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Performance evaluation of SS-FSO communication system incorporating different line coding

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Abstract
In this research paper, high-speed Free-space optical connectivity is explored for the long-distance of data transfer in various weather conditions. The system evaluates information transmission with the data rate of 2.5 Gbps up to a distance of 5 km. A high-speed SS-based free-space optical communication system is incorporated. It has been investigated by changing the WDM spectrum of Highly Non Linear Fiber by the Kerr effect of nonlinearity. The de-multiplexer provides 4 data-carrying channels with the capacity of 2.5 Gbps that are modulated using various modulation techniques. Furthermore, the efficiency of the system is evaluated by varying various parameters of the system including beam divergence angle, receiver/ transmitter antenna diameter, etc. The use of spectrum slicing offers an opportunity for a high data rate, broader bandwidth communication.

Keywords Beam divergence · HNLF · FSO · Quality factor · RZ · NRZ · CSRZ

1 Introduction

Presently, Free-Space Optics (FSO) has attracted much consideration in air communication due to numerous benefits over RF (radio frequency) transmission such as wide bandwidth, license-free operation and security, etc. (Parkash et al. 2016; Liu et al. 2005). The FSO is popular as compared to optical fiber communication, owing to more flexibility and cost-effectiveness, also more rapid and simpler for deployment and re-deployment (HeatleyD et al. 1998). Nowadays, various multiplexing techniques permit to hold the number of independent and autonomous optical carriers that have the ability to support Tbps of information (Ciaramella et al. 2009). Various researches on wireless communication by using the wavelength division multiplexing techniques have been done. Also, WDM provides the numerous ways of optical wireless communication for the data transmission which states

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that by using the WDM approach the performance of a system is not limited to terrestrial transmission but it also permits inter-satellite communication (Gupta et al. 2018; Gupta 2016). The WDM FSO technique is the most prominent and adequate way to deal with the demand for bandwidth-hungry services. Although, the wavelength division multiplexing technique has a number of limitations, such as systems are costly and more complex to run, etc. For the purpose to overcome the drawback of the WDM technique, a SS (spectrum sliced) technique is introduced which has better performance characteristics. The SS technique includes the simple working process as compared to wavelength division multiplexing that avails various origin of intensity working at different frequencies (Rashidia et al. 2017). Also, wavelength division multiplexing systems have the characteristics of wavelength-selective switching which is more prominent to the specific port. As a result, the SS wavelength division multiplexing technique has very similar benefits as WDM techniques like low cost, less complexity, and for the future generation it is power efficient (Thakur et al. 2018). For the execution of the data transmission, the different physical parameters also play an important role in the communication of the system. The performance of the OWC system also depends on the aperture's diameter of the antenna. As we know the antenna is a narrowband device. So, the aperture diameter of both the receiving and transmitting antenna decides the figure of merit of the received signal that leads to the high efficiency of the signal (Shaina 2017). A major performance of the system deteriorating factor is a beam divergence angle which needs to be optimized for a better figure of merit. So far, various fundamental scientific studies have been described to the reproduction of slices of the spectrum (Shaina 2017; Pendock and Sampsom 1996; Lee et al. , 2012), amplifier used to boost and improve the signal strength (Kaneko et al. 2006; Amrutha and Babu 2016; Thakur and Nagpal 2014; Esmail 2021), angle of beam divergence (Kaushal et al. 2017), compensation of scintillation noise (Abtahi and RuschL.A, 2006; Saghir et al. 2021; Verma et al. 2021). Despite, the investigated studies are satisfactory but these techniques either support less data rate or more complexity. The best approach as a concern the spectrumsliced WDM technology is required for high-speed FSO systems by generating high power slices and minimizing deteriorating effects.

In this research article, a high-speed WDM—FSO communication system based on the spectrum slicing technique through SC generation (Thakur 2018) is proposed. The performance of the system is evaluated for the different figure of merits.

