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Performance Analysis of Hybrid Optical Access Networks That Combine Fiber to The Home (FTTH) and Radio Over Fiber (RoF) Using Wavelength Division Multiplexing (WDM) for Network Efficiency

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ABSTRACT

Today, people's need for communication has increased and telecommunication services have become basic needs in life. Therefore, broadband transmission system services are needed to support the quality of information flow between customers and the number of customers need access to available information. Fiber optic communication system is one that can be used to overcome these problems because it is very efficient and has high bandwidth. This system has several types of applications including for Fiber to the Home (FTTH) and Radio over Fiber (RoF). Usually, these two network systems are built separately, so the study of merging these two systems into a hybrid network is needed for future network efficiency. In previous research, several types of network combinations were carried out using the same wavelength, so they had to create separate components. In this research, a hybrid network design simulation was carried out using optisystem software that combines FTTH and RoF using Wavelength Division Multiplexing (WDM) so that only need to utilize existing components, then performance analysis was carried out in the form of power, Q factor, and Bit error rate (BER). WDM was chosen for several considerations, including increasing capacity, reducing costs, flexibility and scalability. The network is simulated using an OptiSystem, there is an FTTH system from transmitter to receiver consisting of OLT, ODF, ODC, ODP, to the ONT or customer device. Then there is the RoF system to support Wireless Gigabyte (WiGig) communications using QAM modulation. From the simulation carried out by varying the length of the fiber cable, the results of the FTTH network can be said to be suitable for meeting good performance parameters where the simulated performance value in the form of Q factor meets the performance feasibility standard of 6 and the BER is above 10^{-9}, while the RoF at long certain cable system performance has not met feasibility. But overall, the hybrid system using multiplexing offered can work with the expected performance.

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1. INTRODUCTION

The need for communication is growing, and having access to telecommunications services is now considered essential [1]. Customers' growing demands for more bandwidth and a rise in customer numbers are the reasons behind this increase [2]. The proliferation of tablets and smartphones, which facilitate multimedia services, has increased the demand for bandwidth [3]. With the aim of reducing air interface length and offering dependable broadband services that can support communications services, a number of methods are being researched for upcoming 4G, 5G, and 6G networks [4], [5].

Broadband transmission system services are crucial to the current state of information technology development because they support both the quantity and quality of information that users can access [6], [7]. Given the growing needs of today's society for services, telecommunication technology that can deliver high-quality service performance is essential. There are many different types of technologies utilized in telecommunications, such as data, video, and audio telecommunications, or what is commonly called the internet [8]. For a large number of users, the network infrastructure should offer an affordable, widely available, high data rate solution. Smooth communication operations and the support of digital transformation depend on an effective communications network infrastructure [9]. Information security considerations must be made while creating a communications network infrastructure that is effective. The infrastructure of a communications network can operate more efficiently when technology is used properly. While choosing a technological system, it's crucial to take operating and installation costs into account [10].

One solution for these issues is the adoption of optical fiber communication systems, which also have the benefit of having a high information carrying capacity, making them the primary element of modern telecommunications [11]. The optical fibre communication system, established in 1970, has been widely used in new applications and installations [12]. It is possible to supply television, internet, and phone services using optical transmission. Optical transmission is becoming more and more popular as a means of satisfying consumer demand for telecommunications services due to its high bandwidth and efficiency [13]. This system has several types of applications, including for Fiber to the Home (FTTH) and Radio over Fiber (RoF) [14].

Fiber to the Home (FTTH) is an access network that makes use of fibre optic cables, which can be used to distribute transmission medium to houses of subscribers. Pulling optical wires from the centre near the customer's house is feasible using a Local Access Fiber Network architecture (OLT) [15], [16]. FTTH networks are more reliable than other internet networks and can extend over large distances without sacrificing quality, they are very popular [17]. Other benefits of FTTH networks include high internet speed and a consistent connection [18]. FTTH technology continues to develop to improve service quality, including the use of an automatic network planning system aimed at customer satisfaction & cost effectiveness [19].

Radio over Fiber (RoF) is a method of sending radio signals using optical fibre cables [20]. The use of optical fibre cables as transmission media will result in transmission speeds that are far faster than those achieved when using coaxial cables [21]. RoF can be used as a solution to improve the efficiency of the communication process by using a more effective networking system [22]. This is especially useful in reducing the amount of data lost during communication, especially in a regulated environment where there is a high loss of bandwidth and a small amount of Reduced Environmental Impacts [23]. Originally designed for long-distance data transfer, RoF research has shifted its focus to tackling bandwidth limitations in mobile network connections between towers and the core network. This shift is driven by the potential of RoF's centralized control system to enable more advanced coordination features in future mobile networks [24]. Nowadays, there is a growing need for broadband services that make use of Radio over Fiber (RoF) technology. The most effective method for delivering high-speed services has been seen to be the integration of wireless and wireline services [25]. Therefore, it will play a key role in the next generation or future mobile communication technologies [26].

Systems for fibre to the home (FTTH) and radio over fibre (RoF) are promising options for wireline and wireless access networks, respectively. While FTTH transmits Baseband (BB) signals, ROF will send Radio Frequency (RF) signals [27]. The integration of two dispersed networks into a single common infrastructure is necessary due to the inefficiency of separate optical access networks. The primary goal is to efficiently and with respectable performance transmit BB and RF signals at various wavelengths across a single cable [28]. The technique will function effectively to provide wide bandwidth for both FTTH systems and wireless access in the future. Therefore, the author is interested in proposing hybrid network performance analysis research for cable service transmission on RoF and FTTH by utilizing an available FTTx network [29].

Several previous studies have carried out hybrid network simulation experiments using different methods. Ilham Bayu Prabowo (2016) used simultaneous modulation and transmission of ON-OFF keying (OOK) BB signals. The results obtained showed the feasibility of a network with a BER of 5.8672 x 10^{-34}, Li (2021) [30] conducted research on hybrid signal networks Digital (BB) and analogue radio frequency (RF) signals simultaneously delivered at a single wavelength are demonstrated for high-capacity wired and wireless optical access networks. So, it is still necessary to analyse the modulation and transmission performance of Baseband and RF signals separately with different wavelengths on one simple and efficient transmission channel without decreasing performance [31]. In this paper, performance analysis was carried out on a hybrid network that combines Fiber to the Home (FTTH) and Radio over Fiber (RoF) using wavelength division multiplexing

(WDM) using several parameters such as power, Q factor, and bit error rate (BER) [32], [33]. The proposed method is simulated and analyzed using OptiSystem software.

