

Enhanced Performance of NG-PON using CWDM and EDFA for Longer Transmission and Higher Data Rates

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Peer Review Information	Abstract
Type: Article Received: 03 Aug 2026 Revised: 11 Sept 2026 Accepted: 01 Oct 2026 Published: 03 Oct 2026	The fast growth of broadband facilities such as Internet of Things devices, emerging 5G/6G networks, high-definition, multimedia, and cloud applications, has twisted a continuous demand for large-capacity and long-reach passive optical access systems. Next-Generation Passive Optical Network methods provide a real approach for growing networks data carrying capacity while holding the advantages of passive optical fiber infrastructure. This research paper examines an enhanced Next-Generation Passive Optical Network design based on Coarse Wavelength Division Multiplexing joint with an Erbium-Doped Fiber Amplifier. Coarse Wavelength Division Multiplexing empowers several optical communication channels to be spread simultaneously over a single fiber, whereas Erbium-Doped Fibre Amplifier recompenses for optical attenuation and increases the received signal strength over long transmission distances. The planned design is calculated using a passive optical communication simulation setup by perceiving Bit Error Rate, Quality factor, and eye height for various fiber lengths of 80, 100, 120, and 140 km. As it shows a progressive degradation of signal quality caused by fiber attenuation and dispersion, hence the eye height also decreases with increasing transmission distance. The results prove that the planned Coarse Wavelength Division Multiplexing - Erbium-Doped Fiber Amplifier's combined design can provide suitable transmission performance at lengthy distances, with the 80 km structure exhibiting the strongest signal strength. This investigation establishes the potential of combining Coarse Wavelength Division Multiplexing and optical augmentation for high-capacity and long-distance optical communication access applications. Keywords: Next-Generation Passive Optical Network; Coarse Wavelength Division Multiplexing; Erbium-Doped Fiber Amplifier; Bit Error Rate; Quality Factor; Passive Optical Network

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Introduction

Passive Optical Network (PON) techniques are predominantly attractive because it allows several subscribers to share optical arrangement over passive components for example optical splitters and wavelength multiplexers. NG-PON expertise address these necessities by introducing higher line rates, improved optical interfaces, wavelength multiplexing, and more flexible optical network architectures. The decline in active equipment in the outside plant can decline operational complication and energy necessity. As user bandwidth desires continue to rise, conventional PON architecture's required technological enhancement to offer higher amassed capacity and longer transmission length. The continuous demand for high-speed broadband connectivity has expended considerably because of the extensive use of cloud computing, mobile broadband, high-definition video, online education, Internet of Things (IoT) devices, artificial intelligence applications, and data intensive digital services. The ancient conventional copper based access networks face significant restrictions in terms of transmission bandwidth, electromagnetic interference, attenuation, and achievable transmission distance. Optical fibre offers significantly greater bandwidth and lesser transmission loss, making it a fundamental standard for modern broadband communication access networks. WDM is a significant technique for raising the capacity of fibre-optic communication systems. Instead of transmitting all data information over a single optical wavelength, WDM allocates separate optical wavelengths to separate channels. Although optical wavelength multiplexing increases capacity, transmission through long optical fiber spans introduces attenuation and dispersion. CWDM is mostly attractive for cost sensitive optical access networks because it employs comparatively huge wavelength spacing. ITU-T G.694.2 postulates the CWDM wavelength grid and describes a nominal channel spacing of 20 nm. These effects reduce received optical power and distort the transmitted waveform. As the transmission length increases, the signal to noise ratio and eye opening may decline, finally increasing BER and reducing the Q-factor [1].

