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Enhanced Transmission of 0.64 Tbps in DWDM-RoF Technique Along 180 km Transmission Distance for 5G Mobile Communication

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ABSTRACT

This paper introduces enhanced filtered channels in the suggested design of the optical communication system formed for 5G mobile communication over optical fiber. The main goal is to overcome the limited bandwidth of radio wave systems and to enable high-data-rate transmission. The dense wavelength division multiplexing based on the radio-over-fiber (DWDM-RoF) system has succeeded in satisfying a high data rate of 0.64 Tbps by a multichannel filtered system through a 180 km distance within the C-Band through a multichannel filtered approach. The design includes 64 filtered channels with an optimized bandpass filter (BPF), making unprecedented channel convergence possible. The system transmits at low power 0 dBm (1.0 mW) over single-mode fiber (SMF) 180 km and uses the dispersion compensation fiber (DCF) 18 km. It converts light to electrical signals and is filtered by a low pass filter at 0.75 of the bit rate (B) set at 10 Gbps. The model is applied in Optiwave 7.0 software the results are the figures showed the overwhelming success enhanced by the opened-eye diagram, the value of the Q factor is 6.72, and the BER is 7.1E-12 across 180 km of the center frequency ν_{24}=193.13 THz (1553.5 nm) for 50 GHz spacing between channels.

Keywords: Optical wireless communication (OWC), Dense wave division multiplexing (DWDM), Radio over Fiber (RoF), Single-mode fiber (SMF) in C-Band, Dispersion compensation fiber (DCF), Erbium-doped fiber amplifier (EDFA).

1. INTRODUCTION

The race in the 21st century for up-to-date data transmission over long lines with high quality is ringing in the cycle of ever-increasing demand for Internet-based services personal communication, video conferencing, and sharing the world for learning. In the current world scenario where that becomes more and more quintessential fiber optics has been the most reliable and has proven superior in telecommunications **(Sharma et al., 2020; Kaushik and**

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Saini, 2023). Consequently, RF networks or mobile communications 5G by themselves will not be able to satisfy future bandwidth needs, necessitating the utilization of optical wireless communication (OWC) systems that require higher frequency spectrums such as visible light (VL) **(Kareem et al., 2021).** Optical fibers are considered the core of many industries, giving benefits like higher capacity, long links, power saving, and interference immunity against copper-based transmission **(Singh et al., 2024; Mohammed and Kbashi, 2009; Thabit et al., 2022)**. Visible light communication (VLC) has gained traction **(Seidel and Rappaport, 1992)** in academia and industry due to its advantages over RF systems: a bandwidth over 1000 times the RF spectrum and the antenna wave can withstand the interferences 1000 times more likely found in the broader frequency band **(Yu et al., 2021)**. Optical systems can support long-distance communication, which usually involves higher power levels that cause various nonlinear effects **(Basil and Moutaz, 2021; Khan et al., 2021)**. Such effects result from larger optical transmitter power, which is required to support and manage long-range communications **(Yu et al., 2020; Garg and Nain, 2022)**. Radio-over-fiber (RoF) **(Singh et al., 2024)** is a desirable technology for implementing wireless access networks. It allows the transmission of millimeter waves through the fiber optic links and can be short or long distances **(Khalil et al., 2021)**. RoF is an optical RF link process, that transmits modulated RF signals **(Ibhaze et al., 2020)** using fiber optic links from a central point to remote radio units (RRUs) for uplink and downlink activity. It allows for two-way transmission of RF signals in this fashion: between the base station (BS) and central station (CS) **(Liu and Li, 2022)**. Another advantage of applying the DWDM technique **(Mohammed, 2013; Almaamory et al., 2010)**with RF signal is the high adaptability and flexibility to handle large data rates for the 5G mobile communication networks carried on multichannel **(Mohsen et al., 2021; Alatwi et al., 2021)**. However, there are two limitations to increasing data rate in optical communication networks **(Ali and Farhood, 2019)** such as attenuation and chromatic dispersion (CD) as a linear effect and self-phase modulation (SPM), cross-phase modulation (XPM), and four-wave mixing (FWM) as a nonlinear effect **(Ali et al., 2022; Sirleto and Righini, 2023; Ali et al., 2021)**. Linear influence can be treated through the design by choosing a suitable amplifier to reduce the attenuation of single-mode fiber (SMF) **(Marcuse and Lin, 1981; Belardi and Knight, 2014)** and dispersion compensation fiber (DCF) at each distance, an Erbium-doped fiber amplifier (EDFA) as an attenuation compensated (α = 0.2 dB/km) for SMF and (α = 0.5 dB/km) for DCF **(Uzunidis et al., 2021; Periyasamy et al., 2023)**. In contrast, the CD is mitigated by dispersion compensation fiber (DCF) **(Yadgeer et al., 2023).** The scattering effects added another nonlinear, stimulated scattering of Brillouin (SBS), and stimulated scattering of Raman (SRS) **(Feng et al., 2020)**. The contributions of this paper are outlined as follows:

- Evaluation and Representation: demonstrate, validate, and assess a DWDM-RoF system considering real-world network load and deployment situations using a variety of performance metrics. By employing distinct frequency ranges for every tier, the goal is to reduce interference and enhance rate and coverage across the whole region, not only at the channel boundaries.
- Addressing interference for the user-channel association is known as interference mitigation. specifically, by using filtering techniques to increase network throughput, which will enhance customer Quality of Service (QoS) and improve network performance as a whole.
- Satisfy wide cover for mobile communication 5G via a long distance of 180 km with 64 transmission channels between two sides in a safe way BL= 115 Tb/s km.

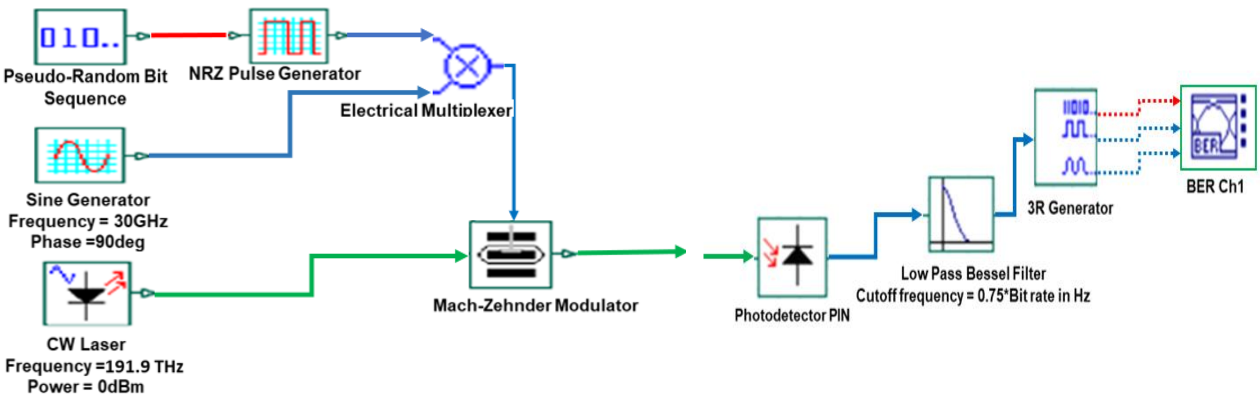
- Filtering technique success is the biggest challenge in channel spacing reduction. It has clear results, although the emergence of FWM depends on it.
- Maintaining the system operating power at a meagre value compared to the distance travelled and the number of input channels.

