Journal of Engineering and Applied Sciences 12 (18): 4579-4584, 2017
ISSN: 1816-949X

Attenuation Evaluation for Optical Wireless Communication Link Measurements under Various Bit Rates

A.A. Anis, A.K. Rahman, C.B.M. Rashidi, M.S. Anuar and S.A. Aljunid
Centre of Excellence Advanced Communication Engineering,
School of Computer and Communication Engineering, Universiti Malaysia Perlis (UniMAP),
Pauh Putra, 02600 Arau, Perlis, Malaysia

Abstract: This study presents the attenuation evaluation for optical wireless communication link measurements under various bit rates. From the numerical analysis, it has been found that 155 Mbps is the most suited bit rate to enhance the performance of the system regarding attenuation effect on the link compared to bit rate 622 Mbps and 2.5 Gbps. It enhanced the system by 4 and 48% compared to the other two bit rates. The system performance is proven better using lower bit rate links for communication. Higher bit rate system is usable but the communication system tends to be less functional for transmission links.

Key words: Attenuation, power received, Bit Error Rate (BER), Optical Wireless Communication (OWC), bit rate

INTRODUCTION

Optical Wireless Communication (OWC) or Free Space Optics (FSO) technology is playing a rising complementary part to the existing Radio Frequency (RF) based methods. It has been >30 years since Optical Wireless (OW) was proposed as an alternative broadband technology for wireless data transmission applications. OW is also very alike to RF wireless but radio waves are substituted with light and antennas with free-space optical transceivers. Despite this superficial similarity between OW and RF links, OW shows some interesting attributes when compared to RF. OW links are inherently broadband and optical frequencies in the infrared and visible spectrum are neither regulated nor licensed. These advantages, however do not suggest that OW is a universal replacement for RF communications. The application of OW systems is restricted when considering area coverage and user mobility where RF technologies prove invaluable. Table 1 displays the comparison between visible light and infrared as both of them are used for optical wireless communication links.

Optical Wireless Communication (OWC) uses light at near-infrared frequency for link transmission. OWC system has three main communication parts which are transmitter, propagation channel and receiver. There are several transmission methods possible for optical wireless systems and these methods are based on the degree of directionality of transmitter and receiver. A transmitter and receiver may have a narrow or broad radiation pattern or Field of View (FOV) and can be combined to make directed, non-directed or hybrid systems. These techniques are Directed Beam Infrared (DBIR) Radiation, Diffuse Infrared (DFIR) radiation and Quasi-Diffuse Infrared (QDIR) radiation (Singh *et al*., 2002). Figure 1 shows the basic block diagram of an OWC system. The OWC system is quite similar to free space optics and fiber optic communication where the small difference relies at the propagation medium. Different from free space optics that is subjected to great losses due to weather and atmospheric attenuation, the OWC channel is vacuum and free from atmospheric losses. OWC channel is considered to be outer space where it is assumed to be vacuum and free from atmospheric attenuation factors as proven in (Nameh, 2009). They provide high security, low cost, low power and high rates due to the unregulated bandwidth (Heatley *et al*., 1998). The wireless optical channel component that is also free-space optics can be used for large distances where the atmospheric attenuation is not the major source of penalties but the pointing angle. For example is in satellite communications (Polishuk and Arnon, 2004; Arnon, 2005).

Optical Wireless (OW) communications can be divided into two groups which are the diffused system and the Line-Of-Sight (LOS) system. Diffused beam is used to cover the whole service area and offer mobility functionality to subscribers. Still, it suffers from severe multipath dispersion which restricts the transmission bit

Corresponding Author: A.A. Anis, Centre of Excellence, Advanced Communication Engineering,
School of Computer and Communication Engineering, Universiti Malaysia Perlis, (UniMAP), Pauh Putra, 02600 Arau, Perlis, Malaysia

Table 1: Comparison between visible light and infrared used to carry information through channels (Saadi *et al*., 2013)

Parameters	Visible light	Infrared
Wavelength	380-780 nm	850 nm
Spectrum	Virtually unlimited	Lower
Thermal radiation	No	Yes
Sun spectrum	Yes	Yes
Achievable data rate	>800 Mbps	16 Mbps
Standardization	IEEE 802.15.7	Infrared Data Association (IrDa)
Acceptable eye safety level	High power	Low power
Services	Communication and illumination	Communication
Link distance	LED in meters LD in km	Up to 3 M
Unregulated	Yes	Yes