2 System architecture

The FSO communication system is analyzed and simulated by the Optiwave OptiSystem. At the transmitter side, a CW laser source with wavelength 1550 nm generates a continuous beam of light which is further coupled into the HNLF (highly nonlinear fiber) of the 2 km length. At the output of HNLF, a wide spectrum is collected which is due to the nonlinearity of fiber, this technique is called self-phase modulation. This wide spectrum is further sliced by demultiplexer into four equally spaced channels 193.0, 193.075, 192.1 50, and 192.225 THz. These 4 carriers are equally separated by 75 GHz of channel spacing and each transmits the data rate of 2.5 Gbps to exhibit the total speed of 10 Gbps as shown in Table 1.

The pseudo-random bit sequence generator (PRBS) generates a signal in the sequence of zeroes and ones with a word length of 2^{15}–1 independently which is introduced along with the carrier signal into the modulator, in order to reshape the signal. Therefore, these

Table 1 The experimental parameters of the system architecture

Serial No	Parameters	Values
i	Link length	5 km
ii	Attenuation	0.1 dB/km
iii	Wavelength	1550 nm
iv	Diameters of transmitter/ receiver	5 cm,10 cm,15 cm, and 25 cm
v	Beam Divergence	0.25 mrad, 0.5 mrad, 0.75 mrad, 1 mrad
vi	No. of channels	4
vii	Spacing of channel	75 GHz

4 equally spaced channels are modulated along with the digital data signal which is generated at the data rate of 2.5 Gbps by the PRBG spectrum.

The Beam divergence angle provides the angular measurement of a signal transmitted by the antenna and also how rapidly the laser beam expands in the free space. The Beam divergence angle is varied accordingly to investigate the Free Spaced Optical communication system. So, the angle of divergence is varied from 1 mrad, 0.75 mrad, 0.5 mrad, and 0.25 mrad. In addition, various modulation techniques used and the diameter of the transmitter/receiver are also varied in order to evaluate the super continuum spectrum sliced (SS-SC) wavelength division multiplexing based free-space optical communication system Fig. 1.

After modulation, these signals are multiplexes and send toward the receiver side wirelessly from the transmitter antenna to the receiver antenna. At the receiver side, received

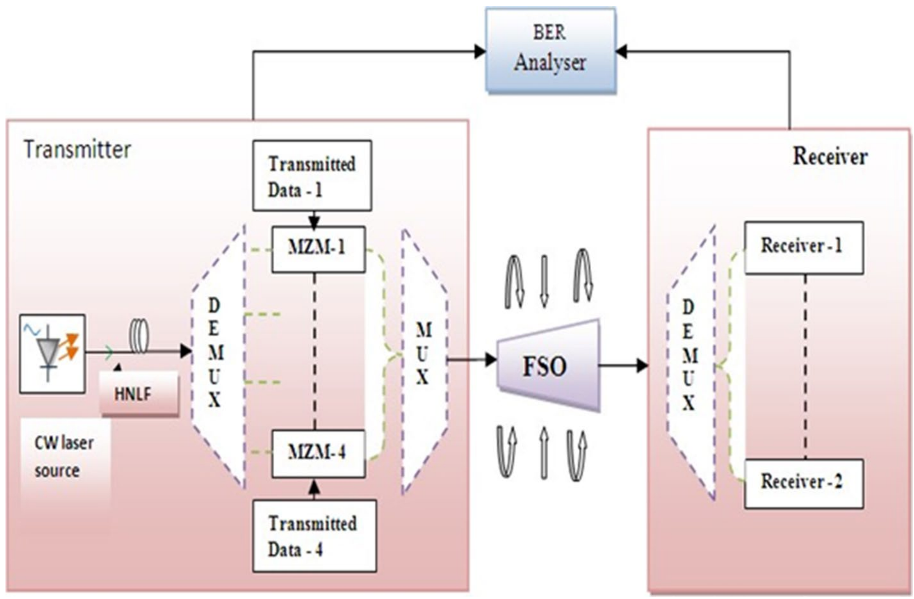

Fig. 1 WDM FSO system with SC-SS

Table 2 Values of Q at different link lengths

Sr. No	Link length (L in KM)	RZ	NRZ	CSRZ
i	1	12.86	14.16	15.2
ii	2	12.86	13.91	14.56
iii	3	12.01	12.69	13.34
iv	4	11.23	11.44	11.54
v	5	9.13	9.44	9.57

