Scientific experiment measurement of optical signal characteristics on fiber optic access network prototype for distance learning education purposes

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ABSTRACT

This research developed a fiber access network prototype system to enhance practical learning experiences in the Telecommunications Transmission Laboratory. A requirements analysis was conducted to identify the necessary hardware, followed by system design, including architecture and network topology. The implementation stage involved hardware installation, system configuration, and performance measurement using devices such as optical media converters, optical distribution frames, optical rosettes, and testing tools like an optical light source (OLS) and an optical power meter (OPM). The system utilized single-mode fiber optic cables with a light source wavelength of 1310 nm. The measurement results indicated power losses of 3.62 dB on the first link and 3.68 dB on the second link. The error percentage was attributed to decimal accuracy limitations of the OPM, which have resulted in a system accuracy of 91.25%. The results aligned with expected outcomes for fiber access networks, demonstrating reliable performance for installation and troubleshooting purposes. The minimal error observed did not significantly affect system functionality. This prototype improved student's skills in configuring and troubleshooting fiber optic networks and is suitable for use in distance learning environments.

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INTRODUCTION

Technological environmental friendliness is characterized by advancements in technology development and effectiveness. These advancements include the development of technology that enhances network performance. Optical fiber access network technology has developed rapidly in recent years (Bahaweres et al. 2015). This is due to several factors, including high data rates, large capacity, and high reliability. In addition, the development of fiber optic access network technology needs to be balanced with an increase in the quality of education and training in telecommunications. One way to improve the quality of education and training is to provide a fiber optic access network

KEYWORDS

Access network, Accuracy, Error, Fiber, Measurement

simulation system in the laboratory. The rapid growth in internet traffic, driven by the intense use of internet services like Triple Play Services and Cloud Based Solutions, has indeed opened up numerous new business opportunities for telecom operators, enabling them to offer subscribers value-added services (Ellahi et al. 2023; Yu et al. 2023; Abdelgany and Mahmoud 2023).

Several studies have been conducted to build optical fiber access network simulation systems, such as the design of a fiber optic cable network trainer kit for the competency of fiber optic installation technicians and fiber optic practicum (Kussoy et al. 2021). The trainer kit was built and used in carrying out competency certification in the field of fiber optic technician. The other reports were the implementation of the QINQ method on the metro ethernet network to maximize VLAN usage using the GPON technology case study (Pangestu and Yusuf 2021). They used the VLAN QINQ method on gigabit passive optical network (GPON) technology, to solve the problem of VLAN ID limitations that may be encountered when meeting the needs of PT Telkom Indonesia customers. Then, the other researchers reported designing an electrical installation kit for learning media for electrical installation courses (Monitasari et al. 2022). This research consisted of making kit and circuit designs, collecting components, designing kit components and microcontroller programming, wiring components, and checking the circuit with a multimeter. Voltage, power factor, and frequency values were measured to determine the feasibility of the practicum kit.

This research developed a prototype fiber optic network in the Transmission Laboratory. It introduced several novelties compared to previous studies, including the use of open-source software for building the simulation system, allowing it to be freely accessible to anyone. The simulation system was also equipped with various simulation scenarios that can be used to study various aspects of optical fiber access networks. In addition, this simulation system was possibly integrated with an online learning system and could be used for distance learning.

The prototype research method was an appropriate method for this study because it allowed and developed simulation systems quickly, easily, and efficiently. The prototype research method was chosen for this research because it has several advantages, including accelerating the development process. In this case, later prototyping allows us to develop simulation systems quickly and easily. Then, it improved the quality of the system. Based on the detailed procedures developed, the prototype enabled us to gather feedback from users and implement improvements before the final implementation of the simulation system. In addition, this method can enhance efficiency. In terms of work process and usage, prototypes allowed us to test various designs and solutions before choosing the best one.

MATERIALS AND METHODS

The research design, which employed the prototype method, was summarized into simpler steps, as illustrated in **Figure 1**. The steps were as follows:

(i) Concept (needs analysis). A needs analysis was conducted to determine the features required in the simulation system.

(ii) System design (prototype design). A simulation system prototype was designed based on the needs analysis. During the system design phase, we created the blueprint for the simulation system based on the outcomes of the needs analysis. This stage defined the architecture and components of the system, serving as the core structure around which the prototype was developed and implemented.

