PARAMETER OPTIMIZATION OF FREE SPACE OPTICS IN THE PERSPECTIVE OF BANGLADESH

Al-Imran Bin Ayub
Electrical & Electronics Engineering
Chittagong University of Engineering &Technology
Chittagong, Bangladesh
e-mail:aibak1029@gmail.com

Md. Faysal Sarker
Electrical & Electronics Engineering
Chittagong University of Engineering &Technology
Chittagong, Bangladesh
e-mail:faysalcuet@gmail.com

Mohammad Ahsan Ullah
Electrical & Electronics Engineering
Chittagong University of Engineering &Technology
Chittagong, Bangladesh
e-mail:ahsan_cuet@yahoo.com

Abstract— **Free space optics (FSO) has brought a solution to the ever growing need of high speed data transfer. It is sensitive to local weather conditions which results in a considerable loss of signal power over the communication path. This paper reveals the factors which are affecting the quality of data transmission and also states derived optimum parameters to get the finest solution for Bangladesh. Different weather conditions are considered and the parameters for both clear and foul weather conditions have been optimized. Simulation shows that the FSO system in worst weather condition achieves 2.5 Gbps data rate with 1550 nm wave length at the bit error rate (BER) of around 10^{-9} for 3km link range without using any optical amplifier. By using optical amplifier the link rang can be extended.**

Keywords—FSO, parameter optimization, optical amplifier, attenuation, link range, data rate

I. INTRODUCTION

Global telecommunication network is expanding tremendously day by day which results in increasing bandwidth requirement that leads us towards research in optical communication. The main problem with the prevailing copper wire based technology is the unavailability of the bandwidth within access network which gives rise to 'access network bottleneck' problem i.e. limits the data rate to the end user. A wide variety of solution have been proposed to overcome this bottleneck including fiber to the home (FTTH), power line communication, local multipoint distribution service (LMDS), ultra wideband technology (UWB), and free space optics (FSO). FTTH can provide a wide range of bandwidth i.e. high data rate to the end user but higher cost makes it prohibitive for wider deployment. The UWB provides unlicensed spectrum in the 3.1 to 10.6 GHz range approved by the federal communication commission in 2002 [1]. But the data rate is not as praiseworthy as in the backbone. Moreover interference of the UWB signals of the same frequency spectrum may occur [2]. LMDS system has the disadvantage of having the carrier frequency in the licensed band [3].

FSO also known as optical wireless communication (OWC) has eliminates the above problems. OWC uses infrared ray (IR) as carrier signal and the atmosphere, water and vacuum as transmitting medium. It provides fast and low cost installation, re-deployment, no requirement for cable, unlicensed spectrum. It can be used in both indoor and outdoor applications. It also faces some challenges due to the atmospheric condition. Atmospheric attenuation (ATT) reduces the quality of data or signal power predominantly owing to fog and rain. This paper optimizes the channel parameters so that high data rate can be ensured. The 1550 nm wavelength light offers 17 dB extra margin of power for higher data rate than 8oonm wavelength light at the eye safety level.

II. SYSTEM ANALYSIS

A. WDM SYSTEM DESIGN

Fig. 1 show the block diagram of FSO communication link which is divided into three parts. Those are transmitter, receiver, and FSO link. In transmitter part continuous wave (CW) laser, modulator, bit generator, non-return to zero (NRZ) pulse generator are used. The system requires CW laser with variable power according to environment condition, for modulation Mach-Zehnder modulator, Pseudo-Random bit generator and NRZ Pulse generator for encryption technique. The system also need optical amplifier for long distance communication. Receiving part

