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Dual Polarization DQPSK ROF System with Duo Binary Precoding and Hybrid Amplification for Effective Hybrid SMF FSO Transmission Medium

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Abstract: This article demonstrates the utilization of a hybrid amplification technique on the transmission part of the proposed hybrid medium transmission system which includes both using Single Mode Fiber (SMF) with 60 km and Free Space Optic (FSO) with a range between 5 km and 25 km. It has included four weather situations with an investigation of the FSO medium-based system performance. The system uses 64 channels based on Dual Polarization-Differential Quadratic Phase Shift Keying (DP-DQPSK) Dense Wavelength Division Multiplexing (DWDM) for the Radio over Fiber (RoF) system using the Duo Binary coding scheme to improve the system efficiency in general and the cross-talk in particular. The investigations will include using the hybrid amplifiers of Erbium Doped Fiber Amplifier (EDFA) and Optical Amplifier (OA) for transmission. The analysis results show that using the hybrid amplification could improve the transmission to reach 25 km for light air case, meanwhile, for light haze, it could reach up to 20 km. Moderate haze could improve transmission efficiency for a distance of 7 km. Finally, for moderate rain situations, the transmission could be further improved to cover a distance of up to 5 km.

Keywords: FSO (free space optic), ROF Radio over Fiber, WDM wavelength division multiplexing, 5G

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1. INTRODUCTION

Optical transmission has surpassed all other technologies in terms of capacity and transmission quality, making it the technology of choice for high-capacity, long-distance transportation networks. This has caused the optical transmission to ascend to the top of the priority list. To put it more simply, Optical Wireless Connectivity (OWC) is an effort that makes use of optical radiation as a carrier signal to transmit data from one remote location to another over free space. The light signal may be dispersed throughout a deep region, the atmosphere, or the oceans; nevertheless, the terrestrial Free Space Optical (FSO) technology is the primary focus of this study, and the atmosphere is the channel of interest.

The FSO connection relies heavily on the fact that there is a direct Line of Sight (LoS) between the two communication stations. The transmitter and receiver-based FSOs (also known as Tx-FSO and Rx-FSO) need to have a clear LoS connection with each other to facilitate the effective transmission of information. This makes it possible for OWC communication to take place under the following circumstances: both the Tx-FSO and the Rx-FSO have a straight line of sight, and the beam strength is sufficient to reach the other end [1,2].

To satisfy the requirements of telecom operators, the FSO technology has been released into the market at a speed of 10 Gbit/s for the very first time. The vast majority of Radio Frequency (RF) technologies, including LTE (Long Term Evolution), GSM (Global System for Mobile Communications), Wi-Fi (Wireless Fidelity), and Bluetooth, will compete against it in the foreseeable future. On the other hand, FSO technology is based on the under-atmospheric optical transmission of a component of the visible or infrared light spectrum. This allows for the transmission of a section of the light spectrum. The establishment of a LoS connection between two distinct places at a high data rate was the motivation for the development of FSO systems. In addition, FSO enables the transmission of any type of data at a rate that is competitive with that of fiber optics while retaining the adaptability and benefits of a wireless network [3,4].

The FSO technology has a variety of feasible applications. These technologies include wired and wireless communications, as well as Fiber to The x (FTTx) [5,6]. FSO may initially support a fiber connection, which is only one of its many applications. It is possible to employ FSO connections instead of the main fiber link that has been destroyed or is unavailable. The transmission of data between base stations and network equipment may happen very quickly, which is the second advantage. This results in an increase in bandwidth for wireless mobile networks and base stations [7,8]. The FSO approach makes advantage of wide-area RF waves, which enables reception to take place close to the system; nevertheless, demodulation and decoding are still required. The beam divergence of the FSO connection, on the other hand, is so minimal that it makes it impossible to intercept the communication. The use of laser transmission hardware is ideal for a wide variety of network designs and applications [9]. Therefore, the efficient way to enhance the system performance is to include a hybrid amplification technique with the proposed transmission system to enhance the transmission over different atmospheric situations including the mitigation of nonlinearity impairment that is represented by cross talk and Four Wave Mixing (FWM).

2. RELATED WORK

Because the FSO is so important in terms of providing improved data rates under a wide variety of circumstances, several approaches to addressing it have been devised. As an example, [10] makes use of DP-DQPSK with SMF cable and FSO channel. The proposed system is capable of handling data rates of up to 10 Gbps, distances of up to 50 km SMF, channels of up to 800 m FSO, and a wide range of weather conditions. The Quality Factor (QF) measurements were found to be in the neighborhood of 4.5 dBm, and the Bit Error Rate (BER) was in the neighborhood of 10 e-6, both of which point to lower values that may not be sufficient for reliable transmission. Therefore, such a system has to have its functionality improved and enhanced. In addition, the influence of non-linearity has not been taken into consideration in the work that has been recommended.

Quantum Dash Laser was examined as a potential laser source for system-based DP-DQPSK transmission across SMF and FSO channels by other researchers who contributed to [11]. This research looked at both self-injection and injections given by other people. According to the findings obtained from transmissions carried out at distances of 10 kilometers SMF and 4 meters FSO, the external injection has the potential to increase system performance to 128 Gbps. The data transmission capacity for self-injection has been proven to be 20 kilometers over SMF and 10 meters over FSO. On the other hand, the suggested system has only been tested over very short distances, and the demonstration of the proposed laser source needs somewhat greater distances.

In addition, the authors of [12] solved the problem of offering a system with different weather conditions based on FSO medium transmission. As a result, a QPSK system with a transmission capacity of 128 Gbps was established. Attenuation was measured at 0.19 decibels for lengths of 15, 25, 35, and 50 kilometers in this study. According to the findings, running the system at a distance of 25 kilometers would result in a decrease in the received signal and an increase in the error rate. In addition, the suggested technique was not successful in transporting data in fog, which resulted in an attenuation of 15.5 dB. The technology delivered satisfactory results, exhibiting low attenuation of up to 1.5 dB.

A high-speed front haul system was described by the authors of the paper [13]. This system was based on 128 Gbps DP-QPSK, Digital Signal Processing (DSP), and homodyne detection. The work was evaluated on an FSO channel that was 2.65 kilometers in length under clear weather conditions. When it came to BER, Optical Signal to Noise Ratio(OSNR), and Bean Divergence, the findings from the proposed system were compared to the results from the B2B model. Because the suggested technology has only been tested over short distances, it is possible that it will not be enough for communication at 5G and higher speeds.

