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RoFSO- Theoretical Study and Review

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ABSTRACT

Radio frequency (RF) communication technology is facing challenges in fulfilling the transmission medium demand of this IOTs (Internet of things) world due to exponential growth of wirelessly communicating electronic devices. Everybody and everything need some wireless spectrum to transmit information, but RF spectrum is limited. Speed of increasing data hungry devices is much more than emerging technologies trying to keep pace with growing demand for wireless channels. Free space optics (FSO) is one of such technologies working towards fulfilling spectrum demand till the last mile connectivity point in collaboration with existing RF technology. This paper presents review of basic RoFSO (Radio over Free Space Optics) link designing factors such as weather adaptive channel modelling, different techniques to compensate link attenuation factors and their possible outcomes along with their mathematical equations for different kinds of environmental attenuations.

KEYWORDS

RoFSO, FSO, RF, Optical fiber communication (OFC)

1. INTRODUCTION

In today's data rich world, high speed connections have become most important as the internet expands. Everybody and everything need wireless channels in this IOTs (internet of things) world, but the radio frequency spectrum is limited. The only option left to satisfy wireless spectrum demand is to utilize the available spectrum precisely. A lot of technologies such as Cognitive radio, Software defined radio, Multiple input multiple output (MIMO), Dense multiplexing techniques are already employed to increase spectrum utilization but are insufficient to meet need of today's data hungry devices [2]. There is an intense need for some innovative technologies for providing more wireless propagation medium so to fulfill spectrum demand of world for today as well as for future.

Free space optics (FSO) is the technology to transmit information through optical beam in free space. Optical fiber communication (OFC) is already an established technology transmitting information signal at speed of light and the only difference between OFC and optical wireless transmission is that light beam is travelled through free space in FSO. FSO or OWC can provide huge bandwidth for data transmission. One of exciting features of this technology is, there are no spectrum licensing requirement, dramatically reducing deployment time and costs. FSO technology provides solutions to some of the world's most demanding customers where lack of infrastructure is a problem bypassing the challenges to create instant high-speed networks in cities [2]. Proven technology, industry-leading design, and solutions to a wide range of problems for the customers who want high speed access and the service providers who want to deliver high speed data; FSO is bridging the gap with a shortcut to broadband.

Some of the important parameters which any transmission system needs are high speed, low bit error rate and low installation cost and these all are featured by this emerging technology for signal transmission through optical rays.

1.1 Advantages of FSO over RF technology

FSO technology can serve the purposes of bridge between wired infrastructure already available and wireless communication system to further support users to utilize benefits from both systems such as wired communication is fast and secure and wireless communication provides flexibility to users [4].

In comparison with RF technology, FSO has more bandwidth available and unlicensed spectrum is being used by it. Spectrum fee to be paid for licensed spectrum is eliminated in this and high data rate in order of Gbps is provided by this technology. Optical signal being immune to electromagnetic interference can provide noise free transmission [5]. Point to point transmission provides low probability of interception resulting in secure network. FSO link components are cheap in comparison with RF components.

1.2 Advantages of FSO over optical fiber communication (OFC)

Although OFC is successfully providing high speed and secure services through cable network, but installation of OFC In all such kinds of places, FSO can work as high speed, high bandwidth potable network as it doesn't require such kind of preparations for data transmission [7]. FSO link is portable, easy to install, replicable and low-cost network as compared to existing optical fiber network. One further application and advantage of FSO over OFC is Satellite links such as satellite to earth station and inter-satellite Human exposure to High frequency Radiations Exposure to radio waves for long durations is dangerous for human tissues and specifically to infants as their organs gets heated and as a result tissues can damage. Light beam causes this damage less as compared to radio waves. This is one of the important points of FSO communication considering health issues which is most important.

Applications of FSO technology [7]

- Satellite applications
- Indoor connectivity at ultra-high speed
- Monitoring/Video surveillance
- Metro network extension
- Unlicensed spectrum utilization
- Last mile applications

Organization of the paper constitutes of various sections where section II describes the RoFSO for terrestrial communication along with advantages of this technology over RF and optical fiber communication. Various atmospheric losses are presented in section III. Section IV presents different channel modeling schemes. Section V represents recent techniques utilized to enhance FSO link quality along with their outcomes, followed by conclusion part.

2. ROFSO FOR TERRESTRIAL COMMUNICATION

network is not always feasible over all kinds of terrestrial locations such as over railways or roads due to digging issues, hilly areas, and allowance issue from landowners.

