University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 32 Number 1 January 2026

Performance Optimization of Intensity Modulation with Direct Detection Based Wavelength Division Multiplexing Link for 5G Fronthaul Cloud-Radio Access Network

Mohammad A. Mohammad [1, *], **Assad M. J. Al-Hindawi** [2], **Serwan Ali Mohammed** [1]

[1]Department of Electrical and Computer, College of Engineering, University of Duhok, Kurdistan Region, Iraq
[2]College of Engineering, Gilgamesh University, Baghdad, Iraq

ABSTRACT

The paper presents the design and modeling of a twenty-channel, bidirectional WDM-PON architecture with IM/DD for the 5G fronthaul in C-RAN systems. The proposed architecture is fully compliant with the ITU-T G-series Supplement 66 requirements on next-generation fronthaul interfaces. Each channel has a data-carrying bit rate of 25 Gbps, thus yielding a total capacity of 500 Gbps for the entire system. The entire design has been simulated in OptiSystem V.22. The analysis of the BER for different lengths of fiber and continuous wave laser power conditions provides the performance evaluation. Through simulation results, it can be confirmed that the system conforms to the F1 and Fx functional split specifications that are under consideration for split options 1 through 7a, using 25 Gbps in each direction. The results also indicate that the system can work efficiently over 11.5 km of bidirectional single-mode fiber without any need for DSP or optical amplifiers. The simplicity, low cost, and conformance to the standard fronthaul requirements make the proposed WDM-PON configuration a very strong candidate for the deployment of short-reach 5G fronthaul applications, featuring high-capacity, bidirectional connectivity, and reliable performance in C-RAN operational environments.

Keywords: Cloud-Radio Access Network (C-RAN), Optical Line Terminal (OLT), Optical Network Unit (ONU), Remote Radio Head (RRH), Baseband Unit (BBU).

1. INTRODUCTION

Growing users' demands for high data rates, particularly following the rollout of 5G networks, necessitate base station (BT) design to meet not only the users' demands but also system reliability and scalability. BTs are increasingly incorporating emerging technologies with the perspective of augmenting both radio access and baseband processing capacity**(Agrawal, 2012; Qutaiba, 2025)**. One of such innovations is the C-RAN, which is

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2026.01.12

Article received: 24/07/2025
Article revised: 28/11/2025
Article accepted: 24/12/2025
Article published: 01/01/2026

considered a prospective candidate for the next-generation mobile networks since it can offer more throughput, scalability, energy efficiency, and CAPEX, OPEX, and latency savings **(Rodoshi et al., 2020; Najwan and Firas, 2025)**. The fronthaul (FH) in the C-RAN architecture between RRH and BBU is central to determining the system's performance, capacity, and deployment cost **(Peng et al., 2015)**. In order to satisfy the high data rates and low latency needed by today's applications, three technologies dominate the use for fronthaul links: Microwave Radio Transmission (MRT), Fiber Optics (FO), and Free Space Optics (FSO). Of the two, ITU-T favors fiber optics owing to its high capacity, low latency, and scalability **(Sousa et al., 2020; Cezanne et al., 2023)**. Among the most likely fronthaul access technologies employing fibers is the Passive Optical Network (PON), which is likely to apply Wavelength Division Multiplexing (WDM) to boost capacity by enabling numerous users to be carried on one fiber**(Hamadouche et al., 2020; Antariksh et al., 2025)**. Originally conceived in the late 1980s for the purpose of enabling high-bandwidth residential service, WDM-PON is today increasingly recommended for fronthaul deployment in 5G networks **(Sharma et al., 2016; Hamadouche et al., 2024)**. For instance, **(Effenberger and Zhang, 2022; Xu et al., 2025)** examines the feasibility of WDM-PON in 5G wireless uses, underscored by its suitability for service areas aimed and suggesting a hybrid framework integrating WDM-PON with 50 Gb/s Time-Division Multiplexing PON (TDM-PON). Similarly, **(Arpita and Lokesh, 2018)** have suggested a cost-effective bidirectional WDM-PON architecture using devices like an Erbium-Doped Fiber Amplifier (EDFA), Avalanche Photodiode (APD), and WDM mux/demux to enable long-haul transmission via spectrum slicing over 170 km. The system capacity was, however, limited to 15 Gbps since it employed only five channels. To overcome such limitations, **(Aly and Mohamed, 2019; Cheng et al., 2024)** proposed an 80 Gbps total capacity Time-Wavelength Division Multiplexed PON (TWDM-PON) system using eight optical channels divided into eight 10 Gbps individual time slots each. The system recommends launching power levels of 5–10 dBm per channel in order to achieve BER values less than 10^{-13}. Nevertheless, ITU-T recommendations in **(Dias et al., 2023)** indicated TWDM-PON's latency limitation and recommended WDM-PON as the better alternative in accordance with its performance superiority in terms of both latency and capacity. In **(Hamadouche et al., 2020)**, a WDM-PON system 2–10 Gbps/λ with 8 channels and an 80 Gbps capacity served by one EDFA was proposed. Meanwhile,**(Martina and Moustafa, 2020)** proposed a Centralized Light Source WDM-PON (CLS-WDM-PON) to reduce Rayleigh backscattering (RB) and optical interferometric noise using a 10 GHz band-reject filter and enhance both downstream and upstream performances. Nevertheless, the data rate per channel demands sophisticated modulation formats and even DSP like Quadrature Amplitude Modulation (QAM)and Quadrature Phase Shift Keying (QPSK), even at the expense of increased system complexity and increased implementation cost **(Keiser, 2021)**. An 18-channel two-way WDM-PON system using IM/DD to meet ITU-T G-series Supplement 66 requirements for 5G fronthaul interfaces. The system runs at 25 Gb/s per channel with an aggregate capacity of 450 Gb/s, OptiSystem V.22 simulated. The functional division is 1 to 7a (F1 and FX interfaces) over a two-way single-mode fiber for 10 km **(Kawan and Assad, 2023)**. They had an 800 Gbps DP-QPSK system in **(Shbair and El Nahal, 2019)**, and a 128-QAM-based Dense WDM system in **(Rasheed et al., 2020)**, both of which were derived based on intricate, high-cost configurations like dispersion compensating fiber (DCF) and coherent detection. In contrast to them, **(El-Nahal et al., 2023; Alqahtani and El-Nahal, 2025)** proposed a simpler setup based on Intensity Modulated/Direct Detection Optical Orthogonal Frequency Division Multiplexing (IM/DD-OFDM) with 16-QAM for the

downstream and On-Off Keying (OOK) for the upstream. Their design achieved a downstream rate of 1.6 Tbps in 16 channels over 30 km using Single Mode Fiber (SMF) and remained affordable by not using DCF and colorless RSOA transmitters.
The architecture of this work provides an aggregated bandwidth of 500 Gbps and is capable of supporting 20 ONUs using a BD-SMF and is appropriate for 5G fronthaul in urban area applications. Using low-cost and low-order components such as Mach-Zehnder Modulators (MZMs) and Non-Return-to-Zero (NRZ) modulation, the system achieves a data rate of 25 Gbps per channel. The WDM MUX used in this design is lower in cost than an AWG.