This research recommends and calculates CWDM and EDFA-based NG-PON design. The most important contributions of this work are development of a combined CWDM and EDFA based NG-PON design for high-capacity passive optical transmission and the analysis of the impact of fibre length on system performance [2]. The objective is to examine how transmission distance affects the efficiency of the proposed network. The principal performance parameters considered are BER, Q-factor, and eye height. The investigation is performed for the various fibre lengths which are of 80, 100, 120, and 140 km. The achieved results offer an understanding of the link between transmission length and optical signal quality in an improved CWDM optical communication access network. The investigation using BER, Q-factor, and eye height of eye diagram shows humiliation with increasing transmission length. Hence is it recognized the practical transmission length trend for the planned architecture.

CWDM-EDFA Technology

1. Coarse Wavelength Division Multiplexing: CWDM is an optical multiplexing technique in which several optical signals operating at different wavelengths are transmitted over the same optical fiber. At the transmitting end, distinct data streams are transformed into optical signals at different wavelengths. A CWDM multiplexer combines these channels before they arrives the transmission fiber [3]. At the receiving side a demultiplexer splits the wavelengths and directs each channel to its analogous receiver. The main characteristic of CWDM is its relatively huge wavelength separation. ITU-T G.694.2 postulates a CWDM wavelength grid with 20 nm nominal channel-spacing. This relatively wide spacing lowers wavelength stability desires and allows the use of relatively economical optical components [4]. For NG-PON planning, CWDM can raise the aggregate capacity without demanding multiple physical fibers. Several wavelengths can be assigned to distinct channels or services. This offers an extra capacity dimension related with systems relying solely on time-domain sharing.
2. Erbium-Doped Fiber Amplifier: An EDFA is an optical amplifier based on erbium-doped fiber. In EDFA the erbium ions are agitated by an optical pump source and transfer energy to the incoming communication signal. The resultant stimulated emission raises the optical power of the transmitted signal. The direct amplification in the optical domain is an important advantage of EDFA [5]. Therefore, it does not necessarily need for an optical signal to undergo optical-electrical-optical change before amplification. In WDM systems, the process in which one amplifier can simultaneously amplify multiple wavelength channels within its operating region is the especially beneficial feature. The amplifier enhances the optical power existing at the receiver, while its operation also presents Amplified Spontaneous Emission noise [6].

Related Work

While controlling transmission impairment the power consumption and deployment cost, the research on next-generation passive optical access networks has gradually focused on increasing capacity. NG-PON characterizes a significant growth in PON technology because it combines time with wavelength division multiplexing and backings multiple wavelength channels. As WDM permits several optical channels to share the same fiber, hence it has become an important approach for optical communications [7]. ITU-T describes NG-PON as a flexible passive optical communication technology designed to support residential services, applications, business and mobile backhaul. The ITU-T G.989 family also shows that NG-PON can support nominal total downstream capacity around 40 Gbit/s, with multiple line-

rate configurations [8]. More recent material from ITU-T describes the system as supporting multiple wavelength channels and providing a path toward capacity growth beyond 100 Gbit/s. CWDM has been widely considered for applications in which moderate wavelength density and relatively economical optical components are desirable. Its wide channel separation makes the system comparatively tolerant of wavelength variations [9]. The ITU-T CWDM grid was specifically designed to support simultaneous transmission of several wavelengths with sufficient separation for practical optical sources [10]. Optical amplification is another important research direction for extending the reach of fibre communication systems. EDFA technology can restore optical power after transmission losses and can amplify multiple wavelength channels without separate electrical regeneration for every channel [11].

The combination of WDM and optical amplification is therefore relevant to long-reach access networks. However, increasing transmission distance does not automatically result in improved system performance. Fibre attenuation, chromatic dispersion, nonlinear effects, connector losses, splitter losses, and amplifier-generated noise progressively affect the received signal [12]. Several performance metrics are commonly used to evaluate optical communication systems. BER provides a direct indication of the probability of bit errors, whereas the Q-factor provides a statistical measure related to the separation between logical signal levels. The eye diagram provides a visual representation of timing and amplitude quality. Eye height is particularly useful for observing the reduction in amplitude margin caused by transmission impairments. The present study extends this general research direction by examining a CWDM-EDFA-based NG-PON configuration over extended fiber lengths and evaluating its performance using three complementary indicators: Q-factor, BER, and eye height. The study examines the combined effect of distance on signal quality and detection performance rather than evaluating only received power of system.

