Investigation between Performances of Free Space Optical Communication Links Under Atmospheric Turbulence

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Abstract —Free Space Optics (FSO) is an emerging field that includes exclusive features of photonics. Optical carriers are used to deliver data in ultraviolet, visible and infrared bands respectively. It establishes a significant link in either terrestrial or ground to water or ground to space. However, as long as its demand is concerned, their performance is bound by some important factors that are needed to be discussed. In this review, focus is to investigate about the major gaps present as obstacles in the way of conceiving an optimized FSO link. This paper deals with the major contributions achieved in FSO as well as the impairments that are needed to be resolve for the establishment of FSO link. Major outcome parameters are discussed as BER performance, optimization of outage capacity, different modulation techniques, enlargement of beam coverage, spatial diversity, mitigation techniques etc. that directly deals with the performance of transmitting, channeling and receiving part of the FSO system respectively.

Index Terms—Free space optical communication, visible light communication, turbulence, optical wireless communication, scintillation, Laser

I. Introduction

The infrared Wireless Communication is the emerging technique in Optical Communication where IR band is used as a transmission medium for Free Space Optical system. An obstacle free Line of Site (LOS) is required to deliver data in form of optical carriers from source to destination through air [1], [2]. In case of direct LOS, point-to-point short range communication systems are created which must be cleared with any kind of obstacles and the transmitted light should be transferred directly towards the receiver. FSO communication is majorly used in mobile technology that is operable for short ranges as compared with optical fiber communication [3], [4].

In last thirty years, wireless devices and systems, consider as the key element for modern society where one cannot imagine their life without these technologies. Wireless communication is limited in terms of frequencies where electromagnetic wave is used in the range from 3 kHz to 300 GHz. This band of EM spectrum is highly accommodated in terms of capacity and usage. In addition, these bands are exclusively licensed, therefore are quite expensive. With the expansion of number of users along with a drastic rate, the demand of this spectrum is surpassing. Due to which now there is a need to consider other feasible options that uses the above range of currently using spectrum [5].

A. History

Free Space Optical communication that is also a subpart of Optical Wireless Communication (OWC) plays the role of a viable option of Radio Frequency (RF) technology. FSO uses light for the transmission of information. Similarly, ancient Greeks used torches for signaling around thousand years ago. In addition, light is used to send signals by the help of reflecting highly polished shields. In the starting of modern era, Carl Friedrich Gauss used a pair of mirrors that were adjusted to control the beam of sunlight to a distant station, which is known as 'heliograph'. This technique was used extensively during battles and wars by military during 19^{th} and starting of 20^{th} century [6].

In 1880, Alexander Graham Bell and his assistant Charles invented the world's first wireless telephone Summer Tainter named as 'Photophone' [7]. Photophone is the first device that uses a beam of light for the transmission of speech which needed lots of upgradation because of showing high sensitivity towards outdoor atmospheric conditions such as fog, mist, haze, rain etc. [8] So, it was further developed by various militaries. Like German army refined it by using infrared transmitting filters and tungsten lamps as a source modulated by prisms or vibrating mirrors [9]. In 1960, because of the invention of lasers, military organizations and researchers boosted their developments and it is the major turning point in the field of FSO. At the initial phase, the results were not very satisfactory because of the limitations of lasers like divergence of laser beam or to endure the effect of atmospheric conditions [10]. In 1970, due to the development of low loss fiber cables, it became an obvious choice to deliver data for long distance communication and move the focus from FSO.

However, from last decade, this field is taken as seriously again not only by military organization but also by several industries and educational institutes. Nowadays, in market, products operable at visible Light Communication (VLC) are highly in demand that promises about a great potential in its existence.

B. Advantages and Applications of Free Space Optics

FSO system is now recognizing as a high bit-rate transmission link for point-to-point communication

Manuscript received January 12, 2018; revised June 20, 2018.
doi:10.12720/jcm.13.7.368-376

system. For building-to-building connectivity, it offers a very high availability of bandwidth and allows delivering data at much higher rate when compared with RF system. It is also developing as the major solution of Last-Mile problem, which is highly affected by the factor of bandwidth limitation. FSO system offers a huge amount of advantages over RF system. Some of the major advantages are as follows:

(a) Bandwidth usage: In present, the allowable bandwidth for FSO system is 100 THz that is a license free zone, due to which its spectrum is still untouchable [11]. Working in Terahertz spectrum also provides an opportunity to explore new world of wireless communication that will be needed when the channel capacity of Gigahertz bandwidth is fully occupied.

