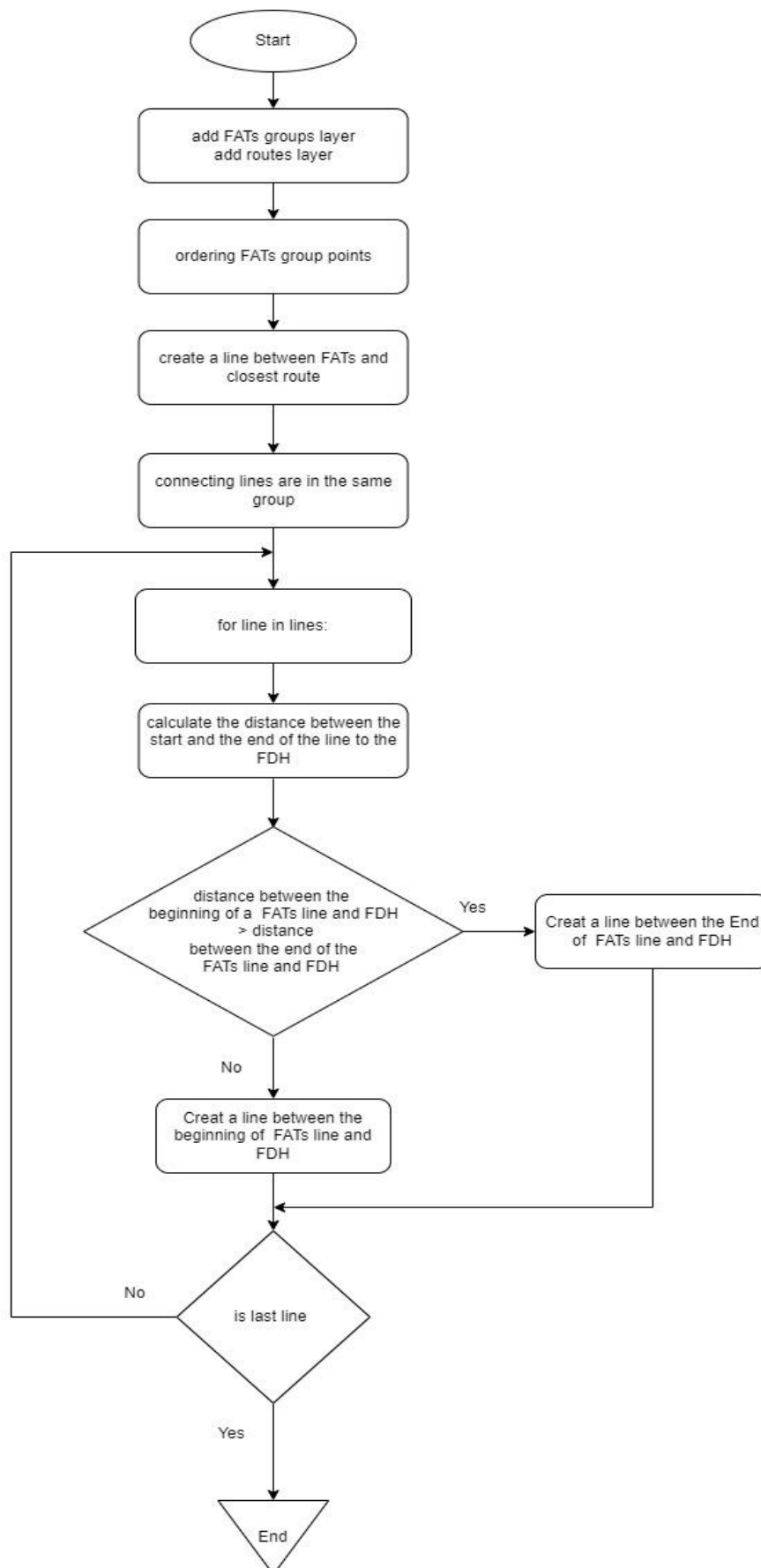
Figure 4.8: Connecting FATs organigram.

4.6.   Testing the algorithms

First, we load our building points with their potential attribute (figure 4.9).

Figure 4.9: Building points.

Figure 4.10: Building points attributes.

According to figure 4.10, there are 295 buildings, and buildings 1 to 13 have four potential subscribers each.

