Performance analysis of erbium-doped fiber amplifier (EDFA) and hybrid optical amplifier in NG-PON2 based on TWDM-PON system

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Abstract. One of the milestones in the optical access network evolution is the Next-Generation Passive Optical Network Stage 2 (NG-PON2) that has 40 Gbps as minimum upstream/downstream capacity. The optical amplifiers have to implement to combat the power degradation in the transmission line. This research aims to analyze the performance of EDFA boosters and hybrid optical amplifiers, which are implemented on TWDM-PON systems based on NG-PON2. Our work used 80 Gbps data speed, which each channel had 10 Gbps on eight channels with a channel space of 100 GHz. The optical link used in this simulation was 60 km with the Erbium-Doped Fiber Amplifier (EDFA) and Hybrid Optical Amplifier (HOA). The performance analysis is based on the variation of ONU and amplifier. Based on the results, the best value in the downstream is the transmission line using EDFA with the received power of -19.184 dBm, Q Factor of 7.975, and BER of 5.852 x 10⁻¹⁶. In upstream transmission, the best value obtained was a hybrid optical amplifier with a received power value of 9.025 dBm, Q Factor of 69.64, and BER of 0. The optical amplifier increased the system performance when implemented on TWDM-PON systems based on NG-PON2.

1. Introduction

Recently, information and communication technology has grown exponentially [1] forced by the customer needs increasing for the high-speed and huge capacity internet. The passive optical network (PON), for instance, EPON and GPON, is the most widely deployed all over the globe [1] to bring high-speed internet. The first generation PON is based on Time Division Multiple Access (TDMA) by providing a 1 Gbps upstream rate and a 2.4 Gbps downstream rate. NG-PON1 can increase data speeds up to 10 Gbps for both streams. There are two scenarios for NG-PON1 technology, namely EPON that is deployed to XG-EPON and GPON used to XG-PON. For enhanced GPON can be deployed to XG-EPON, which is another potential path that can be considered. However, NG-PON1 will not meet the demand for bandwidth and future Quality of Service (QoS) requirements. Therefore, research is investigating the options for NG-PON2 with some of the technologies that NG-PON2 uses with standardization institutions, i.e., International Telecommunications Union (ITU) and Institute of Electrical and Electronics Engineers (IEEE) working together with Full-Service-Access-Network [2]. The Time and Wavelength Division Multiplexing Passive Optical Network (TWDM-PON) can be recommended for the design of multiplexing NG-PON2. This technology develops with the latest developments of PON technology that can transmit information with a higher speed of more than 40 Gbps for the downstream and 10 Gbps for the upstream side [3].

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In recent years, several researchers that analyze the TWDM-PON system in access networks have been published [3,4,5,6]. Hidayat [3] in 2018 examined the impact of the Erbium-Doped Fiber Amplifier (EDFA) and Raman Optical Amplifier (ROA) in the NG-PON2 system using 4-channels with the 40 Gbps downstream and 10 Gbps upstream. They employ a splitting ration 1:256 in TWDM-PON with a booster amplifier for downstream and a pre-amplifier for upstream. In this work, the EDFA and the ROA were observed by Q-factor and BER parameters. Based on the discussion, the system with EDFA had a better performance than the system that used ROA as an optical amplifier. Pratiwi [4] in the 2018 simulated TWDM-PON system to evaluate the performance of the NG-PON2-based system with two variations of bitrate, several variations of the length of the optical link, three scenarios of network capacity and the scenario of the optical amplifier. Based on the discussion, the system performance was enhanced by using EDFA as a pre-amplifier. This system can increase the capacity without the lost performance that was required in the ITU-T standard. Pertiwi [5] in 2018 study the effect of EDFA as a booster amplifier and as a pre-amplifier in the TWDM-PON based in NG-PON2. In this work, Pertiwi observed the effect amplifier for several variations of the length of an optical link and ONT capacity. The length of the optical link with the best performance was 20 km, and both access networks with 64 ONT and 128 ONT can be met the standard of network performance. In 2017, Yasyir [6] simulated the TWDM-PON based NG-PON2 system to obtain the performance of the system that uses EDFA as an optical amplifier. Based on the discussion, EDFA employment can increase system performance. This work analyzes the performance of the TWDM-PON system using EDFA on the OLT as a booster amplifier and HOA as a pre-amplifier in the Optisystem simulator. To analyze the performance, we used a variety of the length of optical link to obtain received power, BER, and Q-factor values. For a better understanding, the rest of this paper is organized as follows. In section 2, we propose a method that uses in this work, and the results of the simulation are discussed in section 3. Finally, the conclusions are presented in section 4.

