NEXT GENERATION WIRELESS COMMUNICATION- FREE SPACE OPTICS (FSO)

Abstract:

This paper deals with communication through optics using one of the latest technologies called the free space optics (FSO).

FSO may sound new and experimental but in fact it predates optical fiber and has its roots in wartime efforts to develop secure communication systems that did not require cable and could withstand radio jamming. FSO has been around for more than a decade, but it is only recently that interest in this technology has started to grow. Here we try to explain some of the important aspects of FSO, its classification and the challenges, which we face in implementing it.

Key words: *wireless communication, Fso, radio, jamming*

Conclusion:

FSO equipment currently is being deployed for a variety of applications, such as last-mile connections to buildings, which may provide the greatest opportunity since FSO provides the high-speed links that customers need without the costs of laying fiber to the end user. In 2005, last-mile access will represent over two-thirds of the total FSO equipment market allows them to provide this optical connectivity cost effectively, quickly and reliably. Such flexibility makes FSO systems an extremely attractive method for service providers to truly solve the connectivity bottleneck. Free-Space Optics communication systems are among the most secure networking transmission technologies. To intercept this invisible light beam, the intruder must be able to obtain direct access to the light beam. Carriers, like Allied Riser and XO Communications, may use FSO in conjunction with other technologies to expand their current networks while others, such as Terabeam, see the technology as a means to break into the broadband market."

Fundamentals Of Free Space Optics:

FSO is an optical wireless, point-to-point, line-of-sight broadband solution.

Lasers Through Free Space:

FSO is an optical technology and simple concept involving the transmission of voice, video and data through the air using lasers. It is not a disruptive technology; it is more of an enabling technology that promises to deliver that ever-eluding high-speed optical bandwidth to the ultimate end users. FSO offers many advantages when compared to fiber. It is a zero sunk-costs solution. The principle advantages of free space optics (FSO) are:

1. Significantly lower cost on average than the build out of a new fiber optical solution, or leased lines
2. FSO can be deployed in days to weeks vs. months to years
3. Bandwidth can easily be scaled (10 Mbps to 1.25 Gbps) per link As opposed to fiber, FSO can be redeployed if the customer moves or cancels service. It is also a fraction of the cost and time, allowing carriers to generate revenue, while also taking advantage of the high capacity of optical transmissions. FSO allows service providers to accelerate their deployment of metro optical networks as well as extend the reach of such optical capacity to anyone who needs it.

FSO: Optical Or Wireless?

FSO systems share several characteristics with fiber optics. FSO can use the same optical transmission wavelengths as fiber optics, namely 850nm and 1550nm and they use the same components such as lasers, receivers and amplifiers. Some systems already include fiber connections inside the transmission link heads, to separate electronics and optics. Similar to fiber optics, FSO systems also target the high-bandwidth market. However, while fiber optics can be used over longer distances, FSO targets shorter distances due to the variability of the terrestrial atmosphere as a transmission medium.

One common feature of FSO equipment commercially available today is that most of these systems perform optical to electrical back to optical (O-E-O) conversion steps in the process of sending and receiving information through the air and connecting back to the attached networking interface fiber. This feature does not automatically constitute a performance limitation, but O-E-O conversion can impact the ability to scale an FSO system easily to ultra-high bandwidth capabilities. The fiber optic communications industry realized from the start the importance of an all-optical system approach, as higher backbone capacity — along with wavelength division multiplex technology. An important breakthrough to reach this goal occurred when fiber systems with erbium doped fiber amplifier (EDFA) became commercially available. It was then, that the concept carrying multiple wavelengths over a single piece of optical fiber achieved commercial attention. The invention of EDFA amplifier technology paved the way for optical transmission at multiple wavelengths over longer distances without the need to perform expensive O-E-O conversion and separate electrical amplification of each specific wavelength at every repeater station.

Bandwidth Drivers/Trends:

The push to build more high-speed networks was spurred by unprecedented growth in bandwidth usage. Telecommunications carriers will implement multiple technologies in their networks and will use the best access technology for the particular situation. The chart below shows how these technologies address different market segments based on technology, technical capabilities (reach, bandwidth), and economic realities.

Fig 1. A Number Of Compelling Factors Are Influencing This Bandwidth Surge:

How It Works:

http://www.freespaceoptics.org/freespaceoptics/images/flightstrata_illustration.gifhttp://www.freespaceoptics.org/freespaceoptics/images/flightstrata_illustration.gifFSOtechnology is surprisingly simple. It's based on connectivity between FSO-based optical wireless units, each consisting of an optical transceiver with a transmitter and a receiver to provide full-duplex (bi-directional) capability. Each optical wireless unit uses an optical source, plus a lens or telescope that transmits light through the atmosphere to another lens receiving the information. At this point, the receiving lens or telescope connects to a high-sensitivity receiver via optical fiber.

