The Need and Challenges of Free Space Optical Communication

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Abstract: Due to various advantages of FSO, it has become the ultimate solution for last mile problem. Compared to radio frequency, FSO link has much higher data rates and high optical bandwidth, which is suitable for LAN to LAN connectivity and MAN extensions. Although offering advantages over RF and Optical Fiber link, it's widespread implementation has been delayed due to FSO links are subject to atmospheric turbulence and obscuration from clouds, fog, rain, and snow causing performance degradation and possible loss of connectivity. Optical turbulence leads to receiver intensity fluctuations, beam broadening, beam wander, and beam break up; among other effects As the signal travels in air, the attenuation is much higher for long ranges. In this paper the need of free space optical communications (FSO) is discussed and also the effect of attenuation due to rain, fog, wind and clean air.

I. INTRODUCTION:

Free space optics transmission systems with narrow light beams propagating through air are currently used more intensively in telecommunication networks, because of a relatively high transmission capacity compared to microwave systems [Fog]. FSO is gaining popularity by offering higher bandwidth and ease of deployment today. Light travels through air for a very less money. Hence, FSO is used due to economic advantages also. Free Space Optics (FSO) is a line-of-sight technology that uses lasers to provide optical bandwidth connections. Currently, FSO offers a bandwidth up to 2.5 Gbps for voice, data, and video transfers. FSO has large range of applications from short range wireless communication link offering network access to computers, to "last mile" connectivity for corporate and service providers. FSO communication usually requires directed LOS and point-to-point laser links from transmitter to receiver through the atmosphere [1]. The main commercial limitation for FSO is that light does not propagate very far in dense fog, which occurs as non-negligible amount of the time.

Optical wireless communication has emerged as a viable technology for next generation indoor and outdoor broadband wireless applications. Applications range from short-range wireless communication links providing network access to portable computers, to last-mile links bridging gaps between end users and existing fiber optic communications backbones, and even laser communications in outer-space links [1]. Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication.

An effective FSO system should have the following characteristics[4]:
(a)FSO systems should have the ability to operate at higher power levels for longer distance.
(b)For high speed FSO systems, high speed modulation is important.
(c)An overall system design should have small footprint and low power consumption because of its maintenance.
(d)FSO system should have the ability to operate over wide temperature range and the performance degradation would be less for outdoor systems.
(e)Mean time between failures (MTBF) of system should be more than 10 years.

II. NEED OF FSO:

As the demand of bandwidth is increasing rapidly in urban networks, service providers are facing big challenge to provide fast and cost effective services with limited capital expenditures [3]. Copper cables are already replaced with fiber cables because a single fiber can carry the equivalent information that required thousands of copper wires. But still economically it's not feasible for service providers to extend fiber network to each consumer's premises. This leaves two options for service provider – Fiber optic network and RF Technology. RF based network offers much longer range than FSO but require immense capital investment to acquire spectrum license and the bandwidth is limited to 622 megabits, which is not sufficient. The RF band of the electromagnetic spectrum is limited in capacity and costly as most sub-bands are licensed. With the ever-growing popularity of high bandwidth wireless communications, the demand for RF spectrum is surpassing supply and there is serious need of other viable options for wireless communication using the upper parts of the electromagnetic spectrum.

Fiber optic network using Dense wave division multiplexing offers immense bandwidth and solves "last mile solution" in metro networks but the sky-high budget of establishment and maintenance of fiber makes it economically restricting. In this situation there is desperate demand for a technology which supports high bandwidth, solves "last mile bottleneck" problem and affordable to service providers. FSO is the most viable solution, which is wireless technology, offers full-duplex Gigabit Ethernet throughput, can be installed in less than a day and no need to acquire spectrum license . FSO link over few kilometer distances has been already demonstrated at multi-Gbps data rates. Table 1 shows the comparison of FSO and RF links.

Table 1: Comparison of FSO and RF link [4]

	FSO Links	RF Links
Typical Data Rate	100 Mbps to ~Gbps	Less than 100 Mbps1
Channel Security	High	Low
Component Dimension	Small	Large
Networking Architecture	Scalable	Non-scalable
Source of Signal Degradation	Atmospheric turbulence and obscuration	Multipath fading, rain, and user interferences

III. FSO TECHNOLOGY:

Based on direct connectivity between different FSO units this technology becomes relatively simple. in each Free Space Optics (FSO) unit the beams of light are transmitted by laser light focused on highly sensitive photon detector receivers to provide bi – directional/full duplex capability . 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. These transmissions will not experience interference from radio frequencies and this type of communication does not require an RF license.

Free Space Optics (FSO) communication is possible over distances of several kilometers as long as there is a clear line of sight between the source and the destination. FSO is easily upgradeable, and its open interfaces support equipment from a variety of vendors, which helps service providers to protect their investment in embedded telecommunications infrastructures. Free Space Optics (FSO) transmits invisible, eye - safe light beams from one "telescope" to other using low power infrared lasers in the terahertz spectrum. 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. [1]