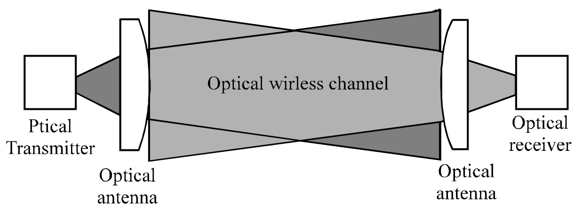

Fig. 1: The basic block diagram of an optical wirless commuication system

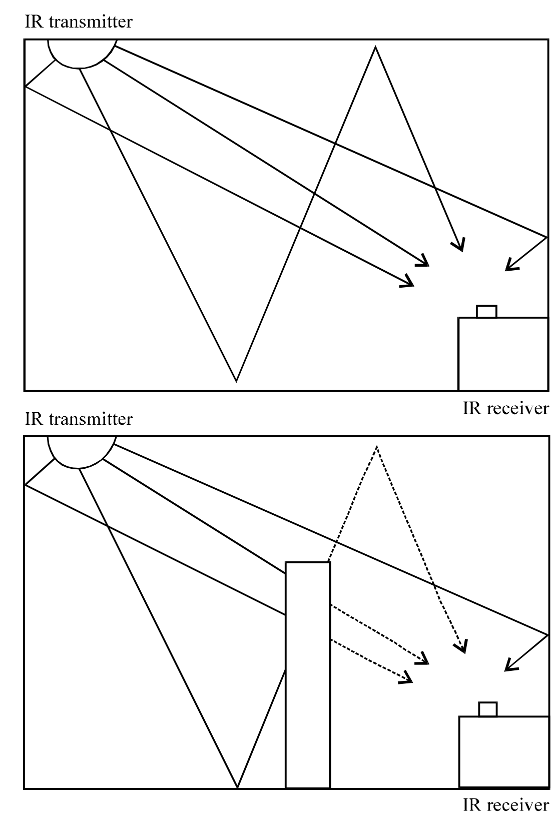

Fig. 2: Propagation model distorted by multipath effects

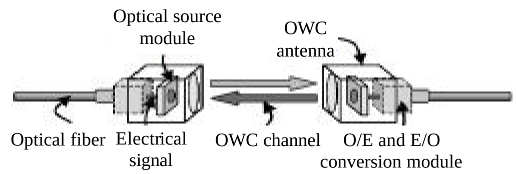

Fig. 3: The conventional optical wireless system (Matsumoto *et al*., 2008)

rate. Plus, it is also not energy efficient. Figure 2 illustrates the propagation model distorted by multipath effects. Optical Wireless Communications (OWC) that use light to carry information through a tether less channel can offer Gbps connectivity to wireless users. This is attributable to its major fundamental feature of point to point large bandwidth that is similar to that obtainable from optical fibre but with an extra benefit of lower deployment time and cheaper (Davis *et al*., 2003). The majority of indoor point-to-point OW links have single element transmitters and receivers. However, great gains can be attained by using multiple-transmitters and receivers in a coordinated fashion.

A transmitter or source converts an electrical signal to an optical signal. The link can be developed using Lasers or Light Emitting Diode (LED) between any two line of sight points in free space for a certain link distance, allowing point-to-point data links at rates surprisingly higher than 1 Gbits/s. The two most appropriate types of device are the Light-Emitting Diode (LED) and semiconductor Laser Diode (LD). Figure 3 illustrates the conventional optical wireless communication system used now a days. A fiber transceiver transforms an electrical signal to optical signal (E/O-conversion) in a conventional system. A laser driver amplifies the electrical signal which provides sufficient current to drive the laser diode. Modulated light from the laser diode is focused through space to the corresponding receiver which directs the beam onto a Photo Detector (PD). The PD changes the optical signal to electrical signal again. The electrical signal is converted at the fiber transceiver back to an optical signal after noise filtering and reshaping.

The principal advantages of laser diodes are their high energy conversion efficiency, their high modulation bandwidth and their relatively narrow spectral width (Rashed, 2015). Lasers research in the visible and near infrared spectrum of the electromagnetic radiations. The essential advantage of using lasers for developing connection between two geologically separated line of sight points offers a well-focussed narrow beam that on one hand is secured and on the other hand is less scattered as it travels through the free space mostly the earth atmosphere (Awan *et al*., 2009).

