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PLANNING AND EVALUATION OF FTTB NETWORK USING THE GPON METHOD AT THE MEDAN STATE POLYTECHNIC

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Abstract

This research examines the design of a Fiber to the Building (FTTB) network based on Gigabit Passive Optical Network (GPON) technology using OptiSystem and Google Earth Pro. The network design and simulation were conducted for the Civil Engineering Department Building and the Telecommunication Laboratory Building at Politeknik Negeri Medan. Network performance was evaluated based on received optical power, attenuation, Bit Error Rate (BER), and Q-Factor. The simulation results show that the received optical power ranged from −19 dBm to −21 dBm. The total attenuation from the OLT to ONT1 through ODP1 was 22.601 dB, while the attenuation from the OLT to ONT2 through ODP2 was 21.588 dB. Both values were below the maximum optical loss budget of 28 dB used for GPON Class B+ evaluation. The obtained BER values ranged from 10^{-37} to 10^{-26}, which were significantly lower than the feasibility criterion of 10^{-9}. The Q-Factor values were also higher than the minimum criterion of 6. Based on the analysis, the designed FTTB network provides good signal quality and meets the technical feasibility criteria used in this study.

Keywords : Attenuation, Bit Error Rate; Q-Factor

INTRODUCTION

The development of information and communication technology has increased the need for networks capable of providing large capacity, high data transfer speeds, stable connections, and low latency. Various administrative, learning, research, computer-based examination, video conferencing, and internet-based activities have made communication networks an essential infrastructure in higher education institutions. Fiber-optic infrastructure is needed to support digital transformation because it provides greater and more stable transmission capacity for interbuilding connections than copper-based transmission media over relatively long distances (Insani & Alijoyo, 2024; Izza, 2024).

The need for reliable network connections became increasingly evident during the COVID-19 pandemic, when many educational, work, and communication activities shifted to online platforms. Even after the pandemic subsided, applications such as Zoom, Microsoft Teams, Google Meet, academic information systems, electronic learning platforms, and real-time communication services continued to be used by educational institutions. This condition indicates that large-capacity networks are required not only during emergency situations but also to support modern educational activities sustainably.

Fiber optics offer several advantages, including high bandwidth capacity, relatively low attenuation, a wide transmission range, resistance to electromagnetic interference, and the ability to support high-speed connections. Fiber-optic technology can also improve network stability between buildings, particularly when the transmission distance exceeds the effective range of Unshielded Twisted Pair cables. Therefore, fiber optics are widely used as the primary transmission medium in modern access network development (Insani & Alijoyo, 2024; Izza, 2024). One of the fiber optic access network architectures is Fiber To The x (FTTx). FTTx implementations can be differentiated into Fiber To The Home (FTTH), Fiber To The Building (FTTB), Fiber To The Curb (FTTC), and Fiber To The Cabinet (FTTCab), depending on the location of the fiber optic termination. FTTB places a fiber optic network up to a building, then the service is distributed to users or devices in the building. This architecture is suitable for application to office buildings, apartments, hotels, and educational buildings that require large-capacity network distribution (Erwanto et al., 2021).

FTTx is generally developed using Passive Optical Network (PON) technology. PON is a point-to-multipoint network that connects one Optical Line Terminal (OLT) with a number of Optical Network Units (ONU) or Optical Network Terminals (ONT) through the Optical Distribution Network (ODN). Signal distribution is carried out using passive components such as optical fibers, connectors, connections, and optical splitters so that it does not require active devices on most of its distribution lines. Such configurations can reduce the power supply requirements on the distribution network and allow a single OLT to serve multiple user terminals (International Telecommunication Union, 2008).

Two technologies that are widely known in the development of PON are Gigabit Ethernet Passive Optical Network (GEPON) and Gigabit Passive Optical

Network (GPON). GPON is an optical access network technology developed in the ITU-T G.984 series of recommendations. This technology supports point-to-multipoint configurations and provides gigabit transmission capacity with commonly used rates of 2,488 Gbit/s downstream and 1,244 Gbit/s upstream. GPON is widely used in FTTH and FTTB design because it is able to support data, voice, and video services through a single optical network infrastructure (Ikhsanto & Setiawan, 2024; International Telecommunication Union, 2008).

