ISSN (e): 2250 – 3005 || Volume, 10 || Issue, 6|| June – 2020 ||
International Journal of Computational Engineering Research (IJCER)

Performance investigation of FSO link employing polarization division multiplexing and coherent detection-orthogonal frequency division multiplexing under different link parameters

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***ABSTRACT**: Free space optics (FSO) is a novel transmission technique capable of providing high-capacity links with large bandwidth and robustness against electromagnetic waves interference. In this work, we demonstrate the development of a 100 Gbps FSO link which employs the hybridization of polarization division multiplexing technique and coherent detection-orthogonal frequency division multiplexing technique. Further, we have investigated the system performance by varying different parameters like the input power, the size of the receiver antenna, wavelength of laser beam, the angle of beam divergence, and the additional losses. The proposed system has been modeled and analyzed over Optisystem test bed.*

***KEYWORDS**:free space optics; polarization division multiplexing; coherent detection; orthogonal frequency division multiplexing; system parameters*

Date of Submission: 10-07-2020 Date of acceptance: 26-07-2020

I. INTRODUCTION

The growth of wireless communications been treated as one of the most noteworthy phenomena in the past of technology. Free space optical (FSO) communication is a major area to research and researcher give emphasis on this technology due to numerous advantages [1-3]. This type of wireless optical communication technology uses highly narrow beam to transmit data from one point to the other one. This LOS (line of sight) technology offers benefits to both telecommunication users and providers [4]. It provides a high data rates up to several Gbps, has immunity to radio frequency interferences, requires no licensing, gives a highly secured communication link due to the usage of a very narrow beam angle, and offers an inexpensive, fast and easy deployment when compared to the fiber optic installation.[5]. Wireless devices and technologies have become pervasive much more rapidly than anyone could have imagined thirty years ago and they will continue to be a key element of modern society for the foreseeable future. Optical communication systems provide the highest available carrier frequencies and thus the fastest data rates possible today [6, 7]. FSO is designed to be a lower cost alternative to conventional fiber-optic cable-based communication links. The most mature technology used in FSO equipment relies on low cost semiconductor lasers or LED's operating in the near infrared at wavelengths of 785 nm or 850 nm [8]. In the past few years, systems operating at 1550 nm have also been developed. At first the vendors of these systems claimed that the 1550 nm wavelength had better propagation characteristics in severe weather than the 785 nm wavelengths [9]. With further analysis and research, those claims were withdrawn. Now there are claims that even longer wavelengths near 10 microns will solve the FSO link availability issues associated with severe weather. Hype about such magic wavelengths for FSO is both a disservice to the investors who will lose the money they are investing based on exaggerated claims, and to the rest of the FSO industry which should be creating realistic expectations for the capability of its equipment [10, 11]. In the weather conditions which normally cause the highest attenuation for FSO systems, namely coastal fog and low clouds, 10 microns offers no propagation advantage over shorter wavelengths [12].
Optical communication in various forms, have been used for thousands of years. The ancient Greeks used a coded alphabetic system of signalling with torches .In the modern era, wireless solar telegraphs called heliographs were developed, using coded signals to communicate with their recipients. On June 3, 1880, Bell conducted the world's first wireless telephone transmission between two buildings, some 213 meters (700 feet) apart. The invention of lasers in the 1960s revolutionized free space optics. Military organizations were particularly interested and boosted their development. In 2008, MRV Communications introduced free-space optics (FSO)-based system with a data rate of 10GB/s initially claiming a distance of 2 km at high availability.

This equipment is no longer available; before end-of-life, the product's useful distance was changed down to 350m. In 2013, the company MOSTCOM started to serially produce a new wireless communication system that also had a data rate of 10GB/s as well as an improved range of up to 2.5 km, Recent advances in FSO technology have opened up mainstream communications uses, from short-term solutions for short distance network bridges to an attractive and viable alternative for service providers to deliver the promise of all-optical networks [13-15]. As an optical technology, FSO is a natural extension of the metro optical network core, bringing cost-effective, reliable and fast optical capacity to the network's edge.

FSO-links are majorly influenced by weather conditions. For that reason, some significant characteristics of the atmosphere have to be elaborated prior to describing the optical wireless systems in more detail. The lowest part of the atmosphere up to 10 km above the Earth’s surface is called the troposphere or the weather sphere. It has a varying refraction index, which is dependent on the height above the Earth’s surface. Normally the refraction index decrease with the height, but at weather inversion situations there is a different relationship. Atmospheric conditions degrade laser communications through the atmosphere in two ways. First, the atmosphere acts as a variable attenuator between the transmitting and receiving terminals. Second, a free space laser link is subjected to scintillations. Attenuation is more in the foggy days and less at the time of thin fog. Moreover the haze also effects the transmission as the medium is air. Rain does not affect the signal at much extent as the drop size are not comparable to laser wavelength [16, 17].

