Power Budget Performances of Free Space Optical Link using Direct Line of Sight Propagation

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ABSTRACT
Optical wireless communication (OWC) systems suffer from average optical signal power loss and random power fading due to the different atmospheric condition. In this paper, we propose a model for free space optical link for link distance of 500 meters and the results of this paper show the Power of the system at different Bit Rates (1Gbps to 3.5 Gbps) using three different atmospheric attenuation 10dB/Km, 40dB/km and 60dB/km. The optical wavelength (window) used for simulation is 1550nm which give the best performance as compare to other window. VCSEL is used as a transmitter because it has a reasonable, nominal average power level of several milliwatts (mw) of output at high-speed operation and high reliability numbers for mean time between failures (MTBF). The NRZ OOK is modulation format which is used here for Laser beam modulation. Different graphs of the average Received optical Power vs. Bit Rate using three atmospheric attenuations of the Free Space Optical link are obtained.

Keywords: Free Space Optical Communication (FSO), Wavelength, Bit Rate, Received Optical Power, VCSEL, Avalanche Photodiode (APD).

1. INTRODUCTION
Free Space Optical Communication (FSO) offers highly directional, high bandwidth communication channels, especially in avionic application. Its links can provide fiber-like data rates over short distances with low probability of interception [7]. In examining FSO performance, it is important to take several system parameters into consideration. In general, these parameters can be divided into two different categories: internal parameters and external parameters. Internal parameters are related to the design of a FSO system and include optical power, wavelength, transmission bandwidth, divergence angle, and optical loss on the transmit side and receiver sensitivity, bit-error rate (BER), receive lens diameter, and receiver field of view (FOV) on the receive side. External parameters, or non-system-specific parameters, are related to the environment in which the system must operate and include visibility and atmospheric attenuation, scintillation, deployment distance, window loss, and pointing loss [1]. Free space optical interconnects can provide high bandwidth with no physical contact, but are hampered by signal fading effects due to particulate scattering caused by atmospheric turbulence. In particular the atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, producing additional space losses as well as possible beam distortion. Even in clear weather, channels may suffer fading due to inhomogeneities in the index of refraction of the optical path [4]. Because of the complexity associated with phase or frequency modulation, current free-space optical communication systems typically use intensity modulation with direct detection (IM/DD). Atmospheric turbulence can degrade the performance of free-space optical links, particularly over ranges of the order of 1 km or longer [5]. The surface of the Earth is the main generator of water vapor in the atmosphere.
The concentration of condensed water is higher at the lower part of the atmosphere, where it is present in the form of clouds or fog. Water is also present in the atmosphere in the form of raindrops and snow. There are two main factors that contribute to the growth of droplets. One of them is the collection of small droplets. The other is the heterogeneous nucleation of aerosol particles that attracts water vapor molecules to their surface at relative humidity levels below 100 percent. This generates cloud drops and fog. Aerosol particles can grow to form fog, clouds, or ice droplets with an increase of relative humidity [6].

2. FREE SPACE OPTICAL LINK DESIGN
As a transmitter the performances of VCSEL is an outgrowth of fiber communications development and has many attractive features. VCSELs revolutionized the transmission component market because of their exceptional cost and performance advantages over previously available technology. Most notably, VCSELs have a reasonable, nominal average power level of several milliwatts of output at high-speed operation and high reliability numbers for MTBF. The average power, not the peak power, determines the link margin. Because of their high efficiency, power dissipation is typically not an issue for VCSELs, and active cooling is not required. In addition, VCSELs emit light in the form of a circular beam instead of an elliptical beam. The round shape of the beam pattern perfectly matches the round core of an optical fiber, facilitating the coupling process and improving coupling efficiency. The success of VCSEL technology has been so tremendous that many VCSEL manufacturers can produce shorter-wavelength laser with direct modulation speeds beyond 3 Gbps [1].
The avalanche photodiode (APD) Photodetector, which iswidely used in optical communication systems for its highperformance and relatively low cost, is used for direct (power) detection [9]. The receiver aperture size plays a critical role indetermining the FSO communication system performance. Fora larger receiver aperture, it usually collects more opticalsignal power with reduced fading level, but it also collectsmore background optical noise in the meanwhile. This paper studies the optimal aperture size that achieves the best averageBER given the same amount of transmitted power [5]. The general setup of the FSO systems over atmospheric turbulence is shown in Figure 1.

