Performance Improvement of a Multi-head Optical Wireless Communication System

Viorel Manea[1](✉), Sorin Pușcoci[1], and Dan Alexandru Stoichescu[2]

[1] INSCC Bucharest, Preciziei 6, Bucharest, Romania
{viorel.manea, sorin.puscoci}@inscc.ro
[2] University Politechnica Bucharest, Bucharest, Romania
dan_stoich@yahoo.com

Abstract. Free space optics represents a fast and economical method to transmit digital data at the speed of the order of the Gbps at a distance of a few kilometers. The major limitation is the atmospheric attenuation, especially fog, which can affect the quality of transmission, transfer rate and transmission distance. A useful metric to monitorize the processes is the BER factor. This paper proposes a combination of adaptive optics that use multiple heads of transmission which are focused simultaneously on a single photodetector at the receiver end, in order to provide redundancy and to sustain a minimum data-rate transfer and/or assuring a transmission distance at an acceptable BER. It is assessed, through the simulation, the optimal (technically and economically) number of optical transmitters for which we get a real quality improvement of the transmission for a given bitrate-distance factors.

Keywords: Free space optics · Adaptive optics · Multi-head transceiver

1 Introduction

This paper comes to follow the article “Wireless Optic Last Mile Multi-Gbit/s Communication System” [1]. It doesn’t take into account the number and arrangement of the transmitter heads and link availability, the performance of the optical link being evaluated by using eye-diagram that provides information about the overall bit error rate of the system.

Many researchers consider that using multiple-beam optical link could provide a more secure communication from the redundancy point of view. In reference [2] is presented a procedure that compares the multi-beam method with the averaging method, using the structure parameter and the optical intensity variation. The main purpose is to reduce the receiving signal fluctuations in multi-beam FSO setup. Spatial diversity in FSO is analyzed in [3], in which a number of copies of the same signal is launched in atmosphere, using a single or multiple receiver. It was made a deep analysis of the distortion of the signals due to the atmospheric disturbances. The effect of fog on FSO links is analyzed on reference [4]. It was calculated the degree of misalignment between the transmitter and the receiver based on the optical energy that arrive at the receiver end. A WDM approach using multiple beams is made in [5].

O. Fratu et al. (Eds.): FABULOUS 2017, LNICST 241, pp. 206–211, 2018.
https://doi.org/10.1007/978-3-319-92213-3_30

It is essential to understand how the multiple beams can carry the WDM signals. The paper shows out the BER variations versus optical power and link range. In [6] is proposed a multi-beam hybrid WDM-FSO system model. One single copy of the signal can carry a number of n-distinct signals. Paper [7] proposes a performance evaluation of a multi beam system that uses space-time coding by making an adaptation of a space-time block code from RF systems that are useful for intensity- modulated optical signals.

An analysis of the beam propagation for laser multi-beam FSO for very strong turbulent atmosphere is made in [8, 9]. All the simulations are made for a transmitter with four heads, with a comprehensive discussion about propagation and power budget. A comparison between different numbers of beams based on link distance received optical power and geometrical loss is made in [9]. A comparison between SISO and MIMO techniques for optical field is made in [10]. An investigation on FSO communication with optical amplification based on 4 × 4 T/R combination is made in [11]. Amplification is needed to overcome losses on passive splitters/combiners needed to divide the original signal into n identical copies and to (re)combine the signals at the receiver end. Reference [12] contain ITU recommendation with some prediction methods required for the design of terrestrial free-space optical links related to our subject.

Free space optics domain is currently carefully considered by universities with teaching programs and research projects related to this field [13–15].

