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Research Article

Performance Comparison of HFC and FTTH using Optisystem Software: A Case Study at PT. Link

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Abstract: This research presents the analysis of the application of Optisystem software technology for both Fiber-to-the-Home (FTTH) and Hybrid-Fiber-Coaxial (HFC) showing that both have the capability for the WDM systems to support a maximum transmission distance of 20 kilometers and can serve up to 32 subscribers. Discrete monitoring and analysis of key factors such as signal strength, Q-Factor (QF), and Bit Error Rate (BER) were performed. Based on the simulation results for HFC technology, the highest BER value was 5.23×10^{-13} and the lowest QF was 7.11 for FTTH technology, the highest BER value was 7.9×10^{-9} and the lowest QF was 11.08. It was found that the FTTH has an average QF of 13.49 and the HFC has an average QF of 7.475. The difference is about 44.59%, which indicates that FTTH has an advantage in terms of signal quality. Meanwhile, the field measurement results show that for HFC technology, the highest BER value was 1.9×10^{-9} and the smallest QF was 6.022, and for FTTH technology the highest BER value was 2.3×10^{-9} and the smallest QF was 7.12. Based on the results of simulation and field measurements, values that meet the reliability standards for signal quality were obtained because the BER value does not exceed the maximum limit of 10^{-9} and the QF value has exceeded the minimum limit of 6. It can be concluded and stated that both technologies are reliable for efficient and high-quality communication services.

Keywords: bit error rate, fiber to the home, hybrid fiber coaxial, Q-factor

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1 Introduction

The availability of large bandwidth is becoming an imperative and a primary need used by people, especially due to today's services such as cloud, ultra-HD video, smart homes, 5G cellular systems, and the Internet of Things (IoT), therefore, rapid changes in the development of advanced infrastructure are a necessity. Optical fiber is the most advanced and only transmission medium capable of supporting current and future telecommunication networks and services due to its higher speed, higher bandwidth, greater distance from the center to the customer, resistance to electromagnetic interference, higher level of security, and minimal value of signal attenuation [1]. The development of hybrid-fiber-coaxial (HFC) with fiber-to-the-home (FTTH) technology has improved significantly in recent years. HFC, with the implementation of the Data Over Cable Service Interface Specifications (DOCSIS) 3, has demonstrated almost equivalent capabilities to FTTH, especially in terms of efficiency and ease of use [2–4]. Recent research shows that HFC still has an important role in providing broadband services, although FTTH offers advantages in terms of capacity and scalability [5]. Furthermore, the researchers [6, 7] proposed an update to DOCSIS 4 with an adaptive modulation scheme for non-metro areas.

Pugh [8] describes requirements such as high bandwidth and capacity for high-speed internet, High Definition Television "HDT" and Voice Over Internet Protocol "VOIP", leading to the proposal of the Fiber-to-Home FTTH Access Network. FTTH based on Giga Passive Optical Network (GPON) technology is a technique that can provide triple play services at a reasonable cost. Suherman *et al.* [9] present the analysis of electrical power consumption in HFC and FTTH networks that the operational cost of maintenance of HFC technology is a very large difference when compared to the operational cost of maintenance of FTTH technology, especially in the last year. In addition, it was mentioned that with the rejuvenation of the infrastructure network, customer growth is also improving along with these technological changes.

A report [10] discusses a capacity comparison of popular FTTH architectures with modern HFC networks, highlighting that while FTTH proponents emphasize the nearly unlimited capacity of optical fiber, the practical capacity of these networks often does not surpass that of modern HFC networks. This paper also explores several methods to exploit the significant unused capacity of HFC networks. Angilella *et al.* [11] discuss the feasibility of using the FTTH networks for attenuation and fiber optic loss. This study aims to determine whether FTTH networks are feasible for providing high-speed internet access to homes and businesses. Budiman *et al.* [12] proposed a method to reduce FTTH network costs by increasing and optimizing the deployment of splitters and Optical Line Termination (OLT) cards. This study applies a mathematical model to determine the optimal placement of splitters and OLT cards in a network, considering factors such as the number of subscribers, the topology of the network, and the cost of deployment. Licup and Materum [13] present methods for optimizing cable network design for FTTH deployments; this study proposes a mixed integer linear programming model to optimize network design, considering factors such as the number of houses passed by each cable, maximum cable length, and cable installation costs. Ali *et al.* [14] discuss solutions in telecommunications networks and/or economic aspects of projects worldwide and finds that GPON is more appropriate to solve PON-FTTH than other networks.

