Performance Analysis for Indoor Optical Wireless Communication System

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Abstract – **The worldwide demand for wireless communications is being met in many places by installed single-mode fiber networks. However, there is still a significant "first-mile" problem, which seriously limits the availability of broadband Internet access. Optical wireless communication (OWC) or free-space optical wireless communications (FSO) has emerged as a viable technology for bridging gaps in existing high-data rate communications networks, and as a temporary backbone for rapidly deployable mobile wireless communication infrastructure. This paper will review the link performance of the indoor optical wireless system. The optical wireless link was modeled and simulated using a commercial optical system simulator named OptSim by RSoft.**

Keyword – Optical wireless communication (OWC), free-space optical wireless communications (FSO)

I. INTRODUCTION

Free-space optical (FSO) communications, also known as optical wireless communications (OW) is an emerging broadband technology that provides fast, secure and reliable data transmission [1]. Although OW test systems of this sort were developed in the '60s, the technology did not catch on. Optical fiber communications had not been developed and a need for a high-bandwidth "bridging technology" did not exist. The proliferation of high-speed optical fiber networks has now created the need for a high-speed bridging technology that will connect users to the fiber network, since most users do not have their own fiber connection [2]. This has been called the "first" or "last" mile problem.

Since the late 1970's, significant research has been done on the applications of optical wireless (IR) technology to high-speed indoor data communications and this is still an active area of research [2-4]. Also, in the past several years, extensive effort has been devoted to understanding and implementing optical wireless technique for long distance inter-satellite systems (outdoor applications). But it is the indoor applications that are the driving force behind optical wireless. The first indoor optical wireless system was developed in 1979 [5]. This system used the infrared radiation which was spread in all directions. Such systems are called diffused infrared systems. Since then several products using IR radiation has been successfully commercialized [2-6]. The advancement of inexpensive optoelectronic devices, such as LEDs and LDs, p-intrinsic-n (PIN) photo-diodes and avalanche photo-diodes (APDs) and various optical components, has resulted in the improvement of these systems. Indoor optical wireless systems have been used in many applications in the past few years, ranging from simple remote controls in home to more complex wireless local area networks. Many other applications are envisaged for the future, including data networking in the indoor environment and the delivery of broadband multimedia services to mobile users within such an environment together with general connectivity to base networks.

II. METHODOLOGY

The OptSim software is develop by RSoft Design Group to perform the optical communication simulation. It provides an easy interface which is common to many other electrical engineering tools. OptSim is an intuitive modeling and simulation environment supporting the design and the performance evaluation of the transmission level of optical communication systems. OptSim is ideally suited for design of all-optical networks such as FSO link.The block diagram design in Optsim of indoor optical wireless communication is shown in Figure 1.

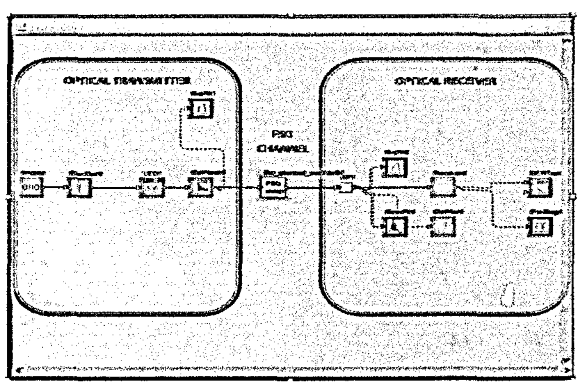


Figure 1: Block diagram of indoor optical wireless

A. Transmitter

In general, for indoor optical wireless transmitter, LDs are preferable over LEDs because they have higher optical power outputs, broader modulation bandwidths and linear electrical to optical signal conversion characteristics [7]. Linearity in signal conversion is particularly important when sophisticated modulation schemes such as multi-subcarrier modulation or multilevel signaling are used. But due to safety reasons (eye safety) laser diode cannot be used directly for the indoor IR systems, where radiation can enter a human eye quite easily. LDs are highly directional radiation sources and can deliver very high power within a small area on the retina thereby resulting in permanent blindness. On the other hand, LEDs are large-area emitters and thus can be operated safely at relatively higher powers. They are also less expensive and more reliable. The safety standard recommends that the indoor system must be Class 1 eye safe under all conditions. Table 1 show that for systems employing laser sources, launch powers must not exceed 0.5 mW at the short wavelengths where most low-cost devices operate [8].