Next, we load the subscribers to the FATs calculation algorithm and enter the number of clusters we choose 9. (Figure 4.11)
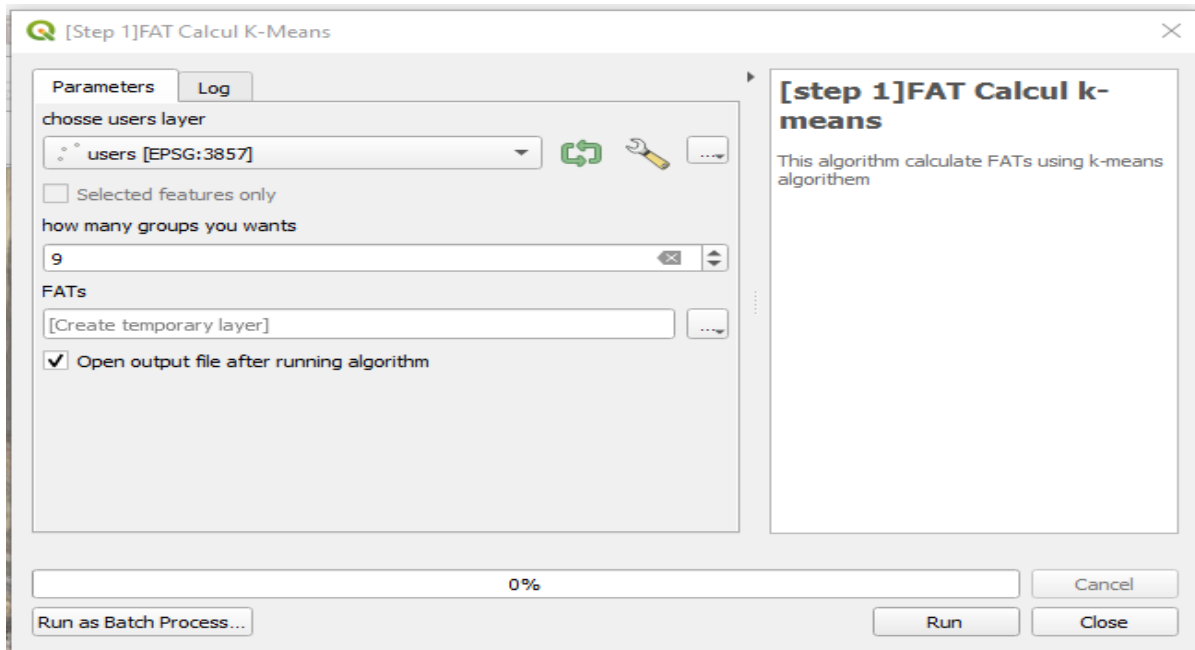

Figure 4.11: GUI of FATs calculation using k-means algorithm.

Figure 4.12: The result of the FATs calculation algorithm

As we can see in figure 4.12, even though the buildings are far away from the other buildings, the k-means algorithm treated them as a separate group, which is what we want.

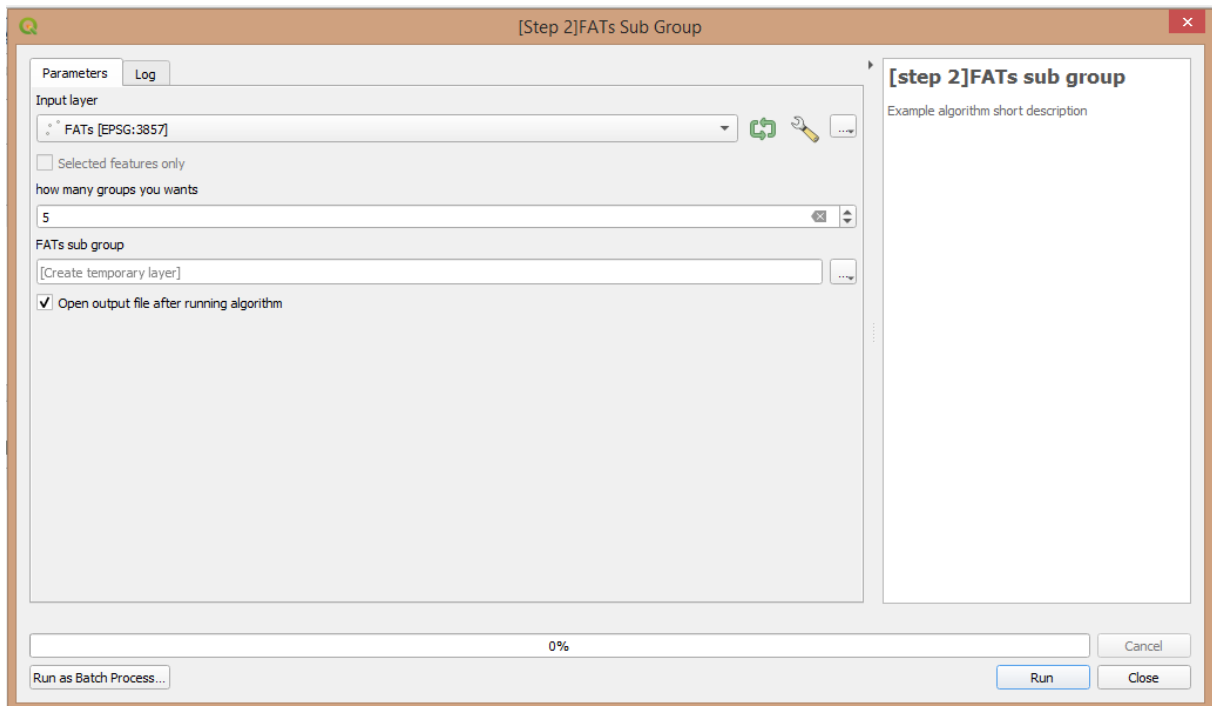Using our previous grouping algorithm, let us group several FATs based on their distance. (Figure 4.13)

