Free Space Optical Communication: A Review

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Abstract -*With the worldwide demand for larger bandwidth and greater mobility there is a rapid advancement of broadband wireless communications. The high capacity and low loss of optical fibre has seen its exploding growth in the last few decades in the LAN's and WAN's. Free space optical (FSO) wireless communication has emerged as a viable technology for bridging the gap in existing high date rate fibre network and as a temporary backbone for rapidly deployable mobile wireless communication infrastructure. Free space optical communication offers the potential to send large amount of data security over moderate distances without the expense of laying fibre optic cable. The technology is helpful where the physical connection of the transmitter and receiver locations is difficult. These robust systems which establish communication links by transmitting laser beams directly through the atmosphere, have matured to the point that mass produced models are now available. FSO system offers many features among them being the low-start up and operational cost, rapid development and high fibre-like bandwidth. It offers capacities in the range of 100Mbps to 2.5Gbps and demonstration systems report data rates as high as 160Mbps.It is a line-of-sight technology that currently enables optical transmission up to 2.5Gbps of data, voice and video communications through the air, allowing optical connectivity without deploying fibre-optic cables or securing spectrum licences. Even though FSOs provide high security as its laser beams cannot be determined with the devices like spectrum analyser or RF meters, there are some challenges (atmospheric turbulence, scintillation, object sway) in the implementation of it.*

Key Words:**atmospheric turbulence, fso, lasers, los (line-of-sight), optical wireless, scintillation, etc.**

1.INTRODUCTION

The proliferation of wireless communications stands out as one of the most significant phenomena in the history of technology. Wireless devices and technologies have become pervasive much more rapidly than anyone could have imagined thirty years ago and they will continue to be a key element of modern society for the foreseeable future. Today, the term "wireless" is used almost synonymously with radio-frequency (RF) technologies as a result of the wide-scale deployment and utilization of wireless RF devices and systems. The RF band of the electromagnetic spectrum is however fundamentally limited in capacity and costly since most sub-bands are exclusively licensed. With the ever-growing popularity of data heavy wireless communications, the demand for RF spectrum is outstripping supply and the time has come to seriously consider other viable options for wireless communication using the upper parts of the electromagnetic spectrum. The increase demand of wireless links which are easier, faster and less expensive to deploy has renewed interest in the use of free-space optics in digital transmission of signal in the atmosphere.

Optical communication systems provide the highest available carrier frequencies and thus the fastest data rates possible today. FSO is designed to be a lower cost alternative to conventional fiber-optic cable-based communication links. FSO is especially attractive within a metropolitan environment where the costs for trenching, cable installation, and street repairs can run from $200K to easily over $1M per mile, depending on the urban location. The idea to use light for Free Space Optical (FSO) Communications is as old as the telephone. FSO is a maturing technology that offers significant enhancements over most wireless technologies, including higher data rate, and the complete avoidance of any spectrum licensure costs. Its primary competition today is from existing fixed fiber installations. Today, a significant percentage of FSO sales are international. This has occurred due to the extensive USA fiber infrastructure that was installed in the 1990's slowing its expansion within the USA.

The most mature technology used in FSO equipment relies on low cost semiconductor lasers or LED's operating in the near infrared at wavelengths of 785 nm or 850 nm. In the past few years, systems operating at 1550 nm have also been developed. At first the vendors of these systems claimed that the 1550 nm wavelength had better propagation characteristics in severe weather than the 785 nm wavelengths. With further analysis and research, those claims were withdrawn. Now there are claims that even longer wavelengths near 10 microns will solve the FSO link availability issues associated with severe weather. Hype about such magic wavelengths for FSO is both a disservice to the investors who will lose the money they are investing based on exaggerated claims, and to the rest of the FSO industry which should be creating realistic expectations for the capability of its equipment. In the weather conditions which normally cause the highest attenuation for FSO systems, namely coastal fog and low clouds, 10 microns offers no propagation advantage over shorter wavelengths.