Patterson and Rolland [15] discuss the HFC technology full-duplex network. Several calculation methods commonly used in various countries are explained, the flat rate, time-of-use charge, dynamic time-of-use charge, and real-time usage time. Other reports [16] mentioned that it is necessary to optimize the performance and cost efficiency of these two systems in providing reliable and fast broadband services to end users. Also, the consideration of production, installation, and network maintenance costs [17] mentioned that the HFC technology is needed, to continue to develop and contribute to the evolution of global telecommunications infrastructure. From a cost management perspective, research [18] has shown that HFCs require significant adjustments in capital expenditure (CAPEX) and operational expenditure (OPEX) to compete with FTTH.

PT. Link is an Internet service provider company that still applies and uses HFC technology. The HFC is a technology of the telecommunications network that combines the two transmission media of the fiber optic cable and the coaxial cable. The problem with the current HFC network seems to be its susceptibility to many types of interference. For example, all incoming noise can propagate to all network devices, and temperature changes can cause cracks or damage to cable insulation. In order to meet the needs of its customers, PT. Link is gradually upgrading its network technology by migrating from HFC to FTTH technology. The maximum speed of the HFC network is 27 Mbps downstream (download speed to the user) and 2.5 Mbps upstream (upload speed from the user) [18]. For the FTTH network, it is known that the difference between downstream and upstream is around 1 Gbps; with the composition of the maximum speed being 2.5 Gbps for the download speed to the user and 1.5 Gbps for the upload speed of the user, respectively. From the capacity point of view, the HFC network is very limited in providing multimedia and data services because it has limited bandwidth and transmission speed. Therefore, the HFC network deserves to be replaced by a higher bandwidth capacity of the network of FTTH.

This research focuses on analyzing the signal quality of HFC and FTTH networks to determine the level of difference in signal quality results from both technologies by using Optysistem software. The parameters used to see the effect of this migration process include Bit Error Rate (BER) & Q-factor values.

2 Research Method

The research methodology used to compare the performance of HFC and FTTH is presented in this section. The research flowchart, the simulation topology design of the FTTH and HFC network, and the simulation design block for HFC and FTTH are explained in detail in this section.

2.1 Research flow Chart

Figure 1 illustrates the research stages carried out in this study. The research began with the analysis of demand-based specification data, followed by a design comparison for the Sari Bumi Indah housing area in Tangerang Banten. Because field construction details were not allowed to be published, the research focus shifted to creating network simulations that approximate real conditions in the field. After obtaining the floor plan, the research continues by designing the HFC and FTTH networks for comparison before entering the implementation stage.

Once the network was complete, the research continued with performance measurements, using Q-factor and BER as metrics, as both are relevant to the electrical end-user experience. Based on the comparison results between FTTH and HFC, we conducted sampling trials to analyze the suitability between simulation results and field test data. It is important to note that this extends existing conditions, where telecommunications infrastructure has been partially built in the residential area.

Comparative analysis is carried out through several sub-chapters, which detail the evaluation process of the two technologies. Although FTTH and HFC share similar topologies, there are disparities in performance. This research determines that the BER target must be lower than 10-9 and the value of the Q factor must exceed 6 [1]. Adjustments in parameters between FTTH and HFC are essential to achieving this goal with an identical topology

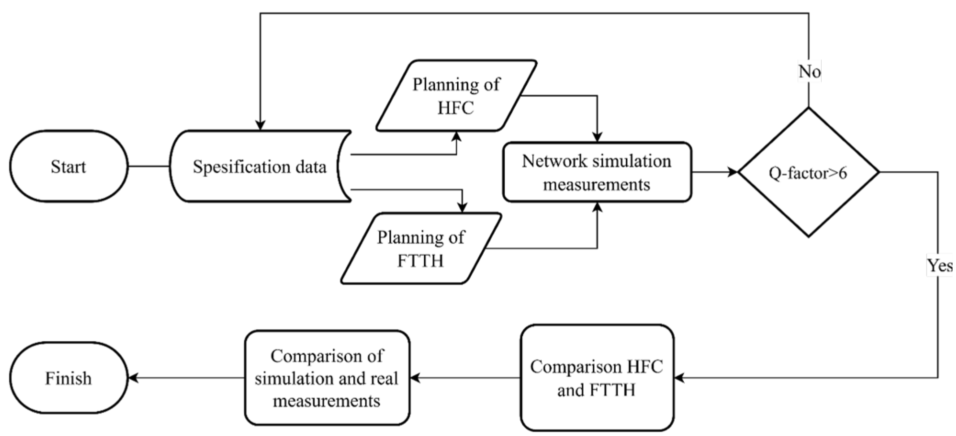


Figure 1: Research flow chart.

