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Literature Survey and issue on Free Space Optical Communication System

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***Abstract*— Present communication era demand a communication link with high bandwidth, maximum performance, minimum errors and good channel capacity. All these can be well achieved by using free space optical communication system. Because FSO system does not require any license for its establishment and the working. Now this paper consists of detailed survey of FSO system, its advantages, disadvantages and different applications. In FSO system no. of modulation techniques used to modulate information signal at source side like: AM, FM, IM, OOK etc. each FSO system uses a high-power optical transmitter for transmit source signal towards destination and receiving side high sensitivity receiver used. But the atmospheric attenuation is major challenge for faced by FSO systems which affect the performance of the link. The other factors which can affect the FSO are humidity, water vapour, signals absorption, smoke, beam scintillation, spreading and wandering are some of the factors.**

***Keywords*— FSO, Modulation Technique, OOK-NRZ-RZ**

I. INTRODUCTION

Free-space optical communication system (FSO) is an optical communication technology which uses air as a medium to transmit signal from one place to other in the form of light propagating in free space to wirelessly. The word "Free space" means outer space like vacuum, air or something similar [1]. It is a next generation technology basically two types outdoor and indoor broadband wireless applications. The wireless infrared communication is called Indoor optical wireless communication, while outdoor optical wireless communication is known as a free space optical (FSO) communication [2].

FSO link is mainly characterized by two types of attenuations: Geometric and atmospheric attenuation. The geometric attenuation can be controlled by changing the parameters like transmitter diameter, divergence angle and link distance etc. the Atmospheric attenuation depend largely on weather conditions like fog and rain [3]. It can be reduced by proper choice of the parameters like modulation techniques, wavelength and attenuation coefficient. The FSO technology is very useful where the physical connections are impractical due to high costs or some other considerations.

FSO involves the optical transmission of voice, video and data using air as the medium of transmission as opposed to fiber optic cable. Transmission using FSO technology is relatively simple. It involves two systems each consisting of an optical transceiver which consists of a laser transmitter and a receiver to provide full duplex (bi-directional) capability. Each FSO system uses a high-power optical source (e.g., laser) plus a telescope that transmits light through the atmosphere to another telescope that receives the information. At that point, the receiving telescope connects to a high-sensitivity receiver through an optical fiber. Unlike radio frequencies, the technology requires no spectrum licenses. It is easily upgradeable, and its open interfaces support equipment from a variety of vendors, which helps carriers protect the investment in their embedded infrastructures.

Now in present scenario FSO has vast application in the different field of technology like LAN-to-LAN connections on campuses at Fast Ethernet or Gigabit Ethernet speeds, Used in Li-Fi technology, Inter space optical Communication, Under water Optical Communication, Speedy service delivery of high-bandwidth access to optical fiber networks, Converged Voice-Data-Connection, Temporary network installation (for events or other purposes) and Reestablish high-speed connection quickly (disaster recovery) and also useful for communications between spacecraft, including elements of a satellite constellation, For inter- and intra -chip communication[4].Ease of Use

A. Depth Review on FSO

FSO is a technique in which we transmit our information in the form of light. In Ancient time there was a various technique that was used to transmit signal like light, fire etc.

Now, In the modern time, number of technique were developed, using coded signals to communicate with their user.

(a) 1880-1905

In June 3, 1880 at Bell's in Washington, Alexander Graham Bell and his assistant Charles Sumner Tainter, Conducted the world's first wireless telephone and created the Photophone. It was best and most important invention on that time especially in communication line. This device used for the transmission of sound on a beam of light.