(b) Attenuation Level: If the operating wavelength of the system is in Terahertz instead of Gigahertz, then the amount of attenuation level automatically decreases as compared with RF and Microwave communication systems. According to the Free Space Path Loss (FSPL) Transmission equation which is often used for FSO systems during the calculation of attenuation level states that the path loss present in a clear line of site having no obstacles present between transmitter and receiver is proportional to the square of frequency i.e.,

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \tag{1}$$

(c) Requirement of less optical power: For the connectivity of internet in a room or in a seminar hall, the required optical power of transmitter is in milliwatt while in RF communication it is in terms of Watt. Therefore, due to lesser beam divergence of transmitter that causes high value of optical intensity at receiver requires low consumption of optical power.

(d) Link Setup: FSO systems are easily established because of availability of devices at low cost as well as due to air that is used as a medium. Therefore, it needs lower maintenance services as compared with other technologies. This link is quickly setup as well as shifted from one place to another.

(e) Transmission security: Quantum Cryptography is used to encrypt data that offers random changes in the state due to which the data is impossible to replicate. Due to which it is highly preventable with respect of hacking. Also due to the presence of air, which is used as a channel, the signal is not penetrating that avoids the condition of eavesdropping.

(f) Full Duplex Transmission: FSO system offers a simultaneous transmission of data from transmitter and receiver. It provides the optimized usage of channel capacity.

C. Applications

FSO system contributes its applications in several fields. Due to the growth in number of users, the need of FSO system is exponentially increased. Some of the important sectors where it is needed are explained as follows:

(a) Organizational/Firm Connectivity: In educational sectors or in business industries, there is a need of better connectivity with high speed. These fields also face the major problems of heterogeneous traffic in network in delivery of voice, data, multimedia etc. Therefore, FSO system can build a bridge and act as a backbone between multiple buildings that can be connected with a single phenomenon. It also does not require the heavy maintenance amount like in the case of optical fiber.

(b) Data Broadcasting: To telecast the live events like matches, news reporting or any kind of ceremony from distant and isolated areas, it just needs a setup link and connectivity with the satellite and it is ready for the live broadcasting with high quality of data transmission.

(c) Coverage of Disaster: FSO links can readily installed on the temporary basis. Therefore, during the natural disasters like earthquake or hurricanes, when landlines are not working, it can become the source to deliver the information about ongoing condition. It also covers the emergencies like terrorist attack or reporting from war zones.

(d) Video Monitoring: Video monitoring is now becoming an essential tool in cases of public safety like during traffic signals as road safety or in case of law enforcements and military applications. These can easily be generated and transmitted by the help of FSO technology without any buffering.

D. Limitations of FSO System

Some of the major drawbacks that are responsible for performance degradation of FSO are as follows:

(a) Turbulence: It occurs because of the change in path of light due to the variation in refractive indices of the layers present in the atmosphere. It causes an adverse effect on the channel in form of fading and scintillation due to which there are random fluctuations in the signal, present in both amplitude as well as phase of the received signal. This is also known as channel fading that causes performance degradation in form of increasing BER and time delay. Physical description of atmospheric turbulence is explained by Kolmogorov theory [12]. It accurately describes the reasons behind the generation of fluctuations that is mainly caused by due to induction of spatial variations present in form of temperature and pressure of the atmospheric conditions.

