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Quantifying Optical Link Loss of Fiber-to-the-Home Infrastructure

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Abstract

Fiber to the Home (FTTH) technology is among the most advanced broadband services, delivering voice, data, and television through a single optical fiber directly to customer premises, ensuring high-speed and reliable connectivity. The study conducted on Nepal Telecom's FTTH networks involved direct measurements from the optical line terminal to the fiber access point and optical network unit, providing detailed insights into network performance. Using the OptiSystem software, the analysis revealed a link loss of 24.99 dB, a Q-factor of 12.98, and a minimum Bit Error Rate (BER) of 7.31E-39, all within standard limits, which underscores the robustness of the network. The study also identified that the highest contributors to signal loss were connector loss, fiber attenuation, and fusion splices, emphasizing the importance of minimizing these factors to maintain optimal network performance. Overall, these findings highlight the critical aspects of FTTH network design and maintenance, ensuring that service providers can deliver high-quality broadband services to customers.

Keywords: *Transmit power, link loss, GPON, FTTH, Received power*.

1. INTRODUCTION

Nepal is a South Asian landlocked country and the history of internet connectivity in Nepal began with dial-up internet connections using telephone lines in 1995 with a maximum speed typically around 56 kbps before the advent of broadband Asymmetric Digital Subscriber Lines and FTTH technology for fixed line connectivity. Nepal has always kept pace with the rest of the globe by embracing new technology to counteract the rapidly evolving communication landscape. The first wave of FTTH technology was introduced to Nepal in the early 2010s, offering substantially faster internet speeds of 20 Mbps to 1000 Mbps and more bandwidth capacity than Asymmetric Digital Subscriber Line (ADSL) [1]. FTTH seems to be the best option for a long-term goal because it will be simpler to expand bandwidth if optical fibers serve all clients. For delivering internet services like video on demand, online gaming, High-Definition Television (HDTV), and Voice over Internet Protocol, FTTH offers a future-proof solution [2].

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Full-Service Access Network (FSAN) made PON, then it is standardized by the International Telecommunications Union- Telecommunication Standardization ITU-T or Institute of Electrical and Electronics Engineers (IEEE) [3]. Gigabit passive Optical Network (GPON) is a technology that was developed by ITU-T G.984. It uses optical fiber as a transmission medium. It uses Time Division Multiple Access (TDMA) in the upstream multiple access technique with a rate of 1.25 Gbps and downstream with a rate of 2.5 Gbps and with a physical reach of up to 20 km. The wavelength used for upstream and downstream transmission is 1310nm and 1550nm respectively. [3-5].

Quantifying the optical link loss of FTTH network infrastructure is important in Nepal due to the country's growing demand for high-speed internet access. This analysis helps to ensure the system meets the required data transmission speeds and that the signal quality is maintained over the distance for end users, in countries like Nepal, where terrain and geographic conditions can pose challenges to installation and maintenance of infrastructure, such analysis is particularly crucial. Additionally, such analysis ensures that the FTTH networks are installed following the requirements and standards of the ITU-T, which are essential for guaranteeing the reliability and quality of the networks.

2. THEORY

The main force behind developing new access technologies that allow for genuine broadband is the rise in demand for high-speed internet. FTTH uses optical fiber as a channel to transmit optical signals from the provider center to the user region. *Optical Line Terminal* (OLT) consists of several *Optical Distribution Networks* (ODN) that work for the transport and distribution of data from OLT to *Optical Network Unit* (ONU). The supporting component is the Passive Splitter, which distributes optical power to all branches. The optical link loss in optical fiber communication is the total loss through the optical network from the transmitter to the receiver end encountering different loss mechanisms such as coupling loss, fiber attenuation, splice losses, and connector losses [3]. The wavelength used for upstream and downstream is 1310nm and 1550nm.

2.1 OPTICAL LINK LOSS PARAMETER

Nepal Telecom has been using Class B+ GPON technology and loss parameters in the optical network are given in Figure 1. Transmitted power from OLT traveled along and encountered many losses in the network as Fiber loss, connector loss, Splice loss, and splitting loss, and available power at the receiver end is used to drive the user end device. The difference between the transmitted power and received power is the link loss in the network and given as the following formula [4, 5].

$$\alpha_{total} = L.\ \alpha_f + N_c.\ \alpha_C + N_s.\ \alpha_S + N_{sp}.\ \alpha_{sp}. \qquad (1)$$

$$\text{Rx Power} = \text{Tx Power} - \alpha_{total} \qquad (2)$$

where: α_{total} = total channel link loss (dB), L = optical fiber length (km), α_f = optical fiber attenuation (dB), N_c = number of connectors, α_c = connector loss (dB / connector), N_s = number of connections, α_s = splicing loss (dB / splice), N_{sp} = number of splitters, α_{sp} = Splitter loss (dB), Rx Power= Received power at ONU, and Tx Power= Transmit power at OLT.

