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FTTH Network Design TWDM-PON Configuration with Symmetrical and Asymmetrical Data Rates in Urban Areas

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Abstract: Fiber to the Home (FTTH) is important for internet access in urban areas. This research studies an FTTH design based on a Time-Wavelength Division Multiplexing Passive Optical Network (TWDM-PON) with symmetric and asymmetric data rate configurations for a 1:128 splitting ratio by using Optisystem. The considered design is simulated with a downstream scheme with a 10 Gbps data rate for both configurations, an upstream 10 Gbps data rate for symmetric data rate configuration, and an upstream 2.5 Gbps data rate for asymmetric data rate configuration. The symmetric configuration shows a loss budget of 26.96 dB at 20 km and Q-factors of 6.22 and 6.11, respectively, for downstream and upstream. Another configuration at 21 km shows a loss budget of 26.95 dB and Q-factors of 6 and 13, respectively, for downstream and upstream. It is found that the dispersion factor is more dominant than the attenuation factor in determining the reachable distance in the proposed design. The results can be a reference for developing a TWDM-PON network.

Keywords: Time-Wavelength Division Multiplexing; Passive Optical Network; Symmetric; Asymmetric; Loss Budget; Q-Factor

1. Prerequisites for the publication

Since the SARS-CoV-2 pandemic started in early 2020, daily life has shifted to prevent more cases of infection. It is common for people to commute to work, school, or other daily outdoor activities. The new normal, recommended by the government to decrease the cases of infection, has changed all of those. Most people's activities are not allowed outside, and contact with others is limited, such as staying away by 1 – 2 meters and taking vaccine dosage when it's already available nearby[1)]. In 2020, many people shifted their work to remote work, called work from home (WFH)[2)]. Some work should be digitalized, such as an online meeting platform for school activities and multimedia entertainment[3)]. Commercial activities cannot avoid this digitization like online shopping and electronic payment used online wallets become more familiar with everyday life[4)] not only for the urban area, that the population density attracted many ICT companies to provide internet access and connectivity, but also for the rural area[5)] because internet access become the essential needs for this digitalized era.

From 2020 to 2022, internet users have increased compared to previous years. In 2018, there were 201 million users; in 2022, there were 224 million users[6)]. Over the years, the same phenomenon also occurred worldwide, leading to growing internet usage every year[7)]. The constantly increasing number of internet users creates a problem with internet access capacity. Moreover, Indonesia is a country that has an average fixed internet access speed that is relatively low compared to other countries, especially in the Southeast Asia region[8,9)]. For example, in America, a study found that 61% of citizens accessed the internet to get information or pay for any government transactions as an easier solution than coming in person to the civil services office[10)]. The number applied to a total of Americans indicated that internet access needs are massive, followed by the desired high-speed internet to have some comfortability surfing internet[11)]. However, the needs of multimedia services such as online meetings require a large service bandwidth. Moreover, the internet user has now developed into non-human users that use internet connectivity to handle automation, like in the factory with Internet of Things (IoT) technology[12)]. With the increasing need for the internet in terms of the number of users and the speed that is usable by the user, a reliable system is needed to provide services with large bandwidth to serve internet access requests with adequate speed.

One of the technologies capable of implementing internet access services for extensive and massive internet usage solutions in urban areas is fiber to the home (FTTH). This technology provides high-speed data transmission to users. This scheme, called Passive Optical Network

(PON), serves internet access, both data requests called downstream and data transmission called upstream from various customers to one central office. The PON schemes were developed according to market demand until they could serve up to several Gbps in a single network known as G-PON (Gigabit Passive Optical Network)[13].

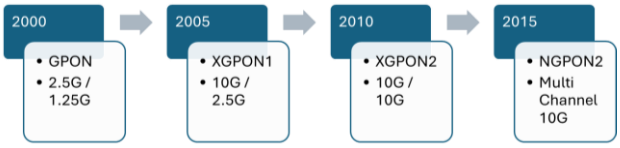

Fig. 1: Gigabit PON technology development.