According to Kolmogorov model, which uses exponential Gaussian function to find out the value of wavenumber spectrum states,

$$\varphi_n(\bar{k}) = 0{,}033 C_n^2 k^{-11/3} \tag{2}$$

where, Cn is the wavenumber spectrum of structure parameter that is rely upon altitude. Another model named Hufnagel and Stanley states [13] that,

$$C_n^2 = k_o z^{-11/3} exp\left(\frac{z}{z_o}\right) \tag{3}$$

Here, k_o illustrates the tenacity of the turbulence and z_o is the effective altitude of the turbulent present in the atmosphere. Generally, for a strong turbulence system, ideally, C_n^2 can be considered as 10^{-13} $m^{-2/3}$ and for the weak turbulence system, it is taken as 10^{-17} $m^{-2/3}$ [14].

Similarly, scintillation that is caused because of aerosols present in air, particularly when the cross sectional area of the channel is relatively large, Scintillation index [15] can be calculated as,

$$\sigma_I^2 = \frac{E\{I^2\}}{E\{I\}^2} - 1 \tag{4}$$

where, 'I' is acknowledged as the intensity of received optical wave and E{.} is the expected value of the intensity. It gives the characterization features of the turbulence strength, which is mainly based on first and second moments of intensity [16]. There are various models adapted to measure the strength of turbulence like for weak turbulence system; the main model that is considered would be lognormal. However, it is not appropriated for the long propagation paths where the features of atmosphere changes between moderate to strong turbulence. Therefore, for the strong turbulence system, Rayleigh distribution model [17] is considered in which Probability Density Function (PDF) of the system is given by,

$$p(I) = \frac{2\alpha}{\Gamma(\alpha)} \alpha I^{\frac{\alpha-1}{2}} K_{\alpha-1}\left(2\sqrt{\alpha I}\right), \ I > 0, \quad \alpha > 0 \tag{5}$$

where, $K_m(.)$ is the modified form of second order Bessel function [18]. So, m is taken as 2 and α is estimated by the amount of scintillation index that is,

$$\sigma_I^2 = 1 + \frac{2}{\alpha} \tag{6}$$

Similarly, another model is considered, which is named as Gamma Gamma distribution. Nowadays, this model is highly adapted because of the applicability for both strong as well as weak turbulence system. It gains a wide acceptance because of the adoption of two separate independent Gamma random variables X and Y that represents the irradiance fluctuations generating on the basis of scale of turbulence which would be large or small respectively [19]. The PDF of this distribution model can be calculated by,

$$p(I) = \frac{2(ab)^{\left(\frac{a+b}{2}\right)} I^{\{(a+b)/2\}-1}}{\Gamma(a)\Gamma(b)} K_{a-b}\left(2\sqrt{abI}\right), \quad I > 0 \tag{7}$$

where 'a' and 'b' are the parameters that represent the effective numbers of cells for large and small scale respectively and Γ{.} is the Gamma function. Calculated SI value for this distribution is [20],

$$\sigma_I^2 = \left(\frac{1}{a}\right) + \left(\frac{1}{b}\right) + \left(\frac{1}{ab}\right) \tag{8}$$

(b) Extinction Effect present in the Atmosphere: Several weather conditions such as rain, mist, haze, fog, clouds, pollution levels etc. affects the performance of FSO link. These factors also degrade the performance of source in form of transmission of light beam. During the condition of fog and heavy cloud, transmission of data is nearly impossible due to the high value of attenuation level. If the conditions are clear, then there are always some problems, which are present in form of air molecules and aerosols. Beer's law [19] is used to calculate the attenuation, Transmittance T of the laser radiation propagates through a distance L, and it states that,

$$T = exp(-\alpha_e(\lambda). L[km]) \tag{9}$$

where $\alpha_e(\lambda)$ describes the level of extinction present in the medium and it is measured in km^{-1} which is an extremely wavelength dependent parameter.