Figure 4.13: GUI of grouping algorithm.

Figure 4.14: The result of the FATs grouping algorithm.

Figure 4.14 illustrates how the FATs are grouped by distance; the FATs layers are categorized based on the sub_group attribute. Figure 4.15 shows the attribute table for the FATs grouped layer.

Figure 4.15: Attributes table of grouped FATs layer.

The next step is to connect the grouped FATs together; to do that, we first download the route of the area we are working in using QuickOSM (Quick Open street map); figure 4.16 explains how to do this. The second is to create a line between FATs points and the closest route. Figure 4.17 shows the GUI of the algorithm we used. The last step is to load the route and FATs closest line, and FDH closest line (figure 4.18); the result is shown in figure 4.19.
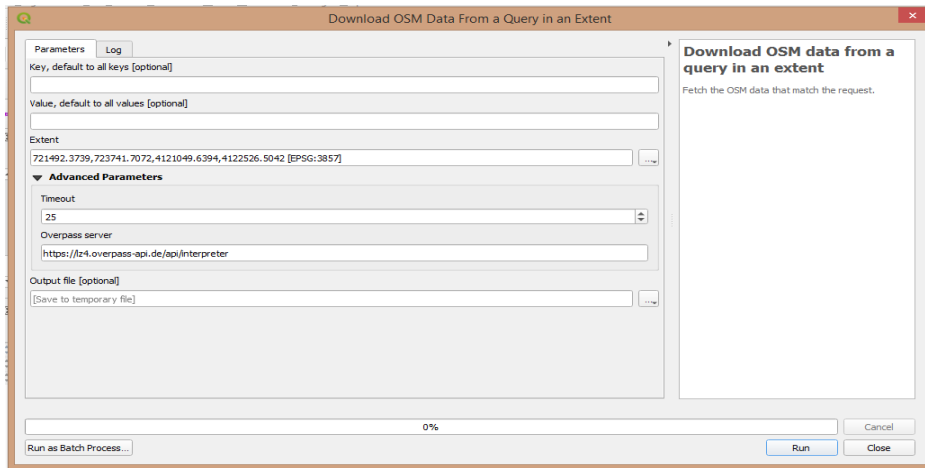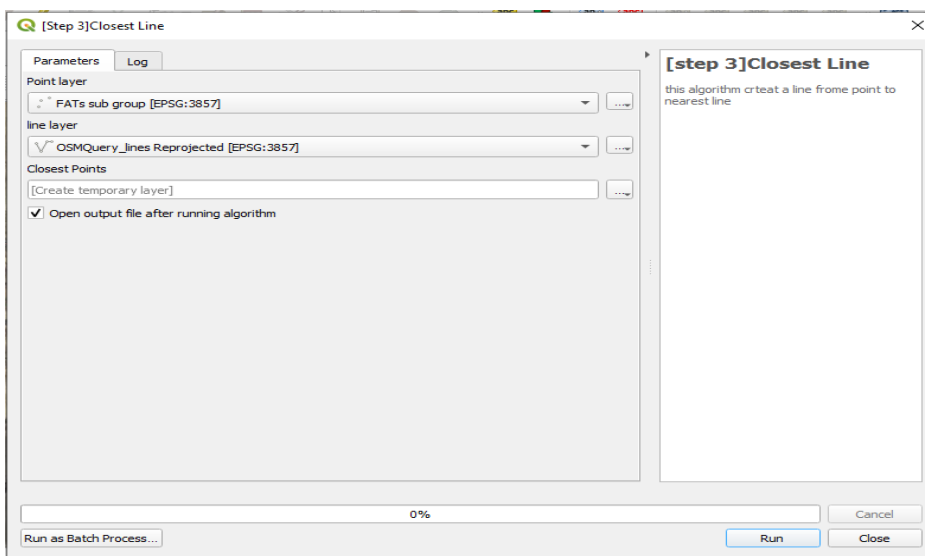
Figure 4.16: GUI of QuickOSM plugin.

