Performance of Fiber Optic Modulation Scheme on Fiber-To-The-Home Networks

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Abstract - Optical fiber, a wired network which provides wonderful speed on information transmission, has got its popularity due to the new technologies which minimize costs to users. Passive Optical Network (PON)-based Fiber-To-The-Home (FTTH) is a common network architecture which provides communication services to the home or premises, with low cost compare to Active Optical Network. The challenge for this technology is on the modulation scheme to be used which will satisfy both users and service providers. The PON systems such as EPON, GPON and G-EPON used TDM scheme which transmits signals at low speed, but less expensive to install. The new scheme WDM seem to be ideal to users, however, its devices are still very expensive, hence the service providers hesitate to move to this technology. Finally the simulation results of Fiber Optic cable length from Central Office to the Home/Office premise shown that the wave dispersion turn to be critical as the distance exceeds the 100km.

Keyword: PON, FTTH, Fiber Optic,

1. INTRODUCTION

The superiority of fiber optic on sending a huge amount of data at high speed has led it to be extremely used by many organizations than any other alternative date transmission media. Optical fiber offers a high-quality and less loss of signals due to its attribute of transmitting data to a long distance without experiencing attenuation. In addition to that, fiber optic has more security and high performance. Due to its high capacity and cost-effective, many ISPs, large organization, and individual homes and offices have implemented fiber [1]. Fiber optic sends massive signals from one place to another in form of light and it is less susceptible to electromagnetic interference.

Although fiber optic systems are having a unique characteristic of sending massive data from one location to another, like any other communication systems, its signals must be encoded at the source and be decoded at the destination to convert carrier signal into user traffic signals[2].

Since the system uses lightwave carrier then signal encoding can be performed by either direct modulation or external modulation of the light source. This article will focus on the external modulation, the more current and improved [2][3]. This article focuses to explain a brief introduction of the optical fiber, factors affecting its performance, FTTH PON as an application of fiber optics and evaluation of the system.

2. INTRODUCTION TO FIBER OPTIC CABLE

The optical fiber is made up of glass or plastic material strand which transmit data in form of light. Optical fiber use "total internal reflection" which contains the light signal within the core of the cable, acting as a guide to direct the signal to the destination with little to no signal loss [1].

The optic cable comprises two sections, core section, and the cladding. The signals are transmitted through the core of the cable. The cladding is used to protect the core from the external interferences and to provide an internal reflective boundary to keep signals contained within the core. [1].

The core region maintains the low-optical-loss properties for the propagation of the optical energy. The higher the refractive index, the slower optical energy propagates [6].

2.1 Types of optical Fiber

According to [3], there are three major types of optical fiber cables. These are Single-mode step index, multi-mode step index, and Graded-index fiber.

Single mode step index, in this type only the central ray can propagate in the core. It is more resistant to attenuation and transmits a large bandwidth compare to multimode fiber, hence suitable for long distance communication.

Multi-mode fiber optic has much larger core diameter and is, therefore, easier to splice and to couple segments together with lower loss. However, it is highly susceptible to multi-path dispersion, which in single mode there is no dispersion problem. Due to that drawback, the multimode fiber is only suitable for a short distance [3].

Graded index fiber differs from the two above, that its refractive index of the core is not constant but rather variable.

2.2 Factors Affecting Optical Fiber Network Performance

Apart from the modulations scheme, there are other major factors which affect the performance of the fiber optic. These are; attenuation, linear and nonlinear scattering, dispersion, and bend loss [8].

When signals are sent along the cable, they become weak due to the distance and effect of external factors against the cable. Attenuation can be determined by comparing two levels of power, the ratio of the input (transmitted) optical power, Pi, into output (received) optical power, Po. Attenuation is measured by decibel per unit length, dB/km-1. Number of decibel, dB = 10log10 (Pi/Po) [8]. In addition to that, the [9] remind us that, total attenuation can be determined by adding all leakages caused by connectors and splices along the cable.

Example given Pi = 150µW and Po = 3µW, determine the overall attenuation on the distance of 8km, assuming there is no connectors or splices. Therefore dB = 10log10(150/3) =

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10xlog1050 = 16.98dB. For each kilometre, then it will be 16.98dB/8km = 2.12dbkm-1.

Linear losses and nonlinear scattering; the scattering attenuation occurs when the transmitted power in the core loose direction and move out of the core. This is caused by leakage or radiation mode which does not continue to propagate within the fiber optical core.