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Class 1	Up to 0.2 mW	Up to 0.5 mW	Up to 8.8 mW	Up to 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

Table 1: Laser safety classifications for a point-source emitter (note that Class 2 only applies to visible light sources). [8]

Contemporary systems now run signals in the far end of the infrared range, with wavelengths in the 780-850 nm range, and even the 1550 nm range. Because retina has no pain sensors, at 800nm the retina could be permanently damaged But the laser beams at 1550nm wavelength are absorbed by the cornea and the lens and do not focus on the retina. The better choice is to use wavelengths near 1550nm because the Eye safety regulations permit 50 times more transmitted power at 1550nm than 800nm.
As for modulation schemes there are many different types which are suitable for optical wireless communication systems each with its own advantages and disadvantages. Most common schemes suitable for indoor optical wireless are the On-Off Keying (OOK) [9].

B. FSO Channel

Like any wireless system, the link power budget for an optical wireless system is strongly dependent on atmospheric loss along the path of the propagation. Since indoor atmosphere is free of environmental degradation, such as mist, fog, particulate matter, and clouds, indoor optical wireless systems encounter only free space loss and signal fading. The free space loss is that part of the transmitted power, which is lost or not captured by the receiver's aperture in figure 2. A typical figure for a point-to-point system that operates with a slightly diverging beam would be 20dB, whereas an indoor system using a wide-angle beam could have a free space loss of 40dB or more [10].

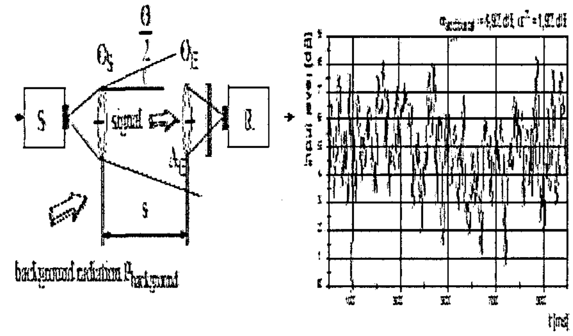


Figure 2: Transmission link via atmosphere and fluctuations of the additional attenuation by turbulences

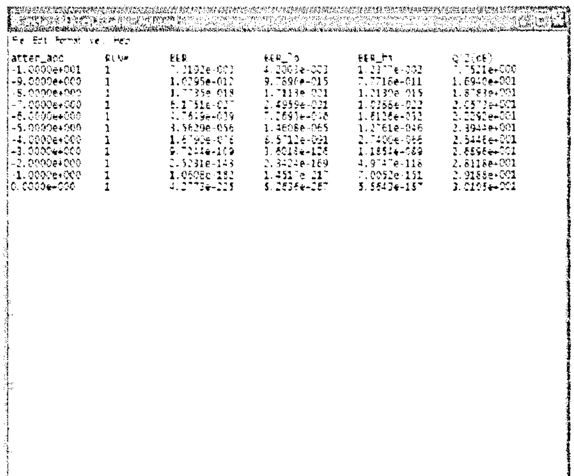
Signal Fading can be observed in indoor optical wireless system. The reason for this is reception of signals via different paths by the receiver. Some of these interfere destructively (out of phase), so that the received signal power effectively decreases. This type of degradation is also known as multi-path signal fading [11].

