EVALUATING OPTICAL BACKHAUL OF A FIBER AND WIRELESS HYBRID BROADBAND NETWORK

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"EVALUATING OPTICAL BACKHAUL FOR A FIBER AND WIRELESS HYBRID BROADBAND NETWORK"** was prepared by **LEE WENG HONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

The backhaul for a fiber and wireless (FiWi) hybrid broadband network is an optical network system. It deployed the optical fiber instead of copper wire for the connection in this system. This fiber sub-network provides large bandwidth and high speed rate compare to the copper wire system. This is achieved due to the use of light in the transmission medium of the optical network system. The major components used in the optical network system are optical line terminal (OLT), splitter, optical network terminal (OLT), optical fiber cables and connectors. OLT is usually located at the centre office (CO) and connected via optical fiber to several optical network terminals (ONT) through optical splitters. The optical network system chosen in this project was Fiber To The Home (FTTH). An Ethernet Passive Optical Network (EPON) for FTTH was configured for evaluating its performance for transmission of data and video content.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

dB	Decibel
Gbps	Gigabit per second
GBps	Gigabyte per second
km	kilometre
nm	nanometer

APC	Angled Polished Contact
ATM	Asynchronous Transfer Mode
BPON	Broadband Passive Optical Network
CO	Centre Office
EMI	Electromagnetic Interface
EPON	Ethernet Passive Optical Network
FBT	Fused Biconical Taper
FC	Ferrule Connector
FiWi	Fiber and Wireless
FSAN	Full Service Access Network
FTTB	Fiber-To-The Business
FTTC	Fiber-To-The-Curb
FTTH	Fiber To The Home
GEPON	Gigabit Ethernet Passive Optical Network
GPON	Gigabit Passive Optical Network
IEEE	Institute of Electrical and Electronics Engineers
IL	Insertion Loss
IP	Internet Protocol
ITU	International Telecommunication Union
LAN	Local Area Network
OLT	Optical Line Terminal

ONT/ONU	Optical Network Terminal/ Optical Network Unit
ORL	Optical Return Loss
OPM	Optical Power Meter
OTDR	Optical Time Domain Reflectometer
PLC	Planar Lightwave Circuit
PON	Passive Optical Network
QoE	Quality of Experience
QoS	Quality of Service
RFI	Radio Frequency Interface
SC	Subscriber Connector
ST	Straight Tip Connector
UPC	Ultra Polished Contact
VoIP	Voice over Internet Protocol
WDM	Wavelength-Division Multiplexing
WMN	Wireless Mesh Network

CHAPTER 1

INTRODUCTION

1.1 Background

With the substantial growth in telecommunications, the way to access network also changed due to the aggravating lag of access network capacity. Therefore, a new technology which is simple, inexpensive, provide mobility, large bandwidth which able to deliver large bundle of data and video, and high quality of service (QoS) is highly desired. To achieve this goal, optical and wireless technologies play an important role.

The fiber-wireless (FiWi) access network is an optimal combination of a back fiber sub-network and a front wireless sub-network. (Qinglong Dai, 2013) In the fiber sub-network, the optical line terminal (OLT) is at the centre office (CO) and connected via optical fiber to several optical network terminals (ONTs). On the other hand in wireless sub-network, a group of wireless routers compose a wireless mesh network (WMN) with the ONTs. Then the subscribers connect to OLT through these routers whose positions are fixed in a WMN.

Wireless mesh networks (WMNs) are networks employing multi-hop communications to forward traffic en route to and from wired internet entry point. (Navid Ghazisaidi, 2009) WMN provide a greater flexibility, increased reliability, and improved performance. Since WMN used fewer wires, so it is low cost to set up a network for large areas of coverage. Furthermore, mesh networks are self configuring means the network automatically incorporates a new node into the existing structure without needing and adjustments by a network administrator. The nodes installed increases, the bigger and faster the wireless network becomes.

For optical access network, optical fiber provides unprecedented bandwidth potential compare to wireless network or any other transmission medium due to the data is transmit in speed of light. A single strand of optical fiber offer 25,000 GHz bandwidth. (Navid Ghazisaidi, 2009) In this project, the optical access network is focused on.

1.2 Problem Statements

The Fiber and Wireless Hybrid Broadband network is needed to increase the speed of data transmission rate. In this project, study was focused on the optical backhaul for the Fiber and Wireless Hybrid Broadband network. Technicians and engineers must have the skill for installation, maintenance and convection of Fiber-To-The-Home network. The PON test bed can be used as a training equipment to evaluate problem and performance of optical fiber network.

1.3 Aims and Objectives

The objectives are shown as following:

- To set up the PON test bed to study the performance of an optical backhaul of a FiWi hybrid network.
- To implement an Ethernet Passive Optical Network for Fiber To The Home for transmission of data and video
- To evaluate the performance of the Ethernet Passive Optical Network test bed.

CHAPTER 2

LITERATURE REVIEW

2.1 Passive Optical Network (PON)

The first Passive Optical Network (PON) is introduced in late 90s in telecommunication services which is called Full Service Access Network (FSAN). Then, a PON which developed by combing the Asynchronous Transfer Mode (ATM) techniques and PON was called APON with the International Telecommunication Union's (ITU) ratification of the G.983 standard. However, APON not able to takeoff to compete the traditional Digital Subscriber Line (DSL) techniques due to APON need high cost to set up and maintenance. After APON, the next generation PON technique is Broadband PON (BPON) with ITU-T ratification of the G.983 standard and Ethernet (EPON) with Institute of Electrical and Electronics Engineers (IEEE) 802.3 protocol. EPON technique is low cost than APON. Then, another PON called Gigabit PON (GPON) is being standardized in parallel with EPON with ITU-T ratification of the G.983.4 which is extension of BPON. GPON is more powerful than EPON to support various types of upper layer frames like ATM cell, general frames including IP packets and Ethernet frames. The next generation of PON techniques will be integrated with Wavelength-Division Multiplexing (WDM)-PON. In this project, we focus on EPON.

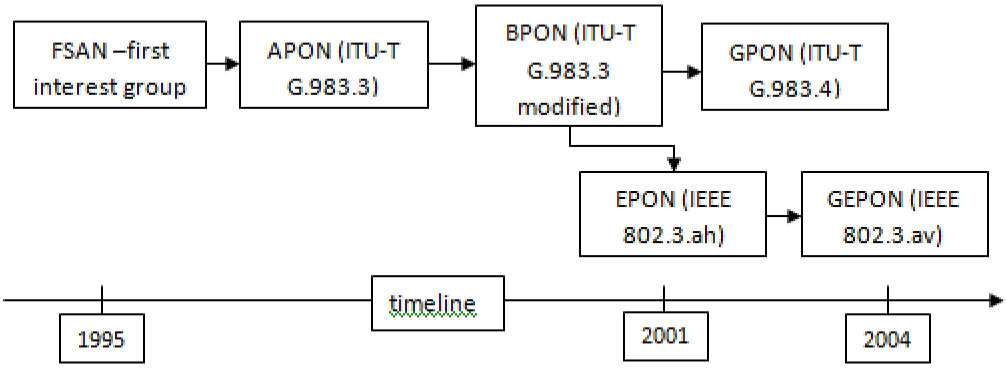


Figure 2.1: Timeline for PON

A PON is a telecommunications network that use point-to-multipoint optical fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises. A PON consists of an Optical Line Terminal (OLT) at the Centre Office (CO) and a number of Optical Network Terminals (ONTs) near the business or home of the end users.

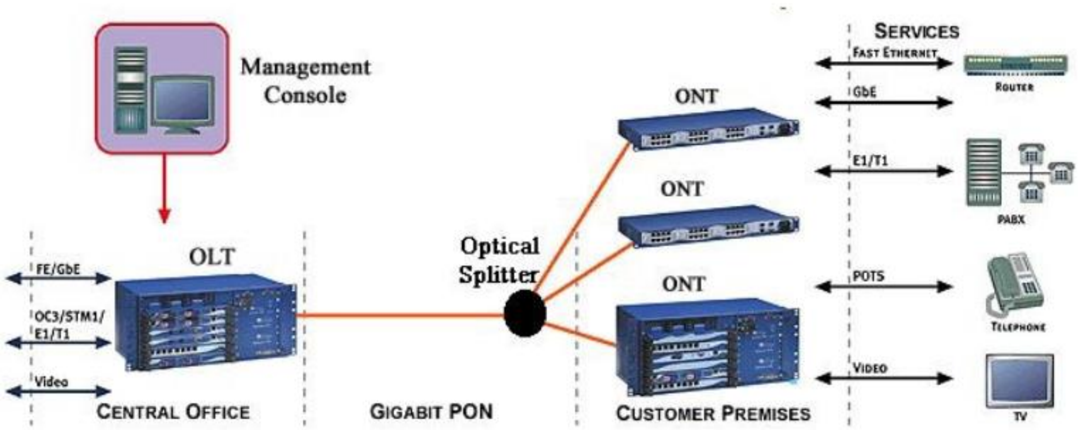


Figure 2.2: PON architecture configurations

2.1.1 Types of Passive Optic Network (PON)

There are several types of PONs such as Asynchronous Transfer Mode PON (APON), Broadband PON (BPON), Ethernet PON (EPON), Gigabit Ethernet PON (GEPON), and Gigabit PON (GPON). Figure below will discuss two current PON techniques: EPON and GPON.

Ethernet passive optical network (EPON) is one of the popular versions of passive optical networks (PONs). EPON is an access network technology that provides a low-cost method of deploying optical access lines between a carrier's Central Office (CO) and subscribers. (The International Engineering Consortium, n.d.) These short-haul networks of optical fiber cable are used for internet access, voice over internet protocol (VoIP), and digital TV delivery in metropolitan areas.

In EPON, data is transmitted in variable-length packets of up to 1528 bytes according to the Institute of Electrical and Electronics Engineers (IEEE) 802.3 protocol. EPON vendors initially on developing Fiber-To-The Business (FTTB) and Fiber-To-The-Curb (FTTC) solutions. Now also developing the Fiber-To-The-Home (FTTH) for transfer data, audio and video over a single platform. EPON offer high and great flexibility in dynamic bandwidth allocation, low cost to set up a system, and have broader service capabilities. Furthermore, EPON is more efficiency in network capacity utilization due to its lower control overhead in each Ethernet frame.

Another popular version of PON with further evolution is Gigabit Passive Optical Network (GPON) was also developed by Full Service Access Network (FSAN) group. It is defined by International Telecommunication Union, ITU-T G.984 series recommendations [ITU09] first published in 2003. GPON provides three Layer 2 networks which are ATM for voice, Ethernet for data, and proprietary encapsulation for voice. In GPON networks, up to 64 ONTs can share one optical fiber connection to the OLT. Furthermore, GPON can operate at 2.488 Gbps downstream and 1.244 Gbps upstream. In addition, the distances between OLT and ONU in GPON network can up to 20km.

2.2 Fiber To The Home, FTTH

With the high demand of bandwidth nowadays, Fiber To The Home (FTTH) technology is the key to solve this issue compare to copper based access network technology. FTTH is the delivery of a communications signal over optical fiber between Central Office (CO) and subscribers or consumers with high bandwidth, thus replacing existing copper cabling system such as telephone wires and coaxial cable. Furthermore, FTTH is trend nowadays due to the advantages of fiber such as high bandwidth over long distances, low maintenance and operational costs, and future upgrade potential compare to copper based system.

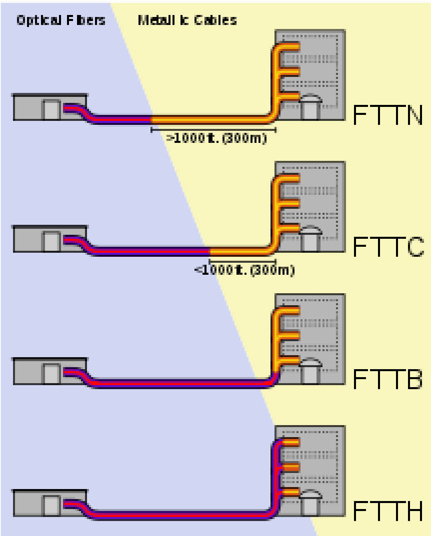


Figure 2.3: Type of FTTx

There are two popular types of fiber topologies in FTTH network. Firstly, is point-to-point (P2P) connectivity architecture also called "direct home run". In this fiber topology, there is a core switch at the Central Office which connects over optical fiber cables to an aggregation switch at the distribution points which basically locate at your home's street corner. The aggregation switches have many fiber ports. Each port will direct connect to an Optical Network Terminal (ONT) which placed at the residential localities using optical fiber cables. The advantages of P2P fiber topology are firstly, the bandwidth in each port of aggregation switch is dedicated to individual resident. Therefore higher bandwidth per port can be achieved. In addition, P2P technology also provides equal bandwidth for upstream and downstream. But the installation and maintenance costs are the main concern for deployment.

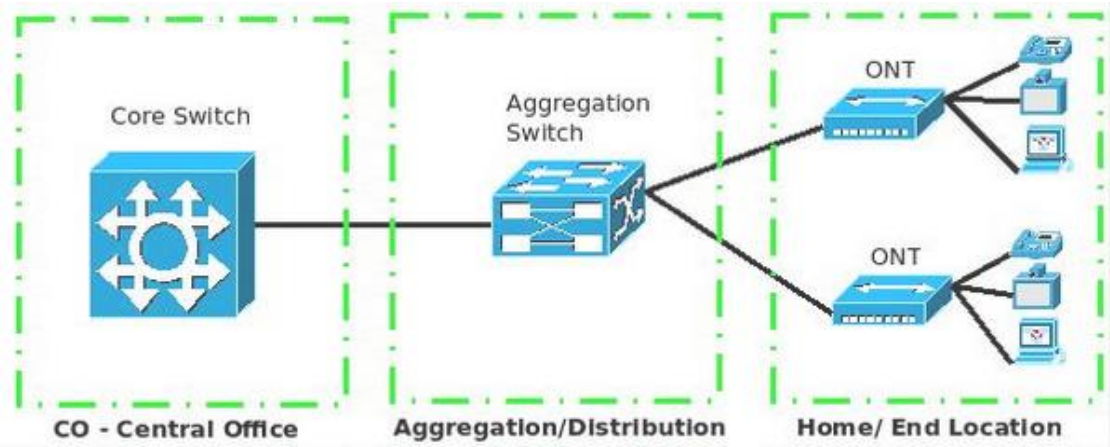


Figure 2.4: P2P FTTH architecture (using active aggregation switch) (K, 2011)

In point-to-multipoint (P2MP) or Passive Optical Network (PON) connectivity architecture, there is also having a core switch at the Centre Office. The only different is in the distribution points which replace with passive optical splitter. The same signal is transmitted to all the individual residents beyond the splitter, but each ONT in each house can identify the information for itself. The ONT used in P2MP is different from P2P. The advantages of P2MP/PON technology are firstly, it is cost effective to implement and maintenance due to less active ports to terminate fiber and led fiber cables are used. Moreover, it provides higher downstream bandwidth and lower upstream bandwidth but both are sufficiently and considerably high.

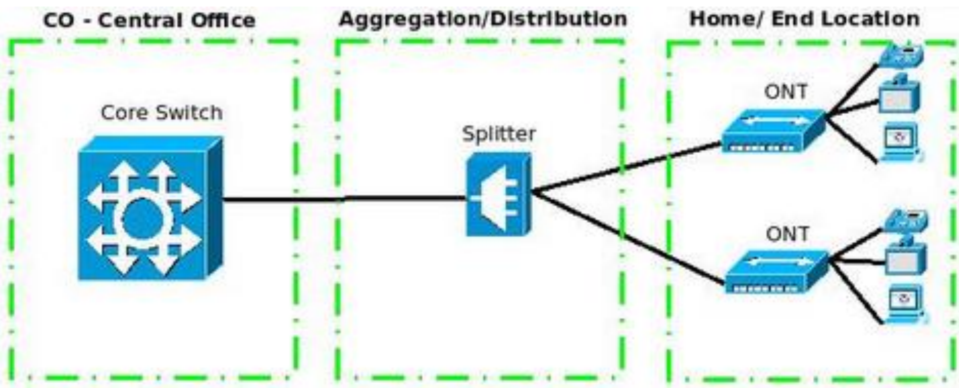


Figure 2.5: P2MP/PON FTTH architecture (using passive optical splitter) (K, 2011)

2.3 Optical Line Terminal (OLT)

Optical line terminal (OLT) also called optical line termination. It is a device which serves as the service provider endpoint of a passive optical network. There are two main functions of optical line terminal. Firstly, it helps to perform conversion between electrical signals used by the service provider's equipment and fiber optic signals used by the passive optical network. Secondly, it helps to coordinate the multiplexing between the conversion devices on the other end of that network.

2.4 Optical Splitter

In Passive Optical Network (PON) Fiber To The x (FTTx) networks, optical splitter plays an important role to split the fiber optic light into several parts at a certain ratio. Optical splitter is no containing any electronics and no need power supply. There are two kinds of passive Fiber To The Home (FTTH) optical splitters. Firstly is the traditional fused type splitter as known as Fused Biconical Taper (FBT) coupler or FBT WDM optical splitter. Secondly is the Planar Lightwave Circuit (PLC) splitter. Planar waveguide is a micro-optical components product, the use of lithography, the semiconductor substrate in the medium or the formation of optical waveguide to achieve branch distribution function. The configuration of PLC splitter is 1x4, 1x8, 1x16, 1x32, 1x64, 1x128, 2x4, 2x8, 2x16 and 2x32. In a PON network, the number of optical splitter use is depends on your designed PON. It may have only a single optical splitter in a PON network, or it can have several splitters cascaded together. The optical splitter used in this project is PLC (2x8) splitter and Table 2.1.3 shown specification of PLC splitter.

