Bit Error Rate (BER) Analysis in Free Space Optical Communication

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Abstract: The concept behind FSO is simple. FSO uses a directed beam of light radiation between two end points to transfer information (data, voice or even video). This is similar to OFC (optical fiber cable) networks, except that light pulses are sent through free air instead of OFC cores. An FSO unit consists of an optical transceiver with a laser transmitter and a receiver to provide full duplex (bi-directional) capability. Each FSO unit uses a high power optical source (laser) plus a lens that transmits light through the atmosphere to another lens receiving information. The receiving lens connects to a high sensitivity receiver via optical fiber. Two FSO units can take the optical connectivity to a maximum of 4kms.

Free–space optical (FSO) communication has recently gained a lot of interest as an attractive solution for high rate last –mile terrestrial applications. FSO has many attractive features including the use of unlicensed parts of the electromagnetic spectrum, ease of deployment, cost efficiency, high security, and high data rates. There are however challenges in the design of FSO communication systems. Specifically, the weather –dependent optical wireless channel introduces attenuation and intensity variations known as turbulence–induced fading, which impose severe challenges for reliable data transmission. Meanwhile, the limitation in transmit power due to eye–safety regulations adds yet another design constraint.In this paper simulations have been conducted to study the Bit Error Rate (BER) performance of free space optical communication system.

1. THE TECHNOLOGY OF FSO

Free space optics (FSO) is a line-of-sight technology that Currently enables optical transmission up to 2.5 Gbps of data, voice, and Video Communications through the air, allowing optical connectivity without deploying Fiber optic cables or securing spectrum licenses.FSO System can carry full duplex data At giga bits per second rates over Metropolitan distances of a few city blocks of few Kms. FSO, also known as Optical wireless, overcomes this last-mile access bottleneck By sending high Bit rate signals through the air using laser transmission. Like fiber, free Space optics uses lasers to transmit data, but instead of enclosing the data stream in a Glass fiber, it is transmitted through the air[1]. It is secure, cost-effective alternative to other wireless connectivity options.

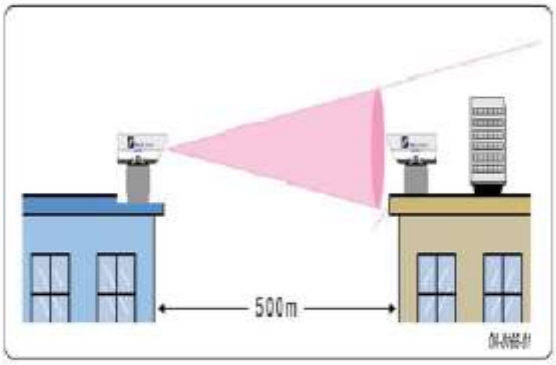

Figure 1: general FSO system

Free space optics or FSO, also called free space photonics (FSP) or optical wireless, refers to the transmission of modulated visible or infrared beams through the atmosphere to obtain optical communication. FSO systems can function over distances of several kilometers. FSO is a line-of-sight technology, which enables optical transmission up to 2.5 Gbps of data, voice and video communications, allowing optical connectivity without deploying fiber optic cable or securing spectrum licenses. Free space optics require light, which can be focused by using either light emitting diodes(LED) or LASERS(light amplification by stimulated emission of radiation). The use of lasers is a simple concept similar to optical transmissions using fiber-optic cables, the only difference being the medium.

As long as there is a clear line of sight between the source and the destination and enough transmitter power, communication is possible virtually at the speed of light[1][2]. Because light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of light. FSO works on the same basic principle as infrared television remote controls, wireless keyboards or wireless palm devices.

2. NEED FOR FSO

The increasing demand for high bandwidth in metro networks is relentless, and service pursuit of a range of applications, including metro network extension, enterprise LAN-LAN connectivity, wireless backhaul[3].

The main reasons for choosing free space optics communication is

- Cost
- Permits
- Trenching
- Time
- Medium of transmission is free space/air.

3. WORKING OF FSO SYSTEM

Free Space Optics (FSO) transmits invisible, eye-safe light beams from one "telescope" to another using low power infrared laser in the terahertz spectrum. The beams of light in Free Space Optics (FSO) systems are transmitted by laser light focused on highly sensitive photon detector receivers. These receivers are telescopic lenses able to collect the photon stream and transmit digital data containing a mix of Internet messages, video images, radio signals or computer files.