(iii) Detail design (prototype implementation). The simulation system prototype was implemented based on the detailed design.

(iv) Assembly. The system design was implemented in the laboratory setting.

(v) Test (prototype evaluation and improvement). The simulation system prototype was evaluated by gathering user feedback. Improvements were made to the simulation system prototype based on the evaluation results. User feedback was collected during the test phase, where the prototype was evaluated for its functionality and usability. This feedback was essential for identifying any issues, which allowed the necessary improvements to be made to the system before its final implementation. It ensured the final system to meet user expectations and requirements.

(vi) Ship (Final Implementation). The simulation system was finalized and deployed for its intended use.

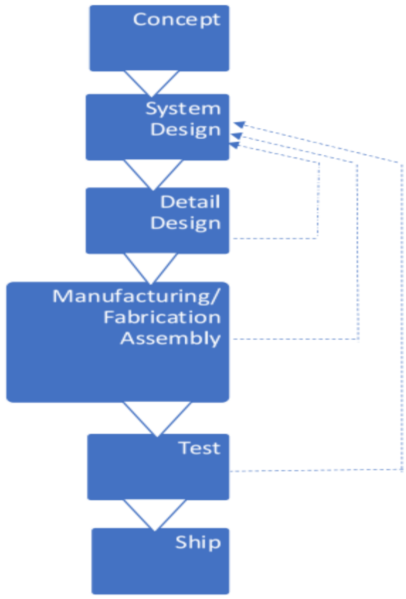

Figure 1: Design of prototype research (Onuh and Yusuf 1999).

The object of this research was network construction in optical fiber networks, which can also be described based on the main tools and materials needed in the form of software and hardware. The software used was for simulating network usage in the form of an IoT-based system, namely IoTCloud. Then, the hardware included an optical light source, an optical fiber patch cord, an optical distribution frame (ODF), an optical distribution cabinet (ODC), an optical distribution point (ODP), an optical Rosette, media converter, and optical power meter (OPM).

Data collection for this research consisted of measurements of power loss in the system, as well as data from tests of the IoT system used for liquid pH measurement, as described in the scientific stage methods (Siagian 2023). In measuring power loss in the system, OLS was used as the light source, and OPM was used as the measuring instrument. **Equation (1)** provides the formula for calculating the attenuation value received by the device:

$$P_r = P_t - \alpha_{total} \quad (1)$$

where P_r is the measured receive power, P_t is the transmitted transmit power, and α_{total} is the total power loss value.

The received power value was also measured based on the internet source through the media converter and compared to the industry standard value. In the measurement of IoT performance, the accuracy of the measurement was compared with measurements taken using a meter. **Equation (2)** provides the formula for calculating the error and accuracy of the acidity value measured by the embedded IoT system:

$$Error = \frac{|reference - measurement|}{reference} \times 100\% \quad (2)$$

Then, the error value can then be derived from the accuracy percentage within the system (see **Equation (3)**):

$$Accuracy = 100\% - Error \quad (3)$$

RESULTS AND DISCUSSION

The results gained are the following:

(i) Concept. At this stage, the need for the fiber optic access network to be built was identified. This research then formulates the problem and analyzes bandwidth requirements, network topology, and target users. The initial specifications of what is expected from the fiber optic system, such as the data capacity to be supported, network coverage, and desired performance (e.g., low latency and high throughput).

(ii) System design. In this step, we design the overall system, including GPON as the selection of technology to be used. Then, the research needs to determine the network architecture to a point-to-multipoint topology statement. There are major components determined such as optical line terminals (OLT) as a source of networks, ODF, ODC, ODP, and optical network terminals (ONT). A block diagram of the fiber optic system, identifying the major components and their interconnections. The technical standards to be used are also determined, such as the type of optical cable, connectors, and transmission or receiver equipment.