2.2 Optisystem Simulation Design

The first step in the execution of the process design of the FTTH and HFC network topologies using Optisystem software is to select components that suit the network's needs. In Optisystem, researchers can specify parameters such as wavelength, transmission power, and modulation type. Afterward, researchers set up the topology by connecting the components according to the desired network scheme, both for FTTH and HFC.

2.2.1 Architecture simulation design in HFC

To perform the simulation for this HFC architecture, the following parameters are used; transmitting power, length of FO and CU cables, total of the end users, losses for each cable, total connectors, connector attenuation, and detector sensitivity as shown on Table 1.

This HFC network simulation design uses four wavelengths, each operating at a speed of 10 Gbps as shown in Figure 2. This simulation uses random bits to represent information transmission, adopting a Non-Return to Zero (NRZ) coding scheme. The implemented modulation system applies information to the laser signal via a Mach-Zehnder modulator. The applied laser transmission power in the HFC context is 0 dBm. Then, the process of multiplexing the four signals using the Wavelength Division Multiplexing (WDM) technique, which functions as the main core in transmitting various communication services.

Table 1: Parameter simulation for HFC

No	Parameters	Value
1.	Transmitting Power	0 dBm
2.	Length of FO Cable	20 km
3.	Length of CU Cable	10 km
4.	Total of the end user	32
5.	Loss of FO Cable	0.2 dB/km
6.	Loss CU Cable	0.2 dB/m
7.	Total Connectors	5
8.	Connector Attenuation	1 dB
9.	Sensitivity of Detector	-29 dBm

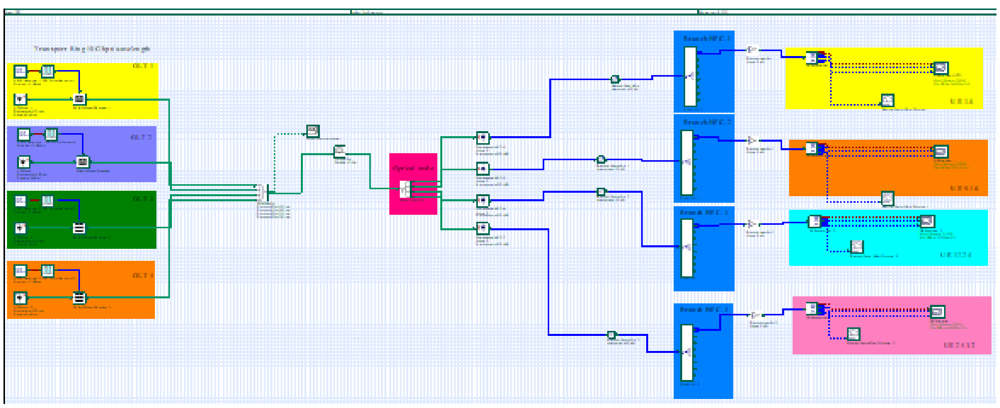


Figure 2: Simulation design block for HFC.

Then, the transmission process after the success of four-wavelength multiplexing. Signals that have been modulated with information are transmitted via Single Mode Fiber (SMF) cables and experience optical power-sharing with a ratio of 1×4, which reflects the function of the optical node in field applications. After optical transmission, a photodetector converts the signal into electrical form. The transmission distance from the multiplexer to the optical node is set at 10 kilometers, similar to the distance from the optical node to the 1×8 electrical power branch. This simulation considers copper cable attenuation of 0.2 dB per 100 meters, resulting in a total attenuation of approximately 20 dB in copper transmission cables. Determination of this distance is based on various considerations, including actual field conditions, applicable international standards, and receiving power considered optimal for information detection. Then, performance measurements on the electrical receiver are carried out post-transmission via a 1x8 power branching system. In this research, three types of measurements were carried out to evaluate system performance. Initial measurements utilize an Electrical Power Meter (EPM) to determine the received power. Then, this research uses electrical detection and an electrical amplifier of 5 dB to improve the quality of the detection signal. The electrical received power range that is considered normal for information detection is between -40 dBm and -70 dBm, which supports reliability in the information detection process.

2.2.2 Architecture design in FTTH

The same parameters as in the architecture design of HFC are used to perform the simulation on the FFTH architecture. The following parameters are listed in Table 2.

Figure 3 describes FTTH, where the simulations performed include four wavelengths, with each wavelength operating at a speed of 10 Gbps. In this research, random bits are used to simulate information transmission using an NRZ coding scheme because it has the advantage of low coding complexity [19].

A Mach-Zehnder modulator is used for a modulation system that applies information to a laser signal. The applied laser power is 0 dBm. Here, it is explained that four signals have been multiplexed using WDM with the premise of being the main central block for the transmission of different services. These four wavelengths were successfully multiplexed as shown in Figure 3.

