

# Survey on FSO Communication System—Limitations and Enhancement Techniques

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**Abstract** Free-space optical (FSO) communication is a line-of-sight communication in which the data modulates the infrared or visible laser light through the air from transmitter to receiver. FSO ensures fast, secure, and reliable data transmission for which it is widely considered as a next-generation high-speed wireless communication technology. FSO systems are mostly the “last mile solution” for commercial systems of metro networks between fixed sites. Because of the inherent benefit of mobility, fast deployment, security, and high data rates, FSO systems are being considered for military systems. The properties of FSO system such as license-free band, cost-effectiveness, and high-bandwidth access allows it to gain rapid popularity as a means of transferring data at high rates over small distances. However, FSO does suffer from certain limitations as well; mostly caused due to atmospheric turbulence that highly degrades its performance. In this paper, various limitations of FSO and the possible means to mitigate their effect are discussed.

**Keywords** FSO • Atmospheric turbulence • Modulation technique  
Photodetector • OOK • DPSK

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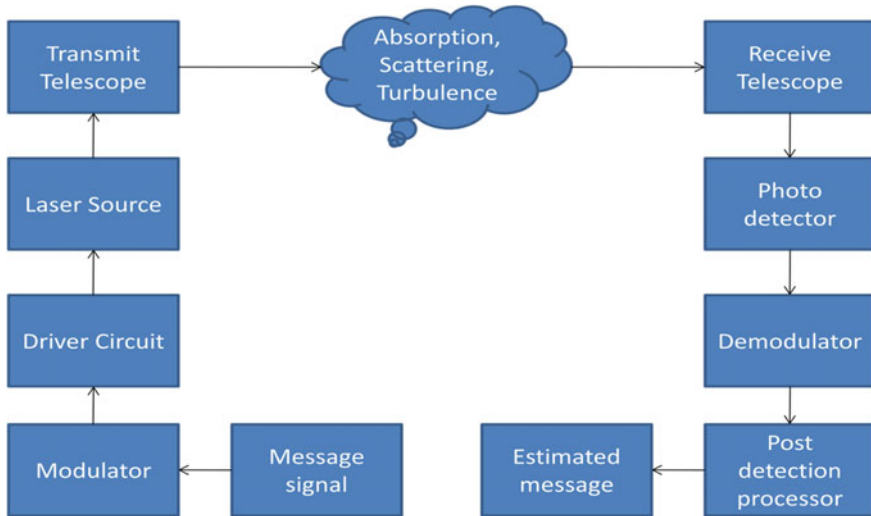
## 1 Introduction

The FSO has been researched upon since Graham Bell's photophone in 1880. Bell made voice signal to modulate sun's radiation and transmitted it over the distance of about 200 m. He used a parabolic mirror with selenium cell at its focal point as a receiver. However, this experiment did not go well due to the crudity of the devices used and the intermittent nature of the sun's rays. However, the fortune of FSO changed after the discovery of laser in 1960. Nippon Electric Company (NEC) built the very first FSO laser link in Japan in 1970 in order to handle commercial traffic. This link was a full duplex He-Ne laser FSO and was of 14 km length. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) have also researched FSO in deep-space applications with programs such as the Mars Laser Communication Demonstration (MLCD) and the Semiconductor Laser Inter-satellite Link Experiment (SILEX), respectively. FSO technology finds various applications in communications networks as well, where a connectivity gap exists between two or more points. This technique also provides a cost-effective optical wireless connectivity and a faster Return on Investment (ROI) for enterprises and mobile carriers. As the demand for greater bandwidth for enterprise and mobile carrier subscribers is ever-increasing, there is a critical need for FSO-based products so that a balance of throughput, distance, and availability is obtained [1]. However, optical wave propagation through the air experiences several hindrances like the fluctuation in amplitude and phase due to atmospheric turbulence and the irradiance fluctuation called scintillation. Scintillation is caused because of the thermal gradients and turbulence within the optical path incurred due to the variation in air temperature and density. Zones differing in density act as lenses which scatter light away from its intended path. These effects can cause scattered laser beam to travel along different paths and then recombine. Atmospheric turbulence degrades the performance of FSO to great extent. Researchers have worked in many ways in order to mitigate the effect of atmospheric turbulence. Different modulation formats have been tested in order to find the one which is least affected by this phenomenon.

## 2 General Block Diagram of FSO System

The general block diagram of FSO is shown in Fig. 1. It simply comprises transmitter, channel, and receiver. The transmitter sends modulated laser beam through free space, which is received, demodulated, and detected at the receiver.

