Polarization Crosstalk Suppression in Wavelength Division Multiplexed Free Space Optical System Incorporating Polarization Diversity

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Abstract-Wavelength division multiplexing is a promising candidate for future Free space optical networks to provide ultra high capacity and high speed systems that can be accomplished with compact, light weight and lower power consumption optical equipments. This research article explores the performance enhancement of 16 X 20 Gb/s WDM-FSO system incorporating polarization diversity and modified return to zero advanced modulation format. The high speed system is attained to fulfill the wide bandwidth requirements of data services in FSO by employing WDM system at channel spacing of 50 GHz. In order to suppress the polarization crosstalk and nonlinearities among adjacent channels of WDM, a polarization interleaving technique is included in the system.

Keywords-Wavelength division multiplexing (WDM), Free space optical (FSO), SOP (state of polarization, PI (polarization interleaving), Polarization extinction ratio (PER)

I. INTRODUCTION

With the proliferation of internet connection and traffic in the variety of new services has set a pressure on conventional low speed architecture of radio systems. Free space optical communication exhibits the shared characteristics of ubiquitous technologies such as fiber optics and wireless [1]. In recent times, Free Space Optical (FSO) communication has been mostly investigated to take benefits of useful properties over optical fiber communication [2]. In the past, lot of researches have been carried out to cater the high speed data requirements and to propose cost effective architecture [3]. Moreover, FSO render fortify communication because of insignificant interception incorporating P2P (point to point) laser signals. Merits of FSO communications are large bandwidth and capacity, license free, operates on low power and saves the cost of trenching, permits etc as in optical fiber communication[4]-[5]. For the geographical areas in India, where the deployment of optical fiber is not possible, FSO is a major candidate and attracted attention due to its applications and numerous advantages. Factors that affect the performance of FSO are the atmospheric degrading conditions such as mild rain, medium rain, high rain, fog, haze etc [6] that enervates the link and become the cause to shut the network transmission. To mitigate the effects of atmospheric instability, many researches has been demonstrated or proposed and numerous solutions to quell the turbulences effects [7-8]. Free space communication is evaluated in the atmospheric instability and effect of beam width also investigated in [9]. Also, OFDM (orthogonal frequency division multiplexing) advance modulations, aperture averaging, diversity and FSO signal amplification are investigated for free space optical channel. Wavelength division multiplexing has been employed for FSO capacity enhancement at ultra narrow channel spacing's and high data rates. Access networks reliant on WDM support many users and are based on spectrum slices of available spectrum. Bidirectional transmission and multiplication of capacity represent the WDM (wavelength division multiplexing) as adaptive and reliable that can give wide coverage over atmospheric instabilities in FSO.

Therefore, in this research objective, high speed FSO system based polarization interleaved wavelength division multiplexing (PI-WDM) architecture is proposed. Utmost approach is to cater the high speed data demands and thus system deliberated and demonstrated for 20 Gbps. Different states of polarizations are incorporated in the system to suppress inter channels and polarization crosstalk which provide enhanced results. Moreover, to make system bandwidth efficient, ultra dense channel spacing of 50 GHz is fed between adjacent channels prior to FSO channel. It is observed that system with polarization interleaving performs better that conventional WDM FSO system.

II. THEORY OF POLARIZATION DIVERSITY

In a lot of, although not all, systems the laser intensity is polarized. This means a state of linear polarization, where the electric field oscillates in a particular path orthogonal to the propagation of the laser intensity. However, fiber lasers do not generate a stable directional electrical field. But not necessarily the laser output is un-polarized, having same powers in two polarizations simultaneously, not including any correlation of the consequent amplitudes. Due to several reasons, state of polarization is not stable such as temperature drifts, randomly switches between diverse directions. In order to generate the pure single direction variation of electrical field vector, some kind of polarization fixing devices are generally needed. Degree of specific state of polarization is generally quantified with polarization extinction ratio (PER), stated as the ratio of powers in the diverse polarization directions and calculated by recording the orientation-reliant power transmission of a polarizer. Polarization diversity is an effective approach to suppress the impact of inter-channel nonlinear effects by fixing the adjacent channels polarization. Approach is extended to designing WDM systems such that the bit streams in two neighboring channels are orthogonally polarized. The even and odd number channels are multiplexed mutually into different branches that have orthogonal states of polarization (SOPs). Polarizations are adjusted using linear polarization controllers to keep channels orthogonal. Basic method of suppression is that both cross phase modulation and four wave mixing are completely reliant on state of polarization of adjacent channels and SOPs are orthogonal in PI systems. As a result, inter channel collisions generates smaller shifts of phase and provide better results.

