

# A Overview of Free Space Optical Communication (FSO)

V. Basil Hans<sup>1</sup>, Rashmi Shenoy<sup>2,\*</sup>

## Abstract

*Free Space Optical communication (FSO) is a wireless communication system that employs light propagation across free space to transport data between two sites without the usage of fibre optic cables. It uses either lasers or light emitting diodes (LEDs) for high speed data transmission with enormous bandwidth, which makes it a desirable solution for modern communication systems. The FSO provides many advantages such as minimal installation cost, excellent security, licence free spectrum and fast implementation. It has wide application in satellite communication, military networks, urban connection and disaster recovery systems. However, FSO communication is susceptible to atmospheric circumstances such as fog, rain, dust and turbulence which can impair the quality of the signal and the reliability of transmission. Recent advances in adaptive optics, hybrid RF/FSO systems and enhanced modulation techniques have improved the performance and reliability of FSO networks. With the increasing demand for high-speed Internet and next-generation communication technologies, FSO is becoming a promising alternative and complementary technology to traditional wired and radio-frequency communication systems.*

**Keywords:** Free space optical communication, optical wireless networks, laser communications, data transfer at high speed, atmospheric disturbance, hybrid RF/FSO systems, adaptive optics

## INTRODUCTION

Free-Space-Optical-Communication (FSO) is an optical communication which employs “free space” as the transmission medium, instead of fibre. Generally, an FSO system consists of a transmitter, where an optical signal is encoded and transmitted, and a receiver, where the optical signal is detected and decoded. Transmitters are usually lasers, LEDs or VCSELs. Receivers are photodiodes or photoresistors. FSO is often used as backhaul for wired and RF networks, wide area networks, remote controllers, satellite communication and inter-chip communication. Unlike fibre optics, FSO does not have a dependable channel to propagate the light. The beams tend to diverge, resulting in geometrical loss, and atmospheric circumstances like absorption and scattering degrade the information further. The highly directed beams increase spatial reuse and network capacity, enabling high-speed data transfer, high-definition video conferencing, and use in stationary applications such as satellite links and building rooftops [1].

### \*Author for Correspondence

Rashmi Shenoy  
E-mail: [vhans2011@gmail.com](mailto:vhans2011@gmail.com)

<sup>1</sup>Research Professor, Department of Management & Commerce, Srinivas University, Mangaluru, Karnataka, India

<sup>2</sup>Assistant Professor, Department of forensic science, St Aloysius (Deemed to be university), Mangaluru, Karnataka, India

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## HOW EFFECTIVE IS FSO

Free Space Optical communication is based on light propagation in free air. For example, an optical source such as a laser or LED encodes and transmits a signal to a receiver that is equipped to detect and decode it. Careful attention to alignment during installation and maintenance is required, since light beams have to be correctly directed from transmitter to receiver. The level of the detected signal at the receiving terminal relies on the level of the signal and atmospheric loss impacting the signal transmission. The amount of information transmitted across the link also depends on the

strength of the signal and on the modulation technique that is utilised. Common approaches transfer data by altering the intensity, which can thus be less power demanding and thus extend coverage range [1]. Error-correcting codes are included to make data resistant against these variable losses at no expense of additional power.

### MAJOR ELEMENTS

Free space optics (FSO) communication systems consist of transmitters, receivers, optics, flexible mounting brackets and control systems. Transmitters use LEDs or laser diodes to encode and transmit optical signals, while receivers use photodetectors to decode the incoming signals. The use of auxiliary optics like collimators and lenses allows the beam to propagate linearly and reduces the divergence. Pointing, acquisition and tracking systems vary the line-of-sight orientation and enable link interruptions to be automatically detected for maintenance. Safety measures prevent unintentional exposure to the high-power beams often necessary for uncooled laser diodes. Auxiliary components, such as power supply, alignment aids, and monitoring systems [2].

Transmitters can use light emitting diodes (LEDs) or laser diodes (LDs). The LEDs have a wide semi-angled beam with a low spatial power concentration but generally have a lesser modulation depth and a higher transmission loss. Laser diodes have the advantages of smaller size, higher power, spectrum purity, and better modulation performance, and can satisfy most of the requirements of modern FSO communications [1].

The receiver sensitivity varies greatly among the photodetector technologies. Silicon photodiodes are well established and offer good sensitivity from the visible into the near-infrared. Special high speed variants can provide data speeds from tens of megabits to gigabits per second. Other technology alternatives include InGaAs, APD, multichannel, avalanche and PIN [3].