Optical fiber signals also suffer radiation loss on a bend or curve of a cable, this is because the energy required to transmit signal at the bend is higher than the velocity of light in the cladding, therefore, the light radiated at this point.

The dispersion of transmitted optical signals leads to the distortion of the signal. The dispersion causes the pulses to broaden when they are transmitted along the channel. When these pulses broaden overlap and become indistinguishable at the receiver input. This effect is known as Inter-Symbol Interface (ISI) [9].

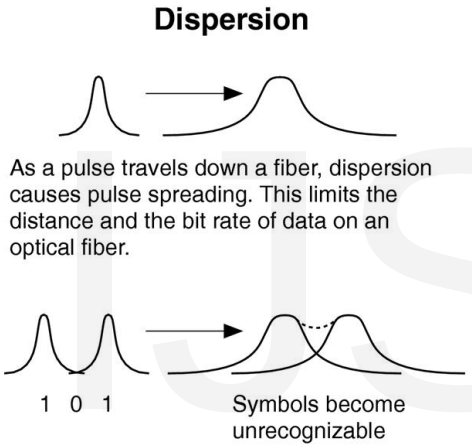

FIGURE: 1 Pulse Dispersion (Source [10])

2.3 Connectors and Splicing

Optical fiber is much speed on transmitting information and considered to be cheaper in terms of cost per distance. Many people rush to install this type of cable in their networks in order to have a robustness network. However, the cable installation is very difficult and needs much care in order to minimize data loss on the connectors. In addition, the connectors and equipment required to install this type of cable are expensive compared to those required by copper cables [2] & [10].

3. INTRODUCTION TO THE FTTH

Fiber to the home (FTTH) (or FTTP = fiber to the premises) means providing broadband data connections (e.g. for Internet access, telephony, and video on demand, sometimes combined to triple-play services) to private households and small offices directly with optical fibers [13].

There are two types of FTTH; these are Active Optical Network (AON) and Passive Optical Networks (PON). Active optical systems comprise the electrically powered equipment, such as a router or a switch aggregator, for signal distribution direct to specific subscribers. The switch enables to direct the incoming and outgoing signals to the intended destination. In such a system, a subscriber may have a dedicated fiber running to his or her house, and have a full assigned bandwidth since there is no channel sharing [4].

On the other hand, Passive Optic Networks do not use a powered switch on the FTTH core network rather they use passive splitters to distribute signals to the subscribers. The other characteristic of the PON is that the data rate on the uplink is smaller than downlink. Example the GPON technology has 1.5Gbps uplink and 2.5Gbps downlink [5]

3.1 PON vs. AON

The difference between these two technologies depends on the system architecture and devices included.

According to [5], PON uses Optical Line Terminator (OLT) at the communication company office, and Optical Network Units (ONUs) to connect to the end user. For AON the Access Node is used at the communication company office and Optical Network terminators are used to connecting end users directly from the Access Node [5].

PON uses devices such repeaters and or optical splitters which do not need electrical power to separate and collect optical signals. On this system, the subscribers or customers share the fiber optic cable and bandwidth, when Time Division Multiplexing used [4]. Fiber optic is designed to carry a maximum bandwidth of 2.5/1.5Gbps downlink/uplink on tradition PON like GPON. Typically the traditional PON has two splitting standards, one split into 32 subscribers, known as 1:32; and the other to split into 64 subscribers or 1:64. Due to this limitation and that of sharing bandwidth from the OLT then each subscriber can have a bandwidth of 78Mbps in the case of 1:32 and 39Mbps for 1:64 [5]. However a new technology of Wavelength Division Multiplexing (WDM) has changed the PON to logical act as an AON, i.e. there is no bandwidth sharing to subscribers or customers.

The AON uses routers and switches to distribute and direct signals to the specific subscriber. According to [5], each subscriber has their own dedicated line that terminates on an Access Node (AN). Since the connection is from the central office (CO) direct to the access node, then the subscriber can be assigned with a large amount of bandwidth, typically from 100Mbps to 1Gbps can be implemented to the subscriber.

3.2 FTTH PON architecture

PON is less expensive compared to the AON since the components included are passive. It is also reliable and less susceptible to failure.

The components included here in the core network are Optical Line Termination (OLT), Passive Optical splitter and Optical Network Termination (ONT) or Optical Network

Unit (ONU). The OLT is a connector between the Central office and the optical splitter. Passive optical splitter is fixed to the outdoor cabinet in a collocation room or in the end subscriber's premises. The optical splitter is a passive multiplexer which multiplies the signal on the fiber optics into subscriber branches.