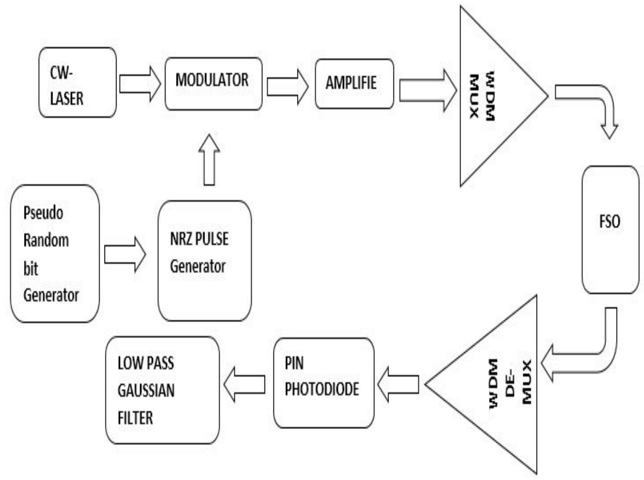

Figure 1. FSO communication link block diagram

TABLE-1 Illustrative characteristics and data observation

Characteristics		**Data observation**
Data rate	2.5 Gbps	Data rate versus bit error ratio
Aperture size	20 cm	Aperture size effect BER
No. of user	Dependent	No. of user versus bit error ratio

consists of PIN photodiode, which detect the optical signal, low pass Gaussian filter, bit error rate analyzer to and optical time domain visualizer. . FSO path link and WDM (multiplexer and de multiplexer) technique are used in channel. The other parameters like data rate, power, aperture size etc. are shown in Table 1. FSO based on WDM system can be optimized to achieve a maximum link range of laser with variable power according to environment condition, for modulation Mach-Zehnder modulator, Pseudo-Random bit generator and NRZ Pulse Generator for encryption technique. The system also need optical amplifier for long distance communication. Receiving part consists of PIN photodiode, which detect the optical signal, low pass Gaussian filter, bit error rate analyzer to and optical time domain visualizer. FSO path link and WDM (multiplexer and de multiplexer) technique are used in channel. The other parameters like data rate, power, aperture size etc. are

TABLE-2 FSO link parameter with constant value

FSO link parameter, constant value	
Gravitational Constant	980 cm/s^2
Viscosity of air	1.8x10^{-4} (g/cm)
Droplet, a	0.001-0.1 cm
Water density	1 g/cm^3
Wavelength	1550 nm
Qscat	2

TABLE-3 Different rainfall rate

Rainfall rate		
Type	mm/h	cm/s
Light	16.08	4.46x10^{-4}
Medium	33.28	9.24x10^{-4}
Heavy	79.37	2.20x10^{-3}

shown in Table 1. FSO based on WDM system can be optimized to achieve a maximum link range of operation. The quality of the received signal is greatly depends on the conditions of the free space channel and the WDM system design. In order to suppress the beam diffraction that occurs naturally with propagation, an optical signal is then sent through an optical fiber to a collimating optical system [4].

B. CHANNEL ANALYSIS

I. RAIN

Intensity factor of rain is capable of attenuating laser power and rain is the highest attenuation factor in environment. In fact weather and installation characteristic could reduce visibility and harm FSO performance. By analyzing the derived mathematical model, it is correlated with local rain data. Beer's law and Stroke's law base numerical model is used in this purpose. Several models are available in propagation literature for calculating atmospheric attenuation. The attenuation of laser power in environment is described by Beer's law [5, 6]:

It represents that

$$T(R) = P(R) \div P(O) = e^{-\beta R} \tag{1}$$

Where, R = link range (km)

T (R) = transmittance in the range R (km)

P(R) =laser power in range R

P (O) = laser power at source

β= scattering coefficient (km^{-1})

The particles are large enough for scattering. So geometric optics help describe the angular distribution of angular radiation. Laser bit's signal are geometrically scattered by Snow, Rain, Hail, Cloud droplet, etc. Stroke's law is used to calculate Scattering coefficient [7]

$$\beta = \pi a^2 NaQscat\ (a/\lambda) \tag{2}$$

where a = radius of raindrop (0.001-0.1 cm),

Na = rain drop distribution,

Qscat = scattering efficiency,

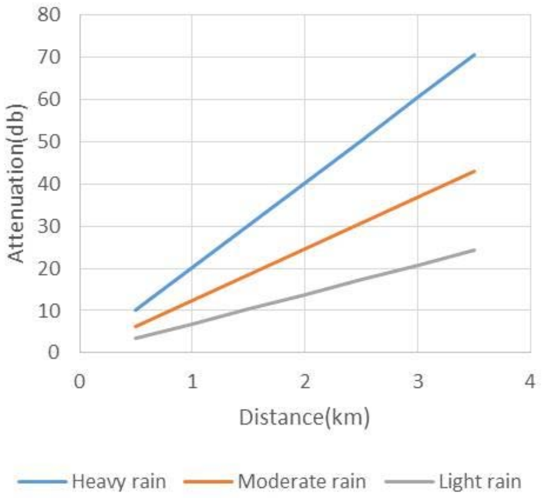

Figure 2. Attenuation for certain link range for Rain

and λ = wavelength.