In practical optical wireless communication systems, numerous methods have been established or are practiced to mitigate atmospheric induced effects such as scintillation or beam wander. These methods consist of Adaptive Optics (AO) use of large receive apertures, diversity techniques and fast tracking antennas (Matsumoto *et al*., 2008). It is also likely to enhance the reliability of optical wireless communication systems by using coding schemes used in RF and wired communication systems. In cellular system, different users have different channel qualities in terms of Signal to Noise Ratio (SNR) due to differences in distance to the base station, fading and interference. Link quality control adapts the data protection according to the channel quality so that an optimal bit rate is obtained for all the channel qualities (Rosmansyah *et al*., 2001; Wang and Li, 2002; Madhukumar and Chin, 2001).

The main impairing factors for direct line of sight optical telecommunication, wireless communication links are power and fog and thus the primary focus of this paper is to find the values of received power and BER over different attenuations. BER is the acronym of bit error rate which means the number of bit errors per unit time and bit error means the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. Theoretically, a communication system desires a system with the lowest BER that could be reached for the optimum performance. Interference and attenuation of the signal is unavoidable. However, there are ways to reduce the effect and thus achieving lowest possible BER or error free (BER $<10^{-9}$) transmission.

MATERIALS AND METHODS

Proposed system design: Figure 4 shows the OptiSystem of the proposed Optical Wireless Communication (OWC) transmission system. In the transmitter side should have an optical sources and a modulator. The input from optical source is modulated by the modulator according to the electrical input from the transmitting satellite system. The modulated optical output is transmitted in Line of Sight (LOS) through optical wireless channel to the receiving satellite. Point-to-point links are capable to remove the majority of ambient light that obstructs the communications. Plus, the directionality of the link eliminates the effect of multipath dispersion as any reflected transmitter energy is fundamentally excluded by the receiver. Nonetheless, a drawback of this link topology is the fact that exact alignment and pointing are essential, making the establishment of mobile links difficult. Multipath dispersion severely restricts the diffuse channel bandwidth and a vast array of modulation. In the OWC design at the transmitter side a CW Laser is used as the optical source. Mach-Zehnder modulator is used as modulator. Pseudo-random bit sequence generator and NRZ pulse generator is used (Singh *et al*., 2014) to give modulating electrical signal input to the Mach-Zehnder modulator. The modulated signal is send through OWC (Optical Wireless Channel). As the altitude

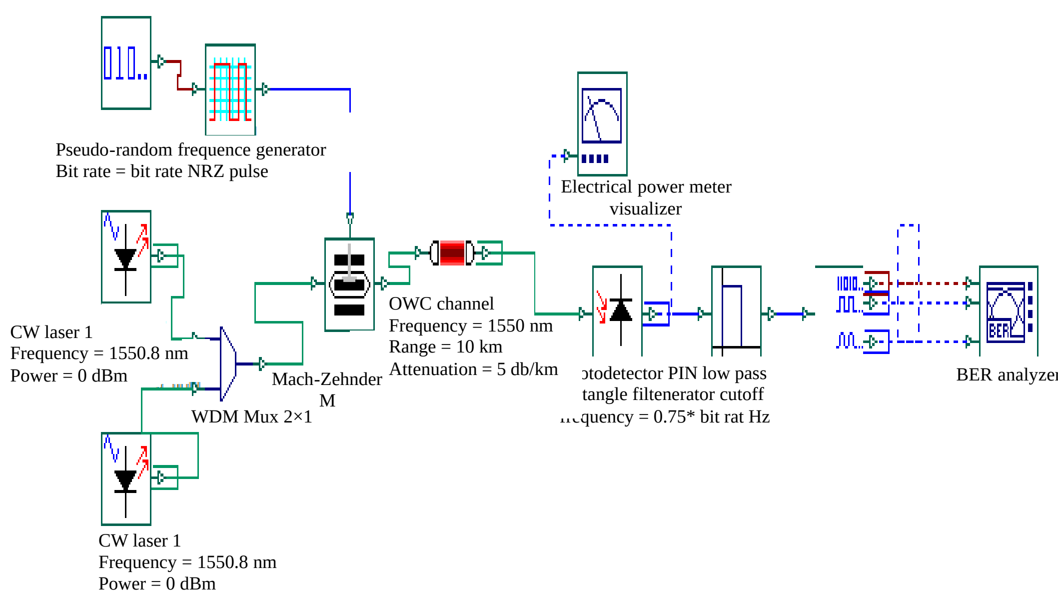

Fig. 4: Optisystem of optical wireless communication transmission link

of the satellites being above the earth's atmospheric layers, there is no attenuation due to atmospheric effects (Hashim *et al*., 2010).