The ONT or sometime ONU, this is the device that terminates the optical signals from the CO to the subscriber and converts into one or more electrical interfaces depend on the technology used by the subscriber, like 100BaseTx, POTS, ISDN or Coax. If the fiber optic is ending to the optical splitter and then the copper cable is used to terminate to the user, then the Optical Network Unit (ONU) is used instead of ONT [5][11].

All PON subscribers receive the same optical from the CO, and the personal allocation of data is carried out via a time multiplex procedure, i.e. each subscriber receives their own time slot to transmit and receive data. The ONT is the device which provides this time slot, so the subscriber will send data and when arriving at the ONT, will be given time to be transmitted into the optical channel [5].

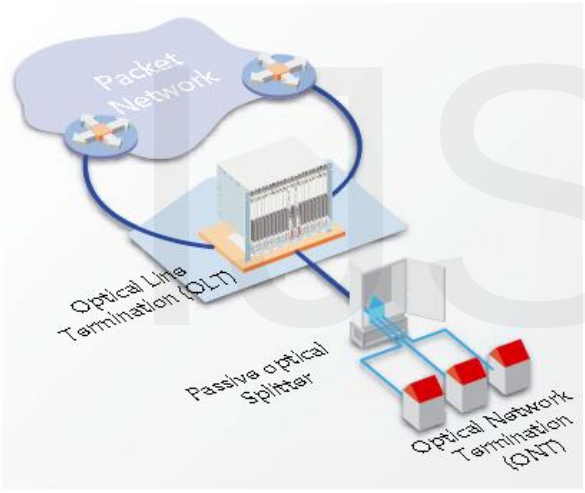

Figure 2. FTTH through PON architecture (source [5])

3.3 Types of PON

The existing today PON technologies are Ethernet PON (EPON), Gigabit PON (GPON) or Gigabit Ethernet PON (GEPON). The EPON has become popular in the Far East and GPON more in the USA and Europe. The discussion on this article will base on the GPON (ITU standard G.984).

3.4 PON bandwidth

The bandwidth of a fiber depends on the fiber length. If there is a long distance of transmission, optic fiber will face the dispersions of the pulse (see Figure 1 in this article). For the long distances, a single multimode cable is recommended to be in the core network, while for short distances i.e. within hundreds of meters a multimode fiber which is cheaper can be installed. Currently, the single mode fiber systems transmit 2.5Gbps or 10Bbps per data channel over 10 kilometres or more depends on the technology used [12].

For GPON's current standard allows a bandwidth of 2.5Gbps downstream and 1.5Gbps upstream per PON interface on the OLT interface. There are two standards of OLT interface, one with 32 subscribers and other with 64 subscribers. Here the distribution of bandwidth will be 78Mbps for 32-interface standard and 39Mbps for 64-interface standard. [5]. The bandwidth is satisfactory to home users, however the IT industries or large organization will need more bandwidth, so the PON current technology may not fit them rather they can use AON which dedicate the service directly from the CO to the premise a bandwidth range from 100Mbps to 1Gbps per subscriber.

The Wavelength Division Multiplexing technology has proved the PON bandwidth to the users from 100Mbps to 1Gbps. The WDM technology is further discussed in the modulation schemes section.

4. WHAT IS MODULATION?

Modulation in a simple definition is the process of converting the user's information signals into the form acceptable to the channel for transmission. Along the channel, signals tend to experience some distortion, therefore the receiver will need to reconstruct carrier signal into original, to get meaningful information; the action is called demodulation. However the distortion and degradation of the signal on the channel can be much to the extent that the receiver can fail to reconstruct the original information, therefore many efforts are done on the selection of best modulation techniques to reduce errors on the transmitted signals [3].

According to [6], we need modulation in fiber optic on prior to transmission in order to preserve optical power and maintaining the desired SNR; to formulate suitable path direction for multiplex and to convert the signal for compatibility with the channel, section or photonics-layer interfaces.

Fiber optic cable functions as a light guide, from the source modulation to the receiver demodulation devices. The cable transmits signals in form of pulses on and off which then at the receiver, the demodulation process must be done to convert these pulses into bits of 1 and 0s [2 & 4].