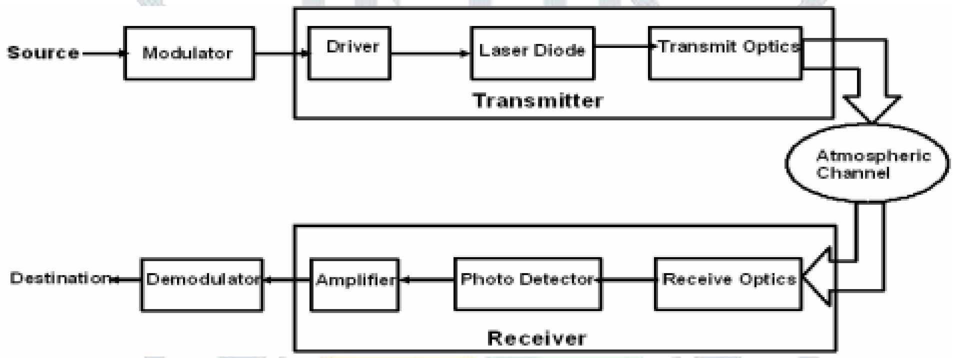

Figure:2 FSO technology

IV. FSO Advantages & Applications :

Advantages: FSO technology has a number of advantages such as, License-free Communication, Easily Upgradable, High data bit rates, requires no security software upgrades, Secured Communication [4], Long range operation, immune to radio frequency interference or saturation, eliminating the need for costly rooftop rights

Applications: FSO can be used for wide variety of applications such as, Bridging Wireless Local Area Network (WLAN), LAN to LAN Building Connectivity [5], Healthcare Campus Network, Education Campus Network, Metro Network Extension, fiber back-up, backhaul for wireless cellular networks, disaster recovery, high definition TV , wireless video surveillance/ monitoring.

V. LIMITATIONS OF FSO:

The performance of FSO networks is affected by fog, snow, Rain , absorption, scattering, physical obstructions, Scintillation, Interference from other light sources, Dispersion.

a) Attenuation due to vapor:

To design FSO link, attenuation must be calculated which is caused by fog, rain and wind. Even clean air also adds attenuation so it needs to be calculated also. This attenuation is relatively small and caused by invisible water vapor. To calculate attenuation due to vapour, sonic temperature needs to be calculated, as it contains information about water vapour density [6]. The sonic temperature Ts helps to find out water vapor density. The sonic temperature can be directly measured by sonic anemometer [7]. The sonic temperature is also calculated from basic atmospheric parameters like air humidity, temperature and pressure through following equation:

$$Ts = T\left(1 + 0.32\,\frac{e}{p}\right)\text{ K}$$

T [K]=t [°C] + 273.1S

$$e = \frac{rhes}{100}$$

where T is the air temperature [K or °C], P is the total air pressure [hPa], e is the pressure of water vapor [hPa], rh is the relative air humidity [%] and es is the pressure of saturated water vapor [hPa]. From the above formulas it is obvious that the sonic temperature expresses the wetness of the air, i.e. the concentration of water vapour. The sonic temperature is very close to the virtual temperature which is defined as the temperature at which dry air has the same density as moist air at the same pressure [8].

If the value of sonic temperature is measured, attenuation due to water vapor can be calculated by:

A(dB/km) = -0.45 (Ts - 273.15) + 5.21 (wavelength = 1550nm)

A(dB/km) = -0.73 (Ts - 273.15) + 6.5 (wavelength = 830nm)

b) Attenuation due to fog:

Weather has always been critical factor in designing FSO link, as the signal travels in free air. Due to Fog and snow scattering and absorption creates complexity and limits the visibility of the signal. Fog can limit the availability of the FSO links since the strong attenuation of the electromagnetic wave due to a scattering mechanism Fog is vapor made of water droplets, which are able to deteriorate the transmitted signal and decreases the distance of FSO link. If the attenuation value exceeds the predefined threshold value the BER increases and the FSO system becomes unavailable [9]. The availability of FSO systems depends on local climatic conditions and is often estimated from atmospheric visibility statistics. The visibility is (roughly) a distance where the 550 nm collimated light beam is attenuated to a fraction (5%, or sometimes 2%) of an original power [9]. So it's very important to estimate attenuation due to fog before designing FSO link. Depending on the wavelength and visibility attenuation can be computed by Kruse Model:

$$A = 10 \log_e \frac{3.912}{V}\left(\frac{\lambda}{0.55}\right)^{-q} \quad [9]$$

Where $q = \begin{cases} 1.6 & V>50 \\ 1.3 & 6<V<50 \\ 0.585V^{1/3} & V<6 \end{cases}$

A (dB/km) is a specific attenuation and V (km) is an atmospheric visibility.

c) Attenuation due to rain:

Though fog is the most crucial atmospheric phenomenon, calculation of rain attenuation also plays significant role in FSO link design. Rain is the most common type of precipitation in climatic conditions. Diameter of raindrops is between 0.1 mm to 7 mm [10]. Drops with diameter smaller than 2 mm are spherical, larger drops are flattened and drops larger than 4 mm sag in the lower base. The real shape is approximated in order to derive scattering properties of electromagnetic waves. Rain drops don't only absorbs the energy but also scatters the light beam in all directions. Practically this attenuation doesn't depend on wavelength, only on rain intensity. A simple formula to find out rain attenuation is [10]:

$$\alpha_{rain} = 1.6\, R^{0.63} \text{ dB/km}$$

where R is rain rate in mm/h.

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VI. Hybrid FSO/RF communication system:

FSO offers wide range of applications and advantages but the link is very sensitive to atmospheric conditions. Depending on the region and climate the availability and reliability varies. Fog and rain can increase the attenuation from few dB/km to hundreds of dBs/km. Compared to FSO, RF is very less affected by weather but RF cannot offer as much bandwidth as FSO. To solve a problem of "last mile bottleneck" we have to design a communication system which gives large bandwidth of FSO and great availability in any weather condition, which is possible by combining FSO with RF technology.

VII. Conclusion

In this paper, the need of Free space optics has been discussed along with its challenges. FSO offers many advantages over optical or radio or microwave. Low cost and time to setup are the main attraction of FSO system. Optical equipment can be used in FSO system with some modification. There are many advantages of free space optics, but as the medium of the transmission is air for FSO and the light passes through it, some environmental challenges are unavoidable

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