In the previous work, **(Mahmood and Rumyantsev, 2019)** the radio signals based on a fiber (RoF) system utilizing the subcarrier multiplexer technique are suggested. The wavelengths identical to the down and up-link subchannels and 1 Gbps data rate are provided via the distance of 10 km in two directions of fiber optic. A chromatic dispersion (CD) is the most important factor due to the finite slot pulse linewidth of the continuing wave (CW) source. Thus, the dispersion-compensated fiber Bragg Greeting (FBG) is applied to mitigate the influence of chromatic dispersion in fiber and increase bandwidth optimization. By OptiSystem 10.0 software, the results show that the FBG system is better than the one without FBG. The low bands and limited capacity access networks in the work (Yang *et al.*, 2021) do not compensate for the needs of huge-band communication consumers. As long as techniques produce evidence for the necessities of the following origination. The RF-based fiber optic (RoF) and the passive optic networks (PON) communication systems merged between the higher-speed and lower-cost features. In this study, optical communication sending and receipting devices are standard on the PON network to satisfy a huge communication capacity. Also, the optical suppressed carrier (OCS) carrying techniques are applied to set up a two-directional optical transmission system on RoF via PON. The simulation of software outcomes demonstrates that the suggested design is influential and more reliable. As shown in the following study **(Garg and Nain, 2022)** which introduces an optimum RoF network involving a cascaded collection of a Mach Zehnder as a modulator (MZM) and the Li-Nb MZM in a sender side via an optical phase as a conjugator form (OPC) along a link to enhance the wider bandwidth quality at the transmission via long distances. The suggested model appears to be a successful optical transmission of 8^{th} 8-input WDM modulated channel signals of mobile signal frequency of 110 GHz across a limited with 100 km of the 12 Gbps input bit rates. This design satisfies a bit rate of errors (BER) value of 10−58 and a value of quality factor (Q) with 15.64 through the spacing between channels set at 0.5 nm. The current optical communication system design produced, radio-based on fiber (RoF) techniques is fundamental to Mobile communication (5G), which leads to improved network coverage, capacity, and cost optimization (**Sliti, 2022)**. A 16-input channel WDM with RoF design was implemented by using dispersion fiber as a compensated (DCF) and Bragg Grating as a manufacturing fiber with specific features (FBG) with spacings between channels of 100 GHz and 50 GHz, and single-mode fiber (SMF) across lengths of 20km and 50km. **(Jain and Iyer, 2023)** presented had wide coverage instead of C-band only and L-band also to provide low fiber attenuation and are thus preferred for Radio over Fiber communication, the main challenge in this design the authors must be treated with two types of optical amplifier instead of one. The Erbium-doped fiber amplifier (EDFA) amplifies the attenuations in the C-band and the Ramman amplifier (RA) in the L-band. The increase in cost and reduction in transmission distance by 60 km are included in this design, but we cannot forget the principled step that this design provided for the possibility of searching or expanding to another communications band without being restricted by the conventional band (C-band). **(Akram and Al-Tamimi, 2023)** introduced different types of modulation suppressed-carrier return to zero (CSRZ), differential-phase shift keying (DPSK), and intensity modulation all these modulations satisfy high transmission distance. The transmission distance is 400 km, and this is achieved by multi loops (number of loops), the main design consists of single-mode fiber with 25 km and 0.2 dB/km attenuation for silica amplified by an Erbium-doped fiber amplifier (EDFA) (25 km × 0.2 dB/km). The group compensated by dispersion compensation fiber (DCF) with 5 km and 0.5 dB/km attenuation for compensation fiber amplified by an Erbium-doped fiber amplifier (EDFA) (5 km × 0.5 dB/km). The main design in these limited values can be repeated to get multi-kilometers for more coverage.

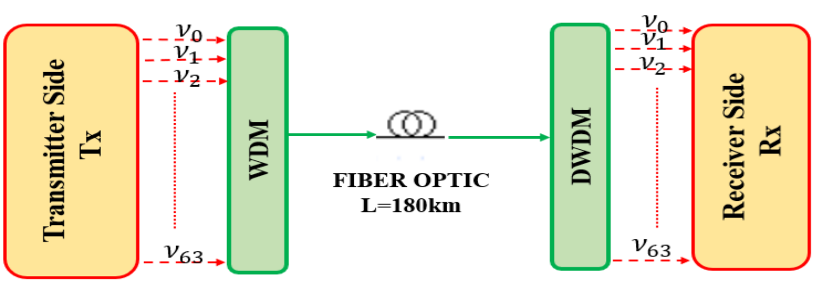
In this paper, the channel spacing is decreased via the same bandwidth in the C-Band (1530 nm-1565 nm) hence the number of channels. In the conventional WDM-RoF system, that range of capacity for 10 Gbps data rate modulated by a subcarrier radio frequency (RF) of 30 GHz and 100 GHz channel spacing between them is about 45 channels. This number cannot be increased due to the overlap between the channels when the spacing is decreased below 100 GHz. So, this project has enhanced the transmission rate by increasing the number of channels from 45 to 64 to enter the dense wavelength multiplexing (DWDM) range. The enhancement involves only transmitting the right side of the optical signal instead of transmitting all the optical signals, including the optical carrier with the left and right sides of the optical modulated signals. The technique used for this enhancement is to extract the right side of the optical signal by using a band pass filter (BPF) centered at the optical RoF-modulated signal carrier.

2. SYSTEM DESIGN DESCRIPTIONS

The suggested design consists of a 64×10 Gbps DWDM-RoF optical communication system simulated by Optiwave 7.0 software adopting SMF as a transmission channel along 180 km as shown in **Fig. 1**.



(a) Transmitter side (one channel). **(b)** Receiver side (one channel).



(c) Default design of DWDM-RoF in the communication system.

Figure 1. The proposed design of a DWDM-RoF.

The mobile signal of 30 GHz is applied with 64 input channels with an external optical Mach–Zehnder modulator MZM. The technique DWDM performs wavelength limits in the C-Band corresponding to frequencies 191.9 THz (1563.3 nm) to 195.08 THz (1537.8 nm) with a channel spacing of 50 GHz. Like any traditional communication system.This design contains three roots: the transmitting side (Tx), the optical transmitting channel, and the receiver side (Rx) as depicted in **Fig. 1(c)**. The transmitting side (Tx) is built of two branches as shown in **Fig. 1(a)** the optical branch CW-laser source and the electrical branch mobile signal. The mobile signal forms from a pseudo-random bit generator as a sequence (PRBS) and a pulse generator with a non-return to zero (NRZ) format. An electrical multiplier equipment summons the PRBS and NRZ within a sine waveform generator. Subsequently, the RF waveform is modulated with a continuous wave (CW) laser via an external optical Mach–Zehnder modulator (MZM).

The optical transmission channel is the path adapted to enhance the design performance. The output optic waveform is collected and demodulated by the receiving side (Rx), composed with a photodetector (PIN) joined by a low-pass Bessel filtering (LPBF) with a cutoff frequency of 0.75*B bit rate in Hz, passes the electrical waveforms, lastly, a 3R-regenerator for filtering, reshaping, and regenerating as depicted in **Fig. 1(b)**.