In terms of power [20], it can be calculated as,

$$P_{out} = P_{in} exp(-\alpha_e(\lambda). L) \tag{10}$$

Another factor that affects the system's performance is visibility level of the atmosphere. This visibility range is dependable upon the weather conditions,

TABLE I: INTERNATIONAL CODES OF VISIBILITY RANGE FOR DIFFERENT WEATHER CONDITIONS [21]

S. No.	Weather Conditions	Visibility Range (in Km)
1.	Thick Fog	0.2
2.	Moderate Fog	0.5
3.	Light Fog	0.770 to 1
4.	Thin Fog/Heavy Rainfall (25 mm/hr)	1.9 to 2
5.	Haze/ Medium Rain (12.5 mm/hr)	2.8 to 4
6.	Clear Weather/Drizzle (0.25 mm/hr)	18 to 20
7.	Very Clear Weather	23 to 50

Kim and Kruse models are considered for measuring the level of attenuation. A Kruse model is designed to reflect the attenuation level in decibel per km and it is given as,

$$\gamma(\lambda) = \beta_a(\lambda) = \frac{10\log(\frac{1}{th})}{V[km]} * \left(\frac{\lambda[nm]}{\lambda_0[nm]}\right)^{-q} \left(\frac{dB}{km}\right) \tag{11}$$

where q is the exponent or parameter related with the particle size distribution of atmosphere. 'th' is the optical threshold (2% or 5%). 2% optical threshold is used in optical communication systems and 5% threshold is used at the airports to measure the runway visual range. λ_o represents wavelength corresponding to the maximum spectrum of the solar band (500nm) and λ will be selected wavelength.

Extinction present in the system is affecting the link equation of FSO channel too which is represented as;

$$M_{link}[dB] = P_{Rx,dB} - S_r - L[K_m]. A_e \tag{12}$$

where P_{Rx} is the signal fluctuation level present in the received signal and S_r is the sensitivity of the signal.

(c) Source Selection: In case of optical fiber the size of source should be compatible with the size of fiber so that coupling provides maximum power to the fiber. However, in case of free space optics, some other factors are also needed to be maintained. One of the major parameter is beam wandering. It is defined as the beam can be deviated randomly through its original path due to the variation of refractive indices of the cells [22].

Second parameter that affects the source is 'scintillation' in which the intensity of the source is fluctuated randomly due to the variation in phase front of the beam. Another factor that would be taken into notice is 'diffraction', which causes due to the spreading of beam.

In case of choosing LEDs, two important factors that are needed to be considered. First one is dimming of light due to which speed of the delivering data gets highly affected. Second one is flickering of light that causes switch on and off conditions for a fraction of seconds due to which data will be lost and couldn't be delivered.

II. Free Space Optical Communication Propogation Modelling

A. Beam Convergence and Divergence

In order to establish an experimental setup, there is a requirement to enhance the proximity level of the beam coverage area between the link of transmitter and receiver [23]. In present system, many alternatives are already proposed that include aperture averaging, which is achieved by enlargement of receiver aperture diameter. Next one is to reduce the spatial coherence of optical beam. Also, compensating the effect of scattering and beam wandering by the use of Spherical Concave Mirror (SCM) that will perform like an optical lens antenna.

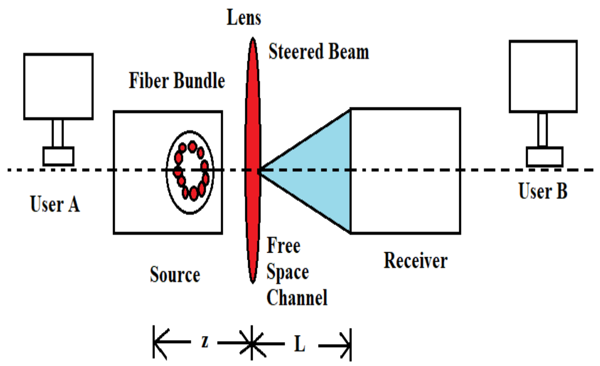

Fig. 1. Trans-Receiver system of FSO communication

Dayong Zhou and *et al*. [23] were investigating in their paper about multiple factors that are needed to increase the coverage area of the source. An approach was conceived for beam steering at transmitter node that provides a continuous beam beyond misalignment at the receiver without the usage of any mechanical devices. It was also experimented that the expediency of applying multiple fibers attached with single lens at the source for boost up the tolerating value of link misalignment with the receiver. Along with, factors that affect the beam radius of source are analyzed. First factor is the transmitted power that depends upon received power as well as power margin of the system. Second factor is transmission geometry, which carries focal length of lens (f), transmission length (L) and the distance between fiber bundle and lens (z), (Fig. 1).