Table 2: Parameter simulation for FTTH

No	Parameters	Value
1.	Transmitting Power	0 dBm
2.	Length of FO Cable	20 km
3.	Length of CU Cable	10 km
4.	Total of the end user	32
5.	Loss of FO Cable	0.2 dB/km
6.	Total Connectors	5
7.	Connector Attenuation	1 dB
8.	Sensitivity of Detector	−29 dBm

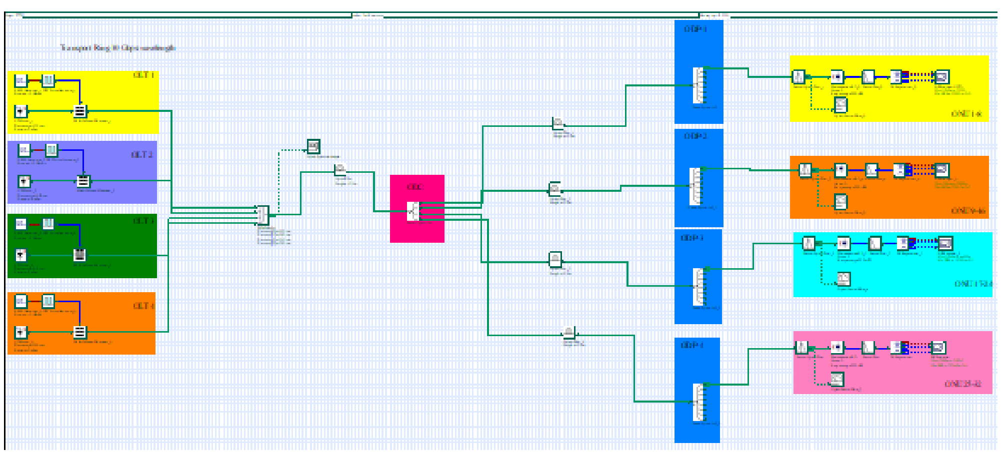


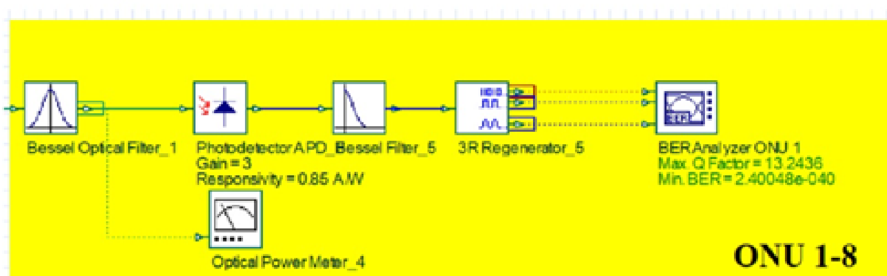
Figure 3: Simulation design block for FTTH.

In addition, to eliminate nonlinear effects such as self-phase modulation (SPM), cross-phase modulation (XPM), and four-wave mixing (FWM), a significant distance was selected between each wavelength [20]. After passing through the multiplexing process, there is an attenuation at each wavelength, and the transmission power generated after the multiplexer is in the range of 1 dBm for each wavelength.

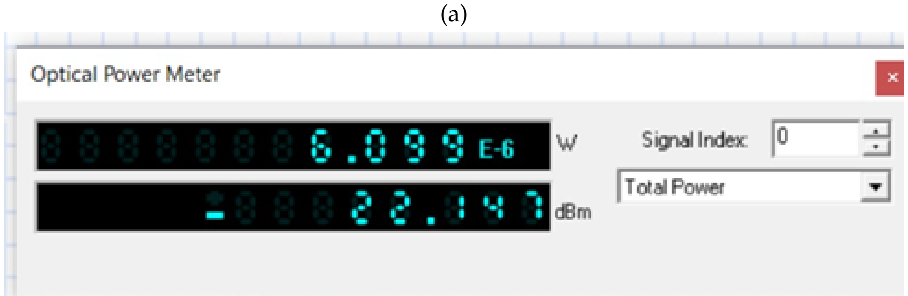
After the multiplexing process of the four wavelengths is completed, the signals containing the information are transmitted over the SMF cable and undergo optical power division at a ratio of 1x4. This power divider represents the Optical Distribution Center (ODC) in real conditions in the field. After power sharing, the transmission process continues over the SMF cable.

The distance from the multiplexer to the ODC and from the ODC to the Optical Distribution Point, respectively, is 10 km. This distance is determined based on several factors. These factors include field conditions, international standards, and optimal receive power for the photodetector. After transmission through the optical distribution point (ODP) 1×8, three types of measurements were performed in this research.