As identified in **Fig. 2** the two successive output signals for a traditional WDM-RoF system. The RoF signals constitute a 30 GHz RF subcarrier frequency that modulates data with a bit rate of 10 Gbps. The first and second optical carriers have 191.9 THz and 192 THz frequencies, respectively. They modulate the RoF signals via MZM modulators to obtain double sideband signals for each frequency, 191.87 THz and 191.93 THz around the first optical carrier 191.9 and 191.97 THz and 192.03 THz around 192.3 THz. The channel spacing between successive carriers is equal to 100 GHz.

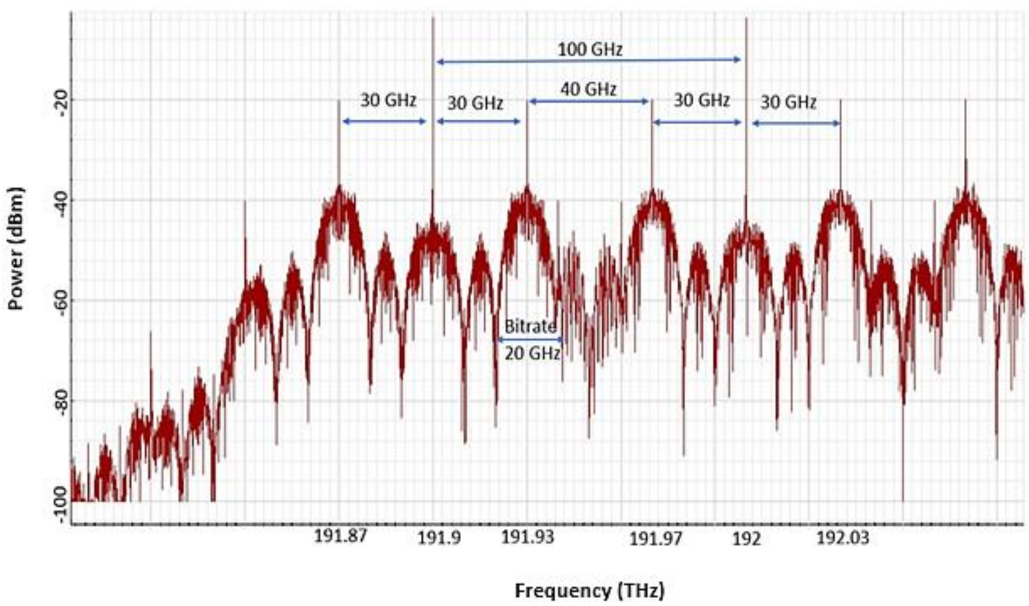


Figure 2. The first two channels at the transmitter side (Tx) in the traditional design of RoF-WDM with a 100 GHz channel spacing.

In this situation, the maximum number of channels WDM can build in the C-Band range is about 43 channels, as indicated in Eq. (3) **(Hoshida et al., 2022)**. The spectral range is the difference between the two extreme wavelengths **(Bayvel and Killey, 2002)**:

$$\Delta\lambda = 1565 - 1530 = 35 \text{ nm} \quad (1)$$

The corresponding spectral range in the frequency $\Delta\nu$ can be found by the relation:

$$\Delta\nu = \nu^2/c \,\Delta\lambda = 4.35 \text{ THz} \quad (2)$$

where c is the speed of light through a vacuum, $\nu = 193.1\,THz$ is the center frequency **(Hamam and Guizani, 2011)**.

Thus, the number of channels N in this range with a spacing of 100 GHz between channels is:

$$N = \frac{\Delta\nu}{100\,GHz} = 43.5 \quad (3)$$

Thus, the maximum bit rate transmitted through this system is 0.43 Tbps. When trying to increase the bit rate by increasing the number of channels via decreasing the channel spacing from 100 GHz to 50 GHz, the signals will start to overlap since each carrier has a bandwidth of 80 GHz as shown in **Fig. 3**. This bandwidth contains the optical carrier and the two sides of RoF signals modulated by the optical carrier.

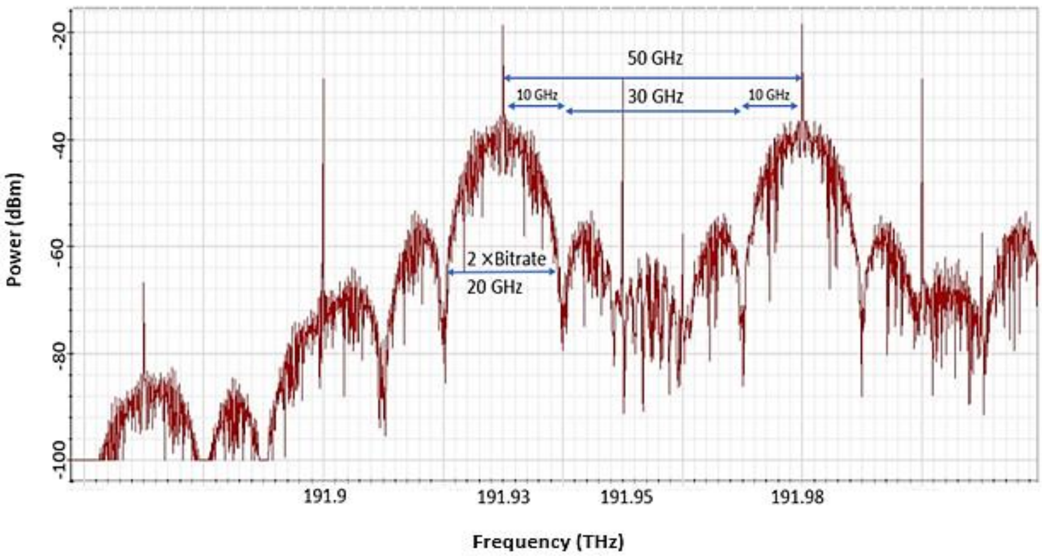


Figure 3. The first two channels at the transmitter side (Tx) in the traditional suggested design of RoF-DWDM with a 50 GHz channel spacing (overlapping occurs).

This system suffers from high power transmitted through the optical fiber, leading to nonlinear phenomena like four-wave mixing (FWM), limitation in the data rate transmission, limitation in the number of channels, and the waste in the bandwidth transmitted through the optical fiber.

Enhancement is made by transmitting the right side of the optical signal only via a bandpass filter centered at the optical RoF signal, as shown in **Fig. 4**. This technique doubles the number of channels transmitted, decreases the power, and has a bandwidth limit.

In this case, the number of channels will be 87 for a spacing between channels of 50 GHz. In our design, the number of channels (N) equals 64. The basic rule from which the design of every project with a constructive idea to achieve a specific goal begins, is the limited budget, after which the cost used is developed according to the development of the stages of production. The earlier the need is for designs with higher speed and coverage, the lower their cost restrictions and vice versa. Therefore, our project required processing the channels before sending them. The transmission of the RF signal is identified within the channels, thus ensuring transmission to a larger number of channels and a greater transmission distance. Transmission of optical signals carrying RF signal through an optical fiber compensated with a dispersion coefficient opposite to the original fiber. Transmission of optical signals carrying RF SIGNAL through an optical fiber compensated with a dispersion coefficient opposite to the original fiber. Therefore, the essence of its work is to reduce dispersion, but the amount of attenuation that occurs in the signal requires increasing it by using optical amplifiers. Therefore, the issue must be dealt with as a trade-off between setting compensated fibers and their values to maintain the project budget and achieve the required design superiority.