In this work, we have developed a very large channel capacity FSO system by employing polarization division multiplexing (PDM) technique along with coherent detection (CO) and orthogonal frequency division multiplexing (OFDM) technique. The modeled FSO system is investigated for different system parameters in this work.

II. LINK SETUP

Figure 1 shows the link setup of the FSO system with PDM, CO, and OFDM techniques. This system is designed over Optisystem test bed. Coherent detection CO-OFDM required more complex transceiver design which shows the crucial performance in spectral efficiency and receiver sensitivity etc. [18]. CO-OFDM is suitable for long haul transmissions and provides high spectral efficiency and it also avoids the interference by using signal set orthogonality. In CO-OFDM systems the optical carrier is generated through laser by using local oscillator thus the less transmitted power required by the CO-OFDM system even though it is more sensitive to phase noise. The main benefits of CO-OFDM system is very beneficial because it provides high spectral efficiency, robustness against PMD and CD as well as it provides high range of receiver sensitivity and least oversampling factor.

In the proposed system simulative analysis of the CO-OFDM-FSO system using PDM under clear weather conditions has been performed and their performance has been investigated for different system parameters like the input power, the size of the receiver antenna, wavelength of laser beam, the angle of beam divergence, and the additional losses based on signal to noise ratio (SNR), total power plotsof a received signal. The basic concept of optical PDM is transmitting the modulated optical signals of the same optical wavelength independently over orthogonal polarizations states. The states of polarization are the most stable characteristic of propagating optical signal and are determined by the pattern traced out by the transmitted light’s electric-field vector in a fixed plane. As distinct modulated optical signal is transmitted through the orthogonal States Of Polarization (SOP) of the same light beam so it provides the enhanced transmission capability [19]. After the generation of 50 Gbps binary signal using Pseudo random bit sequence generator followed by quadrature amplitude modulator mapping, the output from OFDM transmitter is optical modulated using different orthogonal polarization laser signal and then launched into free space on the transmitter side and Polarization beam combiner (PBC) is used to recombine the two signals at transmitter side. At the receiver side, two coherent receivers are placed to detect the two polarizations of received signal, which are being separated with the help of Polarization beam splitter and then amplified optical signal is fed to PIN Photodiode to convert optical information into electrical output. The reverse process as that of the transmitter section is done to retrieve the original transmitted message signal.

