Subjective Review of Free Space Optical Communication System

Harneet Kaur[1], Himali Sarangal[1]
[1]*Guru Nanak Dev University*
(E-mail: harneet.kaur.btech.892691@gmail.com)

***Abstract*—**With the growth of internet traffic in conjunction with increase in number and range of new services has led to the emergence of free space optics technology which has combined features of wireless and fiber optics .It is also called open air photonics or fibreless optics. Free space optics communication system provide high bandwidth, smaller size, light weight, low power and low cost alternative to present microwave systems. FSO enable the deployment of wireless networks with transmission rate comparable to optical wired communication systems .This paper is the study of free space optics systems along with its various applications, advantages and limitations. The goal here is to explain some of the design issues for free space optics system. Free space optics also known as wireless optical communication has very high data rate up to tens of Gbps but is severely affected by the atmospheric attenuation caused by various weather conditions. This paper reviews the basics of free space optics communication system which provides the sufficient information to allow potential users to evaluate the suitability of a specific FSO system for a particular application.

Keywords*—free space optics(FSO), bit error rate(BER),Fog attenuation,Multiple transceiver,Spatial Diversity*

I. INTRODUCTION

Due to growing demand for wireless broadband communication and congestion on bandwidth of RF spectrum, optical wireless has received considerable attention in the communication world. Optical wireless or free space optics is a good alternative solution to existing RF communication system. It is the transmission of modulated visible or infrared beam through atmosphere to obtain broadband communication. Mostly laser beam, LED's, IRED's (IR emitting LED) are used. Optical wireless communication has emerged as a viable technology for next generation broadband wireless applications. . Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication .FSO communication usually involves directed LOS and point-to-point laser links from transmitter to receiver through the atmosphere. Other technologies such as microwave, radio frequency and copper have disadvantages such as not immune to interference, limited capacity , high bit error rate and unable to provide true broadband services. [1]Though fiber optics have many attractive features such as high data rate and low bit error rate but it suffers from various problems such as non-linearity and dispersion. The cost of digging and laying down of fiber is high and is a tedious task also. [2]

II. FEATURES OF FSO SYSTEM

A. *High Data rate and high speed*- It provide us with very high data rate with low bit error rate. The bit rate can be up to tens of Gbps.[3]

B. *Huge modulation bandwidth*- In any communication system, the amount of data transported is directly related to the bandwidth of the modulated carrier. Optical communication therefore guarantees an increased information capacity compared to radio frequency based communication systems.

C. *Narrow beam size* -The optical radiation transmitted by the transmitter is directed narrow beam, a typical laser beam has the divergence of between 0.01 – 0.1 mrad Thus the transmitted power is concentrated within a very narrow area.[4]

D. *Unlicensed spectrum* -The spectrum of FSO system is unregulated and quite vast. It also provide us with huge bandwidth which is the great support for high speed applications

E. *Cheap* - The cost of deploying FSO is lower than that of fiber optics with a comparable data rate. FSO can deliver the same bandwidth as optical fiber but without the extra cost of fiber instalment.

F. *Quick to deploy and redeploy* - It can also be taken down and redeployed to another location quite easily.

G. *High security, less interference and low power consumption*- It facilitates system design and results in significant cost saving. It also consumes low power. It can provide full duplex operation and there is no necessity of Fresnel zone.[5]

III. APPLICATION

A. *Multi-campus communication network* - FSO has found applications in interconnecting campus networks and providing back-up links at Fast-Ethernet or Gigabit-Ethernet speeds. It is used for LAN-to-LAN connections in campuses at gigabit Ethernet speed.[6]

B. *Last mile access* –-FSO is used for last mile bottleneck that exists between the end-users and the fiber optic backbone[7]
C. *Optical fiber back up link* - Used to provide back-up against loss of data in case of unavailability of the main optical fiber link [8]
D. *Cellular communication back-haul* - Can be used to back-haul traffic between base stations and switching centres in the 3rd/4th generation (3G/4G) networks
E. *Disaster recovery areas* - The technology finds application where a temporary link is needed such as for disaster recover areas, for a conference or ad-hoc connectivity in the event of a collapse of an existing communication network
F. *Difficult terrains* - FSO can be used as a data bridge in such instances as across a river, a very busy street, rail tracks or where right of way is not available or too expensive to pursue.[8]
G. Free space optics finds its application for communications between space crafts, aircrafts and satellites. It can also be used for inter- and intra -chip communication.