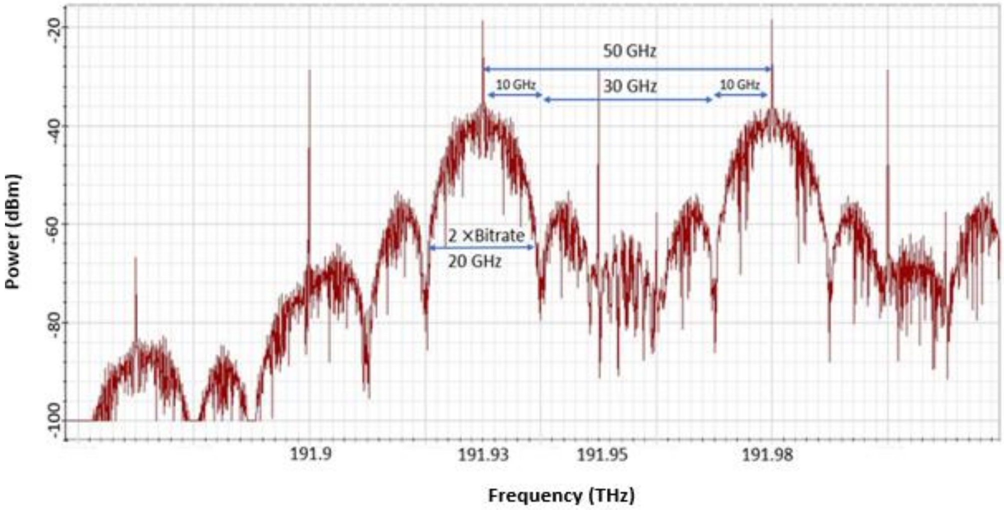


Figure 4. The first two channels at the transmitter side (Tx) in the enhanced suggested design of RoF-DWDM with a 50 GHz channel spacing after the bandpass filter (BPF).

The DWDM-RoF system design is shown in **Fig. 5**. It represents a comprehensive overview of the work, that includes the main three parts: the transmitter, the receiver, and the transmission optical channel. The first two parts are shown previously in **Fig. 1(a)** and **(b)** with details. The transmission channel starts with the booster Erbium-doped fiber amplifier (EDFA1) with a gain of 10 dB. It boosts the loss of power in the DWDM-RoF system through the coupling in the transmitter. Then the optical signal is transmitted over fiber optic type single-mode fiber (SMF) along 180 km followed by the EDFA2 with a gain of 36 dB to compensate for the attenuation affected by the SMF since α = 0.2 dB/km for silica. The optical signal after SMF was compensated by dispersion compensation fiber (DCF) along 18 km followed by EDFA3 with a gain of 9 dB to compensate for the attenuation affected by the DCF since α = 0.5 dB/km for silica at the C-Band. On the other hand, due to the high data rate used, the dispersion parameter (D) plays an important role in the DWDM-RoF system design. For a standard optical fiber, D equals 16.75 ps/nm.km is compensated using dispersion compensation fiber (DCF) of 18 km length with a dispersion parameter of −167.5 ps/nm.km as shown in Eq. (4). Hence, the compensation of dispersion shown in the equation below is competent to reparation the gap due to the different velocity groups that cause the dispersion (GVD) and the most harmful nonlinear influences inside the long transmission channel fiber by depending on the power value is very small. The pulse propagation equation for optical signals travels through segments of the single mode fiber (SMF) and the dispersion compensation fiber (DCF) at length (L) sending distance can be presented as a result **(Meena and Gupta, 2019; Meena and Meena, 2018)**.

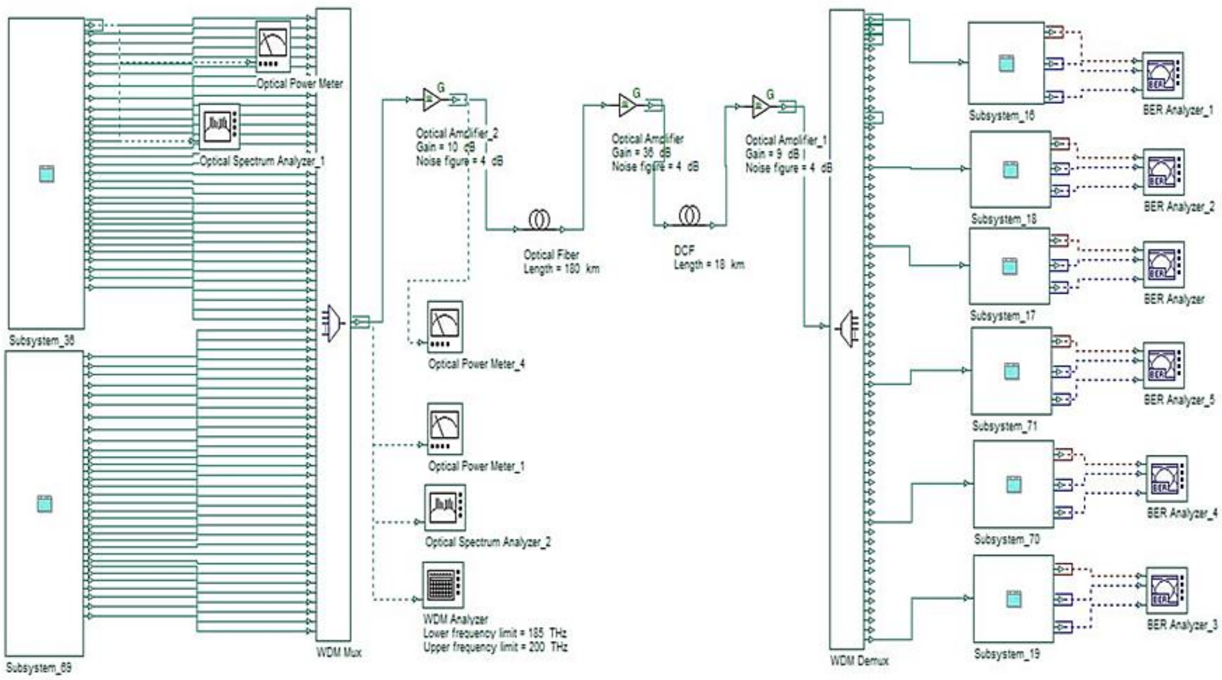


Figure 5. The proposed design of DWDM-RoF with channel spacing of 50 GHz.

If the DCF is after each SMF, then the coefficient ω^2 disappears thus the original shape of an optical slot pulse can be regained. Therefore, the optimum condition for compensated fiber dispersion beside DCF can be introduced as follows:

$$\beta_{SMF}\ L_{SMF} + \beta_{DCF}\ L_{DCF} \tag{4}$$

$$D_{SMF}\, L_{SMF} + D_{DCF}\, L_{DCF} = 0 \tag{5}$$

$$L_{SMF} + L_{DCF} = L_{overall} \tag{6}$$

Where the total distance of fibers in Eq. (6), β_{SMF} and β_{DCF} are the GVD coefficients for the pieces of fibers measured in m^{-1} along the channel transmission L_{SMF} and L_{DCF} continually measured in km; finally, the D_{SMF} and D_{DCF} are the coefficients of SMF and DCF respectively measured in ps/nm.km

and

$$D = {}^{-2\pi c}/_{\lambda^2}\ \beta \tag{7}$$

Where λ is the wavelength symbol of the optical pulse slot measured in nm, and C is the speed of light in free space without any medium $3 \times 10^8 m/s$.