Table 2.1: Specification of PLC splitter.

Type		1x2	1x4	1x8	1x16	1x32	1x64	2x2	2x4	2x8	2x16	2x32	2x64
Fiber Type		9/125 um SMF-28e or customer appoint											
Operating Wavelength(nm)		1260~1650											
Insertion Loss(dB)	Typical	3.6	6.8	10.0	13.0	16.0	19.5	4.0	7.0	10.5	13.5	16.5	20.5
	(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	4.1/4.3	7.4/7.6	10.8/11.0	14.3/14.5	17.3/17.5	20.7/21.5
Loss Uniformity(dB)-Max		0.6	0.6	0.8	1.2	1.5	2.5	0.8	0.8	1.5	2.0	2.5	2.5
Polariation Dependent Loss(dB)-Max		0.15	0.15	0.25	0.3	0.3	0.3	0.2	0.2	0.3	0.4	0.4	0.4
Dimension(WxHxL)(mm) Ribbon/Bare Fiber		4x4x40	4x4x40	4x4x40	4x7x50	4x7x50	4x12x60	4x4x50	4x4x50	4x4x50	4x7x60	4x7x60	4x12x60
Dimension(WxHxL)(mm) ABS BOX(0.9,2.0,3.0mm)		100x80x10			120x80x18		141x114 x18	100x80x10			120x80x18		141x114 x18
Directivity(dB)-Min		55											
Return Loss(dB)-Min		UPC:50 APC:60											
Operating Temperature(℃)		-40~85											
Storage Temperature(℃)		-40~85											
Connector type		FC,SC,ST,LC,MU											

2.5 Optical Network Terminal

Optical Network Terminal commonly called Optical Network Unit (ONU). The optical network terminal translates light pulses into electrical signals that your electronic device can understand such as voice telephone, internet, and television; and converts the electrical signal that you send back into pulses of light.

2.6 Optical Fiber

Nowadays, a variety of industries including the medical, military, industrial especially telecommunication and networking are able to apply and use fiber optic technology in a variety of applications. Fiber optics is long, flexible, thin strands of very pure glass about the diameter of a human hair. They are arranged in bundles called optical cables and used to transmit light signals between transmitter and receiver over long distances. The principle used to transmit data in optical fiber is total internal reflection. In communication system, fiber optics is used instead of traditional copper wire cable. Firstly, fiber optical cables are much thinner and lighter than copper wire cables and can transmit data over longer distances. Secondly, fiber optical cable has higher bandwidths compare to copper wire cable. This means that it can carry numerous data and information. Furthermore, the losses in fiber optics are much lesser than wire cable. Although there are many advantages in fiber optical cable compare to metal wire cable, the installation of fiber optical cables is expensive and they are difficult to splice. Figure 1.1 below is shown the timeline of optical fiber.

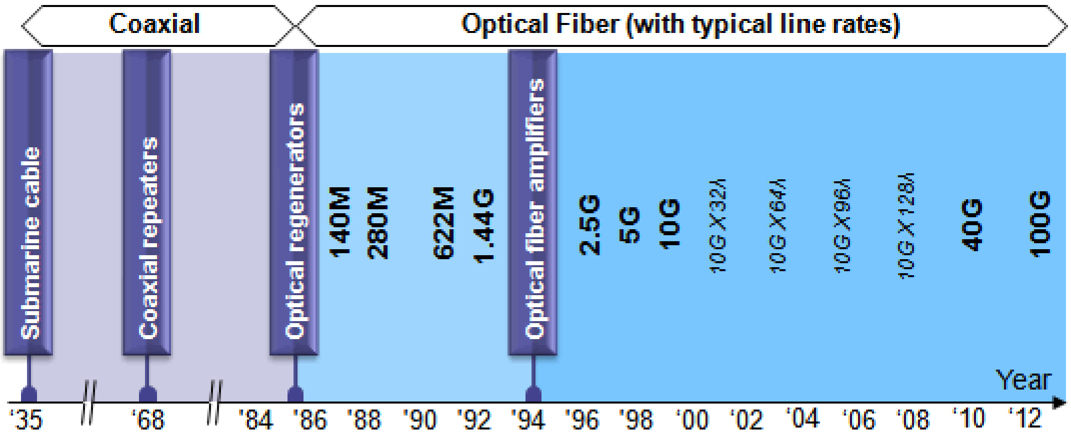


Figure 2.6: Timeline of optical fiber

The glass core of fiber optical cable is surrounded by glass cladding with a lower index of refraction compare to the glass core. Therefore, light is travel in the core by total internal reflection. There are two types of fiber optical cable called single mode fiber and multi-mode fiber.

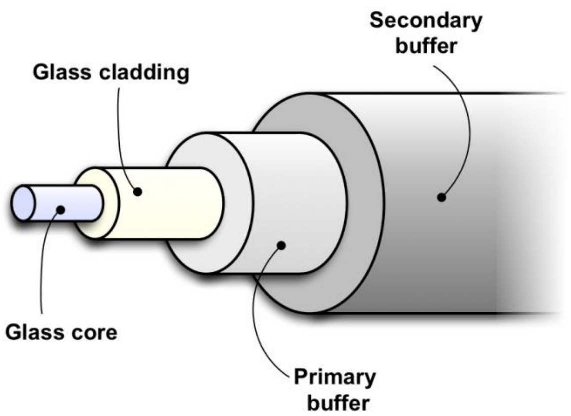


Figure 2.7: Basic structure of fiber optical cable

2.6.1 Single Mode Optical Fiber

Single mode fiber also called mono-mode fiber. It only allows a single propagation mode per polarization direction for a given wavelength. Therefore, the light or signal can transmit faster and further due to the light passes through the core decreases and have less attenuation. It has a small diameter core about 8 to 10 micrometers and only one mode can propagate typically 1310nm or 1550nm bandwidth. Single mode fiber can have a higher bandwidth than multi-mode fiber, but it need a light source will a narrow spectral width. The Figure 1.1.1 in below showed the front and side view of single mode fiber and its thickness. The core of the single mode fiber optical cable is covered by a layer of cladding which its diameter is around 125 microns. Then, it is cover by buffer. Buffer is one type of component that used to encapsulate one or more optical fiber for prevent physical damage and provide mechanical isolation.

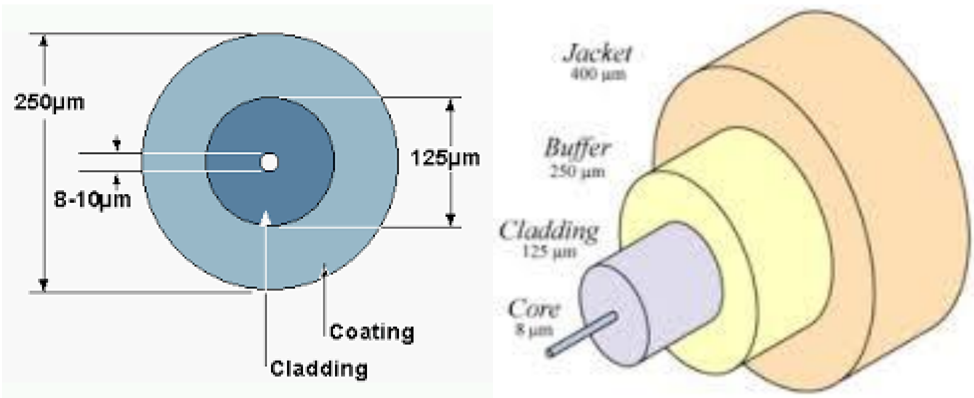


Figure 2.8: Cross section of single mode fiber. (Singh, 2014)

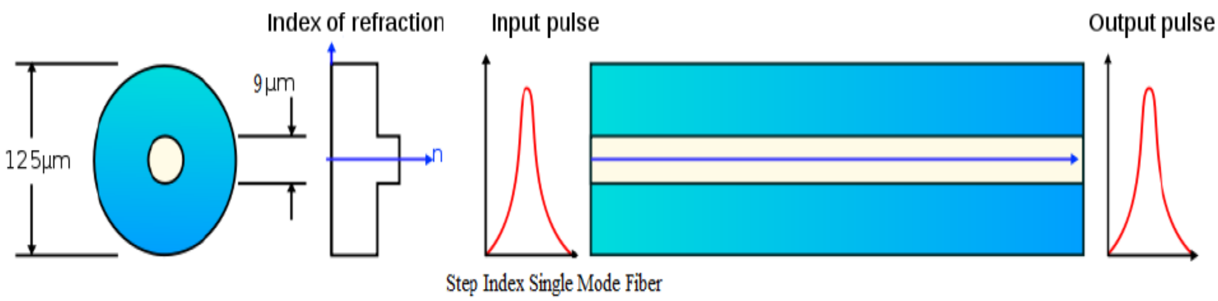


Figure 2.9: Output pulse

Single mode fiber cables can support a transmission distance up to 50 times further than multi-mode fiber cable. From Figure 1.1.2, light rays are enter parallel to the axis of the core while multi-mode fiber allows light rays enter from all directions and angles, and also support the speed up to 10 Gb/s. The single input mode of single mode fiber limits the dispersion of light, which eliminates data waste and increase speed of data transmissions. Furthermore, it can also immune to external noise such as radio frequency interference (RFI) and electromagnetic interference (EMI).

2.6.2 Multi-mode Optical Fiber

Multi-mode fiber is designed to carry light of multiple wavelengths with different angle. This is due to it has larger diameter than single mode fiber which around 50, 62.5, and 100 microns. The large core of this fiber can propagate typically 850nm or 1300nm bandwidth. There are more data passes through because the increase in number of light reflections. Multi-mode fiber has high dispersion and attenuation rate, therefore the quality of the signal will reduce as in long distance. So it specially used for short distance to transmit data, audio and video applications in local area networks (LANs). In multi-mode fiber, when transition between the core and cladding is sharp called step-index multi-mode fiber; while gradual transition is called graded-index multi-mode fiber.

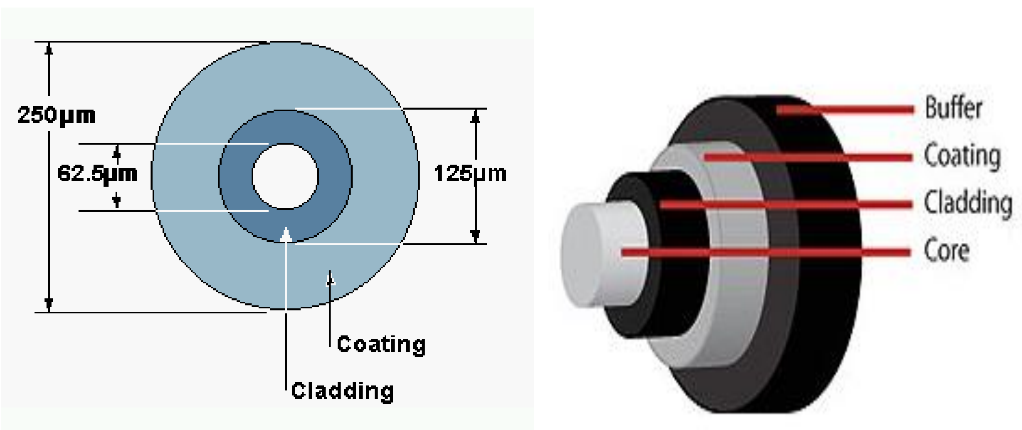


Figure 2.10: Cross section of multi-mode fiber

2.6.2.1 Step Index Multi-mode Optical Fiber

Step index multi-mode fiber is made by doping high purify fused silica glass with different concentrations of materials like boron, germanium or titanium. It has larger core than graded index multi-mode fiber. The layer of cladding has a uniform index of refraction that is sharply lower which causes errant light rays striking the interface to reflect back into the core, which is the primary light-conducting medium. Therefore, some of the light rays that make up the digital pulse may travel a direct route, where the others zigzag as they bounce off the cladding. So the different groups of light rays will arrive separately at the receiving point which shown in Figure 1.1.2.1. Step index multi-mode fiber is suitable for transmission over short distances.

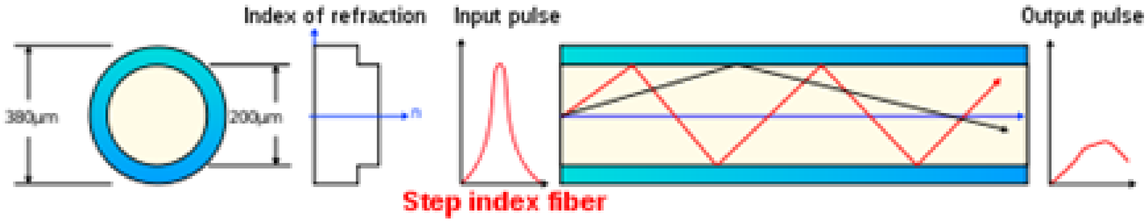


Figure 2.11: Output pulse is dispersion along the step index multi-mode fiber.

2.6.2.2 Graded Index Multi-mode Optical Fiber

Graded index multi-mode fiber is similar with step index multi-mode fiber, only the different is the core is smaller than step index multi-mode fiber. Therefore, the refractive index also changes with the size of core. In graded index multi-mode fiber, the refractive index of has gradually decrease from the centre axis out toward the cladding. This means that the light travelling down the centre of the fiber experiences a higher refractive index than light that travels further out towards the cladding. Therefore, light on the physically longer paths transmit faster than that light on the physically shorter paths. So the light will follow a curved trajectory which shown in Figure 1.1.2.2 and Figure 1.1.2.3. This can keep the speed of propagation of light on each path same with respect to the axis of the fiber. Thus a pulse of light composed of many modes stays together as it transmits through this fiber. Graded index multi-mode fiber is suitable for local area networks.

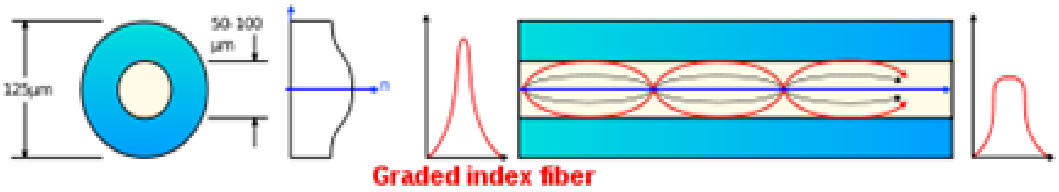


Figure 2.12: Output pulse is dispersion along the graded index multi-mode fiber.

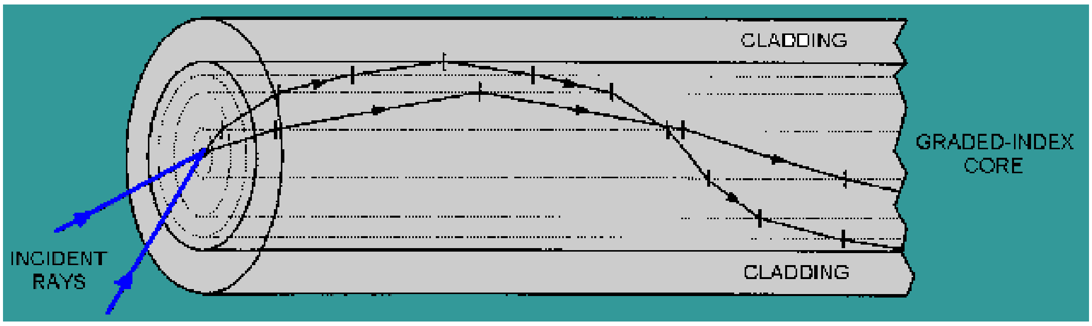
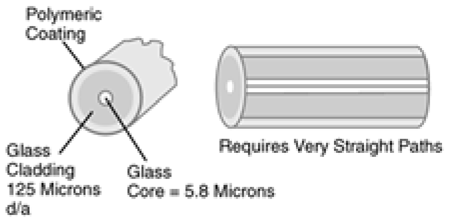
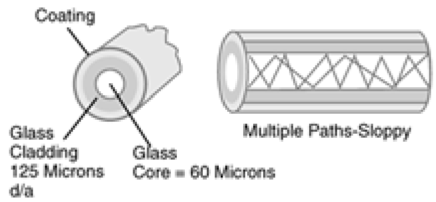


Figure 2.13: Modes travel in different refractive index in graded index multi-mode fiber.

Table 2.2: Difference between single and multi-mode fiber.