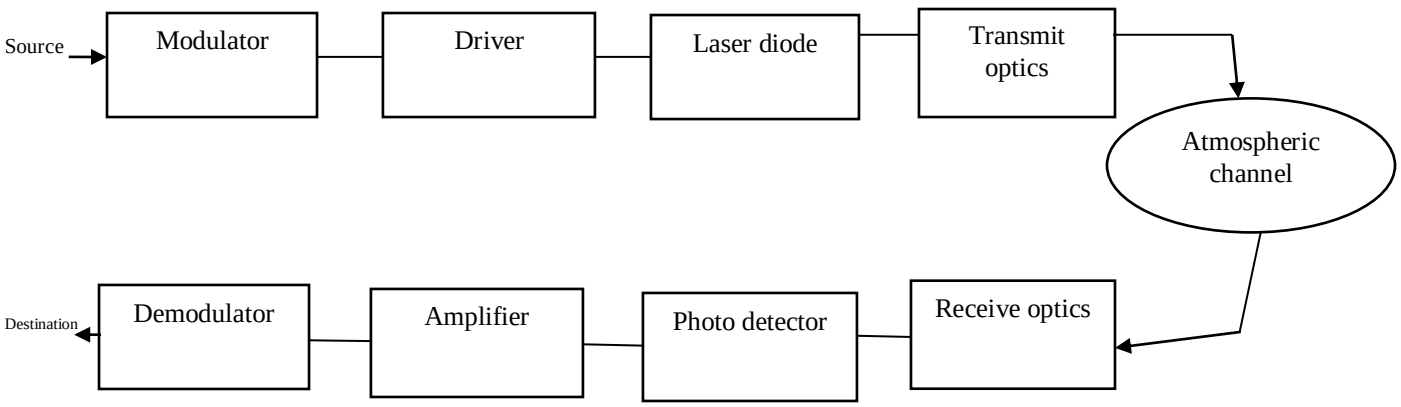
IV. BLOCK DIAGRAM OF FSO SYSTEM

Data produced by source is transmitted to the remote destination. The source output is modulated onto an optical carrier, which is mostly laser. This modulated light beam is transmitted by the antenna into the atmospheric channel. Size, power and beam quality determines laser intensity and minimum divergence of laser beam. On the receiver side, the optical beam is collected and detected. Photo detectors such as PIN and APD are used to detect the optical signal. The important features on receiver side are aperture size and f number .Different types of modulation techniques such as OOK, BPSK, DPSK, CoPSK etc are used .Different light sources such as LED ,VCSEL lasers and QCL lasers are mostly used. Wavelengths such as 785 nm, 850 nm, 950 nm, 1550 nm and 10000 nm are used for FSO system.FSO receiver link is mostly affected by thermal noise and shot noise.LPDC codes and convolutional codes are used to maintain BER levels. Table I shows the various wavelength windows used in FSO systems. Fig. 1 shows the block diagram of the basic free space optics model.

Fig.1: Basic block diagram of free space optics system

TABLE I: Comparison of various wavelength windows used in FSO systems

Wavelength (nm)	Type	Remark
780-850	VCSEL lasers	Cheap available (CD lasers) at 780 nm. Inexpensive detector components available. Lower power density.
1520-1600	Distributed-feedback Lasers Fabry Perot lasers	Best suited for free space communication. High quality. Low attenuation led to the feasibility of WDM FSO systems. Compatible with EDFA technology. 50-60 times more power transmitted than at 850nm inexpensive
~10,000	Quantum cascade Laser(QCL)	Expensive and new Very fast and highly sensitive Better fog transmission characteristics Few Components available Poor glass penetration
Near Infrared	LED	Cheaper Non coherent Lower power density, hence safer Simpler driver circuit Lower data rates and low power [9]



A. *Transmitters:* The VCSEL (850-nm wavelength) has nominal average power level of several milliwatts of output at high-speed operation. The 850- nm VCSEL is cheaper than many of its alternatives because operation speeds are generally below 1 Gbit/s. Because of their high efficiency, active cooling is not required. In addition, VCSELs emit light in the form of a circular beam instead of an elliptical beam. FP and DFB lasers based on InGaAs/InP semiconductor technology with operating wavelengths around 1550 nm were developed for fiber-optic communications systems because of the low attenuation characteristics of optical fiber in this wavelength range. These lower-power laser sources led to the development of FSO system with high modulation speed, wavelength stability, reliability, and long life spans.[9]

B. *Amplification sources:* Amplification sources, such as EDFAs and semiconductor optical amplifiers (SOAs), are used to boost the power of lower-power laser sources. EDFAs can drive the 1550-nm optical output power of a FSO system up to between 1 and 2 W. EDFAs are quite expensive, and their use tends to be limited to very high-end performance systems that operate at or above 1 Gbit/s.

