Analysis of Atmospheric effect in FSO and Various Techniques to Enhance System Performance on free space optical communication network

Nikhlesh K Mishra
Dept. of Electronics & Communication
University of Allahabad, Allahabad, India

Abstract: FSO is a communication system where free space acts as medium between transceivers and they should be in LOS for successful transmission of optical signal. Medium can be air, outer space, or vacuum. This system can be used for communication purpose in hours and in lesser economy. There are many advantages of FSO like high bandwidth and no spectrum license. The transmission in FSO is dependent on the medium. The presence of foreign elements like rain, fog, and haze, physical obstruction, scattering, and atmospheric turbulence are some of these factors. Different studies on weather conditions and techniques employed to mitigate their effect are discussed in this paper.

***Index Terms*-Atmospheric, FSO, WDM**

I. Introduction

1.1 **Atmospheric Weather Conditions:** Atmosphere is the medium of transmission for a FSO link. Attenuation caused by it depends upon several conditions. Weather conditions are the main cause of attenuation. The region in which a link is being established has some specific weather conditions so that the preceding knowledge of attenuation can be gained; for example, fog and heavy snow are the two primary weather conditions in temperate regions. In tropical regions, heavy rain and haze are two main weather conditions and have major effect on the availability of FSO link in that region [12]. Some of the weather conditions are described below.

(a) Fog. Fog substantially attenuates visible radiation. Optical beam of light is absorbed, scattered, and reflected by the hindrance caused by fog. Scattering caused by fog, also known as Mie scattering [21], is largely a matter of boosting the transmitted power.

(b) Rain. Rain attenuation exists due to rain fall and is a non selective scattering. This type of attenuation is wavelength independent [10]. Rain has the ability to produce the fluctuation effects in laser delivery. The visibility of FSO system depends upon the quantity of the rain. In case of heavy rain, water droplets have solid composed and it can either modify the optical beam characteristics or restrict the passage of beam as optical beam is absorbed, scattered, and reflected [7].

(c) Haze. Haze particles can stay longer time in the air and lead to the atmospheric attenuation. So, attenuation values depend upon the visibility level at that time. There are two ways to gather information about attenuation for checking the performance of FSO system: first, by installing system temporary at the site and check its performance and, second, by using Kim and Kruse model [10].

(d) Smoke. It is generated by the combustion of different substances like carbon, glycerol, and household emission. It affects the visibility of transmission medium [13].

(e) Sandstorms. Sandstorms are the well-known problem in outdoor link communication. These can be characterized by two ways: first, the size of the wind particles which depends on the soil texture and, second, necessary wind speed in order to blow the particles up during a minimum period of time [14].

(f) Clouds. Cloud layers are main part of earth atmosphere. The formation of clouds is done by the condensation or deposition of water above earth’s surface. It can completely block the fractions of optical beam transmitted from earth to the space. The attenuation caused by clouds is difficult to calculate because of the diversity and inhomogeneity of the cloud particles [15].

(g) Snow. Snow has larger particles which causes the geometric scattering. The snow particles have impact similar to Rayleigh scattering [16].

