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A Novel of an Optimal Power Received in Outdoor Optical Wireless Access Networks

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Abstract
Optical wireless communication systems are gaining popularity because of its benefits and advantages over conventional radio frequency (RF) communication systems. This paper presents the analysis of optical wireless communication system based on effect of various bit rates on the power received and bit error rate (BER) on the power received. From the mathematical analysis, optical wireless communication system with bit rate of 155 Mbps is proven to be the most suited to improve the performance of the system regarding attenuation effect on the link compared to bit rate of 622 Mbps, 1.5 Gbps, and 2.5 Gbps, respectively. It increased the system efficiency by 17%, 14% and 10% as compared to the three other bit rates in the studies of BER effects on power received. In addition, the plot between distance versus power received, bit rate of 155 Mbps had shown superior performance as it improves the link by 28% and 2% compared to 622 Mbps and 2.5 Gbps, where it is reliable for future optical wireless usage.

Keywords: attenuation; bit rate error (BER); distance; power received; Optical Wireless Communication; pointing loss

INTRODUCTION

Radio Frequency (RF) is having problems such as frequency scarcity, security loopholes, bandwidth limitation, frequency hazards, and electromagnetic interference. These limitations have encouraged the researchers to focus on substitution methods which can not only settle up the limitations related to RF but also well suited in Next Generation Network[1]. Since the late 1970's, important studies and research have been done on the applications of optical wireless (IR) technology to high-speed data communications. Besides that, remarkable efforts have been devoted to understanding and applying optical wireless method for long distance inter-satellite system. Interest in the use of optical wireless links in digital transmission of signal through the atmosphere has been brought by the upsurge request of wireless links which are easier, faster and less expensive to deploy [2-4]. Recently, optical wireless communication systems have become low cost, simple and easy to install, and are thus progressively installed to offer high-speed, broader bandwidth communication links. These systems can simply offer high speed communications without the trouble and cost of installing high-capacity optical fiber cables [5]. Figure 1 below shows the diagram of typical point-to-point optical wireless system. Point-to-point wireless optical links operate when there is a direct, unobstructed path between a transmitter and a receiver of a communication system.

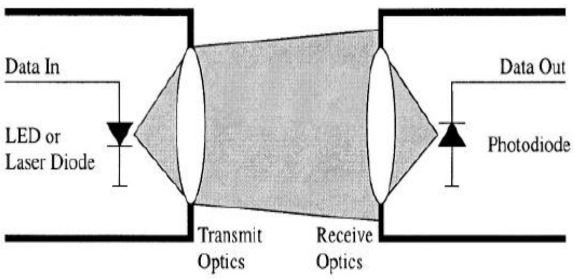

Figure 1: A point-to-point optical wireless communication system [6]

Optical wireless communication refers to the transmission of modulated near-infrared (NIR) beams through the atmosphere to obtain optical communications. It is a superior technology, which uses line-of-sight (LOS) propagation of optical signals (IR) through the atmosphere [7]. OWC is the optical radiations which transmit data in free space or air within the wavelength ranging from infrared to ultraviolet (UV) frequencies. A basic optical wireless system consists of a transmitter (using LEDs or LDs), free space as the propagation medium and the receiver (using APDs or PIN diodes). Input is generally in the form of digital data. It is inserted to the electronic circuitry that modulates the transmitting light source (LEDs/LDs) [8]. LEDs have many advantages such as quick response time, longer Mean Time before Failure (MTBF), high frequency modulation capability, energy efficiency and affordable over conventional fluorescent lamps [1]. The source output passes through an optical system into the free space (propagation medium). The received signal also comes through the optical system and passes along the optical signal detectors (PIN diodes/APDs) and thereafter to signal processing electronics [8].

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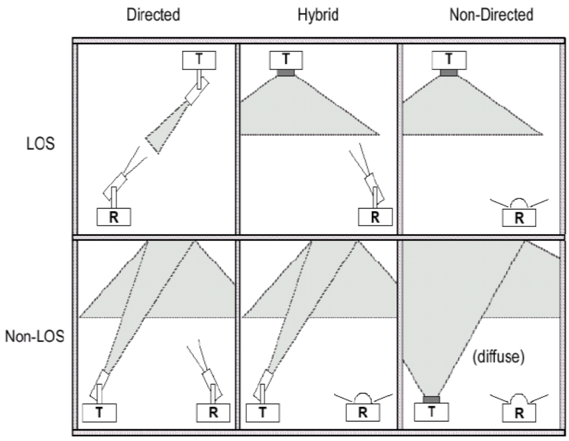

Figure 2. Infrared transmission techniques for indoor optical wireless systems.