Single-Mode	Multimode
	
• Small Core • Less Dispersion • Suited for Long-Distance Applications (Up to ~ 3 km) • Uses Lasers as the Light Source Often Within Campus Backbones for Distances of Several Thousand Meters	• Larger Core Than Single-Mode Cable (50 Microns or Greater) • Allows Greater Dispersion and, Therefore, Loss of Signal • Used for Long-Distance Application, but Shorter Than Single-Mode (Up to ~ 2 km) • Uses LEDs as the Light Source Often Within LANs or Distances of a Couple Hundred Meters Within a Campus Network

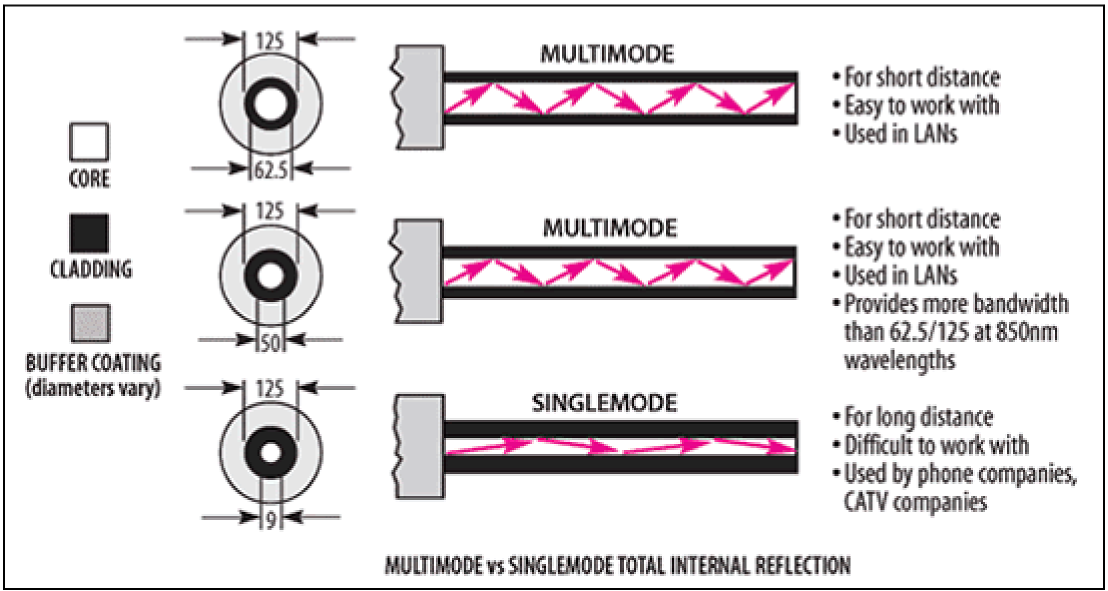


Figure 2.14: Difference between single and multi-mode fiber.

2.7 Types of Connectors

Optic fiber cables are used to transmit pulses of light while optical fiber connectors are used to join optical fibers to allow communication between a transmitter and receiver. Therefore the design on optical fiber connectors are more precise than other connectors to prevent too much loses of light. Even a small amount of dust or slight misalignment between fiber segments can greatly reduce performance and reliability. There are many different types of optical fiber connectors in the market but their design characteristics are similar. The three common types of optical fiber connector are Ferrule Connector (FC), Straight Tip Connector (ST) and Subscriber Connector. Connector can classify into simplex and duplex. A fiber with one connector per end is called simplex while with two connector per end is called duplex.

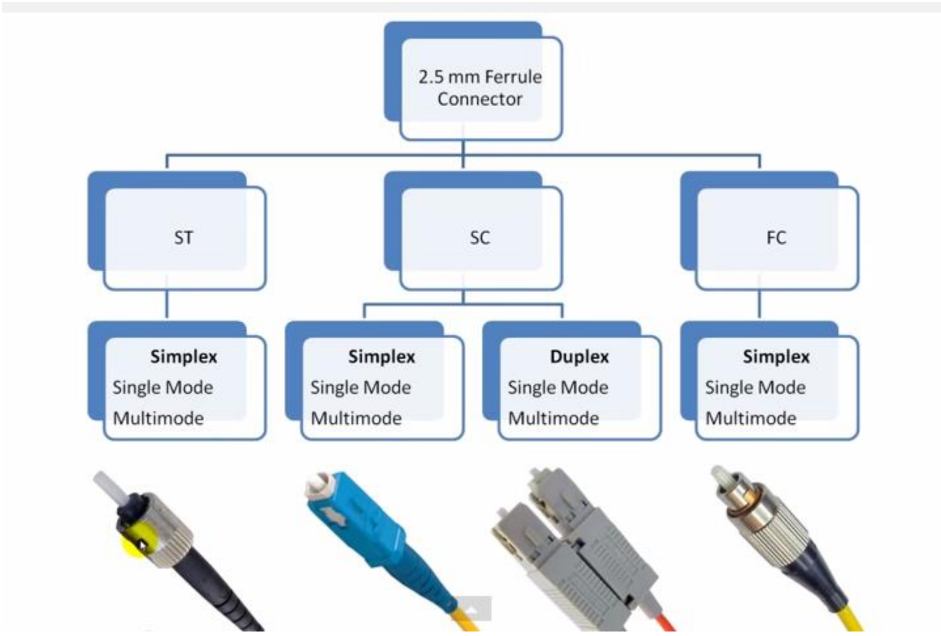


Figure 2.15: Type of connectors.

One of the components of optical fiber connector is called ferrule. The function of ferrule is used to ensure alignment during connector mating. It is cylindrical shape and has a hollowed out centre that forms a tight grip on the fiber. It basically made by hardened material such as ceramic, stainless steel, high quality plastic or tungsten carbide. The ferrule end is polished after insertion of the embedded fiber to provide smooth interface required for coupling. The connector body also called housing which hold the ferrule. It made by metal or plastic.

A good connector design must have these few principles. First of all, the connector should be low coupling loss. Furthermore, the connector should be inter-changeability means that there has no variation in loss whenever a connector is applied to a fiber. A good connector also should be low environmental sensitivity, low cost, reliable operation and repeatability means that connection and reconnection many times without an increase in loss.

2.7.1 The Straight Tip Connector (ST)

Straight Tip connector (ST) is the most common used optical fiber connector in networking application. It also called bayonet fiber optic connector (BFOC) which used a bayonet style twist and lock mechanism and can be used with both single and multi-mode fiber. There are two different styles of ST connectors. Firstly, is original ST connector which used a keyed design. Secondly, is ST-II which is spring loaded. Both also used bayonet style coupling mechanism which connect to another connector through a push and twist action.

The ferrule at the centre of connector is a hard cylindrical tube to protect the fiber and holds it in place for optimal transmission. The ferrule of ST connector is 2.5mm in diameter. ST connector can last between 500 and 1000 mating cycles. The typical insertion loss for matched ST connector is about 2.25 dB.

Figure 2.16: Structure of Straight Tip connector (ST)

2.7.2 The Subscriber Connector (SC)

The Subscriber Connector (SC) is a optical fiber connector that used a push-pull latching mechanism which similar to common audio and video cables. SC connector is used with single mode and multi-mode optical fiber in both simplex and duplex configuration. It provide for accurate alignment via its ceramic ferrule. Its ferrule has a diameter about 2.5mm and moulded housing for protection. It has a square shaped connector body, if in duplex connection, SC connector usually held together with a plastic clip.

SC connector offer low cost, durability and simplicity. It commonly used for Gigabit Ethernet due to simplicity and reduced physical space. It can last around 1000 matching cycles and have an insertion loss of 0.25 dB. The structure of SC connector is shown in Figure below. SC connector is used in this project.

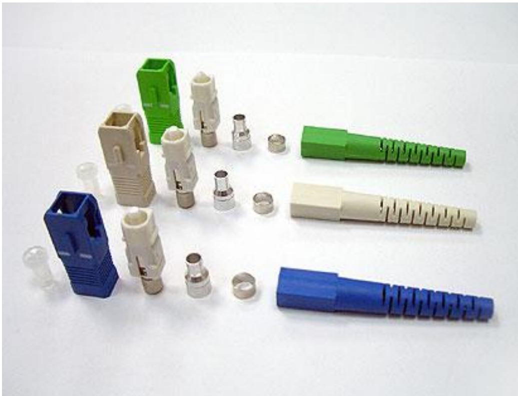


Figure 2.17: Structure of SC Connector

2.7.3 The Ferrule Connector (FC)

The Ferrule connector (FC) is an optical fiber connector which was designed for high-vibration environments. FC connector allows the surface of two connected optical fiber direct contact with each other. Therefore, it offers extremely precise positioning of the optical fiber cable with respect to the transmitter and receiver. This connector is used for single mode and multi-mode optical fiber cables. FC connector is commonly used in telecommunication applications, datacom, single-mode lasers, measurement equipment and provide non-optical disconnect performance.

FC connector is designed with a threaded coupling for durable connections. The ferrule of FC connector is about 2.5mm which made of zirconia ceramic or stainless steel. FC connector allows the process of transmission with low loss, because the tip of FC connector is polished to produce a rounded surface to allow only the core of optical fiber when mated. FC connector can last around 500 mating cycles and with the insertion loss of 2.5 dB.

Figure 2.18: Structure of FC connector

2.8 Optical Time Domain Reflectometer

Optical Time Domain Reflectometer (OTDR) is a precision instrument used to locate events and faults along an optical fiber, typically within an optical communication network. The OTDR output a series of high speed optical pulses in to the optical fiber cable under test and to check the faults of optical fiber. The strength of the return optical pulses is measured and integrated as a function of time, and plotted as a function of optical fiber length. In this report, a model FTB-150 Compact OTDR is used.

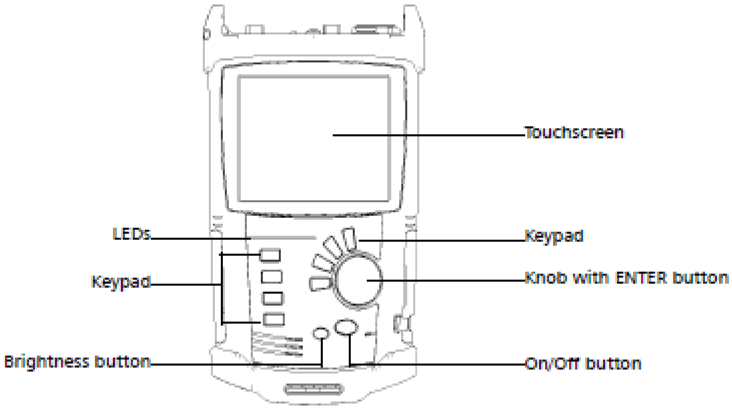


Figure 2.19: Front view of OTDR

CHAPTER 3

METHODOLOGY

3.1 Setup and Implementation

To construct and setup an Ethernet Passive Optical Network (EPON), it is necessary to understand devices and component used in this design such as OLT, optical splitter, ONU, fibers, and connectors. We would learn the optical fiber splicing techniques and able to classify the types of optical fiber and connectors during the design. Furthermore, we should to identify and perform correction on common error in fiber installation. In addition, we will investigate methods for transmitting data, and video over the EPON, FTTH. The test bed setup is as shown in Figure 3.1. The work schedule is represented in Figure 3.2.

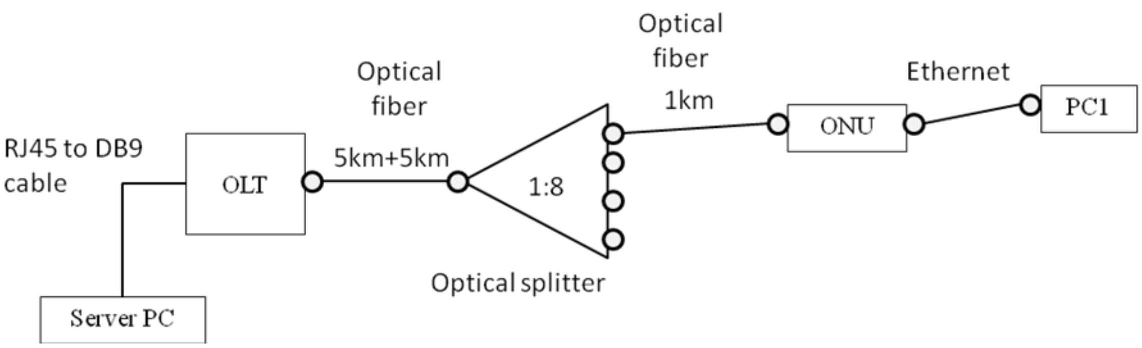
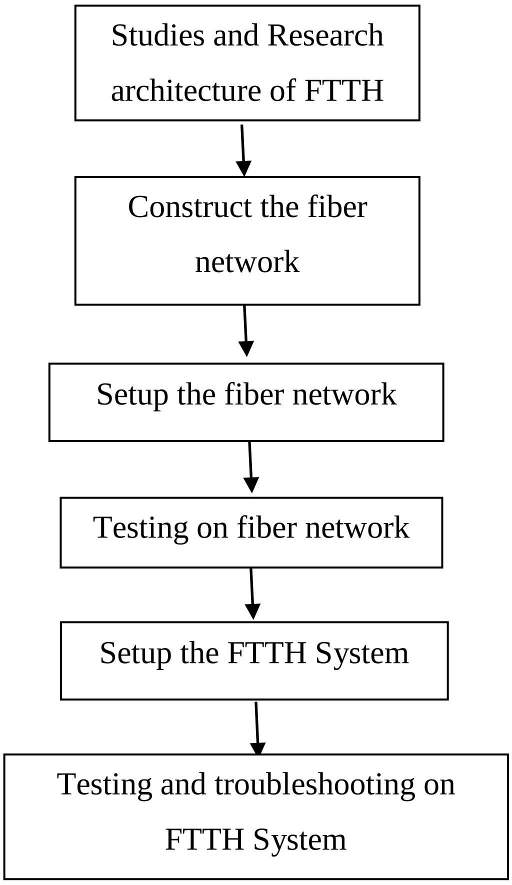


Figure 3.1: Implementation of FTTH of this project.



3.2 Testing and Measurement

In this project we will use the FTB-150 model of Optical Time Domain Reflectometer (OTDR) to implement and testing the FTTH EPON system. Furthermore, a multi-function loss tester (OLTS) is used to measure the loss. Therefore, we will put some fibers which has problem into the passive optical network to collect its “error” data.

3.3 Gantt Chart

The detail project time line is given in Gantt Chart below:

First Trimester

Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12
Project Selection	■	■	■									
Research on Project Work			■	■	■							
Research on the equipment FTTH						■	■	■	■	■		
Design FTTH System									■	■	■	
Write Report											■	■

Second Trimester

Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12
Construct FTTH System	■	■										
Setup/ Configuration OLT/ONU			■	■								
Testing FTTH Link				■	■							
Investigate FTTH Link Performance					■	■	■	■	■	■		
Prepare Final Report											■	■

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Experiment Setup

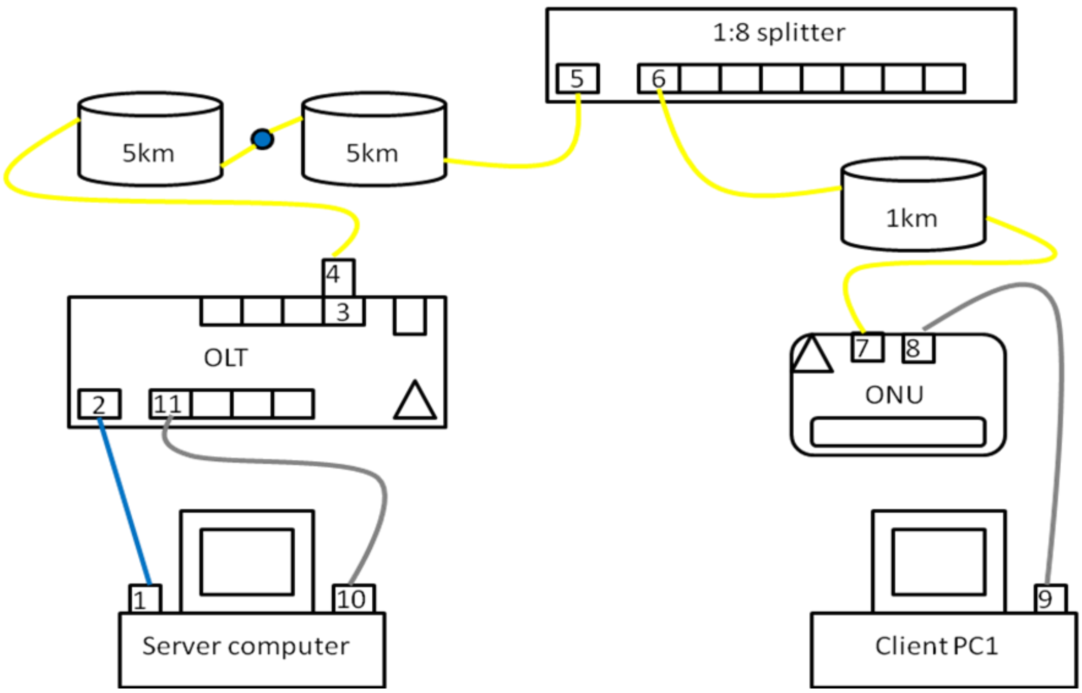


Figure 4.1 FTTH setup

1. Serial port of server computer.
2. Console port of OLT.
3. GEPON port of OLT.
4. Transceiver.
5. Input port of splitter.
6. Output port of splitter.

7. PON port of ONT.
8. Ethernet port of ONT.
9. Ethernet port of client computer.
10. Ethernet port of server computer.
11. Uplink GE optical port of OLT.

4.2 Optical Line Terminal (OLT) Configuration

To configure the OLT, it must be connecting to a computer by using a RJ45 to DB9 cable which shown in Figure 4.3. The RJ45 was connecting to the console port of OLT while the DB9 cable was connect to the serial port of computer. This cable for the console port is the common asynchronous serial interface cable, of which, the RJ45 port can be connected with the device and the other port can be connected with the serial port of computer. The cable in line with the asynchronous EIA/TIA-232 standard can transmit 15 meters. Its default baud rate is 9600 bit/s.

Figure 4.2: OLT FZG-6001

Figure 4.3: RJ45 to DB9 Cable and connection

There were five important things we need to configure. Firstly was the OLT virtual local area network (vlan). Here, the **vlan 2** was created in OLT to allow network node to communicate and the **vlan 2** must keep tag. Secondly, we need to set the flow-control and enable the port admin and then set the port direction to “a”. Thirdly, to let the ONU recognize by the OLT, we need to configure a static MAC address entry of the specific ONU. Then we use the **bind onuid** command to bind a logical ONU port to one ONU of the specified type, and associate the logical ONU port with the MAC address of this ONU. Therefore, the OLT can manage the ONU after the ONU had bind to a logical port. Besides that, the admin IP address, subnet mask and default gateway of the specific ONU also needed to set. Here, the ONU IP address, subnet mask and default gateway were set as 10.10.10.93, 255.255.0.0 and 10.10.10.254 respectively. The last step was to set the IP address for the inband management port. The IP address was set as 10.10.10.254. Furthermore, saving the configuration was very important by using the command **write**.