III. SYSTEM SETUP

For the realization of spectrum sliced free space optical communication, a prominent and comprehensive simulation suit Optiwave Optisystem is used. Figure 1 depicts the proposed WDM free space optical network at 20 Gbps employing modified return to zero (MDRZ) in downstream. Novelty of the system is use of polarization interleaving in WDM FSO to combat with the polarization and inter-channel crosstalk. System proposed is symmetrical and also centralized lightwave that supports 16 WDM channels in this work. Internal structure of modified return to zero (MDRZ) system is depicted in Figure 2. A laser light wave source at 193.1 THz frequency and 0 dBm input power is used. A polarization of even and odd channels is changed in order to analyze effects of nonlinear degradations on system. The linear polarizer transmits the linear polarization component that coincides with the transmission axis of the polarizer and eliminates the orthogonal component. Odd channels from λ_1- λ_{15} carry same polarization and state of polarization (SOP) is fixed to 0degreein linear polarizer. Even channels λ_2- λ_{16} have the state of polarization orthogonal to odd channels i.e 90degree. The investigated range for the proposed link is 9 Km. All WDM channels are modulated in central office with MDRZ modulation. From this point, downstream communication in Free space optical network initiates. The modulated MDRZ-WDM signals are accumulated with the two multiplexer of configuration 8 x 1, as well as the multiplexed signal is transmitted over 9 km FSO link.