Radio over free space optics (RoFSO) is one amongst emerging technologies where Radio Frequency (RF) subcarrier is further modulated on optical beam and transmitted through free space and this technology can be a platform to converge Radio frequency transmission and optical communication through free space as shown in block diagram in figure 1. RoFSO has proven to be an extension to existing RF wireless communication technology to provide wide propagation bandwidth for transmitting information at very high speed and security as optical beam transmission is the fastest possible communication. RoFSO technology is a line of sight (LOS) technology which uses Laser or Light emitting diode (LED) for sources of light and radio frequency subcarrier modulated on it [16]. Basic link equation for LOS (line of sight) communication is [16]

$$P_{Recieved} = P_{Transmittd} \frac{d_R^2}{(d_T + \theta R)^2} 10^{-\alpha R/10} \qquad (1)$$

Where d_R = aperture diameter of receiver

d_T = aperture diameter of the transmitter

θ= divergence of beam

R = range of link

α= attenuation

Atmospheric losses can occur due to absorption as well as scattering. Optical beam propagates through free space in which it suffers from a lot of losses from different sources. Setting all these losses on less is the biggest challenge today. Free space losses can occur for many reasons such as because of many atmospheric impurities, free space losses, beam misalignment, scattering, odd weather conditions, atmospheric turbulences, and beam wander and scintillation effects.

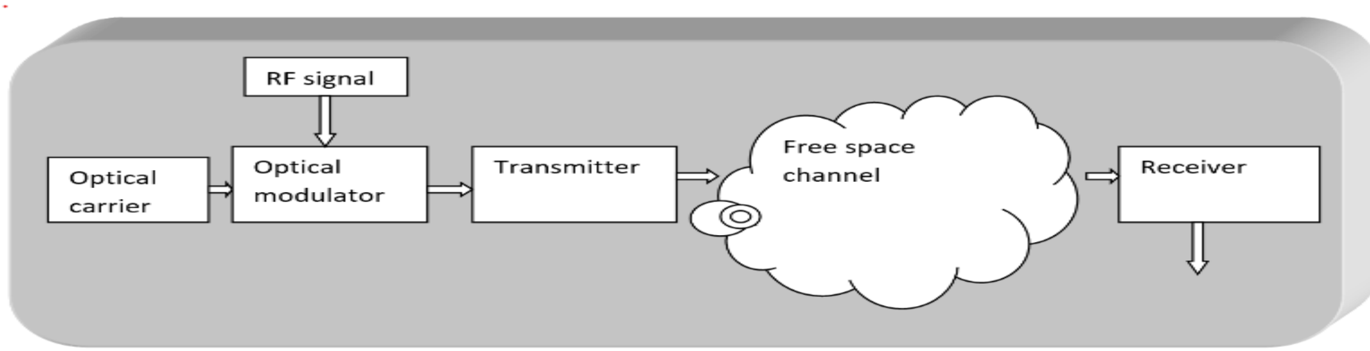

Fig. 1 Basic block diagram of RoFSO transmission

Some of the major channel losses and their mitigation techniques are explained in this paper.

2.1 Free space losses

This is the kind of loss in received signal strength that every wave undergoes when passes through free space. Mathematical loss factor for range link range R is wavelength dependent and given by

$$L_s = \left(\frac{\lambda}{4\Omega R}\right)^2 \tag{2}$$

Because of its dependency on wavelength, this loss is more prominent in Optical wave propagation as compared to RF signal.

Beam divergence loss is spreading out of optical beam due to diffraction and receiver aperture is not able to collect parts of transmitted optical signal resulting in loss of energy.

Geometric loss/Pointing loss can occur if there is even a slight misalignment between the transmitter and receiver. Precise control over pointing, tracking and alignment is required to minimize both losses simultaneously. The expression for diffraction limited loss is given by [27].

$$L_G(Geometric\_loss) = -10\left[2\log\left(\frac{4}{\pi}\right) + \log\left(\frac{A_T A_R}{\lambda^2 R^2}\right)\right] \tag{3}$$

2.2 Atmospheric Impurities

FSO channel consists of many impurities and tiny particles such as rain, fog, dust, aerosol, and some polluting gases resulting in variations in refractive index and reduction in power of received signal and signal scattering. All these losses are at peak when particle size is comparable to wavelength of signal propagated. Expression for signal attenuation due to both absorption and scattering from environmental constituents is given as [27]

$$\gamma(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \tag{4}$$

Where $\alpha_m(\lambda)$ is Molecular absorption coefficient, $\alpha_a(\lambda)$ is Aerosol absorption coefficient, $\beta_m(\lambda)$ is Molecular scattering coefficient and $\beta_a(\lambda)$ is Aerosol scattering coefficient.