(iii) Detailed design. This phase focuses on the detailed design of each component in the fiber optic network system, including technical specifications of the equipment and the setting of important parameters such as wavelength, fiber length, and loss in the network. Detailed specifications of the optical equipment and components to be used in the prototype. It also included the physical design for fiber cable distribution. The detailed design is (a) ODF. The attenuator obtained from the optical connector adapter, optical splicing, and the Connector itself is used in the ODF block. The device components that are inserted next are the ODF component blocks with specifications as in **Table 1**; (b) Optical universal closure. The attenuator is obtained from optical cable splicing in optical universal closure. In this splicing measured 0.01 dB loss occurred; (c) ODC. The attenuator is obtained from the optical connector adapter and cable splicing, and the Connector itself is used in the ODC. The device components that are inserted next are the optical ODC component blocks with specifications as in **Table 2**; (d) ODP. The attenuator is obtained from the optical connector adapter and cable splicing, and the Connector itself is used in the ODP. The device components that are inserted next are the optical ODP component blocks with specifications as in **Table 3**; (e) Optical rosette. The attenuator is obtained from the optical connector adapter and cable splicing, and the connector itself is used in the Optical Rosette. The device components that are inserted next are the optical ODP component blocks with specifications as in **Table 4**; (f) Optical cable. The optical cable used in the prototype fiber optic access network that was created consists of several cable segments with different types and lengths, including those presented in the specifications in **Table 5**. There are 144 core cable types in 12 optical cable tubes, 12 core cable types in 2 cable tubes, and there is also the type of optical drop wire cable.

Table 1: ODF specifications

No	Components	Number	α (dB)
1	Optical connector adapter	1	0.2 (max)
2	Splice Fusion	1	0.01
3	Connector SC	2	0.25 – 0.5

Table 2: ODC specifications

No	Components	Number	α (dB)
1	Optical connector adapter	1	0.2 (max)
2	Splice Fusion	1	0.02
3	Connector SC	2	0.25 – 0.5

Table 3: ODP specifications

No	Components	Number	α (dB)
1	Optical connector adapter	1	0.2 (max)
2	Splice Fusion	1	0.01
3	Connector SC	2	0.25 – 0.5

Table 4: Optical rosette specifications

No	Components	Number	α (dB)
1	Optical connector adapter	1	0.2 (max)
2	Splice Fusion	1	0.03
3	Connector SC	2	0.25 – 0.5

Table 5: Optical cable specifications

No	Components	Number	α (dB)
1	ODF-UC	9	144C/12T
2	UC-ODC	9	12C/2T
3	ODC-ODP	14	12C/2T
4	ODP-Rosette	5	2C DW

(iv) Assembly. At this stage, each network component is connected as previously described in detail. Each network component is connected with a different type of cable based on the needs required. An overview of the implementation of the fiber optic access network prototype is shown in **Figure 2**.

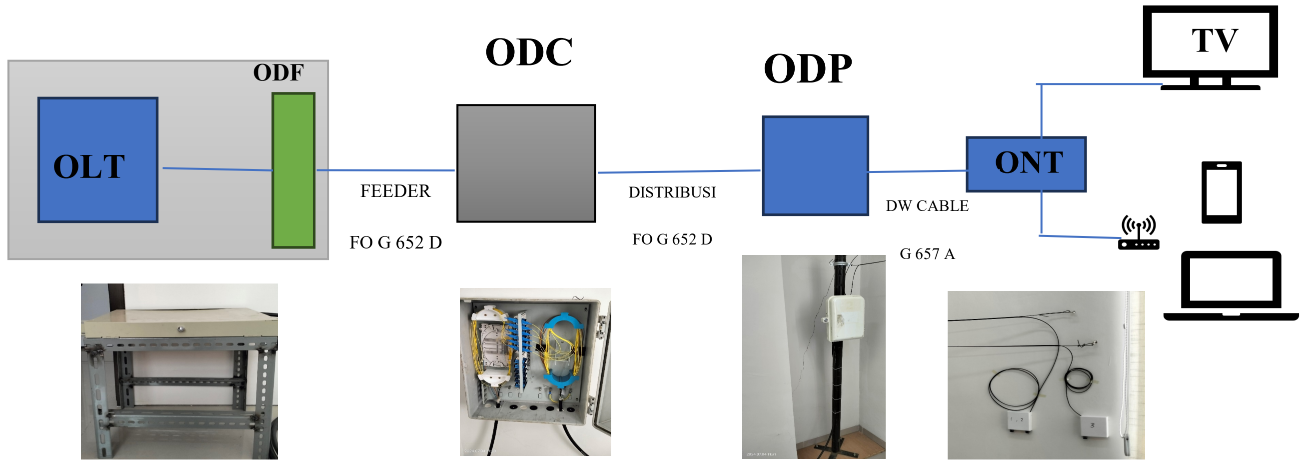

Figure 2: Network prototype implementation assembly.

