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Performance & Analysis of High Data Rate Wireless Optical Communication for Short Range Application

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ABSTRACT: Optical wireless communications offer a viable alternatives to radio frequency (RF) communication for indoor use and other applications where high performance links are needed. These systems use infrared technology (IR), which has significant advantages over RF. This paper presents a review of the most significant issues related to infrared communication technology, which will enable the realization of future high performance and cost-effective indoor optical wireless systems. Several possible configurations for indoor optical wireless systems, modulation, and multi-access techniques are presented as well as their advantages and limitations discussed. In this paper we proposed implementation high speed of 12.5GHz optical communication for short range. Performance of system is checked in terms of bit error rate generated due to transmission channel noise and divergence angle.

KEYWORDS: Wireless Optical Communication, Data Transfer Rate, Bit Error Rate, Footprint, Optical Channel.

I. INTRODUCTION

In recent years, there has been a migration of computing power from the desktop to portable, mobile formats. Devices such as digital still and video cameras, portable digital assistants and laptop computers offer users the ability to process and capture vast quantities of data. Although convenient, the interchange of data between such devices remains a challenge due to their small size, portability and low cost. High performance links are necessary to allow data exchange from these portable devices to established computing infrastructure such as backbone networks, data storage devices and user interface peripherals. Also, the ability to form ad hoc networks between portable devices remains an attractive application. The communication links required can be categorized as short-range data interchange links and longer-range wireless networking applications. One possible solution to the data interchange link is the use of a direct electrical connection between portable devices and a host. This electrical connection is made via a cable and connectors on both ends or by some other direct connection method. The connectors can be expensive due to the small size of the portable device. In addition, these connectors are prone to wear and break with repeated use. The physical pin-out of the link is fixed and incompatibility among various vendors' solutions may exist. Also, the need to carry the physical medium for communication makes this solution inconvenient for the user.

Wireless radio frequency (RF) solutions alleviate most of the disadvantages of a fixed electrical connection. RF wireless solutions allow for indoor and short distance links to be established without any physical connection. However, these solutions remain relatively expensive and have low to medium data rates. Some popular "low cost" RF links over distances of approximately 10m provide data rates of up to 1 Mbps in the 2.4 GHz band for a cost near US$5 per module. Indoor IEEE 802.11 [1] links have also gained significant popularity and provide data rates of approximately 50 Mbps. Radio frequency wireless links require that spectrum licensing fees are paid to federal regulatory bodies and that emissions are contained within strict spectral masks. These frequency allocations are determined by local authorities and may vary from country to country, making a standard interface difficult. In addition, the broadcast nature of the RF channel allows for mobile connectivity but creates problems with interference between devices communicating to a host in close proximity. Containment of electromagnetic energy at RF frequencies is difficult and if improperly done can impede system performance.

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Table -1: Comparison between Wireless Optical and Radio Channel

Parameter	Wireless Optical	Radio Channel
RF circuit design	No	Yes
Data rate	100Mbps	10Mbps
Bandwidth	No	Yes
Security	High	Low
Cost	Low	High