The first measurement uses an optical power meter (OPM) to measure the received power, the results of which are shown in Figure 4. The values recorded on the OPM for each of the receivers are relatively consistent, which indicates that the power divider provides an even and uniform distribution for each of the communication paths. Therefore, the results presented in this study are representative of 32 optical network units (ONU). The measured received power of -22.147 dBm is considered optimal [19], neither too high nor too low, considering that the photodetector specifications used have a minimum received power sensitivity of -27 dBm.



(a)



(b)

Figure 4: (a) Illustration of simulation for optical receiver and (b) The measured received by OPM.

3 Results

The performance evaluation of both the technologies FTTH and HFC results based on the Optisystem simulations, as the maximum distance capability for the WDM systems and the total number of subscribers that can be served up to the end user are shown in this section. The BER and Q-factor values and analysis are also presented.

3.1 HFC Performance Evaluation

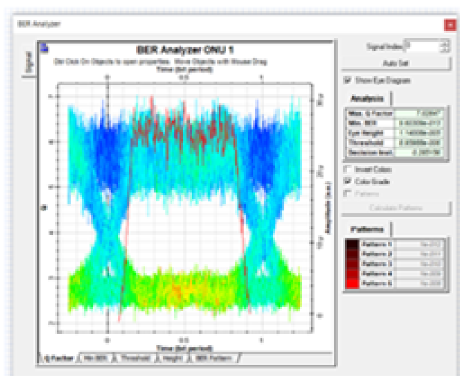
This research examines the performance of User Equipment (UE) selected based on its representativeness, focusing on BER and Q-factor, which are visualized in Figure 5. A homogeneous distribution of the received power is obtained by dividing the optical power with a ratio of 1x4 at the optical node (ODC) and 1×8 at the electrical branch (ODP). The BER and Q-factor analysis was performed separately for four UE groups: users 1 to 8, users 9 to 16, users 17 to 24, and users 25 to 32. The first group (users 1 to 8), which was connected through the optical node and the first branch, obtained a BER of 9.60×10^{-13} and a Q-factor of 7.02, indicating a superior transmission performance. These results indicate that the received power, which exceeds the minimum sensitivity limit of the electrical detector, makes it easier for the binary information to be detected. To increase the signal power, a 5 dB electrical amplifier was implemented in this study before the decoding of the information. The total number of connectors used was 5 pieces.

The second group (users 9 to 16), connected via the second optical node and ninth branch, recorded a BER of 8.7×10^{-14} and a Q-factor of 8.7, which also reflects excellent transmission performance. This confirms that optimal receive power supports precise binary information detection. The third group (user 17 to 24), which is connected via the optical node and the seventeenth electrical branch, produces a BER of 5.23×10^{-13} and a Q-factor of 7.11, which still exceeds the established performance standards. Meanwhile, the fourth group (users 25 to 32), connected via the twenty-fifth optical node and electrical branch, recorded a BER of 3.2×10^{-13} and a Q-factor of 7.07, indicating adequate transmission performance. Thus, this study shows that consistent and effective transmission performance can be achieved through appropriate receive power settings and the use of amplifiers to increase signal power, which contributes to the efficient detection of binary information in each UE. In addition, the average Q factor of a 32 UE HFC network and a transmission distance of 20 km is 7.475.

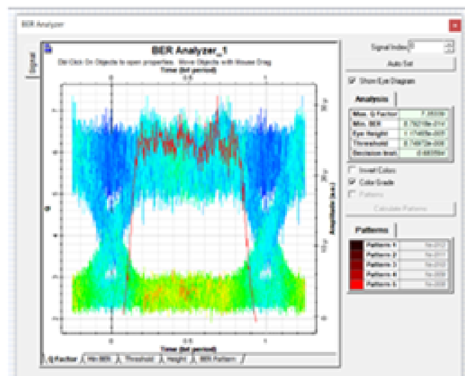
3.2 FTTH Performance Evaluation

To evaluate FTTH performance, the study focused on the BER and Q factor based on a representative selection of ONU, as shown in Figure 6. By dividing the optical power with a ratio of 1x4 for ODC and 1x8 for ODP, a uniform received power is obtained. The BER and Q-factor analysis are performed separately for four groups of ONUs, namely 1 to 8 as the first user, 9 to 16 as the second user, 17 to 24 as the third user, and the last one for users 25 to 32.