2.EVOLUTION OF FSO

Optical communication in various forms, have been used for thousands of years. The ancient Greeks used a coded alphabetic system of signalling with torches .In the modern era, wireless solar telegraphs called heliographs were developed, using coded signals to communicate with their recipients. In 1880 Alexander Graham Bell and his assistant Charles Sumner Tainter created the Photophone, at Bell's newly established Volta Laboratory in Washington, DC. Bell considered it his most important invention. The device allowed for the transmission of sound on a beam of light. On June 3, 1880, Bell conducted the world's first wireless telephone transmission between two buildings, some 213 meters (700 feet) apart.Its first practical use came in military communication systems many decades later, first for optical telegraphy. German colonial troops used Heliograph telegraphy transmitters during the 1904/05 Herero Genocide in German South-West Africa (today's Namibia) as did British, French, US or Ottoman signals. The invention of lasers in the 1960s revolutionized free space optics. Military organizations were particularly interested and boosted their development. However the technology lost market momentum when the installation of optical fiber networks for civilian uses was at its peak. Many simple and inexpensive consumer remote controls use low-speed communication using infrared (IR) light. This is known as consumer IR technologies. A recently declassified 1987 Pentagon report reveals free-space lasers have been mounted on Israeli F-15 fighter jets for the purposes of surveillance, missile-tracking, and targeted weaponry. In 2008, MRV Communications introduced a free-space optics (FSO)-based system with a data rate of 10GB/s initially claiming a distance of 2 km at high availability. This equipment is no longer available; before end-of-life, the product's useful distance was changed down to 350m.

In 2013, the company MOSTCOM started to serially produce a new wireless communication system that also had a data rate of 10GB/s as well as an improved range of up to 2.5 km, but to get to 99.99% up-time the designers used an RF hybrid solution, meaning the data rate drops to extremely low levels during atmospheric disturbances (typically down to 10MB/s).

Recent advances in FSO technology have opened up mainstream communications uses, from short-term solutions for short distance network bridges to an attractive and viable alternative for service providers to deliver the promise of all-optical networks. As an optical technology, FSO is a natural extension of the metro optical network core, bringing cost-effective, reliable and fast optical capacity to the network's edge.

While fiber-optic communication has gained acceptance in the telecommunications industry, FSO communication is still relatively new. FSO enables similar bandwidth transmission abilities as fiber optics, using similar optical transmitters and receivers and even enabling WDM-like technologies to operate through free space.

3.FSO-CHANNEL COMPARED TO RF- CHANNEL

Before starting with the main advantages and differences of Free Space Optics (FSO) and RF-channels it must be mentioned that FSO is a much younger technology compared to RF. When in 1960 the LASER were investigated people had the idea to transmit high data rates through the atmosphere by light for long distances, but then they found out about the problem of fog and clouds for light transmission. Of course in relevance to the high carrier frequencies in optics we have the high usable bandwidth, that is a big advantage compared to RF, but the high frequency also means short wavelengths (some μm), and that means the same size like the small particles within the fog and clouds. So it is not a surprise that Optical Wireless is mainly influenced by fog and clouds. It is the same relation like in RF between RF wavelengths and the size of rain particles. In both cases the Mie-scattering is the main attenuator for the different technologies. Now it is clear, why in 1960 the scientists (in the optical field) searched for better fibres to use light transmission instead of using the atmosphere with the non-predictable weather conditions. But of course work also started in Optical Wireless (a few ambitious scientists still hoped for solving the problems by using high power laser sources and so on). Additional for Inter-satellite Links FSO is a perfect solution, because we have no fog and clouds higher than the troposphere. So the main limiter and attenuator do not exist between the satellites. It must also be mentioned that scientists starting on real channel modelling for FSO the last 10 years, before they only made some measurements on attenuations or they developed FSO-systems. So the channel-modelling in FSO is much younger than in RF. RF started with scientists like Hertz and Marconi 120 years ago and a lot of scientists studied the propagation of RF since this time. At first of course they started experiments and measurements and later they analysed. Now they have a lot of valid models for RF, but still they are evaluating them by newer results. In FSO we are 70 years behind, the LASER were developed in 1960. First single scientists started to work on FSO 30 years ago, and we know the first scientists in our WG3 started with FSO 15 or 20 years ago. Since the last 10 years this technology is becoming more important and much more scientists working in this field. That is also one reason, why we have still only a few models, which we can use for FSO. Additional we have different models for different atmospheric influences. As example in the FSO-field we have models for the attenuation (from fog, clouds, rain etc.) and we have additional models for atmospheric turbulences. The different models are necessary, because the atmospheric turbulences (the so called scintillations) have completely different influences on the transmitted light, they are disturbing the wave-front and they also cause beam-wandering or beam-spreading.