The term wireless is synonymous with radio, and there are numerous radio LAN products on the market today. The majority of these products operate in the industrial, scientific and medical (ISM) band located at 2.4 GHz, which has the advantage of being license free in most countries. However, the available bandwidth is limited to 83.5 MHz, and must be shared with numerous other products on the market such as cordless telephones and baby monitors. Consequently, robust spread spectrum modulation techniques are required, which result in low data rates. As an example, the IEEE 802.11-1997 standard for wireless LANs specifies two radio physical layers for operation in the 2.4 GHz ISM band. These two physical layers use frequency-hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS), and offer maximum user data rates of just 2 Mbit/s [2]. This was improved upon in 1999 with the ratification of IEEE 802.11b, which adds two higher data rates of 5.5 Mbit/s and 11 Mbit/s to the DSSS standard [3]. Many of the products currently on the market today are either based on this standard, or the Home RF standard, which also operates in the 2.4 GHz ISM band, and achieves a maximum data rate of 10 Mbit/s using FHSS [4]. The next generation of radio LAN products, which are just starting to emerge, operate in the so-called 5 GHz band, which has been allocated solely for use by wireless LAN products. Consequently, this allows systems to be optimized in terms of data rate and efficiency, free from the constraints associated with coexisting with other products. There are currently two competing standards in this band, these being IEEE 802.11a and HiperLAN2, both of which specify maximum data rates of 54 Mbit/s [5, 6]. One final radio LAN standard worthy of a mention is Bluetooth, which is a short range, point-to-multipoint standard for voice and data transfer, which again operates in the 2.4 GHz ISM band [7]. Whilst standard class 2 devices have an expected operating range of just 10 meters, and a maximum asymmetric data rate of a mere 723.2 kbit/s, the rationale behind Bluetooth is low cost, allowing it to be integrated into a variety of portable electronic devices which may then communicate with each other via ad hoc wireless networks termed piconets. Products equipped with Bluetooth are just starting to appear on the market.

Along with radio, the term wireless is also applicable to systems which utilize other regions of the electromagnetic spectrum, such as infrared. First proposed as a medium for short-range wireless communication more than two decades ago [8, 9], infrared offers a number of advantages over its radio frequency counterpart, such as [10]: (a) Abundance of unregulated bandwidth: 200 THz in the 700-1500 nm range (b) No multipath fading: intensity modulation and direct detection (c) High security (d) Higher capacity per unit volume (bps/m3): due to neighbouring cells sharing the same frequency (e) Cost effective at rates near 100 Mbps (f) Small cell size at 800-890 nm and 1550 nm absorption effects are minimal.

II. Optical Link Structure

Wireless optical links transmit information by employing an optoelectronic light modulator, typically a light-emitting diode (LED). The task of up- and down-conversion from baseband frequencies to transmission frequencies is accomplished without the use of high-frequency RF circuit design techniques, but is accomplished with inexpensive LEDs and photodiodes. Since the electromagnetic spectrum is not licensed in the optical band, spectrum licensing fees are avoided, further reducing system cost. Optical radiation in the infrared or visible range is easily contained by opaque boundaries. As a result, interference between adjacent devices can be minimized easily and economically. Although this contributes to the security of wireless optical links and reduces interference it also impacts rather stringently on the mobility of such devices. For example, it is not possible for a wireless optical equipped personal digital assistant to communicate if it is stored in a briefcase. Wireless optical links are also suited to portable devices since small surface mount light emitting and light detecting components are available in high volumes at relatively low cost.

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Indoor wireless optical communication systems are envisioned here as a complimentary rather than a replacement technology to RF links. Whereas, RF links allow for greater mobility wireless optical links excel at short-range, high-speed communications such as in device interconnection or board-to-board interconnect.

Communication systems transmit information from a transmitter to a receiver through the construction of a time-varying physical quantity or a signal. A familiar example of such a system is a wired electronic communications system in which information is conveyed from the transmitter by sending an electrical current or voltage signal through a conductor to a receiver circuit. Another example is wireless radio frequency (RF) communications in which a transmitter varies the amplitude, phase and frequency of an electromagnetic carrier which is detected by a receive antenna and electronics. In each of these communications systems, the transmitted signal is corrupted by deterministic and random distortions due to the environment. For example, wired electrical communication systems are often corrupted by random thermal as well as shot noise and are often frequency selective. These distortions due to external factors are together referred to as the response of a communications channel between the transmitter and receiver. For the purposes of system design, the communications channel is often represented by a mathematical model which is realistic to the physical channel. The goal of communication system design is to develop signaling techniques which are able to transmit data reliably and at high rates over these distorting channels.