The layout configuration and description for Proposed EDFA-CWDM NG-PON Design:

In this configuration the many optical channels with dissimilar wavelengths are combined using CWDM and transmitted through a common optical fiber. The projected EDFA-EDFA, CWDM NG-PON design is planned to enhance the signal strength, transmission capacity, and coverage area of next-generation optical communication networks. To amplify the multiplexed optical signal an EDFA is incorporated at the transmitting side before its propagation through the fiber link. A second EDFA is placed at a suitable intermediate section to reward for transmission losses and preserve adequate optical power over long distances.

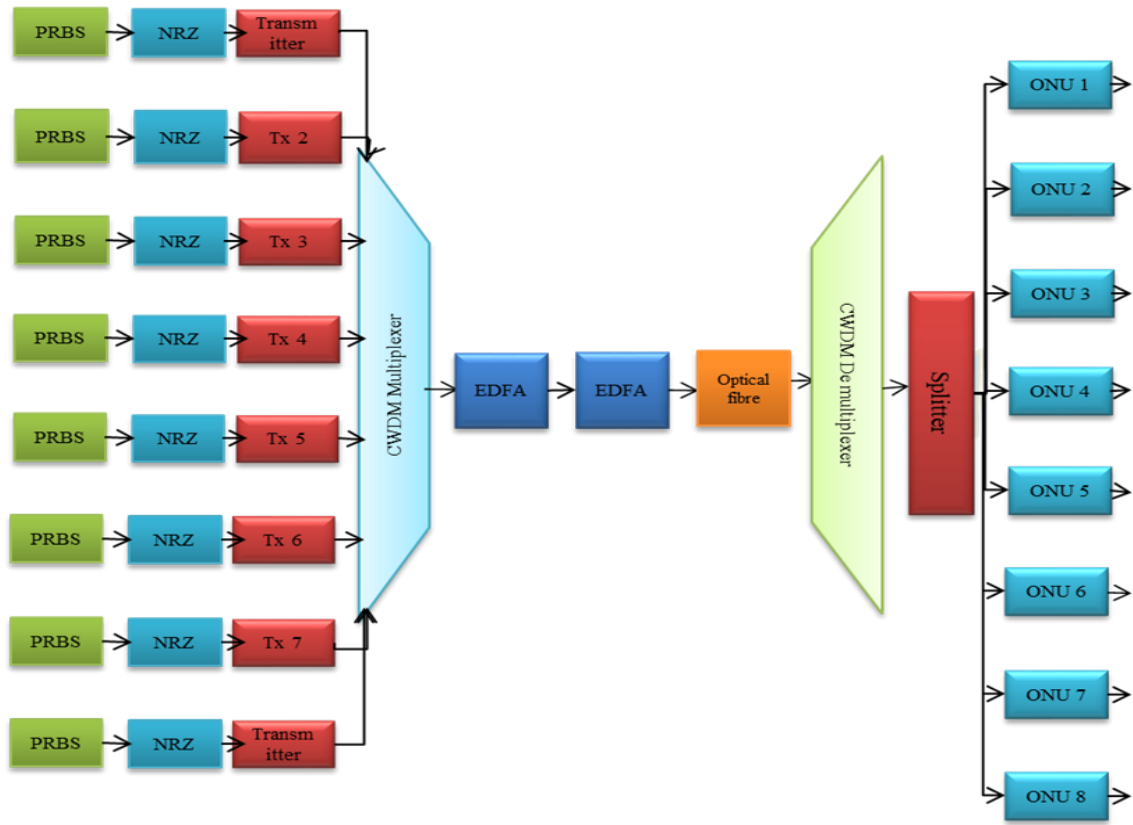


Fig. 1. The Block diagram setup for the planned methodology

At the receiving section, a CWDM demultiplexer splits the distinct wavelength channels, which are then identified and investigated using optical receivers and BER analyzers. The proposed system diminishes power deprivation and improves signal strength with supporting the higher data rates and longer signal transmission length while keeping reliable NG-PON operation.