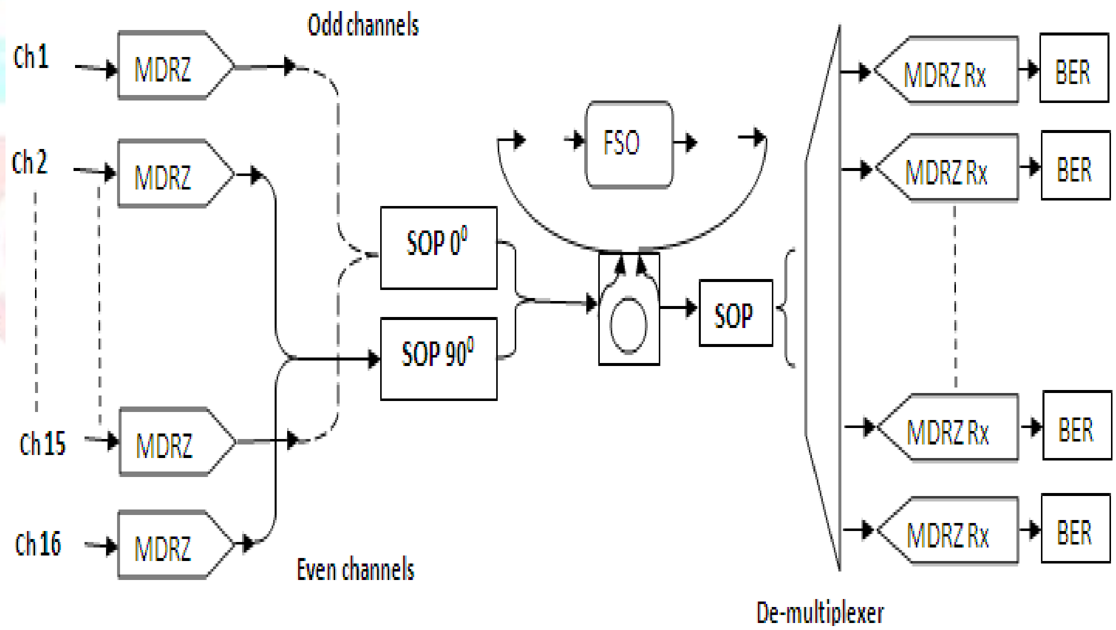


Figure 1 Block diagram of proposed polarization interleaved WDM FSO system

After transmission of 9 km, signal is de-multiplexed by 1 x 16 wavelengths with frequency spacing of 50 GHz as shown in figure 3.4. Receiver section consists of photo-detectors that receives drive with time delay. A p-i-n photodetector with 100% responsivity and 10 nA dark current is placed in the receiver by considering shot, thermal and ASE (Amplifier spontaneous noise) distortions. A 3-R regenerator employed for re-sampling, re-shaping and re-amplification of the received data. Bit error rate analyzer is decision making component which calculate the final received quality factor, bit error rate (BER), signal to noise ratio (SNR) etc of the received signals. PIN photo-diode followed by low pass filter and Eye diagram analyzer.

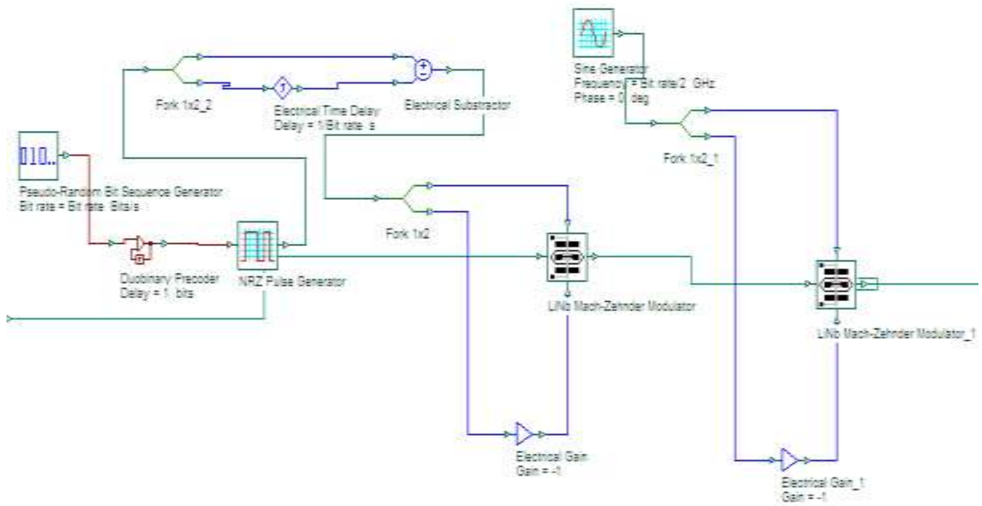


Figure 2 Internal structure of modified return to zero

Internal structure of modified return to zero (MDRZ) system is depicted in Figure 2

IV. RESULTS AND DISCUSSIONS

In order to design a polarization crosstalk suppressed systems, a free space optical network employing polarization interleaving is proposed. A system consists of 16 wavelengths and each wavelength is modulated with MDRZ modulation for downstream at central office. Two WDM multiplexers are used in order to separately combine the 8-8 wavelengths. Even wavelengths and odd wavelengths are combined differently with these two multiplexers. Then odd channels are fed to polarization rotator that pass only horizontal polarization signals and even channels are projected to orthogonal polarizer. Polarizations combined and signal sent over 9 km long stretch of FSO and followed by 1 x 16 de-multiplexer. Received wavelengths are received with receiver that consists of photo-detector, low pass filter and BER analyzer.

First and foremost, the investigation of proposed system has been done by taking different distances into consideration. Loop length is varied from 1 km to 9 km with the gaps of 2 km as depicted in Figure 3.