Fso System Design Issues:

Free-Space Optics Subsystems:

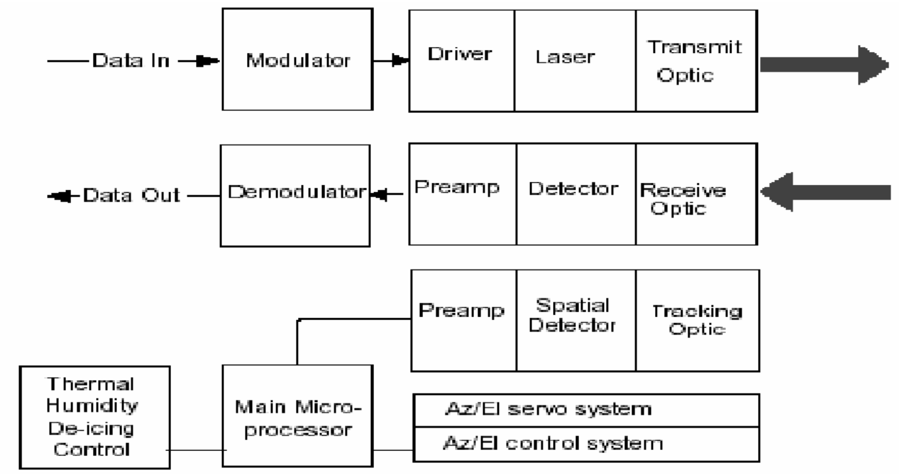

Fig 2. Fso Major Subsystems

Figure2 illustrates the major subsystems in a complete carrier-grade free-space optics communications system. The optical apertures on a free-space system can have an almost infinite variety of forms and some variety of function. They can be refractive, reflective, diffractive, or combinations of these. In figure2, the transmit, receive, and tracking telescopes are illustrated as separate optical apertures; there are several other configurations possible where, for example, a single optic performs all three functions thereby saving cost, weight, and size. On the transmit side, the important aspects of the optical system are size and quality of the system. Size determines the maximum eye-safe laser flux permitted out of the aperture and may also prevent blockages due to birds. Quality, along with the f-number and wavelength, determine the minimum divergence obtainable with the system. On the receive side, the most important aspects are the aperture size and the f-number. The aperture size determines the amount of light collected on the receiver and the f-number determines the detector's field of view. The tracking system optics' field of view must be wide enough to acquire and maintain link integrity for a given detector and tracking control system.

Several means are available for coupling the laser to the output aperture. If a discrete diode is used; the diode is usually micro-lensed to clean up the astigmatism of the output beam and then is free-space coupled to the output aperture by placing the laser at the focus of the output aperture optical system. The distance from the laser aperture to the output aperture must be maintained such that the system divergence remains in specification over the temperature ranges encountered in an outdoor rooftop environment. This can be accomplished with special materials and/or thermal control.

Diode lasers are driven with a DC bias current to put the devices above threshold, and then, on top of that, are modulated with an AC current to provide, for example, on/off keying (OOK) for data transmission. For lasers with output powers below approximately 50 mW, off-the-shelf current bias and drive chips are available; for higher power lasers, custom circuits or RF amplifiers are generally used. The receive detector is coupled to the receive aperture through either free-space or fiber. Depending on the data rate and optical design alignment, tolerances can be extremely restrictive. For example, for data rates to 1.25 Gbit/s, detectors with relatively large active areas (500-micron diameter) can be used, making alignment to the receive aperture fairly straightforward. For fiber-optic coupling into multimode fibers, the correct size is about 63 microns in diameter, which makes alignment much tougher.

Detectors are generally either PIN diodes or avalanche photodiodes (APD). For carrier class free-space optics systems, an APD is always advantageous since atmospheric induced losses can reduce received signals to very low levels where electronics noise dominates the signal-to-noise (SNR) ratio. Of course the APD must be capable of meeting the system bandwidth requirements. Usually a trans-impedance amplifier is used after the detector because in most cases they provide the highest gain at the fastest speed.