2. TECHNICAL BACKGROUND

The massive data rate increase required for 5G networks puts extreme pressure on CPRI-based fronthaul systems, which have been used for many years. Moving to higher-layer functional split options reduces bandwidth and latency pressures by centralizing fewer processing tasks. The design of the fronthaul must, therefore, have a careful balance of performance, cost, and architectural considerations, including throughput, latency, and the level of functional centralization. In C-RAN architectures, the fronthaul segment of the link connecting the RRH and the BBU shown in Fig. 1 plays a significant role in defining overall system performance. To significantly reduce transport demands, the 3GPP has identified several possible functional split points within the radio protocol stack. In April 2017, it standardized the high-layer split known as Option 2, or the F1 interface. Lower-layer splits, including Options 6 and 7, are typically represented using the Fx notation **(Syed et al., 2020; Ullah et al., 2023)**. Various industry groups, including the CPRI consortium, O-RAN Alliance, and the Small Cell Forum, have also introduced their own versions of the Option 7 split **(Wey et al., 2020; Saifuldeen, 2020; Damir, 2024)**. Both 3GPP and IEEE advocate a layered network architecture composed of a Distributed Unit (DU), Central Unit (CU), and Remote Unit (RU) on the radio side, supported by a transport network incorporating elements such as the OLT and ONU, as depicted in **Fig. 2.** To satisfy the strict 5G New Radio (NR) performance requirements at both F1 and Fx interfaces, the ITU-T recommends the use of WDM-PON and PON technologies owing to their highly efficient fiber infrastructure and inherently low latency characteristics **(Wey et al., 2020; Effenberger and Luo, 2024)**.

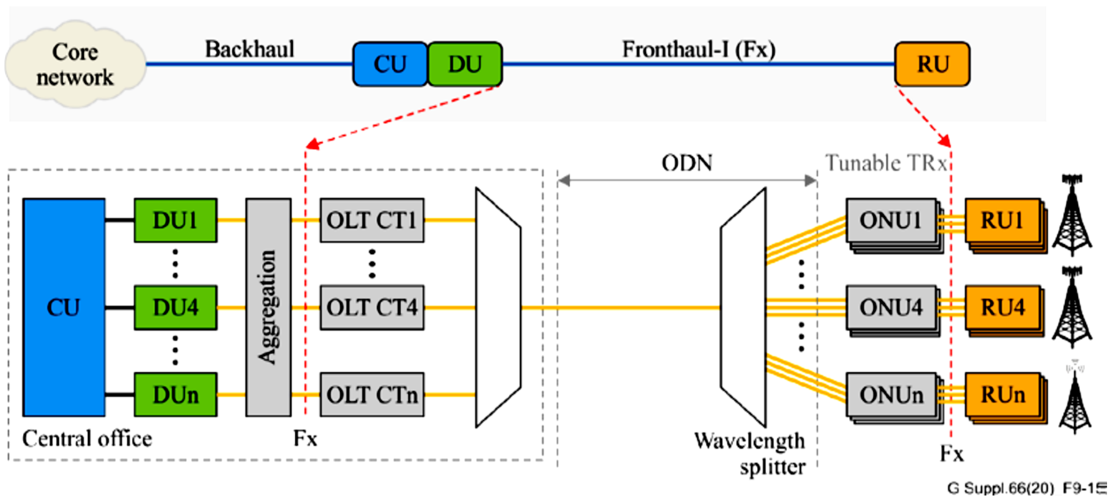


Figure 1. WDM-PON fronthaul Architecture **(Wey et al., 2020)**.

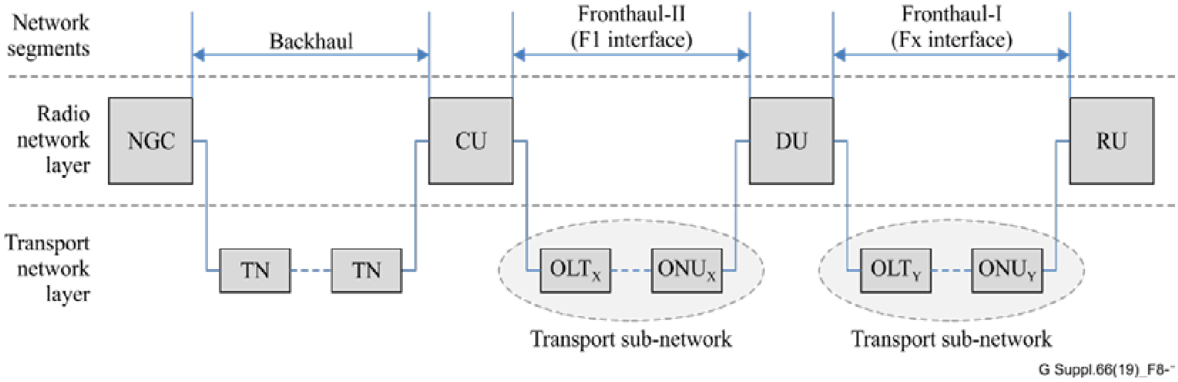


Figure 2. The Network is Structured into a Radio Layer (CU,DU,RU) and a Transport (OLT,ONU) **(Wey et al., 2020)**.

3. MODELLING OF SYSTEM DESIGN

The block diagram of the proposed system is shown in **Fig. 3** and works as a bidirectional 5G fronthaul connection between the BBU pool within a central hub and RRHs at each sector of 5G base stations. The detailed proposed modelling of the system design is illustrated in **Fig. 4**. The system uses nineteen separate optical channels, with efficient and high-capacity transmission. In the downstream trip (from BBU to RRH), each OLT generates a channel, which is first processed by a Pseudo-Random Bit Sequence (PRBS) generator that generates a 25 Gbps binary data stream. The stream is then converted to electrical pulses by the NRZ pulse generator E(t), as shown in Eq. (1) **(Kawan and Assad, 2023)** which conditions the pulses with exponential edge profiles with rise-time (c_r) and fall-time (c_f) coefficients governing them as follows;

$$E(t) = \begin{cases} 1 - e^{-\left(\frac{t}{c_r}\right)} & 0 \le t < t_1 \\ 1 & t_1 \le t < t_2 \\ e^{-\left(\frac{t}{c_f}\right)} & t_2 \le t < T \end{cases} \quad (1)$$

The electrical signals are then modulated MZM by means of CW lasers. The MZMs are interferometric intensity modulators, where the external voltage is used to result in constructive or destructive interference and hence modulate the optical carrier with the input signal. The input and output optical fields ($E_{in}(t)$,$E_{out}(t)$) are related as in Eq.(2) **(Seimetz, 2009; Rao et al., 2024)**:

$$E_{out}(t) = E_{in}(t).\, e^{j\phi_{PM}(t)} \quad (2)$$

Where in Eq.(3) the phase modulation $\Phi_{PM}(t)$ is given by **(Seimetz, 2009; Rao et al., 2024)**:

$$\phi_{PM}(t) = \frac{u(t)}{V_{(pi)}}\pi \quad (3)$$

In this context, u(t) represents the modulating voltage, while $V_{(pi)}$ denotes the voltage necessary to produce a π-phase shift.

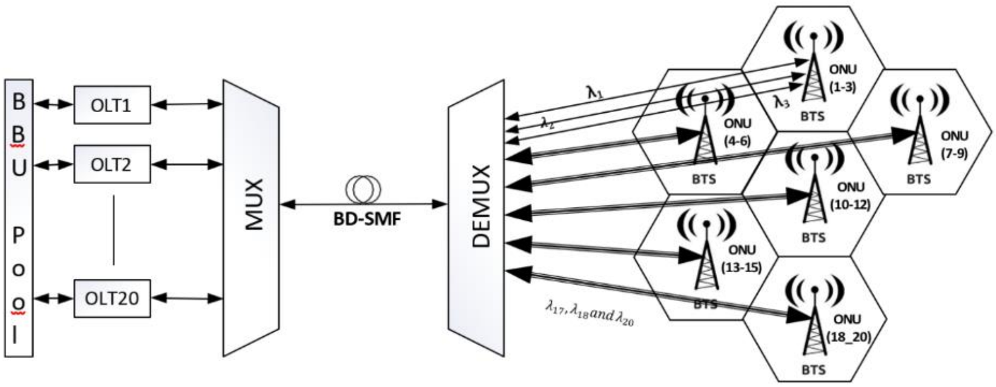


Figure 3. Block diagram of the suggested system architecture.