Kareem presents an overview of the challenges of fiber optic communications. This research offers an outline of the area most relevant for future advances in optical communications. The discovery of modern integrated optics and fiber optics occurred in the field of optical equipment and components [34]. Network architectures that utilize multiple wavelengths per optical fiber are used in central, metropolitan, or wide-area applications to connect thousands of users at varying transmission speeds and capacities. An advanced feature of optical communication links is that they transmit multiple wavelengths over the 1300 to 1600 nm fiber range simultaneously [35].

In previous research, hybrid networks were simulated by combining BB and RF signals at one wavelength so it was necessary to create a new component circuit to integrate the two signals. This research proposes combining the two signals using existing components in the optisystem, namely Wavelength Division Multiplexing (WDM), so that the proposed hybrid network is more efficient. In previous research on hybrid networks that combine baseband and RF signals, the results showed that the power value on the baseband signal tended to be stable, while on the RF signal the power value experienced fluctuations at certain cable lengths [36]. The development of this power value then also affects the value of the Q factor and BER. Meanwhile, previous research related to WDM shows almost similar results, namely that the FTTH performance value can be said to meet standards, while the rof value experiences fluctuations in several cable length values [37].

FTTH-RoF hybrid optical access networks offer a compelling solution to deliver high-speed, reliable and scalable internet access to a wide range of users. This unique hybrid architecture provides many benefits, including flexibility, scalability, broad coverage, efficient resource utilization, centralized management, support for advanced services, and future-ready infrastructure. This network is predicted to play an important role in meeting the growing demand for high-quality internet connectivity in the future.

FTTH-RoF hybrid optical access networks with WDM offer an attractive solution to deliver high-speed, reliable and scalable internet access. However, it is important to consider the challenges and drawbacks before implementing this solution. Some of these are increased hardware complexity, high initial costs, and power management difficulties. With continuous technology development and innovative solutions, FTTH-RoF hybrid networks with WDM can become a more attractive option for various deployment scenarios in the future.

Two proposed scientific contributions are made in this paper. First, use Wavelength Division Multiplexing (WDM) to simulate and assess the performance of a hybrid optical access network that combines FTTH and RoF. The second contribution of this paper is recommendations for a deployment plan of this hybrid optical access network based on the evaluation results.

This is how the remainder of the paper is structured. The study framework, simulation parameter, and performance parameter for the hybrid optical access network are presented in Section 2. The simulation results on each parameter are compiled and evaluated in Section 3, where recommendations and research limitations are also covered. This paper is finally concluded in Section 4.

2. METHODS

Three topics are covered in this section: performance parameters, simulation parameters, and research framework. The system modelling of this study are presented in the framework. Values for simulation parameters are grouped according to specifications. Performance metrics make advantage of standard-compliant provisions.

2.1. Research Framework

In this paper, a hybrid optical access network was designed that combines a Fiber to the Home (FTTH) system which has a Baseband (BB) signal input and Radio over Fiber (RoF) which has a Radio Frequency (RF) signal input [38]. The combination of these two systems was carried out using the Wavelength Division Multiplexing (WDM) technique which was simulated with 3 variations in the number of channels to determine the feasibility of the performance of each system. Simulation variations on the three types of WDM channels are very important to understand the characteristics of different WDM channels, optimize WDM network performance, predict WDM network performance under different conditions, and ensure WDM network reliability. A simple system model is shown in Fig. 1.

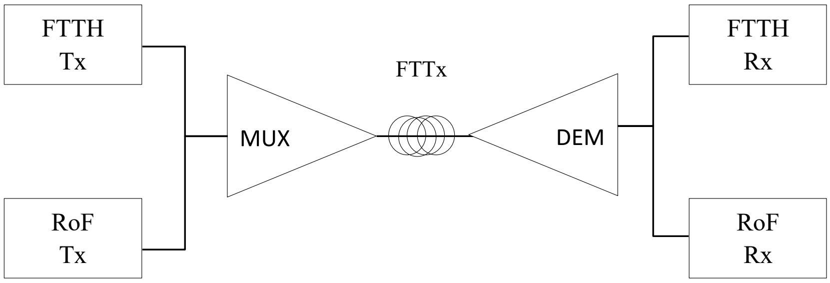


Fig. 1. System model

The system design was carried out by simulation using OptiSystem Software. OptiSystem is fiber optic network simulation software that is powerful and easy to use. This software has many advantages, such as ease of use, accuracy, flexibility, visualization capabilities, and community support. However, OptiSystem also has several obstacles, such as complexity, system requirements, and lack of some features. The system design consists of several stages, namely literature study, system modeling, parameter setting, performance testing and analysis of simulation results. System performance is analyzed based on several feasibility parameters including power, Q factor, and BER [39].

This design begins with collecting data related to the simulation design to be used as a research sample. After all the relevant data is obtained, the next step is to simulate the network with software, where the network is designed from sender to receiver. After that, parameter settings are carried out to obtain appropriate performance results. In this system modeling, there is an FTTH system from transmitter to receiver consisting of OLT, ODF, ODC, ODP, right up to the ONT or customer device [40]. Then there is a RoF system to support Wireless Gigabyte (WiGig) communications. The WiGig specification is based on the IEEE802.01 standard which is the standard for hundreds of millions of devices. This WiGig standard supports communication devices running at the 60 GHz frequency. Then the RoF network is multiplexed with an FTTH network using Wavelength division multiplexing (WDM) with three channel variations, namely 2×1, 4×1, and 8×1. The RoF network is superimposed with the FTTH network until it is finally demultiplexed before arriving at the ODP device. From this model, a network is simulated at a certain distance from the center to the settlement with one ODC and one distribution. This can save network models by combining two types of networks in one transmission channel [41].