Then, software called “PuTTY” is used to let the server computer to configure the OLT. There is few setting need to set correctly to do the configuration. To do this configuration, the connection of the network should be connected which shown in Figure 3.1.

The configuration steps are listed below:

1. Setting the port direction and tag the **vlan 2:**

```
port direction a
port vlan 2 tagged
```

2. Interface the MAC address for the port:

```
mac-addr static mac 00:1a:69:00:3b:a3 port 1/1 vlan 2
mac-addr static mac 00:1a:69:00:3c:46 port 1/1 vlan 2
```

3. Binding the ONU to a logical port:

```
bind onuid 1 mac-address 00:1a:69:00:3b:a3 type m3-0420p
bind onuid 2 mac-address 00:1a:69:00:3c:46 type m3-0420p
```

4. Setting the ONU admin-ip:

```
OPLINK(config)# interface onu 1/1:2
  %Enter configuration commands.End with Ctrl+Z or command "exit" & "end"
OPLINK(config-if-onu-1/1:2)#admin-ip manual 10.10.10.90 255.255.0.0 10.10.10.254 2
OPLINK(config-if-onu-1/1:2)#show admin-ip
Ip address             : 10.10.10.90
Net Mask               : 255.255.0.0
Gateway                : 10.10.10.254
Vlan Id                : 2
OPLINK(config-if-onu-1/1:2)#exit
```

5. Configure the Uplink port of OLT:

```
OPLINK(config)# vlan 2
OPLINK(config-vlan-2)#inband ip-address 10.10.10.254 255.255.0.0
OPLINK(config-vlan-2)#exit
OPLINK(config)# show inband-info
  VLAN interface        : 2
  IP address            : 10.10.10.254
  IP netmask            : 255.255.0.0
```

The IP address, subnet mask and default gateway of the inband management port, ONU admin-IP, server computer and client computer must set it correctly. This was related to the networking. The IP address for those ports was shown in Figure 4.4.

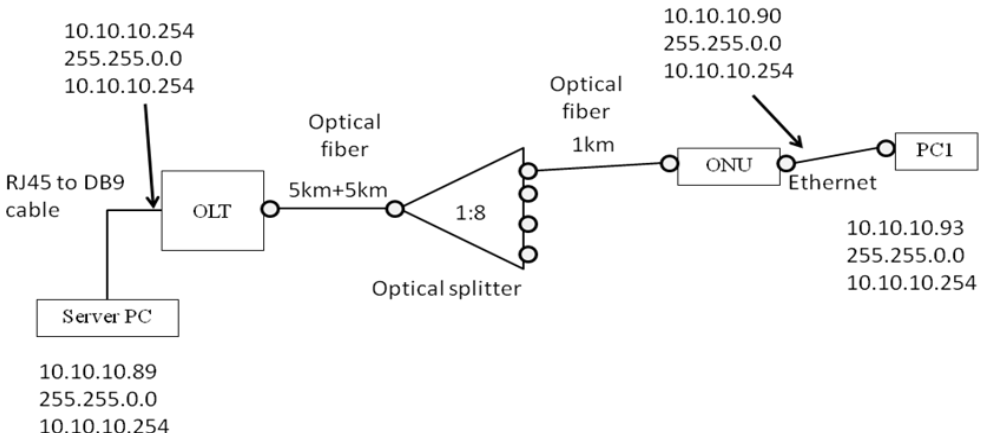


Figure 4.4: IP address of the port and computer

4.3 Optical Network Terminal (ONT)

Based on Section 4.2 above, ONU was configured on the OLT by setting and binding the MAC address on the OLT. MAC address is known as Media Access Control address. Here, MAC address act as a protocol to communicate with OLT. Each ONU has its own MAC address which was assigned by its manufacturer. Before the MAC address of ONU was configure into the OLT, the red LED indicator for Loss of Signal (LOS) will light up which shown in Figure 4.5. This means that there was loss of connection between OLT and ONU. When the MAC address of ONU was set and bind in the OLT, the green LED of PON will light up and blinking which shown in Figure 4.6.

Figure 4.5: ONU with loss of connection

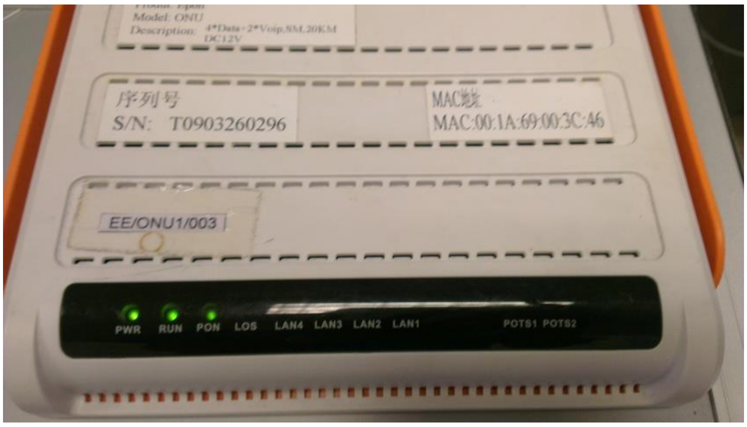


Figure 4.6: ONU is connected

4.4 Implementation of FTTH Architecture

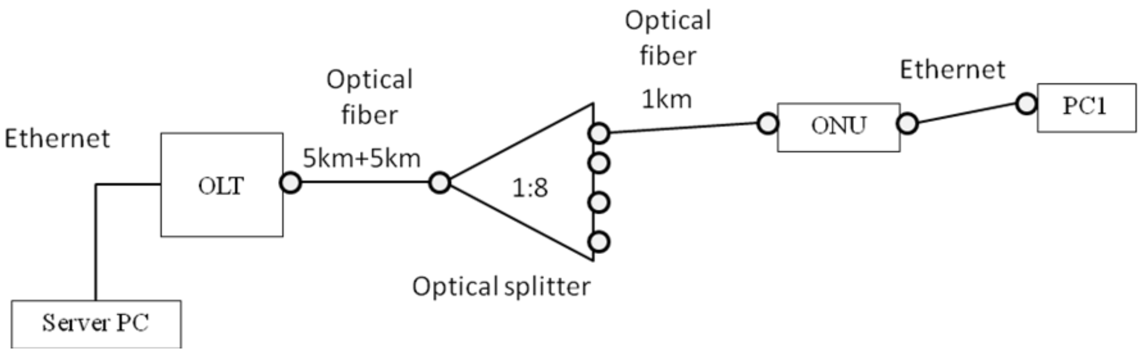
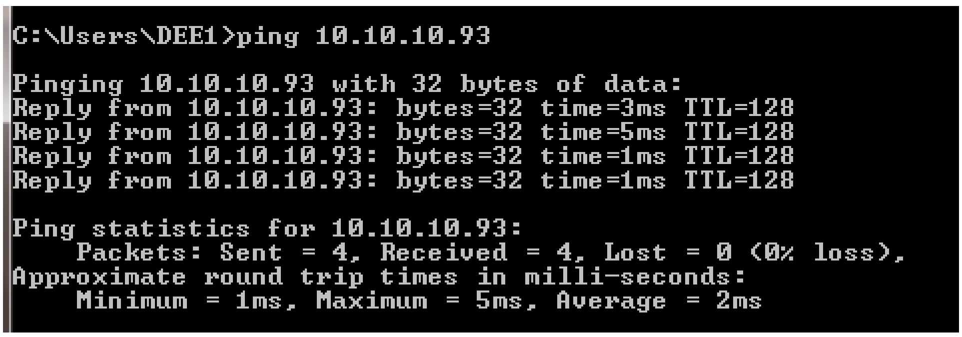


Figure 4.7: FTTH architecture

After the FTTH architecture was setup and configured, we can ping the IP address to check the connection which shown in Figure 4.8 below. Then connection status and response between OLT and ONU displayed is shown below.



```
C:\Users\DEE1>ping 10.10.10.93

Pinging 10.10.10.93 with 32 bytes of data:
Reply from 10.10.10.93: bytes=32 time=3ms TTL=128
Reply from 10.10.10.93: bytes=32 time=5ms TTL=128
Reply from 10.10.10.93: bytes=32 time=1ms TTL=128
Reply from 10.10.10.93: bytes=32 time=1ms TTL=128

Ping statistics for 10.10.10.93:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 5ms, Average = 2ms
```

Figure 4.8: Successfully ping the IP address of client PC from server PC.

A typical calculation for losses over a fiber link is shown below:

Single mode optical fiber (1550nm) : 0.3dBm/km

Connector loss : 0.1dB

Splitter loss : 6dB (1:4)

: 9dB (1:8)

Total loss between OLT to ONU = (Fiber Att Loss) + connector loss + splitter loss

= ((5+5+1+0.2) km x 0.3dB/km) + (0.1dB x 8) +9dB

= 13.16dB

A 200 meter optical fiber was added between the 1km optical fiber and the ONU. This is because when using OTDR to testing the attenuation loss, it needed a 200m to 500m launch cable to help minimize the effects of the OTDR's launch pulse on measurement uncertainty.

4.5 Measurement of FTTH Network by Using OTDR and Multi-function Loss Tester

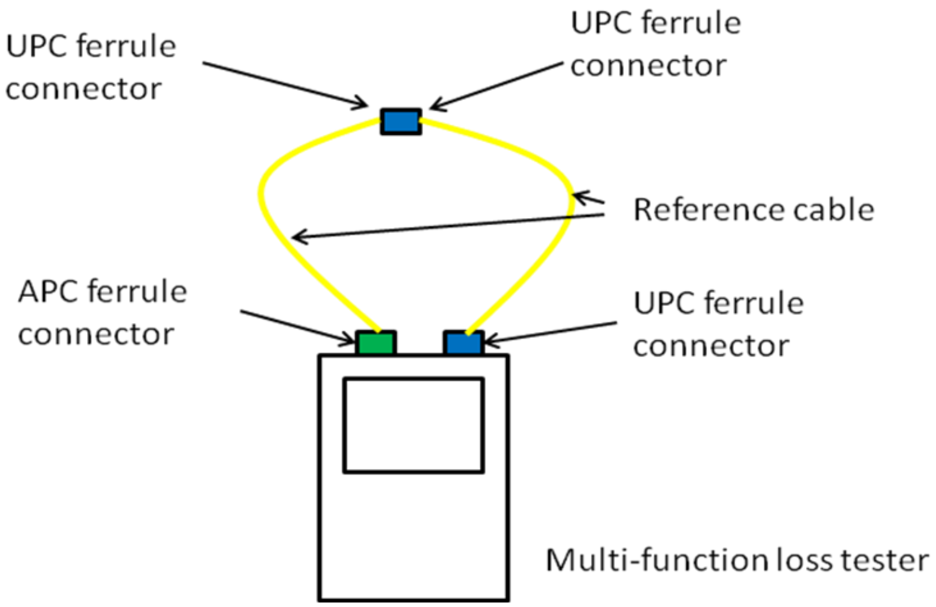


Figure 4.9: Connection to use multi-function loss tester

Figure 4.9 shown the connection to test the insertion loss of FTTH network by using the multi-function loss tester. The green color port of the multi-function loss tester must use the Angled Polished Contact (APC) and the blue color port can use the Ultra Polished Contact (UPC). Therefore, all the measurement must subtract the attenuation loss of this two reference cable. The attenuation loss of this two reference cable was shown in Figure 4.10. The optical return loss (ORL) is also known as back reflection defines the ratio of the incident power to the reflected power and is usually given in positive decibel. It indicates the amount of light that is reflected back to the source from optical devices. Therefore, lower ORL indicates higher amount of light reflected back. . In ideal case, there should be no reflected light at all.


Reference

	1310	1490	1550
IL (dB)	1.27	1.15	1.19
ORL (dB)	2.54	2.30	2.37

Figure 4.10: Attenuation loss of reference cable

4.5.1 FTTH Network Measurement without Launch Cable

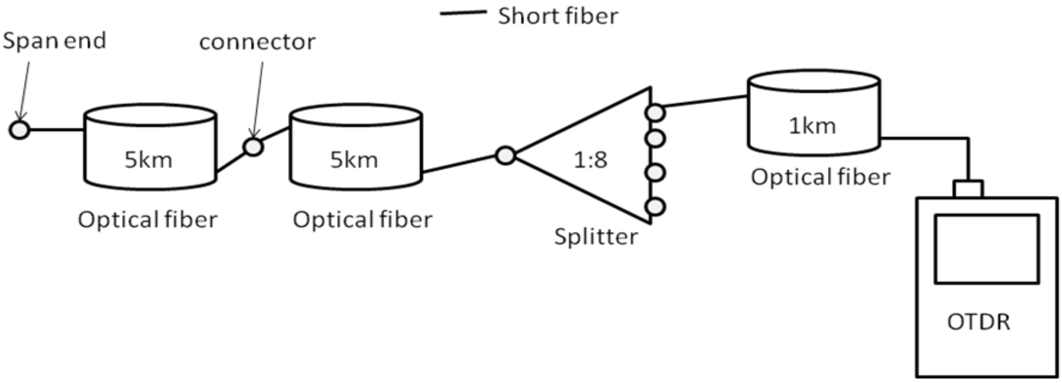


Figure 4.11: Connection to test FTTH network without launch cable

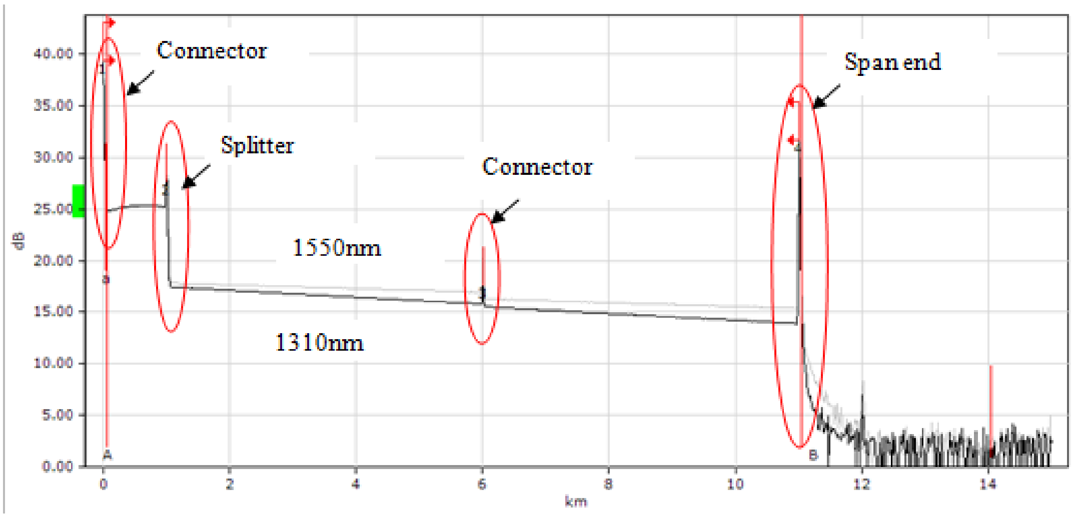


Figure 4.12: FTTH network measurements without launch cable

The attenuation loss will occur when the laser light transmitted through the optical fiber between OLT and ONU. To measure the loss, an Optical Time Domain Reflectometer (OTDR) and a multi-function loss tester was used. In Figure 4.11 above was shown the connection to measure the losses of FTTH network which was measure from ONU side to OLT side. The Figure 4.12 was shown the result from OTDR without a launch cable. The OTDR cannot make any useful measurements without the launch cable. Therefore, we are not able to get the most accuracy result from the OTDR. This can be prove in Figure 4.16 which shown the measurement with same connection but with a 200m launch cable. Without a launch cable, we are not able to measure the first fiber connector loss and some time we will detected some uncertainly event.

Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
☑ C:\Users\Adom Lee\Desktop\Fyp\FYP2\2nd needed results\002.trc						
☑ 1310 nm	- - -	1.015 dB/km	11.168 dB	3.807 dB	7.352 dB	11.0071 km
● ☑ **1550 nm**	**- - -**	**0.866 dB/km**	**9.529 dB**	**3.793 dB**	**6.955 dB**	**11.0059 km**

Figure 4.13: Measurement result for FTTH without using launch cable

The measurement result in Figure 4.13 showed two different wavelengths to measure the FTTH network which was 1310nm and 1550nm. In Figure 4.12 and Figure 4.13 also shown that 1550nm has less attenuation loss than 1310nm. The OTDR also can determine optical fiber length by using the technique of reflection which similar with radar. The attenuation loss after minus the attenuation loss of reference cable for 1310nm was dB while 1550nm was shown in Table 4.1.