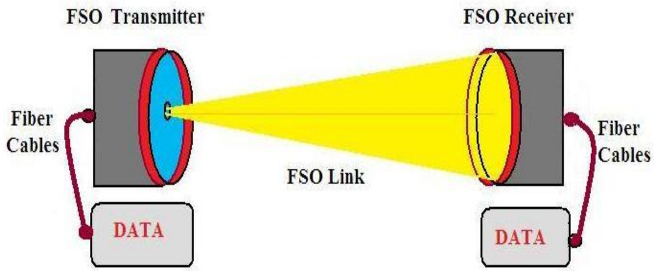

Figure 1 Probabilistic Model for Free Space Optical Communication.

The technically simplest digital modulation scheme is amplitude-shift keying (2 ASK). In optical systems it is referred to as on-off keying (OOK). OOK is an intensity modulation scheme where the light source (carrier) is turned on to transmit a ”one” and turned off to transmit a ”zero”. In its simplest form this modulation scheme is called NRZ (non-return-to-zero)-OOK. Besides NRZ also other codes exist. The most common one besides NRZ is RZ (return to- zero) coding. The advantages of RZ compared to NRZ are its higher sensitivity [3] and the fact that the clock frequency lies within the modulation spectrum. Unfortunately, both NRZ and RZ can lead to loss of clock synchronization if long strings of ones or zeros are transmitted. With such a variant of RZ the clock ofthe digital signal can easily be recovered. These advantages come at the cost of a requirement of twice the bandwidth of NRZ in order to fulfill the Nyquist–Shannon theorem. That RZ can also work when using the same bandwidth as for NRZ [3].

3. SIMULATION & RESULTS

The signal attenuation in this model is based on the FSO range equation that combines attenuation andgeometrical aspects to calculate the received optical power as function of range and receiver aperture size. Therange equation can be given as [2]:

$$P_{RX} = \frac{A_{RX}}{\pi\left(\frac{\theta}{2} * L\right)^2} * T * 10^{-\alpha\frac{L}{10}} * P_{TX} + P_{BG} \quad \text{.........................} (1)$$

Here $P_{RX}$is the received signal, P_{TX}- transmitted signal, A_{RX}-receiver aperture area, Θ - beam divergence angle, T - combined transmitter receiver optical efficiency, P_{BG}- optical power of background radiation, L – link range, and α – environmental attenuation in dB/km. The first term in parenthesis is a geometrical attenuation due to beam spreading and is calculated for given parameters A_{RX}, Θ, and L as a ratio of aperture to signal beam cross-section. The atmospheric attenuation α is a not a linear function of distance, it depends on many factors and changes randomly with time. Combining together optical efficiency and attenuation, we can re-write the above equation in the following form:

$$P_{RX} = 10^{-\frac{[\alpha_{geom} + \alpha_{add}]}{10}} * P_{TX} + P_{BG} \quad \text{.........................} (2)$$

Where α_{add} represents total additional attenuation in dB for given distance and is specified with a mean value and standard deviation. According to lognormal model the logarithm of signal intensity is a Gaussian random variable. Hence, the signal attenuation in dB units, α_{add}, is a Gaussian random variable as well [2]. Table I shows the specification taken in to consideration during the simulation.

Table I
Specifications for FSO Channels

Parameters	Description/Values
Transmitter Type	VCSEL
Tx Wavelength	1550nm
Transmitter optical power	1.3dBm
Tx aperture diameter	180mm
Link distance	500 meter
Pd_ APD Multiplier	0.80
APD ionization Coefficient	1.0
APD Quantum Efficiency	0.8
Filter Type	LP Bessel
APD Dark Current	1µA
Sigma Add	1.9
Divergence Angle	3mrad
Modulation Type	NRZ
Bit Pattern Type	PRBS
Distribution	Gaussian

Received Power at receiver of a system is depends upon the several conditions like distance, bit rates, wavelength and atmospheric turbulences. In our system we have calculated the Received power at different bit rate using optical window 1550nm.

Results of receiver power versus bit rates with three atmospheric attenuations are shown in Figures 2, 3 and 4. From these figures we can see the higher is attenuation the received power at receiver side is very less which degrade the system performances.

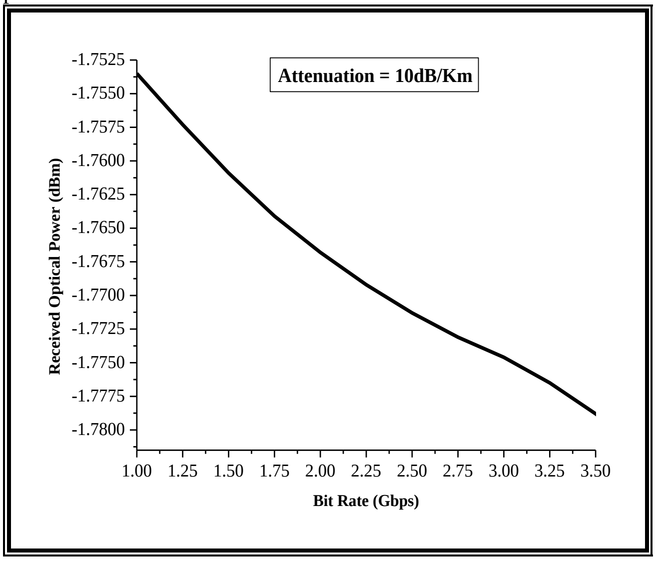

Figure 2 Received Optical Power vs. Bit Rates at Attenuation 10 dB/Km.