There are two classes of modulation process: continuous wave modulation and pulse modulation. Continuous wave modulation is further divided into three major groups, i.e. Amplitude Modulation, Frequency Modulation and Phase Modulation. [3]

4.1 Modulation schemes

The efficiency of a fiber optic depends on many factors, including installation process, the modulation scheme used, link budget (delay, jitter etc). Attenuation is the most important issue which is considered when designing the fiber optic network and electrical cables. However any

network can be designed to minimize attenuation but in additional expenses such as increased cost of the cable, and modulation and demodulation elements [7].

4.2 Modulation scheme used in PON

There are various techniques used in fiber optics technologies, especially FTTH PON. However, this article will discuss only TDM and WDM. In addition to that, the WDM PON is used here as a mode of evaluating the system. This is because the technique is still hot to many researchers and its performance is more interest comparing to traditional techniques applied before to the FTTH-PON.

4.3 Time Division Multiplexing

This is the technique used in fiber optic modulation, which combines the lower capacity channels into one high capacity channel. The subscribers in the PON FTTH are sending data to the multiplexer, then the multiplexer gives a slot of time to each coming channel to send its data into the single fiber strand. The same procedure is done on the downstream, whereby the multiplexer separates the optical signals to the different small channel specifically to the ONU or ONT device which connects the user. The ONT converts the optical signals into electric ON and OFF for sending to the subscribers' machine [6].

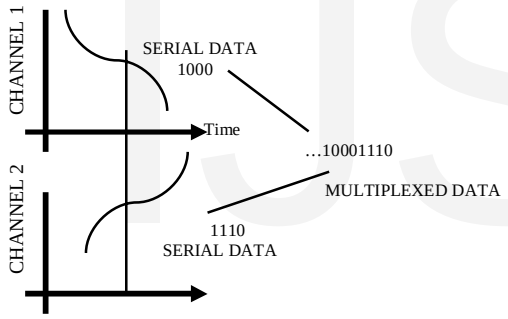

Figure 3 — Time-division Multiplexing (Source [14])

Once the analog information has been put into a digital form, the digital channels are time-division multiplexed (TDM) and sent to the laser transmitter. The digital signal is converted into light pulses; the laser is on for a "1" and off for a "0."

Passive optical networks (PON) the most technology used for FTTH, has been using the Time division multiplexing (TDM) for systems such as Ethernet PON (EPON) and Gigabit PON (GPON). However, the TDM has a limit of the bandwidth of 1.25 Gbit/s and 2.5 bit/s for EPON and GPON, respectively [15].

4.4 Wavelength Division Multiplexing (WDM)

The optical fiber concept has been around for more than a century. However, the experiments done by John Tyndall on the guided transmission light, through the development of light-emitting diodes and lasers, and the emergence of dense wavelength-division multiplexing (DWDM), contributed the growth of applications of optical fiber technology [14].

The TDM has a disadvantage of small bandwidth allowed to the transmission of data into a stream. WDM solves the problem by giving high capacity. Although WDM is physically similar to the TDM, logically it is a point to point scheme. The ONT on WDM-PON has a dedicated wavelength and there is no time sharing of bandwidth. The limit to the bandwidth that the user can receive depends on what the wavelength can carry. WDM PON has an arrayed waveguide grating (AWG) which routes each wavelength to its destination ONT, this replaces the splitter function on TDM-PON. Unlike TDM PON system, a subscriber gets only the information destined for it [17].

According to [16], we can categorize the WDM into three groups of function, Metro/Region WDM system, Long haul Dense WDM and Access WDM systems.

Long haul technology used to bridge long distances between the central offices in two major cities. The long haul employs high-performance optical components to enable reach to have a large wavelength, to utilize high-performance powered optical amplifiers and typically are regarded to 10G, 40G and 100G wavelength transport.

For Metro/Region system the WDM uses ON and OFF ramps for the backbone long-haul networks to terminate traffic in metro core networks. The metro/region WDM also employ the optical modulation schemes borrowed from long haul, but with a small bandwidth of 2.5 to 10Gbps.

According to the study made by [15] in Taiwan shows that there is a challenge in the WDM PON on the transmitter at the ONU located in the customer premises which must have a wavelength that is aligned with a specific allocated WDM grid wavelength. "Although the carrier distributed WDM PONs have many attractive features, a key issue that need to be addressed is how best to control the impairments that can arise from the optical beat noise induced by back-reflections and Rayleigh backscattering (RB) of the optical carrier at the upstream Rx at the head-end office" [15].