Table 1 Values of Q factor vs distance

Distance (km)	With PI	W/O PI
1	31.17	12.23
3	26.5	12.14
5	21.42	10.52
7	17.28	7.45
9	14.11	4.89

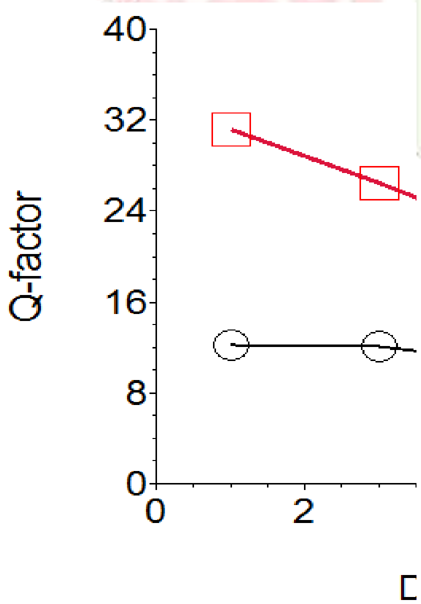


Figure 3 Representation of Q factor versus distance

To evaluate the results, Q factor is noted from Eye diagram analyzer. Figure 4.6 represents the graphical representation of Q factor versus distance for with and without polarization interleaving in WDM-FSO. It is reported that with the increase in the link length, there is significant reduction in Q factor of the signal. Also, two different scenarios are proposed by considering the polarization interleaving and without polarization interleaving. Q factor decreases due to numerous factors such as the attenuation, pulse broadening, crosstalk among different channels etc. However, in this work, analysis is accentuated on polarization crosstalk that emerges in multi-channel WDM systems and plays a vital role in signal degradation. It is evident from the investigation that because of the different states of polarization in even and odd channels of the proposed system, Q factor is obtained well in case of with PI system than without polarization interleaved system. This is due to the fact that different states of polarizations, minimize the interaction of signals between different wavelengths. This phenomenon led to a significant enhancement in Q factor and it is seen that when polarization interleaving is eliminated, Q factor decrease sharply and valid for 8 km distance as compared to with polarization interleaved system as given in Table 1.