A number of previous studies have discussed the design of fiber-optic networks using GPON technology. Ikhsanto and Setiawan (2024) showed that GPON network quality is strongly influenced by the total attenuation of the transmission path. Erwanto et al. (2021) analyzed the implementation of FTTH and FTTB networks in office buildings and demonstrated the importance of selecting a network configuration according to building requirements. Haq et al. (2024) used Google Earth Pro and OptiSystem to design an FTTB network in a university environment and evaluated it based on received optical power, Bit Error Rate, and other transmission quality parameters. These studies show that route mapping and simulation of optical systems can be used to estimate the feasibility of the network before physical implementation. Although various studies regarding FTTH and FTTB have been conducted, each location has different characteristics of distance, building position, cable lines, number of terminals, divider ratio, and service needs. Therefore, the network design needs to be adjusted to the environmental conditions of its application.

At the Medan State Polytechnic, the Telecommunication Laboratory Building and the Civil Engineering Department Building require a network design that can support high-capacity data communication and enable the development of digital services in the campus environment. Based on these problems, this study aims to design and evaluate a GPON-based FTTB network in the Telecommunication Laboratory Building and the Civil Engineering Department Building of the Medan State Polytechnic. Route mapping was done using Google Earth Pro, while network modeling and testing was done using OptiSystem. The evaluation was focused on the optical power received, total attenuation, Bit Error Rate (BER), Q-Factor, and eye diagram characteristics. The results of the research are expected to be an initial reference for the development of campus network infrastructure that is reliable, efficient, and able to meet digital communication needs.

METHODS

1. Research Approach

This study uses an engineering and simulation design approach. The FTTB network is designed based on location conditions and distance between buildings, then modeled using OptiSystem software. The simulation results were analyzed descriptively quantitatively based on optical power, attenuation, BER, Q-Factor, and eye diagram.

The stages of the research include:

1. determine the location and building for which the service is intended;
2. identify the components of the FTTB-GPON network;
3. map paths and measure cable lengths using Google Earth Pro;
4. build a network model within OptiSystem;
5. set the parameters of transmitters, optical fibers, splitters, connectors, connections, and receivers;
6. run simulations;
7. record optical power, BER, Q-Factor, and eye diagrams; and
8. comparing the simulation results with the network feasibility criteria.

2. Research Location

The research was carried out within the Medan State Polytechnic. The design object consists of two service objectives, namely:

1. Telecommunication Laboratory Building as the location of ONT1; and
2. The Civil Engineering Department Building as the location of ONT2.

The Optical Line Terminal is placed in the Directorate Building or Building Z. Signals from the OLT are forwarded to the Optical Distribution Frame, Optical Distribution Cabinet, Optical Distribution Point, ROSET, and ONT.

3. System Diagram

The FTTB network system is divided into three main parts, namely the input block, the process block, and the output block. The input block includes data on the location of the building, the position of the device, the length of the cable route, the number of nodes, the type of components, and the technical parameters of the network. The data is used as a basis for determining the configuration of the GPON network to be simulated. Process blocks are the stages of mapping and simulation. Google Earth Pro is used to determine the coordinates, routes, and lengths of cables between components. OptiSystem is used to build optical transmission models and evaluate the influence of optical fibers, splitters, connectors, connections, and other passive components on signal quality. The output block presents the FTTB network configuration and evaluation results in the form of optical power on the transmitter and receiver sides, total attenuation, BER, Q-Factor, and eye diagram.