2. Proposed Method
This study used a model to analyze the performance of TWDM-PON system that uses NG-PON2. In this section, we elaborate on how simulation was conducted, the NG-PON 2-based network system design model which refers to the figure 1. The TWDM-PON system, in accordance with NG-PON 2, is composed of three main blocks, the transmitter block of Optical Line Terminal (OLT), the transmission block of Optical Distribution Network (ODN) and the receiver block in the form of Optical Network Unit (ONU). The OLT used eight channels with different wavelengths and a bit rate on each channel of 10 Gbps on the downstream and upstream sides. The ODN section used three splitting points, with a total of 64 and 128 users with the most remote transmission distance of 60 km. In this design, it was using an additional optical amplifier that aims to increase the signal receiving power. Types of optical amplifiers were EDFA and Hybrid Optical Amplifier. The OLT block consists of CW Laser, Mach-Zehnder Modulator, NRZ Pulse Generator, and Pseudo-Random Binary Sequence (PRBS). An Optical Amplifier block used EDFA and HOA, which consist of Erbium-Doped Fiber Amplifier (EDFA) and Raman Optical Amplifier (ROA), ideal mux dan pump laser array. EDFA used a length of five meters with Pump Power 100 mW. The Raman Optical Amplifier used a length of 10 km. The transmission media, which is a network connection between the central to the customer, was also called the Optical Distribution Network (ODN). This block consists of Optical Attenuator, Bidirectional Optical Fiber, and Splitter. On the bidirectional optical fiber had a reference wavelength of 1550 nm with a variation of distance from 10 km to 60 km. ONT block was called Optical Network Terminal or Optical Network Unit (ONU). On the main device at ONT is a photodetector that has the function of detecting light emitted from the transmitter as well as converting it into an electric current.
Figure 1. TWDM-PON architecture

ONT consists of Bessel Optical Filter, Photodetector APD, Low Pass Bessel Filter, 3R (Reamplification, Reshaping and Retiming), and BER Analyzer. The system configuration in Optisystem shows in table 1.

Table 1. System Design Parameter

| Parameter                        | Unit  | Value          |
|----------------------------------|-------|----------------|
| OLT                              |       |                |
| Bitrate in each channel          | Gbps  | 10             |
| Optical launch power             | dBm   | 6              |
| Channel spacing                  | GHz   | 100            |
| Bandwidth                        | GHz   | 20             |
| Number of channels               |       | 8              |
| Wavelength Downstream            | nm    | 1596.34 – 1598.89 |
| Wavelength Upstream              | nm    | 1532.68 – 1535.04 |
| EDFA                             |       |                |
| Fiber length                     | m     | 5              |
| Pump power                       | mW    | 100            |
| Pump wavelength                  | nm    | 1480           |
| ROA                              |       |                |
| Fiber length                     | Km    | 10             |
| Pump power                       | mW    | 100            |
Table 1. System Design Parameter

| Parameter          | Unit   | Value  |
|--------------------|--------|--------|
| Pump wavelength    | nm     | 1480   |
| Transmission link  | Km     | 10–60  |
| Optical link       | dB/km  | 0.3    |
| Attenuation        | ps/(nm.km) | 17.46 |
| Disperion          | -      | 0.45   |
| Insertion loss     | dB     | 3      |
| Output port        | -      | 2, 4, 8|
| Responsivity       | A/W    | 0.059  |
| Ionization ratio   | -      | 0.45   |
| Resistance         | Ohm    | 50     |

3. Result and Discussion

The system performance analysis used in this research was the results of the parameters of Q-factor, Bit Error Rate (BER), and received power. The power used in this test was six dBm with optical links variation of 10, 20, 30, 40, 50, and 60 km. For a minimum value on the Q Factor optical link has the value must be < 6 to meet the eligibility standards of the transmitted signal quality. Q Factor itself has a relation with the value of BER that has a maximum value of $1 \times 10^{-9}$ to be able to meet the standard.

