Design and Analysis of 1.28 Terabit/s DWDM Transmission System for Free Space Optical Communication

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Research Article

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ABSTRACT—In this paper, the implementation of a dense wavelength division multiplexing (DWDM) 32×40 Gbps (1.28 Tera bit/s) for the free-space optical (FSO) communication system is investigated. Analysis is performed for return-to-zero (RZ) and non-return-to-zero (NRZ) line codes for 1 km free space optic length. Motivation to the current analysis is to compare RZ and NRZ lines codes in the DWDM-FSO communication system and it is found that the NRZ line code is better than RZ code. A 1.28 Tb/ps wavelength division multiplexed communication system for free space optic channel workplace has been discovered in which 32 channel each of 40 Gbps data streams are combined using wavelength division multiplexed. The study includes the attenuation caused by atmospheric effect and beam divergence. Bit-error rate (BER), quality factor (Q), and eye diagram are indicator of performance evaluation. By comparing one can get a promising system to the high capacity access network with more bandwidth, cost effective and good flexibility.

KEYWORDS: *free-space optical communications, dense wavelength division multiplexing; return-to-zero; non-return-to-zero, Tera bit/s.*

I. INTRODUCTION

OPTICAL communications offer potentially huge band-width and very high speed which make them extremely attractive means of meeting the ever-increasing demand for broad band traffic, mostly driven by internet access and high definition TV broad casting services [1, 2]. Today, the most common type of optical communication systems are using optical fibers and can reach even beyond 1 Terabit/s capacity thanks to the dense wavelength division multiplexing (DWDM) technology. The main features of free space optics transmission is high directivity which provides high power efficiency and isolation from other potential interferences, unlicensed bandwidth, easy installation and it promises multi Gbps applications in next. For the last 40 years, the network providers have continually argued, with each generation, that optical fibre capacity of that generation is sufficient and little more is necessary [3, 4]. However, the availability of high-capacity fibre has provided the impetus for the growth of telecommunication. Free-space optical (FSO) communication system is not being considered a suitable and practical solution for very high-speed communications, such as those of terrestrial wavelength division multiplexing optical networks although it has no limitation in bandwidth [2, 3]. FSO limitation is its lack of reliability, difficult light collimation and

beam tracking. Current FSO systems have much lower capacity than the current fiber systems and, generally, they show error bursts in long-time operation, i.e. high average bit-error-rate (BER) [2], [3], [4], [5]. In [6], E. Ciaramella et. al first developed 1.28 Tb/ps (32 × 40 Gbps) FSO link. Here, we have used dense wavelength division multiplexing in free-space optics link using the return-to-zero (RZ) and non-return-to-zero (NRZ) line codes [6].

II. SYSTEM CONFIGURATION

Simulation set up of 1.28 Tb/ps (32 × 40 Gbps) communication system over FSO channel using the NRZ line codes is shown in Fig. 1. This system is designed using optisystem version 14, which is used as platform for many optical communication design and simulation [1-4]. In Fig. 1 we have used DWDM transmitter at input. The DWDM Transmitter encapsulates different components, allowing users to select different modulation formats and schemes for multiple channels in one single component. It is a transmitter array that allows for different modulation types and schemes. Initial frequency is 193.1 THz and frequency spacing is 100 GHz [4-8]. Modulation type are NRZ and RZ. We have taken 32 channels each one of 40 Gbps. These channels are then multiplexed using ideal multiplexer. At multiplexer, total data rate is 1.28 Tb/ps [2, 3]. After ideal multiplexer there is FSO component. It is a transmitter array that allows for different modulation types and schemes [9-12]. This component allows for simulation of free space optical links. The component is a subsystem of transmitter telescope, free space and receiver telescope. Parameter Range defines the propagation distance between transmitter and receiver telescope [12, 13]. The attenuation of the laser power in depends on two main parameters: attenuation and geometrical loss [5, 6].

The link equation [2, 3]

$$p_{Recieved} = p_{transmitted} \frac{d_r^2}{(d_t + \theta_R)} 10^{-\alpha \frac{R}{10}} \quad (1)$$

d_r : Receiver aperture diameter (m)

d_t : Transmitter aperture diameter (m)

θ : Beam divergence (mrad)

Fig. 1: Simulation set up of 1.28 Tbps free-space optic link using NRZ lines codes.

Component	Parameter	Value/unit
Free-space optics channel	Distance	1 km
	Attenuation	25 dB/km
	Transmitter aperture diameter	5 cm
	Receiver aperture diameter	20 cm
	Beam divergence	2 m/rad
	Wavelength	193.1 THz
	Index refraction structure	5e-015
EDFA	Gain	30dB
WDM transmitter	Initial frequency	193.1 THz
	Frequency spacing	200 GHz
	Power	20 dBm
	Data rate	40 Gb/ps
	Modulation type	NRZ

Table 1 System parameter used in the calculations.

III. RESULTS AND DISCUSSIONS

In Fig. 2, we show the eye diagram for channel no1st, 10th for the NRZ line coding for 1 km FSO link.

Fig. 2: Simulation eye diagram for 1 km free-space optics link using NRZ line codes.

Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)	Noise Power: 0.1nm (dBm)	OSNR (dB)
193.1	-30.592196	-32.172385	1.5801888	-40.234185	9.6419886
193.2	-30.648634	-32.255257	1.6066222	-40.317056	9.668422
193.3	-30.630793	-32.263022	1.7322291	-40.324821	9.7940289
193.4	-30.648937	-32.261626	1.6126889	-40.323425	9.6744887
193.5	-30.531071	-32.261878	1.7308068	-40.323677	9.7926065
193.6	-30.652366	-32.262099	1.6097129	-40.323899	9.6715127
193.7	-28.367822	-46.431265	18.063442	-54.493064	26.125242
193.8	-28.300742	-100	71.699258	-100	71.699258
193.9	-28.300561	-100	71.699439	-100	71.699439
194	-28.372788	-100	71.627212	-100	71.627212
194.1	-28.370209	-100	71.629791	-100	71.629791
194.2	-28.300517	-100	71.699483	-100	71.699483
194.3	-28.372771	-100	71.627229	-100	71.627229
194.4	-28.370209	-100	71.629791	-100	71.629791
194.5	-28.300528	-100	71.699472	-100	71.699472
194.6	-28.300501	-100	71.699499	-100	71.699499
194.7	-28.367698	-100	71.632302	-100	71.632302
194.8	-28.37024	-100	71.62976	-100	71.62976
194.9	-28.367773	-100	71.632227	-100	71.632227
195	-28.300562	-100	71.699438	-100	71.699438
195.1	-28.30049	-100	71.69951	-100	71.69951
195.2	-28.367464	-100	71.632536	-100	71.632536
195.3	-28.370243	-100	71.629757	-100	71.629757
195.4	-28.367697	-100	71.632303	-100	71.632303
195.5	-28.368205	-100	71.631795	-100	71.631795
195.6	-28.366132	-46.540941	18.174809	-54.60274	26.236608
195.7	-30.588915	-32.177113	1.5881988	-40.238913	9.6499985
195.8	-30.646663	-32.259166	1.6125035	-40.320966	9.6743032
195.9	-30.708613	-32.1765	1.4678861	-40.238299	9.5296859
196	-30.647364	-32.262659	1.6152943	-40.324459	9.677094
196.1	-30.717236	-32.163476	1.44624	-40.225276	9.5080397
196.2	-30.651682	-32.257636	1.6059533	-40.319435	9.6677531

Signal Index: 0
Frequency
Units: THz
Power
Units: dBm
Resolution Bandwidth
Res: 0.64 nm

Analysis / Details

Table 2 Calculation results of the proposed system for Tera bit/s DWDM-FSO link.

Fig. 3: Frequency analyzer of 32 channels of NRZ lines codes.

Fig. 4: Optical spectrum analyzer of NRZ.

In Fig. 2, the BER for 1 km free space optics channel using NRZ line coding and in Fig. 6, the BER for 1 km free space optics using RZ line coding for channel no 1st, 10th, is shown. It can be observed from the Fig. 2 that for NRZ line coding when input signal power is less than 8 dBm BER is very high, but when we increase input signal power more than 8 dBm BER starts decreasing rapidly whereas for RZ line coding when input signal power is less than 10 dBm BER is very high, but when we increase input signal power more than 10 dBm BER starts decreasing rapidly.

Fig. 5: Q factor for 1 km free-space optics link using NRZ line codes.

Fig. 6: Simulation eye diagram for 1 km free-space optics link using RZ line codes.

Statistical characteristics of the amplitude noise are determined for finding the relationship between BER and eye-opening at data decision. Figure of merit, Q-factor is used for determining BER. If the ISI distribution does not exist and the dominant amplitude noise has Gaussian distribution, the signal Q-factor is defined:

$$Q = \frac{v_1 - v_0}{\sigma_1 - \sigma_0} \quad \text{Eq. 2}$$

Here v_1, v_0 are the mean values for $v(t)$ amplitude high and low without ISI, whereas σ_1, σ_0 are the root mean square (RMS) of the additive white noise for each Gaussian distribution.

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The BER can be given as [2, 3]:

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q_{BER}}{\sqrt{2}} \right) \quad \text{Eq. 3}$$

where

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-v^2} dv \quad \text{Eq. 4}$$

Q_{BER} is the minimum required Q-factor for a given BER.

There is a random data stream box in which the data output rate is set at a data rate of 10 Gb/s or 40 Gb/s. The DC bias and the constant input is the transfer characteristic setting. This is artificial DC bias input data. The bias voltage changes the refractive index by electro-optic effect. The external modulator can be biased in the linear range at minimum, phase quadrature or maximum transmission regions as shown in Fig. 7.

Fig. 7: Transfer characteristic of external modulator and the corresponding input and output signals.

IV. SIMULATORS

NRZ and RZ AMPLITUDE-SHIFT KEYING Modulation Simulator

Fig. 8: RZ signal pseudo random bit sequence generation SIMULINK platform.

Fig. 9: Random RZ-ASK signals.

(a)

(b)

Fig. 10: (a) RZ binary random sequence and (b) RZ binary eye diagram of the input stream.

V. CONCLUSION

The paper illustrates the simulation and analysis of 1.28 Tbps (32×40 Gbps) for the DWDM-FSO link of 1 km length using NRZ and RZ line coding and it describes NRZ line coding is superior. In simulation results, it is found that as the power increases, the bit error rate decreases and Q-factor increases. We can see using wave length division multiplexing how capacity of free space optics channel can be increased.

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Compliance with ethical standards

Conflict of interest: The author declares that there is no conflict of interest regarding the manuscript. The author is responsible for the content and writing of this article. The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Figures

Figure 1

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Figure 2

Simulation eye diagram for 1 km free-space optics link using NRZ line codes.

Figure 3

Frequency analyzer of 32 channels of NRZ lines codes.

Figure 4

Optical spectrum analyzer of NRZ.

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Figure 7

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Figure 10

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