C. *Photo detector*: For Short-Wavelength Detectors, Si is the most commonly used detector material in the visible and near-IR wavelength range. Si receivers can detect extremely low levels of light. InGaAs is the most commonly used detector material for the longer wavelength range. InGaAs detectors are optimized for operation at either 1310 or 1550 nm[9]

V. MATHEMATICAL MODEL

Link Equations: The link equations for free space optics is defined by

$$P_R = P_T (d^2 / (D+\Theta r)^2 * (10^{-\alpha r/10})$$

Where d is receiver aperture diameter, D is transmitter aperture diameter, θ is beam divergence, r is range and α is atmospheric attenuation

VI. CHALLENGES FACED BY FSO SYSTEM

A. *Effect of weather conditions*: The atmospheric condition such as fog, haze and rain severely effects the link performance. Fog and heavy snow in temperate region is the limiting factor of FSO link availability. In tropical regions with the absence of fog, heavy rain attenuates and distorts the signal in the FSO receiver system. Scattering and absorption is the major atmospheric effect due to attenuation caused by local weather conditions.[10][11]

Table II shows the atmospheric attenuation offered to 850 nm wavelength by various weather conditions. As the attenuation offered by the weather condition increases visibility decreases and thus the link distance between the transmitter and receiver also decreases.

TABLE II: Atmospheric attenuation at different weather conditions for 850 nm wavelength

Weather Conditions	Visibility (km)	Attenuation(dB/Km)
Clear air	23	0.4
Haze	2	6.4
Light Fog	0.8	18.6
Moderate Fog	0.6	27

B. *Atmospheric Turbulence*: The small changes in atmospheric temperature and pressure creates eddies, cells or air packets having varying sizes from ~0.1 cm to ~10 m. These air packets have different refractive indices which causes refraction and diffraction. The fluctuations in both intensity and phase of received light signal causes the impairment of link performance .These fluctuation increases the link error probability limiting the performance of communication systems Atmospheric turbulence is categorized in regimes depending on the magnitude of index of refraction variation and in homogeneities. These regimes are a function of the distance travelled by the optical radiation through the atmosphere and are classified as weak, moderate, strong and saturation. Kolmogorov's equation defines the irradiance in the form of probability density function. The strong turbulence impact leads to the temporal fluctuation of irradiance at the receiver which is known as scintillation. For irradiance fluctuation in turbulence channels three models are used .These are log-normal, gamma-gamma and negative exponential models .Spatial diversity reception and ML detection of ON-OFF keying in turbulence channels can be used to mitigate turbulence effects. For ON-OFF keying ML detection in turbulence channels is done .Symbol by symbol ML detection and Maximum likelihood sequence detection is used in this case .For spatial diversity reception, maximum likelihood diversity detection is used to overcome the problem of turbulence channels.[12][13]

C. *Pointing error:* It is one of the major challenge faced by FSO links and pointing error occurs due to misalignment between the transmitter and receiver. It is also called waveform tilt. One of the key challenges with FSO systems is maintaining transceiver alignment. FSO transceivers transmit highly directional and narrow beam of light but due to base motion, building sway, thermal expansion and vibrations, leads to tracking and pointing error loss. Pointing error angles in range of micro radians

can lead to link failure. Auto tracking systems, multiple beaming and multiple receiving systems can be used to overcome pointing error problems.[14][15]

D. *Solar Interference*: Sun's radiations also effects the FSO system. Direct sunlight may cause link outages for periods of several minutes when the Sun is within the receiver's FOV.

E. *Beam Divergence*: Beam divergence also cause major attenuation loss of up to 20 dB/km. By using automatic tracking and pointing system, beam width can be narrowed significantly

F. *Window attenuation*: FSO system allows communication through windows without rooftop mounted antennas .This can be beneficial for users living in multistoried buildings .Uncoated glass window attenuates 4% per surface because of reflections. So a double pane window attenuates signal at least 15%.The installers must measure the actual attenuation of window before installment on tall multistoried buildings.

G. *Building Sway*: Buildings are under constant motion due to various factors such as thermal expansion, wind, sway and vibrations .Base motion or the building sway can be of two types low, moderate and high frequency base motion. Base motion can cause link degradation in two ways: excess geometric loss due to pointing error which is discussed earlier and the detector coupling loss due to tracking errors. Coupling loss is the ratio of optical power in receiver focal plane to the power incident on active area of the detector.[16]

H. *Signal fading*: Atmospheric attenuation and signal fading due to scintillation and turbulence effects leads to signal degradation and received power is very low at the receiver. Spatial diversity technique is a good option to improve the bit error rate performance and further it leads to the improvement of the link distance and the received power .By doubling the transmitter/receiver combination the received power can be improved by 6 db. Hence there is the improvement of the link performance of the FSO system.[17][18]