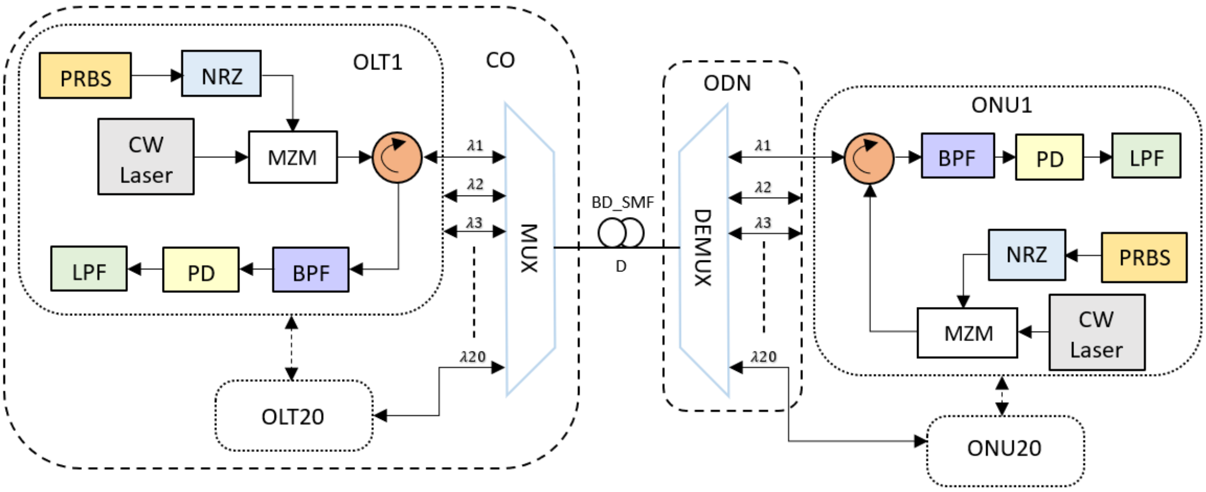


Figure 4. The architecture of the bidirectional WDM-PON system.

All the nineteen OLTs' modulated optical signals are multiplexed by an MUX in the Central Office (CO). The combined signal is transmitted over BD-SMF link to the Optical Distribution Network (ODN). The multiplexed signal is demultiplexed by an MUX on the ODN side, and each individual wavelength is sent to a distinct ONU corresponding to a 5G base station sector. At each ONU, the upstream and downstream signals are demultiplexed by an optical circulator. The downstream optical signal is filtered by a Band-Pass Filter (BPF) to reduce noise and remove unwanted frequency components, and then converted into electrical form by a Photo Detector (PD). This process is in accordance with IM/DD, an inexpensive, high-speed transmission that is simple. On the upstream path (from BBU to RRH), the same process is repeated. ONU signals are multiplexed, transmitted over the same BD-SMF link, and demultiplexed at CO over the same wavelength channel that the downstream uses as shown in **Fig. 4**. To avoid any interference between upstream and downstream, a unit optical delay is added, so the bidirectional communication is interference-free and stable**(Keiser, 2021)**. This bidirectional WDM-PON system is modeled and tested using OptiSystemV.22, which enables precise simulation and performance analysis of the system components and overall link behavior.

For the studied link, the Q factor and BER are crucial metrics for assessing signal quality and reliability. The Q factor in Eq. (4) is a measure of signal quality, is directly related to the BER, indicating the probability of bit errors in a transmitted signal. Higher Q factors correspond

to lower BER values, as shown in Eq. (5), signifying better signal quality and fewer errors **(Keiser, 2021; Fadhela and Alaa, 2022)**.
Q factor and BER are related as;

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0} \tag{4}$$

μ_1 refers to the average level of the signal for logic state of “1”
μ_0 refers to the average level of the signal for logic state of “0”
σ_1 is the noise variance measure for the logical “1”
σ_0 is the noise variance measure for the logical “0”,
and;

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{5}$$

Where erfc(x) refers to the complementary error function.

4. SYSTEM PERFORMANCE TEST AND RESULTS

In order to evaluate the performance of the proposed WDM-PON system, the basic design parameters have been taken into account, as illustrated in **Table 1.** These adhere to the ITU-T requirements for WDM-PON networks. According to the ITU-T standards, the system has been optimized for 25 Gbps data rates in both the downstream and upstream directions, while the same satisfies the performance criteria of passive optical networks. Similarly, the required specifications for the bidirectional optical fiber mentioned in **Table 2** were chosen based on the same ITU-T guidelines, and maintaining these specifications is a prime objective of the suggested system design. **Table 1** also summarizes the optical transmitter parameters, including the upstream and downstream wavelengths allocated accordingly, as mentioned by **(Sachdeva et al., 2025)**. The respective optical receiver parameter values are also presented in the same table. Specifically, the responsivity of the InGaAs photodetector at a wavelength of 1550 nm should be 0.7 A/W, according to **(Agrawal, 2012)**. Lastly, **Table 3** gives the parameter specifications of the MUX.

Table 1. Parameters of WDM-PON Architecture.

parameters	values
Bit rate	25 Gbps
Sequence length	64 bits
Sample per bit	64
Total Sample Count	4096
Continuous Wave Laser	
Input power	5 mW (7 dBm)
Wavelength (Up Link, Down Link),	(1550.1, 1549.32, 1548.51, 1547.72, 1546.92, 1546.12, 1545.32, 1544.53, 1543.73, 1542.94, 1542.14, 1541.35, 1540.56, 1536.77, 1538.98, 1538.19, 1537.4, 1536.61, 1535.81, 1535) nm
Optical Linewidth	10 MHz
Optical Receiver (PON PD)	
Responsivity (InGaAs)	0.7 A/W
Dark Current	10 nA

Table 2. Bidirectional Optical Fiber Parameters

Parameters	Value
Reference Wavelength	1550 nm
Length	11.5 km
Attenuation	0.2 dB/km
dispersion	16.75 ps/nm/km

Table 3. MUX Parameters at ODN

Parameters	Value
Number of input ports	20
Frequency	193.399 THz
Frequency spacing	100 GHz
Bandwidth	80 GHz
Insertion loss	10 dB
Return loss	64 dB
Max. insertion loss	100 dB
Return loss	65 dB
Phase shift	90 deg

For the present system design, Multiplexer MUX, and demultiplexer DEMUX shown in **Fig. 5** are used instead of using two AWG shown in **Fig. 6 (Kawan and Assad, 2023)**, due to the high cost of AWG compared to MUX and also the loss of multiple channels output in AWG.