Third factor is receiver geometry that includes diameter and optical thickness of the lens, focal length, size of the collecting fiber, angle of deflection of the beam at transmitter.

A series of experiments are performed in this system. The experimental results endowed some circumspection in form of beam overlapping due to which distribution of power existed between the beams centers would be flat. Another factor that would be considered as the limitation, at 1310 nm wavelength, the outcomes are not optimized because of misalignment between source and receiver. Last one is the interference that would be generated by beam coupler attached with transmitter splitters at the receiver. To minimize such effects, efforts are required to find out the techniques that compensate the consequences of phase shifts at splitter and combiner.

In furtherance of enhancing the performance of FSO link Mircea Hulea and *et al*. [24] suggested an effective method that is quite helpful in compensating the effect of beam spot wandering and scattering by using a Spherical Concave Mirror (SCM). In a long distance FSO communication, a scheme named Fast Steering Mirror (FSM) is applied that uses a flat mirror to precise a beam-propagating path. Although, it is so complex to implement because of the detector that is highly sensitive towards position and manually control module. This method is also intolerable towards the laser beam scattering effect. Therefore, the use of SCM at the receiver side will be helpful to concentrate the scattered laser beam on photodetector having small consumption area which induces a minimum optical power loss [24], (Fig. 2).

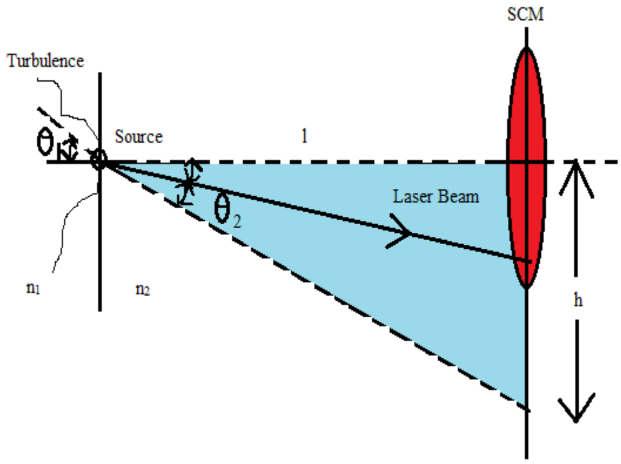

Fig. 2. Illustration of beam replacement in turbulent environment encloses at the optical transmitter node

Another advantage of SCM is to control the laser beam trajectories, which might be helpful in case of using small area photodiodes instead of large ones. The maximum wandering amplitude can be measured as,

$$d = l.\frac{tan\theta_1}{1- k^2 tan^2\theta}.\left\{1- k.\sqrt{1+ tan^2\theta_1.(1- k^2)}\right\} \tag{13}$$

where,

$$k = \frac{\sin\theta_2}{\sin\theta_1} = \frac{n_2}{n_1} \tag{14}$$

'l' is the gap between beam and center of the mirror, 'h' is the altitude in between mirror center and point where intersection of normal turbulence edge and mirror plane occurred, θ_1 and θ_2 represents angles of incidence and reflection respectively [25].

Considerable limitations of SCM are observed at the infrared band where it becomes difficult to track the optical beam due to number of reflections occur that are not even visible. Multiple reflections of optical beam lead the reduction of power level.

B. Outage Capacity of Fading Channel

1) Slow fading channel

Channel capacity is always explained in terms of data rate that can be achieved through a reliable communication link between transmitter and receiver. It depends upon the information available, which is also termed as Channel State Information (CSI). Atmospheric statistical models are considered based on type of turbulence for the calculation of PDF, intensity and atmospheric attenuation.

Apart from atmospheric turbulence, another factor in form of pointing errors [25] are also considered during the derivation of fluctuations in optical intensity at the receiver [26]. In the absence of misalignment error, Poisson noise model and Gaussian noise model are considered for the calculation of ergodic and outage capacities of the channel. To induce the effect of fading, it is recommended to set the values of beam width and code rate in terms of type of modulation for FSO channel. Generation of pointing errors are mainly caused by beam width, size of the detector and pointing error variance. In 2007, Ahmed A. Farid and *et al* found special design criteria for slow fading to optimized FSO link performance. In their model, some assumptions are considered as transmitter is operating at fixed data rate using On-Off Keying (OOK) modulation with a given value of P_t, R, σ_n^2, σ_s^2 and weather conditions.