Figure 1 shows the Gigabit PON technologies development. An example of Next Generation Passive Optical Network Stage 2 (NGPON2) is Time-Wavelength Division Multiplexing Passive Optical Network (TWDM-PON) technology with more outstanding parameters than previous technologies, which only used time division multiplexing (TDM) such as minimum data rate at 40 Gbps for four-channel utilization and minimum optical fiber deployment range of 20 km[14–16]. The researchers have recently developed the possibility of this technology using a specific method that can reach 100 Gbps recently[17]. Research in this area has been studied, such as experiments for symmetric 40 Gb/s TWDM-PON using DML and DCF techniques to improve the power budget for the overall TWDM-PON system[18]. This work covers the design of TWDM-PON symmetric data rate 40 Gb/s that results in performance at an effective range up to 140 km with dispersion compensation technique investigated for power budget 56.6 dB and found that the result varied for the characteristics of system deployment. Another research study about TWDM-PON used a complex fiber to the premise (FTTx) to provide internet access to all premises an average of 150 km from the service center with symmetrical data rates of 5 Gbps per communication channel. With some adjustments, the result shows that TWDM-PON will produce a reliable network with high bandwidth to perform any multimedia need in the various premises[19]. There so many adaptations to TWDM-PON technology, such as lowering the energy consumption[20,21] to reduce carbon emission or boosting the performance of the network using monitoring method[22], using an algorithm to auto-allocate bandwidth real-time[23] while maintaining performance to it, and more tunable semiconductor optical amplifier[24] to ensure the reliability. This research aims to design FTTH networks using TWDM-PON technology by considering symmetric and asymmetric data rate configurations using OptiSystem without using any of the extenders such as a series of amplifiers put neither in OLT (Optical Line Terminal), ODN (Optical Distribution Network), nor ONU to investigate limitation of the proposed FTTH network correlated with FTTH N1 class optical path loss (OPL) that proved to provide secure, available and cheap technology for commercial utilization of internet access. Limited application and information about research TWDM-PON technology made it a topic for further exploration.

Furthermore, this research analyzes the TWDM-PON with symmetric and asymmetric data rate reliability without using any optical amplifier to evaluate the system based on standards set by the International Telecommunication Union, ITU[25]. The scheme is called non-RE (Reach Extender). RE is deployed between some distances for a transmission line to repair signal characteristics continuously[26]. This research is a proposed design investigation to satisfy the ITU standard. Some considered parameters include the link loss budget and BER (bit error rate) to analyze the performances of variousoptical fiber lengths to estimate reliable performance for further deployment. The organization of this paper begins with an introduction discussion related to the prerequisites of publication, continues with necessary theory and information related to NGPON2, and then discusses considered system design related to research methodology. The next part discussion is results and analysis, and then ends with the conclusion.

2. NGPON2

2.1 TWDM-PON

NGPON2 adopts fiber optic-based internet access services developments by sending multiple signals in one channel using the wavelength division multiplexing (WDM) technique. One transmission channel can accommodate several channels with previous 10G technology data rate schemes, such as XG-PON1 (10G-PON / XG-PON) and XG-PON2 (10G Symmetric-PON / XGS-PON). These characteristics allow networks with NGPON2 technology to develop service capacity several times the previous technology on the same network so that future massive scale developments can be carried out in stages by integrating other existing technologies in coexistence[27]. The service capacity of this technology is equal to several previous technologies combined into a single existing PON. Up to 40 Gbps downstream can be 4 XGS-PON combined into 40G-DS/40G-US or 4 XG-PON combined into 40G-DS/10G-US to transmit all the communication channels in one optical fiber that is called Stacked XGS-PON and Stacked XG-PON respectively. From the previous research, the Full-Service Access Network, FSAN, officially declared TWDM-PON as the main technology to support NGPON2 deployment[28].

2.2 TWDM-PON Standard

TWDM-PON is a technology in an optical network to achieve more massive reaches, both in length and the number of customers. Table 1 shows TWDM-PON standard refers to the ITU-T G.989 series for the specification[29]. This standard defines the specifications for the OLT capabilities, channel communication requirements and operating range of whole systems. Systems aim to be reliable at data transmission, so the threshold for packet data loss is defined as a BER of 10^{-9} or inversely proportional to a Q-Factor of 6.