System Modeling and Simulation Setup for the Proposed Design

The simulated system consists of numerous optical data sources, transmitters, CWDM multiplexing, wavelength channels, EDFA as amplification device, optical fiber, receiver-side wavelength separation, photo-detection, and signal-quality measurement device BER. The projected NG-PON architecture was studied using an optiSystem software simulation setup. The theoretical simulation architecture setup is shown in figure 2 given as below:

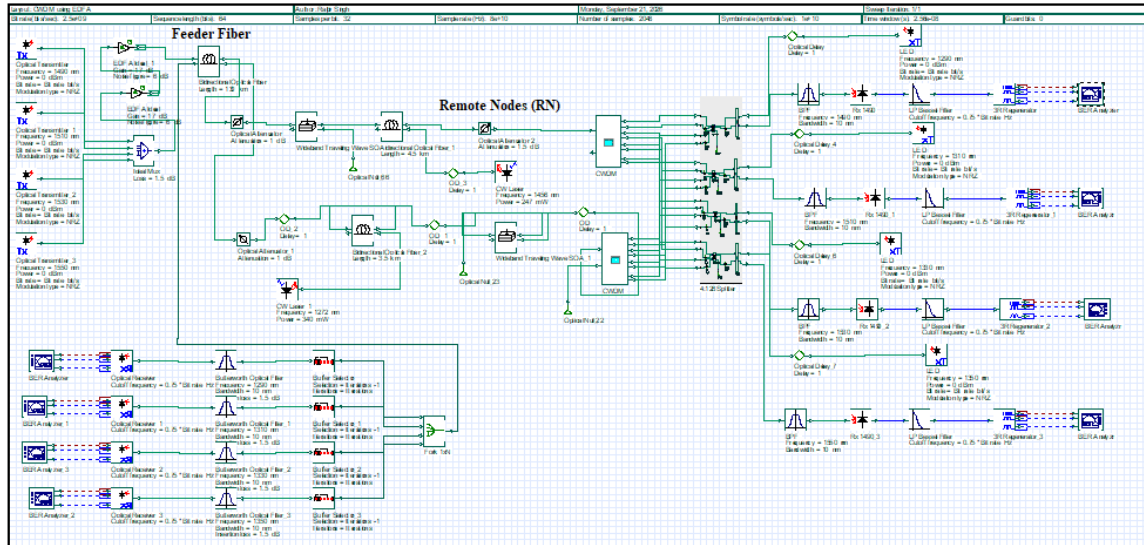


Fig. 2. Simulation set up circuit diagram for the EDFA-CWDM NG-PON.

Multiple channels are produced individually with allocated different optical wavelengths and these signals are combined by CWDM multiplexer into a common optical fiber. After that the combined signal is improved using EDFA to propagate through the fiber. At the receiver end the wavelength channels are separated then converts the optical signals into electrical signals. The resulting waveform is investigated using a BER analyzer and eye diagram measurement system. The Q-factor, BER, and eye height are recorded for each fiber length. The eye diagram is used to examine the eye opening of the received signal. A wider eye opening represents a relatively larger margin, while a narrow eye shows bigger signal distortion and timing. Finally, the system is evaluated at different fiber transmission distances to study how the propagation length affects the quality and performance of the received optical signal. The proposed simulation therefore provides a controlled method for determining how fiber distance affects the performance of an amplified wavelength-multiplexed NG-PON system.

Simulation parameters used: The principal simulation variable in this investigation is optical fibre length. The system is evaluated at fiber lengths 80 km, 100 km, 120 km, and 140 km.