2.1.1. Cable Losses: Cable length, material, and material purity are the main important factors that cause optical fiber cable loss. Typical values of optical fiber loss are given in dB/km and can vary several dB per kilometer. As per the ITU-T G652 recommendations, the fiber attenuation is 0.40dB per km [6].

2.1.2. Connector Losses: Optical fiber connectors are used to connect two sections of cable. When two sections of cables are connected it causes a loss in optical power and represents a loss in dB per connector used in a network. Connectors are used to connect the fiber with different optical components. As per ITU-T G671 recommendations, the maximum value of connector loss is 0.5dB per connector [6].

2.1.3. Splicing Loss: If two sections of cables are to be connected splicing is to be done to connect two sections of cables. The splicing of two cables is not perfect, which causes the loss to the system. A pe ITU-T G671 recommendations, a maximum value of fusion splicing is 0.3dB and 0.5 dB for mechanical splicing [7].

2.1.4. Splitting Loss: Two levels of splitters are used in the optical FTTH network to accommodate the maximum user capacity, primary splitting at the Fiber distribution center (FDC) and secondary splitting at the Fiber access point (FAP) nearby consumer center. In the GPON technology, Splitting is done up to 1:64 and can be extended up to 128 splitting levels. Splitting levels are used as 1:4, 1:8, 1:16, 1:32, 1:64, and 1:128. The splitting of 1:16 means single fiber power is distributed to 8 numbers of fibers and so on in PON technology, which supports the greater number of consumers to be connected in the networks. As per the ITU-T G671 recommendations, the maximum value of splitting loss is 14.1dB for a 1:16 splitter and so son [4]. The technical standard for the FTTH loss parameter is set by the ITU-T G Series recommendation as given in Table 1, which helps to calculate the link loss between the transmitter to receiver end and to compare the standard datasheet with the Observed value [6].

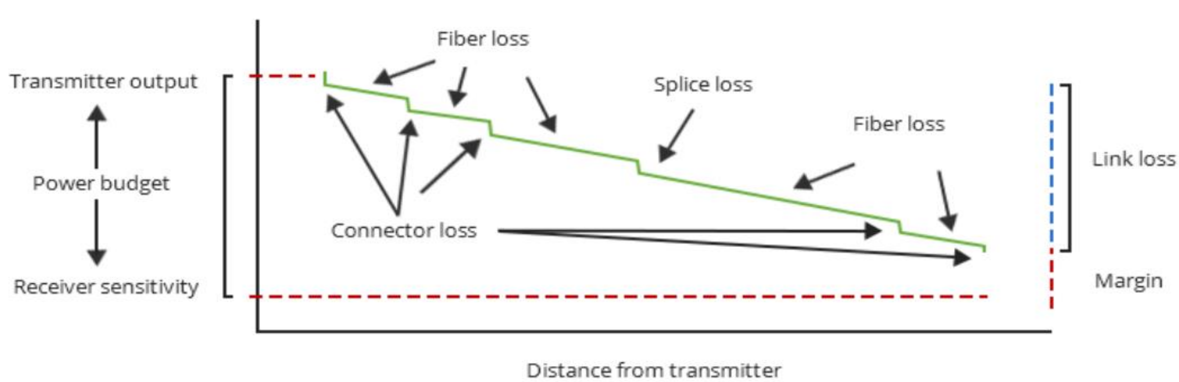


Figure 1: Optical link loss parameter

Table 1: Standard datasheet for loss parameter

Types of Loss→	Connector dB	Splice Fusion dB	Fiber Attenuation dB/km	Splitter Loss, dB				
	≤0.3dB	0.05	0.40	1:4	1:8	1:16	1:32	1:64
				7.4	10.6	14.1	17.5	20.9

2.1.5. Q-factor and Minimum BER: Quality factor (Q-factor) and minimum bit error rate (min. BER) are the performance parameters of the FTTH technology. Q-factor is a measure of the quality of a digital signal in an optical communication system. Q-factor is a function of the Bit Error Rate (BER), signal power, and noise power. The higher the Q-factor value, the better the quality of the signal, as a minimum BER value greater the quality signal, and better to have min. BER as possible as 0. The BER is defined as the fraction of transmitted data that is mistakenly decoded by the receiver, in other words, the BER is the ratio of bits received in error to the total number of bits received, which is a function of the system quality factor, Q and explained by the formula given in equation 1[8].

$$\text{BER}= \frac{\exp\left(-\frac{Q^2}{2}\right)}{Q\sqrt{2\pi}} \tag{3}$$

where; exp is exponential, Q is the Quality factor.

As per the ITU-T recommendations O.201, the Q-factor value should be at least 7.0, and the corresponding minimum BER in the range of 10^{-12}, means a 1-bit error in the 10^{12} bits of the transmission.