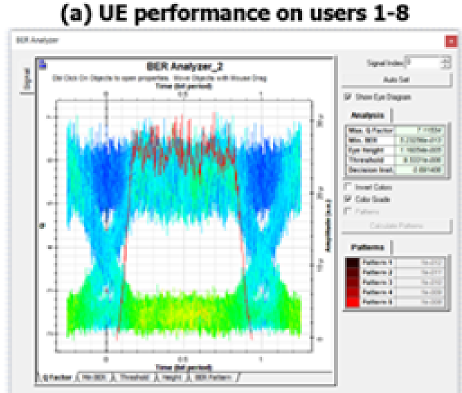
In the first group (users 1 to 8) connected via the first ODC and the eighth ODP, a BER of 2.4×10^{-40} and a Q-factor of 13.24. This indicates excellent transmission performance. The results for the first users indicate that a receiving power higher than the minimum sensitivity of the photodetector facilitates the process of detecting binary information. The



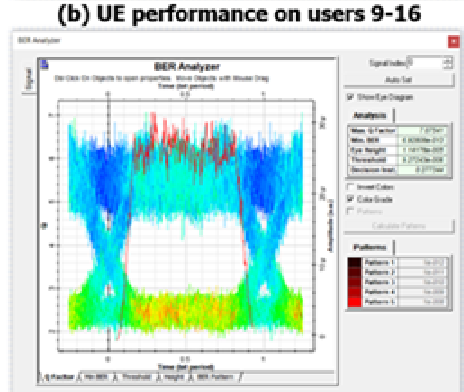
(a) UE performance on users 1-8



(b) UE performance on users 9-16



(c) UE performance on users 17-24

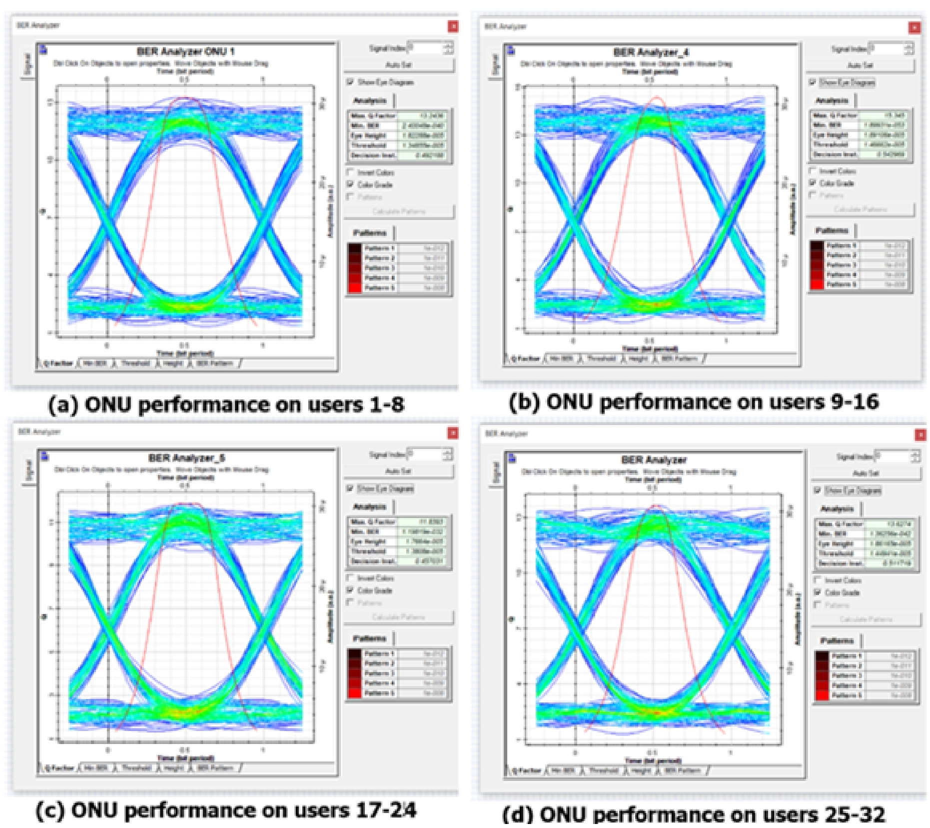


(d) UE performance on users 25-32

Figure 5: UE performance using BER and Q-factor.

noise that occurs after the Bessel photodetector and the transmission data can be overcome and reduced by using two Bessel filters. The second group (users 9 to 16) is evaluated using the same procedure as the first group. Here, a BER of 1.89×10^{-53} and a Q-factor of 15.3 were recorded when connected to the second ODC and the ninth ODP. This is an indication of excellent transmission performance and confirms that optimal receive power facilitates the accurate detection of binary information. The third group (users 17 to 24) performance evaluation, is connected via the third ODC and the seventeenth ODP. Here, the results are given with a BER of 1.1×10^{-32} and a Q-factor of 11.8. These results still exceed established performance standards. Finally, the fourth ODC and the twenty-fifth ODP are connected to the fourth group (users 25 to 32). It is recorded that the BER is 1.3×10^{-42} and the Q-factor is 13.62. This indicates that the transmission performance is reasonable.

