Bidirectional Hybrid Optical Communication System Based on Wavelength Division Multiplexing for Outdoor Applications

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Abstract

The simulation and investigation of a 32×10 Gb/s WDM all-optical bidirectional hybrid communication system for outdoor applications is presented in this article via multidisciplinary softwares. In order to track the system condition, a strain sensor based on fiber Bragg grating (FBG) is integrated in-line with the fiber optic link (FO-link). Then, a free space optical link (FSO-link) with 4-channel is simulated to act backup or rescue to the FO-link in the event of disaster or bombing. The FO-link is working well until the strain reach to 180 $\mu\epsilon$, after that the FO-link has degraded. Therefore, an optical switch is incorporated in between these systems (FO-link & FSO-link) to turn-on the FSO-link which act as a backup system to FO-link and maintains the continuity of the data transmission. According to the hybrid link results, there is an efficient enhancement in the Q-factor as compared with the FO-link even when there is heavy rain.

1. Introduction

The FSO-link is assumed as an stand by solution for FO-link when; 1) the FO-link installation become very costly, impracticable, or unattainable to install [1], [2], 2) the FO-link is collapses as a consequence of a bombing during wars or natural disaster [3], 3) there is a traffic issue on the first mile or last mile of the FO-link [4]. As a result, the integration of FO-link and FSO-link to build a hybrid communication system has received a lot of attention in the last decade [3]–[10]. In spite of the FSO links have all these features, the optical to electrical and electrical to optical transformation limit the communication bandwidth and considered as the main cruel problem facing the traditional FSO link. This problem was tackled out by using advanced optics system in the fiber ends in order to directly transmitting/ receiving the optical signal from/to the optical fiber [10], [11].

Furthermore, Yi-Lin Yu et al. Incorporated an optical strain sensor based FBG into a hybrid optical communication system. The FSO-link works as an emergency system on a bridge to the FO-link. When the strain reach to a critical level an optical switch was used to change the link path between FO and FSO [3]. Although, good matching between the FO and FSO link was achieved in terms of eye diagram results. However, there are several issues that must be addressed, such as; a very short distance (10 m) for FSO link and limited WDM channels were used in transceiver about (4 channels) as well as the authors did not use any technique to compensate the chromatic dispersion and neglecting the impact of weather conditions. Antonio Jurado et. al, used hybrid FO-FSO communication system with different turbulent conditions. The FSO communications are considered as an alternative and promising mean complementing the traditional optical communications in many applications where the use of fiber cable is not justified [7]. But there are several issues need to be considered, for example; short FSO distance (423m) and work within first communication window of 850 nm this wavelength standardized for short furthermore the system work in one direction.

Takeshi Tsujimura et. al, proposed bidirectional communication system with a single-mode optical fiber line and a FSO network linked directly without any photoelectric equipment. FSO-link is realized between

the two sides of a window pane and moves across the panel through a laser beam. High quality communication at 1310 and 1550 nm wavelengths was obtained with accuracy at up to 4 Gbps [12]. But there are many issues that need to be considered, for example; very short FSO distance (90 mm) and used WDM with only two wavelengths 1310 nm and 1550 nm.

It is known that practical design is more reliable than theoretical design, but theoretical design decreases the design cost as well as offer high tolerance for the designers to determine the proper design parameters and achieve the optimum performance parameters. In this paper, a hybrid optical communication system was simulated via multidisciplinary softwares and demonstrated for outdoor applications. The proposed FSO link work as a backup to the FO-link in the bombing wars or disaster areas which extend about 2 km with rainy weather. Three computer programs were used in this study: OptiSystem 7, OptiGrating 4.2.2, and MATLAB R2017b.

2. Experiment Setup

The hybrid optical communication system was designed using the OptiSystem 7 software, the FBG strain sensor was simulated using the OptiGrating 4.2.2 software, and both the optical switch and the power comparative system (PCS) were simulated by MTLAB R2017b. Figure 1 depicts the proposed WDM all-optical bidirectional hybrid communication scheme (a). This architecture is comprised of two major components: the FO link within FBGs (shown in Figure 1(b)) and the four-channel FSO link within PCS (shown in Figure 1(c) (c). The optimal option is used in the FSO portion to optimize the transceiver design parameters. As a result, the transmitter diameter, beam divergence, and detector diameter were optimized to be 15 cm, 1 mrad, and 20 cm, respectively. To evaluate the effects of miss point loss on the reliability of the suggested system, different MPL values were chosen to be (100%, 75%, 50%, and 25% of the maximum value of 14.1 dB), which represented 14.1 dB, 10.75 dB, 7.05 dB, and 3.52 dB, respectively, for FSO1, FSO2, FSO3, and FSO4. To simulate the reliable design, two SMF spans of 100 m length were used in the transmitting and receiving parts, as these two SMF spans depict the connecting fiber between the modulation/demodulation components and the transceivers. To improve the performance of the proposed system, a simple MATLAB code is simulated to act as a PCS. In practice, this method functions similar to a tracking system by choosing the lowest attenuation channel and multiplying the output power by the number of channels used. The connection between the FO link and the FSO link optical switch that designed by MATLAB when the Q factor and BER are less than the required condition (6 for Q-Factor and $10E-9$ for BER), it automatically converts to FSO link, thereby ensuring continued service. The input signal is obtained from a continuous laser array of 32 laser diodes, 16 for upstream (193 –to– 194.5) THz and 16 downstream (194.6 –to– 196.1) THz with channel spacing of 100 GHz. The over all input power is set to 10 dBm, and the bit rate is set to 10 Gbps within the non-return to zero modulator. The design parameters for both the FO and FSO systems are illustrated in Table 1.