Table 4.1 Attenuation loss of FTTH network without using launch cable

Wavelength	1310nm	1550nm
IL (dB)	**12.35 dB**	**10.98 dB**
ORL (dB)	**24.70 dB**	**21.96 dB**

Fiber ID	P/F	Wavelength (nm)	Dir.	Event 1 Launch Level 0.0000 km Loss (dB)	Event 1 Refl. (dB)	Section 1.0057 km Loss (dB)	Section Att. (dB/km)	Event 2 Non-Reflective Event 1.0057 km Loss (dB)	Section 5.0018 km Loss (dB)	Section Att. (dB/km)
Fiber0007	✗	1310	A->B	---	>-17.2	0.251	0.250	7.352	1.655	0.331
Fiber0007	✗	1550	A->B	---	>-17.8	0.101	0.100	6.955	0.912	0.182

Event 3 Non-Reflective Event 6.0075 km Loss (dB)	Section 4.9996 km Loss (dB)	Section Att. (dB/km)	Event 4 Reflective Event 11.0071 km Loss (dB)	Event 4 Refl. (dB)	Section 1.0041 km Loss (dB)	Section Att. (dB/km)	Event Positive Event 12.0111 km Loss (dB)
0.262	1.647	0.329	---	-14.0			
0.631	0.931	0.186	---	-14.0	1.508	1.500	---

Figure 4.14: The event of 1310nm and 1550nm fiber trace

4.5.2 FTTH Network Measurement with Launch Cable

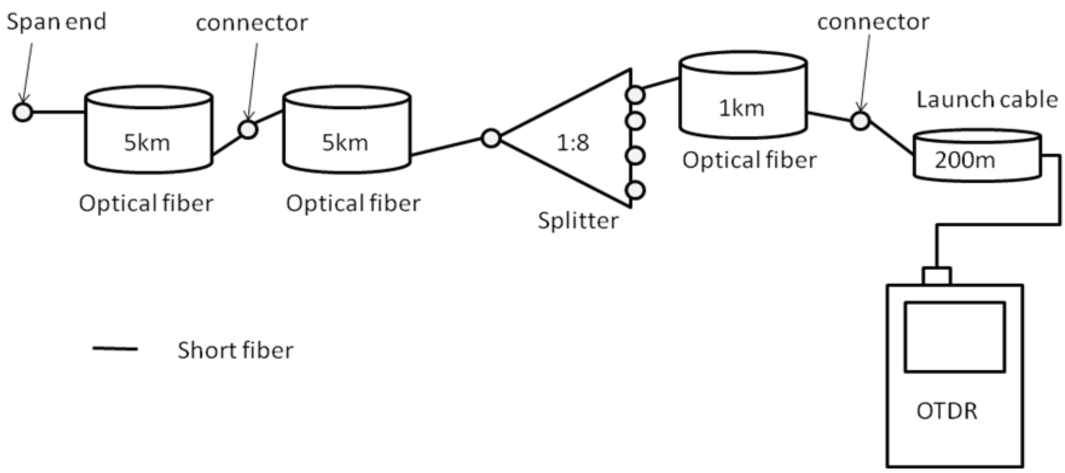


Figure 4.15: Connection to test FTTH network with launch cable

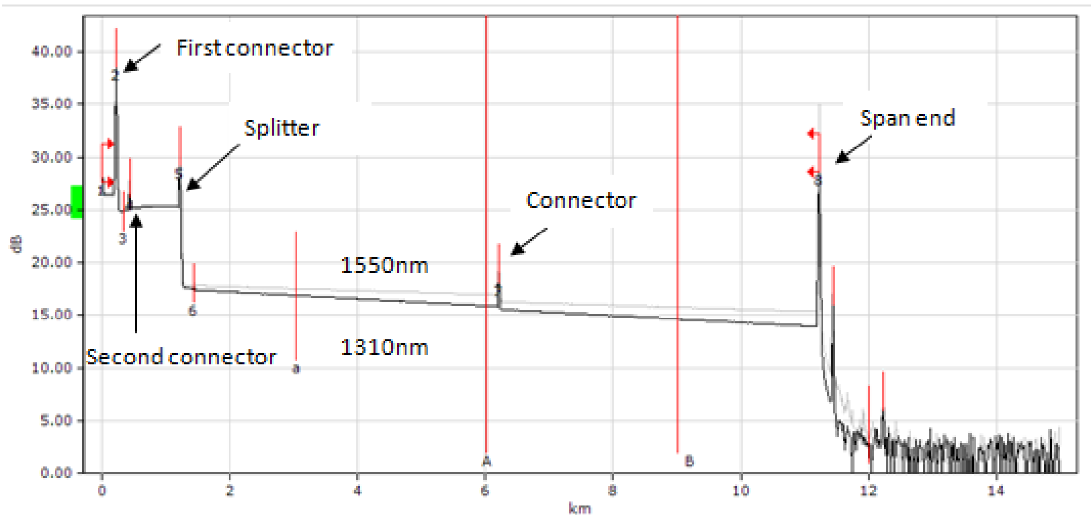


Figure 4.16: FTTH network measurements with 200m launch cable

We can observe clearly in Figure 4.16 that there was first and second connector and a 200m long cable before the first connector. By comparison with Figure 4.12 which showed only one connector but actually were two connectors. This shown that the result of OTDR with launch cable was more accurate. The launch cable also can call pulse suppressor, it help the OTDR trace to settle down after the test signal (wavelength) was sent through the optical fiber. Therefore, we can analyze the beginning of the cable that was testing. The attenuation loss after minus the attenuation loss of reference cable for 1310nm was dB while 1550nm was 12.74dB and 11.11dB respectively.

	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
	☑ C:\Users\Adom Lee\Desktop\Fyp\FYP2\2nd needed results\001.trc						
	☑ 1310 nm	- - -	1.120 dB/km	12.559 dB	1.485 dB	7.481 dB	11.2155 km
●	☑ **1550 nm**	**- - -**	**0.972 dB/km**	**10.901 dB**	**1.768 dB**	**7.114 dB**	**11.2148 km**

Figure 4.17: Measurement result for FTTH with launch cable

Table 4.2: Attenuation loss of FTTH network with using launch cable

Wavelength	**1310nm**	**1550nm**
IL (dB)	12.74 dB	11.11 dB
ORL (dB)	25.48 dB	22.22 dB

Fiber ID	**P/F**	**Wavelength**	**Dir.**	**Event 1**		**Section**		**Event 2**	**Section**	
				Launch Level				Non-Reflective Event		
				0.0000 km		0.2097 km		0.2097 km	0.1270 km	
				Loss	Refl.	Loss	Att.	Loss	Loss	Att.
		(nm)		(dB)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)
Fiber0007	✗	1310	A->B	---	-50.8	0.078	0.371	1.489	0.040	0.313
Fiber0007	✗	1550	A->B	---	-52.5	0.053	0.255	1.461	0.023	0.100

Event 3	**Section**		**Event 4**	**Section**		**Event 5**	**Section**	
Positive Event			Positive Event			Non-Reflective Event		
0.3367 km	0.0986 km		0.4353 km	0.7791 km		1.2144 km	0.2256 km	
Loss	Loss	Att.	Loss	Loss	Att.	Loss	Loss	Att.
(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)
-0.144	0.025	0.250	-0.280	0.195	0.250	7.481	0.084	0.371
			-0.413	0.078	0.100	7.114	0.103	0.456

Event 6	**Section**		**Event 7**	**Section**		**Event 8**		**Section**	
Non-Reflective Event			Non-Reflective Event			Reflective Event			
1.4400 km	4.7762 km		6.2162 km	4.9993 km		11.2155 km		0.2250 km	
Loss	Loss	Att.	Loss	Loss	Att.	Loss	Refl.	Loss	Att.
(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB)	(dB/km)
0.107	1.579	0.331	0.260	1.647	0.329	---	-13.9	0.383	1.700
0.028	0.874	0.183	0.648	0.932	0.186	---	-13.9	0.338	1.500

Event	Section		Event
Positive Event			Positive Event
11.4405 km	0.7803 km		12.2208 km
Loss	Loss	Att.	Loss
(dB)	(dB)	(dB/km)	(dB)
---	1.327	1.700	---
---	1.171	1.500	---

Figure 4.18: The event of 1310nm and 1550nm fiber trace with 200m launch cable

4.6 Fault Insert Into Optical Fiber

In this project, there was some fault was insert into the FTTH network to test how was the fault cable affecting the performance of FTTH network. The fault cable insertion was broken fiber, mismatch connector, contamination surface of connector, scratches surface of connector, macrobend fiber and combination of fault.

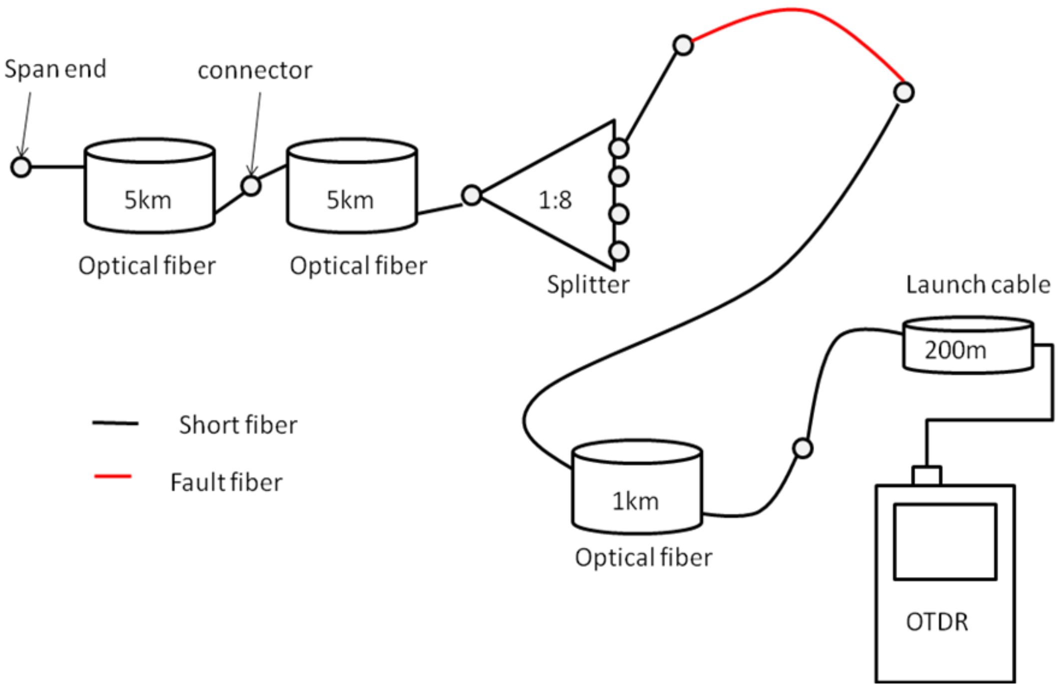


Figure 4.19: Connection for fault optical fiber insertion

4.6.1 Broken Optical Fiber

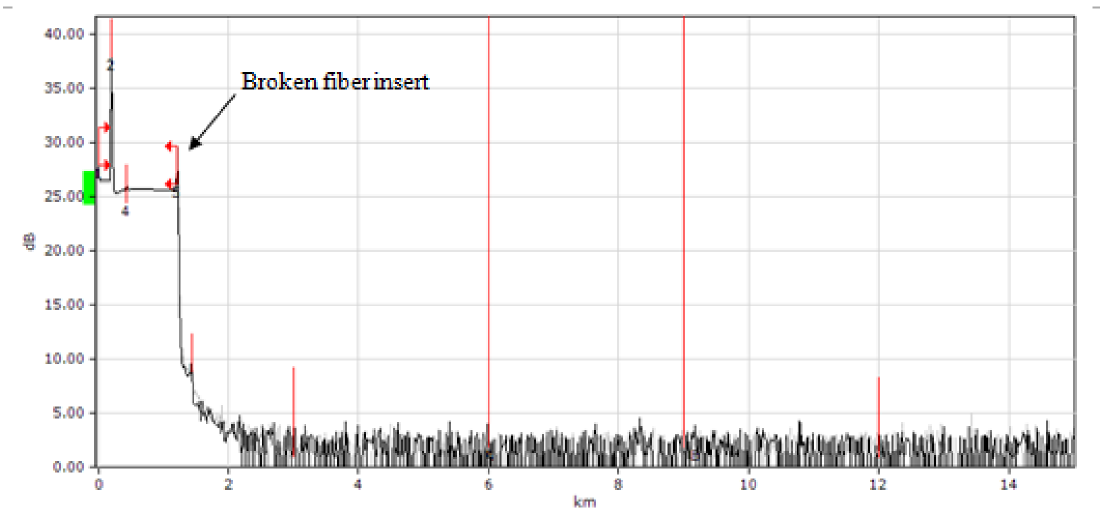


Figure 4.20: Broken fiber trace

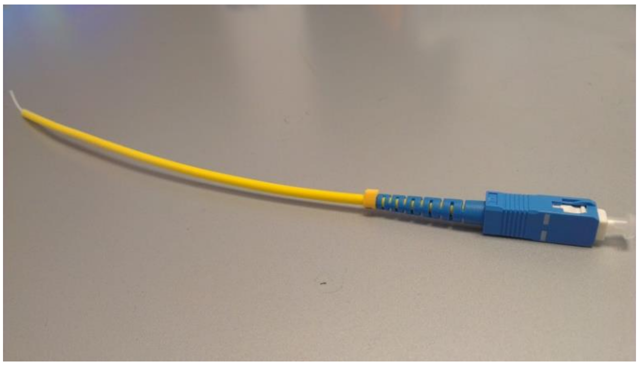


Figure 4.21: Broken fiber

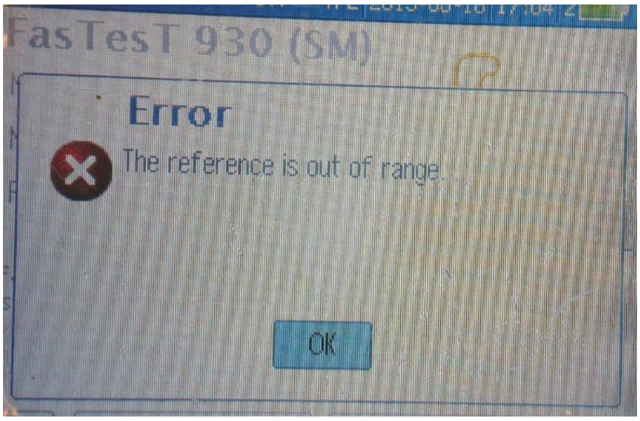


Figure 4.22: Attenuation loss testing failed using broken fiber shown in multi-function loss tester

The broken fiber was inserted in between the splitter and 1km optical fiber. The fiber trace shown in Figure 4.20 shown that there were all noise signals after around 1.3km. This means that the OTDR cannot detect the reflected laser signal after the broken fiber. Furthermore, the multi-function loss tester also cannot measure the broken optical fiber loss. The screen of the multi-function loss tester was shown in Figure 4.22. The signal waveform cannot pass thought the broken fiber. Therefore, there was no information reach the destination.

4.6.2 Mismatch Connector

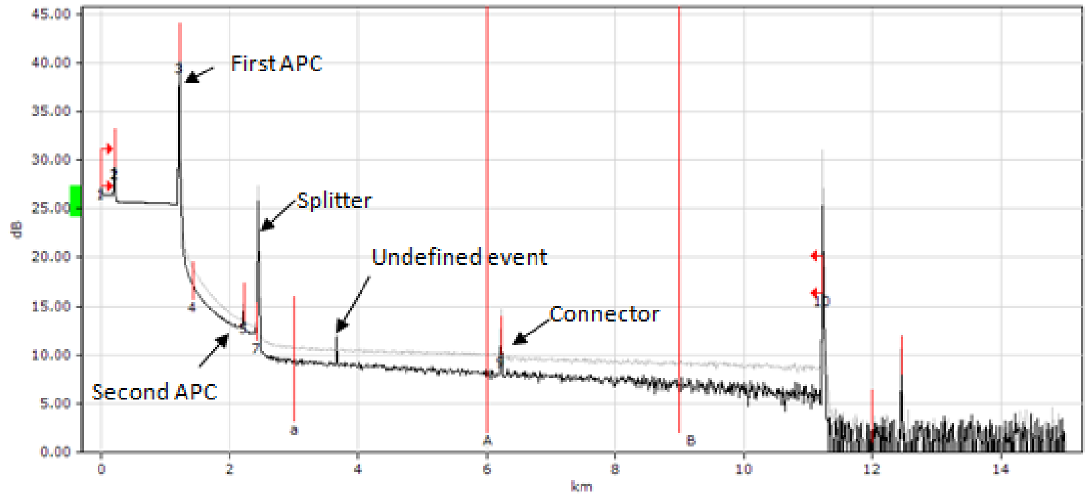


Figure 4.23: Mismatch connector between APC and UPC

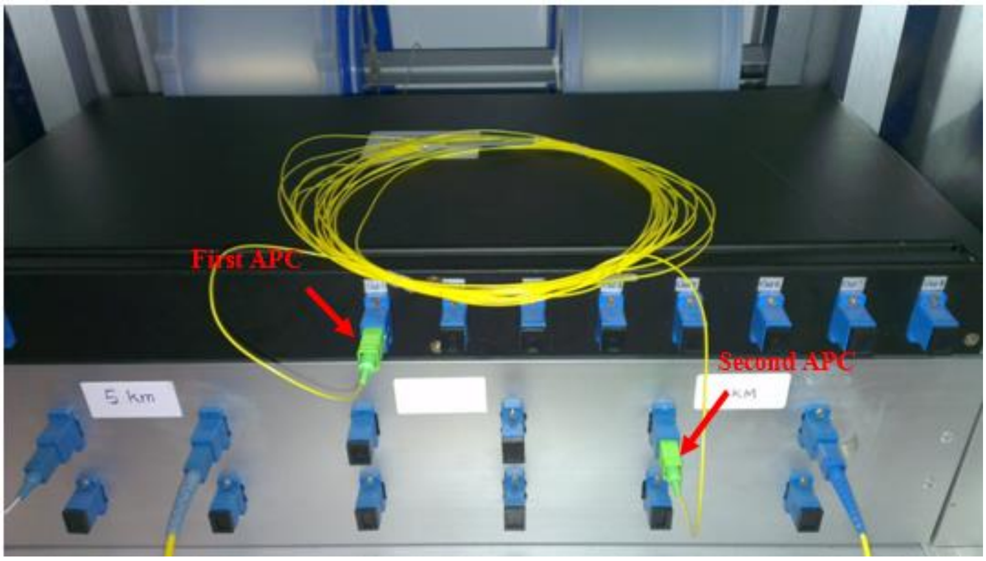


Figure 4.24: Connection of mismatch connector between APC and UPC

Table 4.3 Attenuation loss of FTTH network with using mismatch connector

Wavelength	**1310nm**	**1550nm**
IL (dB)	20.30 dB	17.67 dB
ORL (dB)	40.60 dB	35.34 dB

Figure 4.25: FC UPC ferrule connector

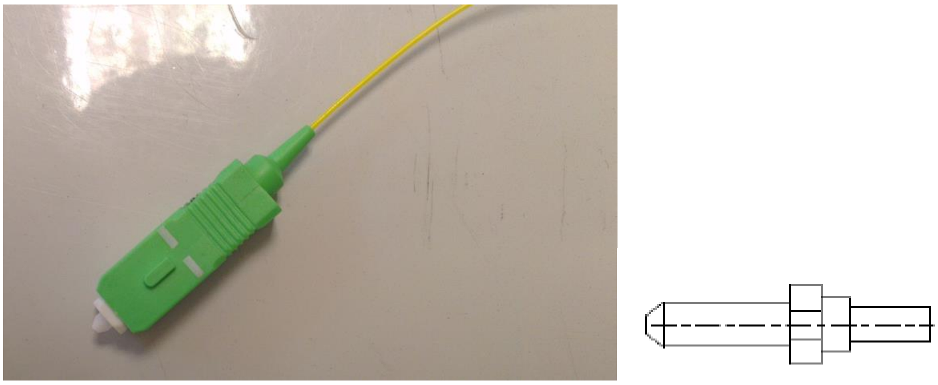


Figure 4.26: FC APC ferrule connector

The Figure 4.24 had shown the mismatch connector between Angled Polished Contact (APC) and Ultra Polished Contact (UPC). The APC was the green color connector while the UPC was the blue color connector and their ferrule connector was polished in different angle. APC connector has an 8 degree angle cut into its ferrule. Figure 4.27 had shown the contact of UPC polish and APC polish. Since the ferrule contact was different, when this two type of connector was connected together, maybe they were not contact correctly and misalignment or maybe there have a gap. Therefore, some light sources will loss in the contact of these two connectors.