Thus, the FTTH performance evaluation study can state that consistent and effective transmission performance can be achieved through appropriate receive power settings and the use of noise reduction filters, which are conducive to the efficient detection of binary information in each optical ONU. In addition, the average Q-factor of the FTTH network with 32 ONUs and a transmission distance of 20 km is 13.49.



(a) ONU performance on users 1-8
(b) ONU performance on users 9-16
(c) ONU performance on users 17-24
(d) ONU performance on users 25-32

Figure 6: ONU performance using BER and Q-factor.

4 Discussion

The performance evaluation and comparison results of FTTH and HFC technologies, as well as the comparison of simulation results with real-field measurement data, are discussed and presented in this section.

4.1 Comparison of FTTH and HFC Performance

Performance comparisons are carried out using the Q-factor, which is an indicator of signal quality in optical and copper communication systems. Higher values indicate better signal quality and lower error probability. BER measures the error that occurs during data transmission. Lower values indicate lower error rates and better transmission performance. The performance comparison between FTTH and HFC is illustrated in Table 3.

Table 3: Performance comparison between FTTH and HFC

Group	Q-factor(FTTH)	BER(FTTH)	Q-factor(HFC)	BER(HFC)
1-8	13.24	2.4×10^{-40}	7.02	9.60×10^{-13}
9-16	15.34	1.1×10^{-53}	8.7	8.7×10^{-14}
17-24	11.8	1.1×10^{-32}	7.11	5.23×10^{-13}
25-32	13.62	1.3×10^{-42}	7.07	3.2×10^{-13}

Table 3 shows that both technologies, FTTH and HFC, show excellent performance with high Q-factor and low BER. However, in general, the Q-factor value for FTTH is higher than that of HFC, which is an indication of better signal quality in FTTH. Meanwhile, the BER value for FTTH is lower, which is an indication of a lower error rate in optical data transmission of FTTH than HFC. This difference may be due to the inherent characteristics of each technology. FTTH has advantages in purely optical data transmission, while HFC optimizes the combination of optical and electrical transmission.

4.2 Comparison of Simulations and Real Data

Field measurements were obtained from PT. Link via observations sourced from field updates. The author collected various field measurement data to obtain BER and Q-factor values using mathematical calculations. Field tests were conducted to evaluate the agreement between the designed simulations and field measurements with similar configurations. The instrument used in this test is the JDSU DSAM XT A Wavetek Series Field Meter, which allows the performance to be evaluated by means of the BER test, as shown in Figure 7. Based on data from the field test, the tested configuration produces a BER of 10^{-9}, which means it's equivalent to a Q-factor of 6. Meanwhile, the simulation results show a minimum Q-factor of 7.11. This comparison shows that the similarity between the field and simulated results, or the measured field value is consistent with the simulated results. Therefore, it is concluded that the configuration used in the simulation can be applied with high confidence in the field test.

To strengthen the analysis of the design and measurements in the field, and to prove that the estimates were similar to the field data, we measured the electrical signal that had been converted by the photodetector using a JDSU DSAM Wavetek Series Field Meter. This

Figure 7: BER measurement in the field.

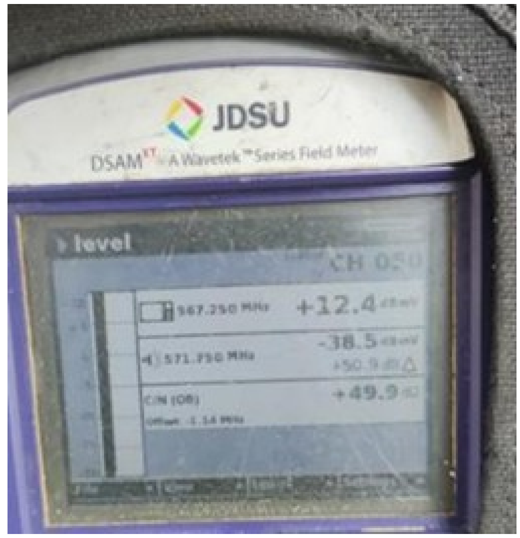


Figure 8: Measurement of the electric signal strength level in the field on channel 50.

instrument is used to measure the level of signals in a field application, such as a cable television network. The measurement results from this tool are as follows: downstream (DS) at 567.250 MHz is +12.4 dBmV, and upstream (US) at 571.750 MHz is -38.5 dBmV. The carrier-to-noise values for DS and US are C/N (DS) +50.9 dB and C/N (US) +49.9 dB, respectively, as shown in Figure 8. This display shows the downstream and upstream frequencies and their signal levels in dBmV, as well as the carrier-to-noise ratio for the downstream and upstream signals in decibels (dB). Although the current version of OptiSystem simulation does not have automatic C/N measurement, the results of this measurement prove that the proposed topology will produce values similar to the existing field configuration.