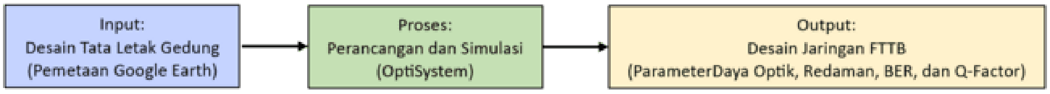

Figure 1. Network System Block Diagram

4. Network Design Layouts Using Google Earth Pro

Google Earth Pro is used to help with geospatial mapping and determine the route of network cables. The use of mapping applications can help determine the position of devices, cable lengths, and distribution lines that are close to the geographical conditions of the research location (Irsal & Saragih, 2023). The architecture used is point-to-multipoint. One OLT in Building Z distributes signals to two ONT through ODF, ODC, and ODP. The network paths on the mapping are differentiated into three parts:

1. the yellow line shows the path from the OLT in Building Z to the ODC in Building U;
2. the blue line shows the path from ODC to ODP1 in the Telecommunications Laboratory Building; and
3. the red line shows the path from ODC to ODP2 in the Civil Engineering Department Building.

The mapping is carried out taking into account the efficiency of the cable length, the position of the building, and the possible installation path. Although the networks in this study have not been physically implemented, mapping was used to produce a simulation model that is close to actual location conditions.

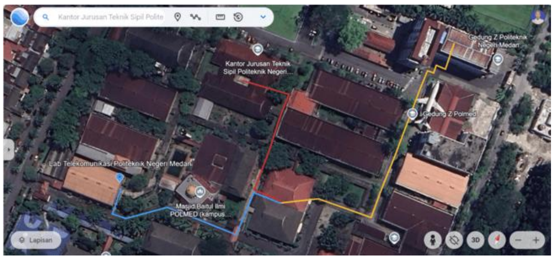

Figure 2. Fiber Optic Length Measurement Using *Google Earth*

5. Design Layout Network Using Optic System

The simulation layout of the Fiber to the Building (FTTB) network based on GPON technology was developed using OptiSystem software. OptiSystem enables optical communication network configurations to be modeled and evaluated based on the parameters of the devices and components used (Fauzi, 2021; Haq et al., 2024).

The network layout reflects the Point-to-Multipoint (P2MP) architecture, which connects one central point, namely OLT in the Directorate Building or Building Z, with two receiving points, namely ONT1 in the Telecommunications Laboratory Building and ONT2 in the Civil Engineering Department Building. The relationship is carried out through several stages of optical distribution consisting of ODF, ODC, ODP, and ROSET.

On the transmitter side, the configuration starts from the Optical Line Terminal (OLT) which is equipped with an optical transmitter at a wavelength of 1490 nm, output power of 5 dBm, and Non-Return-to-Zero (NRZ) modulation with a bit rate of 2.5 Gbit/s. The use of NRZ line coding can affect pulse characteristics and transmission quality in fiber optic networks (Sayoga et al., 2021). The optical signal then passes through the Optical Power Meter and connector with an insertion loss of 0.25 dB, as well as an optical attenuator with a damping of 0.1 dB. Next, the signal is passed to the Optical Distribution Frame (ODF), which uses two connectors with a damping of 0.25 dB each and one fusion splice with a damping of 0.05 dB.

An Optical Power Meter is also installed on the ODF to monitor the signal power before it is further distributed. From ODF to ODC, the signal is sent via a 0.23 km long optical cable with a damping coefficient of 0.28 dB/km.

In ODC, the optical signal is divided using a power splitter 1 × 2 with a loss of 3.7 dB. The first output line is directed towards ODP1, while the second output line is directed towards ODP2. The path to ODP1 uses a cable of 0.18 km, while the path to ODP2 is 0.13 km long. Both lines are equipped with multiple connectors with a damping of 0.25 dB, an optical attenuator of 0.1 dB, and a fusion splice of 0.05 dB to connect each cable segment.

In the ODP1 in the Telecommunication Laboratory Building, the signal is received by the splice attenuator with a attenuation of 0.1 dB. The signal then passes through eight adapters with a damping of 0.25 dB each and is redivided using power splitters 1 × 4 with a loss of 7.25 dB.