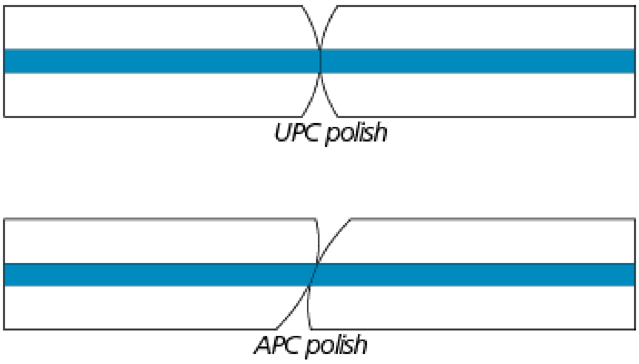


Figure 4.27: Contact of UPC polish and APC polish (Damico, 2014)

In the fiber trace (Figure 4.23), there have an undefined event occur and there have a high loss between the first and second APC connector. This undefined event and losses was cause by the mismatch connector. The insertion loss for mismatch for 1310nm and 1550nm were 20.30dB and 17.67dB respectively. The every event for this fault insertion was shown in Figure 4.29.

	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
	☑ C:\Users\Adom Lee\Desktop\Fyp\FYP2\2nd needed results\008.trc						
	☑ 1310 nm	- - -	1.930 dB/km	21.663 dB	2.545 dB	7.850 dB	11.2238 km
●	☑ 1550 nm	- - -	1.697 dB/km	19.042 dB	1.829 dB	5.844 dB	11.2235 km

Figure 4.28: Measurement result for FTTH with mismatch connecter

Fiber ID	P/F	Wavelength (nm)	Dir.	Event 1 Launch Level 0.0000 km Loss (dB)	Event 1 Refl. (dB)	Section 0.2094 km Loss (dB)	Section Att. (dB/km)	Event 2 Non-Reflective Event 0.2094 km Loss (dB)	Section 1.0044 km Loss (dB)	Section Att. (dB/km)
Fiber0007	⊗	1310	A->B	---	-51.7	0.077	0.370	0.628	0.326	0.324
Fiber0007	⊗	1550	A->B	---	-53.3	0.057	0.272	0.538	0.185	0.184

Wavelength (nm)	Event 3 Non-Reflective Event 1.2138 km Loss (dB)	Section 0.2256 km Loss (dB)	Section Att. (dB/km)	Event 4 Non-Reflective Event 1.4394 km Loss (dB)	Section 0.7794 km Loss (dB)	Section Att. (dB/km)	Event 5 Non-Reflective Event 2.2188 km Loss (dB)
1310	7.850	0.384	1.700	3.342	1.325	1.700	1.171
1550	5.844	0.399	1.500	1.836	1.108	1.500	3.963

Wavelength (nm)	Section 0.1962 km Loss (dB)	Section Att. (dB/km)	Event 6 Positive Event 2.4150 km Loss (dB)	Section 0.0144 km Loss (dB)	Section Att. (dB/km)	Event 7 Non-Reflective Event 2.4294 km Loss (dB)	Section 1.2406 km Loss (dB)	Section Att. (dB/km)	Event 8 Non-Reflective Event 3.6700 km Loss (dB)
1310	0.277	1.316				2.423	1.717	0.452	
1550	0.295	1.500	-1.615	0.007	0.251	3.612	0.858	0.699	0.111

Wavelength (nm)	Section 2.5567 km Loss (dB)	Section Att. (dB/km)	Event 9 6.2267 km Type	Event 9 Loss (dB)	Event 9 Refl. (dB)	Section 4.9970 km Loss (dB)	Section Att. (dB/km)	Event 10 11.2238 km Type	Event 10 Loss (dB)	Event 10 Refl. (dB)
1310			Positive Event	-0.141	---	2.284	0.457	Reflective Event	---	-14.5
1550	0.492	0.193	Non-Reflective Event	0.344	---	1.008	0.202	Non-Reflective Event	---	---

Wavelength (nm)	Section 1.2275 km Loss (dB)	Section Att. (dB/km)	Event Positive Event 12.4512 km Loss (dB)
1310	0.307	0.250	---
1550	0.569	0.464	---

Figure 4.29: The event of 1310nm and 1550nm fiber trace for mismatch connector

4.6.3 Contamination Surface of Connector

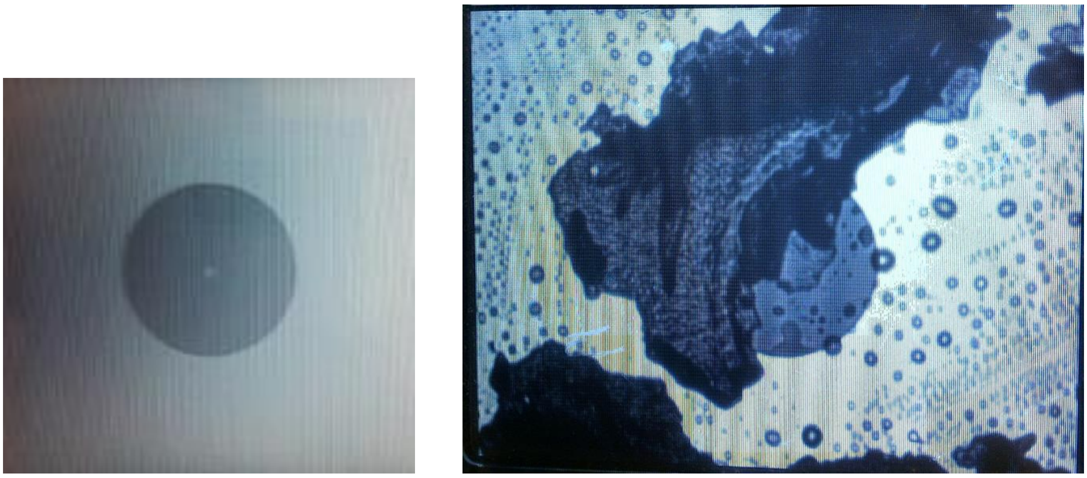


Figure 4.30: Clear surface (left) and contamination surface (right) of ferrule

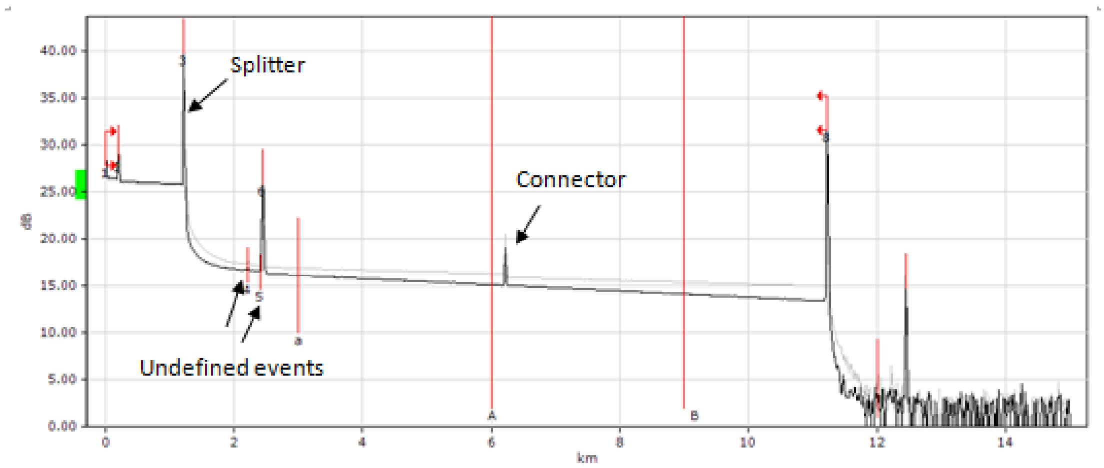


Figure 4.31: Contamination surface connector fiber trace

A little black maker pen ink was applied on the ferrule of the connector to test the effect on the performance. The view of the surface of ferrule was shown in Figure 4.30. Figure 4.31 was the fiber trace take by OTDR. There were two undefined events occur which were event four and five. Event four was the non-reflective event while event five was the positive event which shown in Figure 4.33. The non-reflective event showed only a drop in the strength of the Rayleigh backscatter signal from OTDR.

By using the multi-function loss tester, the insertion loss for contamination surface of ferrule was shown in Table 4.4. For 1310nm wavelength, the insertion loss was 14.27dB while for 1550nm wavelength was 12.12dB.

Table 4.4: Attenuation loss of FTTH network with using contamination surface of ferrule

Wavelength	1310nm	1550nm
IL (dB)	14.27 dB	12.12 dB
ORL (dB)	28.54 dB	24.24 dB

	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
☑	C:\Users\Adom Lee\Desktop\Fyp\FYP2\2nd needed results\015.trc						
☑	1310 nm	---	1.260 dB/km	14.129 dB	1.790 dB	7.823 dB	11.2164 km
● ☑	**1550 nm**	**---**	**1.023 dB/km**	**11.473 dB**	**1.767 dB**	**7.811 dB**	**11.2158 km**

Figure 4.32: Measurement result for FTTH with contamination surface of ferrule

Fiber ID	P/F	Wavelength	Dir.	Event 1		Section		Event 2	Section		Event 3
				Launch Level				Non-Reflective Event			Non-Reflective Event
				0.0000 km		0.2094 km		0.2094 km	1.0047 km		1.2141 km
				Loss	Refl.	Loss	Att.	Loss	Loss	Att.	Loss
		(nm)		(dB)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)
Fiber0007		1310	A->B	---	-50.9	0.079	0.376	0.261	0.336	0.335	7.823
Fiber0007		1550	A->B	---	-52.5	0.052	0.248	0.241	0.189	0.188	7.811

Section		Event 4	Section		Event 5	Section		Event 6	Section	
		Non-Reflective Event			Positive Event			Non-Reflective Event		
1.0069 km		2.2210 km	0.1956 km		2.4167 km	0.0265 km		2.4431 km	3.7762 km	
Loss	Att.	Loss	Loss	Att.	Loss	Loss	Att.	Loss	Loss	Att.
(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)
1.712	1.700	0.632	0.118	0.601	-0.453	0.007	0.250	0.688	2.926	0.334
0.636	0.631	0.271	0.111	0.528				0.179	0.705	0.186

Event 7	Section		Event 8			Section		Event
Non-Reflective Event								Positive Event
6.2193 km	4.9971 km		11.2164 km			1.2291 km		12.4455 km
Loss	Loss	Att.	Type	Loss	Refl.	Loss	Att.	Loss
(dB)	(dB)	(dB/km)		(dB)	(dB)	(dB)	(dB/km)	(dB)
			Non-Reflective Event	---	---	0.307	0.250	---
0.332	0.947	0.190	Reflective Event	---	-15.0	0.261	0.213	---

Figure 4.33: The event of 1310nm and 1550nm fiber trace for contamination surface of ferrule

4.6.4 Scratches Surface of Connector

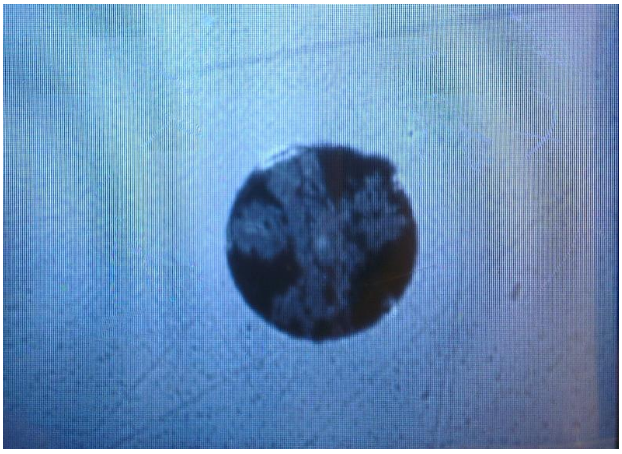


Figure 4.34: Scratches surface of the ferrule

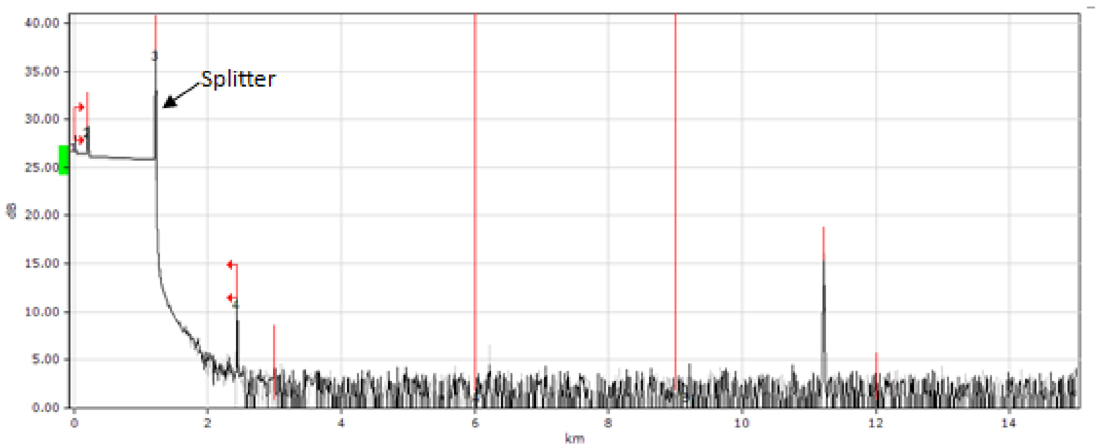


Figure 4.35: Scratches surface connector OTDR trace

The OTDR trace for scratched surface of ferrule was similar to broken fiber OTDR trace. The surface of the ferrule was scratched by sharp and hard metal. This can damage the ferrule. This affects the light signal loss from the core. The insertion loss for this fault in this FTTH network for 1310nm and 1550nm wavelength was 33.56dB and 28.07dB respectively. This fault has the largest insertion loss compare to the other fault insertion.