3.1. Performance of the system design without an amplifier

In the first scenario was the simulated system 80 Gbps TWDM-PON without using amplifier on the downstream or upstream. The following are the test parameters used on the system without using an amplifier Received Power, Q Factor, Bit Error Rate (BER).

![Figure 2](image-url)

**Figure 2.** Received power in the system without amplifier (a) downstream received power, (b) upstream received power

Based on the results of the simulation in Figure 2 (a), the value received power for the system, without using an amplifier on the downstream side, was obtained the value of received power at 64 ONU with the highest value received power of -25.459 dBm at a distance of 10 km while for the smallest value of -29.458 dBm at a distance of 30 km. Whereas at 128, ONU obtained the highest
received power value from the distance of 10 km, amounting to -19.184 dBm to a distance of 60 km, amounting to -29.188 dBm. On both, the ONU has already qualified the value of received power from 64 ONU only up to 30 km while the 128 ONU qualifies from a distance of 10 km to 60 km. In this case, the enormous received power value is influenced by a long-range Link. Connection received power with distance compared to the upside, which is the length of a link, then the value received power obtained will be smaller and vice versa.

Based on the simulation results in Figure 2 (b), for the received power value without using amplifier on the upstream side, where obtained the value of received power at 64 ONU without using amplifier obtained the highest value received power of 24.686 dBm on the distance of 10 km while for the smallest value of -28.690 dBm at a distance of 30 km. While at 128 ONU obtained, the highest received power value from the distance of 10 km is 9.025 dBm to a distance of 60 km is at 3.314 dBm. On both, the ONU has already qualified the value of received power from 64 ONU only up to 30 km while the 128 ONU qualifies from a distance of 10 km to 60 km. In this case, the large received power value is influenced by a long-range Link. Connection received power with distance compared to the upside, which is the length of a link, then the value received power obtained will be smaller and vice versa.

Based on the simulation that has been done with the first scenario, the system without using an amplifier on the downstream side and upstream side obtained the Q Factor result as follows in figure 3.

![Figure 3. Q-factor in the system without amplifier (a) downstream Q-factor, (b) upstream Q-factor](image)

The Q Factor value gained in simulated results with a bit rate of 80 Gbps on the downstream side, indicating that the scenario I without using the amplifier at 64 ONU obtained a value of 7.159 at a distance of 10 km where the distance is fulfilled Terms of Q factor while the other distance does not meet its standard value. At the same time, the 128 ONU obtained the highest score of 7.975 at a distance of 10 km and for the smallest value of 6.011 at a distance of 40 km. Based on the results of the Q factor shown on the chart, for users, 64 ONU only meet the standard at a distance of 10 km while for users 128 The ONU meets the standard ranging from 10 km to 40 km. This is because the increasing number of users used then for the higher Q factor value will be further the resulting distance. The Q Factor value obtained in the simulated results with a bit rate of 80 Gbps on the upstream side, indicating that scenario I without using the amplifier at 64 ONU obtained the highest value of 16.635 at a distance of 10 km and the smallest value obtained is of 6.368 at a distance of 40 km. Where at a distance of 10 to 40 km already qualified Q factor while the other distance does not meet its standard value. In comparison, the 128 ONU obtained the highest score of 49.624 at a distance of 10 km and for the smallest value 13.950 at a distance of 50 km. Based on the results of the
Q factor shown on the chart, for users 64 ONU that meet Q factor standards at a distance of 10 km to 40 km. Whereas for users 128 ONU who meet Q factor standards ranging from 10 km to 60 km. This is because the more the number of users used, then the higher the Q factor value will be further the resulting distance.