The raindrop distribution, Na can be calculated using equation [7, 8]:

$$Na = Za \div \{(4/3)(\pi a^3)Va\} \tag{3}$$

Za is rainfall rate (cm/s),

a = droplet radius and

Va = limit speed precipitation

Limiting speed of raindrop is also given as

$$Va = (2a^2\rho g) \div 9\eta \tag{4}$$

ρ is water density (g/cm^2),

g is gravitational constant and η is viscosity of air. The constant values of these parameters are shown in Table 2. Table 3 represents light, medium and heavy rainfall rate.

II. HAZE

The effect of haze in FSO link is more than rain because haze stays longer in atmosphere than rain. Haze represents serious degradation on FSO performance. By measuring the actual system, the FSO parameter can be measured [9]. For doing this, FSO devices temporary installed on the site and observe it performance. If it gives satisfactory result then adjustment of FSO parameters is needed.

Without installing physical instrument alternate process in this case can be used. The mathematical model of Kim and Kruse is using as alternative method [5, 7, 8, 10-13].

$$\beta = (3.91/\ V\ ) \ \div (\lambda/550nm)^{-1} \tag{5}$$

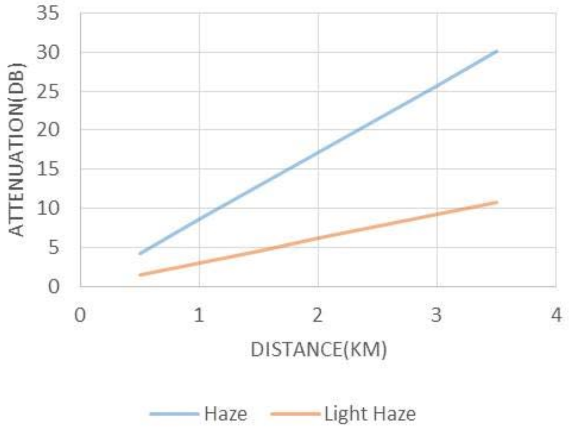

Figure 3. Attenuation for certain link range for Haze

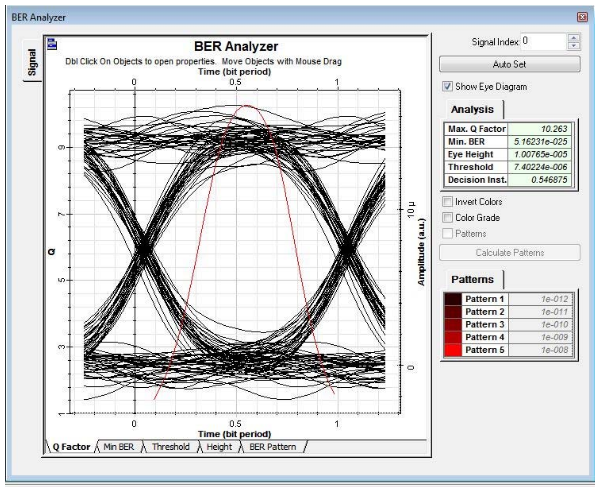

Figure 4. Eye diagram for 50 dBm power for heavy rain

where, β = haze attenuation, V = visibility in kilometers, λ = wavelength in nanometers and q = the size distribution of the scattering particles {1.3 for average visibility (6 km < V< 50 km) and 0.585 for low visibility (V<6 km)}. In other references, it adds as 1.6 for very high visibility (V>50 km) [5]. The losses occur due to divergence of optical beam is known as geometrical loss. But in this article it is not considered (Assume that no beam spreads).

III. RESULT AND DISCUSSION

The acquired simulation result is divided into the following two sections A. Normal weather condition B. Worst weather condition.