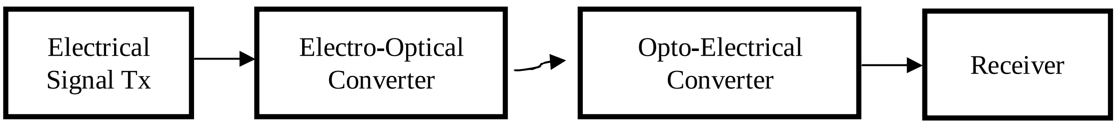

Fig.1. Block Diagram of Optical Trans receiver

III. CHANNEL CHARACTERISTICS

The basic channel characteristics can be investigated more fully by considering the operation of the optoelectronic devices alone. Device physics provides significant insight into the operation of these optoelectronic devices. This section presents an overview of the basic device physics governing the operation of certain optoelectronic devices, emphasizing their benefits and disadvantages for wireless optical applications.

(A) Light Emitting Devices:

Solid state light emitting devices are essentially diodes operating in forward bias which output an optical intensity approximately linearly related to the drive current. This output optical intensity is due to the fact that a large proportion of the injected minority carriers recombine giving up their energy as emitted photons.

To ensure a high probability of recombination events causing photon emission, light emitting devices are constructed of materials known as direct band gap semiconductors. In this type of crystal, the extrema of the conduction and valence bands coincide at the same value of wave vector.

(B)Laser Diodes

Laser diodes (LDs) are a more recent technology which has grown from underlying LED fabrication techniques. LDs still depend on the transition of carriers over the band gap to produce radiant photons; however, modifications to the device structure allow such devices to efficiently produce coherent light over a narrow optical bandwidth.

(C) Photodetectors

Photodetectors are solid-state devices which perform the inverse operation of light emitting devices, i.e., they convert the incident radiant light into an electrical current. Photodetectors are essentially reverse biased diodes on which the radiant optical energy is incident, and are also referred to as photodiodes.

The incident photons, if they have sufficient energy, generate free electron-hole pairs. The drift or diffusion of these carriers to the contacts of the device constitutes the detected photocurrent.

Inexpensive photo-detectors can be constructed of silicon (Si) for the 780– 950 nm optical band. The photonic energy at the 880 nm emission peak of GaAs is approximately by Eg=1.43eV. Since the band gap of silicon is approximately 1.15 eV, these photons have enough energy to promote electrons to the conduction band, and hence are able to create free electron-hole pairs.

IV. INDOOR WIRELESS SYSTEM

Since the late 1970's, significant research has been done on the applications of optical wireless (IR) technology to high-speed indoor data communications; this is still an active area of research [12,15,16]. 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 [17]. 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 have been successfully commercialized [12,15,16,18,19]. The advancement of inexpensive opto-electronic 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. Several companies have introduced data communication products using optical wireless technology and many other computer communication products are entering the market [18,20,21].

A block diagram of a typical indoor optical wireless system is illustrated in Fig.1. 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). Information, typically in the form of digital data, is input to electronic circuitry that modulates the transmitting light source (LEDs/LDs). The source output passes through an optical system (typically has telescope and optical diplexer) 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. The wavelength band from 780nm to 950nm is the best choice for indoor optical wireless systems. In this range, low cost LEDs and LDs are readily available. Also, this band coincides with the peak responsivity of inexpensive, low-capacitance silicon photodiodes. The optical wireless system uses IR technology in which links are based on intensity modulation and direct detection (IM/DD) of the optical carrier. Intensity modulation is performed by varying the drive current of LED or LD (direct modulation). Direct detection is performed by PIN photo-diodes or APDs which produce an electric current proportional to the incident optical power.

(A) *Transmitter:*

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 [22]. 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. Consequently, LEDs are the preferred light source for most indoor applications. To compensate for the lower powers, array of LEDs can be used. However, LEDs cannot be used beyond 100 Mbps due to the limitations imposed by the mechanism by which they emit light, whereas LDs can be used for transmission at bit rates of the order of a few Gbps. A comparison between LEDs and LDs is shown in Table 1 [23].

(B)*Propagation Medium:*

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, clouds etc., indoor optical wireless systems encounter only free space loss and signal fading.

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Free Space Loss: It is that part of the transmitted power, which is lost or not captured by the receiver's aperture. 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 [23].