However, the Automatic Base Wavelength Locking feature offered by the Ethernet WDM PON nowadays seems to some extent solve the problem above. Here an un-modulated Broadband Light Source (BLS) located at the OLT in the central office, is used to generate the sending signals for "locking" the wavelengths of the remotely located ONU. The BLS is sent downstream to the passive remote node containing the passive wavelength filter. Then the BLS wavelength spectrum is sliced into small narrowband Dense WDM (DWDM) channels by de-multiplexer. Then each spliced spectrum is sent through a single distribution fiber and injected to the ONT equipped with Laser Diodes. When the LD current is modulated with the electrical data signal, the injected seed signal forces the laser to operate in a narrow wavelength range.

Moreover, without the locking technique, the LD lasers operate at a multiple wavelength which can be affected by the DWDM and wavelength filtering routers and hence

generate the mode transmission noise. The locking technique simplifies the installation process of the PON, whereby the operator simply connects the fiber to the PON unit and to the outside the plant fiber [16].

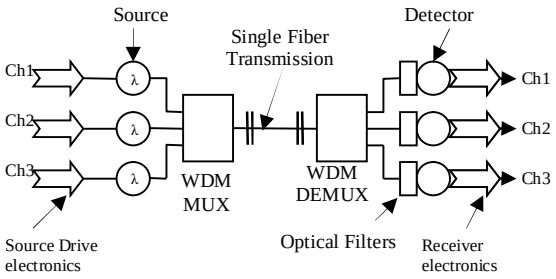

Figure 4: WDM (Source [6])

In the figure above [6], shows that multiple wavelengths from different sources are combined together by the multiplexer and be transmitted in a single transmission fiber. On the other side, the optical carriers are separated spatially and coupled into separate receiving fibers. Once fiber carriers are separated then they are detected by the photodetectors designed for wavelength operation. Then individual receiver process the individual transmission channel [6]. This is similar to our case, however the on the FTTH the sender side act as a single wavelength that is CO, which uses OLT to process the multiplexing.

4.5 Wave dispersion per distance

When the dispersion of the pulses becomes higher it leads to the distortion of information received at destination. Many researchers have been trying to design dispersion decreasing systems to counterbalance the decreasing of fiber nonlinearity. [18] Shows that the rising idea of Novel of dispersion compensation stopped the researchers to continue trying to design the dispersion decreasing fiber system. However, the difficulty of formulating such type of fiber has also made the idea not to become a reality.

It is well known that the higher the magnitude of the average dispersion, the higher the energy of stationary pulses. Due to that reason, there is a need to design the networks which will minimize the dispersion effect. Here the issue of link budgeting should be considered during the designing of fiber devices and during the system installation.

5. METHODOLOGY

In this article we measure the performance of the single mode fiber optic cable to find its capacity of data transmission from CO to the home or office premises. The MATLAB simulation application was used to measure the level of dispersion in several lengths. The parameters used to determine the Full Width Half Maximum (FWHM) of fiber optic cable were 0 kilometers, 100 kilometers and 200 kilometers. The aim was to find out the recommended length of a cable in which the signal in transmission will tolerate the dispersion and clearly arrive at the destination.

6. PERFORMANCE EVALUATION OF OPTICAL FIBER

The following are the results of the simulation done through MATLAB, to measure the pulse dispersion on different lengths of a single mode fiber optic.

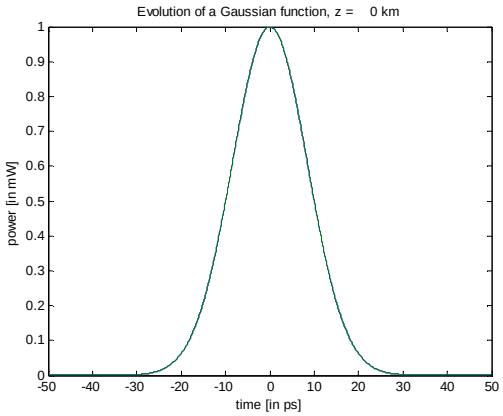

Figure 5a: Gaussian graph when distance is 0km

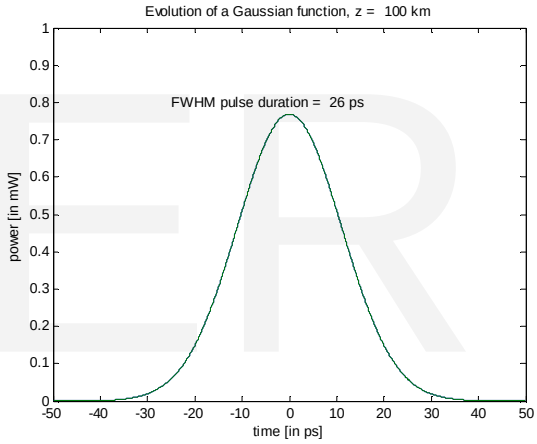

Figure 5b: Gaussian graph when the distance is 100km.