The OWC in OptiSystem simulation is between an optical transmitter antenna and optical receiver antenna at each end. The transmitter and receiver gains are 0 dB. The transmitter and receiver antennae are also assumed to be ideal where the optical efficiency is equal to 1. At the receiver side an APD photodiode is used as photodetector which converts the optical signal to electrical signal. A low pass Bessel filter is used to filter out unwanted frequencies (Singh and Singh, 2012). Bessel filter has better shaping factor and flat group delay and phase delay. The received signal is analyzed using an eye diagram analyzer. The 3R regenerator is used to regenerate electrical signal of the original bit sequence and the modulated electrical signal as in the transmitter to be used for eye diagram analysis.

Mathematical model and simulation of OWC

System performance: The system performance can be assessed in multiple ways for example by investigating the BER and Q-factor. BER can be defined as the ratio of the number of bit errors identified in the receiver and the number of bits transmitted. Bit errors occur as the result of incorrect decisions being made in a receiver due to the existence of noise on a digital signal (Iniguez *et al*., 2008). Meanwhile, Q-factor is a measurement of the signal quality. It is proportional to the system's signal to noise ratio. In optical wireless communication system, the value of BER is usually too small to be measured thus Q-factor is more appropriate to be used in calculation. The relationship between BER and Q-factor can be given as:

$$BER = \frac{1}{2}\text{erfc}\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{\sqrt{2\pi Q}}\exp\left(-\frac{1^2}{2}\right) \quad (1)$$

From the Eq. 1, it can be observed that the BER is inversely proportional to Q-factor. Hence, the Q factor will automatically decrease if the system's error increases. To be precise, Q-factor which represents the Signal to Noise Ratio (SNR) at the receiver can also be formulated as:

$$Q = T_0\frac{1_1 - 1_0}{\sigma_0 + \sigma_1} \quad (2)$$

Where:

T_0 = The maximum transmittance

1_0 and 1_1 = The average detected signal current

Link budget of optical wireless communication: An equation is used to calculate the link power budget by using the data of power received by the system. The power received is the resultant signal or power received at the receiver after degradation due to power losses and attenuation and also amplification of the transmitter and receiver gain. Table 2 shows the list of parameters used in the research. The values are set to determine the power loss of the link by calculating the bit error rate of the system. Equation 1 is used to calculate the received power in an OWC System (Marcuse, 1991):

Table 2: List of parameter

Parameters	Symbol
Received power	P_R
Transmit power	P_T
Transmitter optics efficiency	η_T
Receiver optics efficiency	η_R
Signal wavelength	λ
Transmitter-receiver distance	z
Transmitter optical antenna gain	G_T
Receiver optical antenna gain	G_R
Transmitter pointing loss	L_T
Receiver pointing loss	L_R

Table 3: List of parameters used in simulation

Parameters	Values
External modulator	Mach-Zehnder
Tx. Power	6 dBm
Wavelength	1550 nm
Attenuation	1-10 dB/km
Tx. Apperture diameter	10 cm
Rx. Apperture diameter	10 cm

$$P_R = P_T\eta_T\eta_R\left(\frac{\lambda}{4\pi Z}\right)^2 G_T G_R L_T L_R \quad (3)$$

The term in parentheses is the free-space loss. Parameter geometrical gain defines whether the user will enter the transmitter and receiver gain directly or estimate the gain for a diffraction-limited beam. The gain of the transmitter, G_T(4) and receiver, G_T(5) optical antennae is formulated by:

$$G_T = \left(\frac{\pi D}{\lambda}\right)^2 \quad (4)$$

$$G_R = \left(\frac{\pi D}{\lambda}\right)^2 \quad (5)$$

where, D is the diameter of the optical antenna. Conventionally, optical system transmitter utilizes laser diode with narrow-beam-divergence angle and the receiver with narrow field view. Thus, the main and major contributor to signal attenuation is pointing loss. It is the critical flaw of LOS communication. Pointing loss factor can be estimated by Eq. 6 as shown in Table 3.

$$L = \exp\left(-G\theta^2\right) \quad (6)$$

where, θ is the divergence angle.