In other words, if the SMF has a dispersion coefficient positive value ($D_{SMF} > 0$), so it must be the DCF has an inverse sign ($D_{DCF} < 0$) as provided in Eq. (5),

$$L_{DCF} = -L_{SMF}\ ({}^{D_{SMF}}/_{D_{DCF}}) \tag{8}$$

Further, to vanish the remaining effect of dispersion quickly from the optical transmission networks, the slope of the dispersion (S_{DCF}) of the DCF must be investigated as follows:

$$S_{DCF} = -S_{SMF}\left({L_{SMF}}/{L_{DCF}}\right) = S_{SMF}\left({D_{SMF}}/{D_{DCF}}\right) \quad (9)$$

Where S_{SMF} is the slope of the dispersion of the SMF.

The operating power of the CW lasers is optimized to have a maximum quality factor, as displayed in **Fig. 6**. **Table 1** shows these values. It found the maximum Quality factor (Q) at 0 dBm.

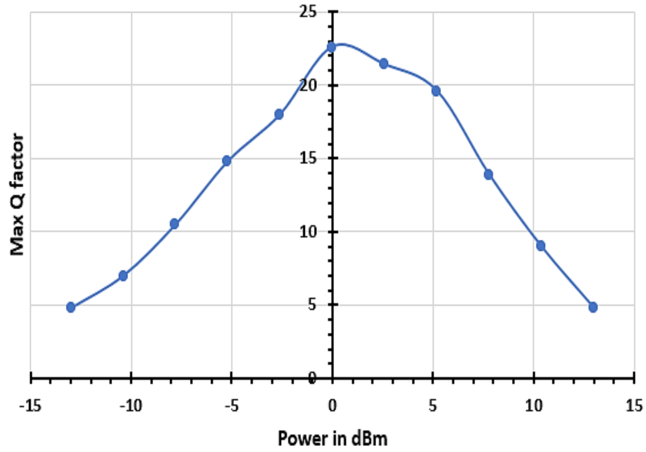


Figure 6. The bell curve of Max. Q factor (Power(dBm)).

Table 1. The sweeps process

Iterations	Power	Q factor
1	-13	4.8
2	-10.4	7
3	-7.8	10.5
4	-5.2	14.8
5	-2.6	18
6	0	22.6
7	2.6	21.4
8	5.2	19.6
9	7.8	13.9
10	10.4	9
11	13	4.84

3. RESULTS AND DISCUSSION

The next sections have been allocated to show and argue the outcomes and provide substantiated arguments that would submit the credibility of the DWDM-RoF system design, gained to high data rate transmission within the C-Band.

3.1 Performance of 64 DWDM-RoF at Different Repeated Distances

A 10 G bps NRZ data signals modulate the mobile signal carrier at 30 GHz. The optical carrier then modulates the RoF signal. A DWDM is built with 64 channels. The DWDM signal is transmitted via a graduated in the length values of the transmission channel, consisting of a standard single-mode fiber with α = 0.2 dB/km and D = 16.7 ps/nm.km. A DCF compensates for dispersion with α = 0.5 dB/km and D = −167.7 ps/nm.km. Two optical EDFAs are used to amplify the optical signal to reduce attenuations occurring by the SMF and the DCF for EDFA2 and EDFA3. Multi sweeps organize how far the modulated signal can reach. The transmission repeater distance is changed by increasing the length of the fiber optic from 0 km to 180 km for 64 channels starting with a frequency of 191.93 THz (1563.3 nm) to 195.08 THz (1537.7 nm) via channel spacing 50 GHz. The performance of the system is measured via the BER and the Q-factor for different DWDM-RoF channels at various distances.

3.1.1 BER vs Repeated Distance

The BERs for different DWDM-RoF channels at different long distances are listed in **Table 2.** These results are displayed in **Fig. 7**. The designed system ensures a high-quality transmission link at which the BER remains significantly below 10^{-9} for all channels after

180 km of fiber length. However, at different distances, the channels at two-ended and center frequency, 191.93 THz, 195.08 THz, and 193.13THz, have a very low BER, except the other channels at 192.73 THz, 193.53THz, and 194.53, which show shallow performance due to the constant dispersion used for all channels over the standard SMF for cost reasons.

Table 2. The Minimum bit error rate (BER) values along the different Transmission distances for the 1st, 16th, 24th,32nd,52nd, and 64th signals at the Receiver Side for the DWDM-RoF with 64 channels.

Distance km	Frequency (Hz)					
	Channel 1 191.93 THz	Channel 16 192.73 THz	Channel 24 193.13 THz	Channel 32 193.53 THz	Channel 52 194.53 THz	Channel 64 195.08 THz
0	2.50E-300	8.80E-290	1.20E-301	1.16E-300	3.34E-290	1.40E-300
20	4.10E-298	8.03E-288	1.00E-297	9.90E-285	4.70E-285	1.70E-290
40	3.10E-260	5.88E-258	3.70E-271	6.30E-266	3.80E-256	8.80E-285
60	7.30E-235	1.88E-220	5.10E-250	1.20E-238	3.20E-223	1.20E-240
80	8.10E-205	6.20E-195	3.30E-225	1.90E-195	1.40E-194	9.60E-209
100	2.50E-179	8.80E-153	1.10E-183	2.30E-179	4.40E-145	1.40E-157
120	4.80E-153	3.50E-103	8.90E-150	2.00E-95	1.30E-99	1.30E-140
140	1.30E-75	1.50E-60	3.90E-73	1.99E-70	5.50E-63	5.50E-84
160	9.90E-26	4.50E-21	5.80E-30	1.30E-20	4.70E-15	4.50E-20
180	3.80E-10	8.70E-09	7.10E-12	4.10E-09	4.32E-10	6.40E-12

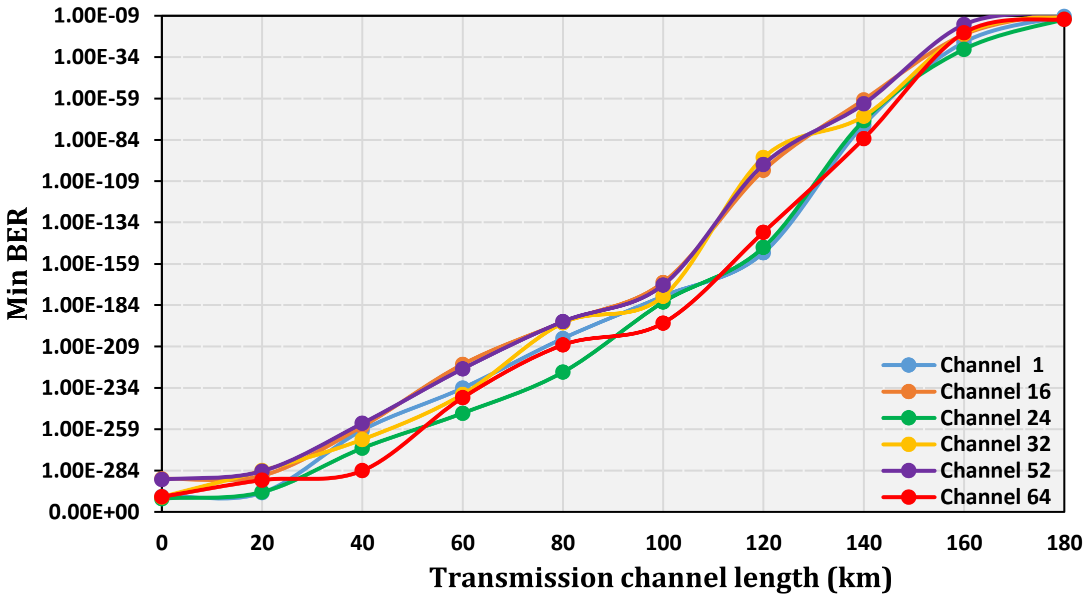


Figure 7. The Minimum bit error rate (BER) values along the different Transmission distances for the 1st, 16th, 24th,32nd,52nd, and 64th signals at the Receiver Side for the DWDM-RoF with 64 channels.