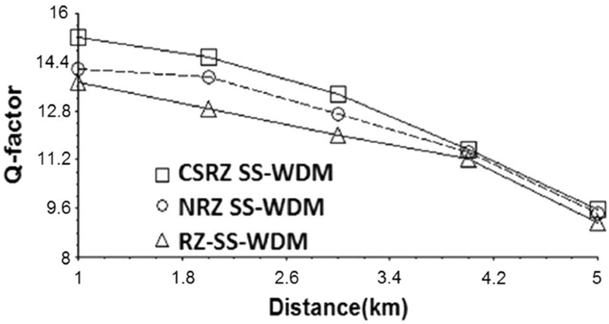

Fig. 2 Q-factor versus distance between the Tx/Rx Antenna

signals are reconstructed back to the original data stream by the de-multiplexer. The demonstration of the figure of merits of the FSO also depends upon different parameters like attenuation, the divergence of the beam, line width, etc.

3 Result and discussion

In this work, a high-speed SS-WDM-based FSO communication system based on suspended particulate matter in HNLF is investigated. The performance of the system is also investigated by varying various parameters like beam divergence angle, link distance, different modulation techniques, and the diameter of the receiving and transmitting antenna. Moreover, the performance of an FSO communication system is independent of various environmental weather conditions. In order to demonstrate the quality factor (Q) of the system, the length between the transmitter and receiver antenna is varied from 1 to 5 km mentioned in Table 2. In the Free-space optical system, the strength of the received signal also depends upon the link length of the transmitter/receiver.

The figure visualized how the Q-factor is varying as the distance increase for the various technique of modulation. Also, the graphical representation depicted that as the link length increase the quality of the received signal is decreased. It is observed from the figure that out of RZ, NRZ and CSRZ, the best one in terms of Q factor is CSRZ. Figure 2 shows that on account of dispersion tolerance characteristics and constant power supply, the carrier suppresses return to zero modulation formats performs excellently (Fig. 3).

For further investigation beam divergence angle is diversified as 1 mrad, 0.75 mrad, 0.25 mrad, and 0.5 mrad. The investigation has been done with the intention to analyze the BER of the received signal that is increased as the value of the beam divergence angle is increased and that leads to the degradation of the quality of the signal. As shown in Fig. 4, the maximum Qfactor is attained at 0.25 mrad beam divergence angle and a minimum for

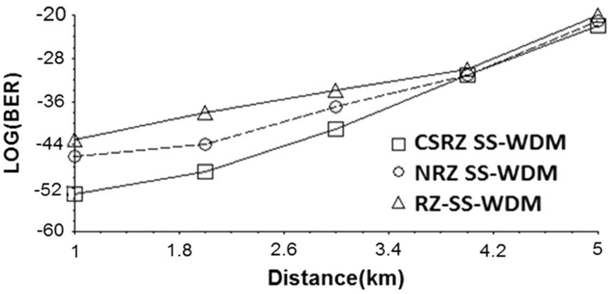

Fig. 3 Graphical representation of Distances (km) versus Log (BER)

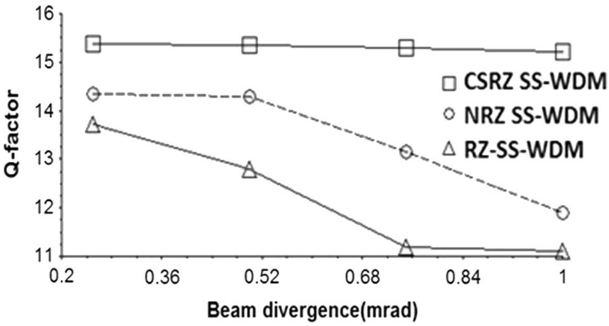

Fig. 4 Graphical representation of Q-factor v/s Beam divergence angle

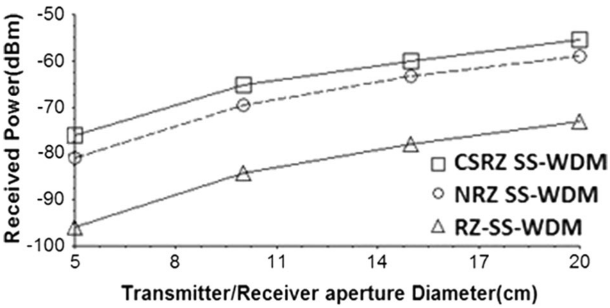

Fig. 5 Graphical representation of transmitter/receiver antenna diameter v/s received power

