RECENT ADVANCEMENTS IN FREE SPACE OPTICS

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Abstract
To circumvent the concerns of conventional communication media like optical fibers in which the installation of optical fibers require significant investment for infrastructure and radio frequency technology which being licensed spectrum requires huge investment to utilize few bands from restricted spectrum, FSO comes to rescue. Because of the number of prime advantages of FSO over other communication media, it is a viable option to provide plentiful, affordable and reliable connectivity by delivering high-bit-rate line-of-sight transmissions over lengthy distances of up to several kilometers. And hence improving the quality of life for those who live in isolated and rural areas. An overview of Free Space Optical communication and recent developments in FSO are presented in this paper.
Keywords: Free Space Optics, Communication, Fibre, Obstacles in Communication, Advances.

1. Introduction

The demand for high-speed internet traffic and multimedia services has increased dramatically in recent years. As a result of the rising demand, high-capacity networks, which focus on increasing transmission capacity and coverage area, have become more popular. Free space optics (FSO), as a high-bandwidth medium with high data rates, is a promising technique for achieving the highest transmission rate with the fewest errors. The transmission speeds supplied by FSO are far higher than those available with RF technology[1]. FSO (free space optics) is an optical communication technology that allows optical connectivity by transmitting data via light propagation in free space without the need of laying an optical fibre cable. The working principle of FSO networks is similar to OFC (optical fibre cable) networks, with the exception that optical beams are delivered through free air rather than glass fibre cores in OFC cores. An optical transceiver is used on both ends of the FSO system to give full duplex (bidirectional) functionality. FSO communication isn't a brand-new concept. It dates back to the eighth century, but it has since evolved. FSO is a LOS (line of sight) technology that allows for data, voice, and video communication at speeds of up to 10 Gbps[2].

The following features should be included in an efficient FSO system: [2]:

1. For longer distances, FSO systems should be able to function at higher power levels.
2. High-speed modulation is critical for high-speed FSO systems.
3. Because of its maintenance, an overall system design should have a small footprint and low power consumption.
4. The FSO system should be able to function across a wide temperature range, with less performance degradation for outdoor systems.
5. The system's mean time between failures (MTBF) should be greater than ten years.

2. Applications

The FSO communication link is currently in use for a variety of services in a variety of locations. These are detailed descriptions below:

1. Outdoor wireless access: Unlike microwave bands FSO is the unlicensed medium of communication and can be utilized by wireless service providers for communication.
2. Storage Area Network (SAN): It can be formed using FSO links. It's a network that's notable for allowing users to access aggregated, block-level data storage. FSO links can be used to form a SAN [2].
3. Last-mile access: It is very expensive for service providers to lay user cables in the final mile because the cost of digging to lay fibre is so high, and it would make sense to lay as much fibre as possible. FSO can be used to remedy such a problem by integrating it with other networks in the last mile. It's a high-speed connection. It's also utilised to get around other sorts of networks' local-loop system[3].
4. Enterprise connectivity: the easy installation feature of FSO systems allows it to enable communication between two buildings or other properties by interconnecting LAN segements [3].
5. Fiber backup: In the event that a fiber-based trans-

mission link fails, FSO can be used to provide a backup link [3].

6. Metro-network extensions: It can be used to expand a metropolitan area's fibre rings. The FSO system takes less time to setup, and configuring new networks and core equipment is simple. It can be used to finish SONET rings as well. [3].
7. Backhaul: It could be useful in transferring high-speed and high-data-rate cellular communications from antenna towers back to the PSTN. Transmission speed would be improved. [3].
8. Service acceleration: It can also be utilised to provide clients with immediate service while their fibre infrastructure is being installed [3].
9. Bridging WAN Access: In the WAN, FSO is useful because it supports high-speed data services for mobile users and small satellite terminals, as well as serving as a backbone for high-speed trunking networks [4].
10. It can be used for short and long-range communication between point-to-point links, such as two buildings or two ships, and point-to-multipoint links, such as aircraft to ground or satellite to ground [5].
11. Military access: FSO being secure and undetectable technology is excellent for military applications and can safely connect huge areas with little planning and deployment time [6].