Recent work in [14] resulted in the construction of a DP-QPSK system with hybrid modulation, which was then tested at 340 Gbps at distances ranging from 1.6 to 50 kilometers under a variety of climatic circumstances. The findings revealed that the transmission process was effective in a variety of settings. It is necessary to carry out an analysis on several aspects, including the data transfer rate of 300 Gbps and the Tx laser source of 10 dBm.

In addition to that, in [15], an analytical technique for Binary PSK (BPSK) exploiting the FSO channel was presented for transmissions across distances ranging from 1-4 kilometers. The authors conducted their research using the (G-G) fading type and the FSO channel. There was an inverse relationship between the effectiveness of the system and the distance traveled. On the other hand, by using this technology, a data rate of 10 Gbps was accomplished.

This work uses Polarization Division Multiplexing (PDM), DQPSK modulation, and a direct detection receiver to achieve a maximum data rate of 1.792 Tbps using the 64-channel DWDM method [16]. According to the specifications established by 3GPP, IEEE, and ITU-T for 5 G communication, the RF frequency has been fixed at 3.5 GHz. The objective of the proposed system is to develop a hybrid transmission system that makes use of both SMF and FSO. If successful, this system would be able to further improve the transmission and efficiency of the proposed system described in [17]. And this was made possible by using the power of hybrid amplification, denoted by (EDFA+OA), which will have various benefits, including decreasing the transmission power and lowering the effect of the FWM problem. Also, boost the transmission distances under different weather conditions.

3. METHODOLOGY

The methodology that satisfies the needs of the proposed system would be listed below:

3.1 Hybrid Optical Amplifier (HOA)

When it comes to meeting the needs of big-capacity DWDM systems, hybrid optical amplifiers (HOA) are the technology that is widely regarded to be the most suitable and appropriate solution [18]. According to, the primary goal in the development of high-density optical fibers HOAs is to first increase connection distance while simultaneously retaining acceptable performance levels. [19-22] Increasing the capacity of the communication connection in terms of both the capacity of each channel and the total number of channels is the second objective. Thirdly, to reduce the amount of signal deterioration produced by the optical fiber's inherent nonlinear effects as much as possible. Even though HOAs have many benefits to provide, there are a few significant concerns that are associated. To broaden the gain spectrum of an Erbium Doped Fiber Amplifier (EDFA), it is possible to use a hybrid configuration consisting of an Optical Amplifier (OA) and EDFA. In an earlier study [23], the use of a variety of HOA was investigated and analyzed.

3.2 SMF and FSO

FSO or SMF-based fiber optic communication is being utilized all over the globe to manage the large amounts of high-speed internet traffic that are being generated. These technologies can provide enormous bandwidth while simultaneously transferring data at extremely fast speeds and using a very little amount of power. FSO is a highly useful technology that may rapidly extend an existing network into challenging geographical locations. On the other hand, the performance of its connection is heavily reliant on unpredictable weather conditions. A fiber optic connection that is based on SMF has a very low loss, and its performance is practically unaffected by the many types of weather. However, both the installation and maintenance of fibers are somewhat difficult and expensive processes. Individually, FSO and SMF linkages each have their limits, and it is necessary to integrate them to make use of their combined advantages [24]. As a consequence of this, the proposed system would be investigated based on its integration of both mediums and the use of the effective HOA approaches, in addition to the management of the nonlinearity effects.

The major issue carried out in this work is to propose a novel fiber optic-based RoF transmission system by using an effective precoding scheme with a direct detection technique at the receiver to achieve maximum efficiency in handling transmission over a hybrid medium represented by the SMF and FSO and for longer distances and under the influence of different weather conditions. Additionally, using the optimum hybrid amplification technique can contribute to increasing the reliability of the overall results.

3.3 System Setup

The proposed system using the optisystem with version 19 program. The channel parameters have been considered as per the ITU-T G.694.1 standards. The wavelengths lie within C-band (1530–1565 nm). The optical distribution medium consists of multi-span propagation of km SMF, km DCF, and 7.463 dB optical amplifier (EDFA) in an in-line configuration. BER analyzers have been used at each receiver to find the Q factor and BER. Figure 1 illustrates the schematic view of the proposed system design where it can be seen it consists of 64 dedicated channels combined by using the DWDM technique. The system consists mainly of three major parts which are the transmitter part, the transmission part, and the receiver part. All these parts are connected to form the proposed system. From the same previous figure, it can be seen that the contribution of this work focuses on using HOA in the second part of the system. The rest of the other components forming the DP-DQPSK DWDM PMD system are clarified in [16]. The hybrid medium will be formed from the SMF of 50 km distance and Dispersion Compensation Fiber (DCF) of 10 km to form a total fixed standard SMF range of 60 km. Also, the FSO will include an investigated transmission range between 5 km and 25 km and under different weather situations represented by four different attenuation values. Their values were (0.43, 1.537, 4.2, and 5.8) dB/km which represent the cases of (light air, light haze, moderate haze, and moderate rain) respectively.