Figure 4.17: GUI of closest route algorithm.

Figure 4.18: GUI of FATs connection algorithm.
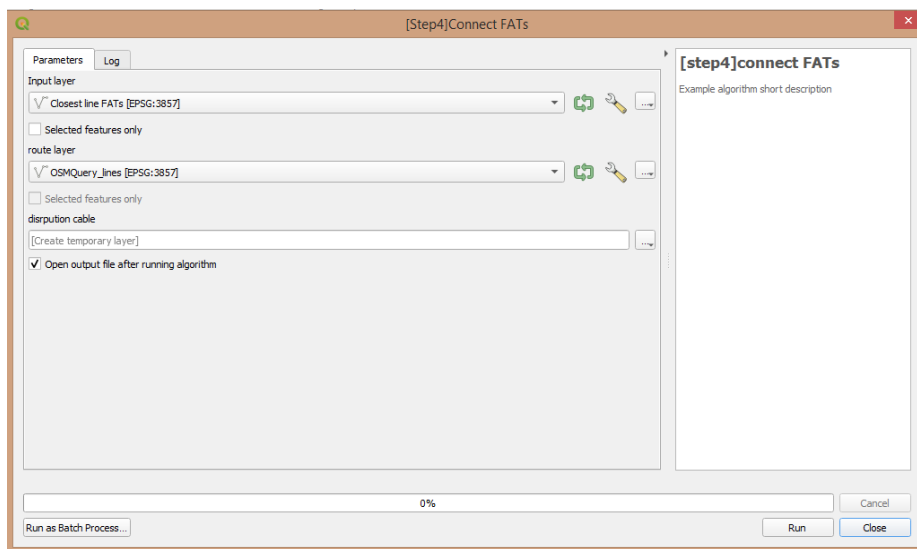
Figure 4.19: The connection FATs algorithm's result.

Finally, now let us connect the distribution cable with the FDH point. To do that, we use this algorithm to calculate the distance between the beginning and the end of the distribution cable, choose the shortest way, and create a cable. (Figure 4.20)
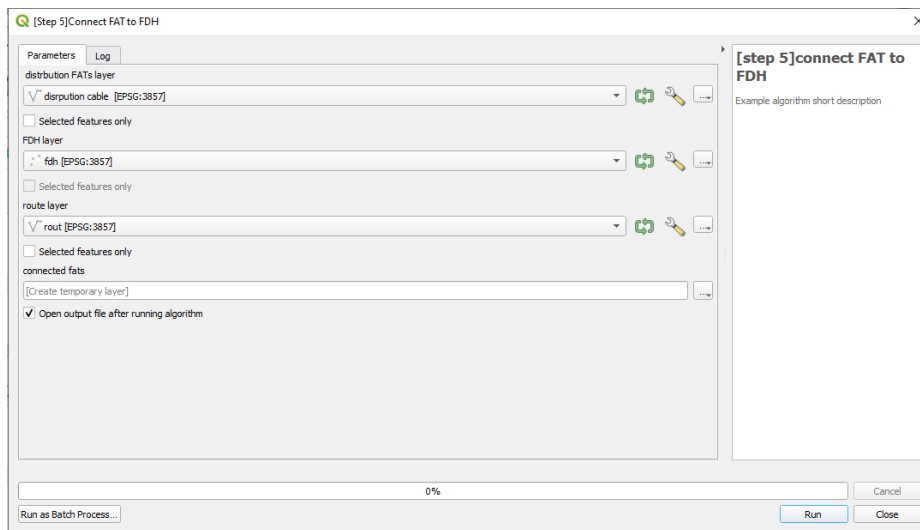
Figure 4.20: GUI of connecting distribution cable with FDH.

Figure 4.21: Final OSP.

In figure 4.21, we can see the final outside planning.

Figure 4.22: Table attributes of connected FATs layer.

As shown in figure 4.22, there are 33 lines connecting a group of FATs; each line has four attributes are:

- Group: The group of connected FATs.
- Line number: the line number.
- FATs are connected: number of the FATs that were connected.
- Length: the total length of the cable.

Table 4.1: Determine active and passive devices.