2.2. System Modelling in OptiSystem

This system is designed from the sender point to the customer point using OptiSystem software. This Optisystem software is easier to obtain so that the system can be simulated and calculated loss on optical devices without incurring high costs, and will obtain a level of calculation accuracy.

2.2.1. Fiber to the Home (FTTH) system model

In Fig. 2 is the designed FTTH system circuit. In this circuit, the system is divided into 4 blocks, the first of which is Optical Line Termination (OLT) using Binary Phase Shift Keying (BPSK) modulation on Pseudo Random Binary Sequence (PRBS) with a Bit Rate used of 2.5 Gbps. then forwarded to the Non-Retun to Zero (NRZ) block to modulate the signal according to the standard limit of 70%. The signal from the Non-Retun to Zero (NRZ) Block is modulated on the Mach Zehnder modulator with an Extraction Ratio of 8.2 dB according to the ITU-T G.984.2 standard and then the signal is superimposed on the light beam produced by the CW Laser with a Frequency of 1550 nm and Power 5 dBm as Carrier signal. The transmitter in Optical Line Termination (OLT) uses the External Modulated Laser (EML) type [42].

From the Optical Line Termination (OLT), a core patch cable is used with a connection that has an attenuation of 0.5 dB and a connector that has an attenuation of 0.25 dB, then it is connected to an Optical Distribution Cabinet (ODC) with a 1:4 Splitter which has an attenuation of 7.25 dB. Before going to block 2, namely the Optical Distribution Panel (ODP) using G.652.D Distribution cable which has an attenuation of 0.3 dB/Km. On the ODP there is a 1:8 splitter with attenuation of 10.3 dB per port. Next, go to block 3, namely Optical Network Terminal. From the ODP to the ONT, a single core G.657.A Dropcore cable is connected with an attenuation of 0.3 dB/Km. in block 3 there are two connectors and one connection which has an attenuation of 0.25 dB for the connector while the connection is 0.5 dB. Supporting components determine attenuation using an Optical Power Meter (OPM) [43]. And find out the BER value using the eye analyzer diagram [44].

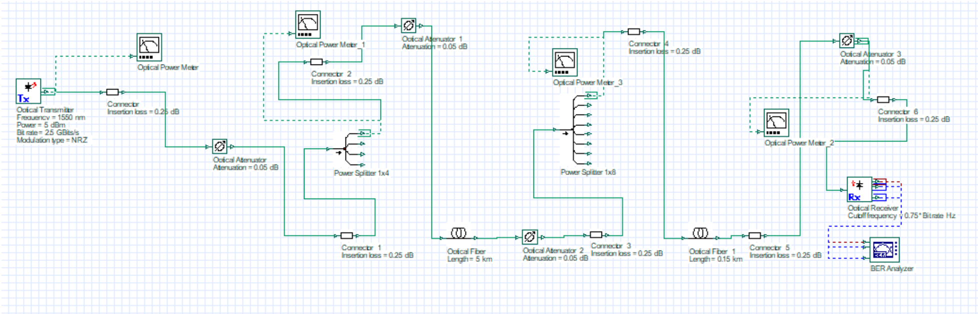


Fig. 2. FTTH system model

2.2.2. Radio over Fiber (RoF) system model

As shown in Fig. 3, a number of simulations are used in this paper to model the Radio Over Fiber (ROF) system. The simulation series includes an electrical power meter, a quadrature modulator, a 3R generator, a BER analyser, an eye diagram analyser, an optical fibre, a photodetector PIN, a band pass bessel filter, an optical spectrum analyser, two RF spectrum analysers, an oscilloscope visualizer, and a pseudo-random bit sequence generator. This simulation setup utilizes external modulation where digital information signals are generated by a PRBS with a bit rate of 2.5 Gbps. The information signals are then modulated using QAM with a frequency of 60 GHz and bits per symbol of 2, 4, and 6. Subsequently, they are transmitted back to a Mach-Zehnder modulator (MZM), which converts the electrical signals into optical signals and modulates them with a CW LASER with a frequency of 1550 nm and an input power of 10 dBm used externally. The optical output from the MZM is then transmitted through an optical fibre, which serves as the transmission medium in this external modulation system model. In the receiver section, the device receiving the information signals from the transmitter consists of a Band Pass Filter with a frequency of 60 GHz and a bandwidth of 3.75 GHz. The output from the filter is demodulated using a quadrature demodulator with a cutoff frequency of 7.25 GHz, and the performance results are displayed on a BER analyser component.

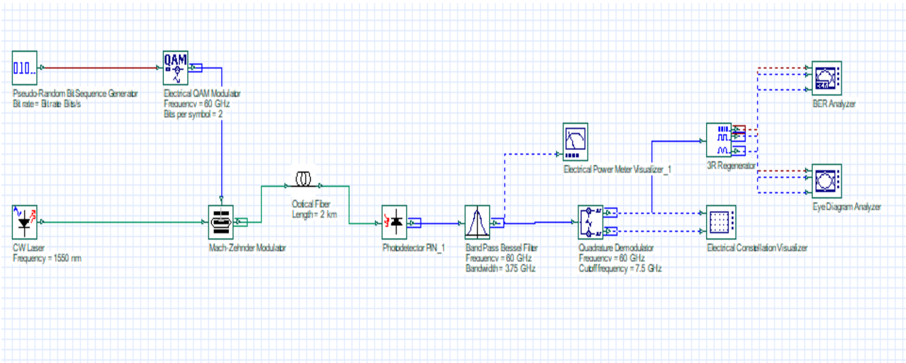


Fig. 3. RoF system model

2.2.3. Hybrid optical access system model

The FTTH and RoF networks that have been designed are multiplexed using Wavelength division multiplexing (WDM) with three channel variations, namely 2×1, 4×1, and 8×1. The purpose of these channel variations is to compare the extent to which the designed network can work at the expected performance. Fig. 4 shows a hybrid network model with 2×1 WDM channels. Simulations were carried out with channel spacing 1 with an FTTH wavelength of 1550 nm and RoF of 1551 nm.