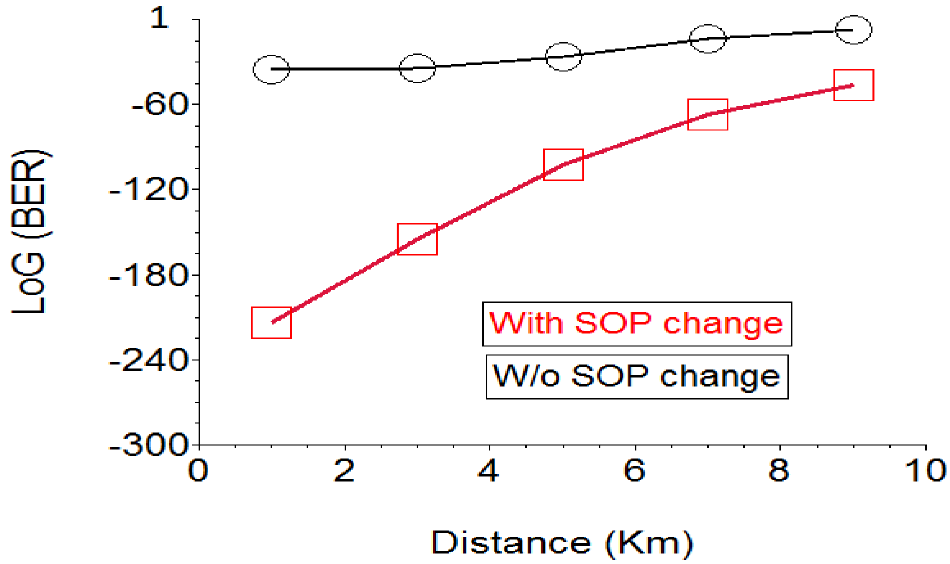


Figure 4 LoG (BER) versus distance of WDM FSO system

Figure 4 represents the LoG (BER) values when link length is varied from 1 km to 9 km. It is evident that as distance prolongs, there is increase in bit errors. Bit error rate is an important measure to evaluate the system performance. In proposed system that incorporates polarization interleaving, exhibits less errors as compared to without interleaved WDM free space optical network. Modified return to zero advanced modulation format is employed in the system to suppress the crosstalk between WDM channels. However, MDRZ has done another task of inter symbol interference suppression due to two different phases. Other problem is also exists that is the inter channel interference in WDM FSO. LoG (BER) is more in without polarization interleaved system and thus polarization inter leaving is recommended to use for better results. Distance is considered for the evaluation of the systems in terms of Q factor and BER. However, the next study is on the effect of input power on the system performance. Results such as Q factor, LoG (BER) and signal to noise ratio are accessed for investigation. So, in the proposed WDM free space optical network, launched power is varied from the laser source from 0 dBm to 4 dBm with the difference of 1 dBm. Figure 5 depicts the variation of Q factor with the launched power for with and without polarization interleaved system. From the results as given in Table 2, it is observed that with the more power coupling into FSO, Q factor tends to increase. Increase in launched power serve as a power budget in the system. However it is also seen that high power input initiates the nonlinear effects due to the variation in power of adjacent channels. But, in this setup power is limited to 4 dBm and this power level do not initiates the nonlinear effects. Thus, it is seen that WDM free space optical network with polarization interleaving provide better Q factor than without polarization interleaving. Figure 6 represents the LoG (BER) versus launched power in the system. It is observed that power increase, improves the BER and provide less BER for high powers that are launched in optical fiber. Bit error rate is more in the case of simple WDM passive optical network without incorporation of polarization interleaving.

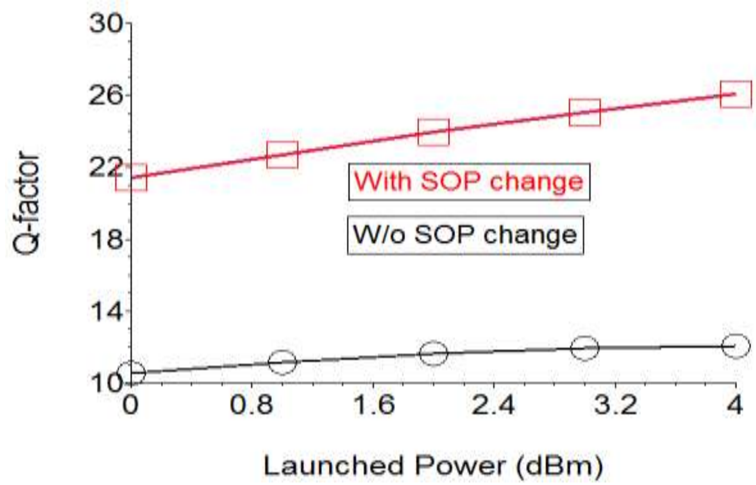


Figure 5 Representation of launched powers versus Q factor of WDM FSO system employing with and without polarization interleaving

Table 2 Values of Q factor vs launched power

Power (dBm)	With PI	W/O PI
0	21.42	10.52
1	22.71	11.17
2	23.93	11.62
3	25.06	11.91
4	26.1	12.06

