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A Review on Atmospheric Effects on Free Space Optical Link

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Abstract: **-- Free space optics, an emerging technology which is going to revolutionize the high speed communication by providing data rates up to tens of Gbps is grabbing the attention of the researchers to employ it on an operational basis. Although the present day microwave frequency bands support a good quality communication, their speeds are low and they cannot accommodate more data in the available bandwidth as much as the free space optics can. Any communication system operating in free space is vulnerable to the atmospheric attenuation. So the atmospheric effects which degrade the performance of free space optical signal need to be studied in order to renew its standard potential even under bad climatic conditions. . In this paper we discuss some of the atmospheric effects which degrade the standard performances of a Free Space Optical Link at different geographical locations.**

Index Terms **— Free space optics, microwave, bandwidth, attenuation, atmospheric effects, degrade, performance.**

I. INTRODUCTION

Free space optics is an optical communication technology where light signal (carrier) is modulated according to the information using electro optic modulators and is released into the free space for the purpose of communication.The modulated light signal then travels through the atmosphere and reaches the photo detector at the receiver end where the light signal is converted into electrical pulses which is a suitable form for reading the message. The block diagram of a simple FSO model can be given as.

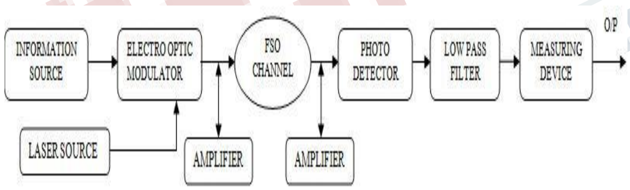

Fig 1: Free Space Optics Model.

It is a well known fact that communication using light sources is a perfect line of sight communication where the power received at the receiver is more concentrated which means that it can pack more number of bits in its available bandwidth.Free space optics supports many advantages like license free communication, high data rate, high bandwidth, and high ease of deployment, low bit error rates etc. From the recent demonstrations it is proved that optical technology can satisfy the needs of the end users like HD transmissions, interference free communication etc [12]. As the signal travels in free space it may undergo degradation due to the components of atmosphere generally termed as transmission impairments.

1.1 IMPAIRMENTS

There are many transmission impairments, because of which the free space optical signal degrades. They can be given as geometrical losses, scattering losses, terrestrial scintillation, fog, haze, beam dispersion, rain attenuation. These transmission impairments need to be thoroughly predicted before establishing the communication links at any geographical location. The prediction include estimation of some important parameters like received optical power, attenuation loss, visibility, BER, availability of the signal, elevation angle, quality factor, fluctuations in peak to peak amplitude. The analysis of eye diagram also contributes to the estimation process. With the help of simulation and some experimental analysis these parameters are estimated and the behavior of the impairments for different geographical locations can be known.

II.SIMULATION OF TRANSMISSION IMPAIRMENTS

The atmospheric effects such as fog,snow and rain attenuation on a Free Space Optical link was simulated using MATLAB by Saurabh Dhawan and Mandeep Singh. The fog attenuation models Kim, Kruse were simulated for different visibility distances (in meters) at different wavelengths and found that Kim's model does not give good results for distances greater than 10km as the attenuation was wavelength independent for distances greater than 10 km. Kruze model showed that under dense fog conditions the 1550nm surpassed the performance of 850nm and

950nm.The Al Naboulsi et al model also did not exhibit any wavelength dependent atmospheric attenuation. The simulation of the effect of snow using the relation

α_specific=〖a.S〗^bwherea=5.42*〖10〗^(-5)*λ+5.4958776, b=1.38S=Snow Rate, α=Specific ***Attenuation***

Showed that the specific attenuation due to dry snow is wavelength independent and the same case is with the wet snow. The simulation of rain rate showed that with the increase in rain rate the specific attenuation also increased [1].

The effect of fog on Free Space Optical links was studied by Reza NasiriMahalati and Joseph M. Kahn in 2011 at Stanford USA employing imaging receivers. The link was analyzed in the presence of misalignment and atmospheric effects. The results showed that atmospheric conditions degrade the performance of a Free Space Optical link by blooming the image of the signal spot and attenuating the received optical power. It is concluded that for the cases of medium to heavy fog, image blooming loss is dominant over attenuation loss [2].