2 Description of the Proposed Solution

The starting point is the model for multi-beam FSO BER analysis presented in Fig. 1. Mono and multi-beam measurement conditions are:

- Transmitter: n-CW lasers (n = 1, 2, 4 or 8), f = 1.93 THz, power = 33 dBm, aperture diameter 2.5 cm, beam divergence 0.25 mrad, λ = 1550 nm, transmitter losses 2 dB,
- Type of modulation: L-PPM (L = 8);
- FSO Channel: Range: approx. 1 km, attenuation 30 dB/km (worst case, fog attenuation), minimal BER factor: 10^{-9};
- Receiver: Aperture diameter 20 cm, APD type, gain 3.
- Overall bitrate target: 2.5 Gbit/s

The simulation platform is the OptiSystem suite from Optiwave Corporation. The theoretical assumptions are made in the initial paper [1]. Geometrical attenuation equation is given in [12]:

$$\mathrm{A_{geo}} = \mathrm{P_{rec.}}/\mathrm{P_{tr.}} = 10\log_{10}(\mathrm{S_{tr}}/\mathrm{S_{rec}}) \tag{1}$$

where $\mathrm{P_{rec.}}$ and $\mathrm{P_{tr.}}$ are received power and transmitted power respective, $\mathrm{S_{tr.}}$ and $\mathrm{S_{rec.}}$ surface area of transmit beam at range *d* and receiver capture surface respective.

$S_{tr.}$ could be approximated by:

$$S_{tr.} = \pi(d\theta)^2/4 \tag{2}$$

where θ is beam divergence and d is the link distance in km.

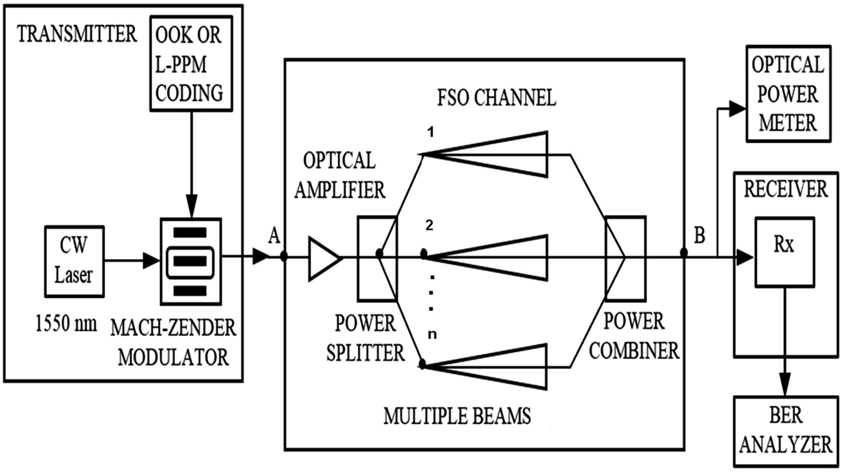


Fig. 1. Model for multi-beam FSO BER analysis

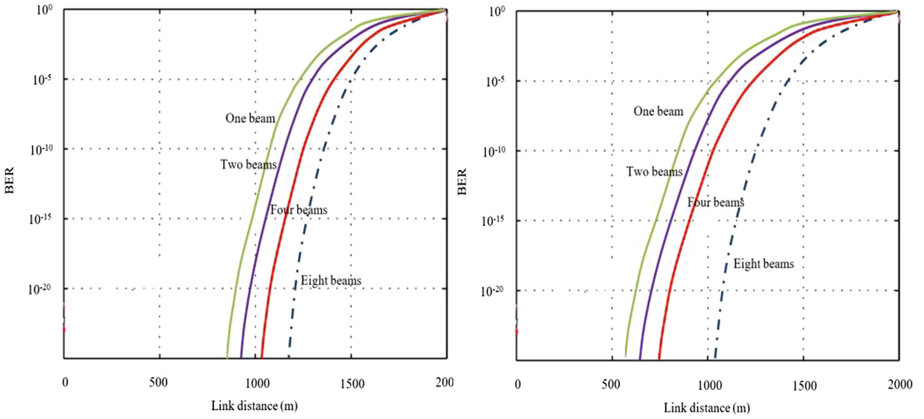
On very short links it is possible for the capture area to be greater than the beam area. In consequence, the value of A_{geo} is mandatory to be set to zero because all of the optical energy is collected by the receiver.