3. Advantages

1. A flexible network that gives faster speeds than broadband is free space optics [1].
2. Digging of streets is not needed as a result of which Installation is very simple [1].
3. It requires a small initial investment [3].
4. It's a simple system to set up. There is no need for a spectrum license or for users to coordinate frequencies as in radio and microwave systems [7].
5. Because of the line of sight operation, it is a secure system, and no security system upgrades are required. [7].
6. The data rate is comparable to that of optical fibre cables, but the error rate is very low, and the incredibly narrow laser beam allows for an unlimited number of FSO lines to be deployed in a given area [7].
7. FSO is highly immune to Radio Frequency Interference and Electromagnetic interference[7].
8. Dense spatial reuse is offered by [8].
9. The FSO system benefits from low power consumption per transmitted bit [8].
10. The bandwidth is relatively high [8].
11. The medium of transmission of optical beam is air as a result of which transmission occurs at a speed of light Transmission of optical beam is done in air [10].

4. Drawbacks

The benefits of free space optics are numerous. However, because FSO uses air as its transmission medium and the light passes through it, some environmental issues are unavoidable and unforeseen. Some of these restrictions, which have a broad impact on FSO performance, are briefly discussed below [11]:

1. Physical obstructions: When flying birds, trees, or tall structures emerge in the line of sight (LOS) of the FSO system's broadcast, they can momentarily block a single beam [1].
2. Scintillation: The heat originating from the earth and man-made drives like heating ducts would cause temperature fluctuations among distinct air packets. Temperature differences can induce signal amplitude fluctuations, resulting in "picture dance" at the FSO receiving end. Light Pointe's multibeam system addresses the effect of scintillation [1].
3. Geometric losses and Beam Dispersion The spreading of the beam causes geometric losses, also known as optical beam attenuation, which reduces the signal's power level as it travels from the transmitter to the receive[7].
4. Absorption: The water molecules floating in the terrestrial atmosphere are responsible for absorption. These particles would absorb the photon's energy. As a result, the link margin, energy intensity of the optical carrier, availability, and useful distance of the link all decrease. Signal absorption can also be caused by carbon dioxide. [9].
5. Atmospheric turbulence: The atmospheric disturbance is caused by weather and the structure of the surroundings. Wind and convection are to blame, as they combined air parcels of varying temperatures. The density of air fluctuates, resulting in a change in the refractive index of the air.
6. Atmospheric attenuation: Fog and haze are the usual causes of atmospheric attenuation. Dust and rain play a role as well. Atmospheric attenuation is thought to be wavelength dependent, although this is not the case. Haze is a wavelength-dependent phenomenon. In a fog weather state, attenuation is independent of wavelength.
7. Scattering: When the optical beam and the scatterer

clash, scattering occurs. It's a wavelength-dependent phenomena in which the energy of an optical beam remains constant. However, only directional redistribution of optical energy occurs, resulting in a decline in beam intensity over longer distances.

8. Atmospheric Weather Conditions: The transmission medium for an FSO link is the atmosphere. Its attenuation is dependent on a number of factors. Attenuation is mostly caused by weather conditions. The place in which the FSO communication channel is being constructed has some special weather circumstances that can be used to get prior knowledge of attenuation; for example, in temperate regions, fog and heavy snow are the two most common weather situations. Heavy rain and haze are two primary weather factors that affect the availability of FSO links in tropical locations [13].

5. Recent Advancements In FSO:

Because of the high bandwidth and data rate requirements, optical communication technology has grown in importance. Optical Wireless connections, WDM, wavelength interleaving, newer modulation schemes, and other areas of research fall under the heading of Optical Communications. In the realm of Free Space Optical Communication, several scenarios of optical communication techniques such as WDM, RoFSO, bi-directional link, and under water optical transmission have benefited from exploiting optical bandwidth in recent years (FSO). Free Space Optical (FSO) communication may deliver very high data rates up to Gbps without the use of cables. Due to its low power, bandwidth scalability, unregulated spectrum, mass need, rapid deployment speed, and cost-effectiveness, it is a rapidly emerging topic of research these days. FSO's recent rise can be attributed to significant advancements in communication technology, which has resulted in the examination of a variety of intriguing simulation and experimental implementations. However, because the system is influenced by unpredictably changing atmospheric and weather conditions, the optical link's performance suffers. Research trends and recent developments in FSO communication are the focus of current work. The design for a future mobile communication system is depicted, as well as solutions to make FSO a more efficient technology[14].