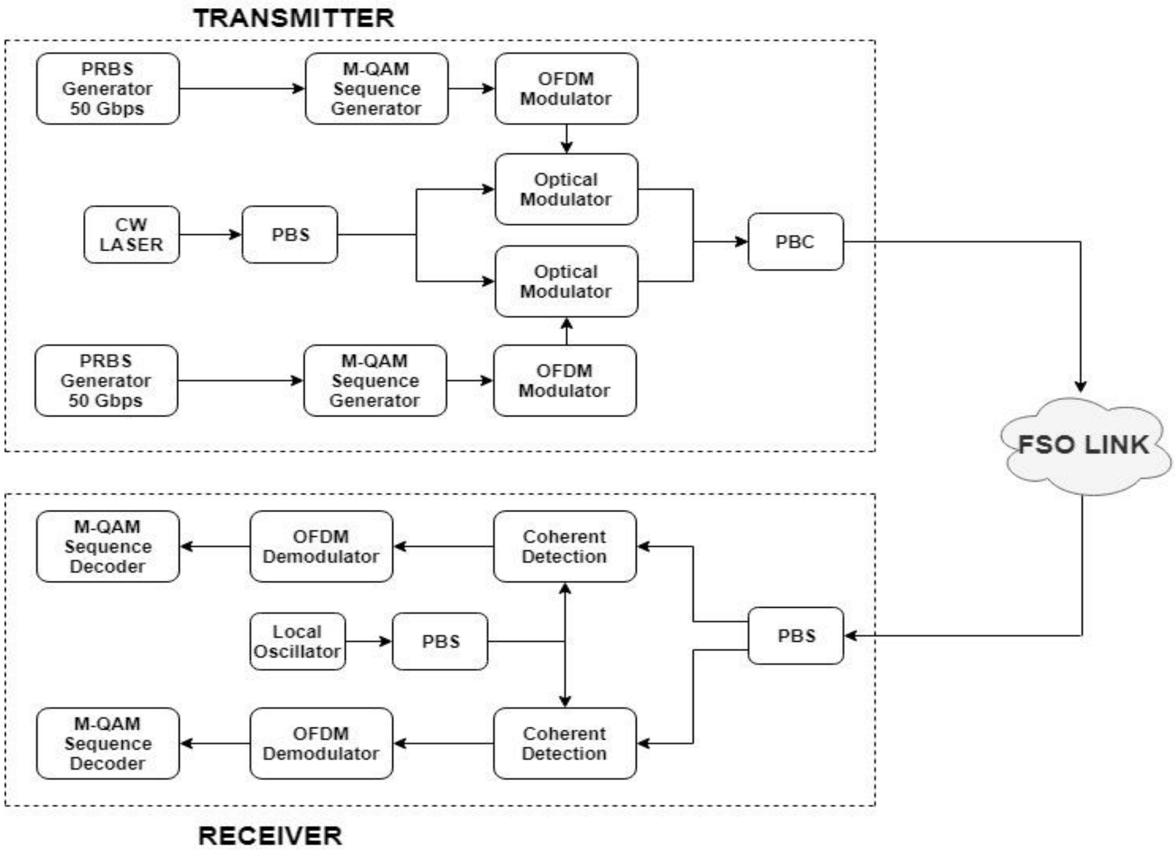


Figure 1 Proposed FSO system with PDM-CO-OFDM techniques

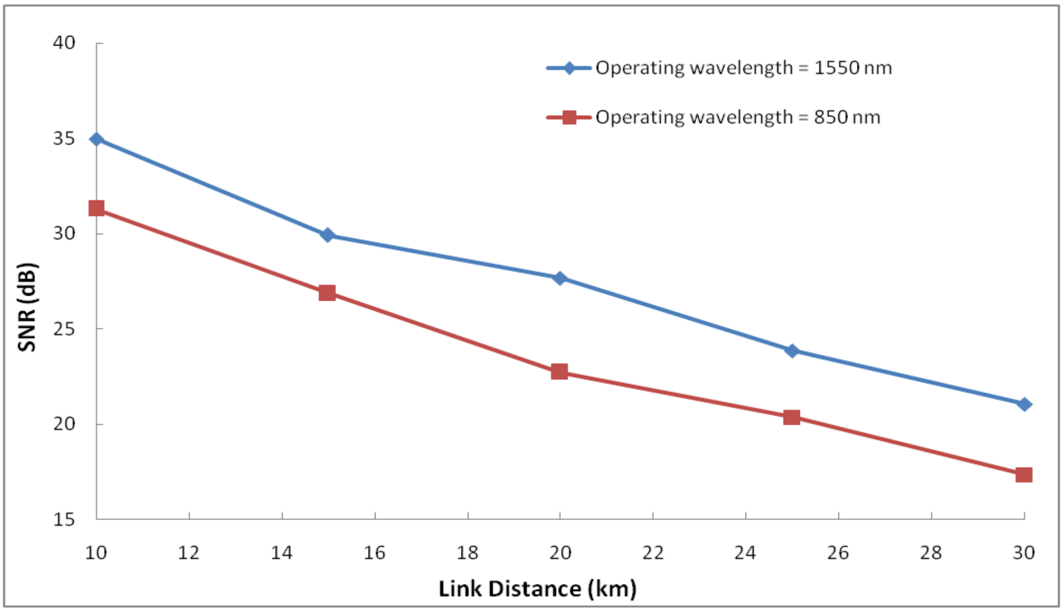
The FSO link equation is described as [20]:

$$P_{Received} = P_{Transmitted} \left(\frac{d_R^2}{(d_T + \theta Z)^2}\right) 10^{-\sigma Z/10} \qquad (1)$$

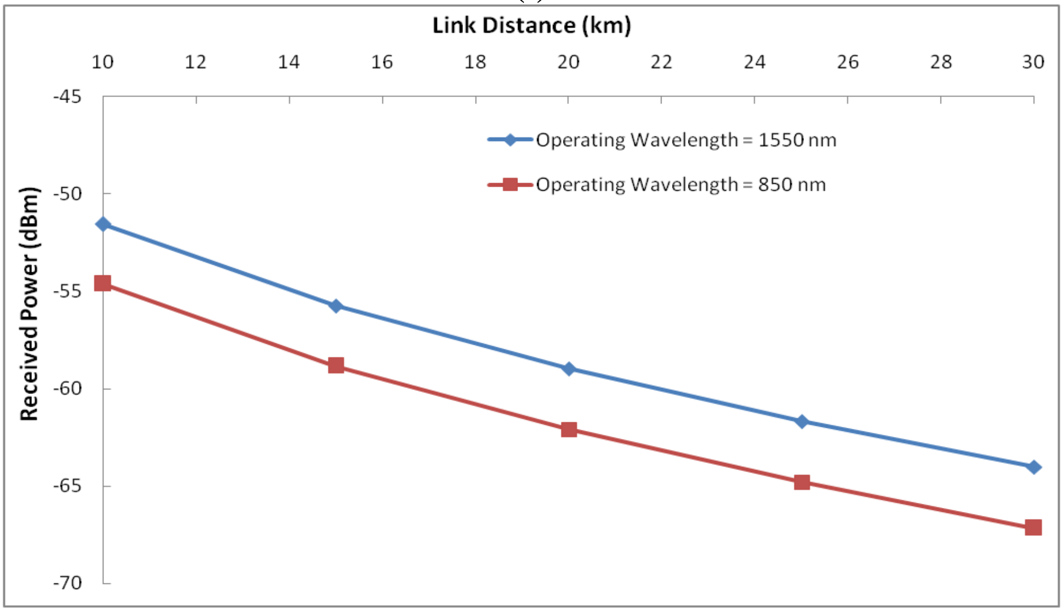
whereas d_R defines receiver aperture diameter, d_T is the transmitter aperture diameter, θ is the beam divergence, Z is the range σ and is the atmospheric attenuation. The FSO link is supposed to operate under clear weather conditions. The simulation parameters are taken into consideration for practical scenario of FSO system.