Figure 9 shows a portable electronic measuring instrument known as the DSAMXT JDSU Series Field Meter. This tool displays various settings and measurements on its screen, which is very important in testing or measuring signals in the telecommunications field. The information displayed includes a downstream frequency of 112,250 MHz with a signal level of +9.6 dBmV and an upstream frequency of 116,750 MHz with a signal level of -40.4 dBmV. Additionally, the signal-to-noise (C/N) ratio for the downcurrent and upcurrent were both recorded at +50.0 dB. This C/N ratio of 50 dB is a very good quality indicator, exceeding digital communications standards which are generally above 20 dB. This indicates that the signal strength measured by the tool is much greater than the noise level, which is key information in determining efficient and reliable telecommunications network performance.

The comparative analysis between the field data and the simulation results has been carried out by considering parameters such as BER and Q-factor as shown in Table 4. The results of field measurement analysis for HFC technology show that the highest BER value is 1.9×10^{-9} and the lowest Q-factor value is 6.022. Meanwhile, in FTTH, the highest BER value is 2.3×10^{-9} and the lowest Q-factor value is 7.12. Thus, there is a difference of around 38.5% between the measured BER results and the simulation results and a difference of about 18.5% between the Q-factor of the measured results and the simulation results. This difference was not considered significant, indicating that the simulation results provide a fairly accurate representation of field conditions. However, it should be noted that simulations may not fully reflect complex natural conditions. Therefore, although the simulation results show good suitability, it is still important to perform further validation in the field to ensure the reliability of the proposed design. The analysis and comparison of the efficiency, quality, and reliability of the FTTH network using HFC was performed by observing the simulation results generated by Optisystem. Since the simulation is more detailed in transmission measurements, the efficiency is obtained from how much efficiency HFC has on FTTH. In addition, the quality and reliability of HFC systems are significantly impacted by noise and interference.

Figure 9: Measurement of the electric signal strength level in the field on channel 2.

Table 4: Comparison of BER and Q-Factor values from simulation results and real measurements in the field between FTTH and HFC

Node	Measurement Results in Simulation				Field Measurement Results			
	HFC		FTTH		HFC		FTTH	
	BER	Q-Factor	BER	Q-Factor	BER	Q-Factor	BER	Q-Factor
1-8	9.60×10^{-13}	7.02	2.4×10^{-40}	13.24	1.9×10^{-9}	6.051	4.6×10^{-11}	7.94
9-16	8.7×10^{-14}	8.7	1.1×10^{-53}	15.34	2.0×10^{-9}	6.022	9.3×10^{-10}	8.18
17-24	5.23×10^{-13}	7.11	1.1×10^{-32}	11.8	1.9×10^{-9}	6.052	5.4×10^{-10}	7.12
24-32	3.2×10^{-13}	7.07	1.3×10^{-42}	13.62	2.0×10^{-9}	6.025	2.3×10^{-9}	7.92

5 Conclusion

By using Optisystem simulation for HFC technology, it is obtained that the highest BER value was 5.23×10^{-13} and the lowest Q-factor was 7.11, while for FTTH technology the highest BER value was 7.9×10^{-9} and the lowest Q-factor was 11.08. The field measurement results show that for HFC technology, the highest BER value was 1.9×10^{-9} and the lowest Q factor was 6.022, and for FTTH technology, the highest BER value was 2.3×10^{-9} and the lowest Q factor was 7.12. For both technologies, FTTH and HFC it can support a transmission distance of 20 kilometers with a 4-wavelength WDM system, 32 end users can be served. The results of the measurements, both in the Optisystem software simulation and in the field measurements, met the reliability standards for signal quality. The BER value did not exceed the maximum limit of 10^{-9} and the Q-factor value exceeded the minimum limit of 6. It can be concluded that HFC and FTTH technology are capable of providing efficient and high-quality communication services. However, it should be noted that the simulation may not fully reflect the complex natural conditions. Therefore, although the simulation results show good suitability, it is still important to perform further validation in the field to ensure the reliability of the proposed design. In the future, the Master of Electrical Engineering program at the Catholic University of Jakarta and PT Link will continue this collaborative research and focus on how to achieve higher transmission speeds and improve system reliability in FTTH.

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