Fig. 5 shows a hybrid network model with 4×1 WDM channels. In this model the network is designed with 1 input and 1 FTTH output, while the rest is for RoF. This is in accordance with the real situation where there will only be 1 FTTH transmitter in one area and there can be several transmitters in RoF if there are different providers. Simulations were carried out with channel spacing 1 with an FTTH wavelength of 1550 nm and RoF of 1551 nm, 1552 nm, 1553 nm.

Fig. 6 shows a hybrid network model with 8x1 WDM channels. This model is the same as the concept of the 4×1 channel. Simulations were carried out with channel spacing 1 with an FTTH wavelength of 1550 nm and RoF of 1551 nm, 1552 nm, 1553 nm, 1554 nm, 1555 nm, 1556 nm, 1557 nm.

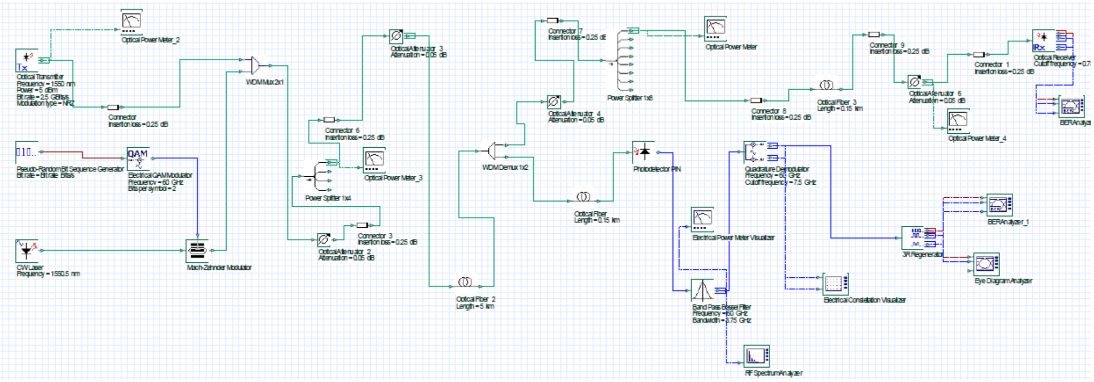


Fig. 4. Hybrid optical access network model with 2×1 WDM channel

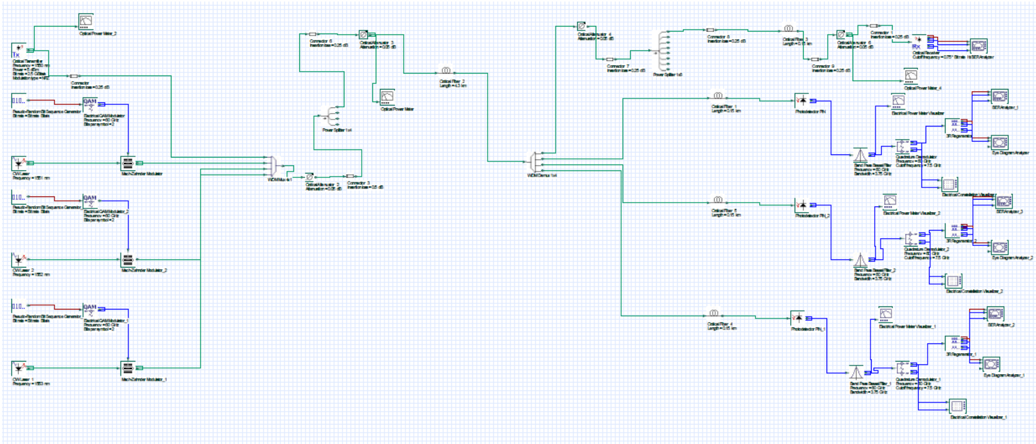


Fig. 5. Hybrid optical access network model with 4×1 WDM channel

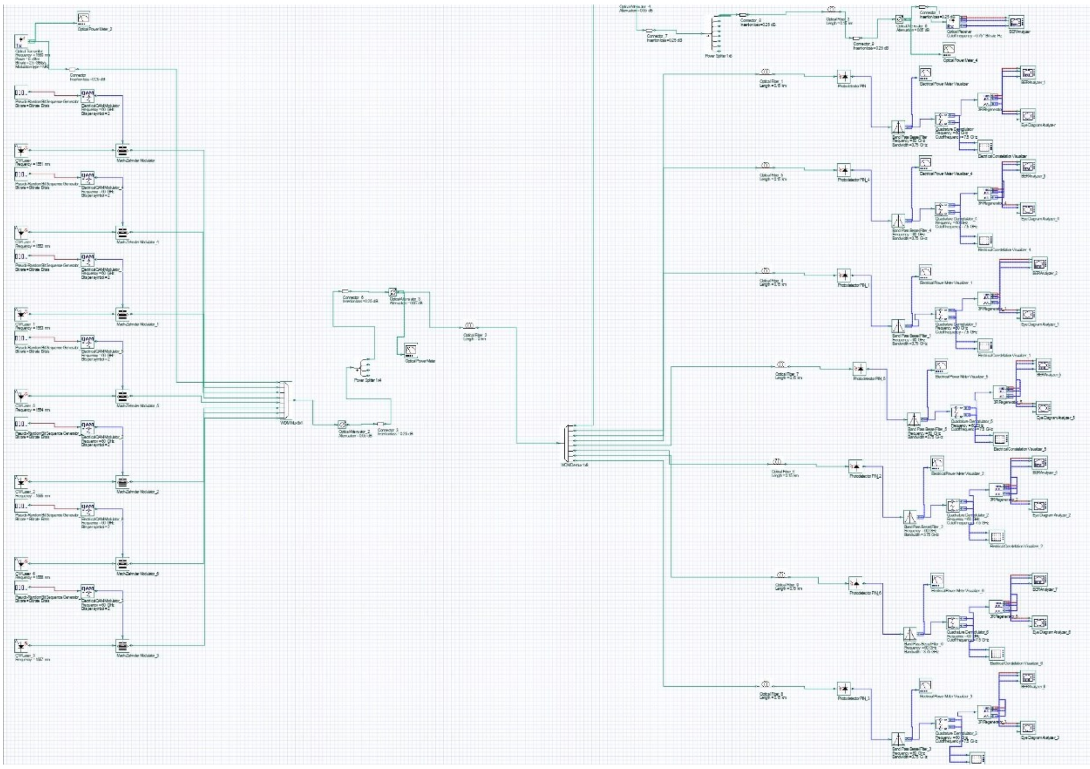


Fig. 6. Hybrid optical access network model with 8×1 WDM channel

2.3. Performance Parameter

Some of the test parameters used in this research are as follows:

2.3.1. Bit Error Rate

Bit-Error-Rate (BER), which is the ratio of the number of error bits to the total number of bits communicated during the communication process, is a statistic used to assess the performance of a communication system [45]. The need for BER varies for each application, some data communications require a BER equal to or better than 10^{-12}, BER for optical communication systems is 10^{-9}.