Scientists and researchers are busy in making this cost effective and low power consuming technology more common and realistic by working on some important factors like increasing the range of transmission, decreasing the effect of environmental factors, increasing number of users etc.

Recently, the experimental investigation of Free Space Optical Link in an indoor room with controlled atmospheric turbulence that mimics the outdoor environment was carried out by Shilpi Gupta from Shri G. S. Institute of Technology and Science, Indore, India. It was observed that the reliability of the FSO link can be increased by building an atmospheric chamber as a prototype to examine the free space channel and its characterisation in a controlled environment, rather than having to wait as long as with outside FSO links. An indoor chamber with fans and a heating coil was built to imitate outdoor weather conditions, allowing human control of the temperature and wind velocity within the chamber. On the FSO system, an attempt was made to characterise the combined effect of wind and temperature-induced scintillation. Using a laboratory test, the effect of perpendicular wind flow on a rain-interrupted FSO link was also examined. The performance of various modulation formats were assessed in terms of communication metrics[14].

Indian operator BSNL, however, said in May 2019 that it is considering using FSO for backhaul in the states of Rajasthan and Gujarat. BSNL told ETTelecom that it is currently studying the technology and its potential use[15].

The other recent advancements in various types of communications are discussed as follows:

(a) Space-Borne Communications:

Despite the cancellation of the Mars Laser Communication Demonstration project in 2005, space-based FSO communications are still operational. In 2006, ARTEMIS, the European Space Agency's Advanced Relay and Technology Mission Satellite, relayed an optical signal from its SILEX laser link to an aircraft flying at altitudes of 6 and 10 km, a feat equivalent to targeting a golf ball over the distance between Paris and Brussels from its geostationary position at 36,000 km altitude. The bandwidth potential for FSO communications is two orders of magnitude bigger than RF or microwave transmission," says Stefano Badessi, an applications engineer at ESRIN, the ESA Centre for Earth Observation in Frascati, Italy[16].

A superconducting nanowire single-photon detector (SNSPD) was employed by the Massachusetts Institute of Technology's (MIT) Lincoln Laboratory (Lexington, MA) to establish an error-free photon-counting communication link at a data rate of 781 Mbit/s (the fastest at that time in 2006). "Right now, we're working on a free-space communications system for NASA that will connect a lunar-orbiting satellite to a ground-based telescope array," says Andrew J. Kerman, an MIT Lincoln Laboratory technical staff member."The Lunar Laser Communications Demonstration (LLCD) initiative will act as a trailblazer for NASA, demonstrating the potential of photon-counting laser communications"[15].

Closer to home, there's a DLR spinoff ViaLight Communications (Gilching, Germany) specialises in FSO networks from the ground up, including unmanned aerial vehicles (UAVs), planes, and high-altitude platforms. These "mobile" FSO networks have average 1 Gbit/s speeds and a range of 100 km. Unlike in space, however, terrestrial FSO networks are constantly challenged by shifting atmospheric conditions.

(b) Terrestrial Links:

FSO networks, which were originally designed for secure military communications, have vastly improved and continue to use their 'covert' strengths "LightPointe (San Diego, CA) CEO Heinz Willebrand says (see Fig. 3). "A typical FSO beam divergence is on the order of 2-5 mrad; in other words, at a distance of 1 km, the beam spot is only 2-5 m, compared to a radio antenna that can spread out the signal over 100 m or more. In addition, there is a huge amount of "free" spectrum in the optical communications band. While unlicensed and licenced RF and microwave systems up to about 40 GHz commonly operate in relatively small spectrum bands (20, 30, 50 MHz),For instance, the available spectrum in the optical communications range surpasses several hundred gigahertz".LightPointe's FSO systems use numerous transmitters and receivers to achieve full-duplex speeds of up to 1.25 Gbit/s. "Not only does this increase the power we can launch from the terminal, but it also increases the overall receive lens surface," Willebrand explains, "while minimising the impact of 'heat shimmer' or 'scintillation,' which can negatively effect the performance of FSO systems having long transmission length evaluated in terms of BER(Bit Error Rate)"[15].