In an FSO system, the message signal is modulated in the modulator block that essentially is an intensity modulation (IM). Several modulation techniques have been implemented on FSO system such as OOK, BPSK, QPSK, PPM. In the intensity modulation, the modulated signal is used to vary the intensity of the light coming out of the laser source. The transmitter telescope directs the modulated laser



**Fig 1** Block diagram of FSO system

beam toward the receiver telescope. The receiver comprises a photodetector that can be a PIN or an APD. The photodetector converts the light signal into corresponding electrical signal so that it can further be demodulated and processed.

As FSO is a LOS communication, there should be no obstruction between transmitter and receiver. The architecture of FSO can be summarized as:

- Transmitter:** In transmitter, the intensity modulation is done in which the intensity of light is varied depending upon the modulating signal. The intensity of laser is varied by controlling the laser current in the driver circuit. The transmit telescope is used to transmit the intensity-modulated light signal with high directivity. The light source is chosen depending upon the wavelength and properties.
- Channel:** The modulated light signal gets degraded in the channel. The channel used in FSO is free space, that is, air. Atmospheric turbulences such as fog, rain, snow cause the scattering, absorption, and fading of the transmitted signal which eventually degrades the performance of the FSO system.
- Receiver:** At the receiver, the receive telescope collects the modulated light signal and the photodetector converts the light signal into corresponding electrical signal. The detected electrical signal is then demodulated and processed in order to retrieve the transmitted data (Fig. 2).

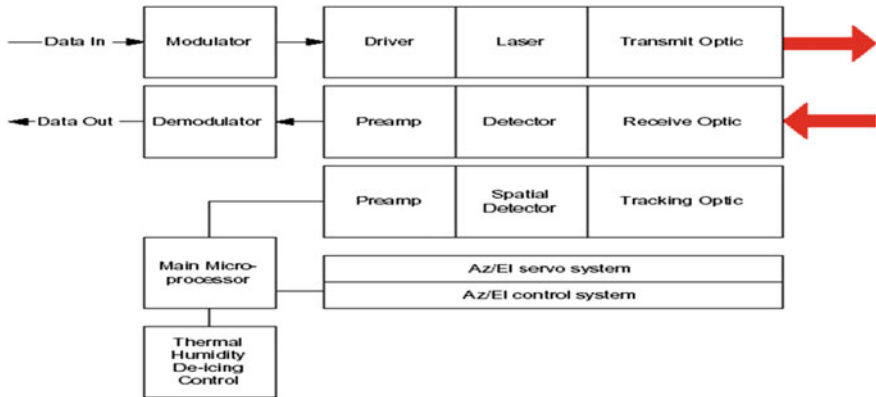


Fig. 2 FSO major subsystem

### 3 Key Points of FSO

Number of key points in terms of advantages and applications are there that has significantly attracted the researchers' attention and become vibrant area of research among academia and industrial people.

#### 3.1 Advantages: FSO Communication Has Got a Lot of Advantages like

- High-Bandwidth Availability: FSO has got a 2000THz data bandwidth which offers a very high channel capacity [23].
- Narrow Beam Width: As FSO uses laser at the transmitter end, the beam width is very narrow which provides high-level secrecy that cannot be achieved by RF communication [23].
- Unlicensed Spectrum: FSO communication takes place in ISM band, which is an unlicensed band. Hence, FSO is free from spectrum distribution which makes it convenient and cost-effective [23].
- Low Installation Cost: The installation cost of FSO is very low as compared to RF for the same data rate [23].
- Easy Deployment and Redeployment: The installation time in FSO is very low. It takes as less as four hours to install an FSO. In addition, it can easily be redeployed from one place to another [23].

### ***3.2 Applications: The Number of Potential Applications in Various Fields of FOS Communication System Has Been Observed as Mentioned Below***