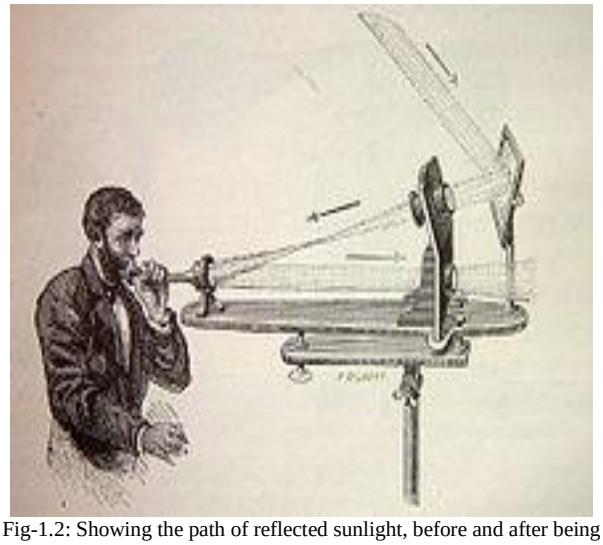

Fig-1.2: Showing the path of reflected sunlight, before and after being modulated using Photophone transmitter [5]

But the help of that device signal transmission at very short distance approximately 213 meters (700 feet) that was communicated between two buildings [5-6]. In Fig-1.2 shows the Photophone transmitter, showing the path of reflected sunlight, before and after being modulated [5]

For improving signal transmission distance as well as quality & security. German military invent another optical transmitter system is called Heliograph Telegraphy transmitter. But In 1904/05 first time that technique used in practical purpose in military communication systems, first for optical telegraphy. German army used Heliograph telegraphy transmitters during the 1904/05. The practical reason for using that technology was that because during the World War I when wire communications were not possible & often cut, Then German think about using optical Morse transmitters called Blinkgerät, their communication distances at daylight up to 4 km (2.5 miles) and at night it was up to 8 km (5 miles) i.e much better as compare to Photophone technology used in 1880. In addition, special blinkgeräts were also successfully used for communication with tanks, ballons and airplanes [5-6].

Fig-1.2.1: Heliograph [6]

In Heliograph technology used a mirror which consist a small unsilvered spot in the centre. At sender side the sender aligned the heliograph towards the target by looking at the reflected target in the mirror and moving his head until the target was hidden by the unsilvered spot. Observance his head still, then adjusted the aiming rod so its cross wires bisected the target. He then turned up the sighting vane, which covered the cross wires with a diagram of a cross, and aligned the mirror with the tangent and elevation screws so the small shadow that was the reflection of the unsilvered spot hole was on the cross target. This indicated that the sunbeam was pointing at the target. If the sun was in front of the sender, its rays were reflected directly from this mirror to the receiving station. If the sun was behind the sender, the sighting rod was replaced by a second mirror, to capture the sunlight from the main mirror and reflect it to the receiving station. But military especially interested in Photophone.

(b) 1906-1960

In continuous research the German Army developed a Photophone in which tungsten filament and IR transmitting filter was used as a light source for improve security of signal as well as distance [7]. In 1962, MIT Lincoln Labs built experimental OWC links which use a light emitting GaAs diode and was able to transmit TV signals over a distance of 30 miles. But After the invention of laser, OWC was envisioned to be the main deployment area for lasers but due to large divergence of laser beams and the inability to cope with atmospheric effects were disappointing. After that in1970s With the development of low-loss fiber optics they became the obvious choice for long distance optical transmission and shifted the focus away from OWC systems.

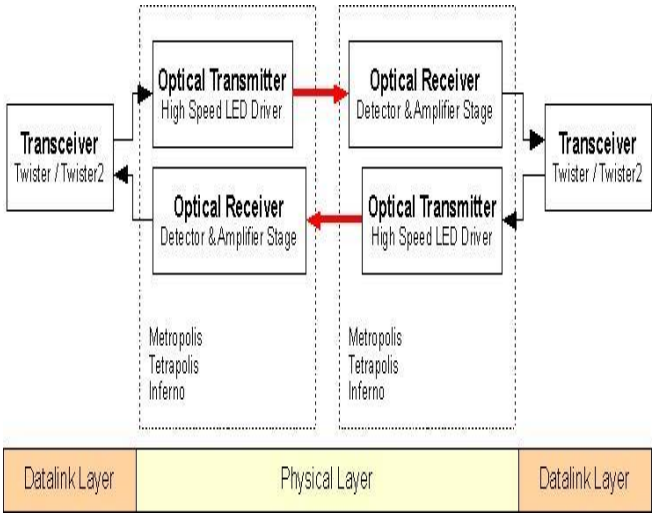

Fig-1.2.2: Optical High Speed LED [7]