	Group 0	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Total**
FATs number	47	32	23	36	36	175
Cable length 36 fiber (km)	8.032	8.2	3.970	6.644	6.323	33.169
Splitter 1:8	6	4	3	5	5	23
GPON PORTs	6	4	3	5	5	23

As shown in Table 4.1, we divide the area into 5 groups, and every group has a subgroup. For simplicity, we calculate the total FATs number and cable length as one group instead of subgroup.

4.7. advantages and disadvantages of hand and automated designing

In this section, we will see the advantages and disadvantages of automated design to evaluate design performance.

4.7.1. The advantages and disadvantages of automated design are as follows:
- The advantages:
  - ➢ The ability to connect and calculate quickly.
  - ➢ Accurate 90%-95%.
- the disadvantages :
  - ➢ Not reliable: FATs are connected together by a single cable, so if the cable fails, so does the connection.

4.7.2. The advantages and disadvantages of hand design are as follows:
- the advantages:
  - ➢ Accurate 100%
  - ➢ Reliable: The design is split into two sections, feeder and distribution. This gives more reliability.
- The disadvantages :
  - ➢ Time-wasting: Calculating the FATs number and putting color coding on the splicing table takes time.

After we have seen the advantages and the disadvantages, it is efficient to use automated design; also, we can make changes to the final automated design for more accurate results.

4.8.   Conclusion

This chapter describes how to implement the automated FTTH design process. For this, we used the k-means clustering algorithm and PyQGIS libraries. We need to enter valid data into GIS (count of potential subscribers; choose the right roads, number of right clusters) to get a valid FTTH design.

General conclusion and future work

General conclusion

In order to meet the enormous demand for bandwidth and broadband service offerings, the FTTH technology is now a technology that must be adopted since it has several advantages. Also, the FTTH network enables us to achieve much higher speeds than today's ADSL connections.

In the first chapter, we examined the optical communication system. We saw it was composed of three main components:

- **The transmitter:** this device is essential because it converts the electrical signal to an optical signal, and there are two types of optical transmitters which are LEDs and LASERs. There are significant differences in the speed and Spectral Width of the optical signal and the manufacturing cost.
- **Fiber optic cable:** This device is also essential since, without it, an optical signal will not be transmitted from the transmitter to the receiver; there are two types of optical cable: single-mode and multi-mode, with significant differences in the core diameter and type of use.
- **The receiver:** this device is the last device in an optical communication system because it converts the electrical signal to an optical signal. There are two types of optical receivers, PIN-PD and APD, and the difference is basically in sensitivity and operating voltage.

By using those components, we can build a medium-range optical communication system with a (between 1 and 40 km).

During the second chapter, we studied the different types of access networks, and the description of FTTx networks called PON, such as FTTA and FTTB, and FTTH; After that, we saw the different architectures such as P2P and P2MP, and we found out P2MP is a more practical solution for FTTH network because it has low cost to deploy.

Also, we saw the different components of the Optical Distribution Network, such as OLT, FDT, and FAT, and the last component is ONT. The most common OLT and ONT used by Algeria Telecom are ZTE C300 and ZTE F660, and optical cables use the standard G.652 because it has low attenuation at 1550 nm and zero-dispersion wavelength near 1310 nm. For those reasons, this standard is ideal for FTTH networks.

Finally, we saw there are different types of standards of FTTH, such as APON, EPON, and GPON, and each standard has different speeds and protocols.

In the third chapter, we studied the steps to design an FTTH network. The three main steps are site survey and optical power budget calculation, and fiber cable deployment. Then we applied those steps to real-life scenarios using QGIS in two types of neighborhoods: urban and suburban in Zeribet El Oued city. We found out that the theoretical optical power budget is in the operational range (under 24 dB), giving more control in designing the network. Also, we found that using 1:8 splitters is more practical in both neighborhoods.

In the last chapter, we saw that there are some problems in designing an FTTH network, such as calculating the number of FATs and FATs grouping and connecting them; we solve those problems using PyQGIS libraries and unsupervised learning (k-means algorithm), which we then applied in real-life scenarios using QGIS in urban neighborhoods in Zeribet El Oued city.

Therefore, we conclude that the thesis was successful in its purpose and was able to plan the Fiber To The Home network in two types of neighborhoods urban and suburban areas, Zeribet El Oued city.

🞢 **Future Work:**

- Design an FTTH network using P2P architecture for a business area.
- Design an FTTH network in rural places.
- Calculate an accurate optical power budget for each FAT using QGIS software.
- Implement an algorithm group FATs based on number and distance (k-means cluster based on distance only).
- Design WDM-PON not PON only.
- Design other optical communication systems such as DWDM and OTN networks.

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