4.PRINCIPLES AND PROPERTIES OF FSO

FSO-links through the troposphere are mainly influenced by weather conditions. Therefore, some important characteristics of the atmosphere have to be discussed before describing the optical wireless systems in more detail. The lowest part of the atmosphere up to 10 km above the Earth's surface is called the troposphere or the weather sphere. It has a varying refraction index, which is dependent on the height above the Earth's surface. Normally the refraction index decrease with the height, but at weather inversion situations there is a different relationship. Atmospheric conditions degrade laser communications through the atmosphere in two ways. First, the atmosphere acts as a variable attenuator between the transmitting and receiving terminals. Second, a free space laser link is subjected to scintillations. Attenuation is caused by the weather conditions along the transmission path. Generally, there is low atmospheric attenuation during clear days and high attenuation during foggy days. Rain does not influence optical transmissions heavily, because raindrops have the size of a few millimetres and are large compared to laser wavelengths (1.5 microns) and thus cause minimal scattering of the laser energy. Furthermore, water has minimal absorption at a 1550 nm laser wavelength. Therefore, it is not surprising that the optical transmission is not heavily impacted by rain (only about 3 dB/km). Similarly it is not astonishing that optical transmission is impacted dramatically by heavy fog (30 dB/km), because the fog aerosols have a comparable size as the used wavelengths.

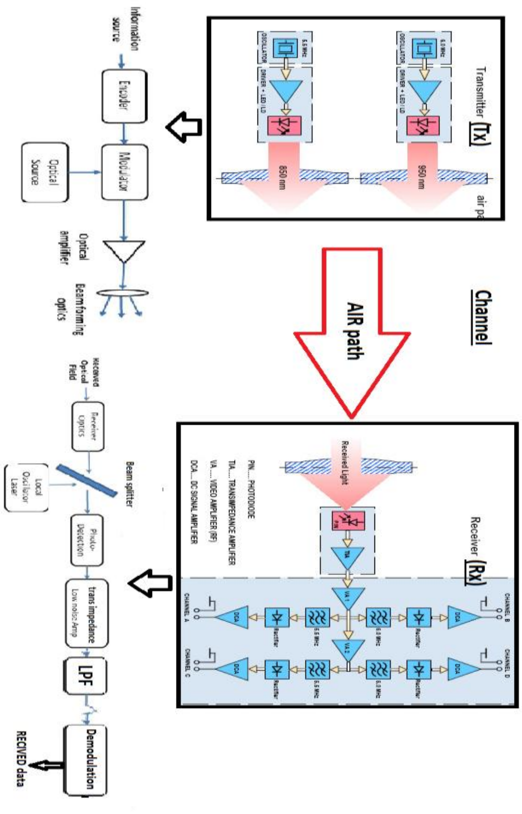

Fig -1: Different Subsystems of FSO

3. APPLICATIONS OF FSO

Rather than major challenges due to atmospheric conditions (mainly in long distance communication), it has many great applications for short range communication.FSO systems are appealing for a wide range of applications some of which are elaboratedin the following

Enterprise/campus connectivity: Today's corporations and school/university campuses are experiencing a heterogeneous network traffic (i.e., voice, data, fax, multimedia traffic) that is overwhelming the typical connections. FSO systems can bridge multiple buildings in corporate and campus networks supporting ultra-high speeds without the cost of dedicated fiber optic connections.