The solution proposed in this paper does not take into account the temporal delays between spatially separated optical beams that arrived at the receiver surface. We assume that all the optical beams arrive at the same time on the receiver surface.

The maximum optical energy for one spot is concentrated into the center of the optical beam and ideally must correspond with the center of the receiver lens. Solution proposed in the scientific literature and industrial realizations use a set of paralleled n-beams (usually n – even number), un-collimated individually on the receiver lens. For this case an optical misalignment is occurred. The calculus for traditional (parallel beams) method include the optical losses and misalignment losses. If the multiple beams are perfectly focused on the receiver lens, we could consider that we have a single centered spot multiplied by n factor. In this case we consider only the optical losses (attenuation introduced by lens) without optical misalignment losses.

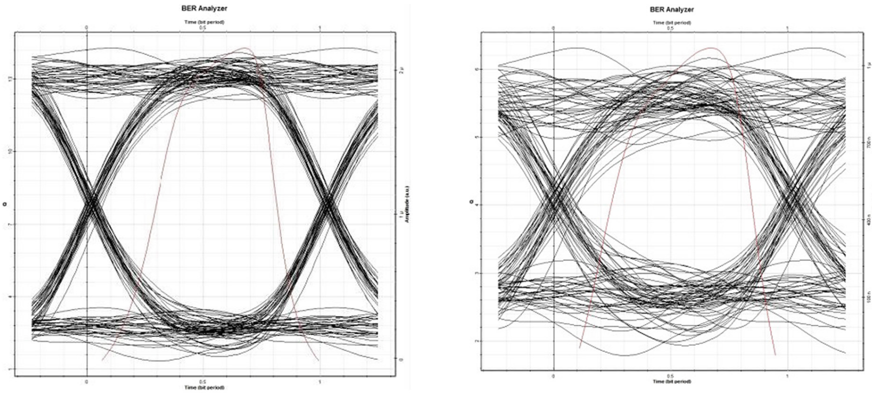
3 Results

Figure 2a shows the BER versus link distance for n = 1, 2, 4, and 8 heads with alignment and Fig. 2b BER versus link distance for n = 1, 2, 4, and 8 heads realized in the traditional way. Figure 3 shows out the eye diagram for scenario with four heads with alignment (a) and traditional (b).



(a) (b)

Fig. 2. BER versus link distance for n = 1, 2, 4, and 8 heads with alignment (a) and traditional (b)



(a) (b)

Fig. 3. Eye diagram for scenario with four heads with alignment (a) and traditional (b)

Table 1 shows out the number of heads, geometrical loss, received optical power and link distance for traditional disposal of the laser heads for un-collimated heads. Collimated head (on the receiver lens area) means that the maximum optical energy for one spot is concentrated into the center of the receiver lens, even if the axis of the head beam does not correspond with the main axis of the transceivers.

Table 1. Number of heads, geometrical loss, received optical power and link distance for traditional disposal of the laser heads.

Head number	Geometrical loss (dB)	Received optical power (dBm)	Achievable link distance (km)
One beam	30.24	−32.2	0.85
Two beams	32.51	−33.1	0.89
Four beams	33.87	−34.6	1.02
Eight beams	34.02	−34.9	1.27

Table 2 shows out the number of heads, geometrical loss, received optical power and link distance for individual focalized laser heads. The geometrical loss decreased and received optical power increased with the consequence of increased link distance.

Table 2. Number of heads, geometrical loss, received optical power and link distance for individual focalized laser heads.

Head number	Geometrical loss (dB)	Received optical power (dBm)	Achievable link distance (km)
One beam	28.02	−34.7	1.21
Two beams	30.24	−35.1	1.29
Four beams	31.76	−35.9	1.42
Eight beams	32.02	−36.7	1.62

4 Conclusions

The proposed solution is suitable only for laser transmitter. It is not recommended to use LED sources due to very high divergence of the optical beam shown in [15], even if we use a beam collimator.