Figure 2 above shows the techniques of infrared transmission for indoor optical wireless systems. Infrared transmission has shown several promising benefits to the communication field as a medium for indoor communication. However it also has some drawbacks. Some aspects impair and reduce greatly the performance of indoor IR transmission systems. They are speed limitations of the opto-electronic devices, high path losses leading to the requirement of higher transmission power levels, multipath dispersion, receiver noise, shot noise induced by the background ambient light, and the interference induced by the artificial light sources [9-11].

TABLE I. LASER SAFETY CLASSIFICATIONS FOR A POINT-SOURCE EMITTER [8].

CLASS	650 nm (visible)	880 nm (infrared)	1310 nm (infrared)	1550 nm (infrared)
Class 1	< 0.2 mw	< 0.5 mw	< 8.8 mw	< 10 mw
Class 2	0.2 - 1 mw	N/A	N/A	N/A
Class 3A	1 – 5 mw	0.5 – 2.5 mw	8.8 – 45 mw	10 – 50 mw
Class 3B	5 – 500 mw	2.5 – 500 mw	45 – 500 mw	50 – 500 mw

In some applications, transmit power is restricted, in order to observe eye and skin safety regulations and on the other hand, sensitivity of optical receivers is influenced by the shot noise due to the background light [12]. Hence, link budget management becomes very crucial and challenging [13]. Moreover, OW systems run under strict eye safety regulations, while at the same time incoherent OW receivers' present lower sensitivity than their RF counterparts because of their photo-electric conversion mechanisms and the impact of ambient light noise sources [14]. Eye safety consideration highly restricts the discharged amount of optical power by the transmitter, thus the coverage of an optical wireless system is limited to certain level only. Both indoor and outdoor optical wireless systems are capable of causing hazard if LDs are run at high output power. The eye safety standards are set by International Electro-technical Commission (IEC), where LDs are categorized regarding their total emitted power into Class 1, 2, 3A and 3B as shown in Table I. They dictate that all transmitters must be Class 1 eye safe under all situations and launch power must be lower or equal to 0.5 mW for the systems employing laser sources.

TABLE II. COMPARISON OF WIRELESS OPTICAL TOPOLOGIES

	Point-to-point	Diffuse	Quasi- Diffuse
Rate	***High***	***Low-moderate***	***Moderate***
Pointing required	Yes	No	Somewhat
Immunity to blocking	Low	High	Moderate-high
Mobility	Low	High	Moderate high
Complexity of Optics	Low	Low-moderate	High
Ambient light rejection	High	Low	high
Multipath distortion	None	High	Low
Path loss	Low	high	moderate

Table II displays the comparison of optical wireless topologies. A new conception of Optical Wireless includes the use of single-mode fibers (SMF) directly as light launchers and light-collectors. As this technique by-passes the conversion into the electrical domain, an all-optical treatment of the information can be done so that high performances accomplished by optical fibers can be exploited [15]. Optical wireless systems are able to work over distances of several kilometers [16-17]. The communication is achievable as long as there is a clear line of sight between the source and the destination and the transmitter power is sufficient. The performance of OWC systems influenced significantly by the channel conditions. Due to changes in refractive index, atmospheric interference is named as the major impairment of OWC links. The three most significant conditions that affect optical transmission are absorption, scattering and scintillation. All these three can reduce the amount of energy arriving at the receiver, thereby compromising the overall reliability of the system and BER levels of the received information [18]. Figure 3 shows the effects of atmospheric attenuation on OWC system.