1 mrad. To obtain less error in the received signal, we should use the beam divergence degrading effects tolerant modulation as CSRZ.

Furthermore, the various combinations of transmitter and receiver aperture diameters are investigated which help to the analysis the performance of the free-space optical communication system. The aperture size of an antenna is directly proportional to the range. Figure 5 illustrated that as the diameter in the communication system increases that will leads to an increase in range. The antenna aperture sizes are varied as 5 cm, 10 cm, 15 cm, and 20 cm respectively. To obtain the maximum power and quality factor at the reception, we need to increase the aperture size of the Rx up to 20 cm. The figure shows that the larger the aperture size of the Rx antenna larger the received power of the received signal is obtained. The evaluation of the performance of the system is investigated by using various modulation techniques that are non return to zero, return to zero, and carrier suppressed return to zero. Among these three techniques of modulation, the CSRZ provide the excellent result in term of quality factor and receiver signal strength shown in Fig. 5, 6 respectively.

Figure 7 revealed the Eye Diagram of the super-continuum SS WDM FSO communication link. The resulting eye patterns of signal demonstrate the data handling ability of a digital transmission system. The investigation of the received signal is demonstrated by varying different parameters and the modulation format. The result revealed that the CSRZ modulation technique provides better performance of the system. After traveling in the free space the analysis of signal and de-multiplexing is done. The DEMUX technique separates the received signal into their respective data stream than these data stream routes to their respective wavelength ports. So, this property of the DEMUX (de-multiplexing) is also called the data distributor. The signal at the receiver is received in the form of a beam of light. The beam of light is inputted at the port of the PIN photodiode which converts the light signal into the electric signal. The photo-detector is followed by the Bessel filter which removes the unwanted signal that is noise from the received signal and only passes the desired signal. The optical regenerator is a 3-R regenerator placed after the Bessel filter. At the receiver side, the optical communication repeater is used in order to regenerate the received optical signal. The regeneration of the signal includes retiming, reshaping and re-amplification of the received data. The 3-R regenerator is followed by the BER analyzer. The BER analyzer determines the number of errors in the received signal. As the BER is increased the performance of the system is degraded. So it is necessary to maintain the system performance, the BER should have a low value. The BER shows the quality factor, Eye diagram, BER, etc. The OSA (optical spectrum analyzer) is a device designed for the analysis of the power distribution of a source of light over a specified wavelength range. The observation specified that the eye-opening in the supercontinuum spectrum-sliced (SC-SS) wavelength division multiplexing free-space optical communication system is superior to the simple wavelength division multiplexing technique (WDM) system. The investigation of the supercontinuum spectrum sliced (SC-SS) WDM FSO communication system has a more excellent performance characteristic in the case of the CSRZ modulation technique than the other modulation technique.

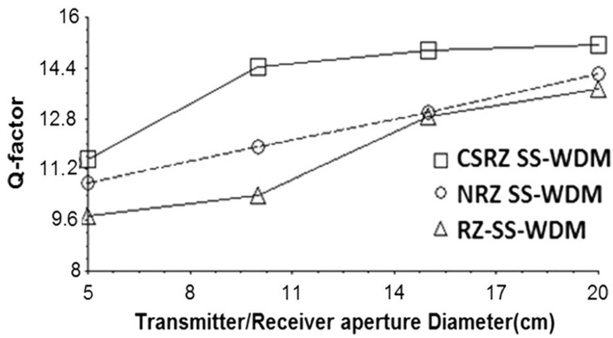

Fig. 6 Graphical representation of transmitter/receiver antenna diameter v/s Q factor