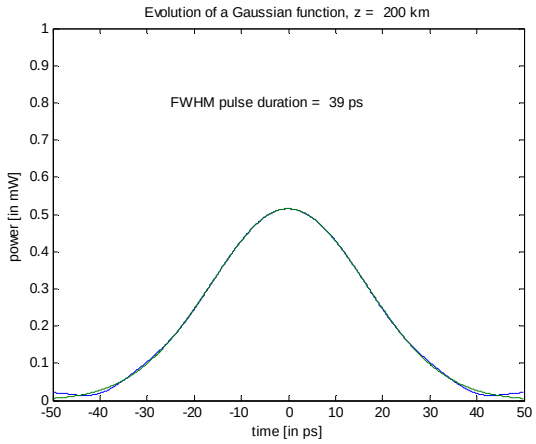

Figure 5c: Gaussian graph when the distance is 200km.

The above three Gaussian graphs are the results of the simulation taken through MATLAB, which measure the performance of the cable from the CO to the subscriber. The

results reveal that the longer the distance the higher pulses dispersion. This can cause undistinguishable pulses at the other end. According to the results obtained, it has been revealed that the distance between the CO and home or office premise should be from 0km to 100km for the better signal transmission. It is also found that when the 200km length used as a perimeter in this measurement, the Gaussian curve was scattered. This shows that the level of dispersion is high. The pulse dispersion in the Gaussian graphs above is measured by Full-Width Half Maximum (FWHM).

6.1 Quality of services for the FTTH-PON system

Today FTTH is used to provide triple play service (telephony, data, and TV down one single line), so the Quality of service is needed than it was before [5]. Here we look at the system scalability, bandwidth, cost issues and standardization.

Bandwidth: As discussed earlier in this article that the WDM PON logically points to point architecture, so it provides individual bandwidth to each customer contrary to the TDM which all customers of a single stream share the bandwidth. With WDM PON can provide a bandwidth from 100Mbps per subscriber [17].

Scalability: WDM PON is flexible to that the service providers can easily deploy and integrate multiple services to a subscriber. WDM PON also can allow convergence and different networks can be collapsed on to the same infrastructure. The bandwidth upgrade can be done easily as each ONT is dedicated to its own wavelength. In addition, unlike tradition PON which has a limit of 32 to 64 subscribers per fiber, with WDM PON service provider can subscribe many customers per one fiber deployment with high bandwidth [17].

6.2 Challenges of the system

All other tradition PONs are standardized and they can share the devices. However, for WDM, there is a problem of standardization and interoperability to other technologies. In order to employ the WDM, you need to have WDM devices which are very expensive. Due to this problem, service providers hesitate to adopt the technology

WDM devices are still very expensive; [17] says that the WDM products are approximately three times expensive than those used by TDM scheme. However, the researchers continue to be done so as to lower down the cost.

Finally, since the WDM PON needs the replacement of the devices of the tradition PON, it will take longer to adopt the system because the service providers want to return the cost of the devices deployed for the existing PON technologies [17].

7. CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Although there are many communication technologies raised today, researchers are continuing to improve the optical fiber to perform at its best. This is due to its large bandwidth at a long distance at a speed of light. Despite the power losses and dispersion of the cable, the optical fiber is regarded to have high security and can not be affected by electromagnetic interferences.

The article discussed the overview of the optical fiber cable and Fiber To The Home (FTTH) PON system as the common application. In addition to that, the WDM modulation technique used to ensure the maximum performance of the PON was discussed here.

Finally, the simple simulation results are included, which shows that the longer the distance the waves travel they suffer on the dispersion of the pulses. Furthermore, the quality of service of the system was explained in the context of FTTH-PON based on WDM bandwidth, scalability, cost issues and technology standardization.

7.2 Recommendation

We recommend that for the successful PON the subscriber must be near the CO at most 100km. However, the power distributed to the source can be applied in order to sustain a long distance before experiencing the dispersion. Alternatively, the amplifiers can be used after every 100km.

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