

Light Attenuation Measurements at 650 and 850nm Wavelengths in Dense Fog and Smoke for FSO Applications

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ABSTRACT: The spectrum attenuation of free space optical (FSO) communication systems operating at visible and near infrared (NIR) wavelengths (650nm and 850nm) under fog and smoke was experimentally investigated. Fog and smoke are generated and controlled homogeneously along a dedicated atmospheric chamber of (93*63*60)cm dimensions. Comparison of the new proposed model with the measured continuous attenuation spectrum from (visible – NIR) in the fog and smoke channels, shows a closer relationship than the semi-empirical Kim fog models. The experimental results also show the selection of the possible appropriate wavelengths from (visible – NIR) for FSO links to achieve the maximum link span in dense fog conditions.

KEYWORDS: (FSO)communication, (Fog, Smoke)attenuation, Kim Model, Visibility.

I. INTRODUCTION

Free space optical communications uses visible or NIR light sources to transmit a high data rate through the atmospheric channel [1]. The FSO communication link can be defined as telecommunication technology, which uses an infrared optical beam to transmit information between two static points. FSO has become a high-bandwidth, viable wireless alternative to optical fiber cabling. The main advantages of FSO related to optical fiber are significant cost savings and its rapid deployment time, while the FSO disadvantage over the optical fiber is that the attenuation of laser power through the atmosphere is difficult to predict and variable because it is weather dependent, therefore, factor limits the distance at which FSO should be deployed. FSO links offer data rates in gigabit per second with low system complexity. It is a broadband communication technology, which needs direct visibility between transmitter and receiver, called Line of Sight (LOS). This technology uses optical modulated pulses for fibreless optical data transfer. In free space optics light pulses are transmitted via the atmosphere. Due to atmospheric conditions FSO technology has a number of drawbacks. Whenever the medium's condition is unstable and unpredictable, it becomes difficult to manage the FSO transmissions [3]. However, the constitution of the real outdoor atmosphere, particularly aerosols (fog and smoke) have similar particle size distributions compared to the propagating optical wavelengths. This can potentially result in scattering and absorption of visible and IR optical beams, thus degrading the FSO link performance and its availability [4]. Absorption is the process of conversion photon energy to internal energy, when electromagnetic radiation is captured by matter. It is mostly caused by the carbon dioxide and water vapor present along the transmission path. There are many reservation bands for atmosphere gases, which called transmission windows that permit specific frequencies of light to pass through. The molecule attenuation varies for different wavelengths. The concentration of gas molecules and therefore the gas absorption decrease at higher altitude. The concentration of particles and steam, as well as the distribution of the particle size may have local variations. This affects the wavelength dependent absorption and scattering. The attenuation caused by absorption and scattering in aerosols depends on the concentration and the size of the particles. Large particles like rain and snow give a transmission that is wavelength independent. For small particles like fog and smoke the transmission becomes more dependent on wavelength. Scattering is defined as the beam dispersal of radiation or of particles into a directions range due to of physical interactions. When an electromagnetic wave intercepts by a particle, some of the wave's energy is eliminated by the particle and reradiated to the solid angle centered on it. The scattered light is polarized and been in the same wavelength as the incident wavelength that means no loss of energy to the particle.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

II. THEORETICAL CONCEPT

The atmosphere consists of many types of gases to aerosols; amongst the particles that attenuate the optical beam is the fog, which consists of very fine spherical particles of water in the air with variable size (1- 25 μm in diameter). Fog particles reduce the visibility near the ground and the meteorological definition of fog is when the visibility drops to near 1 km. Different types of fog are categorized based on a number of factors, including the location, the particle size distribution and the average particle diameter [5]. Fog originates when the relative humidity of an air parcel reaches saturation. Thus, some of the nuclei grow by condensation into droplets of water. Fog and certain types of haze have similar origins and the increase in humidity is enough to transition haze into the fog. This transition is quite gradual and an intermediate state is referred to as a mist. While perceptible haze extends to an altitude of several kilometers, fog is typically just a few hundred feet thick. Attenuation of the optical signal at a distance R, due to fog and haze, is determined by the Beer-Lambert law[6]

$$Att_{fog} = e^{-a(fog)R} \quad \text{----- (1)}$$

$$\sigma(fog) = \frac{3.91}{V} \left(\frac{\lambda}{\lambda_0}\right)^{-q} \quad \text{----- (2)}$$