### ADVANTAGES AND DISADVANTAGES

The free space optical (FSO) communications are point-to-point systems with double modulation at the transmitter and the receiver, optical to radio frequency (RF) signal conversion before multiplexing [1]. Data bandwidths are sometimes multi-gigabit at significant link distances because line-of-sight propagation removes unwanted intersymbol interference produced by multi-path propagation, weather (rain, fog, snow, haze) and atmospheric turbulence.

Diffraction, beam divergence losses and air absorption significantly limit coverage, availability (40%), and transmitted data rates. FSO systems enable high capacity and large spatial reuse due to the high collimation of the sources used (e.g. laser, light-emitting diode) and the large angular divergence generated by atmospheric scintillation.

The link establishment and maintenance requires very directed beams and strict alignment accuracy within the desired link distance. Actuator jitter and thermo-mechanical disturbances cause misalignments and pointing error budgets that grow with the link range. Therefore, the link architecture has to adjust for such non-line-of-sight (NLoS) intervals while guaranteeing that time-division multiplexing techniques preserve the numerous access advantages offered by such systems [3].

### FSO APPLICATION

Free-space optical (FSO) communication systems provide specific benefits for high-capacity data networks. FSO lines use light rather than radio waves to communicate through the atmosphere, well outside the electromagnetic spectrum regulated by government bodies. The license-free nature of the spectrum allows for flexibility in equipment location and deployment. The components used to make an FSO link are widely available which makes it even more attractive. Consequently, FSO communication solutions have emerged in many forms to cater to a multitude of applications.

Datacentre and campus backhaul FSO is a mature market. Top vendors offer links with specific designs to be able to deliver high-throughput access, and yet stand up to tough outside circumstances, including wind, rain, fog, and dust. Other urban and enterprise connectivity solutions are designed to provide point-to-point distribution of broadband services, and to allow for temporary network installation following a natural disaster. Mobile FSO for transport network extension is considered along with satellite FSO links for terrestrial backhaul. Variable.

### **PERFORMANCE FACTORS**

The performance of free-space optical (FSO) systems is governed by several factors. First, there are problems posed by meteorological conditions such as rain, snow, fog and haze. Second, the received signal is affected by atmospheric turbulence and scattering. Thirdly, alignment difficulties also impact on performance. In particular jitter and pointing accuracy at both transmitter and receiver deteriorate the quality of service. Finally, the distance of the link and the size of the aperture at each end are also of consequence. Larger apertures are useful for longer distances; larger and smaller apertures are also useful for short links.

### **BASICS OF MODULATION AND CODING**

Modulation is the technique of encoding information onto a carrier light wave for transmission. The most common used methods are On-Off Keying (OOK), Quadrature Phase Shift Keying (QPSK) and Pulse Amplitude Modulation (PAM). OOK: The carrier signal is either present (1) or absent (0). QPSK uses four different phase angles to encode two bits of binary data. PAM sends one digit at a time using three different power levels. You can also mix modulation methods.

Coding prevents corruption of information in transmission. For example, just before transmission data is encoded to generate parity bits. Now the transmitted code consists of the original data plus these extra bits. The codes are verified at the conclusion of reception. Any code with a bad parity bit can be detected and fixed.

Performance is affected by duty cycle, baud rate, and data rate. The duty cycle is the percentage of the duration for which the signal is active. baud rate is the rate at which the signal changes symbols. Data rate is the number of binary digits sent in one second.

### **SECURITY AND LINK DESIGN.**

Link design is done by link budget calculation. Link budget defines the propagation of light via the medium and contains important characteristics such as transmitter power, losses, receiver sensitivity and margin. The transmitter power is constrained by eye-safety restrictions, and the losses include free-space route loss, atmospheric attenuation and various other types. In addition to the link budget, safety and environmental issues should be taken into account by FSO designers. Link alignment is a crucial operational feature that significantly affects performance, and maintenance tests help to identify variations due to thermal or mechanical variables over time [4].

### **REAL WORLD APPLICATIONS**

FSO systems are being deployed more and more. Many companies have installed FSO equipment for commercial and industrial applications. Its customers are municipalities, big corporations and academic institutions [1]. Installations normally connect buildings, towers or other structures that are distant by some hundreds of meters to some kilometres. Fielded systems may perform differently than evaluated in the laboratory. Environmental effects, equipment mounting, etc., may reduce the available link budget or cause impairments. Systems built and implemented by organisations such as the Massachusetts Institute of Technology Lincoln Laboratory [3] feature modifications to counteract these field effects.

Fine-tuning and major changes in subscribers, business requirements and link prices could suddenly demand a connection from flat buildings, remote workplaces, lossy metropolitan areas and even data

centers from multiple providers. Availability measurements, such as the percentage of time the system is up, have shown positive values. Wherever pathways exist, practical and economical options can be utilised to maintain the institution network until the building and installation of the permanent link is completed. Customers report latency under 1 ms and throughput rates of several gigahertz and upgrades to 10–20 gbit/s within multiple years of working.