Table 4.5: Attenuation loss of FTTH network with using scratches surface of ferrule

Wavelength	1310nm	1550nm
IL (dB)	33.56 dB	28.07 dB
ORL (dB)	67.12dB	56.14 dB

	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
	☑ F:\017.trc						
	☑ 1310 nm	- - -	9.469 dB/km	23.119 dB	10.312 dB	20.330 dB	2.4415 km
●	☑ **1550 nm**	**- - -**	**0.415 dB/km**	**0.504 dB**	**0.267 dB**	**0.267 dB**	**1.2142 km**

Figure 4.36: Measurement result for FTTH with scratches surface of ferrule

Fiber ID	P/F	Wavelength	Dir.	Event 1		Section		Event 2	Section		Event 3
				Launch Level				Non-Reflective Event			Non-Reflective Event
				0.0000 km		0.2094 km		0.2094 km	1.0047 km		1.2141 km
				Loss	Refl.	Loss	Att.	Loss	Loss	Att.	Loss
		(nm)		(dB)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)
Fiber0007	✗	1310	A->B	---	-51.3	0.079	0.377	0.295	0.329	0.328	20.330
Fiber0007	✓	1550	A->B	---	-52.7	0.057	0.270	0.267	0.181	0.180	---

Section		Event 4			Section		Event
							Positive Event
1.2275 km		2.4415 km			8.7758 km		11.2174 km
Loss	Att.	Type	Loss	Refl.	Loss	Att.	Loss
(dB)	(dB/km)		(dB)	(dB)	(dB)	(dB/km)	(dB)
2.087	1.700	Non-Reflective Event	---	---	2.194	0.250	---
1.842	1.500	Positive Event	---	---	0.877	0.100	---

Figure 4.37: The event of 1310nm and 1550nm fiber trace for scratches surface of ferrule

4.6.5 Macrobend Fiber

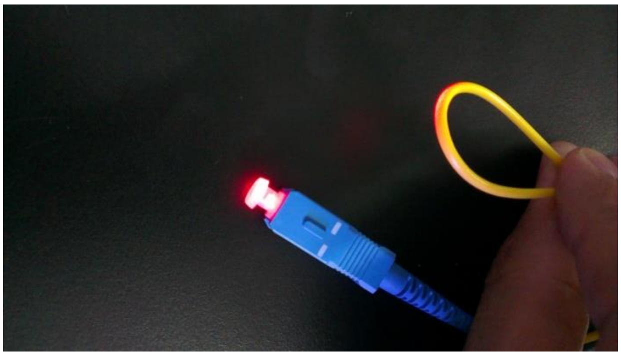


Figure 4.8 Macrobending fiber

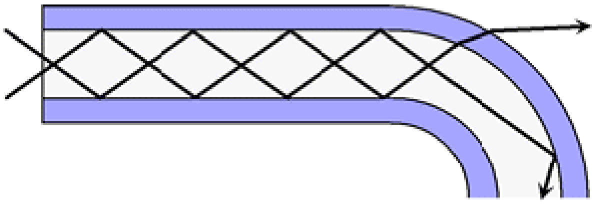


Figure 4.39: Cross sectional view of macrobend fiber

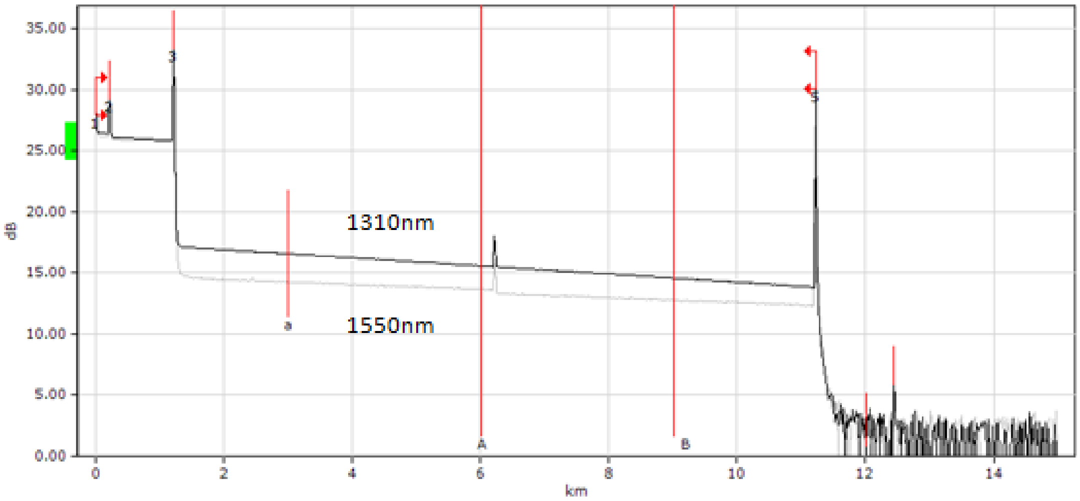


Figure 4.40: Macrobending fiber trace

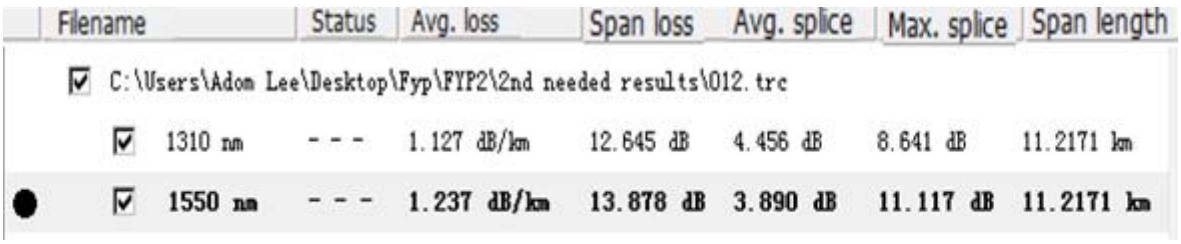
Macrobend optical fiber was bending an optical fiber in a critical angle. Then, some of the light in the core of optical fiber was penetrate out of the clad of the optical fiber which shown in Figure 4.39. This cause the light was loss from the optical fiber. In this test, the optical fiber which inserted between the 1km optical fiber and the splitter which bend in diameter 2cm.

From the OTDR trace in Figure 4.40, although it seems there were no any fault along the optical fiber. In this case, the 1550nm wavelength has a higher loss compared to 1310nm wavelength. Compare to the previous case, the 1310nm wavelength has higher loss compare to 1550nm wavelength. This shown that, for the macrobend loss, the higher the wavelength, the higher the losses will occur by using a same diameter of macrobend optical fiber. The results taken from multifunction loss tester also prove that the 1550nm has a higher loss than 1310nm wavelength which the difference in loss was 1.44dB.

Although in OTDR trace in Figure 4.40 it cannot determine the location of the macrobend optical fiber, in Figure 4.43, it shown that the macrobend was located in event three in the OTDR trace.

Table 4.6: Attenuation loss of FTTH network with using macrobend optical fiber

Wavelength	1310nm	1550nm
IL (dB)	12.78 dB	14.22 dB
ORL (dB)	25.56 dB	28.44 dB



	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
	☑ C:\Users\Adon Lee\Desktop\Fyp\FYP2\2nd needed results\012.trc						
	☑ 1310 nm	- - -	1.127 dB/km	12.645 dB	4.456 dB	8.641 dB	11.2171 km
●	☑ **1550 nm**	**- - -**	**1.237 dB/km**	**13.878 dB**	**3.890 dB**	**11.117 dB**	**11.2171 km**

Figure 4.41: Measurement result for FTTH with macrobend optical fiber

Fiber ID	P/F	Wavelength	Dir.	Event 1		Section		Event 2	Section	
				Launch Level				Non-Reflective Event		
				0.0000 km		0.2094 km		0.2094 km	1.0047 km	
				Loss	Refl.	Loss	Att.	Loss	Loss	Att.
		(nm)		(dB)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)
Fiber0007		1310	A->B	---	-51.0	0.071	0.339	0.271	0.329	0.327
Fiber0007		1550	A->B	---	-52.6	0.046	0.221	0.246	0.185	0.185

Event 3		Section		Event 4	Section		Event 5	Section		Event
Non-Reflective Event				Non-Reflective Event			Non-Reflective Event			Positive Event
1.2141 km		5.0062 km		6.2203 km	4.9968 km		11.2171 km	1.2297 km		12.4468 km
	Loss	Loss	Att.	Loss	Loss	Att.	Loss	Loss	Att.	Loss
	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)
	8.641	3.333	0.333				---	2.091	1.700	---
	11.117	1.025	0.205	0.308	0.950	0.190	---			

Figure 4.42: The event of 1310nm and 1550nm fiber trace for macrobend optical fiber

4.6.6 Combination of Fault

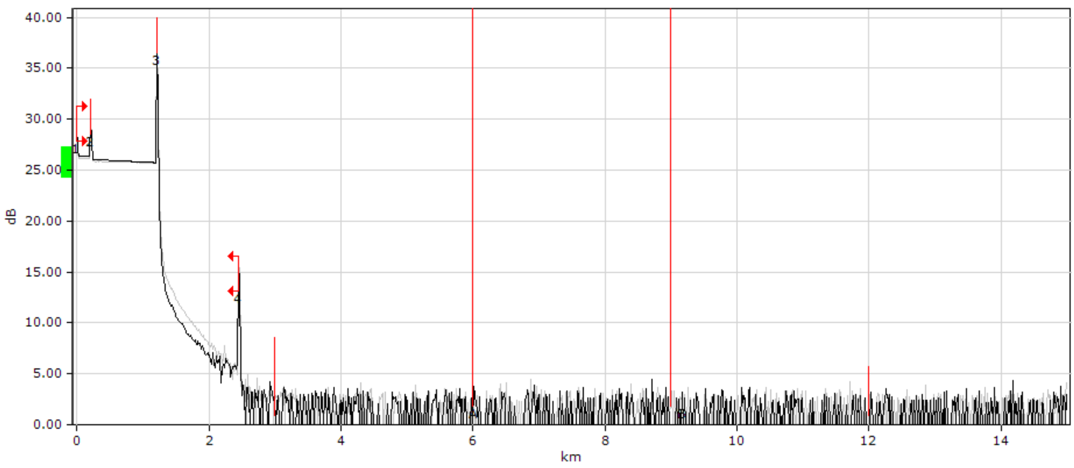


Figure 4.43: OTDR trace of combination fault inserted in FTTH network

The combination of fault was using scratches surface of ferrule, contamination of ferrule, macrobend optical fiber and mismatched connector except broken fiber. The broken fiber was not use in combination of fault because there will be no connection and cannot get any results when using broken fiber.

The OTDR trace of the combination of fault was similar with the OTDR trace of broken fiber which shown in Figure 4. 20. The Rayleigh backscatter signal from OTDR was become very noisy start from around 2.5km from ONU of the FTTH network. The insertion losses for 1310nm and 1550nm wavelength were 36.20dB and 38.46dB respectively.

Table 4.7: Attenuation losses of FTTH network with using combination of fault

Wavelength	1310nm	1550nm
IL (dB)	36.20 dB	38.46 dB
ORL (dB)	72.40 dB	76.92 dB

	Filename	Status	Avg. loss	Span loss	Avg. splice	Max. splice	Span length
	☑ C:\Users\Adon Lee\Desktop\Fyp\FYP2\2nd needed results\016.trc						
	☑ 1310 nm	---	8.656 dB/km	21.159 dB	9.332 dB	18.394 dB	2.4444 km
●	☑ 1550 nm	---	0.397 dB/km	0.482 dB	0.242 dB	0.242 dB	1.2142 km

Figure 4.44: Measurement result for FTTH with all combination of fault

Fiber ID	P/F	Wavelength	Dir.	Event 1		Section		Event 2	Section		Event 3
				Launch Level				Non-Reflective Event			Non-Reflective Event
				0.0000 km		0.2090 km		0.2090 km	1.0050 km		1.2141 km
				Loss	Refl.	Loss	Att.	Loss	Loss	Att.	Loss
		(nm)		(dB)	(dB)	(dB)	(dB/km)	(dB)	(dB)	(dB/km)	(dB)
Fiber0007		1310	A->B	---	-50.8	0.074	0.355	0.270	0.329	0.328	18.394
Fiber0007		1550	A->B	---	-52.5	0.052	0.250	0.242	0.188	0.187	---

Section		Event 4		
1.2303 km		2.4444 km		
Loss	Att.	Type	Loss	Refl.
(dB)	(dB/km)		(dB)	(dB)
2.092	1.700	Non-Reflective Event	---	---
1.845	1.500	Positive Event	---	---

Figure 4.45: The event of 1310nm and 1550nm fiber trace for all combination of fault

Table 4.8: Insertion loss of different losses

Fault	Insertion Loss (dB)	
	1310nm	**1550nm**
Without fault	12.74 dB	11.11 dB
Broken fiber	--	--
Mismatch connector	20.30 dB	17.67 dB
Contamination surface of ferrule	14.27 dB	12.12 dB
Scratched surface of ferrule	35.56 dB	28.07 dB
1cm diameter macrobend fiber	12.78 dB	14.22dB
Combination of fault	36.20 dB	38.46 dB

4.7 Performance of FTTH Network

One of the objectives of this project was to implement an EPON for FTTH for transmission of data, audio and video. For transmit data or file, a free File Transfer Protocol (FTP) can be downloaded which was "Filezilla Server" and "Filezilla Client". The Filezilla server was installed in the server computer while the Filezilla client was installed in the client computer. When the Filezilla server and client were connected, the client computer can copy the data or file from the server computer or on the other way cam said that the data and file can be downloading from the server and client computer.

From this project, the transfer rate for every fault optical fiber inserted in FTTH network was tested. The entire transfer rates were shown in Table 4.8. For the broken fiber, there was totally cannot transfer any data and file due the there was no connection between Filezilla server and client.

Table 4.9: Transfer rate for all fault fiber

Fault insert	Speed rate (Megabyte per second)
Without fault	6.0MBps
Broken fiber	--
Mismatch connector	5.8MBps
Contamination of ferrule	5.8MBps
Scratches of ferrule	5.7MBps
Macrobend fiber	5.8MBps
Combination of all fault except broken fiber	5.5MBps

For the video streaming, the VideoLAN (VLC) media player was use to stream video from the server computer to client computer or vice versa. For this testing, it was very hard to get the explicit results. This was because when streaming the video, the server side cannot view the video and only the client side can view the video. Therefore, we are hardly to differentiate the whether there was a delay, lagging and hanging.

Therefore, a live video was used to replace the streaming test. For the live video, two external cameras and software called “Bigant” were used. This software also needs a server and client, the server was provided a bridge to let all the clients to communicate. It was like messenger but here was not using the internet. This software provides the user to send text message, voice call and video call. Figure 4.46 shown the video call was processing. The performance of live video was smooth and no lagging, no hanging and no delay. During the live video capture, the audio sound was clear.

Figure 4.46: Video call using “Bigant”

The fault insertion fiber also applies to this test to. Table below was shown the quality of experience (QoE) for fault insertion. Table 4.10 was shown the quality of image effect by the diameter of macrobend optical fiber. The smaller the diameter of the marcobend optical fiber, the lower the quality of the image. In Table 4.10, we can observe that the image was start become blur when diameter of macrobend optical fiber was 4cm. This was due to some of the signal was loss to the air when the light penetrate out from the core of optical fiber.

Table 4.10: Quality of image took by video camera in macrobend test

Diameter of macrobend optical fiber	**Quality of the image**
Without macrobend	
12cm	
10cm	

8cm	
6cm	
4cm	

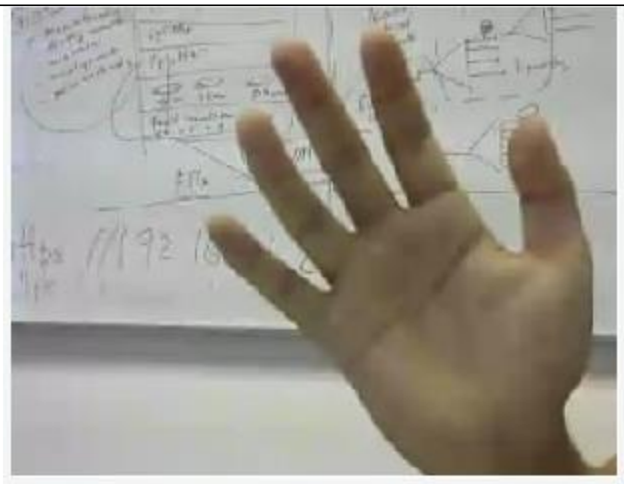
2cm	
1cm	

Table 4.11: Insertion loss of different diameter of macrobend optical fiber

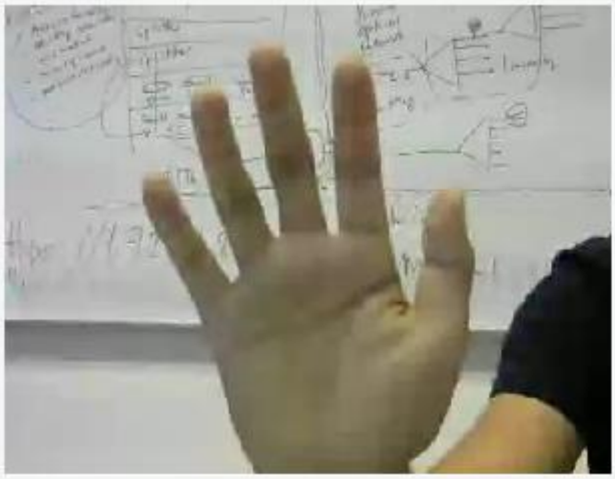
Diameter of macrobend optical fiber	**Insertion loss**	
	1310nm	**1550nm**
Without macrobend	12.29dB	10.36 dB
12cm	12.29 dB	10.37 dB
10cm	12.29 dB	10.37 dB
8cm	12.29 dB	10.37 dB
6cm	12.29 dB	10.38 dB
4cm	12.31 dB	10.40 dB
2cm	12.40 dB	11.36 dB
1cm	12.96 dB	15.64 dB

From Table 4.11, we can observe that the insertion loss of optical fiber was increase when the diameter of macrobend increases. Furthermore, the insertion loss of 1310nm wavelength only increases in 4cm diameter of macrobend. On the other hand, the insertion loss of 1550nm wavelength was sensitive with the change in diameter of macrobend fiber. There was a large loss during the optical fiber was bend in only 1cm diameter. The difference between normal optical fiber and 1cm diameter macrobend fiber was 5.28 dB with 1550nm wavelength.

Table 4.12 shown the quality of image took from the live video with different fault insertion. The fault insertion testing here were scratches surface of ferrule, contamination surface of ferrule, mismatch connector and combination of fault. For the scratches surface of ferrule, contamination surface of ferrule, and mismatch connector, the quality of the image was a little blur compare to a normal optical fiber in the first few second of the live video start. After two to three seconds, the quality of image of the fault insertion optical fiber was quite similar with quality of image of normal optical fiber. The signal maybe is not stable and was disturbed by the fault insertion in the optical fiber. Furthermore, there was no delay, lagging and hanging occur during this three fault insertion optical fiber was tested.