3.1.2 Q-factor vs Repeated Distance

High-quality factors are obtained for different DWDM-RoF channels at different repeated distances as shown in **Table 3** and plotted in **Fig. 8**. The quality factor stays higher than 6 for all the transmission channels ranging from 191.93 THz to 195.08 THz over 180 km. The low-quality factor observed for the last channel operated at 195.08 THz is due to the same reason as for the BER.

Table 3. The Maximum Quality Factor (Q-factor) values along the different Transmission distances for the 1st, 16th, 24th,32nd,52nd, and 64th signals at the Receiver Side for the DWDM-RoF with 64 channels.

Distance km	Frequency (Hz)					
	Channel 1 191.93 THz	Channel 16 192.73 THz	Channel 24 193.13 THz	Channel 32 193.53 THz	Channel 54 194.53 THz	Channel 64 195.08 THz
0	37.3	36.7	39.5	37.6	36	39.6
20	36.8	34.98	37	36	35.5	37.3
40	35	34	36	34	33	34.9
60	34	33	35	32	32	33
80	31	30	32	29	30	31
100	28	28	29	25.5	27	26.7
120	25	26	27	21.7	20	25
140	20	19	24	18	17	20
160	10	8.6	19	9.9	7.8	9.6
180	6.2	6	6.72	6	6	6.72

However, at different distances, the channels at the two-ended and the center, 191.93 THz, 195.08 THz, and 193.13THz, have a very high Q-Factor, except the other channels at 192.73 THz, 193.53THz, and 194.53, which show shallow performance due to the constant dispersion used for all channels over the SMF for cost reasons.

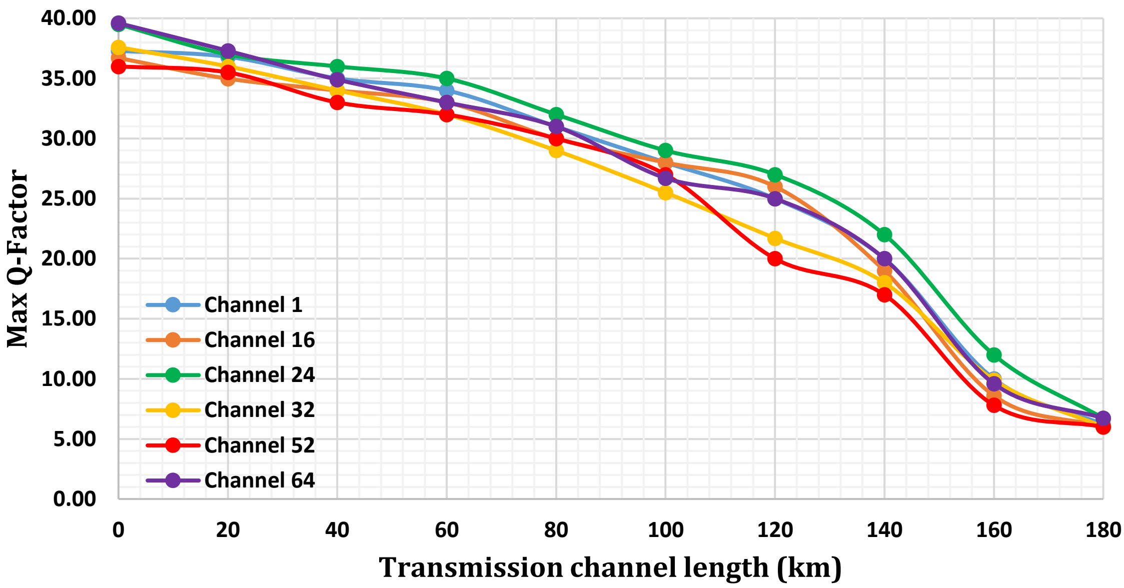
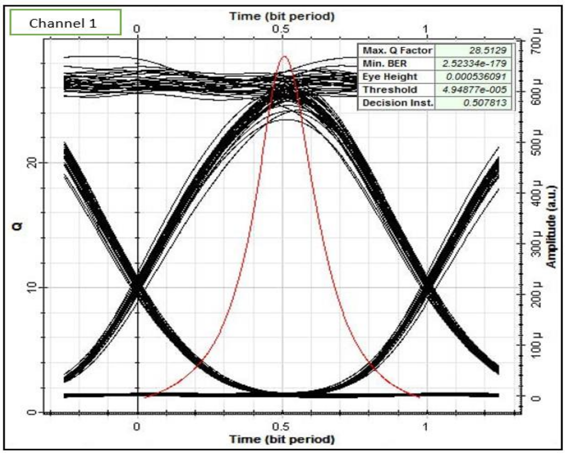


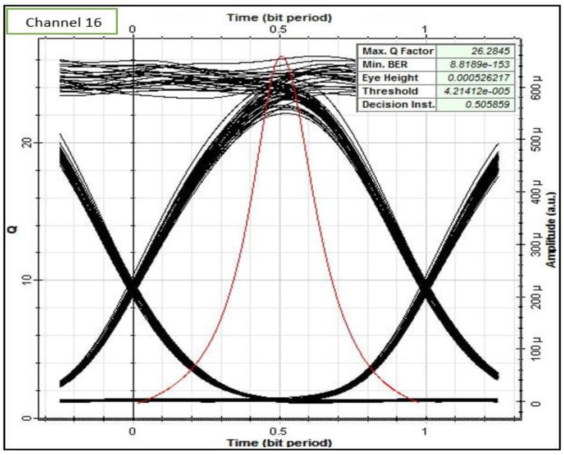
Figure 8. The Maximum Quality Factor (Q-factor) values along the different Transmission distances for the 1st, 16th, 24th,32nd,52nd, and 64th signals at the Receiver Side for the DWDM-RoF with 64 channels.

3.2 Eye Diagrams

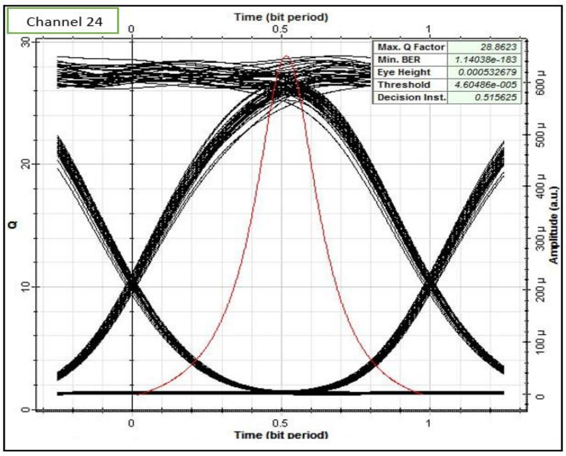
The performance of the DWDM-RoF system can be illustrated via the eye diagrams with the Q-factors for different channels, as shown in **Figs. 9** and **10** for 100 km and after 180 km channel length, respectively. The system shows high-opening eyes for all channels with high-quality factors.