III. RESULTS

This section discusses the results of the investigation of the proposed FSO system. Figure 2 (a) and (b) discuss the impact of operating wavelength on the performance of the proposed link in terms of SNR and receiver power with increasing link range. Figure 2 (a) shows the SNR for 1550 nm is reported as 34.97 dB at 10 km; 27.66 dB at 20 km; and 21.04 dB at 30 km whereas for 850 nm, the SNR is reported as 31.28 dB at 10 km; 22.71 dB at 20 km; and 17.33 dB at 30 km respectively. Figure 2 (b)shows the received power for 1550 nm is -51.56 dBm at 10 km; -58.98 dBm at 20 km; and -64.02 dBm at 30 km whereas for 850 nm is computed as -54.62 dBm at 10 km; -62.08 dBm at 20 km; and -67.16 dBm at 30 km respectively. From the results reported in Figure 2 (a) and (b) it is seen that 1550 nm is a better choice for long-reach FSO links.



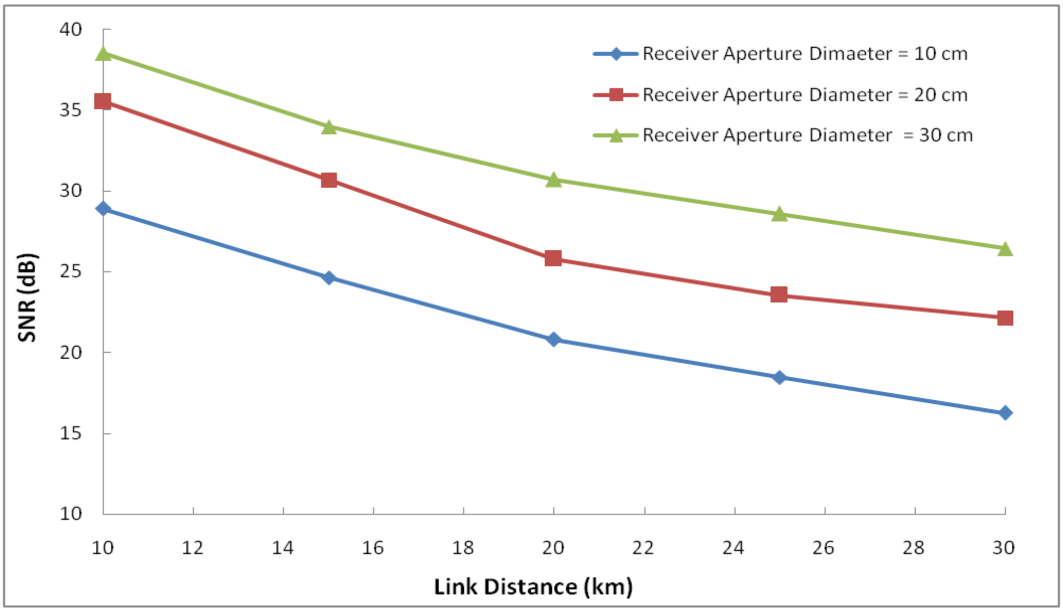
(a)



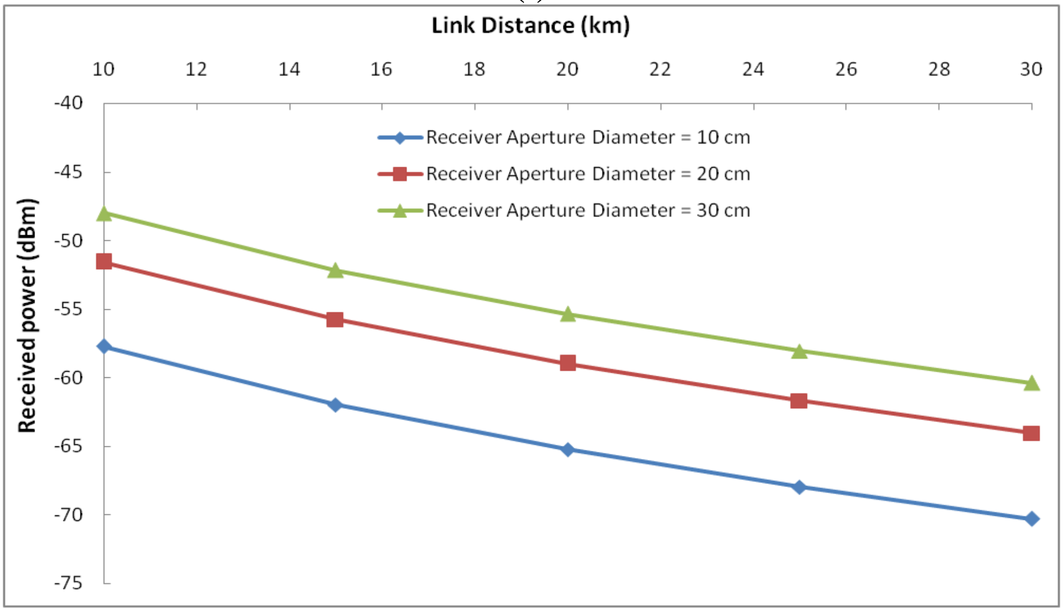
(b)