Table 1. Principal simulation Parameters used for the proposed methodology

Components Name	Simulation Parameters
Simulator	OptiSystem V. 22.0
Transmission distance	80, 100, 120, and 140km
EDFA gain	17 dB
Attenuation	0.2dB/km
Isolator Insertion loss	0.9dB
Network technology	NG-PON
Multiplexing technique	CWDM
Performance parameters	Q-factor, BER, eye height
Primary objective	Long-reach and high-capacity transmission

Table 2. The values for *Q*-factor, BER, and Eye Height at various fiber lengths

Fiber Length	Q-factor	BER	Eye Height
80	49.6824	9.9901E^{-08}	07.51488E^{-05}
100	31.7711	1.7455E^{-07}	06.02129E^{-05}
120	18.4955	3.3045E^{-07}	5.10924E^{-05}
140	09.5621	5.2055E^{-07}	1.27565E^{-06}

The simulation keeps the principal system configuration unchanged while varying fiber length. This approach makes it possible to isolate the effect of transmission distance on the observed performance. The *Q*-factor is used as an indicator of signal separation. A higher *Q*-factor generally indicates better distinction between logical one and zero levels and therefore improved receiver performance. BER is used as the direct error-performance parameter.

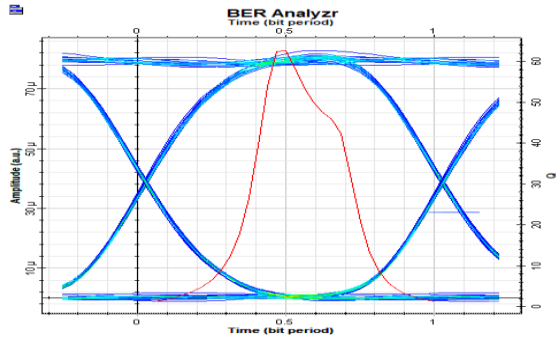
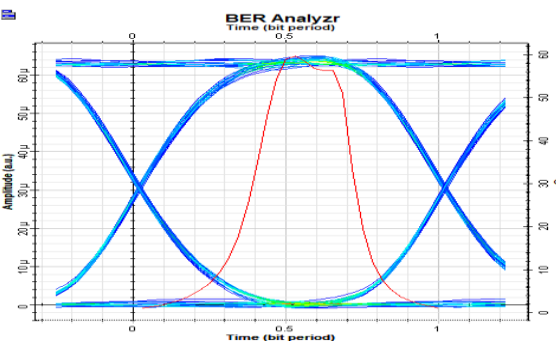
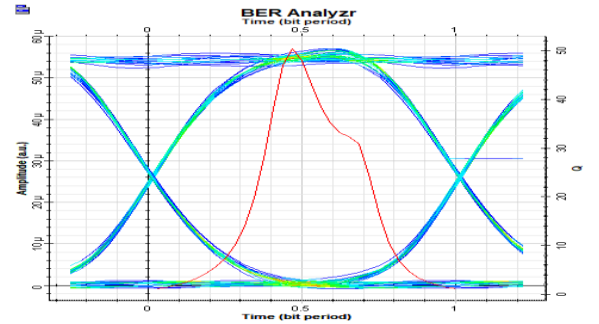
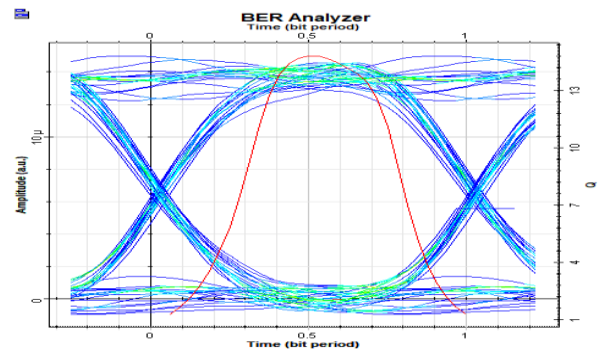
Result and Discussions