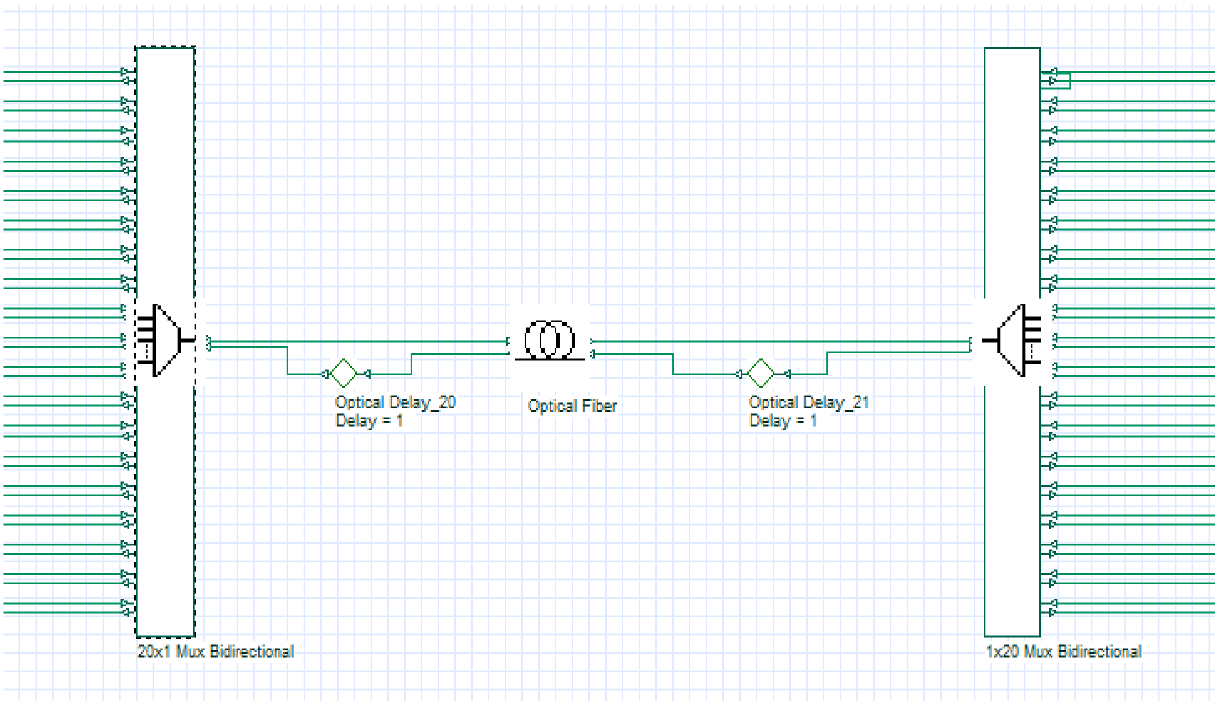


Figure 5. The used MUX, DEMUX in the present system design.

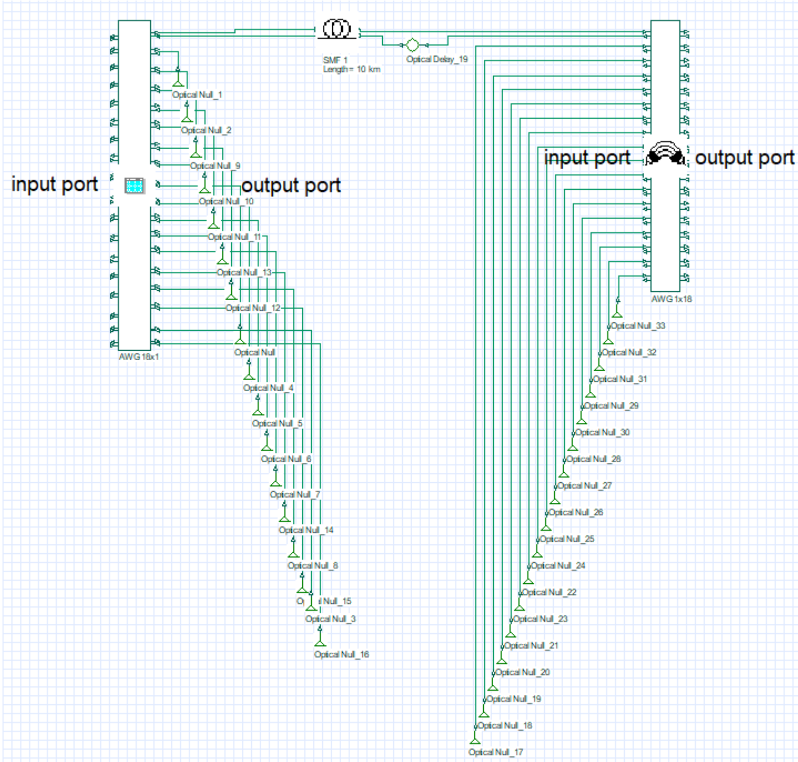
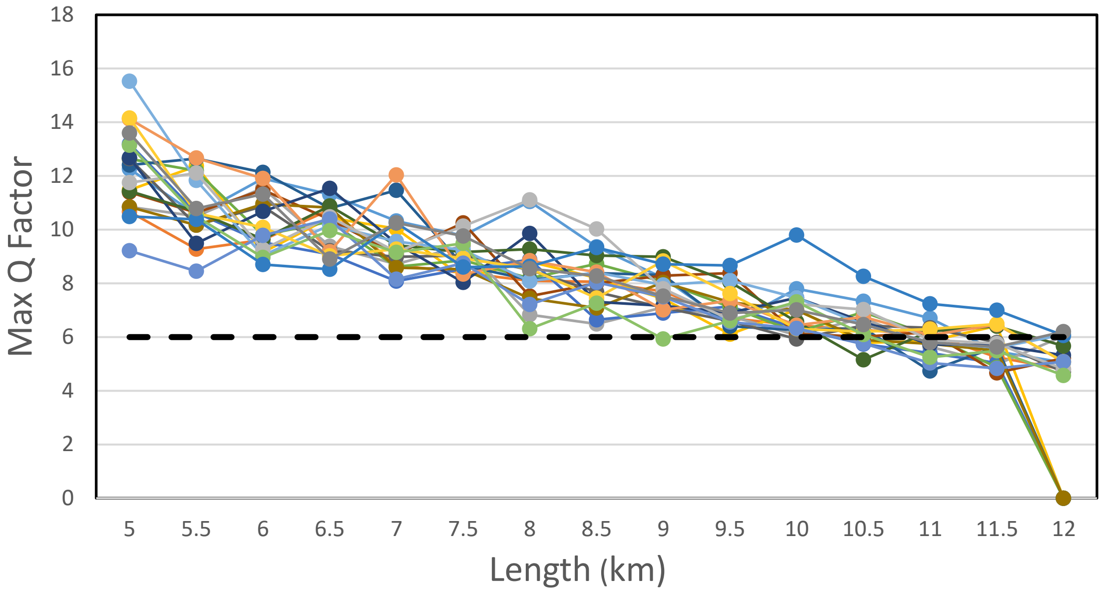


Figure 6. The AWG used in the designed system **(Kawan and Assad, 2023).**

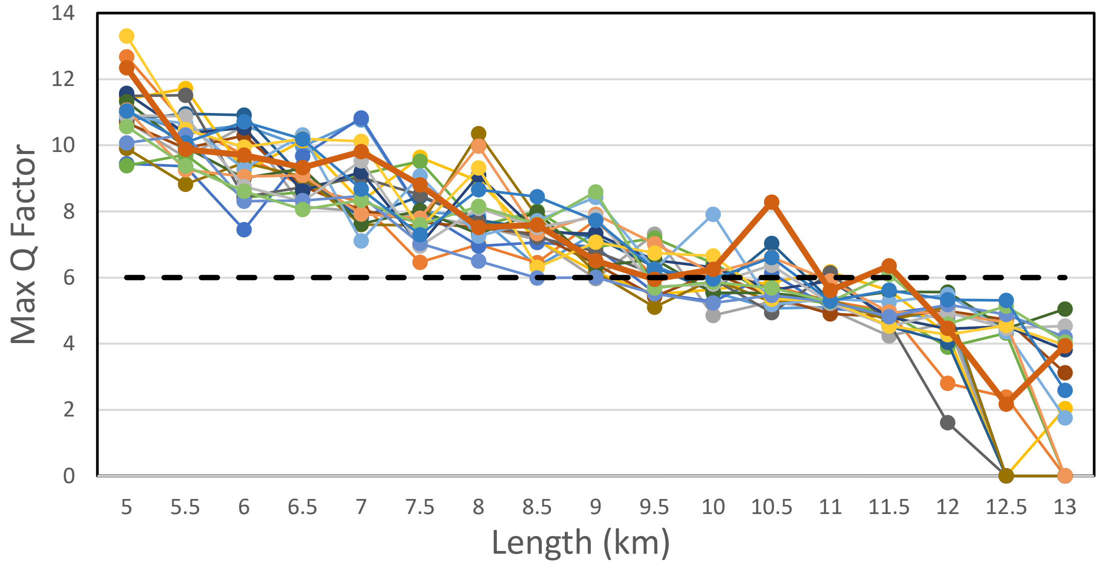
4.1 Channel Optimization

To validate the proposed system design, the minimum logarithmic BER across different optical fiber lengths was compared against established reference thresholds, specifically log(BER) = –9 and –13 and the min acceptable max Q factor = 6 as cited in **(Hamadouche et al., 2020; Hayam and Al-Yasiri., 2024)**, respectively. It is found that when the fiber length is below 9 km, and the transmitted power is 0 dBm, the increasing number of channels (of 25 GHz each) up to 20 channels gives acceptable evaluation results in both downlink and uplink directions.