(c) 1960-2014

But the transmission rate very low so in continuous development. In 2001 RONJA (Reasonable optical near Joint Access) FSO device from Czech Republic invent first device that transmit date at 10 Mbps wirelessly using beam of light and their range is 1.4 Km/0.87 miles. But their signal not much secure then In 2007 Fuji television demonstrated a LED backlit, LCD television operated whilst that transmit information signal to a PDA via Light. The best thing of device it's also transmits information securely. In 2008 MRV communication has introduced FSO based telescope TS-10GE system with 10 Gbit/s data rate at distance 350m [08]. Now presently research by MOSTCOM company in 2013 invent Artolink M1-10G with high data rate 10 Gbit/s and their distance up to 2.5 Km. In outer space range of FSO communication is currently several thousand Kilometer(Km)[09] and by using optical telescope as beam expanders[10] range of FSO communication extend to Millions of Km[11]. The basic working model of FSO is well defined in section 2

II. FSO DESIGN

In Block diagram [12] Fig-2 shows Basic Working Model of FSO system. In FSO Design consist source, transmitter, receiver and atmospheric channel. Where the message originates that is source that fed the input signal to modulator and producing data input that is transmitted towards a remote destination. In transmitter part a modulator that modulate input signal to optical pulses. The modulation of the source data can be modulating of various ways: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), Intensity Modulation (IM), On-Off Keying (OOK) etc, by varying phase, amplitude and frequency we also achieve high data rate. For transmit data in FSO system basically three types wavelength commonly used are 850nm, 1310nm, 1550nm. But 1550nm wavelength laser generally preferred because it provides large range, long life, eve safety, high data rate range between 20 to 40 Gbps and high power beam level as well as also provide less solar effect [13]. On other ways 850nm and 1310nm laser not preferred due to low power, less range and data rate 2.5 Gbps only[14].750nm and 10µm another wavelength that also use full the 10µm laser are provides high switching speed but it's expensive and 750nm laser consume less power but support only low data rates [15,24].

A. Source

Source is the first part of FSO where the message originates and information signal fed to the modulator part. A source that producing input data and transmit signal towards destination with the help of transmitter and atmospheric channel.

B. Modulator

The modulation of the input/source data into the EM wave carrier there are basically no. of technique used to transmit data like: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM),. For an optical wave, some another modulation technique is also used like intensity modulation (IM), On-Off Keying (OOK). Each of above technique can be theoretically implemented at any frequency and by varying phase, amplitude and frequency we can also achieved high data rate.