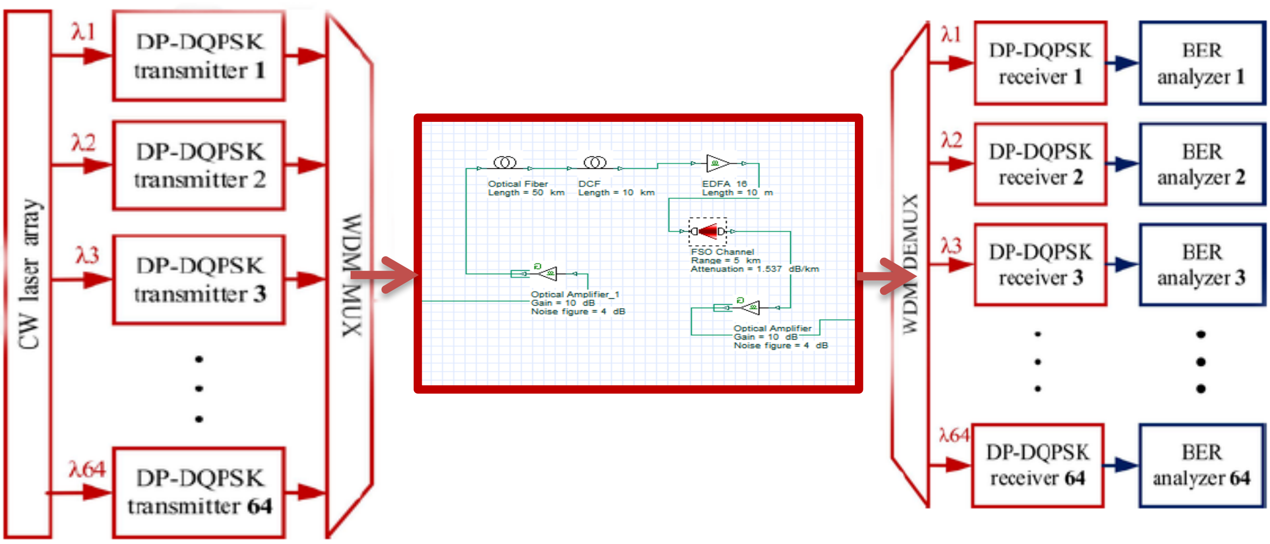


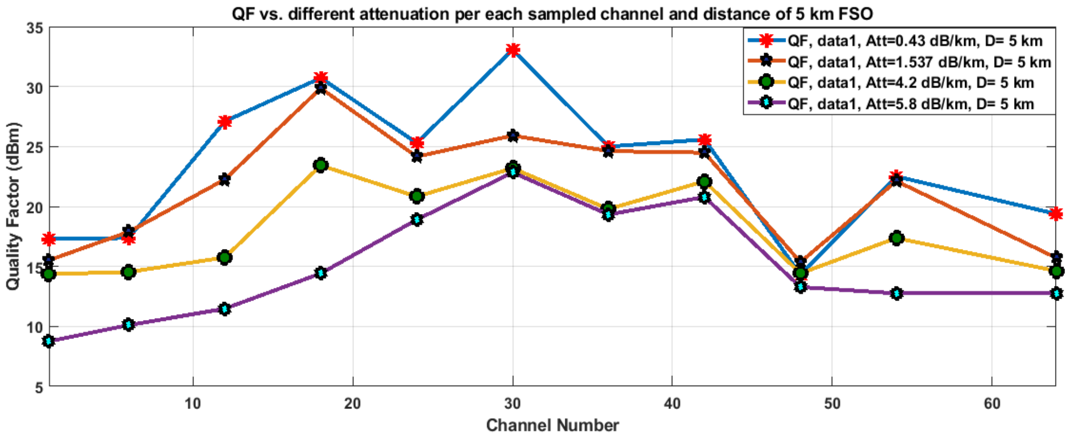
Figure 1. The schematic view of the proposed system design including the HOA and hybrid transmission medium

4. RESULT AND DISCUSSION

4.1 Results-based HOA utilization for different weather conditions

These results would be studied based on the four investigated weather conditions and based on the parameters of QF and BER that are gained from the simulation of the proposed system by using the optisystem software.

For the first case of a 5 km transmission distance over the FSO channel and fixed SMF distance of 60 km as seen in Figures 2 and 3 for the QF and BER parameters respectively., it can be seen that the proposed system performed well under all the four conditions for a distance up to 5 km. Also, it can be noticed from Figure 2 a reverse relation between the raising of attenuation impact and the QF values. The same relation can be noticed concerning the transmission distance and the QF parameter. For the BER values analyzed in Figure 3, it can be seen a direct relation between the raising of the distance and the error in the transmitted bit. The same relation can be noticed concerning the increase in the attenuation impact.



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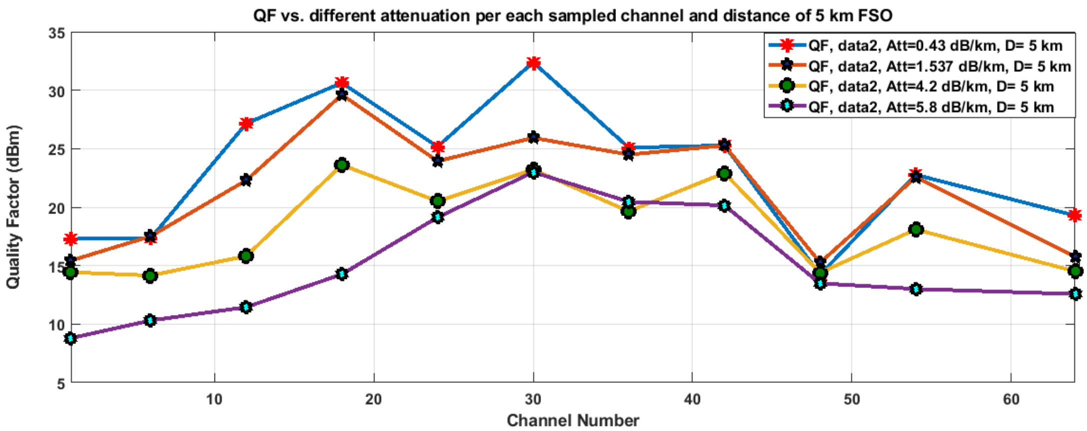
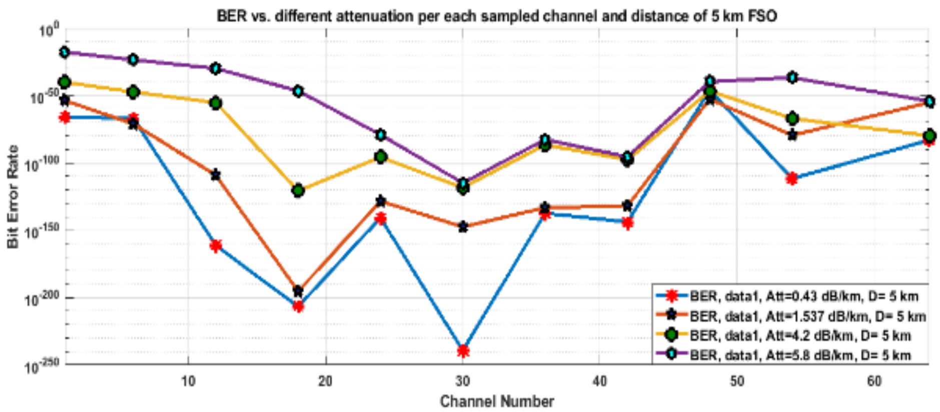


(b)

Figure 2. QF vs. different attenuation impact for distance of 5 km: (a) data 1, (b) data 2