II. Different Studies Based on Attenuation Effect

Different studies are going on different weather condition to design new models based on the effectiveness of the system. The main focuses of these studies are fog, haze, rain, and snow weather conditions. Based on these studies results, measures can be taken in practical system.
In a study authors followed theoretical and experimental research to study the effect of fog and smoke. Experimental results validated the laboratory-based empirical model that 830, 940, and 1550nm are most durable wavelength windows. Empirical model is used to compare the experimental result for the continuous attenuation spectrum of fog and smoke conditions and results show that the disambiguation is decreasing linearly [13]. In another study, author studies whether fog is wavelength dependent or not. A fog-like environment is developed in a chamber for experimenting. It is verified that attenuation caused by fog is wavelength dependent parameter. FSO link employed with 830nm and 1550nm in parallel in the same chamber and power is measured at the receiving end for both the cases: with fog and without fog. Fog particles lead to Mie scattering so Mie theory is applicable to measure the scattering. One model from the three famous models, that is, empirical, Kim, and Ferdinandov, can be used to calculate the attenuation due to fog [17].
In rain based study, a correlation of precipitation rates with rain attenuation is studied on the short wavelength (785nm). The four-existing-model rain attenuation is utilized to find the result and measured data is compared with calculated results to determine the turbulence model [7]. The effects of rain intensity variation on its attenuation prediction are the focus of another study. The analysis of 7 reduction format models is done to study the FSO link with rain intensity variations. Six of the models have a reduction factor value of unity where one model has 0.7. It reduces the effective path length of FSO link. Rainfall distribution for longer path seems to be more widespread in case of low rain rate and more concentrated in case higher rain rate [18]. In a study, single and multiple transceiver concept is used to study the effect of tropical Malaysian weather on FSO link based on the value of link distance and received power. It is concluded that four-beam FSO system can successfully operate under heavy rain for larger distance depending upon the value of signal to noise ratio (SNR), geometrical and atmospheric losses, and bit error rate (BER) [16].

III. Various Techniques to Enhance System Performance

Various techniques to enhance the system performance are being introduced. Some of these techniques are discussed below in detail and their comparison is done in the following section.

(a) Performance of SAC OCDMA Based FSO System. Spectral Amplitude Coding Optical Code Division Multiple Access technique is used in FSO system by the researchers. This multiplexing scheme has several advantages like flexibility of channel allocation, asynchronously operative ability, privacy enhancement, and network capacity increment. KS (Khazani-Syed) codes are used with SDD (spectral direct decoding) technique. An optical external modulator (OEM) is used to modulate the code sequence with data. The data is an independent unipolar digital signal. Mach-Zehnder Modulator (MZM) is used and combination of modulated code sequences is transmitted through the FSO link and these sequences are separated by an optical splitter at the receiver end. The overlapping chips are discarded to avoid the interference at receiver end and decoder will only filter the nonoverlapping chips. Optical band pass filters serve the purpose of encoders and decoders. A low pass filter (LPF) is used to recover the original data. The performance of this system with SDD technique is analyzed along with FSO system using intensity modulation with direct detection (IM/DD) technique. SDD technique performs better and the link distance is improved by 22.7% [4].

(b) High Speed, Long Reach OFDM-FSO Transmission Link Incorporating OSSB and OTSB Schemes. By introducing the OFDM scheme, an effort has been made to probe the impact of the environment conditions and to design a high speed and long reach FSO system free from the multipath fading. Different weather conditions like clear, foggy, and hazy channel are used to model different types of condition in system. CW laser diode is used at the line-width of 10MHz and 1550nm wavelength. The power to be used by hybrid system is 0dBm and ideal antenna aperture is 15cm. The data rate is 5Gbps and a 4-QAM sequence generator generates the data and OFDM modulator using 512 subcarriers is used. The data is transmitted over FSO link using OTSB/OSSB schemes instead of ODSB scheme which is prone to fading problem. This modulation is done by Dual Electrode Mach-Zehnder Modulator (DEMZM) and a phase shifter. It is concluded that hybrid OFDM-FSO system performs better in diverse channel conditions and upon comparing both OSSB and OTSB schemes OSSB performs better than OTSB at high data rate as it has more immunity against fading due to weather conditions [3].

(c) Optimization of Free Space Optics Parameters Using WDM System. A unidirectional WDM system is designed by the investigators. Different characteristics like data rate, power, link range, number of users, and channel spacing are needed to be optimized according to the weather conditions. The attenuation for different type of rain is 6.27, 9.64, and 19.28dB/km for light, medium, and heavy rain, respectively. 1550nm wavelength is best for both rain and haze as there is less attenuation than any other wavelength. The priority for optimization of parameters is required to be done for the better performance of system. Geometric losses are not considered during this work. Optical Amplifier Gain is having the highest priority and the rest of priority decrementing series is laser power, data rate, and aperture size and link length is having the lowest priority. A 622Mbps of data rate is maximized for all types of rain as concluded from results. For clear weather condition, data rate could be 2.5Gbps for the distance of 150km. For critical weather conditions, short link distance and lower data rate can be used to optimize the FSO system for successful transmission [10].