Video surveillance and monitoring: Surveillance cameras are widely deployed in commercial, law enforcement, public safety, and military applications. Wireless video is convenient and easy to deploy, but conventional wireless technologies fail to provide high throughput requirements for video streams. FSO technology presents a powerful alternative to support high quality video transmission.

Back-haul for cellular systems: Wireline connections such as T1/E1 leased lines and microwave links are typically deployed between the base stations and the mobile switching center in a cellular system. The growing number of bandwidth-intensive mobile phone services now requires the deployment of technologies such as FSO which allow much higher throughput.

Redundant link and disaster recovery: Natural disasters, terrorist attacks, and emergency situations require flexible and innovative responses. Temporary FSO links can be readily deployed within hours in such disaster situations in which local infrastructure could be damaged or unreliable. A tragic example of the FSO deployment efficiency as a redundant link was witnessed after 9/11 terrorist attacks in New York City. FSO links were rapidly deployed in this area for financial corporations which were left out with no landlines.

Security: Today's cryptosystems are able to offer only computational security within the limitations of conventional computing power and the realization of quantum computers would, for example, make electronic money instantly worthless. Based on the firm laws of physics, quantum cryptography provides a radically different solution for encryption and promises unconditional security. Quantum cryptography systems are typically considered in conjunction with fiber optic infrastructure. FSO links provide a versatile alternative in cases where the fiber optic deployment is costly and/or infeasible.

Broadcasting: In broadcasting of live events such as sports and ceremonies or television reporting from remote areas and war zones, signals from the camera (or a number of cameras) need to be sent to the broadcasting vehicle which is connected to a central office via satellite uplink. The required high-quality transmission between the cameras and the vehicle can be provided by a FSO link. FSO links are capable of satisfying even the most.

4.FACTORS AFFECTING FSO

Many factors affect the performance of the FSO system. It is important to keep the following factors and their effect on the system performance while designing the system to achieve maximum performance.
Scattering (Rayleigh scattering, Mie Scattering), Absorption, Snow, Fog, Visibility, Distance, Bandwidth, Scintillation effect.

5.LIMITATIONS AND FUTURE SCOPE

Free Space Optics (FSO) has become a viable, high-bandwidth wireless alternative to fiber optic cabling. The primary advantages of FSO over fiber are its rapid deployment time and significant cost savings. The disadvantage of FSO over fiber is that laser power attenuation through the atmosphere is variable and difficult to predict, since it is weather airports, the link availability as a function of distance can be predicted for any FSO system. These availability curves provide a good indication of the reasonable link distances for FSO systems in a particular geographical area. The carriers and ISPs are another potential large user of FSO systems, especially for last-mile metro access applications. If FSO systems are to be used in telecommunication applications, they will need to meet much higher availability requirements. Carrier-class availability is generally considered to be 99.999% . An analysis of link budgets and visibility-limiting weather conditions indicates that to meet carrier-class availability, FSO links should normally be less than 140m (there are cities like Phoenix and Las Vegas where this 99.999% distance limitation increases significantly). This calculation is based on a 53 dB link budget. This concept is extended to the best possible FSO system, which would have a 10 W transmitter and a photocounting detector with a sensitivity of 1 nW. This FSO system would have a 100 dB link margin, which would only increase the 99.999% link distance to 286 m. A more practical solution to extending the high availability range would be to back up the FSO link with a lower data rate radio frequency (RF) link. This hybrid FSO/RF system would extend the 99.999% link range to longer distances and open up a much larger metro/access market to the carriers. It is important to realize that as the link range increases, there will be a slight decrease in overall bandwidth. To show the geographical dependence of FSO performance, the first map of FSO availabilities contoured over North America is presented. This map is the first step to developing an attenuation map for predicting FSO performance, which could be used in similar fashion to the International Telecommunication Union (ITU)/Crane maps for predicting microwave performance.

6.CONCLUSIONS

In our survey, we observed that most of the applications of FSO are for short range communication. However with effective reduction in atmospheric turbulences using different modulation techniques the distance may be extended up to a larger extent.

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