(v) Test. Based on the measurements scenario that has been made, the measurement data of the loss of the optical fiber access network prototype system is obtained as in **Table 6**.

Table 6: Loss measurement between OLT to roset

Core Connection	P_t (dBm)	P_r (dBm)	α (dB)
Number 1	- 6.48	- 10.10	3.62
Number 2	- 6.86	- 10.54	3.68

(vi) Ship. At this stage, a trial was conducted on the meter measurement system based on the Internet of Things (IoT) and implemented with a WiFi network. In the acidity measurements carried out, the pH value of a solution was obtained as 3.2 which was compared to the measurement by the pH meter of 2.92. Therefore, the measurement accuracy value (α) can be calculated as 0.28 dB.

Based on the research methods that have been carried out, a fiber optic access network prototype with a fiber-to-the-home (FTTH) design has been developed. In the measurement of power loss between the OLT to Rosette, a loss value of 3.62dB is obtained in core connection number 1 and a loss of 3.68 dB in core connection number 2. This value can be compared to the Powerlink budget formula [see **Equation (4)]** as this calculation follows their connection (Siagian 2023).

$$\alpha_{tot} = (L \times \alpha_{serat}) + (N_C \times \alpha_C) + (N_{CA} \times \alpha_{CA}) + (N_S \times \alpha_S) + (\alpha_{SP}) \quad (4)$$

Using this formula, we can calculate the minimum and maximum attenuation values that can occur in the system. The calculation of each attenuation value is as follows:

(i) The type of cable used was a single-mode cable with an attenuation value of 3.5 dB per km. The cable attenuation value is calculated based on the total cable length of 3.5 dB/km with each cable length of 9; 9; 14; and 5 m, respectively. Therefore, the cable attenuation (α_{core}) is 0.013.

(ii) In terms of the type of connector used, there is a similarity because it uses an SC connector. The total attenuation value for the connector is 0.5 dB multiplied by 8, and 0.2 dB multiplied by 4 (SC connector adapter). Thus, α_c is 2.

(iii) In terms of the type of connector adapter used, there is a similarity because it uses an SC connector adapter. The total attenuation value for the connector adapter is 0.2 dB multiplied by 4. Thus, α_{CA} is 0.8.

(iv) In terms of splicing carried out in ODF, ODC, ODP, and rosettes, the total splicing attenuation value obtained is 0.07 dB. Therefore, α_{SP} is 0.7, and α_{tot} is 3.513.

There is a discrepancy between the calculation results and the measurement results for the first link, with an error of 3.05% For the second link, the error is 4.7%

Furthermore, the system was tested by measuring the pH value using the Internet of Things (IoT) system, with the obtained pH value denoted as x and the pH value from the meter comparison denoted as y. Based on these values, the accuracy of the system was determined. The error calculation for the IoT system was as follows: the error was 8.75%, meaning the accuracy percentage of the system was 91.25%

Finally, this study contributed to addressing current challenges in developing supporting devices for education, particularly for distance learning purposes, as reported elsewhere (Azizah et al. 2022).

CONCLUSION

In the first measurement at the OLT termination point, the Power transmitted (Pt) by the OLS was measured at -6.48 dBm. In the second link, the power received was measured again at the rosette (end-user) as -10.10 dBm, resulting in a loss of 3.62 dB in the first link. Then, Pt by OLS was measured at -6.86 dBm, and the power received at the rosette (end-user) was -10.54 dBm, corresponding to a system loss of 3.68 dB. This value remained within the standard allowable connection loss value of -28 dBm. The system was further tested by measuring the pH using the Internet of Things (IoT) system. The obtained pH value, denoted as x, was compared with the pH value measured by the pH meter, denoted as y. Based on this comparison, the accuracy of the system was determined to be 91.25%

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

AF is the primary contributor, providing support for grants and writing the manuscript. ES provides support and advice for this research. DFW contributes to the research and edits the final manuscript. MDD is responsible for conducting the pH measurements.

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