2.3 Weather attenuation

Fog is dominant factor for beam attenuation because of its particle size is comparable to wavelength of optical signal of interest but rain, haze, dust, low clouds, and combinations of these can also affect adversely because optical beam gets trapped in all these particles in different quantities depending upon particle size [27].

(i) Loss exp. due to fog: this loss is predominant in FSO link and expression based on common empirical models for Mie scattering is given as

$$\beta_{fog}(\lambda) = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-p} \tag{5}$$

Where 550 nm is taken as reference wavelength and p= size distribution coefficient.

(ii) Loss exp. due to snow: this loss varies depending upon the size of snowflakes and snowfall rate. They produce deeper fades as compared to raindrops because their size is larger [27].

Expression of snow loss is.

$$\beta_{snow} = aS^b \tag{6}$$

Where 'a' and 'b' are different parameters of wet and dry snow and 'S' is snow rate.

(iii) Loss exp. due to rain: attenuation expression for rain rate R is

$$\beta_{rain} = 1.076\mathbf{R}^{0.67} \tag{7}$$

2.4 Scintillation

Thermally induced fluctuations in the light intensities cause in homogeneities in refractive index which is known as Scintillation. Although these fluctuations occur for very small-time durations, scintillation causes rapid fluctuations in the received signal.

C_n^2 is a scintillation parameter which depends upon the temperature and time of the day. Optical turbulence due to scintillation is measured by scintillation index equation.

$$\sigma_I = \frac{<I^2>}{<I^2>} - 1 \tag{8}$$

where 'I' is irradiance fluctuations of the wave and '<>' is long time average.

3. DIFFERENT MODELS FOR LINK DESIGNING

Depending upon the level of atmospheric turbulence, different statistics channel models for propagation through free space are developed. Basic channel statistics assumed for all models are given by.

$$y = S_m + n = \eta I_m + n \tag{9}$$

In which y = receiver signal, I_m= the intensity gain and η is ratio of photocurrent conversion.

3.1 Kolmogorov Spectrum Model:

This is used for weak fluctuations and turbulent cells are assumed in size from macro scale to micro scale, but each turbulent cell is homogeneous. Scintillation index is defined by Rytov variance and given by equation.

$$\sigma_r = 1.23 C_n^2 k^{\frac{7}{6}} L^{\frac{11}{6}} \quad (10)$$

Where L is propagation path, k is optical wave number and $C^2{}_n$ is refractive index fluctuations (29).

3.2 Log-normal Model:

This model is also used for weak fluctuations but overcomes Kolmogorov spectrum model when cell turbulences are not homogeneous. This model is simple mathematical model where pdf (probability density function) of received signal is given by [29]

$$F_{Im}(I_m) = \frac{1}{I_m \sigma_m \sqrt[2]{\pi}} \exp\left(\frac{\ln l_m + \frac{\sigma_m^2}{2}}{2\sigma_m^2} \right) \quad (11)$$

Where I is irradiance (normalized),

3.3 Gamma-Gamma Distribution Model:

This model is not restricted to weak fluctuations as previous models, but irradiance fluctuations are developed as a multiplicative of two random processes and the gamma-gamma pdf given by this distribution is.

$$f(I) = \frac{2(\alpha\beta)^{\alpha+\frac{\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)-2}{2}} k_{\alpha-\beta}\left(\sqrt[2]{\alpha\beta I}\right) \quad (12)$$

Where I is the intensity of signal and $\Gamma(.)$ is gamma function (29).

3.4 K-channel model:

K-channel model is suitable for achieving link range of 1 km. [27,28]. Mathematical expression for this model is

$$P_I(I) = 2 \frac{\alpha^{\frac{\alpha+1}{2}}}{\Gamma(\alpha)} \frac{I^{\frac{\alpha+1}{2}}}{\xi^{\frac{\alpha+1}{4}}} K_{\alpha-1}(2\sqrt{\alpha I}) \quad (13)$$

3.5 Negative Exponential Distribution:

This model is suitable for a link range of several kilometers with strong atmospheric turbulences [29].

$$f(I) = {}^{I}\!/\!_{I_o} \exp(-{}^{I}\!/\!_{I_o}), I > 0 \quad (14)$$

Mathematical expression shows that amplitude of signal varies exponentially negative.