These evaluation results for all channels in both uplink and downlink directions are presented for max Q factor and min log of BER in **Figs. 7 and 8**. The slight BER variations are caused by factors such as crosstalk, which are inherent in WDM-PON systems, particularly where a single wavelength is used for downlink and uplink transmission. Common wavelengths in bidirectional WDM-PON systems lead to signal interference and crosstalk, whose negative impact on BER and signal integrity is undesirable. Furthermore, during bidirectional transmission, self-phase modulation will also distort the signal, leading to BER degradation.

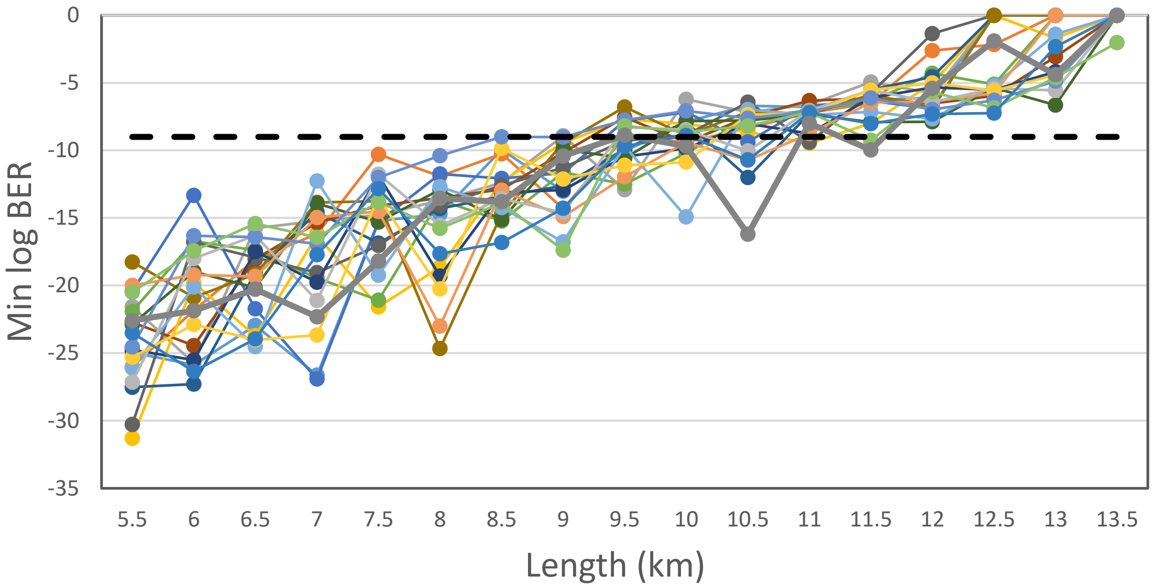


(a)

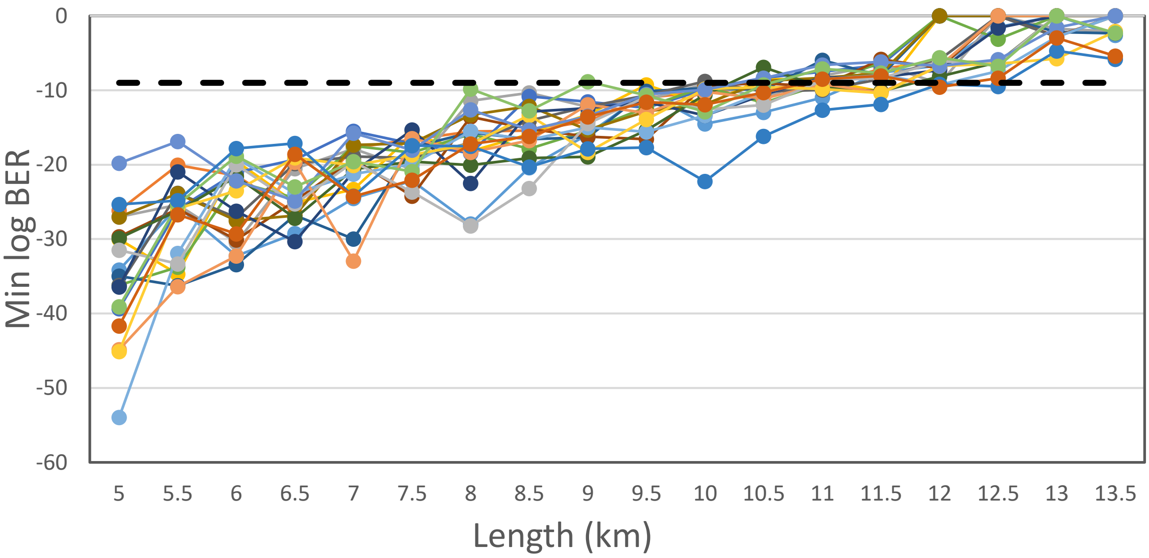


(b)

Figure 7. Max Q Factor Vs Optical Length (a) Downlink and (b) Uplink for 20 Channels.



(a)



(b)

Figure 8. Min log BER Vs Optical Length (a) Downlink and (b) Uplink for 20 Channels.

4.2 Power and Length Optimization

To achieve this optimization, the transmitted power is changed from -3dBm to 10dBm when the fiber length is fixed at 11.5 km for both down and up links. It is found that 7dBm level of the transmitted power is the optimal value to obtain the acceptable values of Q-Factor and Min log BER for all 20 channels. **Figs. 9 and 10** show the variations of Q-Factor and Min log BER, respectively, when the fiber length is changed at a fixed transmitted power of 7dBm for all 20 channels.

Additionally, **Fig. 8** illustrates that optimal values of Q-Factor for all channels are greater than 6 and also **Fig. 9** depicts that the values of Min log BER are greater than -9 when the transmitted power is 7 dBm and the length of an optical fiber is up to approximately 11.5

km. Nevertheless, after that point, a decrease below the threshold is noticed due to the top reasons being chromatic dispersion and attenuation of the optical fiber. The graph also illustrates the fluctuations in Q-Factor values, which are outcomes of the same causes stated in Section 4.1. The differences are actually outcomes of signal degradation by crosstalk, generating noise and distortion, and thus affecting signal integrity.