Bit Error Rate, Data Rates, And Range:

In figure3, which depicts a set of buildings in Denver, Colorado, the effects of fog on visibility range are illustrated. The tall building in the foreground is about 300 m from the photographer. The left photo shows clear air, at 6.5 dB/km (2000 m visibility range), as measured with a nephelometer mounted at the photographer's site. The distant mountain ranges are easily visible at many miles distance. During a fog which measured about 150 dB/km (visibility range of about 113 m), as shown in the middle photo, the building is still visible at 300 m, but the scenery is washed out beyond this range. As shown in the right photo, at 225 dB/km (visibility range of about 75 m) the building is completely obscured.

Fig 3. Denver, Colorado Fog/Snowstorm Conditions

Weather Condition	Precipitation (mm/hr)	Vis (m)	FSO unit 1000 850nm BER<10^{10}	FSO unit 2000 1550nm BER<10^{10}
Dense Fog		0		
		50	115	160
Thick Fog		50	115	160
		200	310	500
Moderate Fog		200	310	500
	Wet Snow (100/hr)	500	610	1250
Light Fog	Dry Snow (50/hr)	500	610	1250
	Snow/Cloudburst (100/hr)	770	830	1840
	Snow/Cloudburst (100/hr)	1000	980	2260

Environmental Attenuation:

FSO Systems And Network Security:

FSO systems operating in the near infrared wavelength range do not require licenses worldwide for operation. FSO system installations are very simple, and the equipment requires little maintenance. Because FSO systems send and receive data through the air—or the “free space” between remote networking locations—network operators and administrators are concerned about the security aspect of this technology.

Such concerns are not valid for FSO systems. FSO systems operate in the near infrared wavelength range slightly above the visible spectrum. Therefore, the human eye cannot visibly see the transmission beam. The wavelength range around 1 micrometer that is used in FSO transmission systems is actually the same wavelength range used in fiber-optic transmission systems. The wavelength range around 1 micrometer translates into frequencies of several hundred terahertz (THz) which is higher than that used in commercially available microwave communications systems operating around 40 GHz. FSO systems use very narrow beams that are typically much less than 0.5 degrees. E.g., a radial beam pattern of 10 degrees roughly corresponds to a beam diameter of 175 meters at a distance of 1 kilometer from the originating source, whereas a beam of 0.3 degrees divergence angle typically used in FSO systems corresponds to a beam diameter of 5 meters at the same distance1. This wide spreading of the beam in microwave systems, combined with the fact that microwave antennas launch very high power level is the main reason for security concern. To overcome security concerns, the microwave industry uses wireless encryption protocols (WEP) to protect the transmission path from being intercepted.

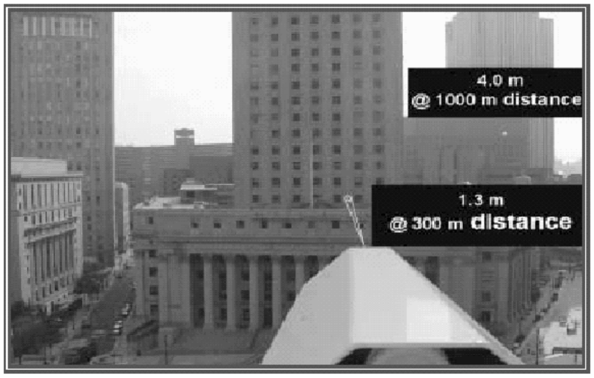

FIG 4. Example of beam spot diameters at various distances for a beam divergence angle of 4 mrad.

The interception of FSO systems operating with narrow beams in the infrared spectral wavelength range is by far more difficult. The small diameter of the beam of typically only a few meters in diameter at the target location is one of the reasons why it is extremely difficult to intercept the communication path of an FSO system

The intruder must know the exact origination or target location of the (invisible) infrared beam and can only intercept the beam within the very narrow angle of beam propagation.

Fig.4. shows an actual example of a 4 m rad beam projected onto the target location where the opposite terminal is located. At a distance of 300 meters the beam diameter is about 1.3 meters, while at a distance of 1 kilometer the beam expands to 4 meters.

The direct interception of an FSO beam between the two remote networking locations is basically impossible because the beam typically passes through the air at an elevation well above ground level. Due to the fact that the transmission beam is invisible and that any attempts to block the beam would occur near the FSO equipment terminus points, the transmission process imposes another obstacle.

Picking up the signal from a location that is not directly located within the light path by using light photons scattered from aerosol, fog, or rain particles that might be present in the atmosphere is virtually impossible because of the extremely low infrared power levels used during the FSO transmission process.

The main reason for excluding this possibility of intrusion is the fact that light is scattered isotropic ally and statistically in different directions from the original propagation path. This specific scattering mechanism keeps the total number of photons or the amount of radiation that can potentially be collected onto a detector that is not directly placed into the beam path well beyond the detector noise level. Fig 5 illustrates the physics of this scattering mechanism.