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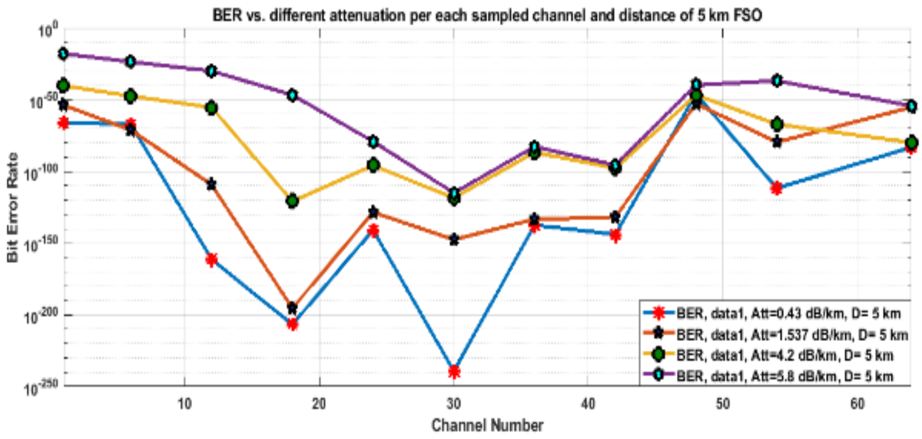
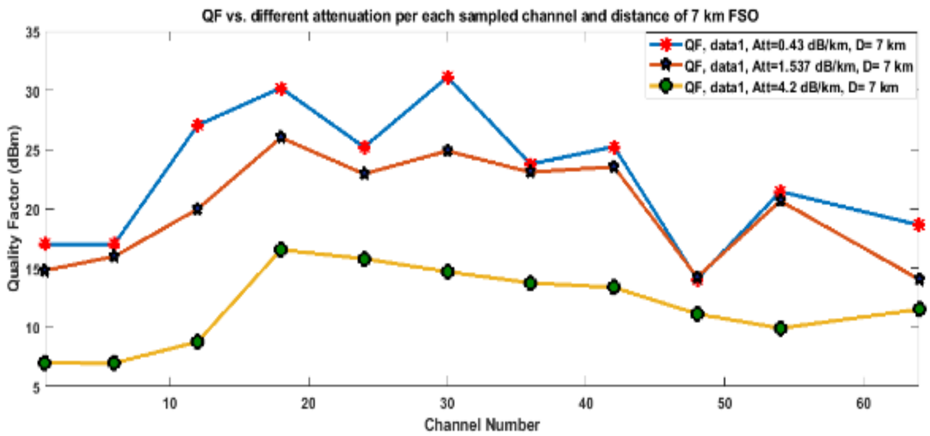


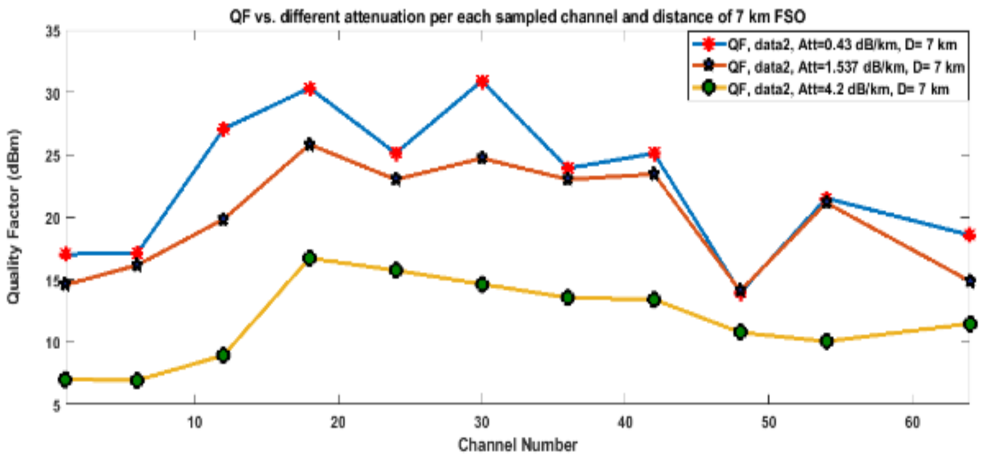
(b)

Figure 3. BER vs. different attenuation impact for a distance of 5 km: (a) data 1, (b) data 2.

For the second case of transmitting data for a 7 km distance over the FSO channel, the analyzed results were listed as seen in Figures 4 and 5 for QF and BER respectively. From Figure 4, it can be noticed the system could perform well in transmission for the cases of light air, light haze, and medium haze. While, when moving for medium rain situations the system fails to perform transmission. The suggested solution for handling such a situation would be by boosting the signal after 5 km and by setting a specific architecture for it which may improve it.

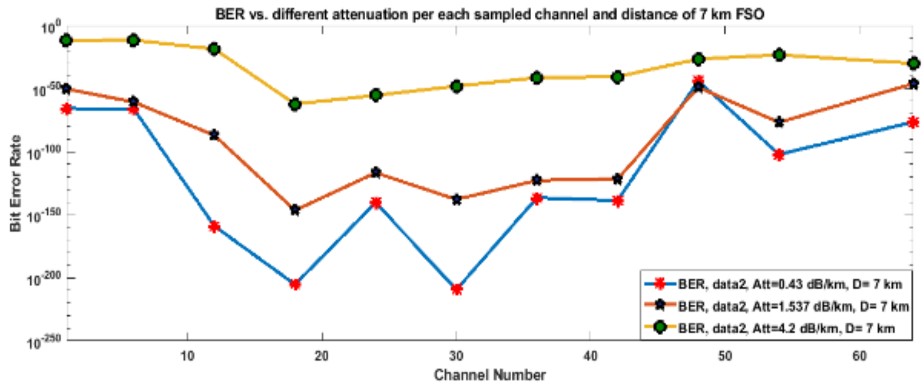


(a)



(b)

Figure 4. QF vs. different attenuation impacts for a distance of 7 km: (a) data 1, (b) data 2.