2.3 Design

Figure 2 shows a diagram of a single-line network of TWDM-PON with a bidirectional configuration. The line diagram consists of a Central Office called CO connected to the network with an optical line terminal known as OLT. Moreover, OLT transmits access to customers with feeder optical fiber on the customer's side with the distribution cabinet to the distribution point until the termination point in the customer's property called ONT, Optical Network Terminal.

Table 1. TWDM PON Specification29).

Parameter	Scale	Value	
		Upstream	Downstream
Nominal Line Rate	Gb/s	9.95328 2.44832	9.95328
Operating Wavelength	nm	1524–1544 (Wide) 1528–1540 (Reduced) 1532 – 1540 (Narrow)	1596-1603
Channel Spacing	GHz	50 (Minimum) 200 (Maximum)	
Line Code	-	Scrambled NRZ	
BER Reference	-	$\leq 10^{-9}$	
Q-Factor	-	≥ 6	
Loss Budget	dB	≤ 29	
Number Subscriber/ Ch	-	≥ 64	

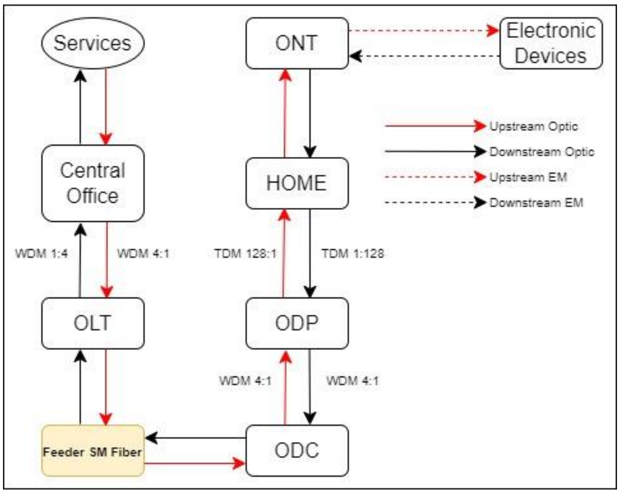

Fig. 2: Diagram of Single Line Network TWDM PON.

Table 2 shows the considered spectrum according to standard ITU-T G.989.2[27]). It shows the difference between each channel downstream and upstream. The interval between the channel spacing is used to reduce redundant internal interference between each channel. Each channel has a pair of downstream and upstream spectrums with different bands, causing the transmission feeder optical fiber to carry eight different optical signals for four pairs of four-channel communication. The minimum length for the network is regulated in ITU-T G.989.2 on the DD20 term[29]). It is a condition used in a network without an extender amplifier across the transmission[30]). From the characteristics of fiber optics, attenuation likely increases when the length of the optical path also increases, converting light energy into heat loss and other forms of energy[31]). The phenomena where the signal contains false information after transmission because of distortion. Those phenomena can be analyzed with a link loss budget and BER analysis. The optical losses can be caused by fiber optic length, splitting ratio, and internal dispersion contribution components from optical fiber or other components connector[32]). Aside from the power parameter, optical parameters also need to be considered like using the interval between each channel called the guard band to minimize the effect of interference and crosstalk[33]) preferrable guard band is 50 GHz, 100 GHz, 200 GHz, or 400 GHz[15,27,31]). Specifications for the laser as preferred light source component, like burst mode laser with minimum deviation signal frequency generated, +/- 20 GHz ensures communication reliability[34]).

Table 2. TWDM PON Specification27).