C. Receiver

There are two basic detectors which is the PIN diodes and the APDs. PIN receivers are commonly used due to their lower cost, tolerance to wide temperature fluctuations and operation with an inexpensive low-bias voltage power supply. PIN receivers are about 10 to 15 dB less sensitive than APD receivers [9]. Increasing the transmitter power and using larger receiver lens diameter can compensate the reduced sensitivity of these receivers. On the other hand, the increased power margin afforded by the APDs provides a more robust communication link, which reduces the criticality of accurate aiming of lenses. This allows in reduction of transmitter power. In addition to this, the better internal gain of APDs increases the Signal-to-Noise Ratio (SNR). However, the APD receivers are costly and need high operating voltages. Systems in which economy is a priority, such as most indoor applications, used PIN receivers. The low pass filters (LPF) after the PIN diode is used to filter out the unwanted higher frequency signals.

III. RESULT AND DISCUSSION

Figure 1 shows an indoor optical wireless design under study. Transmitter consists of PRBS generator, NRZ Driver, and directly modulated LED at 1550 nm. FSO link has a 500 meters range. The environmental additional attenuation is specified. Receiver is a PIN (with electrical filter) and is followed by BER Tester. There are also Optical Meter, Spectrum, Eye Diagram, and Optical Waveform Analyzers.



atten_add	RUN#	BER	BER_Lo	BER_Hi	Q^2(dB)
-1.0000e+001	1	[illegible]	4.2003e-003	1.2377e-002	[illegible]
-9.0000e+000	1	1.0295e-012	9.7696e-015	7.7716e-011	1.6940e+001
-8.0000e+000	1	1.7735e-018	1.7113e-021	1.2130e-015	1.8753e+001
-7.0000e+000	1	6.2751e-027	2.4959e-031	2.0266e-022	2.0573e+001
-6.0000e+000	1	[illegible]	7.2691e-046	1.8126e-032	2.2292e+001
-5.0000e+000	1	3.5629e-056	1.4606e-065	1.2761e-046	2.3944e+001
-4.0000e+000	1	1.6790e-076	6.5712e-091	2.7400e-066	2.5446e+001
-3.0000e+000	1	9.7244e-109	3.8018e-126	1.1852e-089	2.6596e+001
-2.0000e+000	1	2.5231e-145	2.3424e-169	4.9747e-116	2.8118e+001
-1.0000e+000	1	1.0508e-182	1.4517e-217	7.0052e-151	2.9189e+001
0.0000e+000	1	4.2773e-225	5.2536e-267	3.5543e-157	3.0195e+001

Figure 3: Data

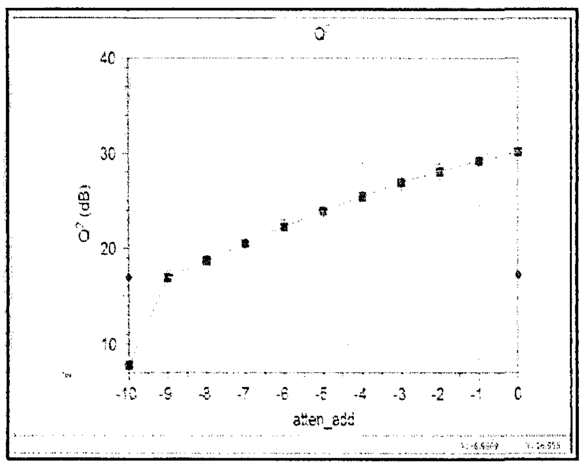


Figure 4: Q-factor additional attenuation of FSO channel. (Blue line corresponds to performance requirement at limit BER = 10e-12)