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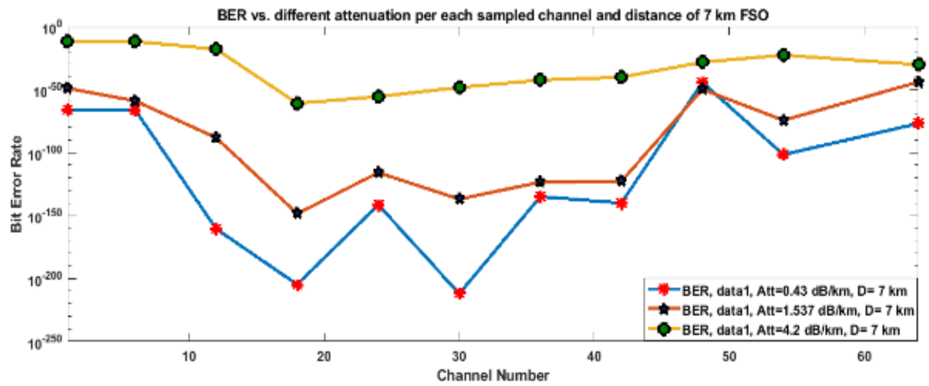
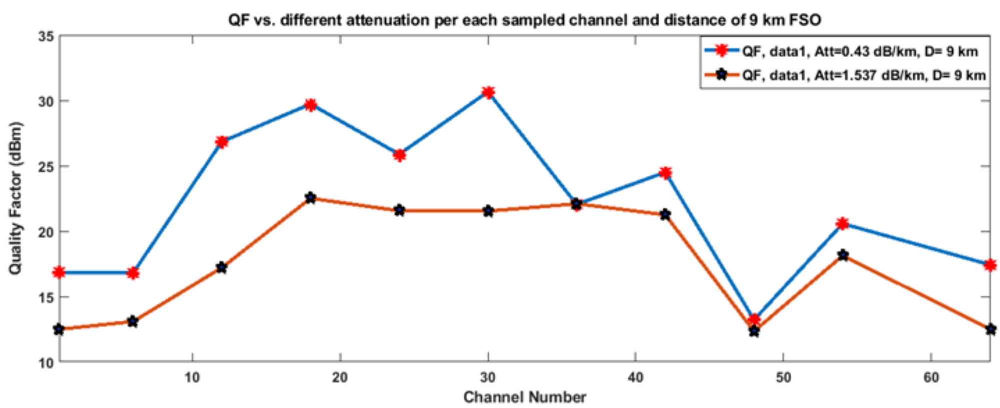


(b)

Figure 5. BER vs. different attenuation impact for a distance of 7 km: (a) data 1, (b) data 2.

For the third case of transmitting data for ranges between (9-15) km distance over the FSO channel, the analyzed results were listed as seen in Figures 6,7, and 8 for QF and BER respectively. From Figure 6, it can be noticed the system could perform well in transmission for the cases of light air and light. While, when moving for the cases of medium haze and medium rain situations the system fails to perform transmission as the gained results were below the minimum threshold of QF which is represented by 6 dBm, and the minimum threshold of BER represented by 10E-6.



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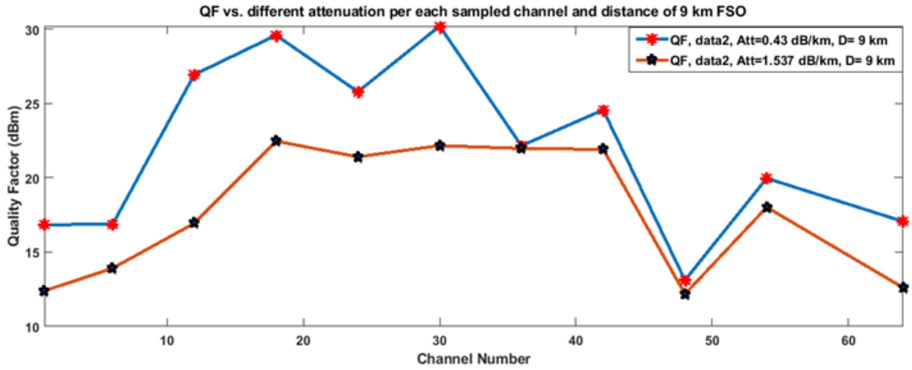
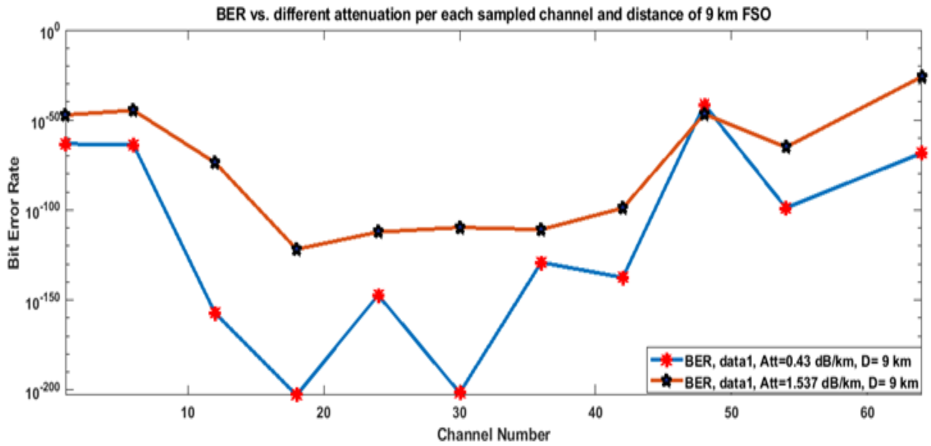


(b)

Figure 6. QF vs. different attenuation impacts for a distance of 9 km: (a) data 1, (b) data 2.



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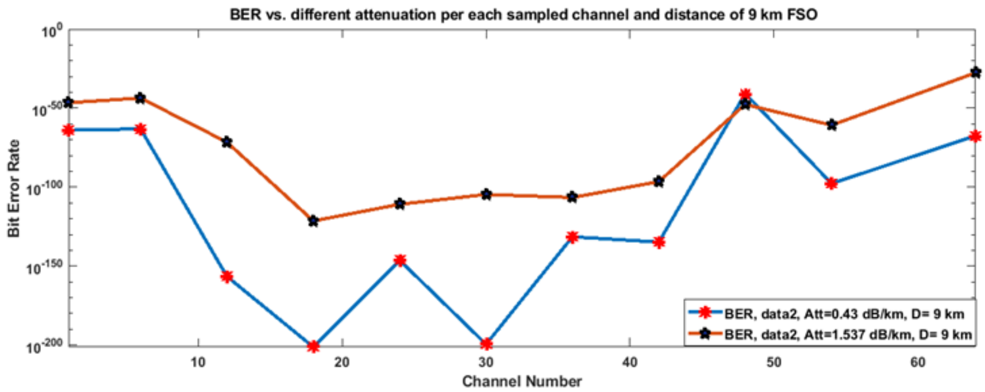
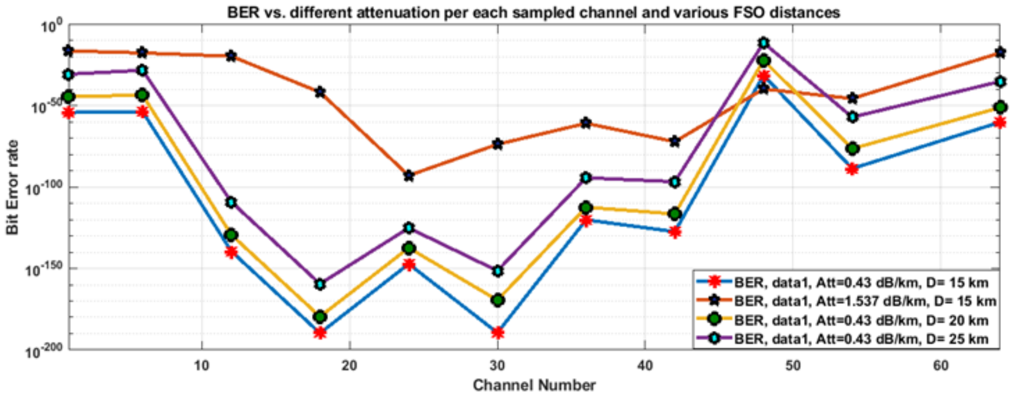