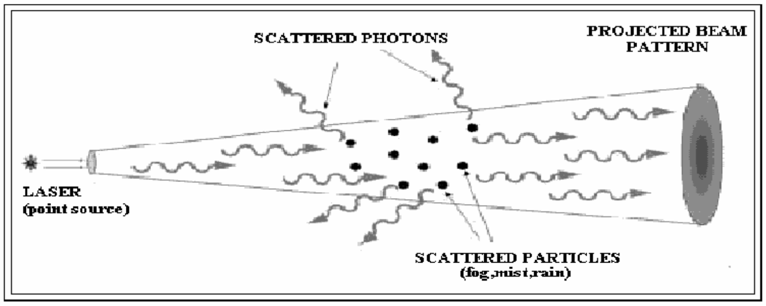

FIG 5 Illustration Of The Physics Of The Light Scattering Mechanism While The Light Beam Travels From The Originating Laser Sources (Left) To The Receiver At The Opposite Communication Location.

Fso Drivers:

The key drivers for FSO: market, economic service, business and environment are as shown

Market Drivers:

Increasing Number of Internet Users/Subscribers
Increasing E-Commerce Activities
MMDS/LMDS
Deployment of 3G and 4G

Economic Drivers:

Faster Service Activation
Ultra-scalability and Bandwidth Allows for Lower Inventory Costs
Multiple Applications/Services Support

Service Drivers:

Increasing Demand for High-Speed Access Interfaces
Need to Eliminate the Metro Gap
Need for Real Time Provisioning

Fso Core Applications:

Metro Network Extensions:

FSO can be deployed to extend an existing metro ring or to connect new networks. These links generally do not reach the ultimate end user, but are more an application for the core of the network.

Enterprise:

The flexibility of FSO allows it to be deployed in many enterprise applications, including LAN-to-LAN connectivity, storage area networking and intra-campus connections. FSO can be deployed in point-to-point, point-to-multipoint, ring or mesh connections.

Fiber Complement:

FSO may also be deployed as a redundant link to back-up fiber. Most operators deploying fiber for business applications connect two fibers to secure a reliable service plus backup in the event of outage. Instead of deploying two fiber links, operators can deploy an FSO system as the redundant link.

Dwdm Services:

With the integration of WDM and FSO systems, independent players aiming to build their own fiber rings may use FSO to complete part of the ring. Such a solution could save rental payment to Incumbent Local Exchange Carriers (ILECs), which are likely to take advantage of this situation.

Fso Challenges:

FSO performance can be affected by some conditions:

Weather Severity At Which FSO Signal Attenuation Can Be Impacted:

Rain at 6 inches per hour, Wet snow rate of 4 inches per hour, Dry snow rate of
2 inches per hour, Fog with visibility of < 6% of the transmission distance

Physical Obstructions:

Birds can temporarily block the beam, but this tends to cause only short interruptions and transmissions are easily resumed.

Building Sway/Seismic Activity:

The movement of buildings can upset receiver and transmitter alignment. Light Pointe's FSO-based optical wireless offerings use a divergent beam to maintain connectivity. When combined with tracking, multiple beam FSO-based systems provide even greater performance and enhanced installation simplicity.

Scintillation:

Heated air rising from the ground creates temperature variations among different air pockets. This can cause fluctuations in signal amplitude which lead to “image dancing” at the receiver end.

Absorption:

Absorption occurs when suspended water molecules in the terrestrial atmosphere extinguish photons. This causes a decrease in the power density (attenuation) of the FSO beam and directly affects the availability of a system. Absorption occurs more readily at some wavelengths than others.

However, the use of appropriate power, based on atmospheric conditions, and use of spatial diversity (multiple beams within an FSO-based unit) helps maintain the required level of network availability.

Safety:

The safety of FSO is often a concern, since it uses lasers for transmission. This challenge has more to do with perception than reality.

The two major concerns typically expressed involve questions about human exposure to laser beams and high voltages within the laser systems and their power supplies. Several standards have been developed covering the performance of laser equipment and the safe use of lasers.

Safety of the lasers does not depend on its frequency, but rather on the classification of the laser. There are two primary classification bodies, the CDRH and the IEC. Commercial systems on the market today are compliant with both standards.

Beam Wander:

Beam wander is caused by turbulent eddies that are larger than the beam.

Beam Spreading:

Beam spreading — long-term and short-term — is the spread of an optical beam as it propagates through the atmosphere.