The optical cable used on the final distribution side has a length of 0.02 km for each segment and a damping coefficient of 0.28 dB/km. Each final signal branching passes through a mechanical splice with a attenuation of 0.2 dB and is then directed towards the ROSET terminal. ODP2 in the Civil Engineering Department Building has a similar configuration to ODP1. The ODP2 is equipped with a 1 × 4 splitter with a loss of 7.25 dB, a splice attenuator of 0.05 dB, several adapters with a damping of 0.25 dB each, and an optical cable. The length of each cable segment from the splitter to ROSET is also around 0.02 km. Each final path to ROSET is equipped with a mechanical splice for the final termination process. On the receiver side, each ONT is equipped with a PIN-type optical receiver that has a responsiveness of 0.85 A/W. All received signals are analyzed using the BER Analyzer and Optical Power Meter to evaluate the transmission performance based on the Bit Error Rate (BER), Q-Factor, and optical power parameters on the receiver side. In general, network feasibility is determined based on total attenuation, optical power received, BER, and Q-Factor. The total attenuation is compared to the maximum optical loss budget of 28 dB used in the evaluation of GPON network class B+ (International Telecommunication Union, 2019).

A visual of the overall network layout configuration can be seen in Figure 3.

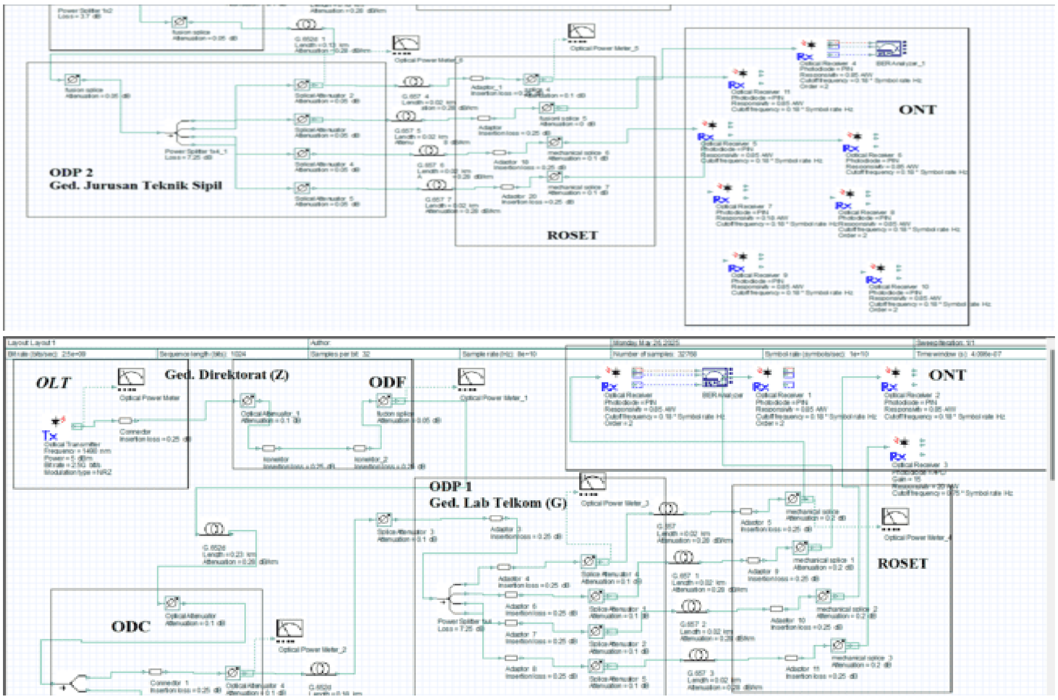

Figure 3. Fiber Optic Network Design in *Software*

RESULTS AND DISCUSSION

The results analyzed in this study included damping, Bit Error Rate (BER), and Q-Factor.