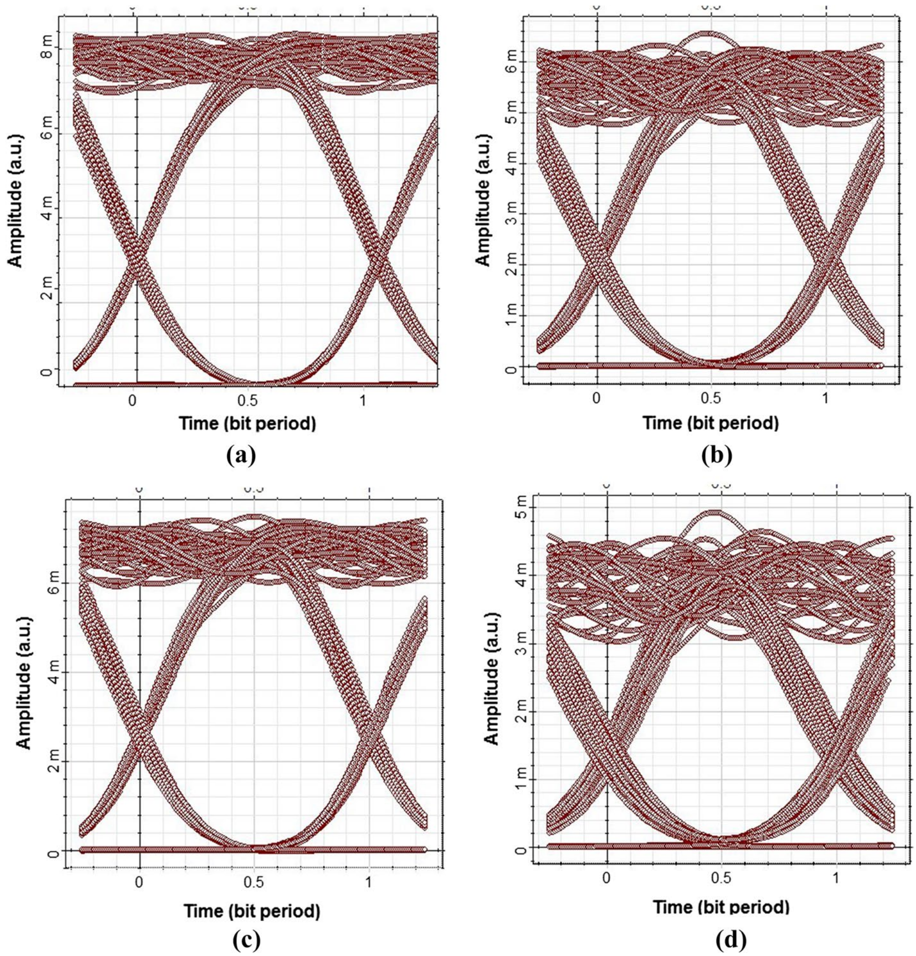

Fig. 7 The eye diagram of SS-WDM FSO link

4 Conclusion

In this research article, four channels spectrum sliced D-WDM FSO system of communication with the data rate of 2.5Gbps is proposed that depends on self-phase modulation in highly nonlinear fiber. In the research work, the analysis has been carried out for various line coding techniques, advanced modulation format, beam divergence, and transmitter–receiver diameters. The comparison has been made for line coding and advanced modulation technique at different distances. The supercontinuum spectrum slice (SC-SS) wavelength division multiplexing (WDM) FSO communication system illustrates the better performance in the case of the CSRZ technique of modulation. The beam divergence effect on the performance of the system is very degrading and results revealed that as divergence increases, the quality factor (Q) is decreases. However, CSRZ is a superior modulation technique to tolerate the beam divergence effects. It is noteworthy that the larger diameter of both the transmitter and receiver antenna enhances the system performance. In this work, without the use of an optical amplifier, the transmitter successfully acquires data of 10 Gbps over the distance of 5 km at 1 mrad beam divergence angle.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Availability of data and material All data generated or analysed during this study are included in this published article.

Code availability Optiwave OptiSystem is used and all the schematic generated are included in the article.

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