Where, a (fog) is the attenuation coefficient, V is the visibility, λ is the wavelength of the transmitted signal, λ₀ is the visibility wavelength reference (550nm), q is the size distribution coefficient of scattering which can be found utilizing Kim modified model using theoretical assumptions for the fog by defining q values [6]

1.6 for high visibility (V > 50 km)

1.3 for average visibility (6 km < V < 50 km)

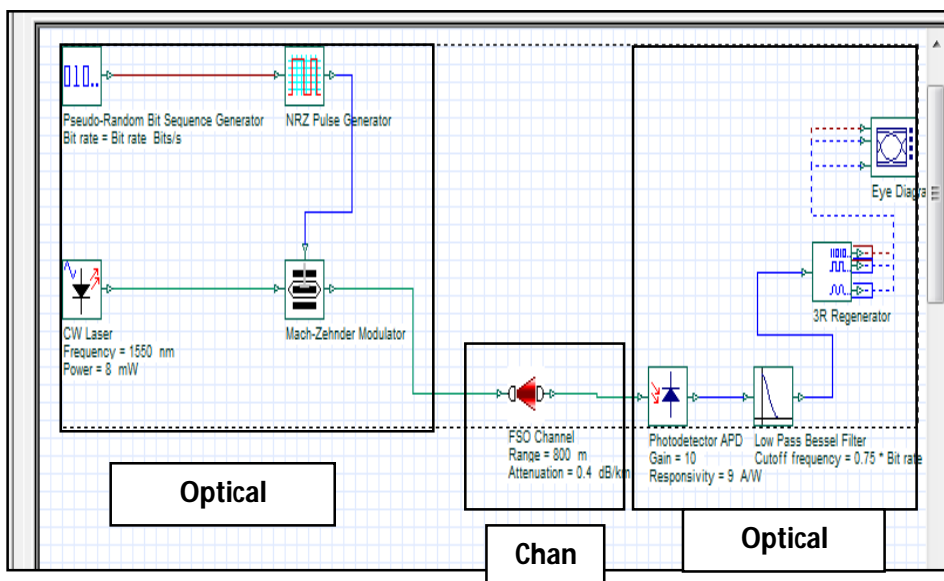
Kim model q = 0.16 V + 0.34 for haze visibility (1 km < V < 6 km)

V - 0.5 for mist visibility (0.5 km < V < 1 km)

0 for fog, visibility (V < 0.5 km)

III. SIMULATION TOTAL FOG AND SMOKE ATTENUATION

FSO communication link Simulation is very important in designing and understanding the context of such link depending on technically and continually parameters, such as changing atmospheric parameters of the transmission optical channel. FSO System Simulation consists of two basic parts they are Steady model and Statistical model, which were used in the buildup programming package and describes experiments carried out. A basic design of FSO system was simulated and modeled for performance characterization has been done by using OptiSystem software (7.0), which is a very good design tool, has ability to plan, simulate and test for every most optical link types. This software is cost effective with decrease required time and related to the links, optical systems design, and other components; it includes many parameters of the system that can be varied to get the optimum system performance. The FSO model that's designed by OptiSystem software is illustrated in Figure 1.



International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

The optical transmitter in our simulation consists of subsystem which is the Pseudo Random Binary Sequence (P-RBS) generator, which is representing the data or information that need to transmit. The P-RBS generator output is the Return-to-Zero (RZ), where a bit stream of binary pulses; a sequence of "0"s (OFF) or "1"s (ON), of a reproducible and known pattern. The free space medium between receiver/transmitters has been considered as a free space optical channel. This free space medium (FSO channel) between an optical transmitter and an optical receiver consider to have an aperture diameter of (5 and 8) centimeter at each end respectively. At the same time, the beam divergence is set to (2mrad). The optical receiver composed of APD (an avalanche photodiode) followed by a low pass filter, front-end amplifier, and a 3R regenerator. The function of 3R regenerator is used to regenerate and modulated electrical as in the optical transmitter that have been used for analysis of BER (i.e. it normalized the signal waveform with Gigabit class transmission). This is with a view to allow transmissions of relay without retro gradation the quality of signal between buildings with distance more than 1 km apart or that do not provide a good LOS. In the steady model of simulation, we can set weather conditions Channel properties which described by item α atm. or due to visibility we can simulate different decreases of signal caused by Fog and smoke.

IV. EXPERIMENTAL WORK

The atmospheric Perspex chamber is composed of three compartments, each having air outlets for air circulation inside chamber. It is possible to generate and control temperature induced turbulence within the chamber can be readily controlled to be as closely as possible the Field atmospheric conditions. The designed chamber allow to carry out the field FSO system characterization and performance measurement under a various levels of turbulences without the need for longer using handmade water vaporizing system, as shown in figure2.