Figure 2 (a) SNR versus link distance (b) Received power versus link distance for different operating wavelengths

Figure 3 (a) and (b) discusses the performance analysis for different receiver antenna aperture diameter. Figure 3 (a) shows the SNR for 10 cm receiver aperture diameter is 28.89 dB at 10 km; 20.79 dB at 20 km; and 16.25 dB at 30 km whereas for 20 cm receiver aperture diameter, the SNR is 35.51 dB at 10 km; 25.76 dB at 20 km; and 22.12 dB at 30 km and for 30 cm receiver aperture diameter; the SNR is 38.51 dB at 10 km; 30.69 dB at 20 km; and 26.44 dB at 30 km. Figure 3 (b) shows that total power for 10 cm receiver aperture diameter is -57.71 dBm at 10 km; -65.23 dBm at 20 km; and -70.30 dBm at 30 km whereas for 20 cm receiver aperture diameter, the total power is -51.56 dBm dB at 10 km; -58.97 dBm dB at 20 km; and -64.02 dBm at 30 km and for 30 cm receiver aperture diameter; the total power is -48.00 dBm at 10 km; -55.36 dBm at 20 km; and -60.36 dBm at 30 km. An improvement in the quality of signal received is observed by increasing the size of antenna as discussed in Figure 3.



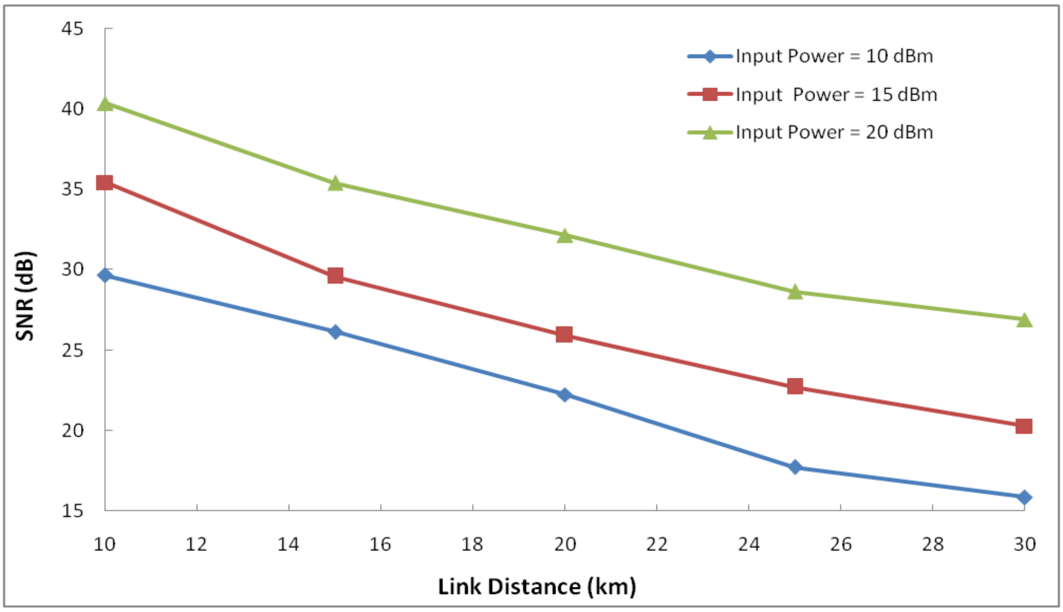
(a)