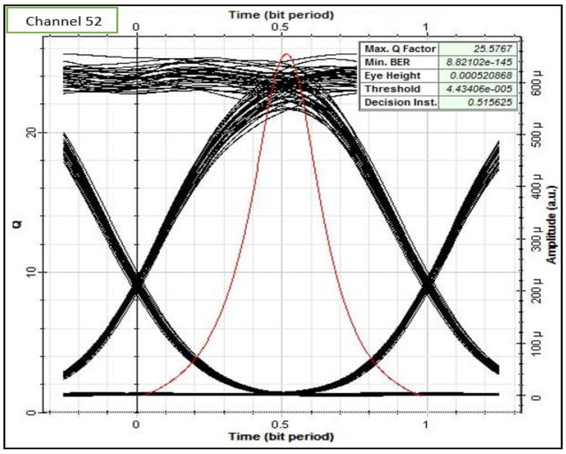
a. Channel 1 (191.93 THz) after 100 km.



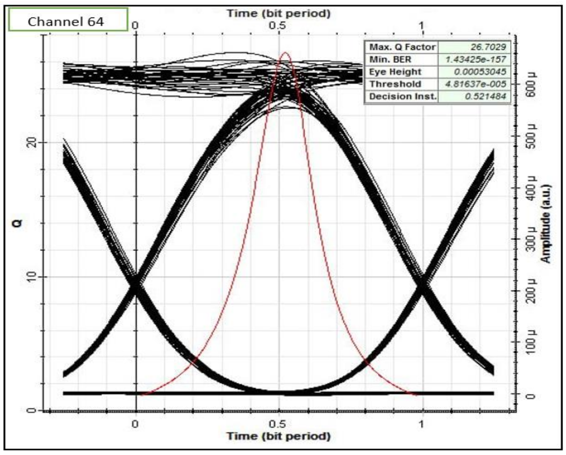
b. Channel 16 (192.73 THz) after 100 km.



c. Channel 24 (193.13 THz) after 100 km.

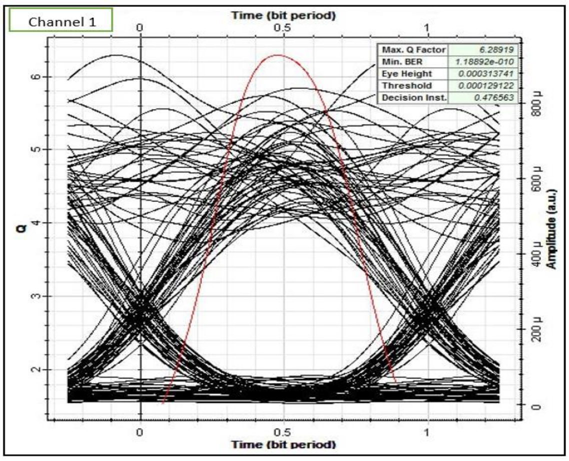


d. Channel 52 (194.53 THz) after 100 km.

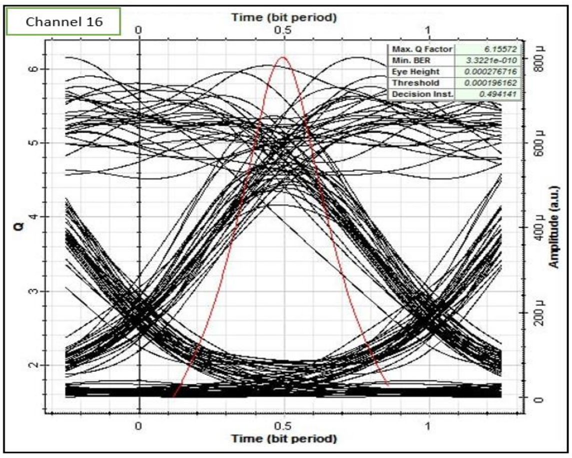


e. Channel 64 (195.08 THz) after 100 km.

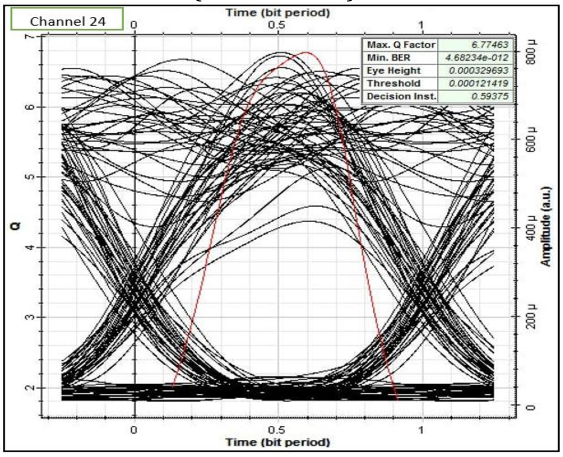
Figure 9. Eye diagram, Q-factor, and BER along 100 km transmission distance for the channels: a. Channel 1 (191.93 THz), b. Channel 16 (192.73 THz), c. Channel 24 (193.13 THz), d. Channel 52 (194.53 THz), and e. Channel 64 (195.08 THz) respectively.



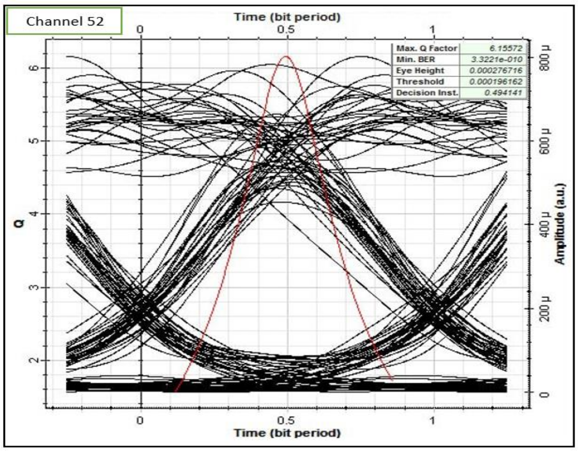
a. Channel 1 (191.93 THz) after 180 km.



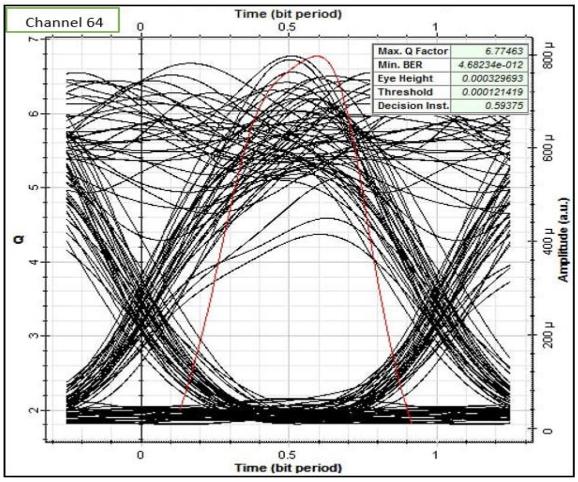
b. Channel 16 (192.73 THz) after 180 km.



c. Channel 24 (193.13 THz) after 180 km.



d. Channel 52 (194.53 THz) after 180 km.



e. Channel 64 (195.08 THz) after 100 km.