(b)

Figure 7. BER vs. different attenuation impact for a distance of 9 km: (a) data 1, (b) data 2.

Finally, higher distances up to 25 km, it has been analyzed as seen in figure 8 where it has been selected the parameter of BER is an example for the investigation of the DP-DQPSK system for higher distances. The system could perform such transmission for only the case of light air conditions and this is because of the small amount of attenuation which will result in a smaller impact on the overall performance. The overall values for both QF and BER obtained from the optisystem per each FSO case and distance would be listed as seen in Table 1 and Table 2 respectively.



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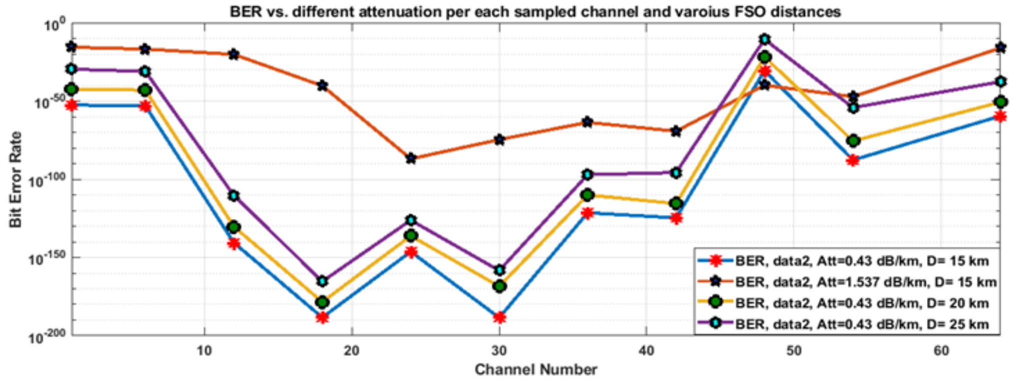

(b)

Figure 8. The transmission of different attenuation impacts for (a) QF, and (b) BER.

Table 1. QF values obtained from the proposed system per different FSO medium transmission

Channel / QF value	5 km		7 km		9 km		15 km		20 km		25 km	
	data1	data2	data1	data2	data1	data2	data1	data2	data1	data2	data1	data2
	Attenuation = 0.43 dB/km											
1	17.3	17.3	17.0	17.0	16.8	16.9	14.9	15.0	12.9	12.9	11.0	11.0
6	17.4	17.3	17.0	17.1	16.8	16.9	13.9	14.0	11.9	11.7	10.0	10.0
12	27.1	27.2	27.1	27.1	26.8	26.9	23.8	23.9	21.7	21.5	19.5	19.3
18	30.7	30.6	30.2	30.3	29.7	29.6	26.7	26.6	24.9	25.0	22.7	22.8
24	25.3	25.2	25.2	25.1	25.9	25.8	22.9	22.8	20.0	20.0	17.7	17.8
30	33.1	32.4	31.1	30.9	30.7	30.2	27.7	27.2	25.9	25.8	23.7	23.6
36	25.0	25.1	23.8	23.9	22.0	22.2	19.0	19.2	17.4	17.6	15.3	15.4
42	25.6	25.3	25.2	25.1	24.5	24.6	21.5	21.6	19.9	20.2	17.8	18.1
48	14.3	14.2	14.1	14.0	13.2	13.1	11.2	11.1	9.0	9.1	6.9	7.0
54	22.5	22.8	21.5	21.5	20.6	20.0	17.6	18.0	15.8	15.9	13.2	13.0
64	19.4	19.3	18.6	18.6	17.4	17.1	15.4	15.1	13.7	13.0	12.0	11.9
	Attenuation = 1.537 dB/km											
1	15.5	15.4	14.8	14.6	12.5	12.4	8.4	8.1	-	-	-	-
6	17.9	17.5	16.0	16.2	13.1	13.9	8.7	8.4	-	-	-	-
12	22.3	22.3	20.0	19.8	17.2	16.9	9.2	9.3	-	-	-	-
18	29.9	29.6	26.0	25.8	22.5	22.5	13.6	13.4	-	-	-	-
24	24.2	23.9	22.9	23.0	21.6	21.4	18.5	18.8	-	-	-	-
30	25.9	25.9	24.9	24.7	21.5	22.2	18.2	18.3	-	-	-	-