2.1.6. Power Loss Budget: The optical power loss budget in an optical fiber communication link is the allocation of available optical power among various loss-producing components such as splitting loss, fiber attenuation, splice losses, and connector losses, to ensure that adequate signal strength (optical power) is available at the receiver. As per *ITU-T* 984.2 Series recommendations, for Class B+ OLT network, the maximum value of link loss is a maximum value of 28 dB in the 1310nm wavelength range [5, 6].

2.2 FTTH Network Architecture

GPON is a specific implementation of PON technology that provides high-speed broadband services and it uses advanced modulation techniques and protocols to achieve higher data rates and greater efficiency compared to other PON implementations. In summary, GPON is a type of PON architecture, which encompasses various types of PON architecture [5]. The network architecture from OLT and its backbone network from where IPTV, Voice, and data services are integrated to transmit from OLT to downstream and vice versa. From OLT to the first layer at FDC, feeder fiber is drawn, and from there distribution fiber up to the second layer at FAP, further drop fiber connected to ONU [3].

FTTH network has different components and architecture as given in Figure 2, there is OLT as a core unit at the service provider’s office center and an optical network unit at the customer premises with primary and secondary splitters in between.

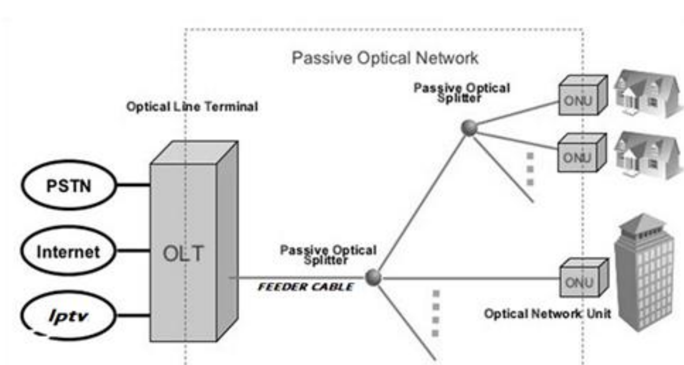


Figure 2: FTTH network architecture

3. METHODOLOGY

Link loss in the optical path is the main consideration for measuring the overall performance of the FTTH system. The following methods were used for the quantifying optical link loss of the FTTH infrastructure in Nepal.

3.1 Experimental Model

The link loss analysis is done with primary data collection from the site with direct measurement using an optical power meter and OTDR meter. The analysis of the link loss is based on parameters like connector loss, splitter loss, splicing loss, and fiber attenuation as per the length of the cable. All these loss parameters were measured with the use of an experimental model, from the direct measurement in the FTTH network from OLT to FAP and CPE as well. The FTTH Network Block diagram of the GPON-based technology under the study is given in Figure 3, which provides the testing tools set up to study the parameters variables that are to be measured in the analysis of the purpose of the study. FTTH Network block diagram consists of OLT and ODF inside the office house and they are connected with the patch chord cables.

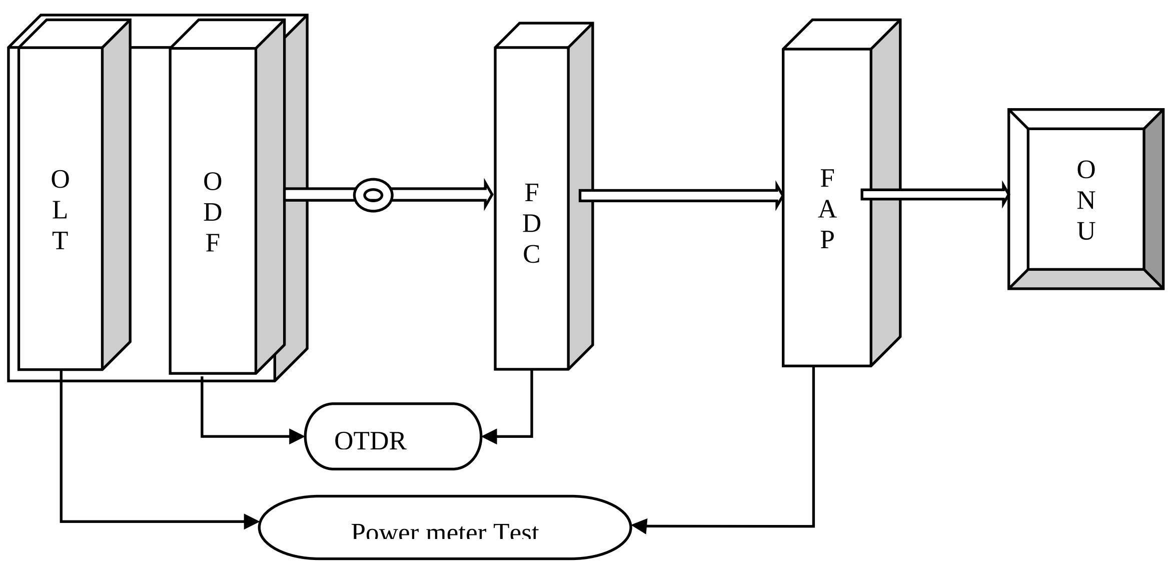


Figure 3: Experimental testing setup tools.