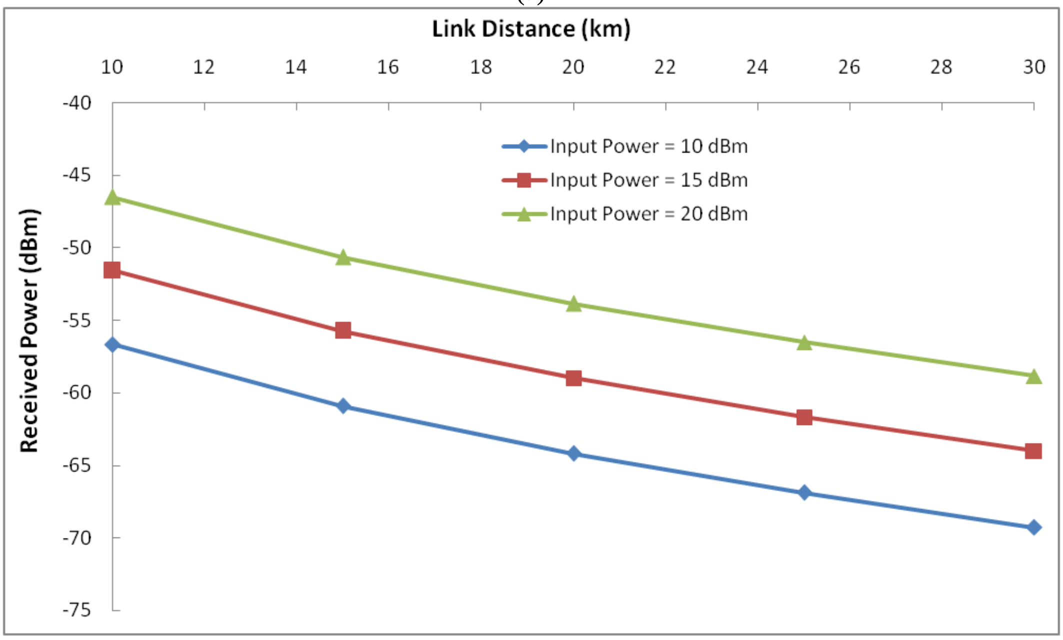
(b)

Figure 3 (a) SNR versus link distance (b) Received power versus link distance for different receiver aperture diameter

Figure 4 (a) and (b) discussesperformance analysis for different input transmission power levels. Figure 4 (a) shows the SNR for 10 dBm input power is reported as 29.67 dB at 10 km; 22.23 dB at 20 km; and 15.84 dB at 30 km whereas for 15 dBm input power, the SNR is reported as 35.43 dB at 10 km; 25.92 dB at 20 km; and 20.27 dB at 30 km and for 20 dBm input power; the SNR is 40.35 dB at 10 km; 32.15 dB at 20 km; and 26.90 dB at 30 km. Figure 4 (b) shows the total power for 10 dBm input power as -56.66 dBm at 10 km; -64.17 dBm at 20 km; and -69.28 dBm at 30 km whereas for 15 dBm input power, the total power is –51.56 dBm dB at 10 km; -58.97 dBm dB at 20 km; and -64.01 dBm at 30 km and for 20 dBm input power; the total power is -46.50 dBm at 10 km; -53.85 dBm at 20 km; and -58.84 dBm at 30 km. An improvement in the quality of signal received is observed by increasing the input power as discussed in Figure 4.



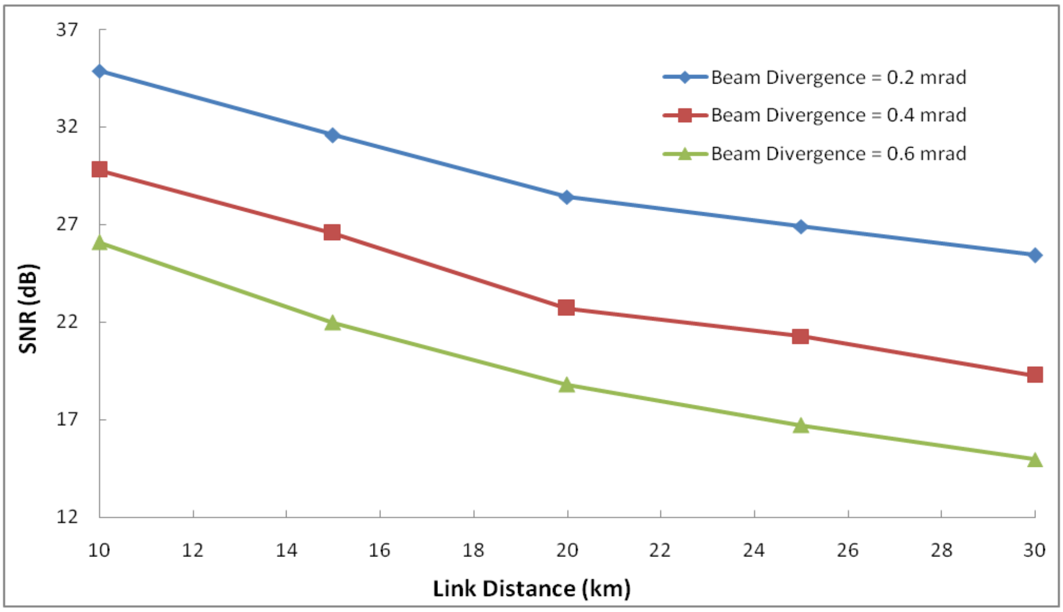
(a)