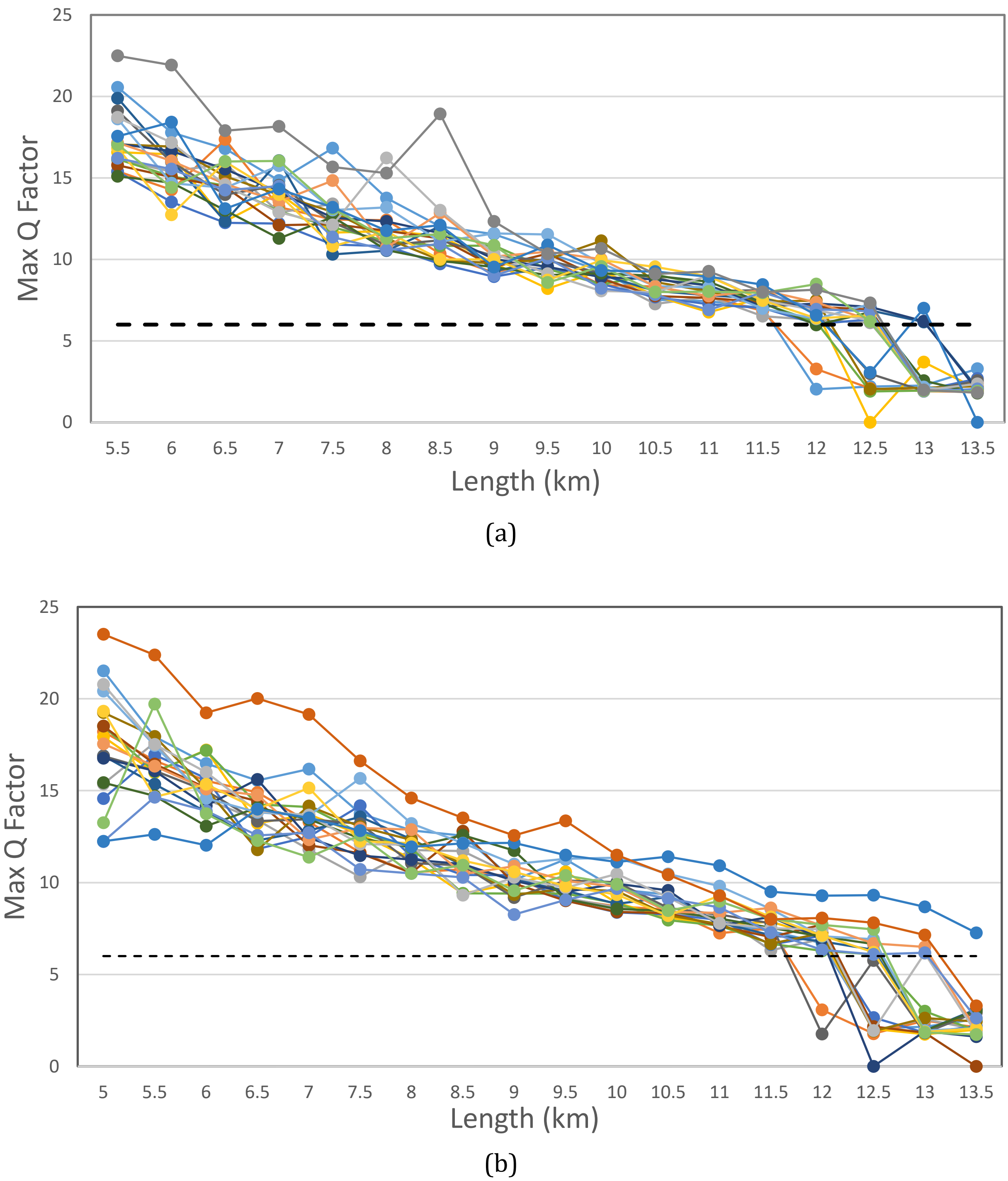
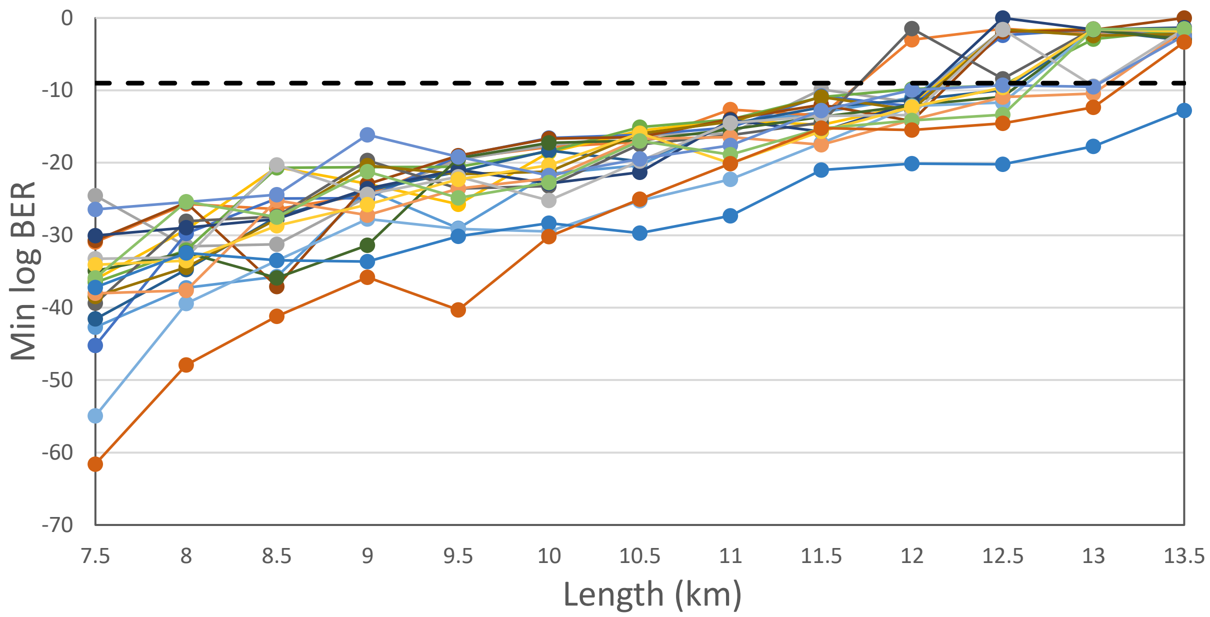
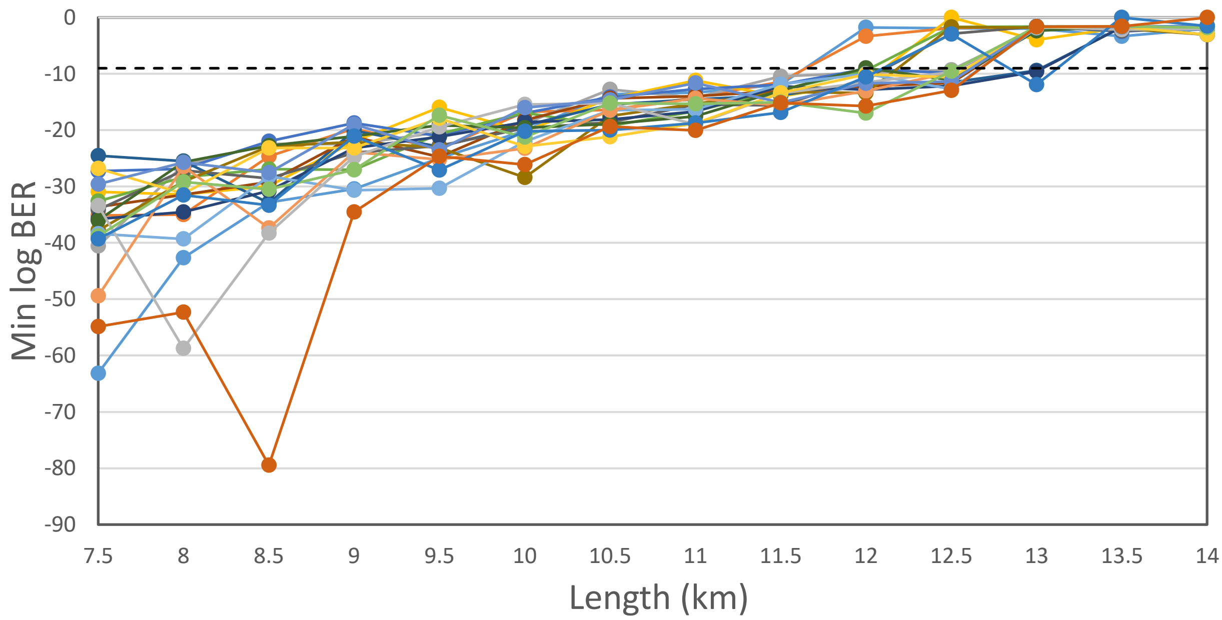


Figure 9. Max Q Factor vs Optical Length for (a) Downlink and (b) Uplink for 20 channels.