A. NORMAL WEATHER CONDITION

For normal weather condition the result is quite satisfactory 2.5 Gbps data rate for distance 20 km at the transmission power 30 dBm is achieved for attenuation 0.233 dB/km.

TABLE-4 Optimized parameter for worst rain

Power (dBm)	Bit rate (Bit/sec)	Min BER	Distance (Km)
50	2.5e+09	5.16231e-25	2
60	2.5e+09	9.3028e-014	2.5
65	150e+06	6.22682e-012	3

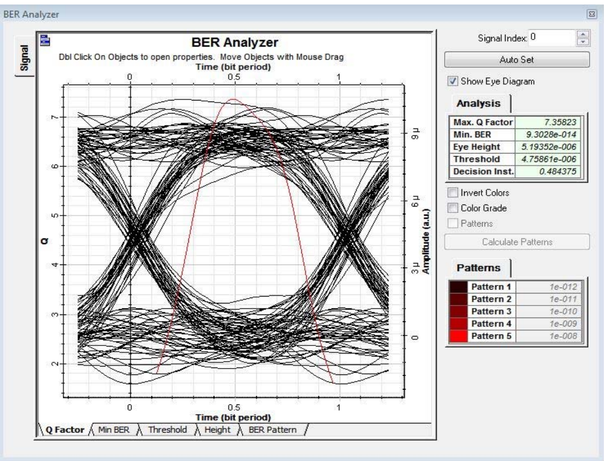

Figure 5. Eye diagram for 60 dBm power for heavy rain

TABLE-5 Optimized parameter for rain and haze

	ATT (dB)	Power (dBm)	Bit rate (bit/ sec)	Distance (km)	BER
Light Rain	6.92	28	2.5e+9	3	2.85191e-008
Moderate Rain	11.26	42	2.5e+9	3	4.48475e-009
Haze	8.59	34	2.5e+9	3	8.06131e-14
Light Haze	3.08	18	2.5e+9	3	1.0218e-09

B. ADVERSE WEATHER CONDITION

At the adverse weather condition the signal strength of laser beam is affected by rain and haze. The effect of rain on the signal is greater than that of haze. For 1550 nm wavelength laser beam light rain, moderate rain, heavy rain, light haze, haze offer the attenuation of 6.92 dB/km, 11.26 dB/km, 20.16 dB/km, 3.08 dB/km, 8.59 dB/km respectively which also have been shown in Table 5 and 7. For worst weather condition 2.5 Gbps data rate is achieved for variable distance which has been included in Table 5 and 7. The simulation also shows that the attenuation is increasing linearly with distance for both rain and haze which is shown in Fig.2 and Fig.3.

IV. OPTIMIZATION OF PARAMETERS

For the achievement of the projected output, the parameters like laser power, bit rate, optical amplifier gain, link range,

TABLE-6 Optimization between aperture size and power

Power (dBm)	Aperture size (cm)		BER
	Tx	*Rx*	
63	10	40	3.3631e-13
65	10	35	2.0138e-16
65	5	35	2.7326e-11
65	5	30	1.3282e-10
45	5	20	1.5347e-09
42	5	30	1.6347e-09