2.3.2. Quality Factor (Q-Factor)

Quality factor (Q-factor) in radio over fiber is a calculation of overall system quality that simplifies measurements of SNR (Signal-to-Noise Ratio) and calculations of BER. Q-factor represents the SNR for an optical communication system and a simplified system performance analysis. The Q-factor can also be optimized to improve the performance of the radio over fiber system in terms of input optical signals and output electrical signals [46]. A higher Q-factor indicates better signal quality [47].

2.3.3. Constellation Diagram

A constellation diagram is a vector depiction that represents a complex projection of the signal in the form of amplitude and phase of the signal transmitted by the modulator in the perpendicular axis direction [48]. This constellation diagram displays points on a complex plane that represent the state of the signal at a particular time. The amplitude and phase of each modulation symbol on RoF can be represented in a two-dimensional diagram known as a constellation diagram. As mentioned earlier, modulation in RoF transmits digital information by periodically varying the phase and amplitude of sinusoidal electromagnetic waves [49].

3. RESULTS AND DISCUSSION

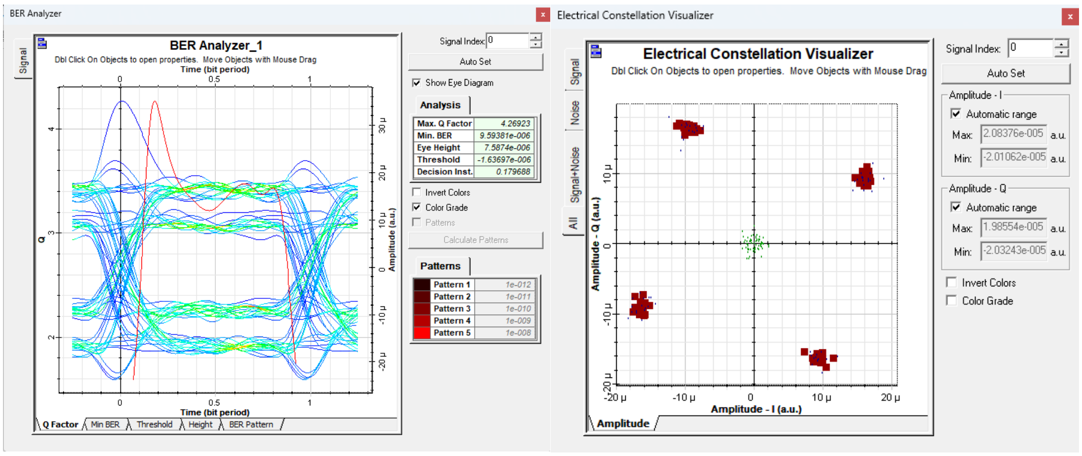
This section mainly consists of three parts: simulation results, constellation diagram arrangement, and overall performance evaluation. Section 3.1 present the process of setting up constellation diagrams to get maximum performance results. Section 3.2 present result of measurement of quality factor (Q-factor). Section 3.3 present result of measurement of Bit Error Rate (BER). Section 3.4 discusses overall performance evaluation.

3.1. Constellation Diagram Setting

A constellation diagram is a vector depiction that represents a complex projection of the signal in the form of amplitude and phase of the signal transmitted by the modulator in the perpendicular axis direction. This constellation diagram displays points on a complex plane that represents the state of the signal at a particular time. To determine the optimal performance for a particular RoF system, a certain phase shift is required to produce maximum Q factor and BER in the RoF system. This phase shift is carried out based on looking at the measurement results of the constellation diagram. Constellation diagrams are one of the important visualization tools in OptiSystem software. This diagram is used to represent optical signals transmitted in fiber optic networks. Constellation diagrams usually consist of a number of points spread across a two-dimensional plane. Each point represents the amplitude and phase value of the optical signal at a certain time. The position and shape of the points on a constellation diagram provide information about the characteristics of the optical signal. Closer dots indicate a stronger signal, more spread-out dots indicate a noisier signal, Dots that are not well positioned indicate distortion in the signal.

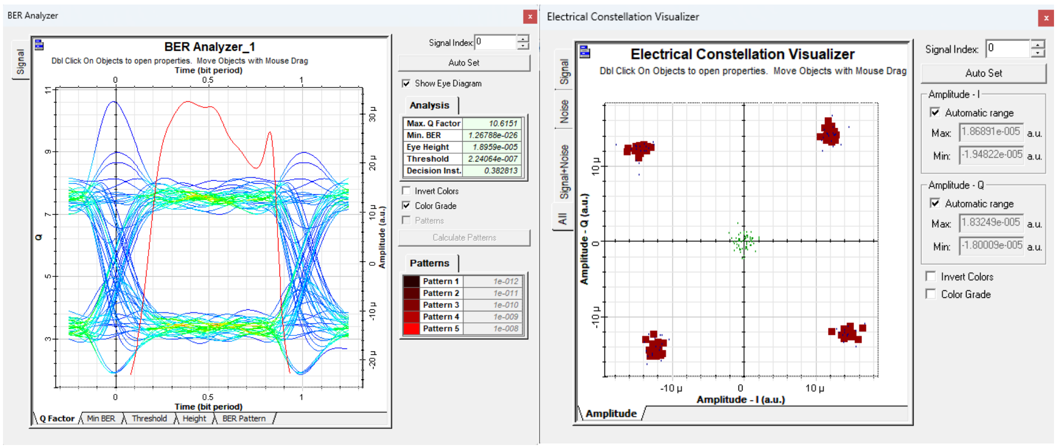
In order to improve the performance of the proposed hybrid network, several phase adjustments are needed in the constellation diagram so that the Q factor and BER results can meet the desired standards. For example, in a hybrid network simulation with 2×1 WDM channels on a fiber length of 1 km, the results obtained were a q factor of 4.26293 and a BER of 9.59×10^{-6} and then when checked the constellation diagram showed the results as shown in Fig. 7.