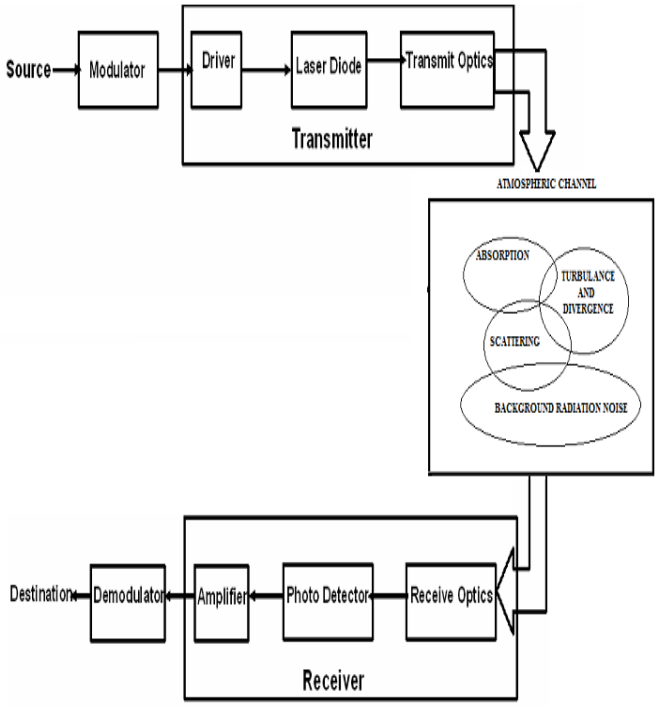

Fig-2: Diagram of FSO Basic Working Model [12]

In modulator part the data signal is modulated with a carrier signal so that it can be transmitted over a channel. There are various methods which are amplitude modulation, phase modulation and frequency modulation. During a transmission of signal over a channel, then it experiences fluctuations in amplitude and phase, known as scintillation which may be due to change of refractive index in different weather conditions. It reduces the performance of an FSO communication. The following are the different modulation approaches used in past.

a) *The Performance of OOK-NRZ and RZ Modulation Techniques*:

To improve the BER performance of a link due to scintillations, selection of appropriate modulation schemes is an important factor which determines the overall system performance. On-Off shift keying is the simple and widely adopted modulation scheme. In this a transmitted 1 is on and transmitted 0 is off. It has simple receiver design, bandwidth efficiency and cost effectiveness. From the view point of the receiver, RZ (Return to Zero) has been reported to offer better performance over NRZ (Nonreturn to Zero) in FSO links [16].

Showing in Fig-2.1 shows digital bit format of RZ & NRZ. In the RZ format, each optical pulse representing bit 1 is shorter than the bit slot, and its amplitude returns to zero before the bit duration is over [16]. RZ coding has come into fashion for long distance because it has a higher peak power, a higher S/N ratio, a lower bit error rate than NRZ encoding [17]. RZ pulses always create distinct transitions between encoded bits (ones being „on" and zeros being „off") and thus create a much cleaner optical signal for the receiver to read [17].

In the NRZ the optical pulse remains on throughout the bit slot and its amplitude does not drop to zero between two or more successive 1 bits. An advantage of the NRZ format is that bandwidth required with the bit stream is smaller than the R[17] .

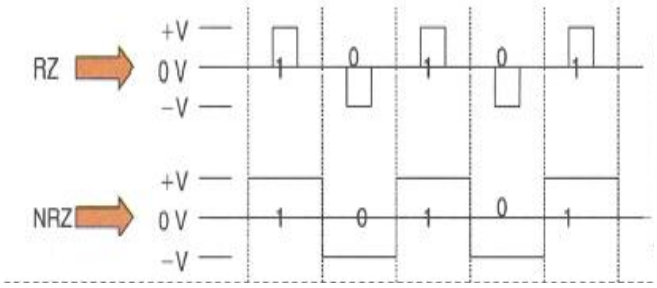

Fig- 2.1: Digital bit format of RZ and NRZ [17]

The improved modulation techniques are DPSK, DQPSK etc. but the above discussed i.e., OOK technique is best known for its simplicity.

b) Adaptive Modulation using RF Feedback

For error free long distance transmission the Adaptive modulation is very useful. In this technique the channel conditions are estimated at the receiver side and feed this signal to the transmitter using an RF feedback channel, so that the transmitter can be adapted relative to the channel conditions. There is an RF backup channel which is used to provide communication under severe atmospheric conditions if some signal loss is there. The Adaptive modulation is a term used in wireless communication to denote the modulation of the data signal with the carrier and then after transmission used to check the weather conditions so that the modifications can be done before transmission [18]. The basic functioning of this feedback channel is that the signal is transmitted through a wireless channel and an optical system is there at the receiver. An optical system collects the incoming light and focuses it onto a detector, which generates an electrical current proportional to the intensity power. The intensity channel estimate is transmitted back to the transmitter by using an RF feedback channel. In this way the performance of a channel is improved using the RF feedback.

