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AN OVERVIEW TO FREE SPACE OPTICS AND ITS ADVANTAGE OVER FIBER OPTICS

SAMEER ASIF[1] & PRASHANT KR. YADAV[2]

[1, 2] B.Tech 4th year, E&C Engg. Department, M.I.T. Moradabad (U.P.), India

ABSTRACT

Free-Space Optical communication (FSO) has become more and more interesting as an alternative to Radio Frequency (RF) communication over the last two decades. It is an emerging technology that has found application in several areas of the short and long-haul communications. The strengths of this technology's inherent are its lack of use of in-ground cable (which makes it much quicker and often cheaper to install), the fact that it operates in an unlicensed spectrum (making it easier from a political/ bureaucratic perspective to install), the fact that it can be removed and installed elsewhere (allowing recycling of equipment), and its relatively high bandwidth (up to 1 Gigabyte per second (Gb/s) and beyond). In this review paper we are going to describe modulation scheme, atmospheric effects, data security, last mile bottle neck and its future perspective.

KEYWORDS: Free Space Optics, Transmission Technology, Amplitude Modulation

INTRODUCTION

Free Space Optics (FSO) is a laser driven technology which uses light sources and detectors to send and receive information, through the atmosphere somehow same as Fiber Optic Communication (FOC) link, which uses light sources and detectors to send and receive information but through a fiber optic cable. The motivation for FSO is to eliminate the cost, time, and effort of installing fiber optic cable, yet to retain the benefit of high data rates (up to 1 GB/s and beyond) for transmission of voice, data, images, and video.

This has been developed in response to a growing need for high-speed and tap-proof communication systems.FSO is the next frontier for net-centric connectivity as bandwidth, spectrum, and security issues. The high speed and large bandwidth offered by light wave communications makes it a very attractive means of meeting the future demand for broadband internet access and HDTV broadcasting services [I].

Specifically, the effective distance of FSO links is limited depending on atmospheric conditions. The maximum range is 2-3 km, but 200-500 meters is typical to meet Telco grades of availability. Thus, at present, FSO systems are used primarily in last mile applications to connect end users to a broadband network backbone.

Although FSO equipment is undergoing continuous development, the emphasis is on improving its application to local area networks (LAN) and, in some cases, MANs but not too long-haul relay systems.

The design goal of a long-haul transmission system is to maximize the separation of relays in spanning distances between cities and countries.

FSO is a free space (wireless) technology, meaning that the signal travels in the free space between transmitter and receiver, rather than through a conductor such as a wire or fiber, or through a waveguide of some sort. Another important feature of FSO is that it is unaffected by electromagnetic interference and radio frequency interference, which increasingly plague radio based communication systems. FSO systems are used in disaster recovery applications and for temporary connectivity while cabled networks are being deployed. Free space optical communication is merely effected by atmospheric distortion. If we overcome this, FSO will become most secure and high speed medium of data transmission.

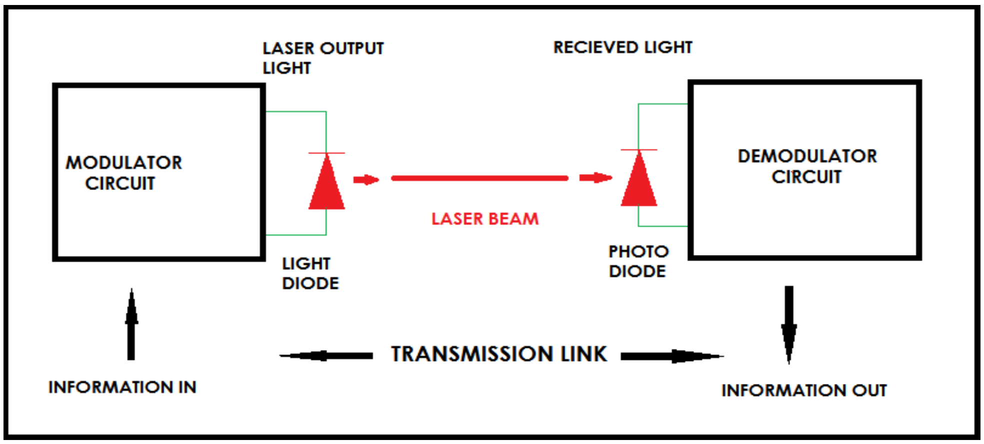

Fig.1: An Overview of FSO System

WORKING OF FSO

A generalized FSO system is shown in fig. 1. The baseband transmission bit stream is an input to the modulator, turning the direct current bias current on and off to modulate the laser diode (LD) or light emitting diode (LED) light source. The modulated beam then passes through a collimating lens that forms the beam into a parallel ray propagating through the atmosphere. A fundamental physical constraint, the diffraction limit comes into play at this point. It says that the beam of an intensity modulated (non-coherent) light source cannot be focused to an area smaller than that at its source [II].