The designed simulation setup results determine a clear relationship between fiber length and optical signal strength. The *Q*-factor decreases and BER increases with the transmission distance increases and the eye height also decreases progressively. At 80 kilometer, the achieved *Q*-factor is 49.6824, representing a relatively strong separation between the detected logical levels. The corresponding BER is 0.0000010 , while the Eye height is 07.51488E^{-05} . These results show that the received signal holds a comparatively clear waveform after 80 kilometer of transmission distance. When the transmission distance is increased to 100 kilometer the *Q*-factor decreases to 31.7711, the BER increases to 2.3455E^{-08} and the eye height decreases to nearly 06.02129E^{-05} . These results imply that further fiber length causes measurable signal humiliation. At 120 km fiber length the *Q*-factor decreases further to 18.4955, the BER increases to 3.3045E^{-07} and the eye height decreases to nearly 5.10924E^{-05} . The relatively significant decrease in *Q*-factor indicates that the signal levels become less distinct at the receiver. The most significant deprivation is observed at 140 km transmission distance.

The results also indicate that 80 km fiber length provides the largest *Q*-factor and lowest BER among the simulated configurations. The 140 km configuration produces the lowest *Q*-factor and highest BER. Therefore, the simulation demonstrates that transmission distance is an important design parameter in the proposed CWDM-EDFA architecture.

Observed Eye Diagrams

Eye diagrams provide a visual representation of the received signal and are particularly useful for evaluating optical communication performance. The opening of the eye represents the available amplitude and timing margin for reliable decision making.

**Fig. 3.** Eye diagram at 80km fiber length**Fig. 4.** Eye diagram at 100km fiber length**Fig. 5.** Eye diagram at 120km fiber length**Fig. 6.** Eye diagram at 140km fiber length

At 80 km, the eye diagram exhibits a comparatively large and well-defined opening. The large eye opening corresponds to the high Q-factor of 49.6824 and the low BER of 9.9901E^{-08} . The receiver therefore has a relatively large margin for distinguishing between the logical signal levels. At 100 km, the eye opening becomes smaller. This reduction is consistent with the decline in Q-factor from 49.6824 to 31.7711 and the increase in BER from 9.9901E^{-08} to 1.7455E^{-07} . At 140 km transmission distance, the eye diagram shows the smallest opening among the inspected cases. The Q-factor decreases to 09.5621 and the BER reaches 1.7455E^{-07} . The very minor eye height of nearly 1.27565E^{-06} confirms severe signal deprivation associated with the shorter transmission distance configurations. The progressive thinning of the eye opening can be recognized to gathered dispersion, noise, attenuation-related effects, and other transmission impairments.