C. Transmitter

In Fig-2 also shows that the transmitter is the combination of Driver circuit, Optical source and Transmit Optics.

For optical transmitters LEDs that produce incoherent light and Laser diodes that produce coherent light are semiconductor devices that are most commonly used. A LED is a forward-biased p-n junction and emitting light through spontaneous emission. In the case of spontaneous emission, photons are emitted in random direction with no phase relationship among them. Therefore, due to their simple design, LEDs are very useful for low-cost applications. A semiconductor laser emits light through stimulated emission rather than spontaneous emission, which results in high output power (~100 mW) there is many other benefits related to the nature of coherent light. The output of a laser is relatively directional, allowing high coupling efficiency (~50 %) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. Furthermore, semiconductor lasers can be modulated directly at high frequencies because of short recombination time.

Feature	LED	Laser Diode
Modulation Speed	100 - 300 MHz for high power	Can be 1 GHz and faster
Power	Depends on speed, limited to around 40 mW for high-speed	100's of mW available. Can also be optically amplified.
Optical Bandwidth	40 to 100 nanometers	< 1 nanometer
Receiver Filtering	Wide – increased noise floor	Narrow – lower noise floor
Light Source	Incoherent, no self-interference	Coherent, self-interference
Minimum output beam divergence	Wide (~0.5 degrees) due to the size of the LED	Narrow (~0.01 degrees), if built with high-grade optics
Lifetime	Long lifetime with little degradation of power levels	Medium lifetime, power levels degrade over time
Temperature Dependence	Little temperature dependence	Very temperature dependent
Drive electronics	Simple modulated current source	Compensating temperature and output power circuitry
System Cost	Low. Off-the-shelf optics and electronics	High. Special high-grade optics and compensating electronics

Fig-2.3: Comparison between LED & Laser Diode[18]

Laser diode that is the light output is controlled by a current applied to the device. For very high data rates or very long distance links, a laser source is operated by continuous wave, and the light modulated by an external device such as an electro-absorption modulator.

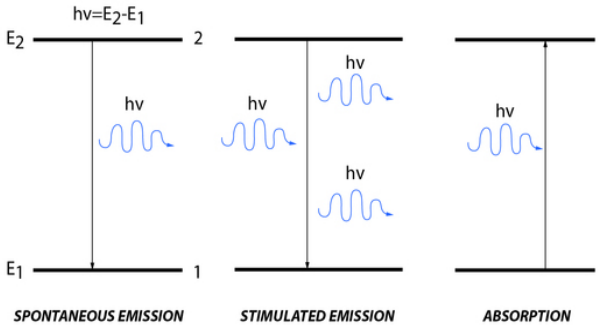

Fig-2.3.1: Diagram of spontaneous emission, stimulated emission and absorption in a two energy level system [18]

Transmit telescope collects the light, adjust the line of sight and directs the beam towards receiver.

D. Atmossphere Channel

The free space link between transmitter and receiver it can be 2-3kms long is called Atmospheric channel. It is open channel due to number of factors that affect the signal like its data rate, long range connectivity and error rate also. The main factors that affect the signal are absorption, turbulence, scattering and beam divergence etc. Some other source that affect on signal is sunlight; if sun goes exactly behind the transmitter then the link can go blank. Some dust particles in the atmosphere, rain, snow fog and precipitation can disturb the link & also affects the bit error rate (BER). It also contains a telescope fitted with a lens that collects maximum light to provide maximum power to photo detector and also a optical filter is used to reject some unwanted noise or signal that added during reception of the signal. The misalignment between transmitter and receiver telescope occurs due to the deviation of link from line of sight path. This can cause pointing error [19] of several micro radians resulting in a huge power loss [20].