1. **Damping**

Attenuation in optical networks refers to the loss or decrease in signal power during the transmission process from a transmitter or OLT to a receiver or ONT. Attenuation can be affected by the length of fiber-optic cables, connectors, splitters, fusion splices, mechanical splices, attenuators, and other optical components (Zulfikar et al., 2022; Purnama & Lammada, 2024). Visualization of optical power measurement results on the transmitter and receiver sides is shown in Figure 4, Figure 5, and Figure 6.

Figure 4. Optical Power Measurement Results on the Transmitter Side

Figure 5. Optical Power Measurement Results on the Receiver Side (ONT1)

Figure 6. Optical Power Measurement Results on the Receiver Side (ONT2)

Based on the measurement results using an Optical Power Meter (OPM), the optical power measured at the observation point after the signal passed through the initial transmitter-side components was 2.397 dBm. Dengan kalimat ini, daya keluaran nominal transmitter tetap 5 dBm, sedangkan 2.397 dBm merupakan daya yang terbaca pada titik pengukuran. The received power on the receiver side of the ONT1 is −20.204 dBm, while the received power on the ONT2 is −19.191 dBm. Based on the difference between the input power and the output power, the total damping on each line can be calculated as follows:

Damping of the ONT1 line

Attenuation = Pinput − PoutputAttenuation = 2,397 − (−20,204)Attenuation = 22,601 dB

ONT2 line attenuation

Attenuation = Pinput − PoutputAttenuation = 2,397 − (−19,191)Attenuation = 21,588 dB

Thus, the total attenuation that occurred in the transmission line from OLT to ONT1 via ODP1 was 22,601 dB. Meanwhile, the total attenuation on the line from OLT to ONT2 via ODP2 is 21,588 dB.

Both values are still below the maximum optical loss budget limit of 28 dB used in the evaluation of GPON network class B+. Therefore, both transmission lines can be declared feasible based on damping parameters (International Telecommunication Union, 2019). The calculation of the optical power attenuation on each transmission line can be seen in Table 1.

Table 1. Optical Power Damping per Transmission Line

Transmission Line	Daya Input (dBm)	Daya Output (dBm)	Redaman (dB)
OLT → ONT1 (ODP1)	2.397	-20.204	22.601
OLT → ONT2 (ODP2)	2.397	-19.191	21.588

Based on Table 1, the damping on the path to ONT1 is greater than the damping on the path to ONT2. The damping difference between the two lines is 1,013 dB. The difference can be affected by the difference in cable length and the accumulated damping of the components that the signal passes through. The path to ODP1 uses a 0.18 km cable, while the path to ODP2 uses a 0.13 km cable. Despite the damping differences, both pathways still met the feasibility criteria used in the study.

2. ***Bit Error Rate (BER)* and *Q-Factor***

Bit Error Rate (BER) is an important parameter used to evaluate the quality of data transmission in an optical network system. BER shows the comparison between the number of bits that have an error and the overall number of bits transmitted. The smaller the BER value, the better the quality of the data transmission produced (Prakoso et al., 2021). In this study, the BER value of $\leq 10^{-9}$ was used as the feasibility criterion for optical network simulation. Meanwhile, a Q-Factor value above 6 is used as an indicator that the signal quality is in good condition. The results of the BER and Q-Factor tests can be seen in Figure 7 and Figure 8.