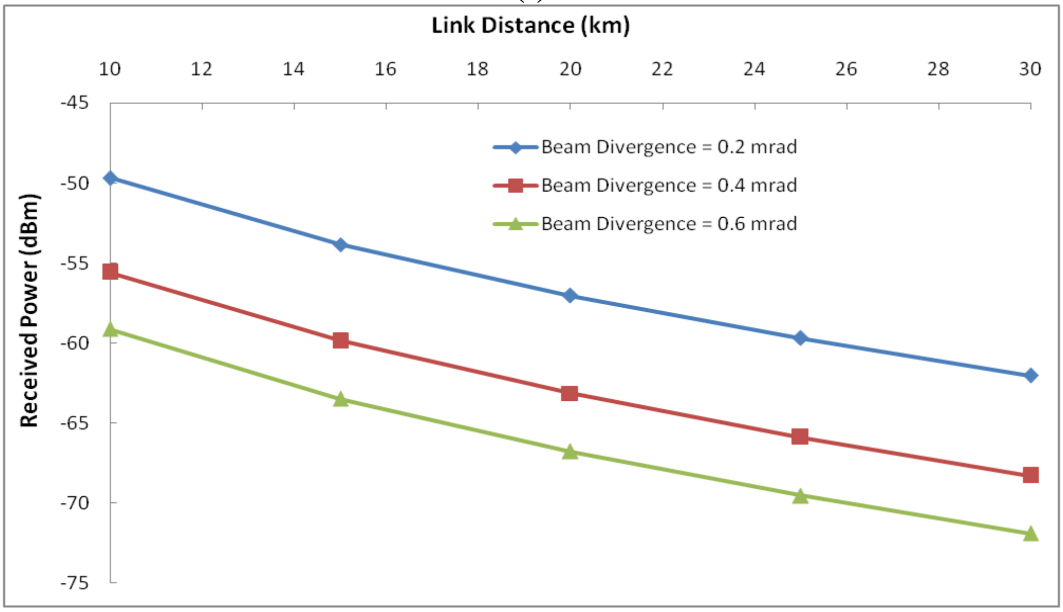
(b)

Figure 4 (a) SNR versus link distance (b) Received power versus link distance for different input power levels

Figure 5 (a) and (b) discusses the performance analysis for different beam divergence angles. Figure 5 (a) shows the SNR for 0.2 mrad beam divergence angle is 34.87 dB at 10 km; 28.40 dB at 20 km; and 25.42 dB at 30 km whereas for 0.4 mrad beam divergence angle, the SNR is 29.79 dB at 10 km; 22.69 dB at 20 km; and 19.25 dB at 30 km and for 0.6 mrad beam divergence angle; the SNR is 26.08 dB at 10 km; 18.78 dB at 20 km; and 14.96 dB at 30 km. Similarly, Figure 5 (b) shows the total power for 0.2 mrad beam divergence angle is -49.68 dBm at 10 km; -57.02 dBm at 20 km; and -62.04 dBm at 30 km whereas for 0.4 mrad beam divergence angle, the total power is –55.59 dBm dB at 10 km; -63.14 dBm dB at 20 km; and -68.27 dBm at 30 km and for 0.6 mrad beam divergence angle; the total power is -59.13 dBm at 10 km; -66.78 dBm at 20 km; and -71.90 dBm at 30 km. A degradation in the quality of signal received is observed by increasing the beam divergence angle as discussed in Figure 5.



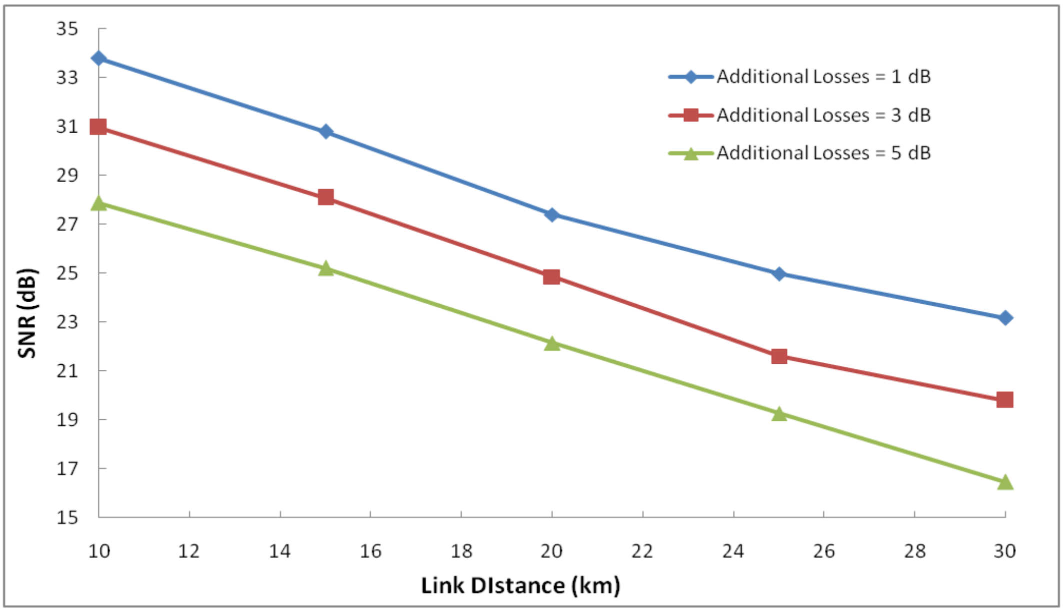
(a)