E. Receiver

There are basically two types of optical receivers that can use in FSO system: non-coherent receivers and coherent receivers.

a) Non-coherent receivers

The non-coherent receiver directly detect the instantaneous power that receive at the end of receiver, due to that often called direct or power detection receivers. These receivers represent the simplest type of implementation and can be used whenever the transmitted information occurs in the power variation (i.e. IM) of the optical field.

b) *Coherent receivers*

The Coherent receiver or heterodyne receivers, it optically mixes a locally generated light wave field with the received field, and the combined wave is photo detected. These receivers are used when information is modulated onto the optical carrier using PM, FM or AM.

The mainly photo detectors are used in receiver side: Avalanche Photo Diodes (APD) or P- I -N diodes. APDs used are highly sensitive and it work in reverse biased it required 100-200 volt in reverse bias for their operation. These can detect visible and near IR wavelengths if we used silicon material for APD manufacturing. Where high voltage detection required the PIN diodes are used, PIN diodes also have fast switching speeds but for shorter distances. These are less expensive and are generally used for longer wavelengths. These diodes can detect different-different wavelengths like PIN manufacturing from InGaAs material that can detect 1550nm and Si material can detect up to 1.1μm.

III. SELECTION OF WAVELENGTH

FSO system has been operated in the near IR wavelength range between 750 and 1600nm.

A. Wavelength range 780-850 nm

These wavelengths are chosen according to the requirement of the system. At 780 nm, inexpensive CD lasers are available, but the average lifespan of those lasers is an issue. Around 850nm, reliable, inexpensive, high performance transmitter and detector components are there like Silicon avalanche Photo Diode (APD) is which VCSEL technique can be used and whose disadvantage is that the demodulation of beam is not possible with this technique [20].

B. Wavelength range 1500-1600 nm

Due to high quality transmitter and detector components these wavelengths are good for FSO. WDM is mainly used in this because we can be able to get more data due to multiplexing technique but interference increases in this technique. So the result 50-65 times as much power can be transmitted at this frequency that can be transmitted at 780-850nm for the same eye safety [17]. Basically the equipment works at one of the wavelength 850nm or 1500nm. But the use of Lasers at 850nm are much less expensive so are used for applications over moderate distances. Direct modulated lasers based on InGaAs semiconductor technology with operating wavelength around 1550nm were developed for FSO because of low attenuation characteristics [22]. The 1550nm wavelength is used because of the following factors:-

a) It can provide high data rates for long distances even in poor propagation conditions like fog, haze etc. In that case, 1550nm can become quite attractive.

b) The 1550nm doesn't focus onto the retina but 800nm wavelength affects the retina. So the lenses operate at 1550nm.

c) Eye safety regulations permit ~50 times more transmitted power at 1550nm than 850nm, which improves penetration through fog.

d) Higher power can be achieved at comparable cost as the sources, in the shorter wavelength range.

e) Receivers enjoy approximately 3dB better receiver sensitivity at 1550nm due to the lower energy per photon because E=hc/λ [21].

IV. FSO DESIGN ISSUES

In Fiber-optic cable and FSO share many similarities. But there is an only difference way of transmits their information from transmitter to receiver side. In fiber technology we uses a relatively predictable medium that is subject to outside disturbances from wayward construction backhoes, gnawing rodents and even sharks when deployed under sea, In FSO we used an open medium that is result atmosphere outside disturbances effect on signal. FSO is also a line-of-sight technology and interconnecting points must be free from physical obstruction and able to "see" each other. The list of atmospheric disturbances is given below.

A. Fog

Fog is the major challenge while FSO communications as well as Rain and snow also show little effect on FSO, but fog is different from rain and snow because fog is formed by vapor composed of water droplets, which may be a few hundred microns in diameter only but it can completely hinder the passage of light through a combination of absorption, scattering and reflection factor. So that Fog shows a major affect on signal quality and reliability.