Channel	Downstream (THz)	Upstream (THz)
1	187.8	196.8
2	187.7	196.6
3	187.6	196.4
4	187.5	196.2

3. System Design

3.1 TWDM-PON Design

Before beginning the design of TWDM-PON, the first is setting the OLT transmitter with a WDM multiplexer (WDM-MUX) for 4 channels with operating spectrum and channel spacing according to downstream specification. The next is setting 4 transmitters to connect to WDM-MUX and setting center frequency and channel spacing following the downstream specification. Second, the BER analyzer component is the receiver for each channel communication in the upstream specification. Then, set 4 receivers to connect to WDM-DEMUX, also setting center frequency and channel spacing following the upstream specification. After all the transmitters and receivers are installed on the OLT side, connect each network to the circulator. All signals will combine in a single optical fiber path with various bidirectional feeder optical fiber lengths. The ONT side will be constructed based on the reverse form of the OLT side. For example, the transmitter installation according to upstream specification and receiver installation according to downstream specification applied to WDM-MUX and WDM-DEMUX. Between the WDM component and ONT, a splitting scheme with the TDM method represents many users that settled 128 users per channel communication. Therefore, there are a total of 512 users in the TWDM-PON design.

In a fiber optic network, several considerations are needed in its deployment: link loss budget and BER. The loss budget is used to analyze the performance of a communication network on a power scale. It indicates the overall power used to reach the receiver from the transmitter, which must be calibrated to keep the equipment functioning according to its specifications. BER is used to analyze the probability of an error occurring in the data sent by an optical signal[35]. An error in reading the signal can be fatal to changes in the contents of the data sent. Equations 1 and 2 are the general correlations to estimate theoretically total loss and BER in optical fiber links, respectively. The main contribution to total loss (L_T) is a connection (L_C) that can come from connector or splicing, attenuation (α) of cable that increases when length increases, the use of splitter to divide power (L_S), and consideration of system margin (M) to secure the power transmission. Meanwhile, the BER parameter is determined by detecting the number of error bits (e) divided by the total number of transmitted bits (b) at a certain time. This condition also corresponds to the factor of Q-factor.

Figure 3 shows a full design of TWDM PON optical path for upstream and downstream, which can differ by CO transmitter to customer receiver as the downstream line and customer transmitter to CO receiver as the upstream line. Figures 4 and 5 show the detailed design of the ODN on the customers' side. Fig. 4 represents the ONT receiver for downstream utilization. Fig. 5 represents the ONT transmitter for upstream utilization. The figures represent a scheme of 1:128 splitter for each channel communication.

$$L_T = \sum L_C + \alpha + L_S + M \tag{1}$$

$$BER = \frac{e}{b} = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{2}$$

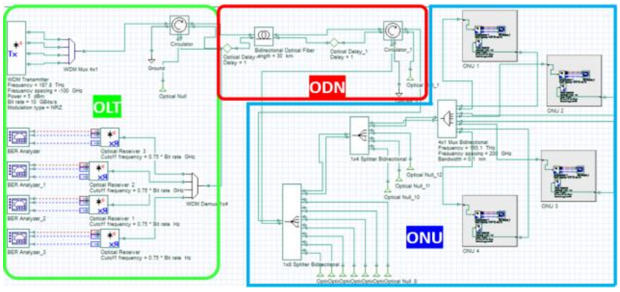

Fig. 3: Design of Network TWDM PON.

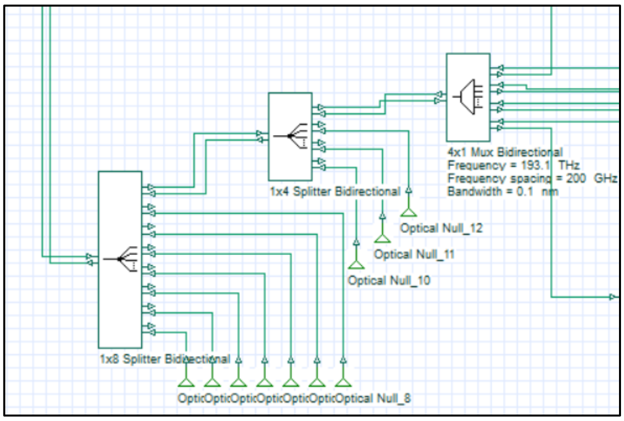

Fig. 4: Design of Bidirectional ODC TWDM PON.