3.2 Software Model

The software model used is Optisystem software for the analysis of data, where input from collected data was given and loss parameters were analyzed. OptiSystem is a software tool for designing, simulating, and analyzing optical communication systems. It is a comprehensive software package that includes various tools for modeling and simulating optical components and systems, including fiber optic communication, optical networks, and photonic devices. It allows users to design and optimize optical communication systems by simulating the performance of the optical components such as lasers, modulators, amplifiers, and detectors as well as the performance of the fiber and channels. Different components of the FTTH network that are required from the Transmitter at the exchange core to the receiver end (ONU) with GUI components are selected on the optisystem design platform as shown in Figure 4 and it gives the output results with the BER analyzer and power meter tools that required for the loss pattern analysis of the network [2].

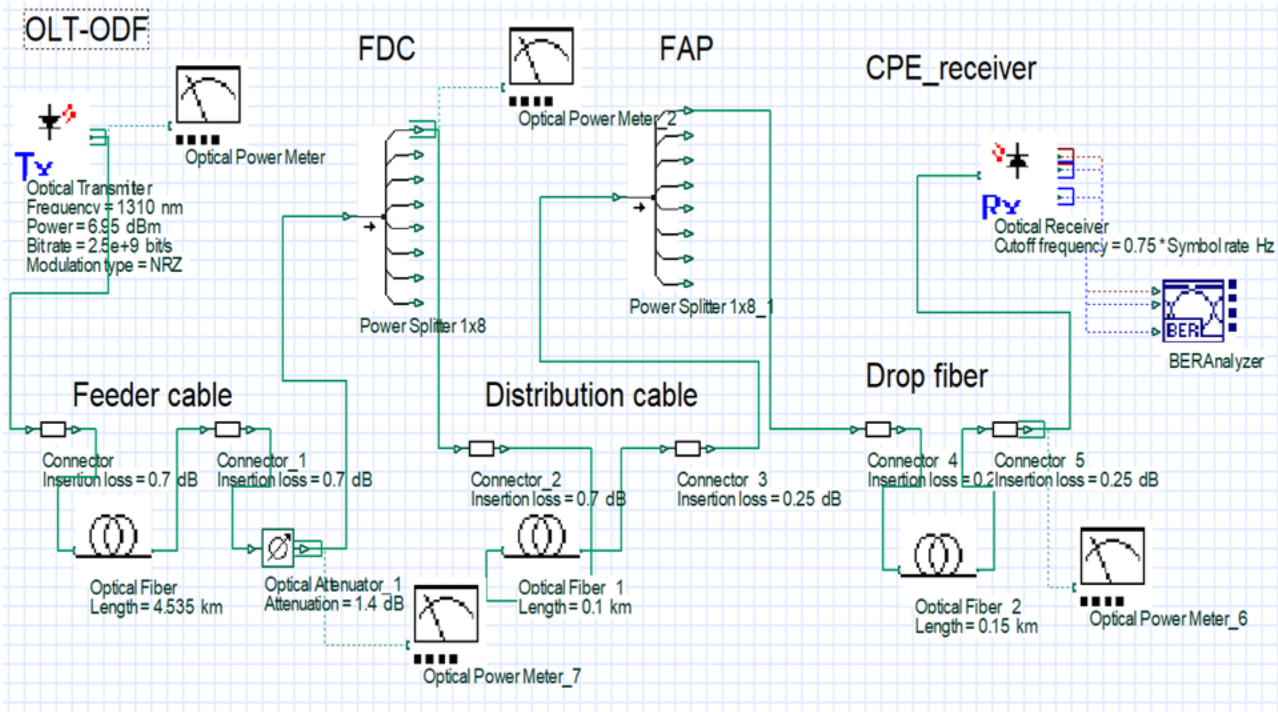


Figure 4: Optisystem software simulation model

4. RESULT AND ANALYSIS

The feeder fiber distance between the Office to FDC site of Budhanilkanth, Kathmandu, Nepal was found 4535m in OTDR, and 96/144 core single mode fiber is used as feeder cable and 12/24 core cable in ariel distribution cable from FDC to FAP and drop fiber used from FAP to ONU with different length of the fiber.

The simulation model design using Opti-system software is made according to the losses and distance from the OTDR and available transmit power in each section. Two different data, the standard theoretical value from ITU recommendations as well as experimental value observed during the field, as inputs were used in the Opti-system software platform and results for both conditions were analyzed. BER analyzer tools give the minimum BER value pattern, eye diagram, and Q-factor of the respective input pattern. Power meter tools give the power available at the different sections, resulting in power loss appearing in each section of transmission networks.