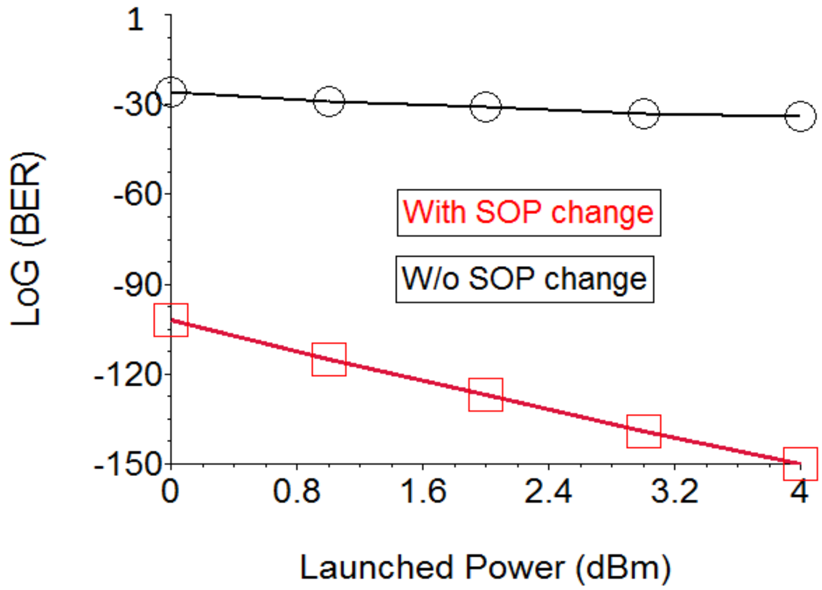
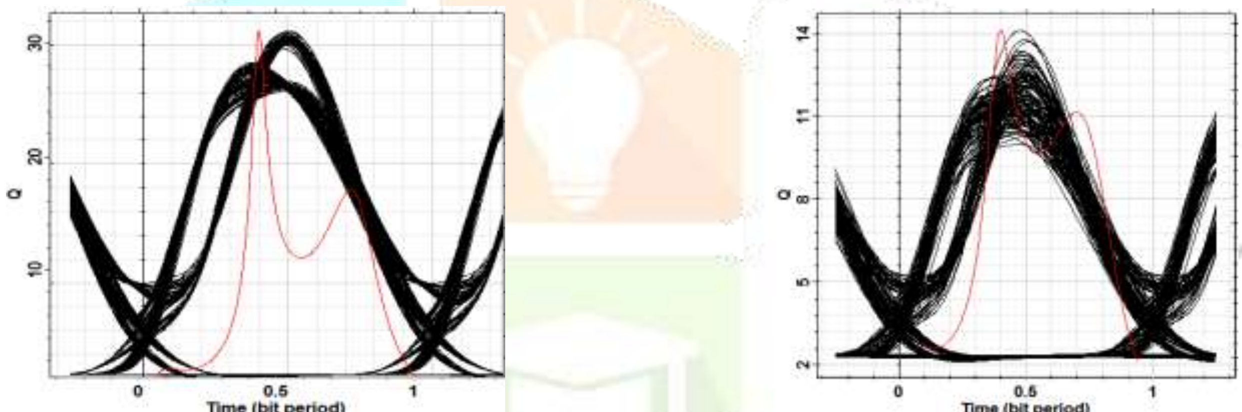


Figure 6 LoG BER versus input power



(a) (b)

Figure 7 Eye diagrams for polarization interleaved WDM-FSO at (a) 1 km and (b) 9 km

Eye diagram of the system with and without polarization interleaving depicted in Figure at different link lengths. It is reported that Eye opening is more in case of 1 km link distance and closer increase with the increase in the distance. This is due to the fact that there significant attenuation, dispersion in the free space optical link. It is reported that at 1 km eye height is more as compared to 9 km and jitter is also less. More thickly the eye diagram appears, more are the errors and less is the Q factor. So from the analysis it is suggested to use the WDM FSO polarization interleaved system for the future applications.

V. Conclusion

In this work, a WDM-FSO system to suppress inter channel and polarization crosstalk is proposed. This research explores the performance enhancement of 16 X 20 Gb/s WDM-FSO system incorporating polarization diversity. The high speed system is attained to fulfill the wide bandwidth requirements of data services in FSO by employing WDM system at channel spacing of 50 GHz. Results are compared in two different systems such that with and without polarization interleaved WDM-FSO system. It is observed that WDM-FSO with polarization interleaving cause fewer errors and provide enhanced performance as compared to without polarization system. At lower distances and less power levels, Q factor reported minimum and BER is more. Systems using MDRZ and polarization interleaving works successfully for 9 km and polarization crosstalk effects are suppressed. Thus, this is an ultimate solution to WDM free space optical systems to support long distances as well as high data rate.

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