Graphs for fiber length Vs. Q-Factor, BER and Eye height

Graphs for Q-Factor vs. fiber length

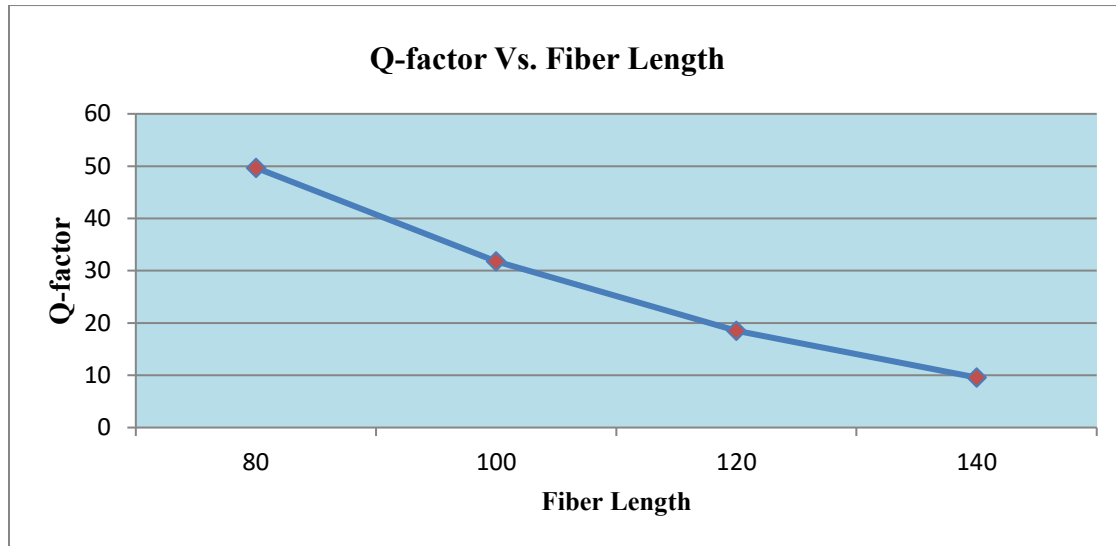


Fig. 7. Graph for the variation of Q-factor fiber length

This graph specifies that the signal quality gradually deteriorates as the transmission distance increases. The Q-factor used to compare the receiver decision margin at different fiber length. The significant drop from 49.6824 at 80 kilometer to 09.5621 at 140 kilometer fiber length indicates that the additional 60 km of fiber length produces substantial degradation.

BER versus Fiber Length

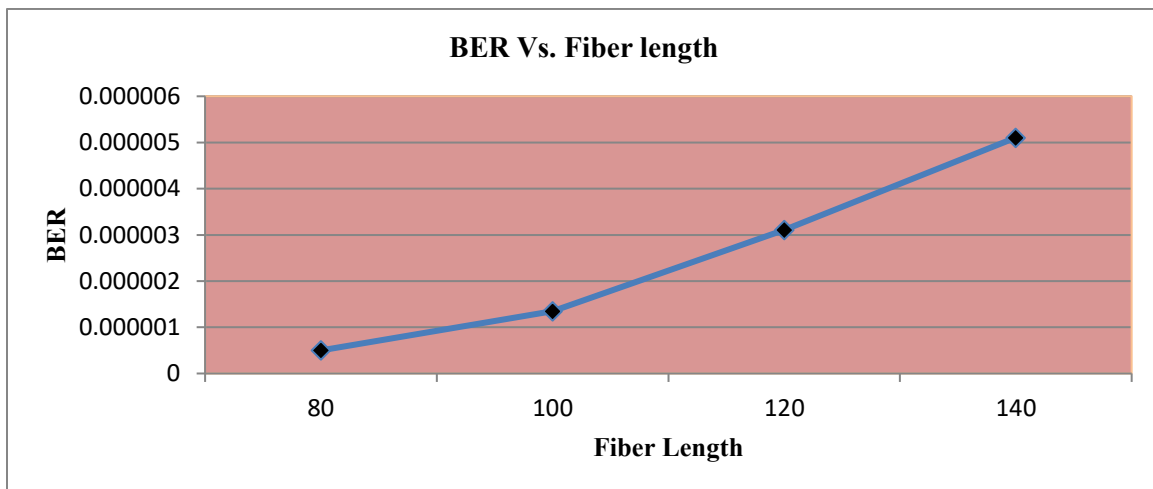


Fig. 8. Graph for fiber length verses BER

The surge in BER specifies that a gradually larger number of transmitted bits become susceptible to incorrect recognition. At the 140 km transmission distance it produces the maximum BER among the examined cases. Hence fall of signal separation usually increases the probability of revealing errors.