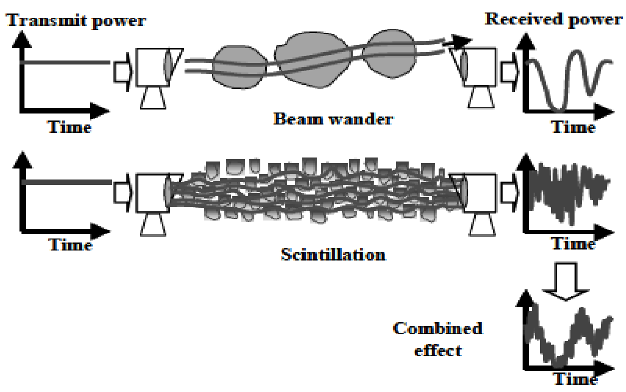

Figure 3. Effects of atmospheric attenuation on OWC system [5]

SYSTEM DESIGN

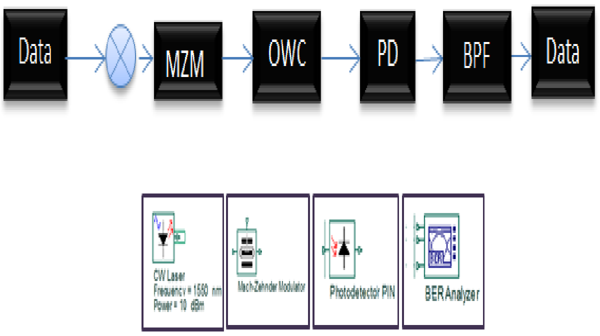

Figure 4. Block diagram of optical wireless communication transmission system

Figure 4 shows the block diagram 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. 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 [18] to give modulating electrical signal input to the Mach-Zehnder modulator. The modulated signal is send through OWC (Optical wireless Channel). As the altitude of the satellites being above the Earth's atmospheric layers, there is no attenuation due to atmospheric effects [19].

The OWC in OptiSystem simulation is between an optical transmitter antenna and optical receiver antenna at each end. The transmitter and receiver gains are 0dB. 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 [20]. 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

A. 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 [21]. 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

$$BER = \frac{1}{2} erfc(\frac{Q}{\sqrt{2}}) \approx \frac{1}{\sqrt{2\pi Q}} \exp(-\frac{1^2}{2}) \qquad (1)$$

From the equation 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

$$Q = T_0 \frac{I_1 - I_0}{\sigma_0 + \sigma_1} \qquad (2)$$

where
T_0 = The maximum transmittance
I_0 *and* I_1 = The average detected signal current

B. Link Budget of Optical Wireless Communication

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 III 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 [22].

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

where
P_R= Received power
P_T= Transmit Power
η_T= Transmitter optics efficiency
η_R= Receiver optics efficiency
λ= Signal wavelength
Z= Transmitter-receiver distance
G_T= Transmitter optical antenna gain
G_R= Receiver optical antenna gain
L_T= Transmitter pointing loss
L_R= Receiver pointing loss

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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_R(5) optical antennae is formulated by

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

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

where,

D = 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 equation 6 as shown below

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

where

θ = the divergence angle

Along with specifications concerning the frequency and distortion performance, the noise sources of a wireless optical link are crucial factors in determining performance. The determination of noise sources at the input of the receiver is important as this is the location where the incoming signal contains the least power. Noise is produced because of the random motion of carriers in resistive and active devices. An estimation of the signal-to-noise ratio of the system can be determined by equation (7)

$$SNR_{link} = \frac{P_{signal}}{P_{noise}}$$

$$= \frac{1}{2} \cdot \frac{m^2(R_p P_r)^2}{i_{circ}{}^2 + 2qR_p(P_r + P_{amb})B_{eff}} \quad (7)$$

where

q = electronic charge

B_{eff} = equivalent noise bandwidth of the system

TABLE III. THE LIST OF PARAMETERS USED IN THE RESEARCH

S.No.	Parameter	Values
1	Modulator	Mach-Zehnder
2	Tx. Power	6 dBm
3	Wavelength	1550 nm
4	Attenuation	1-10 dB/km
5	Tx. Apperture Diameter	15 cm
6	Rx. Apperture Diameter	15 cm