Table 1: Design parameters of the proposed system.

Transmitter	Value	FSO	Value	FBGs	Value
Bit rate	10 Gbps	Transmitter diameter	15 cm		193 - 196.1THz
Power	10 dBm	Receiver diameter	10 – 20 cm	Grating length, L	7 mm
Linewidth	10 MHz	Beam divergence	1 – 10 mrad	Modulation Index	0.0005
Frequency	193–196.1 THz	Max. MPL	14.1 dB	Grating period, Λ	0.534 m
Space	100 GHz				

3. Results And Discussion

A. Characteristics of the FO–link

In this section the quality of the FO–link is examined under different strain levels ranging from 0 to 300 $\mu\epsilon$ for both upstream and downstream frequencies, as shown in Figures 2 and 3, respectively. As shown in Figure 1, the signal power is set to 10 dBm, and the applied strain values are determined using an FBG sensing system. The results show when the applied strain increased, the Q–Factor decreased and the BER increased for both up and down streams.

At 180 $\mu\epsilon$ of the applied strain, the receiving signal degrades to the threshold values 6 for Q–Factor or $10E-9$ for BER, and the signal power degrades to –40 dBm. This attitude indicates that the applied strain changed the grating period of the FBG which caused a red shift in the signal wavelength, then deform the data in the receiving terminal. These results demonstrate that the FO–link can be used at strains less than 180 $\mu\epsilon$, but it degrades beyond this strain point. As a result, an emergency communication device should be used to ensure the transmission of information.

B. Characteristics of the FSO link

This part dedicated to optimizing the transceiver design parameters of the proposed FSO system, and the PCS is used to improve the performance parameters such as Q–Factor, BER, and maximum link range. Four weather conditions have been used, namely clear, hazy, light rain, and heavy rain, with attenuation losses of (0.23, 2.33, 4, and 10) dB/km, respectively. The proposed system's performance was tested over 32 channels, but the results of only two frequencies are seen in this work, namely 193 THz and 196.1 THz, as shown in Figures 4 and 5, respectively. The obtained results show that increasing the communication distance degrades system efficiency, resulting in both the Q-factor and BER is less than the communication conditions. The maximum achieved connection range is approximately (15, 5, 4, and 2) km for clear, hazy, light rain, and heavy rain situations, respectively.

Table 2 describes the results obtained under various weather conditions in detail. The FSO–link results demonstrated that this system can be used in a various weather conditions with a maximum link range of up to 2 km. As a result, as will be discussed in the following section, the proposed system can be regarded as an alternative system for the FO–link.

Table 2: The obtained results from the proposed FSO system.

Weather Condition	Specific attenuation, dB/km	Maximum link range km	Operating frequency is 193 THz			
			Q–Factor	BER	Q–Factor	BER
Clear	0.23	15	6.256	1.71E-10	6.728	7.42E-12
Hazy	2.33	5	7.424	4.77E-14	7.934	9.02E-16
Light rain	4	4	6.012	8.19E-08	6.630	7.92E-09
Heavy rain	10	2	6.673	3.41E-13	7.162	3.42E-13

C. Characteristics of the hybrid link

This section demonstrated the effect of applied strain on the Q–factor for both the FO– and hybrid connection under various weather conditions, as shown in Figure 6 (a) and (b) for upstream 193 at THz and downstream 196.1 THz, respectively, with a maximum FSO–link distance of 2 km. The FO–link is degraded beyond strain $> 180\mu\epsilon$, according to the results and as previously illustrated. At this stage, the FSO–optical link's switch will be enabled, allowing it to serve as an emergency system and continue to transmit data. The results show that the Q–factor is clearly improved within a hybrid zone, and it remains within the communication condition even during heavy rain. Figure 7 shows the eye diagrams for the FO– and hybrid links at applied strain of $180\mu\epsilon$ (a) FO–connection, (b) Hybrid link in clear weather, (c) Hybrid link in hazy weather, (d) Hybrid link in light rain, and (e) Hybrid link in heavy rain.

4. Conclusion

In the present work, a hybrid optical communication system based bidirectional architecture was simulated and demonstrated for outdoor applications via multidisciplinary software's. The strain affected the FO–link and is degraded at $180\mu\epsilon$. The proposed FSO–link work as a stand by solution to the FO–link in the bombing wars or disaster areas that extend about 2 km at a specific attenuation of 10 dB/ km with the heavy rain conditions.

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Figures

Figure 1

Free space optic, fiber optic communication, hybrid optical communication

Figure 2

Effect of strain on the performance of upstream FO-link: (a) Q-Factor (b) BER.

Figure 3

Effect of strain on the performance of downstream FO-link: (a) Q-Factor (b) BER.

Figure 4

The FSO-link performance versus link range for several weather conditions at 193 THz (a) Q-Factor (b) BER.

Figure 5

The FSO-link performance versus link range for several weather conditions at 196.1 THz (a) Q-Factor (b) BER.

Figure 6

Effect of the strain on the Q-factor for both of the FO and hybrid link at several weather conditions for: (a) upstream 193 at THz (b) downstream at 196.1 THz.

Figure 7

The eye diagram for the both of FO link and hybrid link within several weather conditions at applied strain of $180 \mu\epsilon$. (a) FO-link (b) Hybrid link at clear weather (c) Hybrid link at hazy weather (d) Hybrid link at light rain (e) Hybrid link at the heavy rain.