Bit Error Rate (BER) is a comparison of the bit rate loss that will occur in a digital transmission system that has a standard parameter value of 10^-9. If the value system generated on BER Analyzer is smaller to generate the value of the BER, then otherwise the system is not good because it is less qualified value is generated. Based on the simulation of the scenario, I obtained a result as follows in figure 4.

The value of the simulated results in the scenario I in the user 64 ONU obtained a value of 3.423 x 10^-13 at a distance of 10 km while the other distance does not meet the standard value of BER. In user 128, ONU obtained the highest value of 7.764 x 10^-10 at a distance of 40 km while for the smallest value of 5.852 x 10^-16 at a distance of 10 km. Based on the results shown in the graph form, the user 64 ONU that meets the standard values only at a distance of 10 km while the user 128 ONU meets the standard value from 10 km to 40 km. The relationship between Q Factor and BER is inversely proportional, where the greater the Q Factor value, then the resulting BER value will be smaller. Where the smaller the value of the BER will be better with a small likelihood of an error occurring on a network.

The value of the simulated results in the scenario I in user 64 ONU obtained the highest value of 9.472 x 10^-11 at a distance of 40 km while for the smallest value is obtained at 1.675 x 10^-62 at a distance of 10 km. At the user 128 ONU obtained the highest value is of 1.373 x 10^-44 at a distance of 60 km while for the smallest value of 0 at a distance of 10 km.

![Figure 4. BER value for the system without amplifier (a) downstream BER, (b) upstream BER](image)

Based on the results shown in the form of graphs, the user 64 ONU that meets the standard values from the range of 10 km to the distance 40 km the rest is not meeting BER standard value. In comparison, the user 128 ONU meets the standard values from a distance of 10 km to 60 km.

3.2. Performance of the system design using amplifier
The second scenario conducted simulated system 80 Gbps TWDM-PON using the EDFA amplifier on the downstream side and HOA on the upstream side. This simulation uses three divider points with the number of users, i.e., 64 and 128 ONU with a variation distance of 10, 20, 30, 40, 50, and 60 km. Where the system is simulated by using pre-defined parameters. The test parameters used in the system use the amplifiers Received Power, Q Factor, Bit Error Rate (BER).
The second scenario was using the EDFA amplifier on the downstream side and HOA on the upstream side. The Send power is the maximum left power value and the appropriate receiving power to be accepted by the sensitivity of the photodetectors to the device that is worth-30 dBm. To view the value received, power can be used component Optical Power Meter (OPM).

Figure 5 (a) is simulated results on the downstream side in the form of graphs where the value of received power in the second scenario at 64 ONU with the highest received power value of -16.174 dBm at a distance of 10 km. The lowest value is amounting to -26.295 dBm at a distance of 60 km. In user 128, ONU obtained the highest value of -19.184 dBm at a distance of 10 km while the smallest value -29.382 dBm at a distance of 60 km. In the results of this simulation seen from both users, 64 and 128 ONU meet the standard value Up to 60 km. Where the relationship is received power with the distance inversely due to the more extended a link, then the resulting value received power will be smaller as well as vice versa. Therefore, the received power measurement is crucial to identify how the sensitivity of the photodetectors still receives the receiving power.

In figure 5 (b) is simulated results on the upstream side in the form of graphs where the value of received power in the second scenario at 64 ONU with the highest received power value of 8.677 dBm at a distance of 10 km. In contrast, the lowest value is 2.201 dBm at a distance of 60 km on user 128 ONU obtained the highest value of 9.025 dBm at a distance of 10 km while the smallest value is 3.314 dBm at a distance of 60 km. In the results of this simulation seen from both users 64 and 128, ONU meets the standard value of sensitivity Minimum range of up to 60 km. where the connection received power with distance is reversed because the length of a link then the value received power will be smaller as well as vice versa.