VI CONCLUSION

In this paper, the characteristics and properties of several design parameters in FSO communication system are discussed .FSO has higher data rate and is similar to fiber optics but with lower error rate and no non linearities. Free space optics is a key solution for last mile problems and broadband requirements.FSO has combined advantages of wide bandwidth, high security and capacity with easy link installation. Despite of many applications and advantages, free space optics suffers from some transmission impairments such as local weather condition, atmospheric attenuation, turbulence and building sway etc. The qualitative analysis would help in designing longer FSO links over longer distance and enhance the usage of this technology beyond the last mile solutions in future. Integration of RF and FSO technology to form hybrid networks will be a boom for next generation communication systems

ACKNOWLEDGMENT

The authors would like to thank Guru Nanak Dev University for providing us with optisystem software which helped us to explore free space optics and to work with it.

REFERENCES

[1]. Sushank Chaudhary, Angela Amphawan, Kashif Nisar, "Realization of free space optics with OFDM under atmospheric turbulence", journal of optic (2014) in science direct

[2] A. Ramli,S. M Idrus and A.S.M. Spa 'at, "Optical wireless front end receiver design" IEEE international RF and Microwave conference preceedings,2008

[3]Michelle D'Amico, Angelo Leva and Barbara Micheli, "Free space optics communication systems: First result from a pilot field – trial in the surrounding area of Milan, Italy" IEEE microwave and wireless component letters, Vol.13, No.8, August 2003

[4] D. Killinger, "Free space optics for laser communication through the air," Optics & Photonics News, vol. 13, pp. 36-42, Oct. 2002

[5]. Valerio Annovazzi-Lodi, Giuseppe Aromataris, Mauro Benedetti and Sabina Merlo, "Secure chaotic transmission on a free-space optics data link", IEEE Journal of quantum electronics, Vol. 44, No. 11, November 2008

[6] A.K. Majumdar and J.C.Ricklin," Free-Space Laser Communications: Principles and Advances" New York: Springer, 2008.

[7]. Gary Shaulov,Jigesh Patel, Brent Whitlock, Pablo Mena, "Simulation–assisted design of free space optical transmission systems"IIT Kanpur, downloaded from IEEE xplore May 24,2009

[8].H. Willebrand and B. S. Ghuman, "Free Space Optics: Enabling Optical Connectivity in today's network". SAMS publishing, 2002

[9] Scott Bloom, Eric Korevaar, John Schuster and Heinz Willebrand "Understanding the performance of free-space optics", Journal of optical networking, vol.2, No 6, June 2003

[10] A.Z. Suriza , Islam Md Rafiqul,A.K.Wajdi,A.W.Naji, "Proposed parameters of specific rain attenuation prediction for free space optics link operating in tropical region", Science Direct journal of atmospheric and solar terrestrial physics94(2013)

[11]. Hilal A. Fadhil, Angela Amphawan, Nasim Ahmed, "Optimization of free space optics parameters: An optimum solution for bad weather conditions "Science Direct Journal of Optik 124(2013)

[12] Xiaoming Zhiu and Joseph M. Fellow, "Free space optical communication through atmospheric turbulence channels"IEEE transactions on communications, Vol. 50, No. 8, august 2002

[13].Gilberto Kirk Rodrigues,Vitor Gouvea,Andrezo Carneiro,Alberto Rubin da Cruz, Maria Thereza M. Rocco, " Evaluation of the strong turbulence impact over free space optical links", Science Direct journal on Optics communications305(2013

[14]. Nazmi A. Mohammed, Amr S. El-Wakeel* and Mostafa H. Aly, "Performance evaluation of FSO link under NRZ-RZ line codes,

different weather conditions and receiver types in the presence of pointing errors", The Open Electrical & Electronic Engineering Journal, 2012 ,Bentham

[15]Amur S. El Wakeel and Modtafa H. Aly, "Pointing error in FSO link under different weather conditions", International journal of Video & Image processing and network security IJVIPNS-IJENS Vol: 12 No: 01

[16]. Xian Liu, "Free-space optics optimization models for building sway and atmospheric interference using variable wavelength", IEEE transactions of communication, Vol.57, No.2, February 2009 Nazmi A. Mohammad,

[17] S.A. Al-Gailani, A.B. Mohammad, R.Q. Shaddad, "Enhancement of free space optical link in heavy rain attenuation using multiple beam concept "Science Direct journal on optic , 124 (2013)

[18]. Nur Haedzerin M D Noor, Ahmed Wathik Nazi and Wazdi AL-Khateeb "Performance Analysis of a free space optics link with Multiple transmitters/receivers", IIUM Engineering Journal, Vol.13 No 1 2012