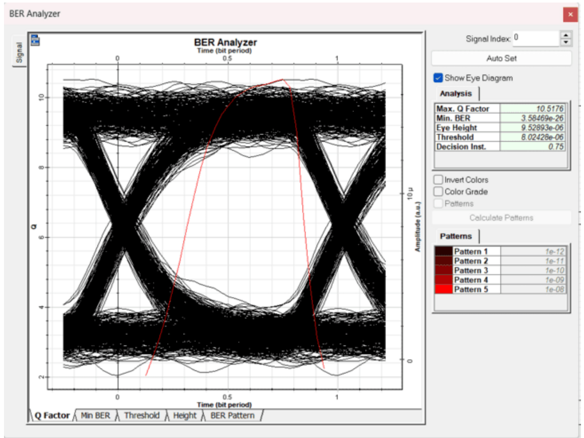

Figure 7. BER Analyzer ONT1 di OptiSystem

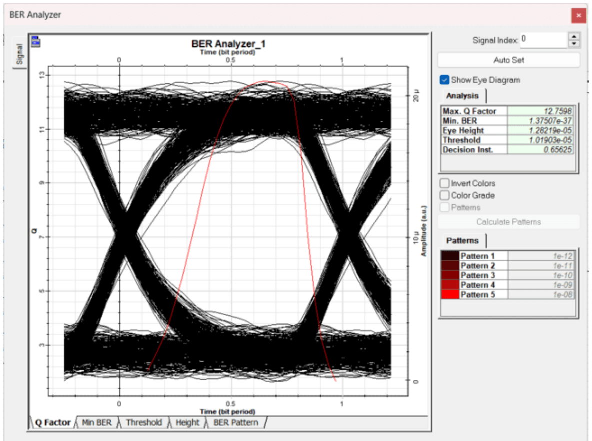

Figure 8. BER Analyzer ONT2 di OptiSystem

The test results at two receiving points, namely ONT1 and ONT2, produce the parameters as shown in Table 2.

Table 2. BER and Q-Factor in ONT1 and ONT2

Parameter	ONT1	ONT2
Q-Factor	10.5176	12.7598
Minimum BER	3.65489×10^{-26}	1.37507×10^{-37}
Eye Height	9.5299×10^{-6}	1.28219×10^{-5}
Threshold	8.02428×10^{-6}	1.01903×10^{-5}
Decision Instant	0.75	0.65625

The results of the eye diagram analysis on both ONT showed wide eye openings and relatively clean signal edges. This condition indicates that the signal is received with excellent quality and only undergoes minimal distortion.

The minimum BER value obtained was 3.65489×10^{-26} in ONT1 and 1.37507×10^{-37} in ONT2. Both values are much lower than the eligibility threshold of

10^{-9}. These results show that the probability of bit errors in both transmission lines is very small.

The Q-Factor value obtained was 10.5176 in ONT1 and 12.7598 in ONT2. Both values are above the minimum Q-Factor criterion of 6. This indicates that the digital signal is well received, has a low noise level, and has a clear separation between bit 1 and bit 0. ONT2 shows better performance compared to ONT1. This can be seen from the lower damping value of ONT2, higher acceptance, smaller BER value, higher Q-Factor, and greater eye height. Nonetheless, the test results showed that both ONT met the eligibility criteria used in the study. Thus, the design of the GPON-based FTTB network can support the process of transmitting data from the OLT to both receiving points with good signal quality.

CONCLUSION

Based on the results of the research that has been conducted, several main points can be concluded as follows:

1. The design process of the FTTB network in the Medan State Polytechnic area begins with the determination of the coverage area, the identification of network elements such as the Optical Line Terminal (OLT), Optical Distribution Cabinet (ODC), Optical Distribution Point (ODP), and Optical Network Terminal (ONT), as well as the determination of the cable path and length for the distribution, feeder, and drop segments.
2. The total attenuation in the transmission line from OLT to ONT1 via ODP1 was recorded at 22,601 dB, while the line from OLT to ONT2 via ODP2 had a damping of 21,588 dB. Both values are below the maximum limit of optical loss budget of 28 dB so they can be declared feasible based on damping parameters.
3. The Bit Error Rate (BER) values at both receiver points are well below the maximum threshold of 10^{-9}, i.e. reaching the order of 10^{-26} for ONT1 and 10^{-37} for ONT2. In addition, the Q-Factor values were 10.5176 and 12.7598, respectively. Both values exceed the minimum Q-Factor criterion of 6, thus indicating excellent signal quality.
4. A very small BER value indicates the stability and reliability of the network. A high Q-Factor value reflects a clean signal and a low level of interference or noise. Meanwhile, the wide-open shape of the eye diagram shows optimal

optical transmission quality, minimal signal distortion, and low inter-bit interference.

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