These results certainly do not meet the performance standards for optical network systems, so based on observations on the constellation diagram, a phase shift of -20 is required to obtain maximum results. From Fig. 8 it can be seen that after the phase shift was carried out in the constellation diagram, the Q factor and BER values were 10.6151 and 1.26×10^{-26}, which values met the system performance standards. This phase shift applies to almost every fiber length variation if the performance value does not meet the standard. The value of the phase shift depends on the needs of observing the constellation diagram.



(a) (b)

Fig. 7. (a) Q factor and BER results, and (b) constellation diagram of hybrid network with 2×1 WDM channels before phase adjustment

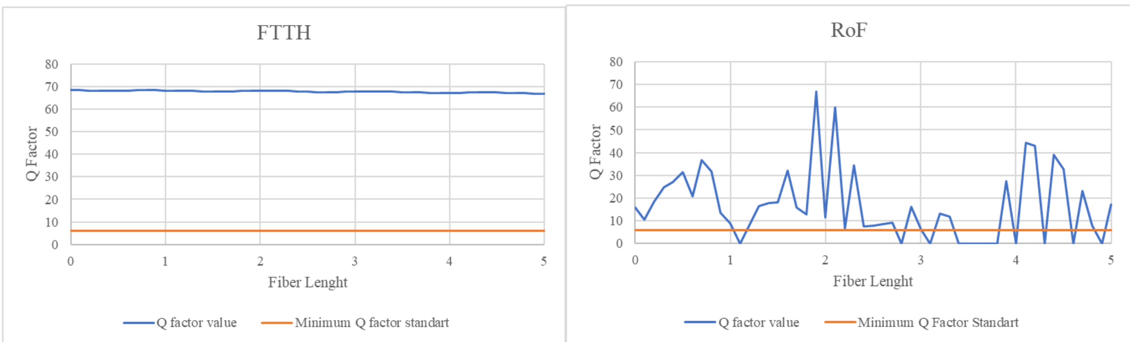


(a) (b)

Fig. 8. (a) Q factor and BER results, (b) constellation diagram of hybrid network with 2×1 WDM channels after phase adjustment

3.2. Result of Quality Factor (Q-Factor)

Fig. 9 displays a graph of performance simulation results in the form of quality factors on a hybrid network using 2×1 channel WDM for each system.

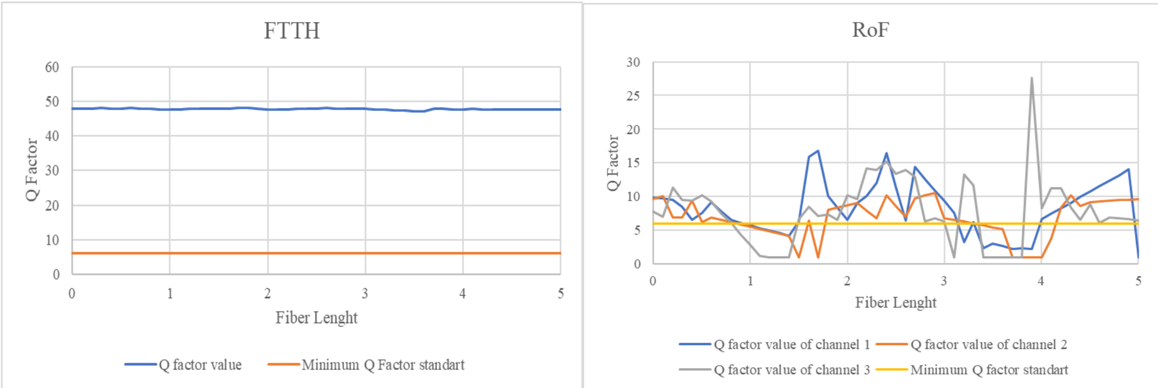


(a) (b)

Fig. 9. Graph of Q factor measurement results for (a) FTTH, and, (b) RoF network with 2×1 WDM channels

The blue line displays the measurement results of Q factor on the FTTH dan RoF system. The results of the Q factor show that the FTTH system performance is always above standard. This is in accordance with previous research where the FTTH system with a cable length of 0-5 km has performance above the standard [50]. Meanwhile the RoF performance is fluctuates with a value range of 66,712 to 68,362. This value meets the minimum Q factor standard in optical network, which is 6 shows in orange line. It can be seen that at certain cable lengths the system displays inappropriate results up to a value of 0, namely when the cable length is 1.1 km, 2.9 km, 3.1 km, 3.4 km - 3.8 km, 4 km, 4.3 km, 4.6 km, and 4.9 km. This is in accordance with previous research where the performance of RoF systems with a frequency of 60 GHz will decrease at fiber lengths of 1, 3, and 5 km. However, overall system can work properly with the q factor value at range 6,314 to 66,983.

Fig. 10 displays a graph of performance simulation results in the form of quality factors on a hybrid network using 4×1 channel WDM for each system.