Another problem is represented by saturation of the receiver, for the very small atmospheric attenuation. For foggy atmosphere all the transmitters are used at the full power. For clear atmosphere it's used only one transmitter. It is mandatory to use an automatic gain control system to control the amount of light that arrives at the receiver. Using the concept of "mobility of the heads", it is not important the disposal (position) of the laser heads in the transmitter plane. The main disadvantage is represented by the necessity to (re)align the angle of the laser heads every time when the transmission distance between transmitter and receiver is modified. It is mandatory that every laser head from the transmitter configuration to be focused in the center of the receiver lens in order to assure an optimal signal/noise ratio in fog affected environment.

Future researches will include the calculus of the reliability of the multi-beam optical link using a probabilistic method.

References

1. Viorel, M., Sorin, P., Dan Alexandru, S.: Wireless optic last mile multi-Gbits communication system. In: ICEWC 2015: 17th International Conference on Electronics and Wireless Communication, Istanbul, Turkey, 26–27 October 2015
2. Hovorak, P.: Decreasing of turbulent atmosphere effect by multi beam transmission in FSO. Institute of Radio Electronics Brno University of Technology (2016)
3. Harma, P., Sarangal, H.: Performance evaluation of multiple transceiver FSO for different weather conditions. Int. J. Sig. Process. Image Process. Pattern Recogn. **8**(12), 149–156 (2015)
4. Mahalati, R.N., Kahn, J.M.: Effect of fog on free-space optical links employing imaging receivers. Optical Society of America (2012)
5. Sahu, N., Prajapti, J.C.: Optimization of WDM-FSO link using Multiple Beams under different rain conditions. Int. J. Adv. Res. Electron. Commun. Eng. (IJARECE) **4**(5), 1125–1131 (2015)
6. Robinson, R., Pavithra, R.: Investigation on multi-beam hybrid WDM for free space optical communication system. Int. J. Photonics Opt. Technol. **2**(2), 24–28 (2016)
7. Anguita, J.A., Neifeld, M.A., Vasic, B.V.: Multi-beam free-space optical link using space-time coding. Department of Electrical and Computer Engineering College of Optical Sciences University of Arizona (2016)
8. Kashani, F.D., Hedayati, M.R., Mahzoun, M.R., Ghafary, B.: Beam propagation analysis of a multi beam FSO system with partially flat-topped laser beams in turbulent atmosphere. Optik **123**(2012), 879– 886 (2012)
9. Al-Gailani, S.A., Mohammad, A.B., Shaddad, R.Q.: Enhancement of free space optical link in heavy rain attenuation using multiple beam concept. Optik **124**, 4798–4801 (2013)
10. Kadhim, S., Aldeen, S., Taha, A., Baki, A.Q.: Characterization study and simulation of MIMO free space optical communication under different atmospheric channel. IJISET – Int. J. Innovative Sci. Eng. Technol. **3**(8) (2016)
11. Kaur, H., Sarangal, H.: Simulative investigation on free space optical communication with optical amplification based on 4 × 4 transmitter/receiver combination. IJRECE **3**(1) (2015)
12. Recommendation ITU-R: Prediction methods required for the design of terrestrial free-space optical links. Question ITU-R 228/3, p. 1814 (2007)
13. Marian, V., Paul, S.: Advanced educational program in optoelectronics for undergraduates and graduates in electronics. In: Proceedings of the SPIE, Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies VII, vol. 9258, p. 92580B (2015)
14. Marian, V., Dan Tudor, V.: Redundant uplink optical channel for visible light communication systems. In: Proceedings of the SPIE, Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies VII, vol. 9258, p. 92581J (2015)
15. Marian, V., Dan Tudor V.: Automated platform for determination of LEDs spatial radiation pattern. In: Proceedings of the SPIE, Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies VII, vol. 9258, p. 92581F (2015)