In combination of fault insertion, the image was very blur the image was often delayed, lagging and hanging. This was due to too many disturbances in the FTTH network that affect the signal to travel along this network. The signal was loss at every fault in the optical fiber.

Table 4.12: Quality of image took from live video with different fault insertion

Fault insertion	Quality of image
Without fault insert	
Scratched surface of ferrule	

Contamination surface of ferrule	
Mismatch connector	
Combination of fault	

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The purpose of this project was to set up the EPON test bed to evaluate the performance of an optical backhaul of a FiWi hybrid network. The two major performances of the FTTH in transmission of data and video had been successfully tested in this project.

This project can be separate into two parts namely hardware and software part. The hardware part was to construct the whole FTTH network by using the OLT, 1:8 optical splitter, ONT, optical fiber cable, and also the server and client computer. This was the basic structure of the FTTH network. For the software part, the most important software was the PuTTy. PuTTy helps us to configure the OLT by giving command the OLT to function as you want to. If any steps during the configuration was done wrong or some steps was not followed. This will cause the OLT not to function correctly.

Furthermore, Filezilla server and client, VLC media player and Bigant messenger were use to test the performance of the FTTH network in transferring data and video between the server computer and client computer.

Some fault was inserted to the optical fiber cable to study the affect the performance on transferring data and video through the FTTH network. It was found that the effect of single fault insertion was small. However when combination of multiple faults was apply in the same FTTH network, it will affect on the become observable. With multiple faults inserted, the transfer rate was slower and during the live video capture, the image was delay, lagging and hanging. The similar FTTH network will be apply in real life, therefore, we have to make sure all the optical fiber cable and connectors are in good condition to avoid degrading the performance of the network.

For the further work of this FTTH network the setup can include an additional client ONT and also configure the OLT connect to internet. This will allow the study of the FTTH connection to the internet. The fully configured optical network can be connected to the existing wireless mesh network in the campus to facilitate the evaluation of the performance of a full FiWi hybrid network.

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APPENDICES

The OLT connection of the system used for the configuration is shown in Figure A.1. The connection on the actual hardware is shown from Figure A.2.

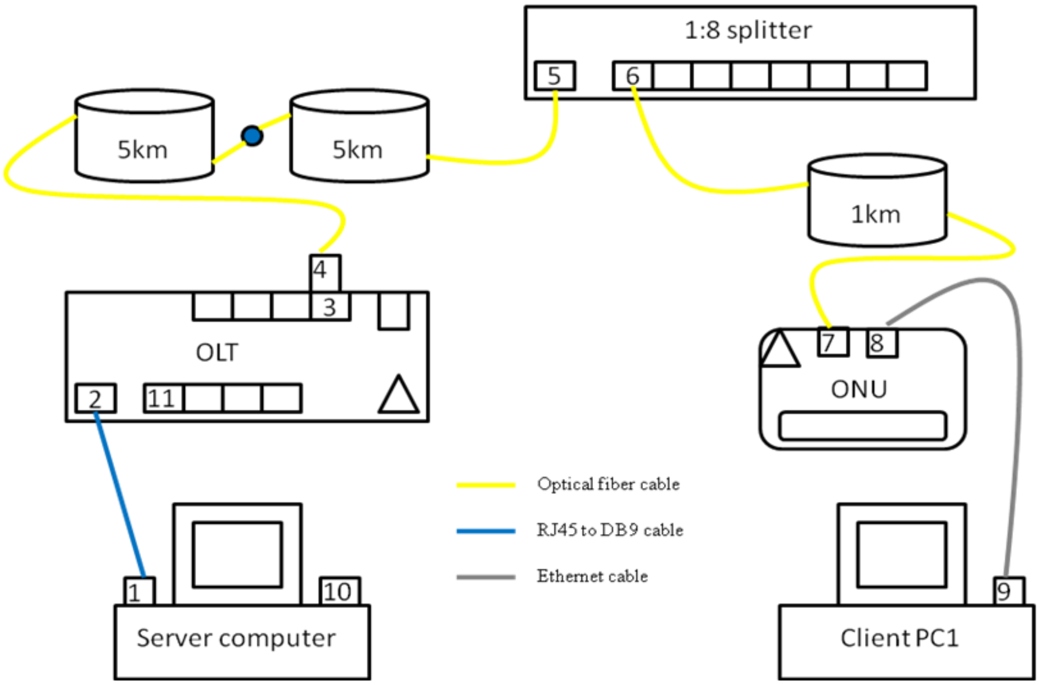

Figure A.1: Connection of the system during configure the OLT

1. Serial port of server computer.
2. Console port of OLT.
3. GEPON port of OLT.
4. Transceiver.
5. Input port of splitter.
6. Output port of splitter.
7. PON port of ONT.

8. Ethernet port of ONT.
9. Ethernet port of client computer.
10. Ethernet port of server computer.
11. Uplink GE optical port of OLT.

Step 1:

Connect the ac supply and ground of the OLT.

Figure A.2: Front view of OLT FZG-6001

Figure A.3: Ground connection of OLT

Step 2:

A RJ45 to DB9 cable was used to connect the server computer to the OLT. The DB9 was connectted to serial port of server computer while the RJ45 was connectted to the console port of the OLT. The connection is as shown in Figure A.4 and Figure A.5.

Figure A.4: Console port connection

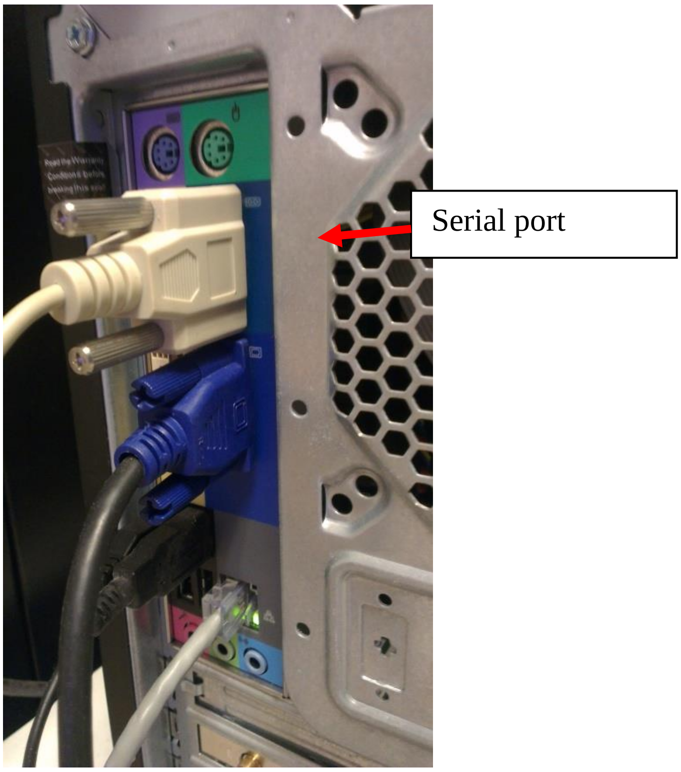

Figure A.5: Serial port connection

<u>Step 3:</u>

A transceiver was plugged into the GEPON (SFP) Interface of OLT locating at the back side of the OLT. Then an optical fiber cable was plugged into the transciever. Then this optical fiber was connect to a 5 km long optical fiber. The connection was shown in Figure A.1. Figure A.7 was shown the real connection of the FTTH network in lab.

***Every connectors of the optical fiber cable must be clean by using alcohol and tissue paper before use, unless you are purposely dirty it.**

Figure A.6: Transceiver

Figure A.7: Backward connection of OLT

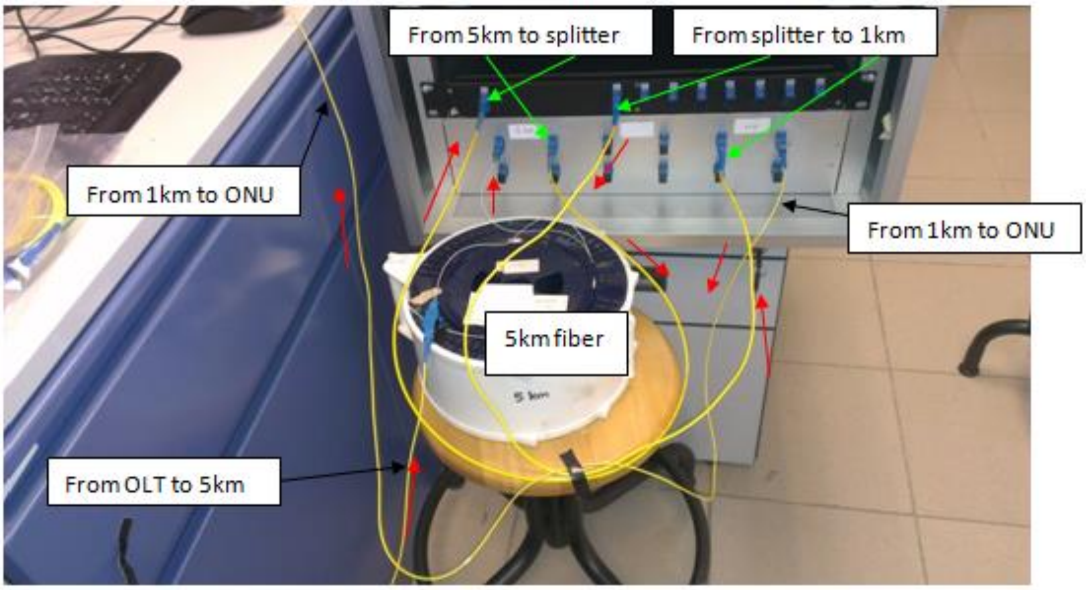

Figure A.8: Connection between OLT to ONU

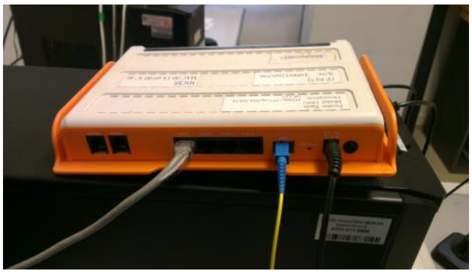

Figure A.9: Connection of ONU

Step 4:

Before turn on the OLT, please make sure the server computer have the software called “PuTTy”. If this software was not available in the server computer, please download from internet. If this software was available in the server computer, swich on the OLT and then open the PuTTy sofrware. The setting that need to choose for PuTTy was shown in Figure A.9.

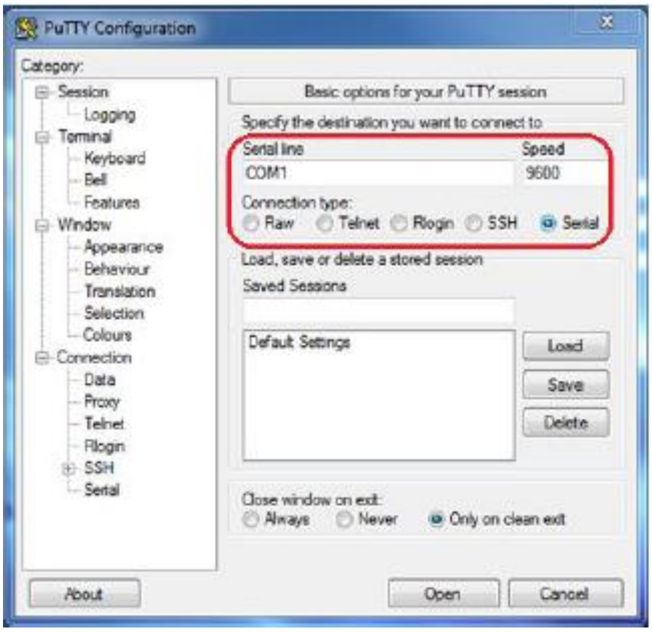

Figure A.10: In PuTTY, select “Serial” to connect OLT

Step 5:

Wait for a few minutes to let the OLT ready to be configure. After that, log in to the OLT with the password and step shown beolw. The step was shown in A.10. After logging in into the **configure terminal**, the very first thing to configure was to create a vlan. Here **vlan 2** was created. Then set the direction of the vlan to **a** and then

tagged the **vlan 2**. Then enable the port flow control where the command was shown in 8.2.3 of the EPON FZG-6001 command manual. The softcopy of the command manual was availble in the desktop of the server computer.

```
Password: ****
OPLINK> enable
Enable Password: ****
OPLINK# configure terminal
```

Figure A.11: Log in OLT

Password: **yotc**
OPLINK> **enable**
Enable Password: **yotc**
OPLINK# **configure terminal**

```
port direction a
port vlan 2 tagged
```

Figure A.12: Setting the port direction and tag the **vlan 2**

Step 6:

Then interface the **mac-address** of the ONU for port 1/1. Port 1/1 was the port you use in GEPON port of OLT. If you use the second port, then you need to interface the **mac-address** of the ONU in port 1/2. After that, use the **bind onuid** command to bind the ONU with the mac-address. The OLT cannot manage the ONU until you bind the ONU to a logical port. The command was shown in 8.1.1 in the manual.

```
mac-addr static mac 00:1a:69:00:3b:a3 port 1/1 vlan 2
mac-addr static mac 00:1a:69:00:3c:46 port 1/1 vlan 2
```

Figure A.13: Interface the MAC address for the port

```
bind onuid 1 mac-address 00:1a:69:00:3b:a3 type m3-0420p
bind onuid 2 mac-address 00:1a:69:00:3c:46 type m3-0420p
```

Figure A.14: Binding the ONU to a logical port

Step 7:

Use the **admin-ip** command to specify the admin ip of ONU in manual mode. The command was shown in 8.1.6.1 of command manual. Here the admin ip of ONU was set to 10.10.10.90, subnet mask to 255.255.0.0 and the gateway to 10.10.10.254.

```
OPLINK(config)# interface onu 1/1:2
  %Enter configuration commands.End with Ctrl+Z or command "exit" & "end"
OPLINK(config-if-onu-1/1:2)#admin-ip manual 10.10.10.90 255.255.0.0 10.10.10.254 2
OPLINK(config-if-onu-1/1:2)#show admin-ip
Ip address           : 10.10.10.90
Net Mask             : 255.255.0.0
Gateway              : 10.10.10.254
Vlan Id              : 2
OPLINK(config-if-onu-1/1:2)#exit
```

Figure A.15: Setting the ONU admin-ip

Step 8:

Use the **inband ip-address** command to configure inband management port which was the Uplink GE optical port of OLT. The command was shown in 18.2.1 in the manual. Here, the inband ip address was set to 10.10.10.254, subnet mask to 255.255.0.0. Lastly, remember to save the configuration. Use the **end** command in 1.1.6 of the manual to exit to the enable view, then using the **write** command in 2.2.7 of the manual to save the current configuration.

```
OPLINK(config)# vlan 2
OPLINK(config-vlan-2)#inband ip-address 10.10.10.254 255.255.0.0
OPLINK(config-vlan-2)#exit
OPLINK(config)# show inband-info
  VLAN interface        : 2
  IP address            : 10.10.10.254
  IP netmask            : 255.255.0.0
```

Figure A.16: Configure the Uplink port of OLT

```
OPLINK(config)# end
OPLINK# write
  This will save the configuration to the flash memory.
  Are you sure?(y/n) y
  Building configuration.....
  [Success]
```

Figure A.17: Save the configuration

<u>Step 9</u>:

Disconnect the concole port of the OLT and use an ethernet cable to connect the Uplink GE optical port of OLT which shown in Figure A.18 and the Ethernet port of server computer.

Figure A.18: Unplug the console port and connect the uplink port using Ethernet cable

Figure A.19: OTDR

Figure A.20: Multi-function loss tester

Figure A.21: PPM 350-C PON OPM

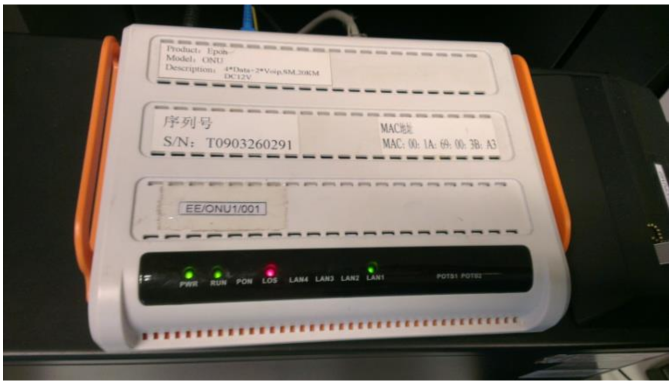

Figure A.22: ONU

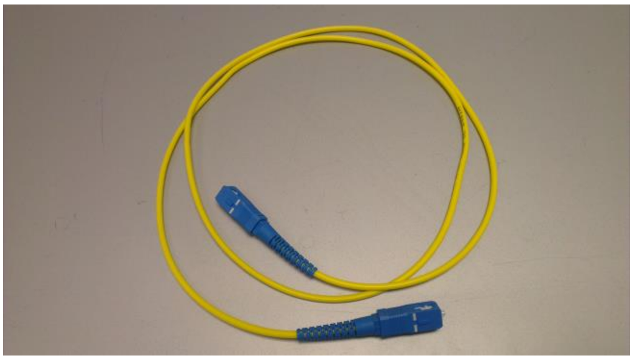

Figure A.23: Optical fiber cable

Figure A.24: Optical fiber spool

Figure A.25: Camera 2.0 (just plug and play)