(a)



(b)

Figure 10. Min log BER vs Optical Length for (a) Downlink and (b) Uplink for 20 channels.

4.3 Comparative Analysis of This Work and Earlier Studies

Table 4 shows a comparison of the findings of this study with those reported in earlier works.

Table 4. Comparison of the present work with previous works.

Paper	Bit rate per channel	No. of channel	System Capacity	Modulation and coding	Amplifier	Transmit Power Tx	Distance (km)	Using DSP	Using DCF	Optical Fiber type
(Aly and Mohamed, 2019)	10 Gbps	8	80 Gbps	MZM and NRZ	No	10 dBm/ 10mW	50	No	No	BD-SMF
(Arpita and Lokesh, 2018)	3 Gbps	5	15 Gbps	NRT	EDFA	0 dBm/ 1 mW	170	No	No	SD-SMF
(Hamadouche et al., 2020)	10 Gbps	8	80 Gbps	NRT	EDFA	6dBm/ 3.98mW	5-80	No	No	BD-SMF
(Kawan and Assad, 2023)	25 Gbps	18	450 Gbps	MZM and NRT	No	0 dBm/ 1 mW	10	No	No	BD-SMF
(Martina and Moustafa, 2020)	10 Gbps-DS and 2.5 Gbps-US	16	160Gbps-DS and 40 Gbps-US	MZM and NRT	No	5 dBm/ 3.16 mW	45	No	No	BD-SMF
(Rasheed et al., 2020)	90 Gbps	8	720 Gbps	Dual polarized 128-QAM	EDFA	10 dBm /10 mW	80	Yes	Yes	SD-SMF
(Shbair and El Nahal, 2019)	100 Gbps	8	800 Gbps	DP-QPSK	2 EDFA	2 dBm/ 1.6 mW	80	Yes	No	BD-SMF
Present work	25 Gbps	20	500 Gbps	MZM and NRZ	No	7 dBm/ 5 mW	11.5	No	No	BD-SMF

Overall, the results show that the proposed system is very well suited for short-reach deployments, in particular, for distances up to 11.5 km. It offers a very cost-effective fiber-optic solution with the capability of 25 Gbps per channel. The design allows for various functional split options as defined in the ITU-T G-Series Recommendations – Supplement 66, covering options 1 through 7a. The proposed network topology supports twenty 25-Gbps channels, yielding a total bidirectional system capacity of 500 Gbps. This makes it an attractive, cost-effective WDM-based solution for early 5G deployment, particularly using existing LTE infrastructure under the non-standalone approach (NSA) configuration.

5. CONCLUSIONS

A bidirectional, twenty-channel IM/DD WDM-PON system operating at 25 Gb/s per wavelength for both downstream and upstream transmission has been designed and simulated. Its performance was evaluated by analyzing the BER with different CW launch powers and variable fiber lengths, so that the requirements of ITU-T 5G fronthaul design were satisfied according to the G-series Recommendations – Supplement 66. The proposed architecture has a very simple and low-cost implementation with no use of optical amplifiers or digital signal processing and offers an aggregated capacity of 500 Gb/s. The simulation results prove that this system can support both F1 and Fx 5G fronthaul interfaces, covering functional split options from 1 up to 7a as defined by ITU-T, while also being suitable for deployment in urban areas with achieved optical spans of up to 11.5 km.

Credit Authorship Contribution Statement

Mohammad A. Mohammad: Conceptualization, Methodology, Experimental work, Data curation, Formal analysis, Writing – original draft. Assad M. J. Al-Hindawi: Methodology, Validation, and Serwan Ali Mohammed: Formal analysis and Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Agrawal, G.P., 2012. *Fiber-Optic Communication Systems*. John Wiley and Sons, New York.

Alqahtani, D., and El-Nahal, F., 2025. Coherent WDM-PON and free space optical (FSO) system for front-haul in next-generation cellular networks. *Optik,* 323**,** pp. 1-7.https://doi.org/10.1016/j.ijleo.2024.172212.

Aly, H., and Mohamed, B., 2019. Evaluation and Optimization of TWDM-PON System Capacity Over Single Bidirectional Optical Fiber: Migration Promising Solution for The Next Generation PONs. *International Conference on Computer and Information Sciences (ICCIS)***,** pp. 1-6.https://doi.org/10.1109/ICCISci.2019.8716461.

Antariksh, S., Vishal, G ., Sourav, C ., Aman, K., Manoj, S., Shippu, S ., Hunny, P., and Manoj, K., 2025. Performance enhancement of WDM-based RoF systems using EDFA amplifiers. *Journal of Optical Communications***,** pp. 1-9.https://doi.org/10.1515/joc-2025-0042.

Arpita, S., and Lokesh, T., 2018. Design and performance evaluation of bidirectional SS-WDM-PON using FTTH architecture. *International Conference on Micro-Electronics and Telecommunication Engineering (ICMETE)***,** pp. 281-284.https://doi.org/10.1109/ICMETE.2018.00068.

Cezanne, J., Jiang, M., Shental, O., Bedewy, A., Sampath, A., Koymen, O., and Li, J., 2023. Design of wireless fronthaul with mmWave LOS-MIMO and sample-level coding for O-RAN and beyond 5G systems. *IEEE Open Journal of the Communications Society,* 4**,** pp. 1893-1910.https://doi.org/10.1109/OJCOMS.2023.3308713.

Cheng, Y., Shao, Y., Ding, S., and Chan, C., 2024. Deep reinforcement learning based joint allocation scheme in a TWDM-PON-based mMIMO fronthaul network. *IEEE Photonics Journal,* 16**,** pp. 1-11.https://doi.org/10.1109/JPHOT.2024.3388571.

Damir, B., 2024. Overview of available fiber optic backhaul solutions for 5G/6G networks. *2024 International Workshop on Fiber Optics in Access Networks (FOAN)***,** pp. 22-26.https://doi.org/10.1109/FOAN63517.2024.10765757.

Dias, I., Ruan, L., Ranaweera, C., and Wong, E., 2023. From 5G to beyond: passive optical network and multi-access edge computing integration for latency-sensitive applications. *Optical Fiber Technology,* 75**,** pp. 1-8.https://doi.org/10.1016/j.yofte.2022.103191.

Effenberger, F., and Luo, Y., 2024. Standardization of wireless fronthaul and backhaul using passive optical network. *Handbook of Radio and Optical Networks Convergence***,** pp. 1123-1140.https://doi.org/10.1007/978-981-97-2282-2_41.

Effenberger, F., and Zhang, D., 2022. WDM-PON for 5G wireless fronthaul. *IEEE Wireless Communications,* 29**,** pp. 94-99.https://doi.org/10.1109/MWC.001.2100420.

El-Nahal, F., Xu, T., Alqahtani, D., and Leeson, M., 2023. A Didirectional WDM-PON Free Space Optical (FSO) System for Fronthaul 5G C-RAN Networks. *IEEE Photonics Journal,* 15**,** pp. 1-10.https://doi.org/10.1109/JPHOT.2022.3232081.

Fadhela, T., and Alaa, H., 2022. Analysis study of quality factor and bit error rate at wavelength change. *Indonesian Journal of Electrical Engineering and Computer Science,* 27**,** pp. 301-308.http://dx.doi.org/10.11591/ijeecs.v27.i1.pp301-308.