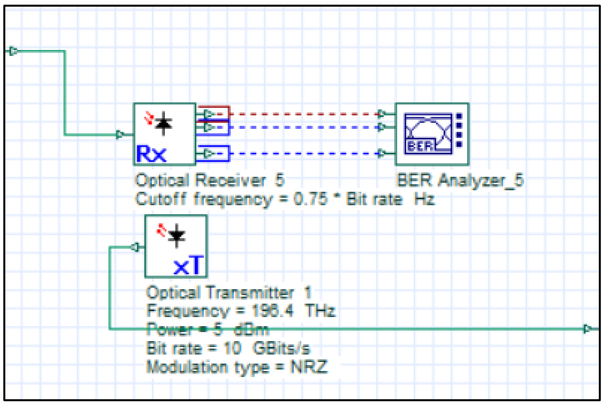

Fig. 5: Design of Bidirectional ONT TWDM PON.

Figure 6 shows the full OLT design for downstream and upstream, respectively, the upper to lower side of the design. For the configuration, each WDM-Mux and Demux, OLT side and ONT side will be assigned according to Table 2 for spectrum allocation for 4 channel communications containing 4 downstream and 4 upstream channels. The considered design is simulated with a downstream scheme with a 10 Gbps data rate for both configurations, an upstream 10 Gbps data rate for symmetric data rate configuration, and an upstream 2.5 Gbps data rate for asymmetric data rate configuration.

4. Result and Discussion

4.1 Loss Budget Analysis

Figure 7 shows the TWDM-PON symmetric data rate design result for downstream and upstream loss budget parameters. The design support for a 1:128 splitter for each channel shows that the loss budget for each scheme is feasible because the result is lower than the preferable N1 Class standard (29 dB) until the deployment length of 28 km at 28.759 dB. While Figure 8 shows the result for TWDM-PON asymmetric data rate design, each scheme is feasible for a deployment length of 29 km at 28.7763 dB.

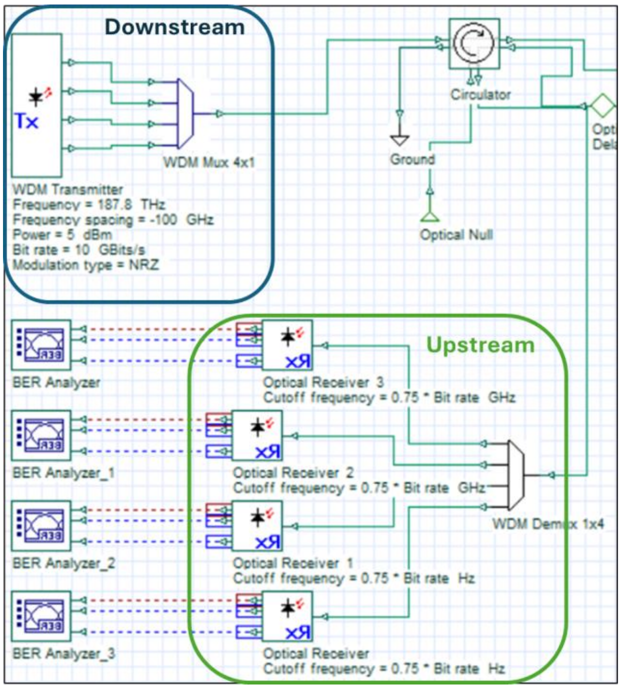

Fig. 6: Design of Bidirectional OLT TWDM PON.

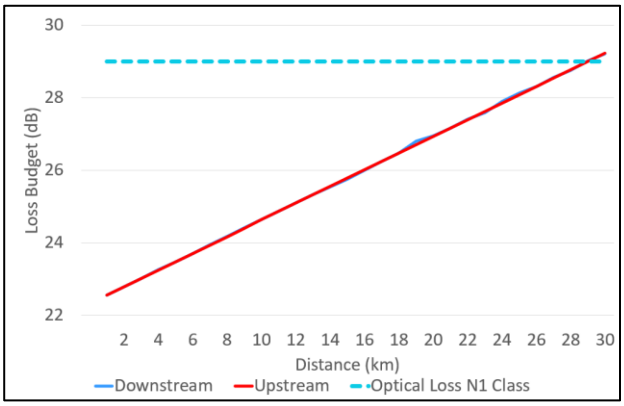

Fig. 7: Simulation results of TWDM-PON Symmetric Data Rate (Loss Budget): Downstream & Upstream.