Signal Fading: This can be observed in both indoor and outdoor optical wireless systems. The reason for this is reception of signals via different paths by the receiver. Some of these interfere destructively (i.e. they are out of phase), so that the received signal power effectively decreases. This type of degradation is also known as multi-path signal fading [22].

(C)*Receiver:*

As mentioned earlier, there are two basic detectors; 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 [24] than APD receivers. 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.

V. RESULTS & DISCUSSION

In this research work an optical link is design which is used to transmit signal with an infrared LED and to receive signal photodiode is used. The transmitter is positioned at d1 distant from surface. Receivers are placed on surface at different location. Hence divergence angle will be 3.2 to cover all receivers. d2 is the horizontal separation distance between BS and the shortest coverage point, which can be varied in order to estimate the transmitter's beam divergence angle θ. δ is the coverage angle at the longest point and β is the coverage angle at the shortest point. Using a simple geometry formula $\theta = \beta - \delta$, $\tan\beta = \frac{d_1}{d_2}$and $\tan\delta = \frac{d_1}{d_2+L}$.

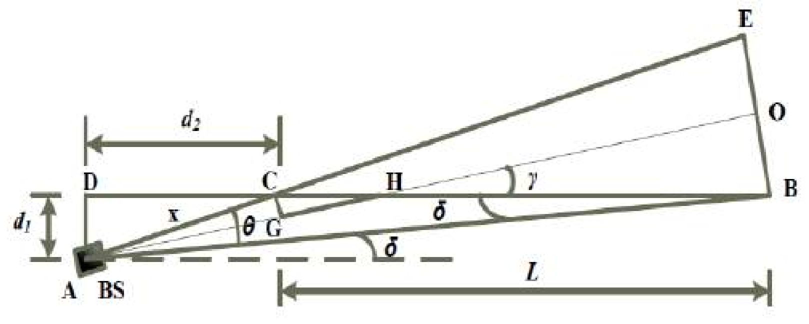

Fig. 2. System Geometry

The estimated transmitter beam divergence angle can be written as

$$\theta = \tan^{-1}\frac{d_1 L}{d_1^2+d_2 L+d_2^2} \quad \text{eq.(1)}$$

Hence, based on the position of the BS and the effective coverage length, the beam divergence angle can be approximated. The optical beam radius of a Gaussian beam is given as [15]:

$$p = p_0\left[1+\left(\frac{\lambda z}{\pi p_0^2}\right)^2\right]^{1/2} \quad \text{eq.(2)}$$

Where wo is the beam waist of the laser source at the transmitter, z is the axis of propagation and **λ** is the operating wavelength of the optical source.

Performance of the system is analyzed in the terms of bit error rate. The BER can be evaluated as

$$BER = F\sqrt{SNR} \quad \text{eq.(3)}$$

Where $F = \frac{300}{x}$ and SNR is signal to noise ratio at receiver

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$$SNR = (\frac{RP_{rx}}{\sigma_{Total}})^2 \text{eq.(4)}$$

Where R is responsivity and σ_{total} is total noise including shot noise, thermal noise and background noise.

The noise source at the detector is the combination of the shot noise, the thermal noise and the background noise. The typical value for the background radiation used is 9.5 μW. The total noise variance can be written as:

$$\sigma_{total}^2 = \sigma_{sh}^2 + \sigma_{th}^2 + \sigma_{bg}^2 \text{eq.(5)}$$

Where σ_{sh} variance due to shot noise, σ_{th} thermal noise and the σ_{bg} background noise

P_{rx} is received power.

$$P_{rx} = \frac{2\,P_{tx}A_{coll}}{\pi\omega^2} e^{-r} \text{eq. (6)}$$

Where r is data rate, P_{tx} is transmitted power, A_{coll} is the collection area at receiver.

ω is optical beam radius.

$$Z = L\cos\gamma + x\cos\theta_{1/2} \text{eq. (7)}$$

The FOV of the receiver using the optical concentrator is given by

$$A_{coll}\sin^2\Psi_c = n^2 A_{det} \text{eq.(8)}$$

Where A_{coll} the effective is light collection area of the receiver and A_{det} is the area of the photodetector.
n is the refractive index of an optical concentrator and ψc is the half-angle FOV of the receiver after the lens.
System parameters are shown in table 2.