- **Inter-Campus Connectivity:** There is a heterogeneous network traffic (i.e., voice, data, fax, multimedia traffic, etc.) that overwhelm the typical connections, be it in the school/university campuses or the corporations. FSO systems have the capability of providing ultrahigh speeds with low cost unlike dedicated fiber optic connections [2].
- **Monitoring and Video Surveillances:** Nowadays, video cameras are deployed almost everywhere; it may be in the supermarkets, airports, malls, and so on for public safety and in military applications. Deployment of video cameras is easy. However, the conventional wireless technology is incapable of providing high throughput required for video streams. FSO technology supports high-quality video transmission, thereby proving to be an efficient alternative.
- **Back-haul for Cellular Systems:** In cellular systems, FSO can prove to be of high use in carrying the traffic of cellular telephone with high speed as well as fast data rates from antenna towers to the PSTN, thereby increasing the speed of transmission [2].
- **Redundant Link and Disaster Recovery:** As FSO links can be deployed easily and in less time, this advantage of FSO can prove to be extremely helpful in natural disasters, terrorist attacks, and emergency situations in which the communication infrastructure may have been damaged or became unreliable. The practical example of the FSO deployment as a redundant link was witnessed after 9/11 terrorist attacks in New York City, where FSO links were rapidly deployed in the area for financial corporations which were left out with no landlines.
- **Military Access:** FSO has got the advantage of being secure and undetectable as it uses narrow beam width for data transmission. Hence, it can provide secure connection in large areas with minimal planning and less deployment time, which makes it most suitable for military access [3].
- **Point-to-Point and Point-to-Multipoint Communication:** FSO communication is possible in point-to-point links, for example, between two shops, two buildings, and also in point-to-multipoint links, for example, from satellite to ground for short as well as long-distance communication [4].
- **Last Mile Access:** Last mile has always been a bottleneck for most of the telecommunication, cable television, and Internet industries. FSO can provide a solution to this problem by deploying it in the last mile along with other networks [2].
- **Storage Area Network (SAN):** SAN is a network that provides access to consolidated block-level data storage. FSO links can be used to form a SAN [5].

Typically, the best use scenarios for this technology are:

- In campuses, FSO is providing fast ethernet or gigabit ethernet speeds for LAN-to-LAN connections.
- In metropolitan area network, FSO provides LAN-to-LAN connections.
- It converges voice data connection.
- For certain specific events or purposes, FSO provides temporary network installation.
- In disaster recovery, FSO provides re-establishment of high-speed connection quickly.
- FSO may be used to upgrade existing wireless technologies.
- FSO provides an effective backup for important fiber connections.

### ***3.3 Limitations: In Spite of Number of Advantages and Applications of FSO, It Has Some Limitations that May Lead to Challenges***

- **Atmospheric Disturbances:** A major impairment on FSO links is caused due to the atmospheric turbulence. It is the result of random variations in the refractive index caused due to inhomogeneities in temperature and pressure. In clear weather conditions, the atmospheric turbulence causes the intensity fluctuation of the received signal called fading which is also known as scintillation in optical communication terminology [6, 7]. Turbulence is caused by the inhomogeneities of temperature as well as pressure in the atmosphere and can, thereby, severely degrade the link performance, particularly for link distances of 1 km or longer. The performance of this technology depends strongly on certain parameters like atmospheric conditions between transmitter and receiver, parameters of the link such as length, operating wavelength. Moreover, other factors such as fog, rain, atmospheric gases, and aerosols also result in beam attenuation due to photon absorption and scattering [8].
- **Pointing Error:** Apart from scintillation effects, the performance of the FSO link degrades because of the building sway, which introduces a pointing error (PE) between transmitter (Tx) and receiver (Rx), representing a particular problem in urban areas, where FSO equipment is placed on high-rise structures [9, 10].
- **Physical Obstructions:** Since FSO is a line-of-sight communication, any obstruction in the path can interrupt or affect the communication. These obstructions may be in the form of birds, tall trees and buildings, etc. [11]. However, interruption of this kind is temporary, and transmissions are easily and automatically resumed.

- **Geometric Losses:** These losses are the form of optical beam attenuation that is caused due to the spreading of beam and results in the reduction of power level of signal as it travels from transmitter to receiver [12].
- **Background Radiation:** Last but not least, background radiation, also called background noise or ambient noise, can degrade the performance of FSO links. In fact, in addition to the useful signal, the receiver lens also collect some undesirable background radiations that may consist of direct sunlight, reflected sunlight, or scattered sunlight from hydrometeor or other objects.

### ***3.4 Possible Solutions***

The above limitations pose a great challenge in the working of FSO; however, many ways have been found to counter these limitations. The primary way to counter fog in the deployment of FSO is through a network design that shortens FSO link distance and adds network redundancies. While to combat absorption, use of spatial diversity with appropriate power levels may help to maintain the required level of network availability. Also, Light Pointe's multibeam system (spatial diversity) is found useful to address physical obstructions, atmospheric turbulence as well as scintillation [11]. Also, further performance enhancement may be obtained by using appropriate channel model (gamma-gamma distributed channel model), multiplexing technique (OFDM), and by the use of optical amplifier (EDFA) in place of electrical amplifier [15, 22].