Figure 10. Eye diagram, Q-factor, and BER along 180 km transmission distance for the channels: a. Channel 1 (191.93 THz), b. Channel 16 (192.73 THz), c. Channel 24 (193.13 THz), d. Channel 52 (194.53 THz), and e. Channel 64 (195.08 THz) respectively.

Technological developments to increase the number of channels or transmission long-haul distances, strategic planning of regulatory and standardization issues that need careful frequency planning and adherence to global standards, which require collaboration and additional resources., and cost-benefit assessments are all used to address these issues. While the DWDM-RoF system offers substantial advantages in terms of bandwidth and the convergence of wireless and optical networks, its effective implementation in the real world depends on resolving these pragmatic issues.

4. COMPARISON WITH PRECEDING WORK

In the next division, the reached-out decisions from the suggested design are measured according to the preceding technique **(Garg and Nain, 2022)**. The comparison is achieved through the difference in communication distances, spacing between channels, and mobile signals with the same operating power (CW Laser) of 0 (dBm) and in line width with 0.1 (MHz). Despite that, a huge RF signal at each channel was acquired in the previous technique, the Q-factor and the BER in our suggested technique are (6.72,7.1e-12) in the 64th channel respectively. The factor of quality (Q factor) and the bit rate of error (BER) in the previous technique are (4.21, 1.14e-5) in the 8th channel respectively. The increased distance in our work led to a higher BL that satisfied the model enhancement, as identified in **Table 4**.

Table 4. Comparison of the present work augmented with previous work **(Garg and Nain, 2022)**.

Parameter	Previous work (Garg and Nain, 2022)	The proposed work
Technique	WDM-RoF (8 channels)	DWDM-RoF (64 channel)
RF signal (GHz)	110	30
Data rate (Gbps)	12	10
Optical band	C (1550 - 1553.3)nm	C (1537.8 - 1563.3)nm
Channel spacing	0.5 nm	50 GHz
Max Q factor at 1553.5nm (193.13 THz)	4.28	6.72
Min BER at 1553.5nm (193.13 THz)	1.14E-05	7.10E-12
Distance (km)	120	180
B × L (Gb/s km)	11500	115000

5. CONCLUSIONS

The proposed DWDM-RoF satisfied 64 channels at a 10 Gbps data rate. The system was admitted for a high-capacity data rate of about 0.64 Tbps along 180 km. The design has proven a tremendous ability to cross the RF signal through the optical transmission channel. The technique proposed using the optimum WDM-Multiplexer setting of the inter bandpass filter (BPF) has the advantage of reducing the band inside each channel. This is necessary to avoid overlapping between optical signals constituent to the optical beam. The submitted work created a high bandwidth distance product, BL equal to 115 Tbps km at shallow linear and non-linear influences. Additionally, this BL of the suggested technique was improved by around ten times, as contrasted with the preceding technique for our filtered technique, which makes RF signal transmission perfect. Thus, the design provided a basic step on which future designs can be based to move toward the next development.

NOMENCLATURE

Symbol	Description	Symbol	Decription
BER	Bit Error Rate, E-09	S_{SMF}& S_{DCF}	The slope of the dispersion of the SMF& DCF, 008 ps/nm^2.km &−0.08 ps/nm^2.km
c	Speed of light (m/s)	β_{SMF}& β_{DCF}	The group velocity dispersion (GVD) of the SMF&DCF (m^{-1})
D_{SMF}& D_{DCF}	The dispersion coefficient of the SMF&DCF, 16.7 ps/nm.km &−167.7 ps/nm.km.	λ	The wavelength symbol of the optical pulse slot (nm)
L_{SMF}& L_{DCF}	The transmission distance of SMF&DCF, 180 km &18 km	$\Delta\lambda$	The wavelength range (nm)
$L_{overall}$	The overall transmission distance, 180 km+18 km	ν	The optical frequency (THz)
N	Number of channels (CH)	$\Delta\nu$	The spectral range (THz)
Q	Quality factor, 6dB	α_{SMF}& α_{DCF}	Attenuation per km for the SMF&DCF, 0.2dB/km & 0.5dB/km

Credit Authorship Contribution Statement

Safa Gh. Mohammed: Investigation, Methodology, Formal analysis, Writing – original draft. Ismael Sh. Desher: Supervision, Investigation, Methodology, Formal analysis, Writing – original draft, 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.

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نقل معزز بسرعة 0.64 تيرابايت في الثانية باستخدام تقنية DWDM−RoF لمسافة إرسال تبلغ 180 كيلومترًا لدعم اتصالات الهاتف المحمول من الجيل الخامس 5G

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الخلاصة

تُقدم هذهِ الورقة قنوات مُرشحة مُحسنة في التصميم المُقترح لنظام الأتصالات البصرية الذي تمَّ تشكيلهُ للجيل الخامس من الأتصالات المتنقلة عبرَالألياف البصرية. الهدف الرئيسي هو التغلب على عُرض النطاق الترددي المَحدود لأنظمة الموجات الراديوية وتمكين الأَرسال بمعدل بيانات عالٍ. وقد نَجَحَت مُضاعفة تَقسيم الطول الموجي الكثيف القائِمة على أَساس الأَلياف البصرية الحاملة للموجات الراديوية (DWDM−RoF) في تلبية مُعدل بيانات مُرتفع قدرهُ 0,64 تيرابايت في الثانية بواسطة نِظام مُتعدد القنوات مُفلترمن خلال مسافة 180 كيلومتر داخل النطاق C من خلال نهج مُتعدد القنوات مفلتر. يشتمل التصميم على 64 قناة تمت تصفيتها مع مُرشح مُمر النطاق المُحسن (BPF)، مِما يَجعل تقارب القنوات غير المسبوق ممكناً. يُرسل النظام بِقدرة مُنخفضة 0 ديسبيل ميلي واط (1,0 ميلي واط) عبر الأَلياف أُحادية الوضع (SMF) 180كيلومتر ويَستخدم ألياف تعويض التشتت (DCF) 18 كيلومتر. يَقوم بتحويل الضوء إلى إشارات كهربائية ويتم ترشيحه بواسطة مُرشح تَمريرمُنخفض عند 0,75 من معدل البت (B) الذي تم ضَبطهُ عند 10 جيجابت في الثانية. يتم تطبيق النموذج في برنامج Optiwave 7,0، والنتائج هي الأرقام التي أظهرت النجاح الساحق الذي عززهُ مُخطط العين المفتوحة, وقيمة عامل الجودة (Q−factor) هي 6,72 و معدل البتات الخطأ (BER) هي $7,1 \times 10^{-12}$ عبر 180 كيلومتر من التردد المركزي193,13 تيراهرتز (1553.5نانومتر) للتباعد 50 جيجاهرتز بين القنوات.

الكلمات المفتاحية: الأتصال الأسلكي البصري (OWC)، مُضاعفة تَقسيم الطول الموجي الكثيف (DWDM)، الأَلياف البصرية الحاملة للموجات الراديوية (RoF)، الأَلياف أحادية الوضع (SMF) في النطاق C، ألياف تعويض التشتت (DCF)، مُضخم الأَلياف المشبع بالأَربيوم (EDFA) .