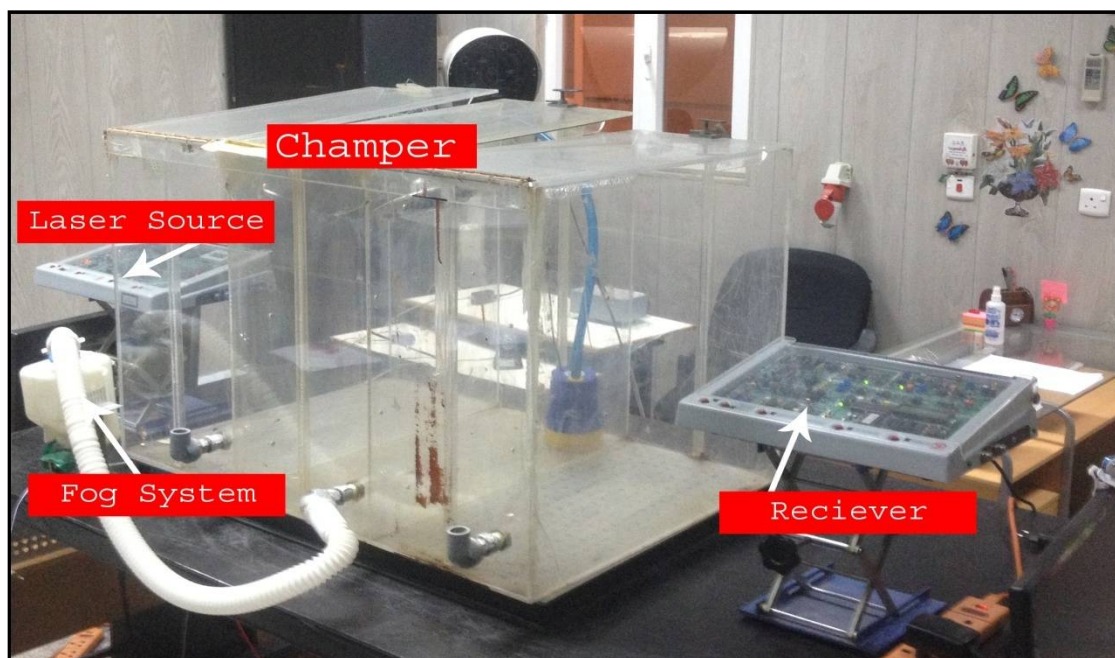


Fig.2.the experimental setup of Lab-controlled FSO- link.

Similarly, smoke is introduced to the atmospheric chamber using a smoke generator. More details on the fog and smoke mechanisms are provided in Table 1. The amount of fog injected into the chamber is controlled by using air blower and a number of ventilation inlet/outlets to achieve different densities. Thus, allowing managing the fog flux inside the chamber homogeneously so controlling the visual contrast (transmittance) of the FSO. Steam fog with different stages (Low, Mid, High) was produced using handmade water vaporizing system steam to mimic the Real Field fog. The mean attenuation data for $0 < V < 1$ km [7] and for $V < 0.6$ km [8] shows good agreement with the measured lab data. Smoke which is mainly formed in Real Field smoke by the combustion of many substances like

International Journal of Innovative Research in Science, Engineering and Technology

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house hold emission, glycerol, and carbon, may be considered as a visible gaseous substance that dry solid small particles disperse and stays for long time in the atmosphere. It is possible to simulate smoke in the lab with different stages (Low, Mid, High) using a glycerin based liquid process to create dry smoke to mimic the Real Field smoke.

Table 1. Main parameters of the experimental FSO- Link

Parameters	Value	
Peak wave length	850 nm	
Maximum optical power	1 mw	
Beam divergence	3 m rad	
Maximum modulation frequency	100 MHz	
Optical receiver	InGaAs	
Spectral sensitivity	1 A/W	
Active area	1 mm ²	
Rate	1 Mbps	
Chamber	Dimension	93× 63× 60 cm
	Temperature range	20 – 80 CO
	Wind speed	1 m/s

V. RESULTS AND DISCUSSION

Results obtained from the estimated of fog and smoke effects using empirical models were obtained and the algorithm which buildup to evaluate the results with the theoretical model have been demonstrated, as inFigure 3 which shows total attenuation at different visibility ranges. It is appeared that with more visibility the least effects of total attenuations will gain on FSO performance.