Apart from the effects of atmospheric processes, even in vacuum, a light beam propagating through free space undergoes divergence or spreading. Atmospheric processes are non-stationary, which means that their influence on a link changes unpredictably with time and position. At the distant end, a telescope collects and focuses a fraction of the light beam onto a photo-detector that converts the optical signal to an electrical signal. The detected signal is then amplified and passed to processing, switching, and distribution stages. Fig. 3 is an illustration of a simplified single-beam FSO transceiver that shows how the major functional blocks of the equipment are arranged and integrated [III].

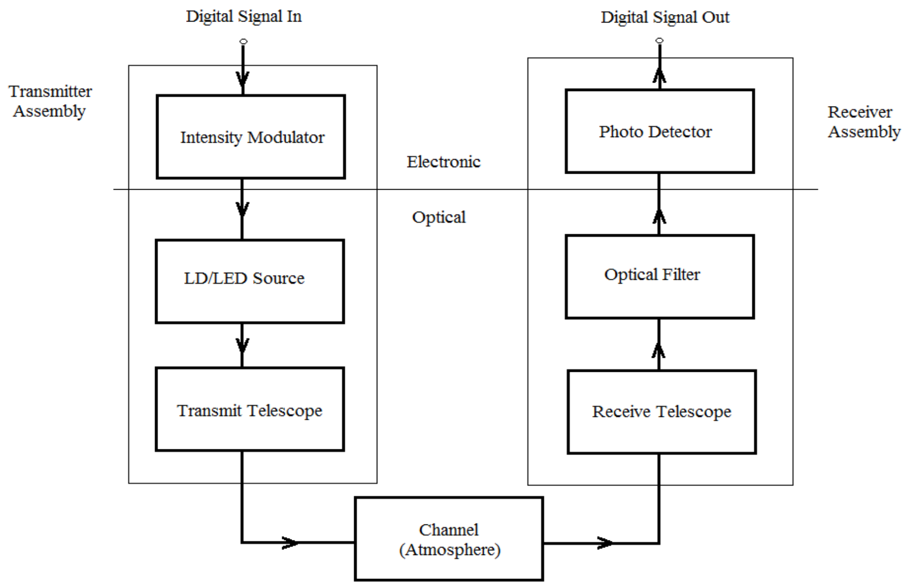

Fig.2: Block Diagram of FSO Communication System

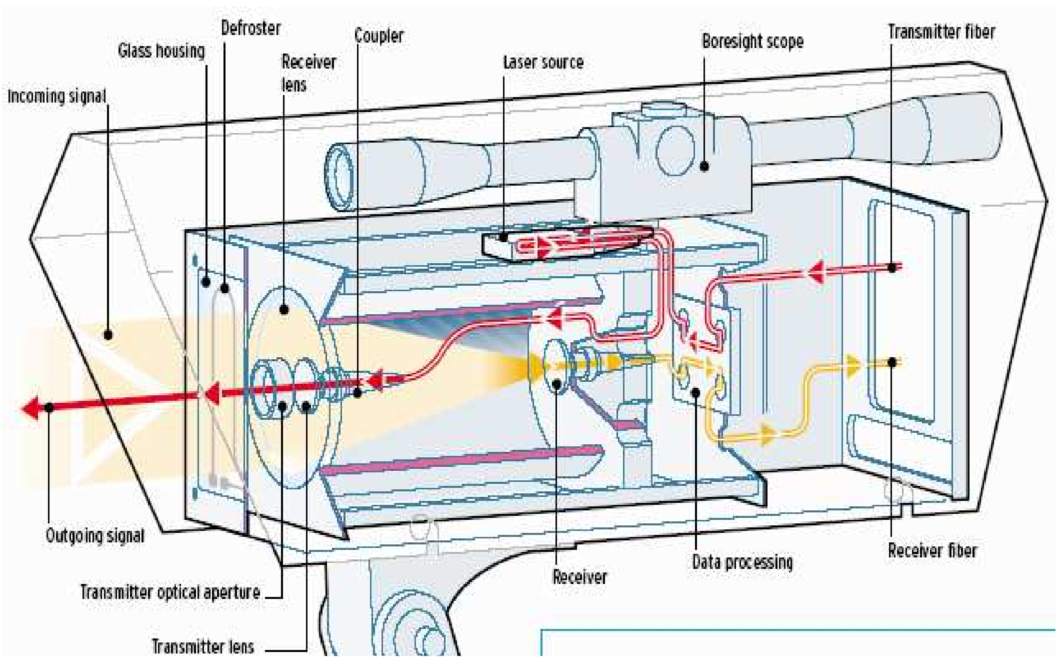

Fig.3: Single Beam FSO Transceiver

MODULATION SCHEME

The optical carrier can be modulated in its frequency, amplitude, phase, and polarization. For simple implementation following two modulation schemes are used:

1. Amplitude modulation with direct detection,
2. Phase modulation in combination with a (self) homodyne or heterodyne receiver.

Amplitude Modulation with Direct Detection

In amplitude modulation, Amplitude-Shift Keying (ASK) also known as on-off keying (OOK) is used [IV]. This is technically simplest digital modulation scheme in optical systems. OOK is an intensity modulation scheme where the light source (carrier) is turned on to transmit a logic "one" and turned off to transmit a "zero". OOK consists of two forms RZ (return to zero) and NRZ (non-return-to-zero). The advantages of RZ compared to NRZ are its higher sensitivity and the fact that the clock frequency lies within the modulation spectrum. Unfortunately, both NRZ and RZ can lead to loss of clock synchronization if long strings of ones or zeros are transmitted. This can be avoided with other coding systems such as Manchester coding, which is related to RZ. With such a variant of RZ the clock of the digital signal can easily be recovered. In order to fulfil the Nyquist–Shannon theorem, twice the bandwidth of NRZ is used.

Optical amplifiers need input signals with constant mean power if they work with control loops to guarantee constant mean output power. Further AC-coupling (high-pass filtering) of the electrical signal at the receiver will introduce a significant amount of inter-symbol interference if the average of the signal is not constant. For this purpose 8B10B coding on top of NRZ can be applied to FSO systems. For 8B10B-NRZ the bandwidth requirement is only 25 percent more than for NRZ [V].

An additional advantage of 8B10B coding is that this coding forces frequent level changes independent of the input stream. Therefore the clock of the signal can easily be recovered even if long strings of "ones" or "zeros" are transmitted. The advantage is that the receiver only detects the currently incoming power and compares it against a certain level. OOK is sensitive to amplitude distortion (fading) and propagation through different routes, while the second one is negligible for clear-sky conditions.

Phase Modulation in Combination with a (Self) Homodyne or Heterodyne Receiver

Phase modulation schemes can also be used in optical communications [VI].

They are of two types:

i. (Binary Phase Shift Keying) BPSK,

ii. (Differential Phase Shift Keying) DPSK

In BPSK, the phase of the coherent laser light is shifted between two states. Coherent receivers rely on the superposition of the received light with the light of a local oscillator. Instead of the local oscillator self-homodyne is also possible. This is used in DPSK systems, which are less sensitive than

BPSK systems. In BPSK systems typically some kind of optical phase-locked loop is required, which allows the local oscillator laser to be tuned exactly to the same frequency (or a frequency with a constant offset) and phase as the received carrier [VII].

Generally, an OOK system is more robust with regard to atmospheric distortion than a coherent modulation system. This is because for OOK the information is only encoded in intensity whereas PSK (Phase Shifting Keying) uses intensity and phase coding. Both the intensity and the phase of a beam are disturbed in atmospheric propagation. Further, OOK has mainly been used in optical fiber communications due to its low complexity.

DATA SECURITY

To overcome the security in a network one must have to intercept enough of the signal to reconstruct data packets and be able to decode that information. If these two primary requirements cannot be met, the security network will remain intact.

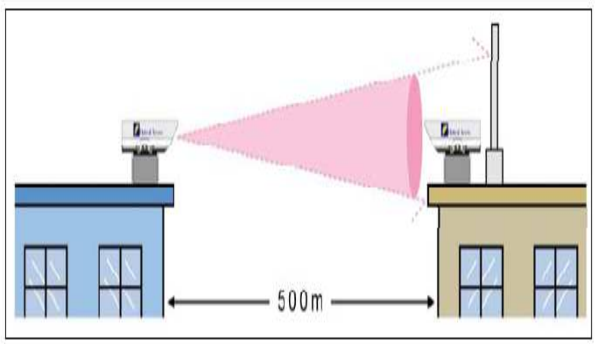

Fig.4: Another View of the Narrow Beam Divergence Inherent in FSO Transmission. (for Clarity Only One Transit Beam is Shown) and a Shield Installed Behind the Receiver.