Table 2: System Parameters

Parameters	Value (degree)
θ	3.20
Γ	2.25
λ	850 nm (eye safety)
A_{det}	10 mm2
P_{tx}	20 mW
R	0.49 A/W
R_{coll}	25 mm
F	50 mm
N	1.5
L	75 m
D	5 mm
P_n	10 μW

To modify the bit error rate performance a co-ordinate coding technique is applied due to which in case of error retransmission is requested. And the results are shown in below figures.
Bit error rate is calculated with respect to variable values of center line of sight to receiver distance. Results are plotted and shown in below fig. 3.

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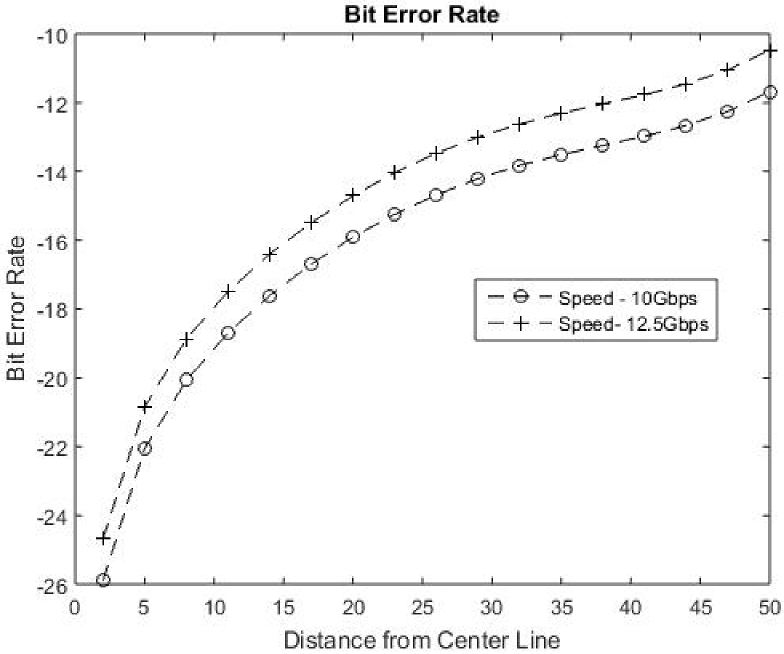

Fig. 3. Bit Error Rate with Increase in Distance from Line of Sight

Value of bit error rate for different values of distance is calculated and listed in table 3.

Table 3: BER at Different Values of Distance

S. No.	Distance	BER for Speed=10Gbps	BER for Speed=12.5Gbps
1	5	-22	-21.8
2	10	-19	-17.7
3	20	-16	-14.8
4	25	-15.76	-13.9
5	35	-14.3	-12.4
6	45	-13	-11.8
7	50	-11.8	-10.5

Bit error rate is again calculated for variable footprint and plotted on fig. 4 as shown below.

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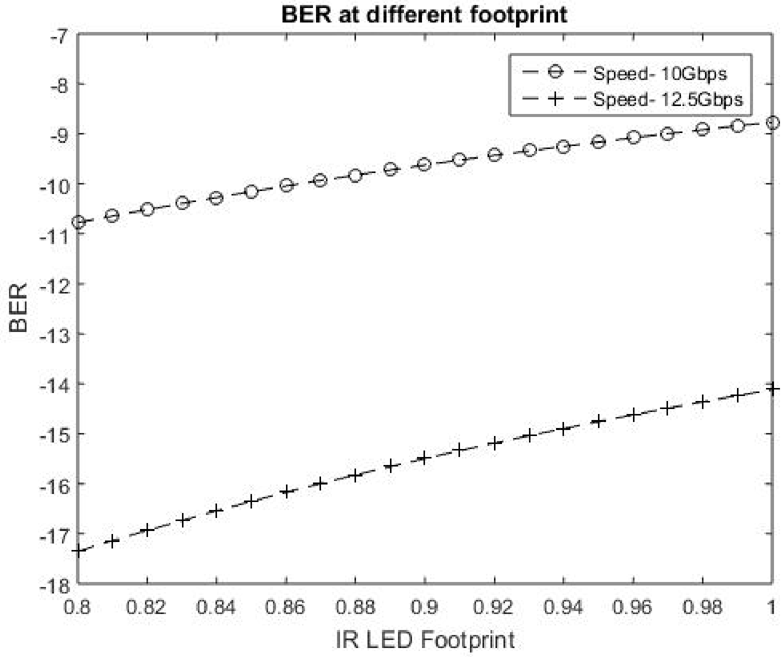