The eye diagram for experimental value and the theoretical value is shown in Figure 5, Figure 6, Figure 7, and Figure 8, where there seems almost clear eye opening in both cases, however, a little bit of disturbance is seen in the observed value, which indicates as power loss increase signal quality decreases.

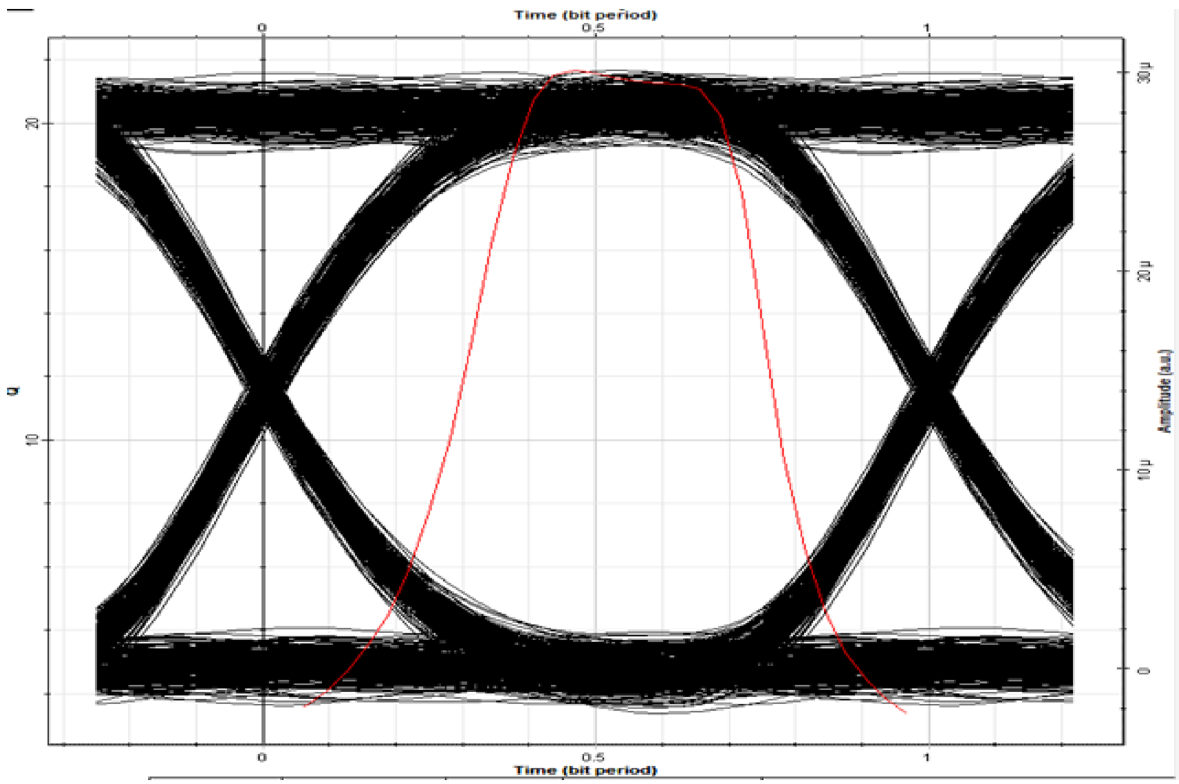


Figure 5: Theoretical value eye diagram at 4590m

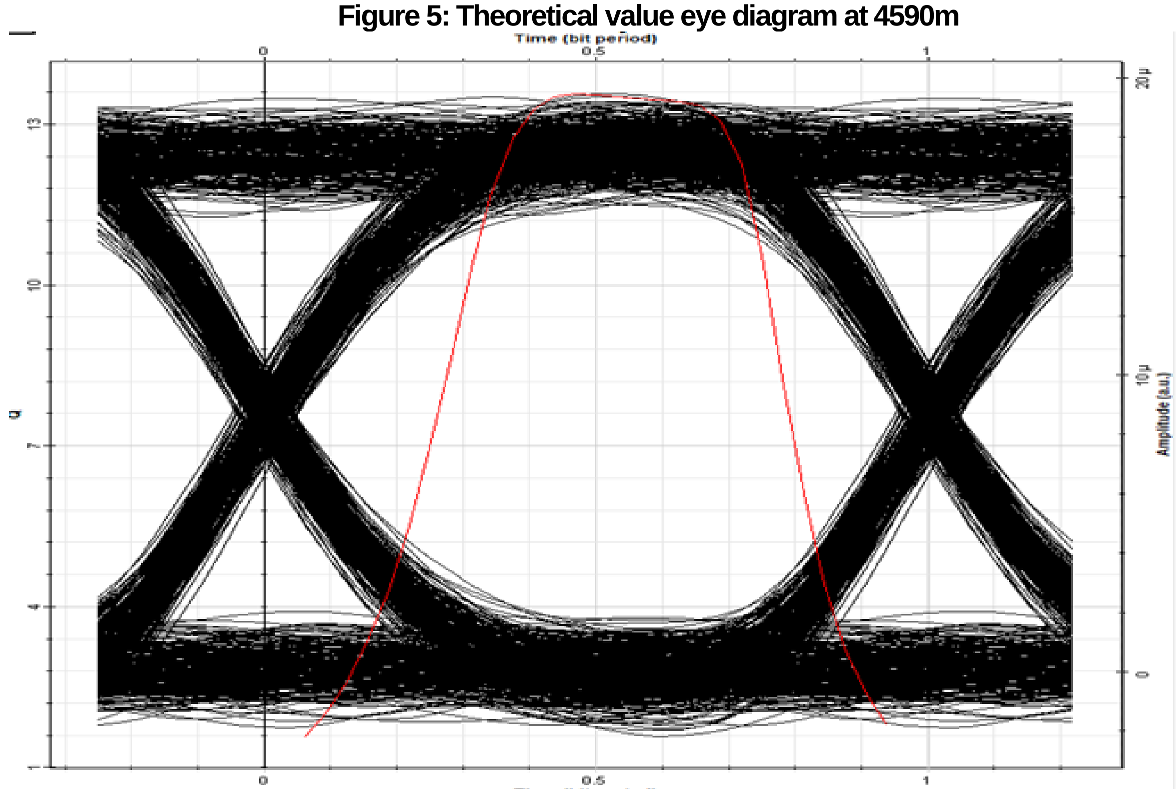


Figure 6: Observed value eye diagram at 4590m