It shows a significant development in terms of achievable rates at the receiver with high outage capacity. However, the main drawback is that it is not feasible for fast fading. In addition, the results of coherent FSO system and non-coherent system show unpredictable results. Mostly the values of data are to be fixed which is not possible at practical conditions, so tuning of data needed very frequently. This model does not allow tuning of data according to need.

For non-coherent FSO system or Intensity Modulation/ Direct Detection (IM/DD) over misalignment in fading channel during atmospheric turbulence, another model is suggested which is based on time diversity scheme. This model shows superior assets than previous scheme in terms of fading. Monte Carlo simulation results are taking in to consideration for achieving the combined value of PDF at different relay locations [27].

The impact of pointing errors is considered negligible in the outage performance analysis of FSO communication, which is taken as a drawback of this model. In addition, it is difficult to maintain a high diversity gain because of the robustness of the system.

2) Additive white gaussian noise fading channel

Another type of fading present in the channel is termed as Additive White Gaussian Noise (AWGN). Scheme that could be considered for dealing with this fading is named as Subcarrier Intensity Modulation (SIM)/ Spatial Modulation (SM)-aided FSO with Receiver diversity [28]. Goal of this scheme is to reduce the number of subcarriers during data transmission due to which power efficiency of the system increases which also combat the effect of turbulence induced fading. Power efficiency of the system is calculated by

$$P_{SIM/_{SM_2}}(\gamma_b) = \frac{3}{2}\, Q\left(\sqrt{\frac{1}{3}\gamma_b}\right) \tag{15}$$

where γ_b is the received SNR per bit.

Merits of the scheme can be observed in terms of performance of the system and is calculated in form of Bit Error Probability Rate (BER). Then analyze the data under different spectral efficiencies along with different fading strengths. Another advantage of SIM/SM model over SIM is that as the number of subcarriers increases, spectral efficiency and performance gain of SIM/SM increases [29]. It is also not affecting the required value of dc bias, which is generally happened in SIM model.

Further, the performance of SIM/SM model will significantly improve by increasing the number of receivers. Nevertheless, this approach will make the system more complex and bulkier, which will be considered as a serious drawback of the model. Another drawback of this scheme is that it is only applicable for lognormal atmospheric channel. If the fading strength increases, then both the scheme show eminently degradation in their performance.

3) Fast fading under strong atmospheric turbulence channel

Theodoros A. Tsiftsis et al. [30] proposed a special model for outdoor system under atmospheric induced strong turbulence fading which uses multiplicative random process, followed by K- distribution function. Previous models are based on Single-Input Single-Output (SISO) system that shows results that are far away from ideal value of BER i.e. 10^{-9} for FSO system. So, a powerful mitigation technique was suggested under which two schemes have been proposed. First one is to generate error control coding for conjunction with interleaving and the second one is Maximum Likelihood Sequence Detection (MLSD). However, some limitations are present in these schemes which includes the requirement of large size interleaves and then later suffers with high computational complexity.

So, to compensate these problems, spatial diversity schemes are suggested which include Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) FSO systems respectively [30]. Meijer G. functions are used to solve mathematical equations, which is a built in function in software packages. This paper shows its relevance because of performing investigation upon a vast range of diversity that includes Optimal Combining (OC), Equal-Gain Combining (EGC) and Selection Combining (SC) at the receiver [31].

By the virtue of the presence of K-distribution, it is now the product of two independent models, which are exponential distribution and Gamma distribution respectively, and the PDF is expressed as,

$$f_{I_{mn}}(I_{mn}) = \frac{2\alpha_{mn}^{\left(\frac{\alpha_{mn}-1}{2}\right)}}{\Gamma(\alpha_{mn})} I_{mn}^{\frac{(\alpha_{mn}-1)}{2}} K_{\alpha_{mn}-1}\left(2\sqrt{\alpha_{mn} I_{mn}}\right), I_{mn} > 0 \quad (16)$$

where α_{mn} is a channel parameter that will relate to effective number of discrete scatters, $\Gamma(.)$ is the Gamma function and $K_V(.)$ is the Bessel function of V order, I_{mn} is the irradiance coming from m^{th} transmission to n^{th} receiver.