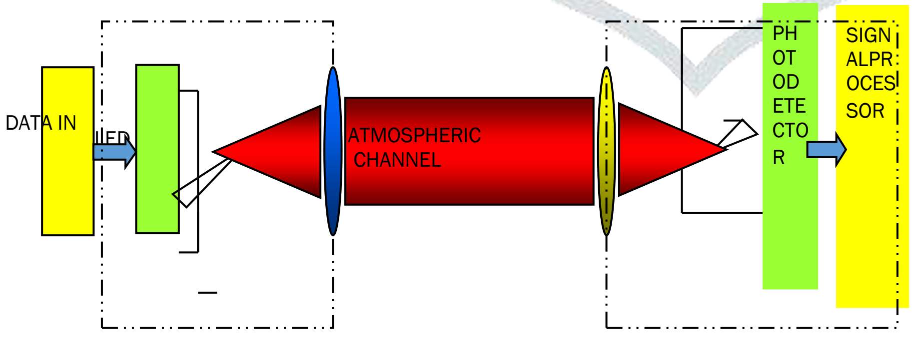

Figure 2: working of FSO

Commercially available systems offer capacities in the range of 100 Mbps to 2.5 Gbps, and demonstration systems report data rates as high as 160 Gbps. Free Space Optics (FSO) systems can function over distances of several kilometers. As long as there is a clear line of sight between the source and the destination, and enough transmitter power, Free Space Optics (FSO) communication is possible.

4. LIMITATIONS IN FREE SPACE OPTICAL COMMUNICATION

Optical wireless systems offer many features, principal among them being low start-up and operational costs, rapid deployment, and high fiber-like bandwidths. These systems are compatible with a wide range of applications and markets, and they are sufficiently flexible as to be easily implemented using a variety of different architectures. Because of these features, market projections indicate healthy growth for optical wireless sales. Although simple to deploy, optical wireless transceivers are sophisticated devices. The different elements considered by the system engineer when designing the product are discussed below.

4.1 WAVELENGTH: Currently available Free Space Optics (FSO) hardware can be classified into two categories depending on the operating wavelength systems that operate near 800 nm and those that operate near 1550 nm.There are compelling reasons for selecting 1550 nm Free Space Optics (FSO) systems due to laser eye safety, reduced solar background radiation, and compatibility with existing technology infrastructure [9].

4.2 EYE-SAFETY: Laser beams with wavelengths in the range of 400 to 1400 nm emit light that passes through the cornea and lens and is focused onto a tiny spot on the retina while wavelengths above 1400 nm are absorbed by the cornea and lens, and do not focus onto the retina.

4.3ATMOSPHERIC ATTENUATION: Carrier-class Free Space Optics (FSO) systems must be designed to accommodate heavy atmospheric attenuation, particularly by fog. However, the fact that 1550 nm-based systems are allowed to transmit up to 50 times more eye-safe power will translate into superior penetration of fog or any other atmospheric attenuator [4].

5. CHALLENGES IN FSO: The advantages of free space optics come without some cost. It should always maintain the LOS (line of sight) path for communication. If there is no LOS path the communication is not carried out. As the medium is air and the light pass through it, some environmental challenges are inevitable.

5.1. FOG: Fog substantially attenuates visible radiation, and it has a similar effect on the near-infrared wavelengths that are employed in FSO systems. Rain and snow have little effect on FSO. Fog being microns in diameter, it hinder the passage of light by absorption[5], scattering and reflection.

5.2. PHYSICAL OBSTRUCTIONS: Flying birds can temporarily block a single beam, but this tends to cause only short interruptions and transmissions are easily and automatically re-assumed. Multi-beam systems are used for better performance [5][7].

CHALLENGE	EFFECTS	OPTIONS
RAIN&FOG	Scattering	Increase transmit optical power
GASES & SMOKE	Phase fluctuation	Diversity techniques

Table 1: list of Challenges in FSO systems

5.3. SOLAR INTERFERENCE: This can be combated in two ways.

 The first is a long pass optical filter window used to block all wavelengths below 850nm from entering the system.

- The second is an optical narrow band filter proceeding the receive detector used to filter all but the wavelength actually used for intersystem communications.

5.4. SCATTERING: Scattering is caused when the wavelength collides with the scatterer. The physical size of the scatterer determines the type of scattering. In scattering there is no loss of energy, only a directional re-distribution of energy which may cause reduction in beam intensity for longer distance[6].

6. BIT ERROR RATE ANALYSIS

***1) Power*:** Suppose we have a signal x(n), wherenis an index of the sample number. We definethe instantaneous power of the signal as:

$$P_{ins} \equiv x^2(n). \qquad (6.1)$$

One way to compute the average power, ‘pav’, of signal ‘x’, using Matlab is:

```
pav = sum(x.^2)/length(x).
```

(6.2)

2) Energy:By definition, power is the time derivative of energy; or equivalently, energy is thetime integral of power. For sampled signals, integration reduces to a summation.

$$\begin{aligned} E_{tot} &= P_{ave} \cdot t, \\ &= \frac{1}{N}\sum_{n=1}^{N} x^2(n) \cdot \frac{N}{f_s}, \\ &= \frac{1}{f_s}\sum_{n=1}^{N} x^2(n). \qquad \boxed{(6.3} \end{aligned}$$

The Matlab command for finding the total energy, ‘et’, of signal ‘x’, that has sampling rate ‘fs’, is*:*

```
et = sum(x.^2)/fs.
```

(6.4)

Bit-error-rate testing requires a transmitter, a receiver, and a channel. We begin bygenerating a long sequence of random bits, which we provide as input to the transmitter. The transmitter modulates these bits onto some form of digital signaling, which we will send though a simulated channel [8][9].We simulate the channel by addinga controlled amount of noise to the transmitted signal. Thisnoisy signal then be-comes the input to the receiver. The receiver demodulates the signal, producing asequence of recovered bits. Finally, we compare the received bits to the transmittedbits, and tally up the errors

To create a graph of bit-error-rate versus SNR, we plot a series of points. Each ofthese points requires us to run a simulation at a specific value of SNR. To obtain the bit-error-rate at a specific SNR, we follow the procedure given below.