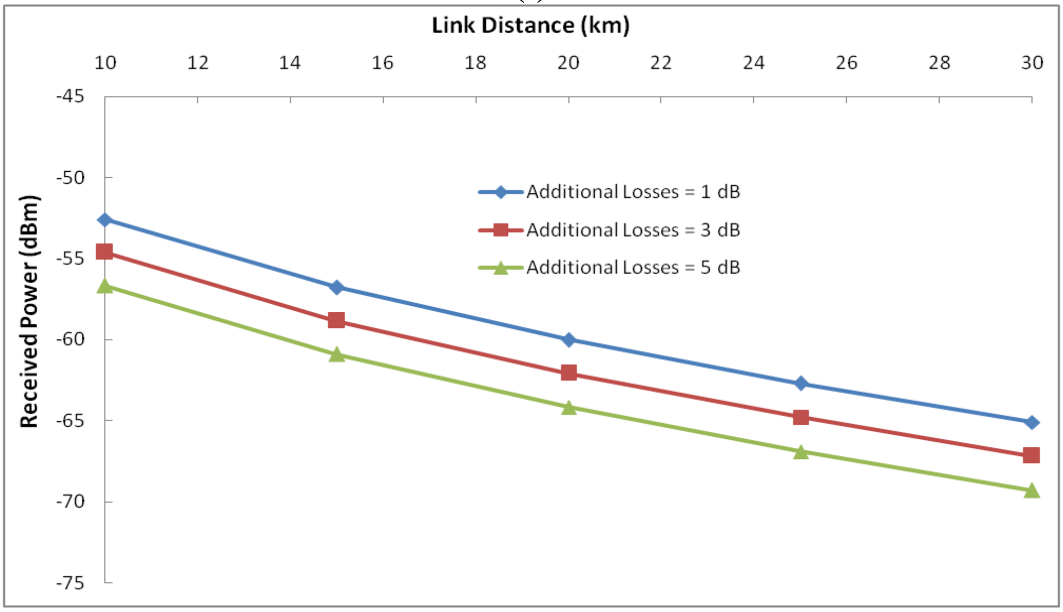
(b)

Figure 5 (a) SNR versus link distance (b) Received power versus link distance for different beam divergence angles

Figure 6 (a) and (b) discussesperformance analysis for different additional losses. Figure 6 (a) shows the SNR for 1 dB additional loss is 33.79 dB at 10 km; 27.39 dB at 20 km; and 23.16 dB at 30 km whereas for 3 dB additional loss, the SNR is 30.97 dB at 10 km; 24.86 dB at 20 km; and 19.78 dB at 30 km and for 5 dB additional loss; the SNR is 27.87 dB at 10 km; 22.14 dB at 20 km; and 16.45 dB at 30 km. Similarly, from Figure 6 (b) shows the total power for 1 dB additional loss is -52.58 dBm at 10 km; -60.01 dBm at 20 km; and -65.08 dBm at 30 km whereas for 3 dB additional loss, the total power is –54.61 dBm dB at 10 km; -62.08 dBm dB at 20 km; and -67.17 dBm at 30 km and for 5 dB additional loss; the total power is -56.66 dBm at 10 km; -64.17 dBm at 20 km; and -69.28 dBm at 30 km. A degradation in the quality of signal received is observed by increasing the additional losses as discussed in Figure 6.



(a)



(b)

Figure 6 (a) SNR versus link distance (b) Received power versus link distance for different additional losses

IV. CONCLUSION

In the presented work, we have modeled a very high capacity FSO system by employing hybrid PDM technique, CO technique and OFDM technique. Two 50 Gbps information signals are transmitted together using the proposed system to make a 100 Gbps FSO system. The proposed FSO system performance is investigated for different system parameters. The results of the analysis of the proposed system conclude that as the receiver aperture diameter and input power escalates,an improvement in FSO system performance is observed. Also, 850 nm operating wavelength is concluded to have a better SNR and total power performance than 1550 nm operating wavelength. Further, it can be concluded that with increase in the additional losses and beam divergence angle of the system, the proposed FSO system quality deteriorates in terms of SNR and total power of the signal receiver.

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Tanu Shri, et. al." Performance investigation of FSO link employing polarization division multiplexing and coherent detection-orthogonal frequency division multiplexing under different link parameters." *International Journal of Computational Engineering Research (IJCER*), vol. 10, no.6, 2020, pp 32-40.