Average error of SIMO system can be calculated as [30],

$$P_{e,SIMO} = \int_I f_I(I) Q\left(\frac{\eta}{MN\sqrt{2N_o}}\sqrt{\sum_{n=1}^{N}\left(\sum_{m=1}^{M} I_{mn}\right)^2}\right) dI \quad (17)$$

where $f_I(I)$ is the joint PDF of vector $I = (I_{11}, I_{12}, \ldots, I_{MN})$

However, the major limitation of this model is that for a meaningful performance, the required number of apertures needed is more than five for strong turbulence channel with transmitter-receiver diversity. It increases the complexity of the system.

III. Performance Analysis of Hybrid Systems

A. *Hybrid FSO/RF System*

A switched base FSO/RF system would be considered that overcome the limitations of each other. For example, FSO system is highly affected by fog conditions while unaffected by rain but 60 GHz RF system shows ineffectiveness towards rainy conditions but highly sensitive during fog. fSONA and MRV launched their products which are based on hybrid FSO/RF system that use mainly RF link as a backup channel.

Muneer Usman *et al*. [32] suggested a scheme, which was based upon rateless code repeat request (ARQ). Apart from this scheme, bit interleaved coded modulation and short length raptor codes are used in accomplishing hybrid FSO system. Switching schemes are also classified as soft switching and hard switching, where hard switching shows some rate loss during process as compared with soft switching. A certain threshold level would be set according to link quality of hybrid FSO/RF system. When a system shows unacceptance and reaching at threshold level, it will be automatically shifted to another mode. The main advantage of hybrid system is that it will extend the FSO link lifetime as compared with the simple one. However, it also shows some limitations like it works efficiently on low complexity system but shows degradation in performance when the system is operating at high complexity. Second is due to simplicity of implemented receiver, transmission of data occurs only through one link at a time. Therefore, simultaneous usage of both link at a time is not possible.

Another positive thing about this model is that it supports quadrature modulation schemes for Intensity Modulation and Direct Detection (IM/DD) FSO system. In addition, threshold can be implemented based on performance of the link like if tripping in a system is high than dual thresholds will be attached. Due to the usage of two thresholds, reduction has been observed in frequent on/off transitions present in FSO link

B. *Hybrid Networking between Li-Fi and Wi-Fi*

Li-Fi in form of Visible Light Communication (VLC) would be taken into account when a hybrid system with Wi-Fi is designed. This hybrid form is mostly suitable for indoor environment where Access Points (AP) of Wi-Fi are selected and then Li-Fi would be categorized into auto cells that covers a significantly smaller area. Yunlu Wang and Harald Hass explain the handover technique between Li-Fi and Wi-Fi networks. Also, they explain about dynamic load balancing between the networks due to which local overloading situations can be avoided. Major factors that are taken into account, present in form of user mobility and handover signaling overhead.

In indoor condition, hybrid integration of Li-Fi and Wi-Fi need to sort out the problem using capacity. In current scenario, due to the presence of various multimedia devices connected in a room increases because of which availability of data is now limited. Hybrid networking will be helpful to sort out the problem of system throughput and improves Quality of Service (QoS). Main challenge in this scheme is to maintain load balance between the small size of Li-Fi auto cells and AP of Wi-Fi. Also, it needs a proper illumination of light because of the presence of other sources of light that will create interferences in a signal. Another parameter that will be required to observe is transmission loss during handover. Depending on the algorithm, average time to need to exchange the information between user and Central Unit (CU) will be calculated. On the basis of transmission time, signal to noise ratio of a system will be detected between Base Stations(BSs). Loss in packets because of transmission delay shows the overall system throughput (Fig. 3).