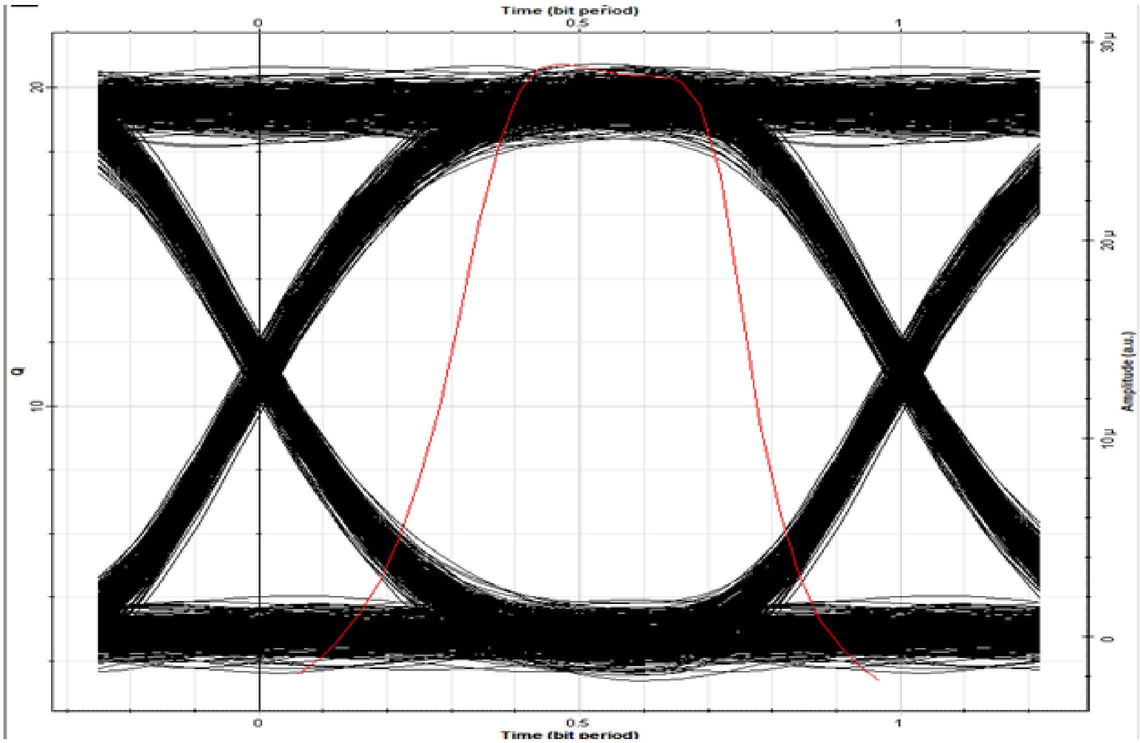


Figure 7: Theoretical value eye diagram at 5185m

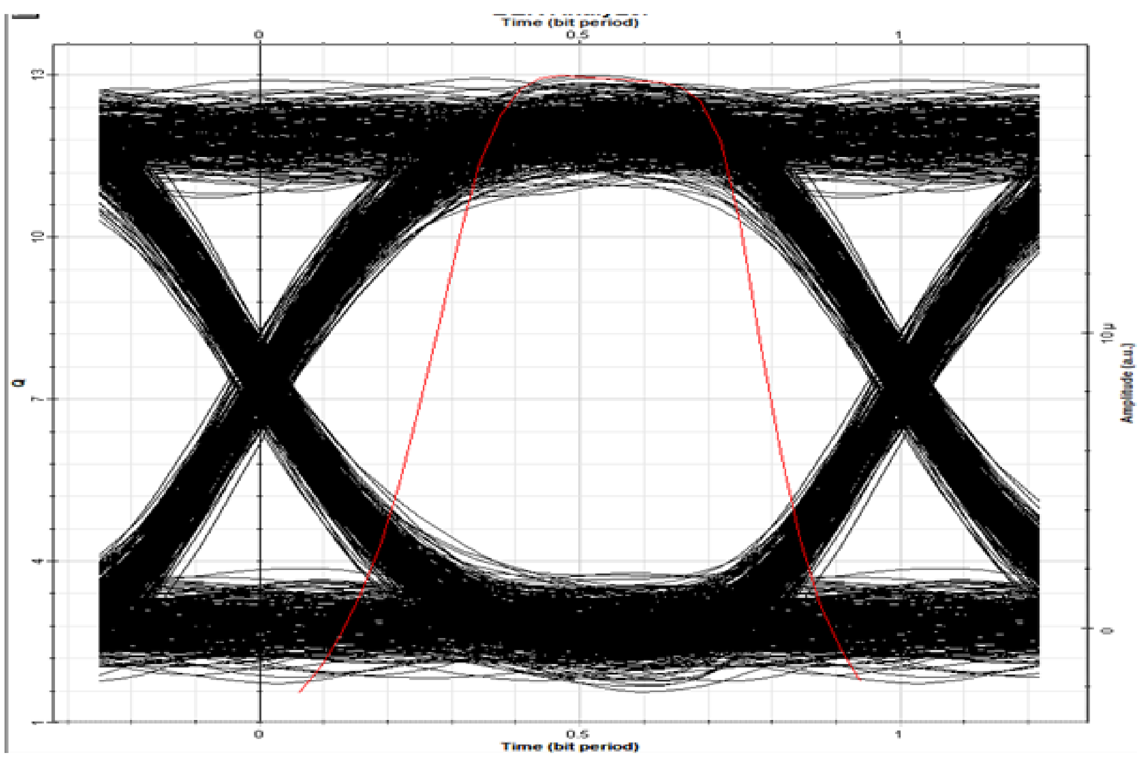


Figure 8: Observed value eye diagram at 5185m

The power meter tools result is shown in Figure 9, the theoretical power loss is 22.65 dB, and the observed power loss is 24.99dB for the length of 5185m length. As distance increases power losses also increase, however, this loss seems within the standard limit value. Q-factor obtained from the BER analyzer tools as shown in Figure 10, theoretical value and observed value were found 20.74 and 12.98 respectively for the end distance of 5185m, which are within the standard limit value and indicates Q-factor decreases with an increase in loss value. Minimum BER obtained from the BER analyzer tools as shown in Figure 11, theoretical value and observed value were found 6.5E-96 and 7.31E-39ob respectively for the end distance of 5185m, which are within the standard limit value and it indicates the minimum BER high as power loss value high.