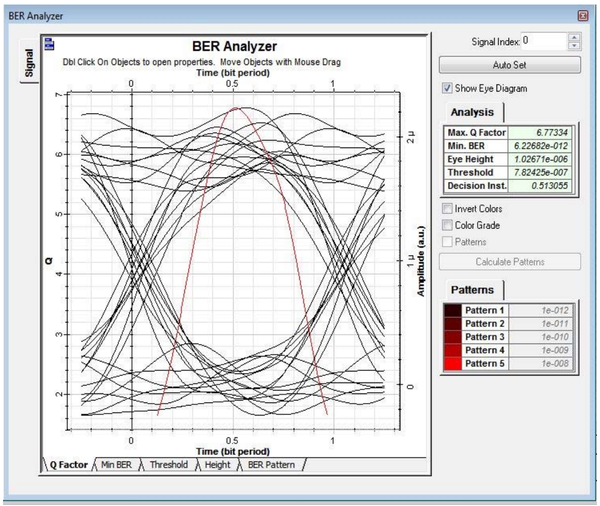

Figure 6. Eye diagram for 65 dBm power for heavy rain

aperture size of the transmitter or receiver have to be optimized. Hence there should be adjustment among the parameters according to the priority. The trade-off between the parameters has been illustrated in Table 4 and Fig.4, Fig.5, Fig.6 for the worst attenuation caused by the rain. With the increase in power the distance has also been increased. But with the increase of distance the data rate has been compromised. Increasing the aperture size greater data rate can be achieved. Table 6 shows the variation of power with the aperture size for 2.5 Gbps data rate and 3 km distance. It also reveals increased data rate can be achieved with the same power by using greater aperture. The effect of attenuation on BER for moderate and light rain has been demonstrated in Table 5.

Unlike the rain the effect of attenuation for haze is not so severe. Influence of haze on attenuation is illustrated in Table 5.

The comparison between Table 4 and 5 reveals rain as the most challenging factor in this territory which causes more attenuation than haze. For thick cloud RF-FSO hybrid system may be necessary. But in this region to communicate between two BTS cloud does not appear.

TABLE-7 Optimized parameter for rain using optical amplifier

Rain	ATT (dB)	Power (dBm)	Bit rate (bit/sec)	Distance (km)	BER
Heavy	20.16	50	2.5e+009	9	6.03164e-007
Light	6.92	50	2.5e+009	25	6.38454e-28

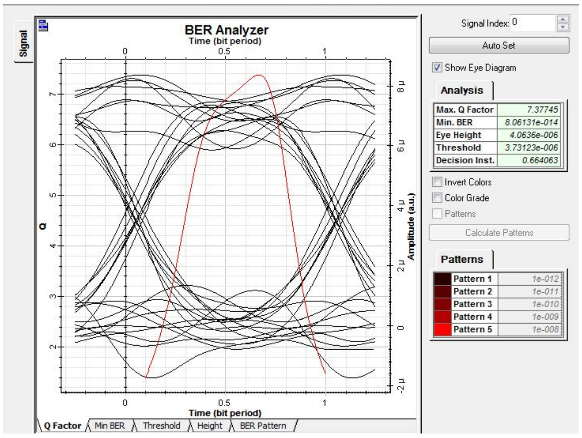

Figure 7. Eye diagram for heavy haze

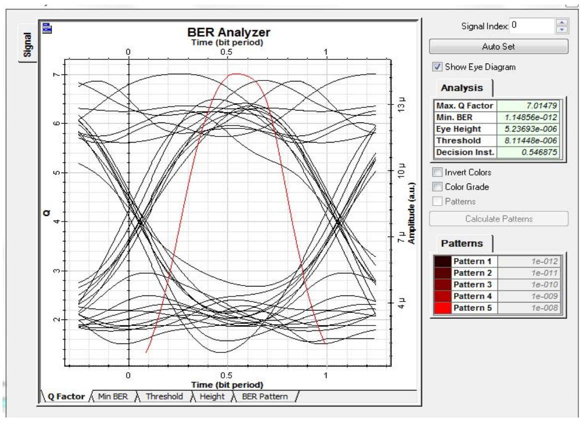

Figure 8. Eye diagram for heavy rain using optical amplifier

Up to this the observation was made without any amplifier. Using optical amplifier the link range can be made large. Table 7 represents the impact of using optical amplifier.

V. CONCLUSION

High speed data transfer has become one of the most fundamental requirements in the field of communication with the advancement of technology. FSO technology is one of the viable techniques in this regard. In the conventional mobile communication to communicate among the BTS radio frequency has been using for several decades which has several limitations. Among which excessive power consumption, high path loss, interference, low bandwidth, especially security threat from side lobe etc. to overcome those problems this research has demonstrated the optimized parameter of FSO. Here the characteristics and properties of several important design parameters in FSO communication systems are discussed. This simulation has achieved maximum data rate 2.5 Gbps for the distance of 3 km by using 65 dBm power. Exchanging among these values the optimized parameter without using optical amplifier is obtained. By using optical amplifier the distance can be increased which has been shown in Table 7. All simulations in this project were done by “OPTISYSTEM” version 13.0.2.

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