FSO uses collimated laser light as the transmission medium, therefore the signal is very narrow throughout the entire path. To intercept the signal one has to come in path of the transmitted signal. But FSO terminals require complete and uninterrupted link for successful operation. If the link will be blocked then communication will be terminated [VIII].

Another way to intercept is by attempting to pick off the narrow beam path from allocation behind the building on which the receiving unit is installed. To prevent this, a shield may be installed behind the receiver so that light cannot continue beyond the point of reception. Further security can be enhanced by encrypting message at information layer or at network physical layer.

ATMOSPHERIC EFFECTS ON FSO

Free Space Optics links are highly weather dependent that reduces the link availability because transmitted FSO beam is transformed by several physical processes inherent to the atmosphere [IX].

The attenuation of an optical beam as it propagates through the air is given by the Beer-Lambert Law as:-

$$I(x) = I_0 e^{-\alpha x}$$

Where, I_0 is the initial optical intensity in watts

$I(x)$ is the intensity after the beam has travelled a distance of x Meters

α is the attenuation coefficient of the medium in m^{-1}

Attenuation of the atmosphere can be caused by several factors, including absorption of beam via molecules of some gases present in air; primarily water vapour, Carbon-di-oxide (CO_2) and Methane. The presence of these gases along a path changes unpredictably with weather over time. Thus their effect on the availability of the link is also unpredictable.

Scattering of light wave is due to aerosols and particles which are mainly composed of fogs, clouds and dust. Their size is same as of light's wavelength and these deflect the light from its original direction. Some scattered wavelets travel longer than the direct (unscattered) rays. As both wavelets (scattered and unscattered) are out of phase at receiver causing destructive interference, this causes attenuation. Refractive turbulence due to changes in temperature causes light refraction to be constant and predictable in laminar region, and changes point to point in turbulent region.

For most FSO application, scattering (especially due to fog) is dominant among all factors. Signal is affected by all components explained above but major factor of attenuation is rain. Attenuation linearly increases with rainfall rate, and the mean of raindrop sizes increases with the rainfall rate.

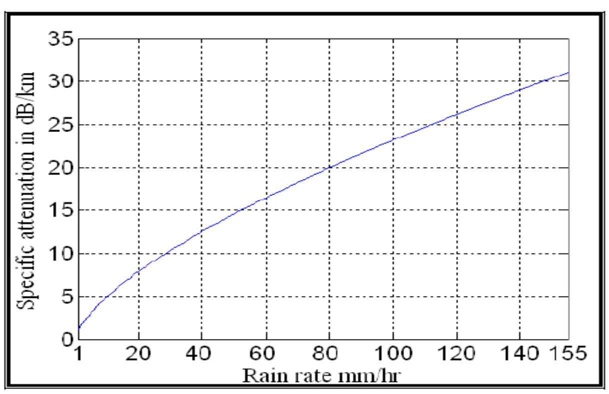

Fig.5: Specific Attenuation of Optical Wireless Links for Different Rain Rate.

Figure shows the effect of rain on the basis or Rain Rate mm/hr v/s. Specific Attenuation in dB/km which indicates the attenuation of signal as rain rate increases.

The major factors influencing the transmission are:

- Divergence
- Absorption
- Scattering
- Refractive turbulence
- Displacement

LAST MILE BOTTLE NECK

Connecting a company's data and voice facilities to the carrier's (telephone companies') infrastructure is considered the "last-mile". The most common carriers are AT&T, MCI WorldCom, Sprint and the Regional Bell Operating Companies. Additionally, there are now hundreds, perhaps thousands of CLEC's (Competitive Local Exchange Carriers). The last-mile is the most difficult and expensive to complete. Current estimates suggest that approximately 95 percent of corporate buildings are within 1.5km of a telephone or Internet Service Provider's fiber-optic infrastructure [X].