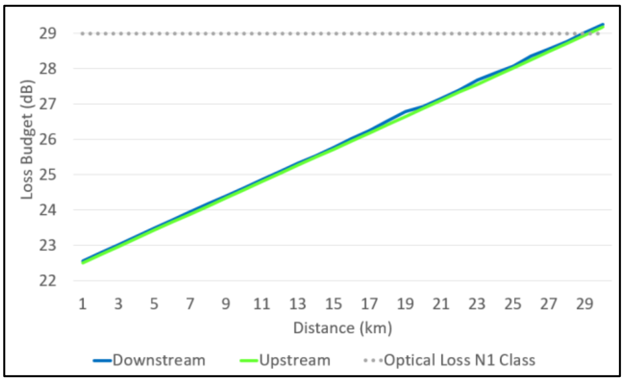

Fig. 8: Simulation results of TWDM-PON Asymmetric Data Rate (Loss Budget): Downstream & Upstream.

This obtained condition indicates that it has linear performance on the attenuation. The comparable results on the upstream and downstream results also indicate that the two wavelengths still provide linearity on the loss performance. Meanwhile, the reachable distance is longer in the asymmetric scheme and is affected by the smaller data rate that uses signals with longer wavelengths. Therefore, the longer wavelengths can reach further distances.

4.2 Q-Factor Analysis

Figure 9 shows the result of TWDM-PON Symmetric Data Rate Design for downstream on the Q-Factor parameter. The result shows that the Q-Factor for the downstream scheme is feasible for a deployment length of 20 km at the lowest of 6.23. Figure 10 shows the result of TWDM-PON Symmetric Data Rate Design for upstream on the Q-Factor parameter. Q-Factor for the upstream scheme is feasible for a deployment length of 20 km at the lowest of 6.11. The result shows that the Q-Factor for each scheme is feasible for the deployment length of 20 km at not lower than six, both combined.

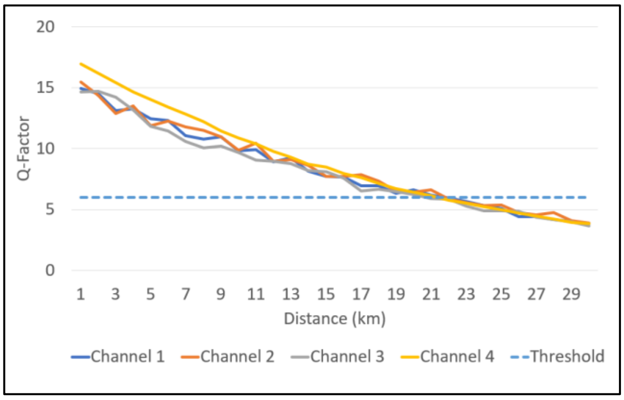

Fig. 9: Simulation results of Symmetric Data Rate Q-Factor Downstream.

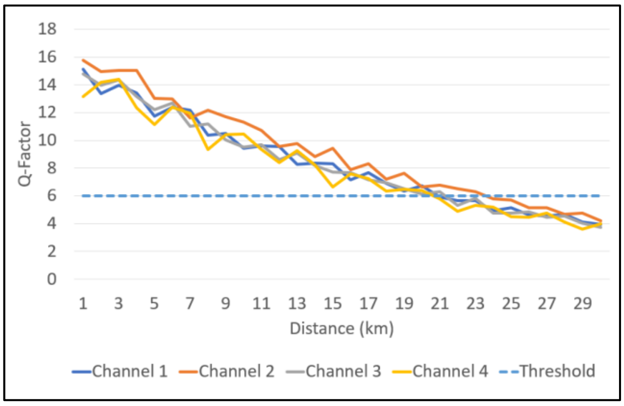

Fig. 10: Simulation results of Symmetric Data Rate Q-Factor Upstream.

Figure 11 shows the result of TWDM-PON Asymmetric Data Rate Design downstream on the Q-Factor parameter that shows the Q-Factor is feasible for a deployment length of 21 km at the lowest of 6. Figure 12 shows the result of TWDM-PON Asymmetric Data Rate Design for upstream on the Q-Factor parameter. Q-Factor for the upstream scheme is feasible for a deployment length of 30 km at the lowest of 7.6616. The result shows that the Q-Factor for each scheme is feasible for the deployment length of 21 km at not lower than six by considering both performances.