![Figure 5](image_url)

**Figure 5.** Received power in the system with the amplifier (a) downstream received power, (b) upstream received power

Based on the simulation that has been done with a scenario using an additional amplifier that is EDFA on the downstream side and HOA on the upstream side obtained the result of Q Factor as follows
Figure 6. Q-factor in the system without amplifier (a) downstream Q-factor, (b) upstream Q-factor

Figure 6 (a) is a simulated result of Q Factor value obtained at 80 Gbps bit rate on the downstream side, indicating that the second scenario with an additional amplifier on the downstream side and upstream side. In the user, 64 ONU obtained the highest value of 7.961 at a distance of 10 km while for the lowest value of 6.248 at a distance of 40 km. While at 128 ONU obtained the highest value of 7.975 at a distance of 10 km and for the smallest value is 6.011 at a distance of 40 km. Based on the results of the Q factor shown on the chart, the user 64 ONU meets the standard at a distance of 10 km to 40 km while for users 128 ONU that meet the standard range from 10 km to 40 km more at a distance of 50 and 60 km. Two users do not meet the minimum Q factor value. This is because the more number of users used then for the value of the larger Q factor will be further the resulting distance. Based on the simulation results of the Q Factor value obtained at 80 Gbps bit rate on the upstream side, indicating that the second scenario with the additional amplifier on the downstream side and upstream side. At 64 ONU users obtained the highest value of 69.642 at a distance of 10 km while for the lowest value of 15.783 at a distance of 60 km. While at 128 ONU obtained the highest value of 49.624 at a distance of 10 km and for the smallest value that is 13.950 at a distance of 60 km. Based on the results of the Q factor shown on the chart, user 64 and 128 ONU are compliant with the minimum Q factor standard value. This is because the more number of users used then for the value of the larger Q factor will be further the resulting distance.

Figure 7. BER value for the system with the amplifier (a) downstream BER, (b) upstream BER
Based on the results of the simulation BER parameter on the user 64 ONU obtained the highest value of $1.699 \times 10^{-10}$ at a distance of 40 km while for the lowest value of $6.460 \times 10^{-16}$ at a distance of 10 km. For user 128 ONU obtained the highest value of $7.764 \times 10^{-10}$ at a distance of 40 km while for the lowest value of $5.852 \times 10^{-16}$ at a distance of 10 km. Judging from the graph results above can be concluded that from both users 64 and 128 ONU value is generated only up to a distance of 40 km. where the relationship between Q factor With BER is inversely proportional, which for the value of the AIR obtained the smaller then, the better signal is transmitted because of the possibility of a very small error. Based on the results of the simulation BER parameter on the user 64 ONU obtained the highest value of $1.769 \times 10^{-15}$ at a distance of 60 km while for the lowest value of 0 at a distance of 10 km. For user 128 ONU obtained the highest value of $1.373 \times 10^{-14}$ at a distance 60 km whereas for the lowest value is 0 at a distance of 10 km. Judging from the above graph, results can be concluded that from both users, 64 and 128 ONU values are produced from a distance of 10 km to a distance of 60 km. Where for the value of the obtained, the smaller, The better the signal is transmitted due to the possibility of a tiny error? This is because the value of the Q-factor in both users has a significant value where the value of the value will affect the value of the given BER will be smaller, which allows the lack of errors.

4. Conclusion

Based on the result of simulation and discussion in the previous section, the employment of optical amplifiers in TWDM-PON based on NG-PON2 can increase the system performance in all parameters. The proposed system meets the ITU-T standard for BER and Q-factor both system 64 ONU and system 128 ONU. Based on the standard, the value of the Received Power parameter obtained the best result in the downstream transmission at 64 ONU with a value of -16.174 dBm and 128 ONU with a value of -19.184 dBm. For upstream transmission at 64 ONU obtained the best value of 8.677 dBm, and at 128 ONU generated a value of 9.025 dBm. Based on the standard value of the parameter Q Factor obtained the best result is downstream transmission at 64 ONU with a value of 7.961, and at 128 ONU obtained a value of 7.975. For upstream transmission at 64 ONU obtained the best value of 69.642, and at 128 ONU produced a value of 49.624. Based on the standard value of the Bit Error Rate (BER) parameter obtained the best results downstream transmission at 64 ONU with a value of 6.46 x 10^{-16} and at 128 ONU obtained a value of 5.85 x 10^{-16}. For upstream transmission at 64 ONU obtained the best value of 0 and at 128 ONU generated value of 0.

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