The scattering effect on terrestrial Free Space Optical link signal was simulated using Optisystem 7.0 with a link distance of 2km by Kazi Md. Shahiduzzaman et.al. The simulation results showed that an optical source of 1550nm was very much useful for a data transmission of maximum of 5Gbits/s with a BER less than 10-9 and can mitigate the atmospheric effects with an avalanche photo diode as a detector element for detecting the photons at the receiver end with a gain of 2 and aperture diameter of 35mm [3].

Different weather conditions like clear air, fog, haze was taken into consideration to evaluate the performance of multiple transceiver FSO system by Priyanka Sharma, Himalisarangal. The FSO link was modeled with the help of commercial optical software called as Optisystem version 7.0. The transceivers of three varieties (1Tx/1Rx, 4Tx/4Rx,8Tx/8Rx) were simulated under three conditions clear air (specific attenuation of 0.43dB/km), fog(specific attenuation of 43dB/km), haze(specific attenuation of 4.3dB/km).The results were analyzed based on eye diagram and quality factor. Under all the weather conditions the 4Tx/4Rx, 8Tx/8Rx systems gave good quality factor and better eye diagrams compared to 1Tx/Rx system due to the effect of spatial diversity[4] .

The propagation of laser beam at 785nm and 1550nm in the presence of fog and haze was analyzed and compared by Issac I. Kim, Bruce Mc Arthur and Eric Korevaar to falsify the fact that the use of 1550nm is advantageous than the use of 785nm in all weather. By observing the past experimental analysis and the Full Mie theory they concluded that in the case of fog where visibility is less than 500m there is no advantage of 1550nm over 785nm by proposing a new equation

σ =3.91/v 〖(λ/550nm)〗^(-q)

Which needs to be verified by new experimental work [5]?

III. EXPERIMENTAL ANALYSIS OF TRANSMISSION IMPAIRMENTS

The performance of a Free Space Optics system had been analyzed by FatinHamimi Mustafaet.al in the year 2001 at UTM JalanSemarkKaulaLampur using PAV light products modeled to work at 700m distance with 810nm wavelength with a power of 14 dBm. The rain intensity data was collected and the specific attenuation was calculated using the Japan model recommended by ITU-R. The equation for calculation of specific attenuation using japan model is given as

A_specific=a*R^b. Where
a=1.58, b=0.63

The results were generated using simulation software named OPTIsim under heavy and lighter rain (drizzle).Finally it was concluded that heavy rain gives higher rain attenuation of -28.6dB and lighter rain gives low attenuation which was found to be -1.3dB with BER of 〖10〗^(-1) and 〖10〗^(-13) respectively [6].

The effect of different atmospheric conditions on the free space earth to satellite optical link in tropical climate was analyzed by Norhanis Aida M.Nor et.al in the years 2011 and 2012 at Kaula Lampur campus Malaysia with the help of the experimental setup consisting of Flight Strata 155,Young Tipping bucket rain gauge and Sentry visibility meter sensor installed on the top of the building for measuring received optical power, rain intensity and visibility values respectively, It was observed that as rain intensity increases the attenuation due to rain also increases which was calculated using Carbonnea model recommended by ITU-R. The equation for calculation of specific attenuation using

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Carbonnea model is given as
A_specific=a*R^b. Where
a=1.076, b=0.67

It was also observed that for 1% outage time attenuation for 1km is 25 dB and by considering the slant path of the rain it is concluded that lower elevation angles produce high attenuation for both theory and practical cases. The analysis of visibility data collected from 3/2/12 to 29/2/12 revealed that elevation angle is important element in defining any attenuation when involving slant path. Analysis is also done for various beam divergence angles and found that for an angle of 0.1mrad the earth to satellite link is feasible at elevation angle of 50 degree. During haze conditions to achieve the availability of 95% the elevation angle greater than 20 degrees was suggested [7].

The performance analysis of Free Space Optical link with haze attenuation consequence is carried out with the help of lab scale experimental setup by M.Zuliyana et.al in tropical rain forest environment. The data was collected from meteorological department from the mid year of 2012 until mid year 2013 and the results proved that haze visibility of below 2.24km was the worst situation which can be solved by placing the system at a range of 500m with a bit rate of 622 Mbps[8].