Graph for Eye Height versus Fiber Length

The Eye height observed from BER analyzer decreases significantly as the transmission distance increases:

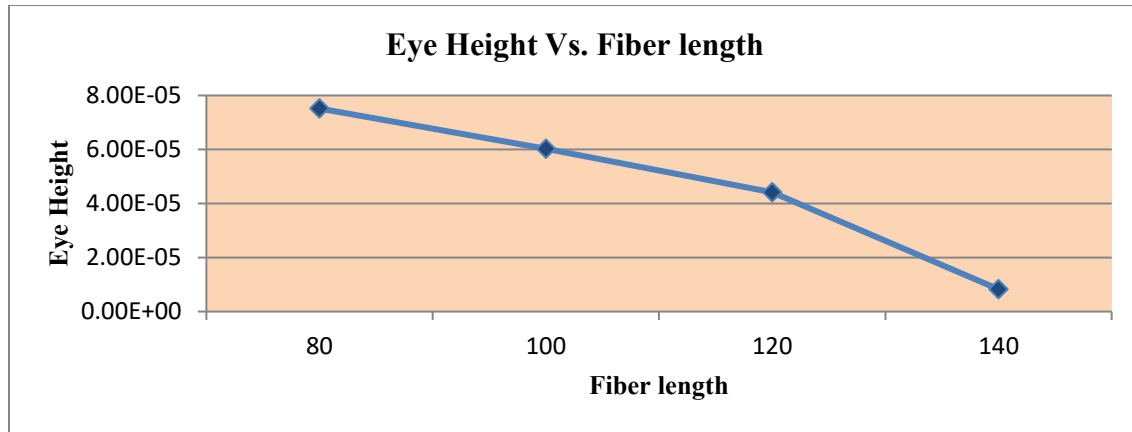


Fig. 9. Graph for fiber length verses Eye height

The reduction in eye height approves that the received waveform becomes progressively distorted with fiber length. A huge eye height affords a larger vertical decision margin, whereas a lesser eye height indicates that the logical signal levels are further difficult to distinguish. First, the Q-factor falls continuously as transmission distance increases. The Q-factor decreases from 49.6824 at 80 kilometer to 09.5621 at 140 kilometer transmission distance. This represents a significant drop in the received signal quality. Second, the BER increases with fibre length. The BER changes from 9.9901×10^{-8} at 80 km to 1.7455×10^{-7} at 140 km. The increase indicates deterioration in bit-detection accuracy. Third, the eye height decreases strongly with distance. The reduction from 7.51488×10^{-5} to 1.27565×10^{-6} demonstrates that the eye opening becomes progressively smaller. The three performance indicators consequently provide mutually consistent evidence of transmission degradation. The Q-factor and eye height decrease, while BER increases. This consistency strengthens the interpretation of the simulation results. The results also demonstrate the importance of selecting an appropriate transmission distance when designing long-reach optical access networks. EDFA can compensate for optical power loss, but its presence does not prevent other impairments from accumulating along a long fibre span.

Conclusion

This research presented a CWDM-EDFA-based NG-PON architecture intended for high-capacity and extended-reach optical access applications. CWDM provides wavelength-domain multiplexing that enables multiple optical channels to share a common fibre, while EDFA provides optical amplification to compensate for transmission loss. The combination therefore offers a promising architecture for investigating capacity enhancement and long-distance optical transmission. The proposed system was evaluated for fibre lengths of 80 km, 100 km, 120 km, and 140 km using Q-factor, BER, and eye height as the primary performance parameters.

The results give a relationship between fiber length and received signal quality. At 80 km fiber length, the configured system attained a Q-factor of 49.6824, BER of 9.9901×10^{-8} , and Eye height of nearly 7.51488×10^{-5} . At 140 km fiber length, the Q-factor abridged to 09.5621, while BER enlarged to 5.2055×10^{-6} and Eye height reduced to nearly 1.27565×10^{-6} . The observed eye diagrams results by showing a progressive decline in eye opening as transmission distance increased. The decrease in Eye opening specifies decreased amplitude and timing margins at the receiving section. This study determines that the proposed CWDM-EDFA design can support high-capacity fiber optical transmission over long distances, while transmission distance remains a critical parameter in determining the reachable signal strength. At the 80 km fiber length arrangement it produced the strongest simulated performance, whereas at the 140 km transmission distance arrangement it experienced substantial degradation.

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