4. RECENT MAJOR CONTRIBUTIONS

Free space optical communication faces several challenges due to all kinds of atmospheric attenuation and odd weather conditions leading to degradation of beam and signal quality.

Different models based on various environmental conditions have been proposed to minimize atmospheric losses. Some major contributions in research for fighting odd weather conditions using different schemes such as Aperture averaging, multiple- beam FSO transceiver, and Space- shift keying, encoding VLD (violet laser diode) listed in table 1.

Table. 1 Some recent techniques utilized and their outcomes in RoFSO communication.

S. N.	Year	Author	Technique Utilized	Outcome	Reference
1	2013	S.A., Al-Gailani	Multiple-beam FSO transceiver for heavy rain in link	• Received power quality improved when used four beams.	8
2	2014	Prabhman-deep Kaur	Aperture averaging and receiver diversity technique under various atmospheric conditions	• BER reduces as aperture diameter is increased. • Further decrease in BER occurs on increasing number of direct detection receivers	23
3	2014	Asaad kaadan, Hazem & Peter g. Lopresti	Optical arrays for trans-receivers	• Technique proved suitable for future FSO communication with up to 60% throughput.	28
3	2015	Pooja Gopal	Threshold detection for OOK, DPPM, DAPPM and optimal detection for PPM and PAPM	• For same transmitted power, performance of PPM is the best in case of downlink and • PPM is best for downlink.	22
4	2017	Anshul aiswal, Manav R. Bhatnagar &Viranderkumar Jain	SSK in FSO Communication	• FSO link performance remains unaffected from moderate to strong turbulences.	12
5	2018	Wei-hun Wang, Huai-Yung Wang & Gong-ru Lin	Encoding the VLD (violet laser diode)with 64-quadrature amplitude modulation	Constellation plot of this link provided • EVM of 8.57% • Signal to-noise ratio =21.34 dB • bit error ratio = 3.17×10^{-3}.	11
6	2018	Mahmoud A. Hasabeln, Selmy &Moawad I. Dessouky	Hybrid FSO &mmW links	• Link parameters shown better performance.	18
7	2018	Rub´enboluda-Ruiz, Antonio garc´ia-Zambrana,	Beam width optimization technique.	• Capacity optimized, achieving improvement of the order of 10 db.	12
8	2018	Wei shao, Sujuan Huang, Xianpeng Liu and Musheng Chen	Perfect optical vortex (pov) beamsMultiplexing.	• FSO link employing POVs reduces bit error rate (BER) for same received power.	10

9	2019	Zizhengcao, Xuebing Zhang and GerwinOsnabrugge	Reconfigurable beam system for non-line-of-sight free-space optical communication	• 30 Gbit/s OFDM signal transmitted with gain more than 17 db.	13
10	2019	Wagdy a. alathwary, & Essam salehAltubaishi	Decode-and-forward multi-hop FSO/RFsystem.	• Outage probability increases on increasing the pointing errors. • Multi-hop system can increase the total transmission coverage	1
11	2019	Richa Priyadarshani& Manav Bhatnagar,	FSO-MIMO employing an arbium doped optical amplifier.	• BER performance improved.	2
12	2019	Petr pesek Stanislav & Paul Anthony Haigh	m-CAP modulation scheme	Scheme used offered • security at physical layer and • low installation cost	3
13	2019	Vuong V. Mai &Hoon Kim	Energy-efficient adaptive beam control using focus-variable lenses.	• Outage probability minimized	24
14	2019	Marzieh Najafi and Robert Schober	Use of intelligent reflecting surfaces (IRS)	• End to end system quality improved.	25
15	2020	Amit Grover, Anu Sheetal &Vigneswaran Dhasarathan	Polarisation shift keying incorporated system based on MDM	• Presented system demonstrated better performance.	26

5. CONCLUSION

This paper reviews basic RoFSO link and various atmospheric attenuations occurring throughout free space in both theoretical and mathematical forms. Different channels models are discussed along with their working range and mathematical functions. It further discusses the various technologies employed by different researchers across the world along with their outcomes to improve link availability in adverse weather conditions.

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