36	24.6	24.5	23.1	23.0	22.1	22.0	16.5	16.9	-	-	-	-
42	24.5	25.3	23.6	23.4	21.2	21.9	18.0	17.6	-	-	-	-
48	15.4	15.3	14.2	14.1	12.3	12.2	13.3	13.3	-	-	-	-
54	22.1	22.6	20.7	21.1	18.1	18.0	14.3	14.5	-	-	-	-
64	15.7	15.8	14.0	14.9	12.5	12.6	8.8	9.0	-	-	-	-
	Attenuation = 4.2 dB/km											
1	14.4	14.4	9.0	8.0	-	-	-	-	-	-	-	-
6	14.5	14.2	9.0	8.9	-	-	-	-	-	-	-	-
12	15.7	15.8	10.8	10.9	-	-	-	-	-	-	-	-
18	23.4	23.6	16.5	16.7	-	-	-	-	-	-	-	-
24	20.8	20.5	15.8	15.7	-	-	-	-	-	-	-	-
30	23.2	23.2	14.7	14.6	-	-	-	-	-	-	-	-
36	19.8	19.6	13.7	13.5	-	-	-	-	-	-	-	-
42	22.1	22.9	13.4	13.4	-	-	-	-	-	-	-	-
48	14.4	14.4	11.1	10.8	-	-	-	-	-	-	-	-
54	17.4	18.1	9.9	10.0	-	-	-	-	-	-	-	-
64	14.6	14.5	11.5	11.5	-	-	-	-	-	-	-	-
	Attenuation = 5.8 dB/km											
1	8.8	8.8	-	-	-	-	-	-	-	-	-	-
6	10.1	10.3	-	-	-	-	-	-	-	-	-	-
12	11.5	11.5	-	-	-	-	-	-	-	-	-	-
18	14.4	14.3	-	-	-	-	-	-	-	-	-	-
24	18.9	19.1	-	-	-	-	-	-	-	-	-	-
30	22.8	23.0	-	-	-	-	-	-	-	-	-	-
36	19.3	20.5	-	-	-	-	-	-	-	-	-	-
42	20.8	20.2	-	-	-	-	-	-	-	-	-	-
48	13.3	13.5	-	-	-	-	-	-	-	-	-	-
54	12.8	13.0	-	-	-	-	-	-	-	-	-	-
64	12.8	12.6	-	-	-	-	-	-	-	-	-	-

Table 2. BER values obtained from the proposed system per different FSO medium transmission

Channel / BER value	**5 km**		**7 km**		**9 km**		**15 km**		**20 km**		**25 km**	
	data1	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**
	Attenuation = 0.43 dB/km											
1	2E-66	2E-66	1E-66	1E-66	6E-64	1E-64	4E-55	3E-53	2E-45	3E-43	2E-31	2E-30
6	6E-68	1E-67	6E-67	9E-67	2E-64	8E-64	2E-54	8E-54	2E-44	9E-44	4E-29	8E-32
12	5E-162	1E-162	2E-161	9E-160	6E-158	3E-157	3E-140	3E-141	5E-130	5E-131	6E-110	4E-111
18	2E-207	3E-206	2E-205	6E-206	1E-203	6E-202	2E-190	4E-189	3E-180	3E-179	3E-160	5E-166
24	2E-141	3E-140	3E-142	4E-141	6E-148	5E-147	6E-148	5E-147	4E-138	7E-137	7E-126	7E-127
30	5E-240	2E-230	7E-213	4E-210	3E-202	3E-200	4E-190	3E-189	4E-170	3E-169	4E-152	4E-159

36	4E-138	3E-139	9E-136	3E-137	8E-130	4E-132	7E-121	4E-122	4E-113	9E-111	4E-95	8E-98
42	1E-144	3E-141	7E-141	2E-139	3E-138	2E-135	4E-128	2E-125	3E-117	3E-116	2E-97	2E-96
48	8E-47	3E-46	3E-45	1E-44	4E-42	1E-41	3E-32	2E-31	5E-23	2E-22	3E-12	3E-11
54	2E-112	5E-115	2E-102	6E-103	2E-99	2E-98	2E-89	2E-88	3E-77	3E-76	7E-58	6E-55
64	6E-84	4E-83	1E-77	3E-77	4E-69	3E-68	5E-61	3E-60	5E-52	2E-51	5E-36	2E-38
	Attenuation = 1.537 dB/km											
1	1E-54	5E-54	8E-50	5E-51	7E-48	3E-47	3E-17	2E-16	-	-	-	-
6	7E-72	6E-69	8E-60	2E-61	2E-45	3E-44	2E-18	1E-17	-	-	-	-
12	5E-110	2E-110	5E-89	8E-88	2E-74	3E-72	2E-20	6E-21	-	-	-	-
18	3E-196	5E-193	2E-149	3E-147	2E-122	4E-122	1E-42	5E-41	-	-	-	-
24	3E-129	7E-127	9E-117	2E-117	6E-113	1E-111	1E-93	1E-87	-	-	-	-
30	3E-148	2E-148	9E-138	1E-138	2E-110	2E-105	1E-74	2E-75	-	-	-	-
36	4E-134	8E-133	2E-124	1E-123	1E-111	3E-107	1E-61	2E-64	-	-	-	-
42	1E-132	3E-141	1E-123	2E-122	1E-99	3E-97	6E-73	5E-70	-	-	-	-
48	1E-53	7E-53	1E-50	9E-50	2E-47	3E-48	1E-40	1E-40	-	-	-	-
54	3E-80	3E-82	3E-75	2E-77	8E-66	2E-61	2E-46	5E-48	-	-	-	-
64	5E-56	3E-56	7E-45	6E-47	1E-26	2E-28	2E-18	7E-17	-	-	-	-
	Attenuation = 4.2 dB/km											
1	5.1E-41	1.9E-41	1.3E-12	1.0E-12	-	-	-	-	-	-	-	-
6	3.5E-48	8.3E-46	1.4E-12	2.1E-12	-	-	-	-	-	-	-	-
12	3.5E-56	1.1E-56	8.9E-19	2.1E-19	-	-	-	-	-	-	-	-
18	1.3E-121	1.3E-123	8.6E-62	5.2E-63	-	-	-	-	-	-	-	-
24	1.3E-96	1.0E-93	2.2E-56	4.5E-56	-	-	-	-	-	-	-	-
30	2.9E-119	1.8E-119	3.7E-49	7.7E-49	-	-	-	-	-	-	-	-
36	2.2E-87	3.2E-86	2.9E-43	4.5E-42	-	-	-	-	-	-	-	-
42	1.6E-98	1.8E-97	5.0E-41	2.7E-41	-	-	-	-	-	-	-	-
48	1.8E-47	2.5E-47	4.6E-29	2.6E-27	-	-	-	-	-	-	-	-
54	7.3E-68	1.8E-73	1.7E-23	4.8E-24	-	-	-	-	-	-	-	-
64	1.3E-80	1.5E-79	5.4E-31	9.4E-31	-	-	-	-	-	-	-	-
	Attenuation = 5.8 dB/km											
1	9.7E-19	7.2E-19	-	-	-	-	-	-	-	-	-	-
6	2.4E-24	3.1E-25	-	-	-	-	-	-	-	-	-	-