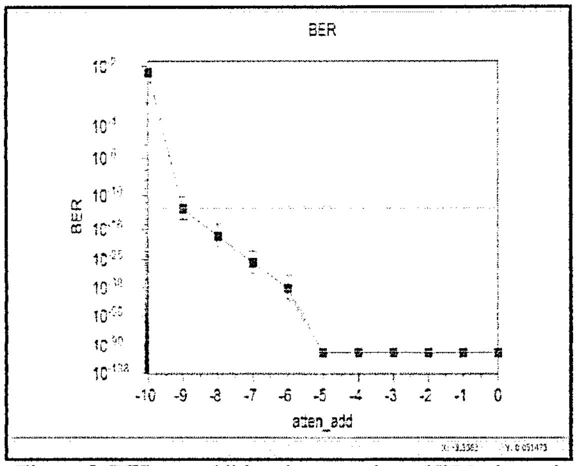


Figure 5: BER vs. additional attenuation of FSO channel. (Blue line corresponds to performance requirement limit at BER = 10e-12)

Figure 3 is accurate data (reading) from the graph of BER and Q-factor versus additional attenuation

Figure 4 and figure 5 shows BER and Q-factor versus additional attenuation for attenuation values from 0 to -10 dB. One can see the higher is attenuation the worse is performance. BER performance requirement is equal or less than 10^{-12} and it can see that the additional attenuation should be less than the threshold value which is –9 dB to satisfy the BER requirements. Total FSO channel loss is a sum of geometrical and additional attenuations. The geometrical loss for given parameters is about -17 dB. This link can tolerate up to –26 dB losses in FSO channel.

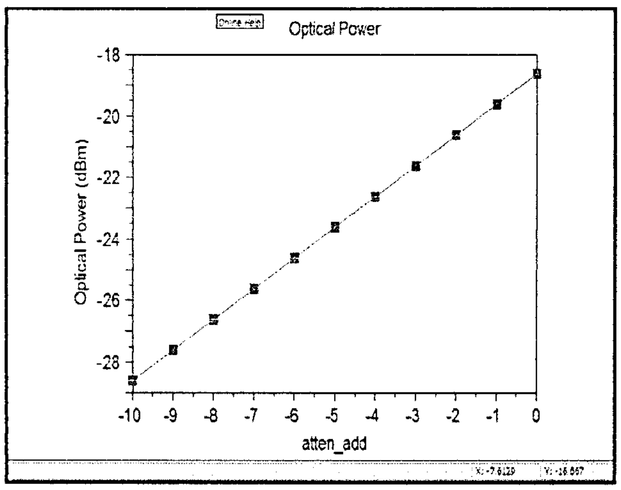


Figure 6: Input power to the receiver vs. additional attenuation of FSO channel

Figure 6 shows optical power into receiver vs. attenuation. The threshold value of additional addition (a_{add}) which is -9 dB corresponds to received power of – 27.5 dBm. The change in receiver input power due to additional variation causes the change in BER. Figures 7 and 8 show the receiver eye diagram and optical signal waveforms corresponding to threshold input power at BER=10^{-12}

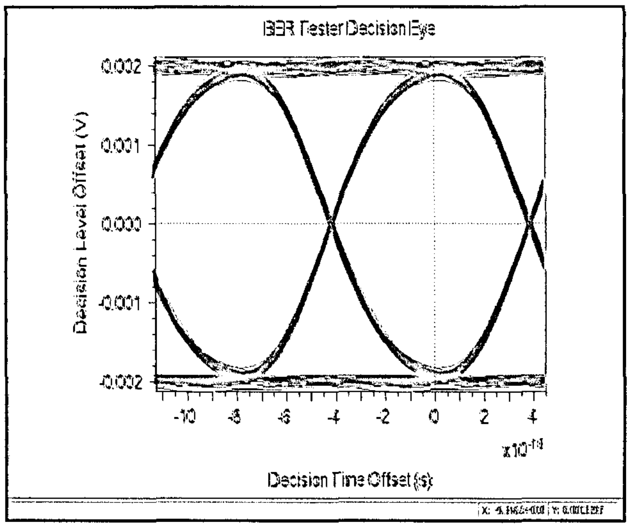


Figure 7: Receiver eye diagram at the threshold attenuation.