The first step in the simulation is to use the transmitter to create a digitally modulated signal from a sequence of pseudo-random bits. Once we have created this signal x(n), we need to make some measurements of it.

3) Establish SNR: The signal-to-noise-ratio (SNR), E_b/N_0, is usually expressed in decibels, but we must convert decibels to an ordinary ratio before we can make further use of the SNR. If we set the SNR to mdB, then $E_b/N_0=10^{(m/10)}$

Using Matlab, we find the ratio, 'ebn0', from the SNR in decibels, 'snrdb', as

$$\mathtt{ebn0 = 10\hat{}(snrdb/10).}$$

(6.5)

4) Determine E_b: Energy-per-bit is the total energy of the signal, divided by the number of bits contained in the signal.

$$E_b = \frac{1}{N \cdot f_{bit}} \sum_{n=1}^{N} x^2(n),$$

(6.6)

Using Matlab, we find the energy-per-bit, 'eb', of our transmitted signal, 'x', that has a bit rate 'fb', as:

$$\mathtt{eb = sum(x.\hat{}2)/(length(x) * fb).}$$

(6.7)

Using Matlab, we find the power spectral density of the noise,'n0', given energy-per-bit 'eb', and SNR 'ebn0', as:

$$\mathtt{n0 = eb/ebn0.}$$

(6.8)

5) Generate Noise: Although the communications toolbox of Matlab has functions to generate additivewhite Gaussian noise, we will use one of the standard built-in functions to generate AWGN. Since the noise has a zero mean, its power and its variance are identical. We need to generate a noise vector that is the same length as our signal vectorx(n), and this noise vector must have varianceσ_n

$$\mathtt{n = sqrt(pn) * randn(1,length(x));.}$$

(6.9)

6) Add Noise:We create a noisy signal by adding the noise vector to the signal vector. If we are run-ning a fixed-point simulation, we will need to scale the resultingsum by the reciprocal of the maximum absolute value, so the sum stays within amplitude limits of±1.0. Otherwise, we can simply add the signal vector 'x' to thenoise vector 'n' toobtain the noisy signal vector 'y' as:

$$\mathtt{y = x + n;.}$$

(6.10)

7) Run Receiver:Once we have created a noisy signal vector, we use the receiver to demodulate thissignal. The receiver will produce a sequence of demodulatedbits, which we mustcompare to the transmitted bits, in order to determine how many demodulated bitsare in error.

7. SIMULATION RESULTS:

The BER for a free space optical communication is shown below

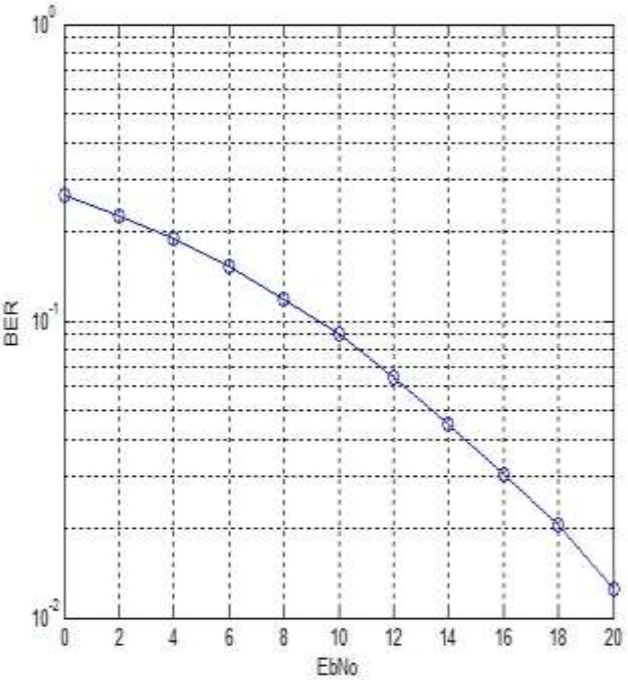

Figure 3: BER plot for FSO communication system

8.FSO AS FUTURE TECHNOLOGY:

Infrared technology is as secure or cable applications and can be more reliable than wired technology as it obviates wear and tear on the connector hardware. In the future it is forecast that this technology will be implemented in copiers, fax machines, overhead projectors, bank ATMs, credit cards, game consoles and head sets. All these have local applications and it is really here where this technology is best suited, owing to the inherent difficulties in its technological process for interconnecting over distances.

Outdoors two its use is bound to grow as communications companies ,broadcasters and end users discovers how crowded the radio spectrumhas become. Once infrared’s image issue has been overcome and its profile raised, the medium will truly have a bright, if invisible, in future

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