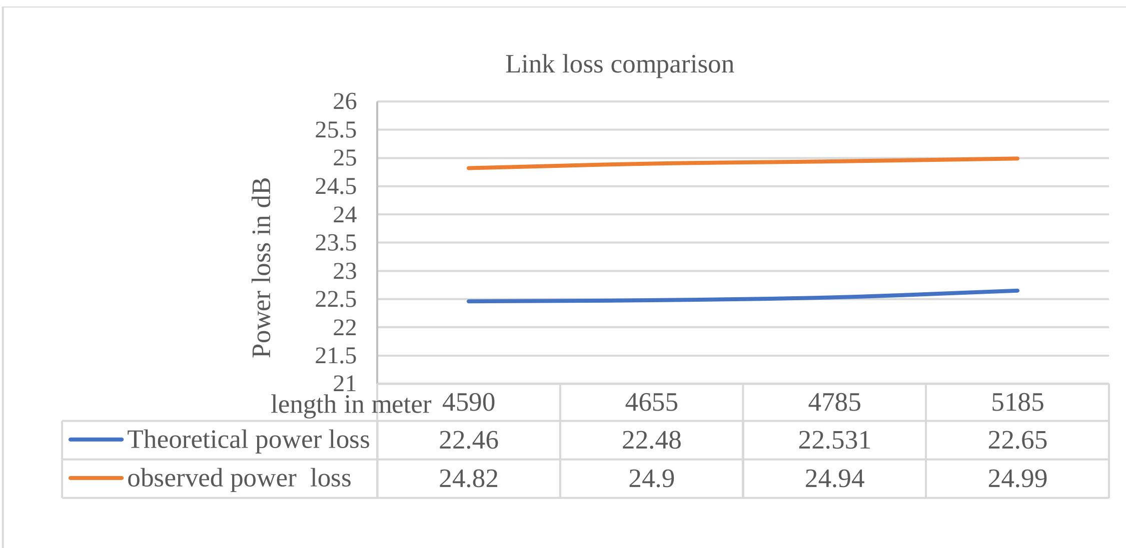


Figure 9: Power loss comparison

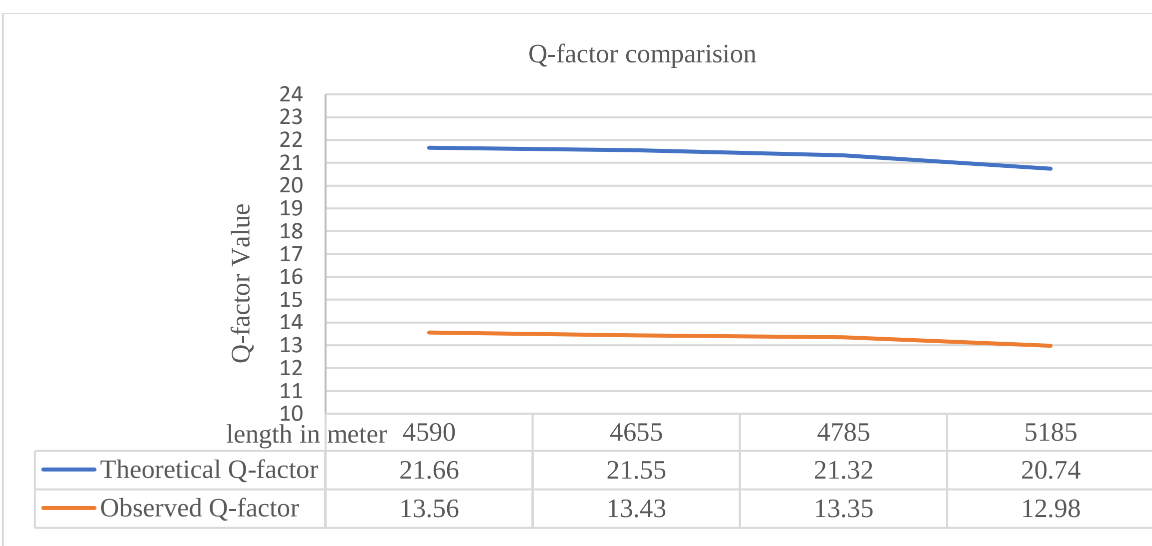
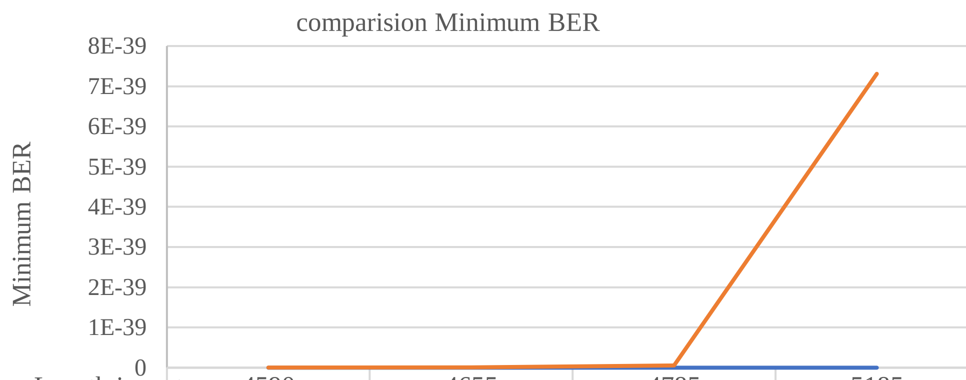


Figure 10: Q-factor comparison



Length in meter	4590	4655	4785	5185
Theoretical Min.BER	2.28E-104	2.61E-103	3.01E-101	6.50E-96
Observed Min. BER	3.3E-42	8.65E-42	5.64E-41	7.31E-39

Figure 11: Minimum BER comparison

5. CONCLUSIONS

Though GPON-based FTTH has a potential physical reach of up to 20 km, the study focused on a shorter 5185-meter distance between FTTH network points. At this observed distance, the network successfully met the ITU-T standards for optical power loss, received power, Q-factor, and minimum BER, confirming the network's compliance with industry benchmarks. Specifically, the study recorded a link loss power of 24.99 dB, a Q-factor of 12.98, and a minimum BER of 7.31E-39, all within acceptable limits. The analysis identified that the primary contributors to signal loss were connector loss, fiber attenuation, and fusion splices, highlighting the importance of minimizing these factors to optimize network performance. Consequently, careful planning, meticulous design, high-quality workmanship during installation, and routine maintenance are essential for ensuring the reliable operation and high-quality performance of FTTH networks. Emphasizing these aspects will help maintain the integrity of the network over time and ensure consistent service delivery to customers.

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