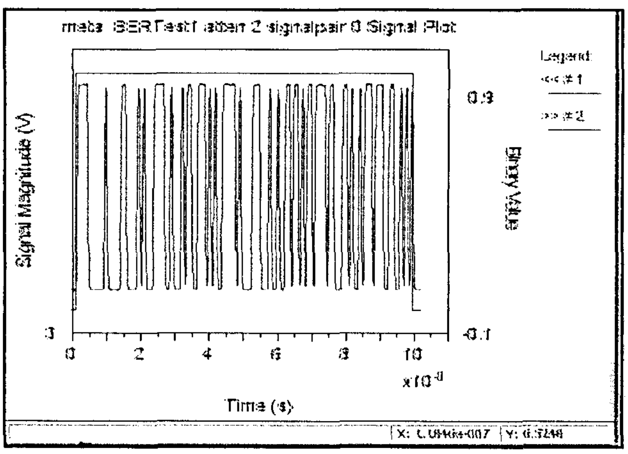


Figure 8: Optical signal waveform at receiver input for threshold attenuation value.

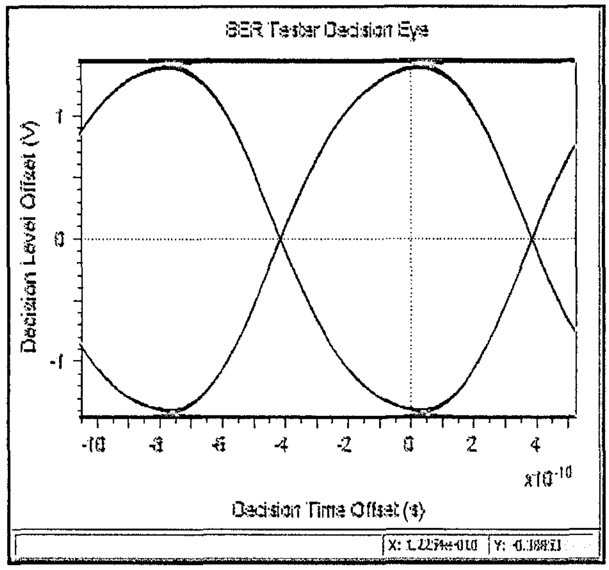


Figure 9: Receiver eye diagram in ideal condition

Figure 9 shown that the receiver eye diagram where the FSO channel is assumed to be ideal where losses this system is neglected. The eye diagram in Figure 7 consists of more jitter and the opening of the eye decreases compare to the Figure 9.

By analyzing statistical simulation data it can estimate the link availability by calculating the probability of additional attenuation is not less than threshold value – 9 dB. Analytically, assuming normal distribution one can derive it as

$$1 - D(\alpha_{dB}) = \frac{1}{2}\left[\mathrm{erfc}\left(\frac{\alpha_{threshold} - \langle\alpha_{dB}\rangle}{\sqrt{2}\sigma_{dB}}\right)\right] \quad (1)$$

Substituting here $\alpha_{threshold}$ = -9 dB, α_{dB} = -4.92dB, and α_{dB}^2 = 1.9 dB which is the α_{dB} and α_{dB}^2 is the additional environment attenuation of FSO channel represent as Gaussian distributed variable with mean value (α_{dB}) and standard deviation(α_{dB}^2). The normal distribution can calculate and the theoretical availability of this link as 98.412%

IV. CONCLUSION AND RECOMMEDATION

In conclusion, there are a variety of ways in which indoor optical wireless links may be configured, each offer the suitability for different applications. In terms of system design, the limitations directly imposed by the channel, such as path loss and dispersion, are largely dependent on the chosen link configuration. The advantage by using optical communication are there are no licensing requirement (a time saving future), no radio frequency (RF) radiation hazard (eye safe power level are maintained) and no tariff are require for its utilization (an operating cost saving). In this OWC, the simulation can be extended to more detailed systems on FSO channel for different settings of link parameters, such as link distances, laser types and power, aperture size at transmitter and receiver, modulation techniques which is one of the suitable modulations of the indoor optical wireless is DPSK, and so on.

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