Hamadouche, H., Merabet, B., and Bouregaa, M., 2020. Performance analysis and improvement of (2-10) Gbps WDM PON using EDFA amplifiers. *2020 1st International Conference on Communications, Control Systems and Signal Processing (CCSSP)*,pp. 90-94.https://doi.org/10.1109/CCSSP49278.2020.9151806.

Hamadouche, H., Merabet, B., and Bouregaa, M., 2024. The performance comparison of hybrid WDM/TDM, TDM and WDM PONs with 128 ONUs. *Journal of Optical Communications,* 44**,** pp. 1-12.https://doi.org/10.1515/joc-2020-0046.

Hayam, A., and Al-Yasiri., 2024. A new protocol to design cellular systems with variable spreading factors. *Journal of Engineering,* 10**,** pp. 1-12.https://doi.org/10.31026/j.eng.2004.01.01.

Kawan, F., and Assad, M., 2023. 450 Gbps low-cost intensity modulation with direct detection (IM/DD) wave length division multiplexing (WDM-PON) for 5G fronthaul. *KSII Transactions on Internet and Information Systems (TIIS),* 17**,** pp. 3310-3329.http://doi.org/10.3837/tiis.2023.12.005.

Keiser, G., 2021. *Fiber Optic Communication Networks*. Springer, Newton Center, USE.

Martina, N., and Moustafa, H., 2020. Performance enhancement of WDM-PONs: Interferometric noise reduction. *Reflection, Scattering, and Diffraction from Surfaces VII,* 11485**,** pp. 1-8.https://doi.org/10.1117/12.2568330.

Najwan, M., and Firas, A. . 2025. Interference mitigation for millimeter wave communications in 5G networks using enhanced q-learning. *Journal of Engineering,* 31**,** pp. 127-152.https://doi.org/10.31026/j.eng.2025.03.08.

Peng, M., Wang, C., Lau, V., and Poor, H., 2015. Fronthaul-constrained cloud radio access networks: insights and challenges. *IEEE Wireless Communications,* 22**,** pp. 152-160.https://doi.org/10.1109/MWC.2015.7096298.

Qutaiba, A., 2025. Performance optimization and architectural advancements in cloud radio access networks (C-RAN) for 5G and beyond. *Journal of Electronic & Information Systems,* 7. https://doi.org/10.22541/au.174466175.58490173/v1.

Rao, X., Yang, L., Su, J., and Xie, H., 2024. High-order coupled-mode theory for angular symmetry chiral fibers manipulating arbitrary-order orbital angular momentum modes. *Journal of Lightwave Technology,* 42**,** pp. 6912-6924.https://doi.org/10.1109/JLT.2024.3413983.

Rasheed, M., Qamar, F., Qamar, N., Shahzadi, R., Ali, M., Khan, M., and Haroon, F., 2020. 128-QAM x 8 channels DWDM communication for optical fiber networks. *International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)***,** pp. 1-6. https://doi.org/10.1109/iCoMET48670.2020.9073828.

Rodoshi, R., Kim, T., and Choi, W., 2020. Resource management in cloud radio access network: Conventional and new approaches. *Sensors,* 20**,** pp. 6-18.https://doi.org/10.3390/s20092708.

Sachdeva, S., Sindhwani, M., Singh, G., Kumar, A., Rasane, P., and Singh, J., 2025. Performance investigation of contention and monitoring in long-reach passive optical networks. *Journal of Optical Communications,* 45**,** pp. 1-8.https://doi.org/10.1515/joc-2023-0159.

Saifuldeen, A., 2020. Securing physical layer for FHSS communication system using code and phase hopping techniques in CDMA, system design and implementation. *Journal of Engineering,* 26**,** pp. 190-205.https://doi.org/10.31026/j.eng.2020.07.13.

Seimetz, M., 2009. *High-Order Modulation for Optical Fiber Transmission*. Springer, Berlin, Germany.

Sharma, R., Dewra, S., and Rani, A., 2016. Performance analysis of hybrid PON (WDM-TDM) with equal and unequal channel spacing. *Journal of Optical Communications,* 37**,**pp. 1-4.https://doi.org/10.1515/joc-2015-0055.

Shbair, W., and El Nahal, F., 2019. Coherent passive optical network technology for 5G. *2019 IEEE 7th Palestinian International Conference on Electrical and Computer Engineering (PICECE)***,**pp. 1-4.https://doi.org/10.1109/PICECE.2019.8747183.

Sousa, Ivo., Sousa, Nuno., Queluz, Maria Paula., and Rodrigues, António. 2020. Fronthaul design for wireless networks. *Applied Sciences,* 10**,**pp. 2-10.https://www.mdpi.com/2076-3417/10/14/4754#.

Syed, S., Hussain, A., Qureshi, M., and Khawaja, W., 2020. Towards the shifting of 5G front haul traffic on passive optical network. *Wireless Personal Communications,* 112**,** pp. 1-11. https://doi.org/10.1007/s11277-020-07115-6.

Ullah, R., Ullah, S., Imtiaz, W., Khan, J., Shah, P., Kamran, M., Ren, J., and Chen, S., 2023. High-capacity free space optics-based passive optical network for 5G front-haul deployment. *Photonics,* 10**,**pp. 1-13. https://doi.org/10.3390/photonics10101073.

Wey, J., Luo, Y., and Pfeiffer, T., 2020. 5G wireless transport in a PON context: An overview. *IEEE communications standards magazine,* 4**,** pp. 50-56. https://doi.org/10.1109/MCOMSTD.001.1900043.

Xu, Y., Wang, S., and Saleem, A., 2025. Simulative analysis of stimulated Raman scattering effects on WDM-PON based 5G fronthaul networks. *Sensors,* 25**,**pp. 3-15.https://doi.org/10.3390/s25103237.

تحسين أداء نظام تعديل الكثافة باستخدام تقسيم الطول الموجي القائم على الكشف المباشر لشبكة الوصول اللاسلكي السحابي الأمامية للجيل الخامس

محمد عبدالرحمن محمد[1]،أسعد مبدر جاسم الهنداوي[2]، سيروان علي محمد[1]

[1] قسم الكهرباء والحاسبات، كلية الهندسة، جامعة دهوك ، اقليم كردستان ، العراق

[2] الكلية الهندسة ، جامعة جلجامش ، بغداد ، العراق

الخلاصة

تتناول هذه الورقة البحثية تصميم ونمذجة نظام شبكة بصرية سلبية ثنائية الاتجاه ذات عشرين قناة (WDM–PON) مع تعديل الكثافة مع الكشف المباشر (IM/DD) لشبكة الوصول الراديوي السحابي الأمامية (C–RAN). يعمل النظام بمعدل بيانات يبلغ 25 جيجابت في الثانية لكل قناة، بسعة إجمالية تبلغ 500 جيجابت في الثانية، وقد تمت محاكاته باستخدام OptiSystem V.22. أجري تحليل أداء النظام بناءً على معدل خطأ البت (BER) لأطوال ألياف بصرية مختلفة ومستويات طاقة ليزر CW. وتُثبت بيانات المحاكاة قدرة النظام على دعم مواصفات واجهة F1 وFx لنطاق تقسيم وظيفي من 1 إلى a7، بسرعة 25 جيجابت في الثانية لكل اتجاه .وتشير نتائج المحاكاة إلى قدرته على استخدام ألياف أحادية الوضع ثنائية الاتجاه بامتداد 11.5 كم، وهو بسيط واقتصادي، ولا يتطلب معالجة رقمية للإشارة (DSP) أو تضخيمًا بصريًا، ويُعدّ حلاً مناسبًا لنشر شبكات الجيل الخامس الأمامية قصيرة المدى.

الكلمات المفتاحية: شبكة الوصول اللاسلكي السحابي ، رأس الراديو البعيد ، وحدة النطاق الأساسي ، طرف الخط البصري .