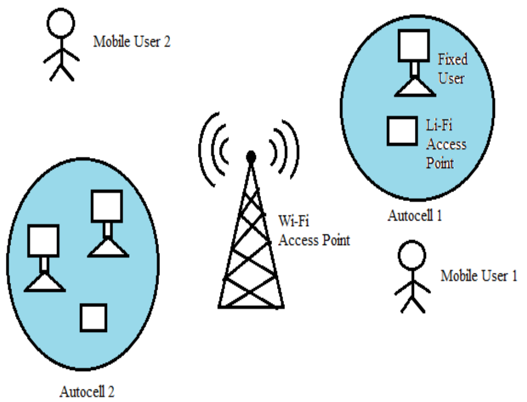

Fig. 3. Hybrid Li-Fi & Wi-Fi system

Load Balancing between networks would require observing at regular intervals because there are random fluctuations present in Channel State Information (CSI) of mobile users. During practical analysis, when small fading is considered, the throughput of Wi-Fi will not have uniformly distributed because of which fluctuations in CSI of moving users are generated. So, it would be difficult to connect the engaging area of Li-Fi with different APs [33]. Therefore, the future researches focus on reduction of the complexity of system and to establish a constant Wi-Fi throughput in space for better designing of network.

IV. Gaps and Discussion

After investigating about research work that has been done by scientists and researchers, there are many scopes to optimize the performance level of FSO link. Some of them are discussed here:

(a) When a FSO system is designed, always-vacuum photon counting channel is used. In this system the rate of photons is considered to be infinite, so the photon energy also becomes infinite which is practically impossible. It is also including two optimization problems, which are present when a FSO system is designed, first is 'Capacity per photon' and second is 'Capacity per unit energy'.

(b) Coherent system is still not used for the analysis of clear air turbulence impairs communication efficiency and in multiple access applications with heavy interuser interference.

(c) In case of OFDM based wireless service, system is highly dependent upon the term Optical Modulation Index (OMI). The value of OMI is 10%, which is quite large.

$$m_{opt} \propto RIN \quad (18)$$

where Relative Intensity Noise (RIN) affects the optical power to reduce the efficiency of the system [34].

(d) K and Gamma Gamma fading models for a multi hop FSO system demonstrate the usefulness of relay assisted transmission as a method to broaden the coverage area but do not highlight its use as a fading mitigation tool [35].

(e) The design problem occurs in case of adaptive FSO transmission under the assumption of practical modulation sizes (i.e. integer values of Q) and average or peak power constraints.

(f) There are several information theoretical limit that are still to find out like investigation of the capacity of turbulent channel, FSO systems with transmit and/or receive diversity, analysis of SISO system consists four aperture FSO system, analysis of MIMO system consists four aperture FSO system and lastly, outage and ergodic capacities of FSO systems with pointing errors [36].

(g) Mitigating fading in FSO channels has been the area of intensive research during in last few years but its solution through channel coding in strong turbulence system is still unanswered.

(h) Most of the existing work on coded FSO system is based upon binary modulation but there is no consideration regarding the deployment of non-binary modulation.

(i) Only few works have been considered in the field of combination of the information bearing symbols at the transmitter in order to optimize the system performance i.e. employing space-time (ST) coding.

(j) In case of effect of fading coefficient, another important question is to see how fading correlation affects the FSO system performance, compared to the "ideal" uncorrelated fading case.

V. Conclusions

In the immediate future, the major challenge that the researchers face is to design a trustworthy and pervasive FSO link. In this paper, extensive work on theoretical analysis have been performed to investigate about the link impairments occur in FSO channel which is imposed by combine effect of atmospheric turbulence and attenuation. Detailed explanation on the origin of FSO system has been given. Best possible efforts are established to find out the major gaps present in FSO link. The design of novel architecture needs to sort out these challenges for achieving higher data rate with the boost in number of users. Several technical challenges are also observed during composition of transmitter in form improvement in of beam coverage, fading effects present in free space channel and outage capacity of the receiver respectively. In this survey, best efforts have been placed to explore the literature of FSO. Prevailing research on growing area of FSO system will hopefully need these efforts.

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