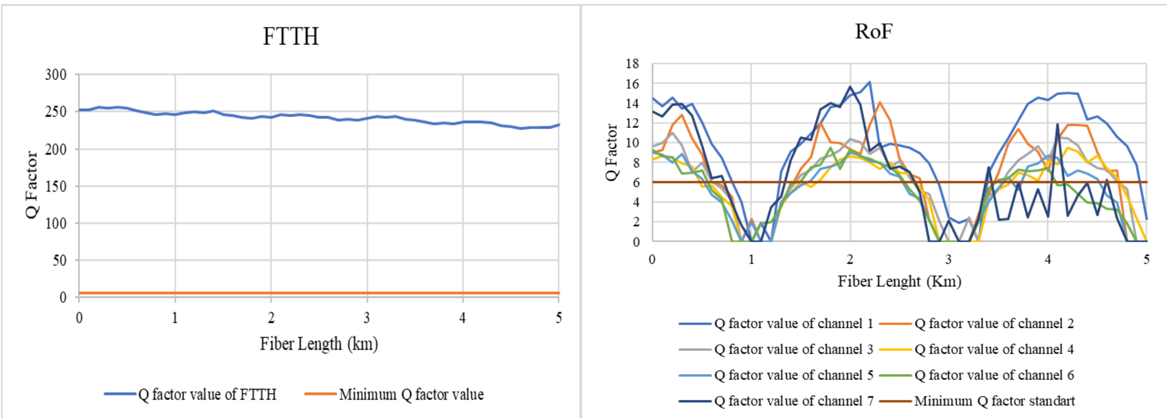


(a) (b)

Fig. 10. Graph of Q factor measurement results for (a) FTTH, and (b) RoF network with 4×1 WDM channels

From this graph it can be seen that the quality factor value of the FTTH system works very well in the value range of 47.584 - 47.937. Meanwhile for RoF, just like the simulation on a 2×1 WDM channel, there are Q factor values that do not meet the standards at certain fiber distances, namely when the cable length is 1 km - 1.4 km, 3.2 km, 3.4 km – 3.9 km, and 5 km at channel 1. When the cable length is 0.9 km – 1.7 km, 3.3 km – 4.1 km at channel 2. And when the cable length is 0.9 km – 1.4 km, 3.1 km, 3.4 km – 3.8 km at channel 3. But in general, the system has a decent Q factor value above 6. This shows that the performance of 4x1 WDM system is almost the same as 2×1 WDM.

Fig. 11 displays a graph of performance simulation results in the form of quality factors on a hybrid network using 8×1 channel WDM for each system.



(a) (b)

Fig. 11. Graph of Q factor measurement results for (a) FTTH, and (b) RoF network with 8×1 WDM channels

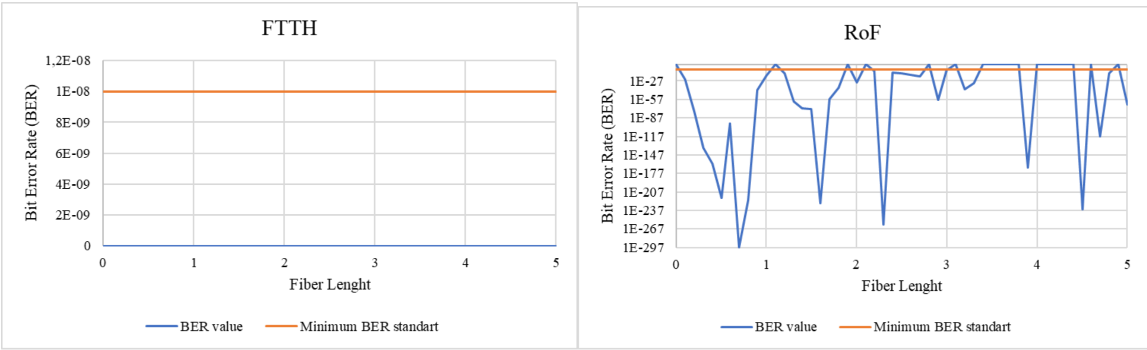
This graph shows that the FTTH system's quality factor value operates most effectively in the range of 252.37 to 231.83. In the meanwhile, RoF has a respectable Q factor value above 6, however like the simulation on a 2×1 and 4×1 WDM channel, there are some Q factor values that fall short of the requirements at specific fibre distances. Namely when the cable length is 0.9 km – 1.2 km, 2.9 km – 3.3 km, 5 km at channel 1. When the cable length is 0.7 km – 1.4 km, 2.8 km – 3.4 km, 4.8 km – 5 km at channel 2. When the cable length is 0.7

km – 1.4 km, 2.7 km – 3.5 km, 4.8 km – 5 km at channel 3. When the cable length is 0.5 km – 1.4 km, 1.6 km, 2.7 km – 3.6 km, 4.8 km – 5 km at channel 4. When the cable length is 0.6 km – 1.5 km, 2.6 km – 3.5 km, 4.6 km – 5 km at channel 5. When the cable length is 0.6 km – 1.4 km, 2.6 km – 3.4 km, 4.1 km – 5 km at channel 6. When the cable length is 0.8 km – 1.3 km, 2.7 km – 3.6 km, 3.8 km – 4 km, 4.2 km – 4.5 km, 4.7 km – 5 km at channel 7. This shows that the performance of 8x1 WDM system is almost the same as 2×1 and 4×1 WDM.

There are several factors that can cause the RoF Q-factor not to meet standards on only some fibre cable lengths. For example, due to the phenomena of dispersion, attenuation, and impedance mismatch. By understanding these factors and applying appropriate techniques, it is possible to overcome these problems and improve RoF system performance.

3.3. Result of Bit Error Rate (BER)

Fig. 12 displays a graph of performance simulation results in the form of BER on a hybrid network using 2×1 channel WDM for each system.

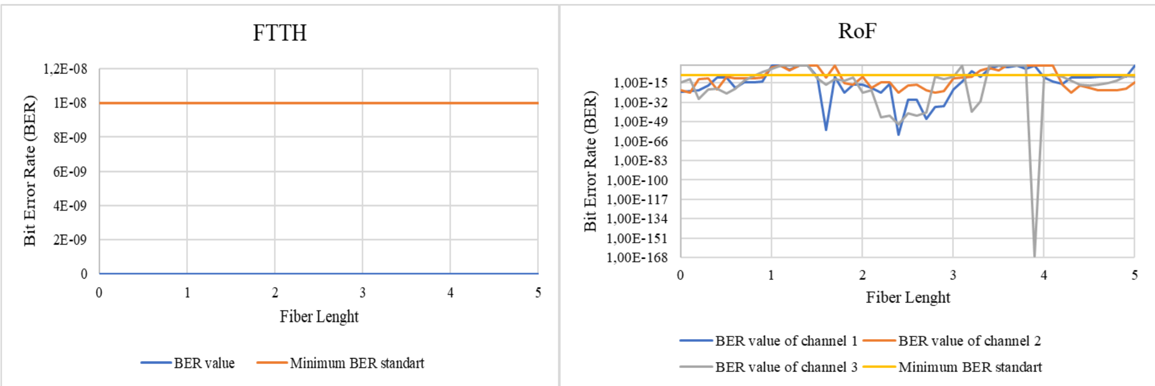


(a) (b)

Fig. 12. Graph of BER measurement results for (a) FTTH and, (b) RoF network with 2×1 WDM channels

From this graph it can be seen that the BER value in the FTTH system works very well for all cable lengths with a value of 0. Meanwhile for RoF, there are BER values that do not meet the standards at certain fiber distances, even up to a value of 1, which is the minimum value. of the BER is 10^{-9}. Namely when the cable length 1.1 km, 1.9 km, 2.1 km, 2.8 km, 3.1 km, 3.4 km – 3.8 km, 4 km – 4.4 km, 4.6 km and 4.9 km.