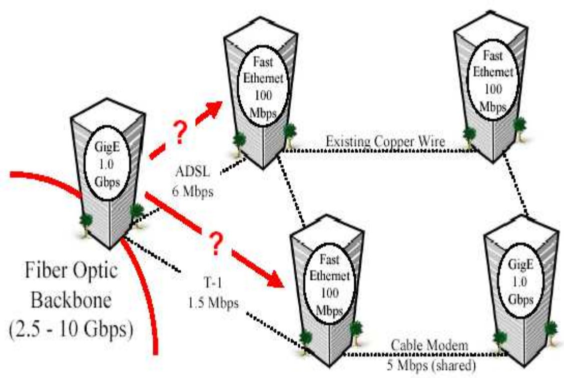

Fig.6: Existing Connection Used for Connecting Different Business to Fibre Optic Backbone

But few of these companies are implementing a high-speed data solution. Connecting the last-mile usually involves laying new fiber-optic or copper cable which can be cost prohibitive due to the cost of having to trench or dig under existing streets, sidewalks, lawns, buildings, etc. Most of these solutions also require a hefty monthly charge, often in the thousands of dollars or more. Security is for the most part non-existent on these connections and is dependent upon preventing physical access to the cabling. A high-bandwidth cost-effective solution to the last mile problem is to use free-space laser communication (also known as or optical wireless) in mesh architecture to get the high bandwidth quickly to the customers.

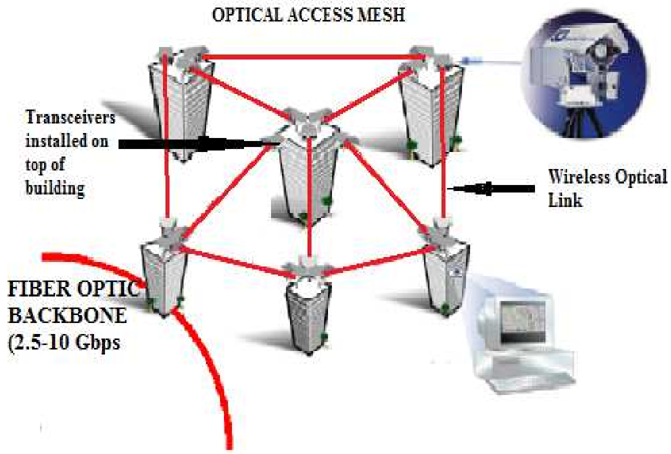

Fig.7: Solution to Last Mile Bottleneck

It offers the speed of fiber with the flexibility of wireless. Given its optical foundation, bandwidth scalability, speed of deployment (hours versus weeks or months), re-deployment and portability, and cost effectiveness (on average, one-fifth the cost of installing fiber-optic cable). Most of the problems regarding last mile is solved using FSO.

ADVANTAGES AND DISADVANTAGE

The attraction of FSO is its high data transmission rate and its exemption from spectrum regulation. The latter is especially significant for military ground forces setting up camps and forward operating bases overseas. At the very least it is time consuming. To be able to circumvent the spectrum management bureaucracy is a huge advantage given urgent communication requirements. Since light beams do not interfere with each other as long as they are not coaxial, commanders need not be concerned with electromagnetic compatibility problems.

FSO is as ready a resource as a light bulb in a socket, and installation of FSO equipment is quick and inexpensive. FSO's drawbacks in the commercial world are perhaps not as serious in the military context. Using short FSO repeater spacing's for camp communications may still be more economical than installing fiber optic cable and it allows more flexibility for re-routing lines of communication as the camp grows. FSO would carry all communication services, not just voice or data separately. In the future the layout of new camps should perhaps plan for lanes for the paths of an FSO network.

Drawbacks or Challenges of the Technology

I. Laser Eye Safety: It is important to keep in mind, especially if FSO is to gain widespread use for camp communications, that lasers must be operated within certain levels of irradiance [w/m2] for eye safety. The harmful level of exposure is a function of wavelength and is tabulated in American National Standards Institute (ANSI) Standard.

Ii. Disruption by Weather: Although FSO may at times be capable of greater range, its greater susceptibility to degradation from incidents of heavy fog or dust will drive down its attainable availability figures. This will depend on which region of the world FSO is planned for. For example, frequent dust storms of such severity as to result in black out conditions often occur in tactical desert conditions. Furthermore, the summer heat in the desert and along coastlines induces extreme refractive turbulence that would cause optical defocusing and beam wander.

CONCLUSIONS

The applications that FSO technology seems most suited to clear weather, short distance link establishment, such as last-mile connections to broadband network backbones, and backbone links between buildings in a MAN or CAN environment. The advantages of FSO result from the basic characteristics of a laser beam, especially from its high frequency, coherency and low divergence, which lead to efficient delivery of power to a receiver and a high information-carrying capacity. The main problems of FSO links working outdoors in the atmosphere result from attenuation and fluctuation of optical signal at a receiver. To improve reliability, a number of new methods can be used. After considering all its advantages and disadvantages it is clear that FSO has good prospects for widespread implementation. FSO technology is ready for utilization as terrestrial links, mobile links and satellite links.

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