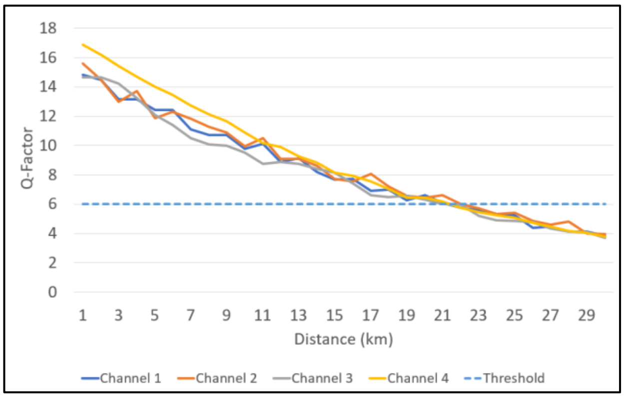

Fig. 11: Simulation results of 4 Channel TWDM-PON Asymmetric Data Rate Q-Factor Downstream.

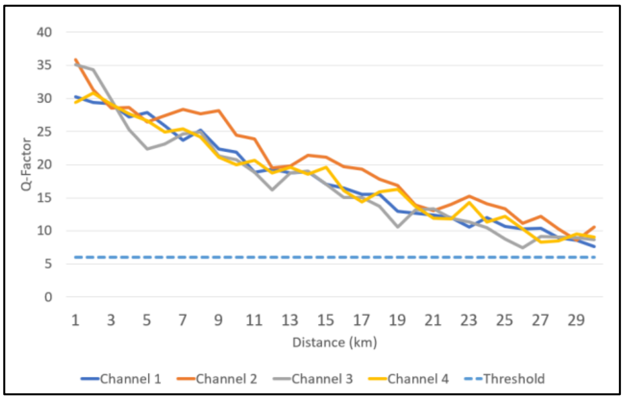

Fig. 12: Simulation results of 4 Channel TWDM-PON Asymmetric Data Rate Q-Factor Upstream.

Results obtained, as shown in Fig. 9 and 10, are comparable in the reachable distance because the use of setting is the same at the data rate. Meanwhile, results shown in Fig. 11 and 12 indicate different results due to the use of different data rates. The lower data rate in the upstream shows a longer achieved distance. This condition is because the smaller data rate is more robust than the higher data rate in terms of dispersion. Its robustness on the dispersion affects the signal transmission still pass the threshold at a further distance. The dispersion indicates that the obtained signal can still be detected for the carried symbol.

The design feasibility should consider both parameters of loss budget analysis and the Q-factor analysis. This condition is necessary to ensure that not only does the receiver reach minimum power through the loss budget analysis but also the detected symbol through the Q-factor analysis to convey the transmitted information. By considering the obtained results, therefore, the design with a symmetric data rate can reach up to 20 km. Meanwhile, the asymmetric design can reach up to 21 km. This condition indicates that the dispersion factor is more dominant than the attenuation factor in the proposed scheme.

The variation of configuration data rate does not affect the overall range of system deployment. Configuration symmetric and asymmetric data rates are comparable with the same deployment condition for each implementation. Depending on the demand, each configuration of the PON system can be used to satisfy the need for broadband internet access. The optimization for other schemes can be applied to fitting the pricing of services in the future[36)].

5. Conclusion

This research has shown the proposed design of TWDM-PON with an unamplified system using symmetric data rate and asymmetric data rate configuration for a splitting ratio of 1:128 and achieved an effective range of 20 km and 21 km for symmetric and asymmetric data rates, respectively. According to the data obtained, TWDM-PON has a slightly better optimal range for asymmetric data rate configuration. Still, TWDM-PON with a symmetric data rate has higher performance with more internet access capacity due to a higher upstream data rate. The proposed design can be a reference for developing NGPON2 technology based on TWDM-PON for further research and deployment.

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