Fig. 4. BER for Different Values of IR LED Footprint

Comparison table 3 for different speed of transmission is compared. With increase in speed of transmission bit error rate is also increases.

Table 4: Comparison of BER for Different Speed of Transmission

S. No.	IR Foot Print	BER for Speed=10Gbps	BER for Speed=12.5Gbps
1	0.8	-10.9	-17.2
2	0.84	-10.75	-16.5
3	0.86	-10.34	-16.2
4	0.9	-9.8	-15.8
5	0.94	-9.6	-15.5
6	0.98	-9.45	-14.5
7	1	-8.8	-14.16

Now footprint is calculated for different values of data rates for different BER values and shown in fig. 5 below.

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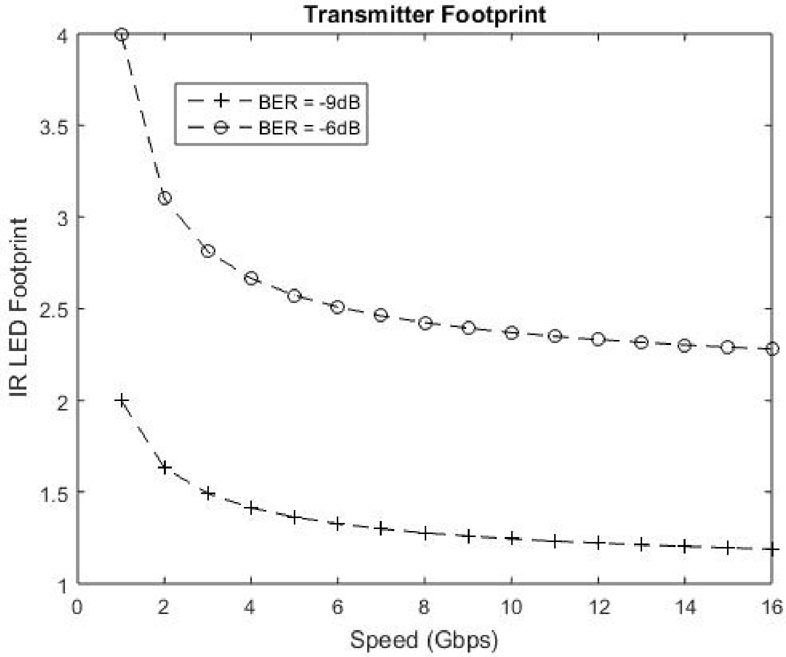

Fig. 5. IR LED Footprint at Different Speed

From above graph in fig. 5 it can be conclude that as transmission speed increases size of footprint decrease, so at higher speed only line of sight communication is possible. If receiver will not be line be in line of sight then only 1Gbps speed can be achieved for quality data transmission.

VI. CONCLUSION

In this paper optical based wireless communication is performed because a high data rate approximately 12.5 Gbps can be achieved. For short range application optical communication is better option than RF based communication as prior high secure and fast. To analyse the performance of optical wireless system bit error rate is calculated at different values of data rate and concluded that slower the transmission rate generate less noise to signal, but after applying coding technique to avoid chance of error less that 10dB bit error rate is achieved. Hence the proposed technique successfully implemented.

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