Fig. 13 displays a graph of performance simulation results in the form of BER on a hybrid network using 4×1 channel WDM for each system.

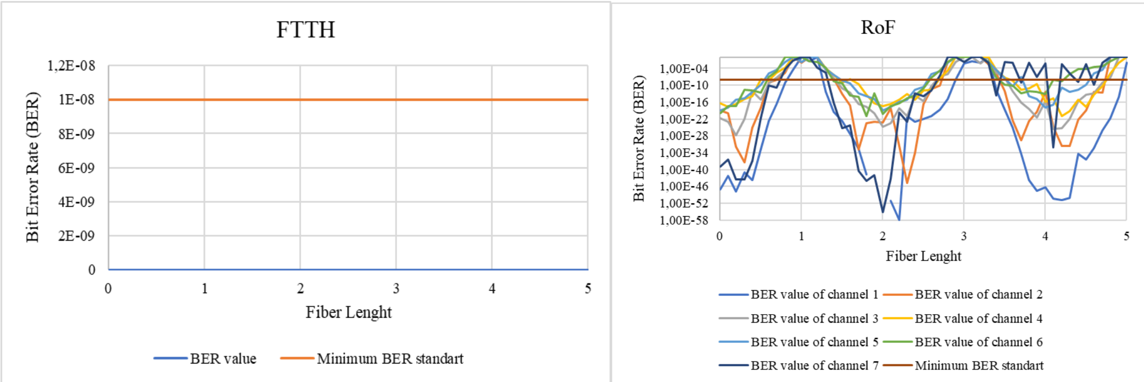


(a) (b)

Fig. 13. Graph of BER measurement results for (a) FTTH, and (b) RoF network with 4×1 WDM channels

From this graph it can be seen that the BER value in the FTTH system works very well for all cable lengths with a value of 0. Meanwhile for RoF, same as used 2x1 WDM channels there are BER values that do not meet the standards at certain fiber distances, even up to a value of 1, which is the minimum value. of the BER is 10^{-9}. Namely when the cable length is 1 km – 1.4 km, 3.4 km – 3.9 km at channel 1. When the cable length is 1 km – 1.5 km, 1.7 km, 3.3 km – 4.1 km at channel 2. When the cable length is 0.9 km – 1.4 km, 3.4 km – 3.8 km at channel 3.

Fig. 14 displays a graph of performance simulation results in the form of BER on a hybrid network using 8×1 channel WDM for each system.



(a) (b)

Fig. 14. Graph of BER measurement results for (a) FTTH, and (b) RoF network with 8×1 WDM channels

This graph shows that the FTTH system's BER value functions admirably for all cable lengths with a value of 0. In the meantime, BER values for RoF, similar to those used in 2×1 and 4×1 WDM channels, do not fulfil standards at some fibre distances, even when the value is as low as 1. 10^{-9} is the BER. Namely when the cable length is 1 km, 1.2 km, 3 km – 3.3 km, 5 km at channel 1. When the cable length is 0.8 km – 1.4 km, 2.8 km – 3.4 km, 4.8 km – 5 km at channel 2. When the cable length is 0.7 km – 1.4 km, 2.8 km – 3.5 km, 4.8 km – 5 km at channel 3. 0.7 km – 1.4 km, 2.7 km – 3.5 km, 4.8 km – 5km at channel 4. When the cable length is 0.6 km – 1.4 km, 2.6 km - 3.4 km, 4.6 km – 5 km at channel 5. When the cable length is 0.6 km – 1.3 km, 2.6 km – 3.4 km, 4.3 km – 5 km at channel 6. When the cable length is 0.8 km – 1.3 km, 2.7 km – 3.8 km, 4.7 km – 5 km at channel 7.

3.4. Overall Performance Evaluation

From the results of the performance analysis on the proposed system simulation, it can be observed that the system is deemed usable and meets the performance feasibility standards, although there are certain cable distance variations where the system performance does not yet meet the feasibility standards. Based on the performance feasibility standards of fiber optic systems, the minimum Q factor value for a system is 6, and the minimum BER is 10^{-9}. From the conducted simulations, the hybrid network system can be classified as feasible, albeit with certain adjustments such as phase shifts in the constellation diagram to enhance system performance.

4. CONCLUSION

This paper presents the performance of a hybrid optical access network design combining Fiber to the Home (FTTH) and Radio over Fiber (RoF) systems using Wavelength Division Multiplexing (WDM). Simulations were conducted with various scenarios by varying the number of WDM channels and fiber lengths. Performance measurements were then taken, including Q Factor and BER. The measured performance results indicate that for FTTH, the Q Factor values for 2×1 WDM channels ranged from 66.712 to 68.362, for 4×1 WDM channels ranged from 131.621 to 187.056, and for 8×1 WDM channels ranged from 252.37 to 231.83, with a BER of 0. Meanwhile, for RoF, the obtained values varied considerably. At certain fiber lengths, the Q Factor value was at position 0, but mostly it was above 6 with several phase adjustments in the constellation diagram, as well as the BER. From the conducted simulations, it can be concluded that the designed system meets the performance requirements, with Q Factor values above 6 and a minimum BER of 10^{-9}. In general, the performance of Hybrid FTTH and RoF systems is similar to the performance results of conventional FTTH and RoF systems.

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