Commercial organisations are already seizing these chances. Systems functioning at storage or document exchange centers to aid tight transmission intervals among data, restoration of alerts and changes as well as emergency signals for mission critical sites when terrestrial channels are down or limited on behalf of disaster recovery and restoration for all corners buffer the situation remarkably. In a time-critical situation where these exchanges and alerts need to be shared at improved reach and rapid speed, the items can still travel along an installed backbone on either attendant FSO or even supporting both; the entire time is further reduced with the same items over different territories.

Consumer off-the-shelf systems can be helpful. That remains a challenge for networks destroyed by earthquakes or hurricanes across Asia, where temporary but fast processes provide competitive bids. The combination of remote building while preserving again the high-end storage facility has an edge for the Organization up to combining waver of equipment held. Messaging can vary from tens to hundreds of packets per month, with on-the-air transmission taking longer, and antenna-up transmission occurring under light conditions but above counters at point-to-point. Restoring larger data can still persist in residential settings after hours, with internal items such as entertainment and urgent alerts further hammering down more punctual, large yet higher expectations [5–7].

## TRENDS FOR THE FUTURE

The demand for high-capacity communication lines is still increasing, especially at the periphery of wired lambda networks and at microwave or millimetre wavelengths in mobile backhaul and fronthaul [1]. Free-space optical (FSO) communication, where transmitter–receiver couples operate in the infra-red, has attracted interest as a feasible option [3] in recent times. In order to preserve the communication links between stationary or mobile nodes in mesh architecture, the LOS between access points has to be formed in a continual manner and new FSO devices have to be detected in an autonomous manner. Automated procedures for LOS finding and link-maintenance for this are being developed.

Link budgets are created that connect the architecture and range of FSO systems to availability, latency and data rate. Future trends are higher data rates, advanced alignment algorithms, integration with RF connectivity to form hybrid RF/FSO networks, adaption to harsh weather and establishment of new eye-safety standards.

FSO uses “free space” as medium and uses transmitters such as lasers, LEDs and vertical-cavity surface-emitting lasers (VCSELs), and receivers such as photodiodes. A significant total link margin results from combining scattering, optical loss owing to beam divergence and air absorption, which is sufficient for backhauling wired and RF networks, wide-area and local connection, remote-control applications, inter-chip linkages and even space communications. Thanks to the extremely directed character of FSO, a typical range of less than 500 m is suitable for network topologies that are difficult to realise with RF, such as rooftop mesh links or point-to-point linkages between buildings many kilometres apart. High bandwidth FSO systems allow applications like HD video conferencing. FSO is an alternative to RF (limited by spectrum scarcity) and retrofits easily into existing infrastructure, besides backhaul for 5G and future 6G networks [8–10].

The main current technique to solve the “Last Mile” problem between the backbone of optical fibres and the user terminals is Free Space Optical Communication (FSO). It can play an important role in bridging cities with isolated rural areas, high rise buildings in cities, buildings on both sides of highways or railways and river banks which are difficult to cross. Furthermore, major efforts have been dedicated

to the development of FSO-based inter-satellite, satellite-to-air, satellite-to-ground, and satellite-to-submarine communications, paving a new approach for building a ubiquitous network interconnectedness of all things. An example of this is SpaceX's Starlink broadband Internet, which aims to create a worldwide network that is not limited by ground infrastructure. The low-orbit satellite constellation is deployed with the use of both conventional and FSO communication technologies. [5]

## CONCLUSION

Free-space-optical communication is a viable alternative to radio-frequency and optical-fiber networking. It sends information via the atmosphere using modified light beams. FSO does not require costly infrastructure and time-consuming installation compared to fibre. FSO has more capacity than radio and allows secure transmission for short-range communication. FSO provides gigabit per second data rates and sub-millisecond latency across distances up to several kilometres and as such is a useful link for communications backhaul and interim links following disasters. Engineers must consider a number of external elements that affect performance, such as atmospheric and alignment impacts, which can be simply addressed by contemporary technologies.

Many components come together to create a comprehensive communication link in FSO systems. For example, a semiconductor laser, a source, converts electrical signals to short optical pulses or continuous-wave beams. A collection of optical elements focus and collimate the beam to reduce spreading and expand the link range. The signal is then broadcast by air to a remote terminal. The receiving terminal has comparable optics to collect the incoming light. A detector such as an avalanche photodiode transforms the light back into an electrical signal. The signal is then amplified and further processed by other circuits according to the modulation scheme.

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