RESULTS AND DISCUSSION

Figure 5 shows the graph of power received versus the attenuation at various bit rates with distance 1-3 km. It is clearly shown that, at distance 1 km the power received for bit rate 155 Mbps, 622 Mbps and 2.5 Gbps are 7.017 dBm, 7.694 dBm and 14.793 dBm, respectively. Meanwhile, at distance 2 km are -7.02, -6.347 and 0.751 dBm. Then, -16.068, -15.39 and -8.292 dBm for distance 3 km. It has been clearly seen that the higher the attenuation, the lower the power received. From the analysis that has been done, the bit rate 2.5 Gbps shows the best performance for transmission link at distance 1 km as it can reduce the effect of attenuation and thus preventing high power loss. The bit rate 2.5 Gbps proved that high bit rate can enhance the transmission link 48% compared to bit rate 155 Mbps and 622 Mbps are 4%. Figure 6 demonstrates the relationship between BER and OWC attenuation with various bit rates. The possible

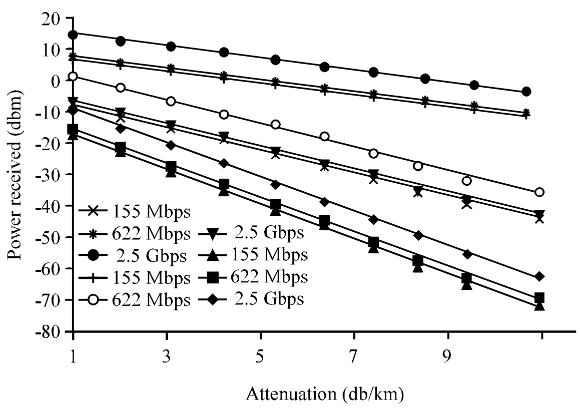

Fig. 5: The graph of power received versus the attenuation against vrious bit rates

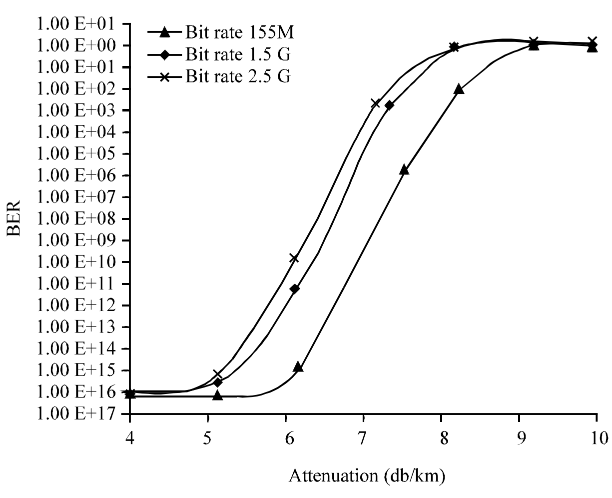

Fig. 6: The graph of BER and OWC attenuation against various bit rates

maximum attenuation that system can be achieved will be a better performance for OWC link system. It is obviously shown that at bit rate 155 Mbps the maximum attenuation are 6.9 dB/km. Meanwhile, at bit rate 1.5 and 2.5 Gbps the maximum attenuation are 5.5 and 5.4 dB/km, respectively. From the analysis that has been done, the bit rate 155 Mbps shows the best performance regarding the higher bit rate. This means that low bit rate results are better performance. High bit rate leads to high speed but high speed is not suitable in this condition because the atmospheric phenomena were unpredictable. Usage of high bit rate transmission in bad atmospheric phenomena will make the system worse.

CONCLUSION

Various bit rates of 155 Mbps, 622 Mbps and 2.5 Gbps for optical wireless communication link has been investigated. The investigations reveal that communication system with 2.5 Gbps bit rate is best suited for optical wireless communication link based on analysis of attenuation effects on power received of the system and bit rate of 155 Mbps is for the analysis of attenuation effect on Bit Error Rate (BER). Based on the studies, OWC System using 155 Mbps bit rate is proven theoretically and practically to improve greatly the link. The maximum power received achieved is 14.793 dBm at 1 km. Most of the power loss due to attenuation is reduced and high rate transfer could be achieved. Nonetheless, optical signal with lower bit rate is a better choice to be used for further distance since the system performance is better at lower bit rates. Then, the receiver sensitivity has the range of -46 to -20 dBm suits the bit rate of 155 Mbps. So, bit rate of 155 Mbp is the most suitable bit rate to reduce the attenuation effects on the transmission link and thus enhancing the performance of the system.

ACKNOWLEDGEMENT

This research was support by the High Ministry of Education Malaysia under the Fundamental Research Grant Scheme (FRGS) #9003-00556.

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