Comparison of these studies is done based on the different parameters like wavelength, power level, data rate, and link distance. Summarization of all parameters with different techniques is done in **Table 1**.

Technique		Weather condition	Attenuation level (dB/km)	Power level (dBm)	Data rate	Link distance (km)
SAC OCDMA-FSO	SDD	Heavy rain	8.68	0	2.5Gbps	1.1
		Clear sky	3	0	2.5Gbps	1.3
	OFDM-OSTB-FSO	Clear	0.155	0	2 Gbps 5 Gbps	10 6
		Mild clear	0.441	0	2 Gbps 5 Gbps	9 5
		Low haze	1.537	0	2 Gbps 5 Gbps	5.4 3.4
		Mild haze	4.285	0	2 Gbps 5 Gbps	3.2 2.2
		Heavy haze	10.115	0	2Gbps 5 Gbps	1.8 1.15
		Low fog	15.55	0	2Gbps 5 Gbps	1.35 1
		Mild fog	33.961	0	2Gbps 5 Gbps	0.720 0.540
		heavy fog	84.904	0	2Gbps 5Gbps	0.360 0.300
OFDM-FSO	OFDM-OSSB-FSO	Clear	0.155	0	2 Gbps 5 Gbps	10.2 6.2
		Mild clear	0.441	0	2 Gbps 5 Gbps	8 5.2
		Low haze	1.537	0	2 Gbps 5 Gbps	5 3.6
		Mild haze	4.285	0	2 Gbps 5 Gbps	2.8 2.5
		Heavy haze	10.115	0	2Gbps 5 Gbps	1.7 1.4
		Low fog	15.55	0	2Gbps 5 Gbps	1.26 1.2
		Mild fog	33.961	0	2Gbps 5 Gbps	0.740 0.590
		heavy fog	84.904	0 0	2Gbps 5Gbps	0.360 0.310

Technique		Weather condition	Attenuation level (dB/km)	Power level (dBm)	Data rate	Link distance (km)
	WDM-FSO	Very clear	0.065	-10	2.5Gbps	150
		Clear	0.233	10	2.5Gbps	150
		light haze	0.55	20	2.5Gbps	150
		Heavy haze	2.37	40	155Mbps	150
					155Mbps	55
		Heavy haze	2.37	30	622Mbps	51.52
					155Mbps	22
		Light rain	6.27	30	622Mbps	20.8
					155Mbps	13.7
		Medium rain	9.64	30	622Mbps	14.9
					155Mbps	7.6
		heavy rain	19.28	30	622Mbps	7.2

Table 1: Comparison table of various techniques based on system parameters on wavelength of 1550 nm [3, 4, 10, 20].

From Table 2, it can be concluded that the more the attenuation the smaller the link distance. With increase in the data rate, link distance reduces. If power level increases, then link distance improves depending upon the value of power level. Effect of attenuation is lesser if power level is high but power level cannot be increased more than value defined by various organizations that define the principle of laser safety. Such as a human eye can be affected by Laser when eye comes in direct contact with it on a particular wavelength at a particular power like 10mW power for Class 1M laser in 1550nm wavelength permissible by IEC (International Electro technical Commission) standards [20].

IV. Conclusion

Many studies are going in this perspective to minimize the effect of attenuation by introducing new system design like WDM based FSO system. Different models based on these studies are used to study the system performance before installing it at the location. This can lead to the improvement of the system. Different techniques like OFDM-FSO, WDM-FSO based system are new approach to improve the system performance with high speed and longer distance. So new techniques can be designed by combination of these and, by enhancing these techniques, system designing can be improved and the demerits of FSO system can be reduced to a minimum level.

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