RESULT AND DISCUSSION

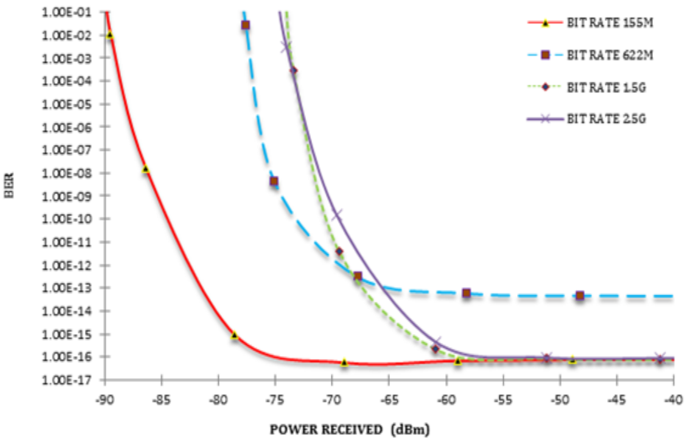

Figure 5. The graph of BER and OWC power received against various bit rates

Figure 5 shows the relationship between BER and OWC power received with various bit rates. It is obviously shown that, at bit rate of 155 Mbps the power received are -86.4 dBm. Nonetheless, at bit rate of 622 Mbps, 1.5 Gbps, and 2.5 Gbps, the maximum power received are -77.5 dBm, -74.4 dBm, and -73.0 dBm respectively. From the analysis that has been done, the system with bit rate of 155 Mbps shows the best performance regarding the lower bit rate transmission links. This means that better performance is achievable by utilizing low bit rate system. High bit rate leads to high speed data transmission however it is not suitable and applicable in this condition because the atmospheric phenomena are unpredictable. A system running using high bit rate transmission links in bad atmospheric phenomena will worsen the system. Most importantly, the system with 155 Mbps bit rate shows respective improvements of 17%, 14% and 10% compared with those OWC system by using a bit rate of 622 Mbps, 1.5 Gbps, and 2.5 Gbps.

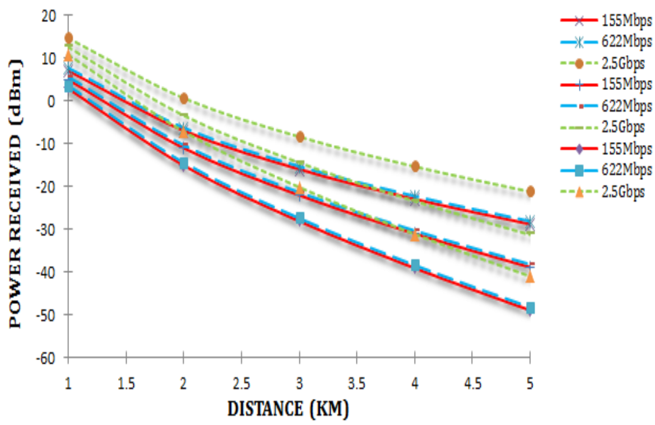

Figure 6. The graph of power received versus the distance at various bit rate with attenuation 1 to 3 dBm.

Figure 6 shows the graph of power received versus the distance (link range) at various bit rates with attenuation 1 to 3 dBm. It is clearly shown that, at attenuation 1 dB 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 attenuation 2 dB are 5.017 dBm, 5.964 dBm and 12.793 dBm. Then 3.017 dBm, 3.694 dBm and 10.793 dBm for attenuation 3 dB. It has been clearly seen that the higher the distance, the lower the power received. From the analysis that has been done, the bit rate 155 Mbps shows the best performance for transmission link that can reduce the effect of atmospheric attenuation and thus preventing high power loss. The bit rate 155 Mbps proved that high bit rate can enhance the transmission link by 28% and 2% compared to bit rate 622 Mbps and 2.5 Gbps.

CONCLUSION

Resolution can be made from the observation, at performance analysis of bit rate 155 Mbps has a better performance and reliable for OWC communication rather than 622 Mbps, 1.5 Gbps and 2.5 Gbps respectively. Furthermore, 155 Mbps capable to achieve an optimum received power which is -86.4 dBm. By using this optical signal with low bit rate, it will be utilized for longer distance in this system for better quality of service in optical access network for future generation usage. The architecture of OWC system presented performance in better at lower bit rate.

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