(c) Longer Wavelengths, Longer Reach:

A 10 m wavelength source provides considerably small scattering than a 1.55 m wavelength source because Rayleigh scattering diminishes with increasing wavelength," says Kumar C. Patel, CEO of Pranalytica (Santa Monica, CA). Patel cites a Stevens Institute of Technology (Hoboken, NJ) study that found that using an FSO system with an 8.1 m source resulted in 2X to 3X greater transmission during fog formation and after a short rain event (that reduced visibility to approximately 1 km) compared to using conventional 1.3 and 1.5 m sources. "We're working on FSO communications using mid-infrared [mid-IR] radiation sources, specifically quantum-cascade [QC] lasers, and developing new detection systems that allow for easy signal demodulation," says Rainer Martini, director of Stevens Institute of Technology's Laboratory for Ultrafast Spectroscopy and Communications. In a collaboration with San Diego State University, Daylight Solutions (San Diego, CA) is also investigating the functionality of FSO communications using mid-IR QC lasers. While these 3-12 m sources excel at detecting the spectral "fingerprint" of atmospheric molecules, FSO transmission is only possible if the launch wavelength avoids the absorption lines of water vapour, CO2, pollution, and other common atmospheric chemicals. "As a result, longer wavelengths between 8 and 12 m are considered ideal prospects for next-generation terrestrial FSO communications networks," adds Daylight Solutions' Sam Crivello. "Our tunable external-cavity QC lasers enable users to tune to a window in a dynamically changing atmosphere to avoid pollution and water interference for full-duplex communications at high baud rates and small values of BER using wavelength Division Multiplexing techniques"[16].

(d) Undersea Challenges, Future Terrestrial Promises:

The Woods Hole Oceanographic Institution (WHOI; Woods Hole, MA) developed an optical/acoustic undersea communications system in early 2010 that transports data from untethered remotely operated vehicles (ROVs) to surface ships or laboratories over a visible-light beam at 1-10 Mbit/s data rates at 100 m distances. At distances more than 100 metres, acoustic communications take over[16].

FSO communications will expand as transmit and receive technology improve and new applications develop, from orbiting satellite-to-satellite linkages to deep ROV research. "FSO is still a small industry," says LightPointe's Willebrand, "with most applications in the enterprise/building-to-building connection arena." "However, next-generation mobile wireless networks will have to give a lot of access capacity to a single handset/smart phone," he continues. "To do so, distances between microcell sites are shrinking to sub 500 m-exactly the 'sweet spot' for high-capacity FSO systems." "The adoption of FSO technology in mobile wireless backhaul networks should significantly increase the total addressable market for FSO"[16].

fSONA (Richmond, BC, Canada) has already begun to deploy its 1550 nm eye-safe SONAbeam FSO networks to enable wireless backhaul and broadband applications. "The fiber-optics industry spends billions of dollars every year developing new components and subsystems for the 1550 nm region," explains fSONA CTO Paul Erickson. "2.5 Gbit/s 1550 nm diode lasers are now on the market, with 10 Gbit/s systems on the horizon. In addition to higher potential speeds, 1550 nm FSO systems have up to 50 times the output power of 800 nm FSO systems, enabling for more reliable operation over longer distances and/or despite heavier fog attenuation"[16].

6. Conclusion:

The numerous advantages of FSO over the conventional approaches grabs the attention of scientists and researchers and hence the area is becoming the growing area of research nowadays. The benefits of the FSO communication system and its application areas make it a popular technology, but there are several issues that arise due to medium attenuation. The FSO system has various issues, such as medium attenuation, which might decrease transmission performance due to power loss. However, extra caution and pre-study of the medium can help determine what types of factors to consider before installing the system. Many investigations are being conducted in this direction in order to reduce the effect ofattenuation.

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