When the attenuation is very low (10dB/Km) the received optical power is very high (-1.750dBm to 1.780dBm) But at attenuation 40dB/Km the received optical power is vary from -16.750 to -16.780dBm which is shown in figure 2.

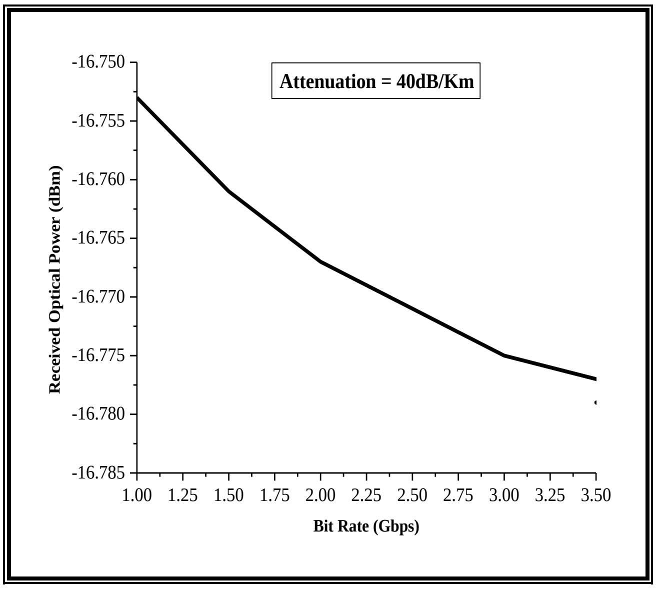

Figure 3 Received Optical Power vs. Bit Rates at Attenuation 40 dB/Km.

While increasing the atmospheric attenuation upto 40dB/Km the received optical Power reduced to -16.750 to -16.785 and the system performances (shown in figure 3) get degrades.

In figure 4 we can see that the power received at the receiver end is very low (-26.750dBm to -26.780dBm) which is unacceptable value for the good OWC links.

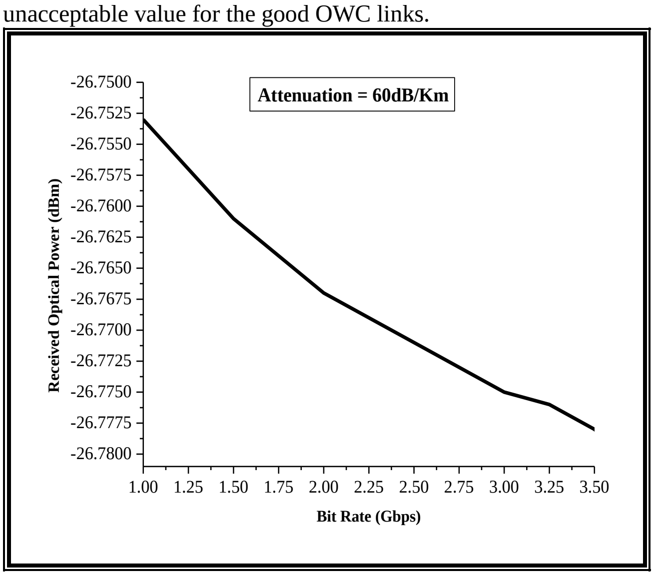

Figure 4 Received Optical Power vs. Bit Rates at Attenuation 60 dB/Km.

From these figures we can say that received optical power of FSO link depend on the variations in Bit Rates and atmospheric attenuation. The all simulations have been done in OptSim software.

4. CONCLUSION

This paper has studied the received optical power performances of the free-space optical Link and experiencing that the received optical power is the function of the Data Rates over a defined window 1550nm. The figure 2, 3, and 4 shows the relation between received optical power and data rates. The power of all transmission using different attenuation we can easily analyze that after increasing the attenuation the Power at receiver is getting low and degrade system performances, which results that high data rates (more than 2.25Gbps) is also not permissible for the optical wireless communications.

5. REFERENCES

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