### ***3.5 Reported Works***

There has been lot of research going on in order to mitigate the limitations of FSO and enhance its performance. In this context, various fields have been pointed out where researchers are working in order to overcome the effect of atmospheric turbulence. These fields can be broadly classified as:

**Modulation Techniques:** Several researchers have chosen different modulation techniques to see the effect of atmospheric turbulence on their performance. In [13], different modulation techniques like OOK, Subcarrier BPSK, and Q-ary PPM in turbulence regime are compared. It was found that the performance of BPSK was better than all others except that when the order of Q in Q-ary PPM was increased then its performance also got improved. Wang et al. [14] proposed that Space Diversity Reception Technique (SDRT) and advanced modulation formats can successfully mitigate the transmission impairments of the atmospheric turbulence. In this paper, modulation formats, which were compared, are OOK, DPSK, and DQPSK. They observed that in strong turbulent scenario, the OOK and DPSK formats can have high SDRT gains in the order of 19.5 and 20.3, respectively, at the

BER of  $10^{-3}$ . In addition, it was also found that in strong turbulent scenarios, DPSK and DQPSK formats have same BER performance under the same symbol rate. Simplicity is the advantage of OOK while DPSK format, which encodes information in its phase, can mitigate severe effect of scintillation to some extent. Moreover, in the comparison of the binary formats like OOK and DPSK, the DQPSK format doubles the spectral efficiency.

However, BPSK SIM offers improved performance across all range of turbulence variances [15, 16]. The performance of FSO systems with APD detectors is severely impacted by turbulence, and an optimum average APD gain must be used to avoid excessive APD noise in the receiver. In these systems, it was found that differential amplitude PPM has better performance than that of other schemes for same peak power [17, 18].

**Diversity Techniques:** An increase in the number of apertures increases the gain and mitigates the effect of atmospheric turbulence. The performance of SISO FSO links is severely degraded from turbulence. The results in [14, 15, 19, 20] demonstrated that significant performance gains can be obtained when multiple apertures are used at transmitter and receiver, thereby enhancing the quality of FSO.

**Performance Enhancement:** The performance of FSO system gets significantly improved by using OFDM technique in place of traditional TDM-FSO link. In [21], an increase in gain and improvement in receiver sensitivity is obtained in OFDM-FSO link as compared to TDM-FSO link. The performance of FSO system is affected by the type of amplifier used. The optical pre-amplifier provides better performance as compared to the electronic amplification. In electronic amplification, the amplification is done after the photodetector while as in pre-amplification, the amplification takes place before the photodetector by means of erbium-doped fiber amplifier (EDFA) [22].

**Channel Model:** Various statistical models have been used in order to describe the optical channel characteristics with respect to the atmospheric turbulence strength like Log-normal, Gamma-Gamma (G-G), I-K, K, Negative Exponential, Rician Log-normal Distribution. There are three main statistical models which are used to describe the atmospheric turbulence channel that are Log-normal, K, and G-G distributed channel model. The G-G distribution out of the three is used to model atmospheric turbulence irradiance fluctuation in both weak as well as strong turbulence regimes. Where for the limit of strong turbulence, Negative Exponential distribution is adopted [15]. Generally, the Log-normal distribution is used in case of the weak atmospheric turbulence regime [15, 16, 23].

**Pointing Error (PE):** The gain of FSO system increases when multiple apertures are used at transmitter or receiver. However, the PE which is generated by building sway degrades the performance of FSO, eradicating the benefits obtained by using multiple apertures. In [24], the effect of PE in Gamma-Gamma fading atmospheric fluctuation of FSO MIMO system is discussed. Two schemes are studied, namely Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC). MRC was found out to be more impregnable for large PE than EGC scheme. However, for low to moderate PE, EGC is preferred over MRC due to its low implementation complexity.



## 4 Conclusion

With the ever-increasing demand for bandwidth and high data rates from the heterogeneous networks, the FSO can be the efficient way out. Terrestrial FSO links with transmission rates of 10 Gbps (assuming a range of few hundred meters) are already in the market, and the speeds of recent experimental FSO systems are promising even more. To further enhance the performance of FSO, tremendous amount of research work has been done and is still going on. This paper provides the overview of FSO communication and its numerous advantages, applications, and limitations. The insight is provided into the research that has been done in order to mitigate its limitation and enhance its performance.

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