B. Absorption

When suspended water molecules in the terrestrial atmosphere extinguish photons then Absorption phenomena occur. Due to that attenuation of FSO beam is decreases and directly affects on system availability. Therefore for maintain and required network stability we required appropriate power as based on atmospheric conditions and use of multiple beams within an FSO unit.

A. Scattering

When the wavelength collides with the scattered the Scattering process occurred. The physical size of the scattered determines only by the type of scattering. When the size of scattered is smaller than the size of wavelength, this is known as Rayleigh scattering. When the size of scattered is of comparable size to the size of wavelength, this is known as Mie scattering. When the size of scattered is much larger than the size of wavelength, this is known as non-selective scattering. In scattering there is no loss of energy unlike absorption, only a directional redistribution of energy that may have significant reduction in the intensity of beam for longer distances.

B. Physical obstructionsand Movement of Building

Flying birds can also temporarily block a single beam, but it's very short time interruptions, and transmissions signal are easily and automatically resumed with in short time. The movement of buildings can also disturb the receiver and transmitter alignment and affects the signal. But by using divergent beam we easily maintain connectivity.

V. PERFORMANCE PARAMETER

Free Space Optics products performance can be characterized by four main parameters:

•Total transmitted power
•Transmitting beam width
•Receiving optics collecting area
• Receiver sensitivity

The relation between transmitted power and received power is given by the equation1 below [23]:

$$P_{Reciever} = P_{Transmitter}(D^2/L^2\theta^2 div)\ 10^{-\gamma L/10}\ \tau_{transmitter}\ \tau_{receiver} \quad (1)$$

Where $P_{Reciever}$ is the Power received (dBm) at the receiver, $P_{Transmitter}$ is the Power transmitted (dBm), D is diameter of receiver, θdiv is divergence angle; is atmospheric attenuation factor (dB/km), τ transmitter and τ receiver are respective optical efficiencies. We know that in each FSO terminal has a loss of 1.8 dB at transmitter and receiver. According to Beers-Lambert Law [24], the atmospheric losses for any laser power are in a form of exponential equation2 of:

$$L = E^{-\sigma l} \quad (2)$$

Where l (km) is the range of the laser transmittance and σ is the typical attenuation coefficients (0.1 for clear air).Power budged model for FSO link is given by in relation 3 [1]:

$$P_{Reciever} = P_{Transmitter} - \alpha sys - \alpha atm \quad (3)$$

Where αatm is the total atmospheric attenuation, αsys is the system attenuation. The transmission and dispersion loss also depends on distance if the distance increases, the transmission and dispersion loss also increases and the power goes to decreases. Mainly two types wavelengths used , technology using wavelength of 850 nm is more economical but in 1550 nm technology can transmit 50 times more optical power as compare to 850 nm wavelength without damage to the human eye [15].

VI. CONCLUSIONS

This paper reviews the historical background of the FSO technology, its present scenario and efficient utilization. This brief survey has focused on signal transmission by using different method of modulation at different value of wavelength. In past, this networking technique is helping to solve the many communications problems. But still this technology is affected by different parameters like rain, fog and bad weather which affect the bit rate. The main problems of FSO links working in outdoors in open atmosphere results from attenuation and fluctuation of optical signal at a receiver. To improve reliability, a number of new methods are being applied. Several design issues, technology implementation and applications have been discussed in the

paper. This optical wireless technology provides a better physical layer connectivity that requires less resources (wires, fibers etc.) thereby providing high data rates also. The paper reviews the historical background of the technology, its present scenario and efficient utilization. Systems that incorporate the most beneficial features, are well-engineered, and thoroughly tested will be top performers and provide the best value. After considering all its advantages and disadvantages it is clear that FSO has good prospects for widespread implementation.FSO technology is ready for utilization as terrestrial links, mobile links and satellite links. In future, we will try design a system which helps to improve the bit rate by changing the different parameter like beam divergence, wavelength and different modulation techniques. This will help to increase the output power signal.

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