The effect of scintillation on Free Space Optical link in Singapore for rainy and Non-rainy events was studied by AnandaEkaputeraSidarta by installing the experimental setup on the top of the building with the help of IDA Tech Group .After conducting tests for 3 months starting from Feb 2002 for a link distance of 1km the results of MATLAB coding revealed that the signal fluctuations are high during the midday because the peak to peak scintillation tend to be higher than that in the morning and the evening. During the rainy event the scintillation was also as high as 6dB [9].

The power law parameters which become the key factors in obtaining the attenuation due to rain were estimated as k=2.03 and α=0.74 by SamirA.Al-Gailani et.al on performing experimental analysis at Johor Malaysia in the year 2012.The data required for experimental analysis is the rain rate for a period of one year (1/11/11 to 26/10/12) collected from Vintage Pro 2 weather station and the received optical power measured using Thorlab P M 100 optical power meter from the FSO link. By correlating the rain rate and attenuation obtained, the results indicate that the ITU-R recommendations underestimate the attenuation due to rain at high rain rates but reach the experimental values at low rain rates .On the other hand attenuation calculation based on DSD cannot be applied to tropical regions as they are modeled based on temperate climates. The new values estimated are highly correlated with the actual measured data. At low rain rates the estimated and actual data correlated with the Japan and Carbonnea models and at higher rain rates they do not. The new values estimated constitute the equation [10].
A_specific=k*R^α. Where
k=2.03, α=0.74.

The performance of free space optical link with multiple Transmitter/ Receivers was analyzed by NurHaedzerinet.alwith the help of simulation, experimental setup and theoretical approaches. The experimental setup used here was Flight Strata 155 by light Pointe with multiple lenses both at the transmitter and the receiver ends. The simulations were carried out using Opti System 7.0.The data of the experimental setup was recorded using Flight Manager PC version1.0.15.0 from 2nd august 2010.The theoretical approach revealed that doubling the number of transmitters and receivers can increase the received power resulting in 6dB/octave of gain. The simulation approach correlated with the theoretical approach and the eye diagrams showed that the 4Tx/4Rx system performed well compared to the other combinations. The experimental results deviated from simulation but followed the same pattern i.e. 4Tx/4Rx system gave good performance. [11]

A four beam FSO system which operated successfully at a distance of 1142.2m at a BER of 10-9 with -34.5 dBm as the optical power at the receiver was implemented by S.A.Gailani, A.B.Mohammad and R.Q.Shaddad in the year 2012 at Johor Bahru (Malaysia) where rain attenuation becomes major concern as it is a region with tropical climate. To obtain the required results rain intensity data was collected using Vantage Pro 2 weather station from 1st November 2011 to 26th may 2012.Recommondations given by ITU-R like JapanandCarbonnea were taken into consideration ,but only Carbonnea model whose equation is
A_specific=a*R^b. Where
a=1.076, b=0.67 was utilized as Japan model did not suite

the climatic conditions. As the system designed is a multiple beam FSO system it is observed from the simulated results that as the number of beams increase the received optical power also increased accordingly [12].

Space Communications and Navigation (SCaN) which is part of NASA recently demonstrated optical communication technology using lasers with Lunar Laser Communications Demonstration (LLCD) from October 2013 to April 2014 during themission named Lunar Atmosphere and Dust Environment Explorer (LADEE). The demonstration worked with Downlink speed of 40-622 Mbps and Uplink speed of 10-20 Mbps and the corresponding ground receiving stations are White Sands, NM, NASA JPL's Table Mountain, CA, European Space Agency Tenerife, Spain (Canary Islands) [13].

IV. FUTURE SCOPE

SCaN at present is working on Laser Communications Relay Demonstration (LCRD) with an uplink speed of 1.2Gbps and downlink speed of 1.25Gbps with 2 ground stations whose flight is going to be in 2019 to serve for longer period. SCaN is going to introduce optical communications on an operational basis on the Next Generation Tracking and Data Relay Satellite (TDRS) in the 2022 timeframe.Mars Reconnaissance Orbiter (MRO) mission would take 1.5 hours to transfer its information to earth using microwave frequency bands. If optical communication is used it would take less than 5 minutes to reach the earth [13].

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