12	8.4E-31	1.1E-30	-	-	-	-	-	-	-	-	-	-
18	2.0E-47	1.8E-46	-	-	-	-	-	-	-	-	-	-
24	6.3E-80	7.1E-82	-	-	-	-	-	-	-	-	-	-
30	9.3E-116	2.9E-117	-	-	-	-	-	-	-	-	-	-
36	1.7E-83	2.2E-93	-	-	-	-	-	-	-	-	-	-
42	2.5E-96	1.2E-90	-	-	-	-	-	-	-	-	-	-
48	1.5E-40	9.8E-42	-	-	-	-	-	-	-	-	-	-
54	1.4E-37	5.3E-39	-	-	-	-	-	-	-	-	-	-
64	4.8E-55	2.0E-54	-	-	-	-	-	-	-	-	-	-

4.2 Comparison of Results with literature

In this section, a brief comparison would be carried out concerning the presentation of the original DP-DQPSK DWDM system but without considering the utilization of polarization division multiplexing(PDM),Carrier Suppressed Non Return to Zero(CSNRZ), or using the Dio Binary coding scheme [17]. The comparison would be carried out based on comparing the results of QF and BER obtained from the work in [17] and the proposed work in this article and as listed in Table 3 and Table 4 respectively. It is worth to mention the comparison would be formed based on the averaged values of QF and BER gathered from the two scenarios and all the selected test channels

From these tables, it can be seen the significance of using the HOA to boost the QF and BER values and reduce the impact of FWM as the proposed system works by using an input power of – 10 dBm. From comparison also it can be noticed that the proposed methodology could support higher distance transmission for the cases of light air to reach 25 km and for the case of light haze to reach 15 km instead of 9 km for the original system utilization. Also, for the cases of medium haze and rain, it can be noticed that using the HOA for handling such transmission could improve the efficacy of the data transmitted for the distance of 5 km as compared to the original base system values.

Addressing the problem of limited transmission over different weather conditions can be carried out using two techniques, the first was at the transmitter side which includes using a dedicated precoding scheme (Duobinary precoding). Where during transmission there is an error occurred known as the error of propagation, and this error can be avoided by using a precoder before the duobinary encoder at the transmitter. The precoder ties the present sample and the previous sample, resulting in better improvement in the performance of the system by reducing propagation errors.

On the other hand, using hybrid optical amplification can contribute to different energy levels thereby affecting the generation of the active area for instance in EDFA the generation is carried directly in the transmitter part, while in SOA amplifier type the generation is carried in the semiconductor which will have a great impact on the energy supply. Hence, using the significance of hybrid amplification can achieve by considering the powerful point of each amplifier and use it together to boost the transmission as mentioned in the context of 5 Km.

Table 3. Comparison between averaged QF values obtained from both the proposed work and the original system proposed in [17]

Attenuation / QF data in (dBm)	**5 km**		**7 km**		**9 km**		**15 km**		**20 km**		**25 km**	
	data1	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**
Attenuation = 0.43 dB/km												
Proposed	23.4	23.3	22.8	22.8	22.2	22.1	19.5	19.5	17.6	17.5	15.4	15.4
Ref. [17]	20.0	19.9	18.0	18.0	15.9	15.9	-	-	-	-	-	-
Attenuation = 1.537 dB/km												
Proposed	21.6	21.6	20.0	20.1	17.7	17.8	13.4	13.4	-	-	-	-
Ref. [17]	17.2	17.1	16.4	16.4	15.2	15.2	-	-	-	-	-	-

Attenuation = 4.2 dB/km												
Proposed	18.2	18.3	13.3	13.2	-	-	-	-	-	-	-	-
Ref. [17]	13.2	13.2	11.6	11.5	-	-	-	-	-	-	-	-
Attenuation = 5.8 dB/km												
Proposed	15.0	15.1	-	-	-	-	-	-	-	-	-	-
Ref. [17]	14.0	13.9	-	-	-	-	-	-	-	-	-	-

Table 4. Comparison between averaged BER values obtained from both the proposed work and the original system proposed in [16]

Attenuation / BER data	**5 km**		**7 km**		**9 km**		**15 km**		**20 km**		**25 km**	
	data1	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**	**data1**	**data2**
Attenuation = 0.43 dB/km												
Proposed	7.5E-48	2.9E-47	3.1E-46	1.1E-45	3.4E-43	1.4E-42	2.5E-33	2.2E-32	4.7E-24	1.5E-23	2.3E-13	2.3E-12
Ref. [17]	5.9E-17	3.6E-17	5.6E-17	6.3E-17	3.6E-17	3.1E-17	-	-	-	-	-	-
Attenuation = 1.537 dB/km												
Proposed	1.5E-54	7.1E-54	6.7E-46	5.9E-48	1E-27	2.2E-29	3E-18	2.7E-17	-	-	-	-
Ref. [17]	4.4E-17	7.2E-17	3.2E-17	2.1E-17	1.1E-16	7.5E-17	-	-	-	-	-	-
Attenuation = 4.2 dB/km												
Proposed	4.6E-42	1.7E-42	2.5E-13	2.9E-13	-	-	-	-	-	-	-	-
Ref. [17]	1.2E-16	2.7E-16	1.8E-12	1.5E-10	-	-	-	-	-	-	-	-
Attenuation = 5.8 dB/km												
Proposed	8.8E-20	6.6E-20	-	-	-	-	-	-	-	-	-	-
Ref. [17]	4.8E-14	2.7E-11	-	-	-	-	-	-	-	-	-	-

5. CONCLUSION

This article proposed a methodology for using the HOA represented by the EDFA and OA along with a hybrid transmission medium represented by the utilization of FSO with a range between 5 km and 25 km and SMF with a fixed distance of 60 km. The utilization of the desired HOA technique was based on the previous investigation among other tested methods. The investigated system of transmission has been built with 64 channels and based on the utilization of the DP-DQPSK – DWDM – RoF system including using the direct detection method, CSNRZ as a method for modulation, and Dio binary as a major coding scheme to reduce the impact of cross-talk effects. The proposed system was designed and tested by using an optisystem and then the obtained results were compared with the original system (without duobinary precoding) presented in [16]. Overall results obtained indicate the major significance of using the HOA method for hybrid transmission where the FSO ranged raised by 16 km for the light air case and raised by 6 km for the case of light haze. Meanwhile, for the rest cases of moderate haze and rain, the method could improve the quality of the received data which will improve the Quality of Service (QoS) to meet the requirements for 5 G-based applications and beyond. Hence, using the powerful Duobinary precoder at the transmitter side that incorporates the hybrid scheme of amplification may contribute in boosting the performance of the proposed system to handle the transmission over SMF and FSO systems and different weather situations.

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