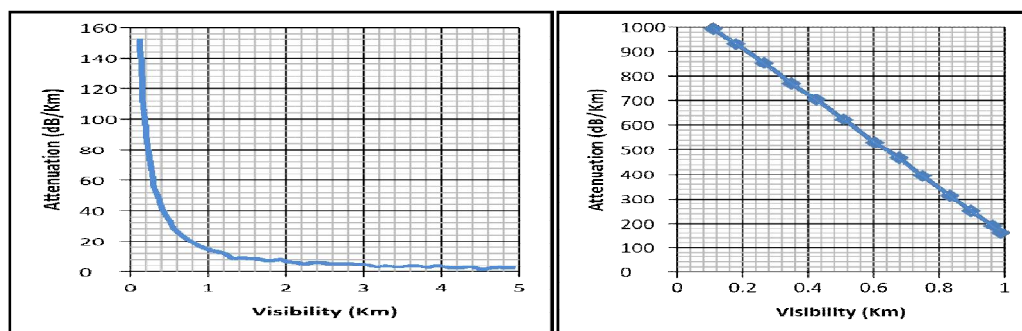


Fig.3: a- Fog attenuation versus average visibility (left) b- Smoke attenuation versus average visibility (right).

Visibility close to zero at larger than 150 dB/km of fog attenuation, and any decreases in attenuation there is small change in visibility within 1 km. Large increment of visibility after 20 dB per km. Smoke attenuation will decrease as a straight line with average visibility.

The log-log plot of the measured average fog attenuation (in dB/ km) against the measured visibility for 0.65μm and 0.85μm wavelengths are shown in Figure 4 which confirms the physical characteristics of lab based fog that resembles the Real Field fog. According to these results, the predicted attenuation is lower at the NIR wavelength than at the visible wavelengths, for all V ranges.

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(An ISO 3297: 2007 Certified Organization)

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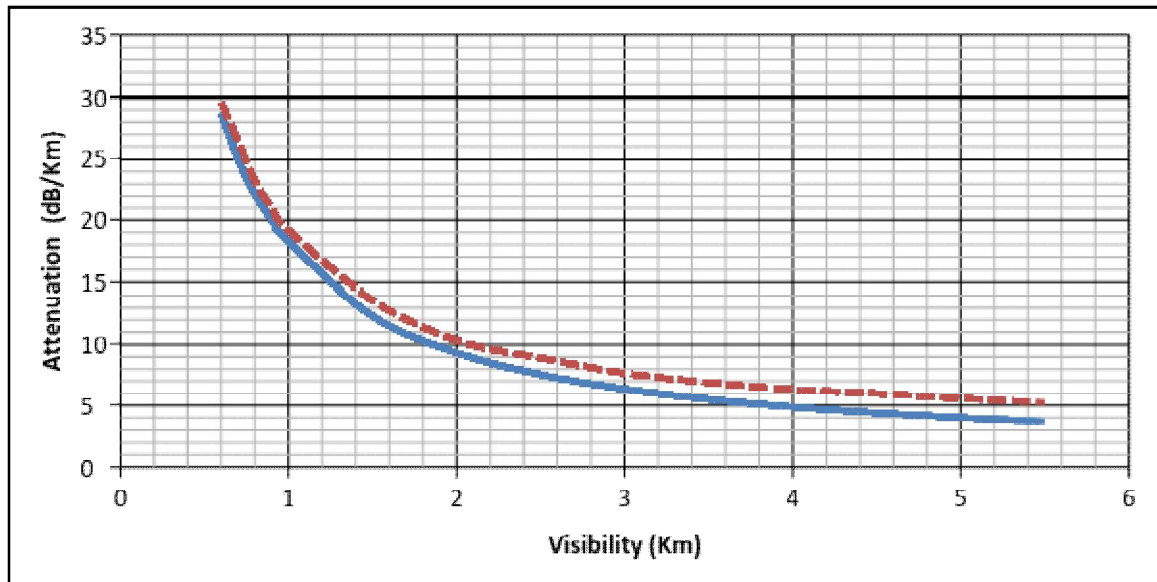


Fig.4: Fog-attenuation in (dB/Km) as a function of visibility for 0.650µm (red) and 0.85µm (blue) wavelengths.

The log-log plots of the measured attenuation of smoke in (dB/ km) against the visibility for 650nm and 850nm wavelengths are shown in Figure 5 which confirms the physical characteristics of lab based smoke that resembles the Real Field smoke.

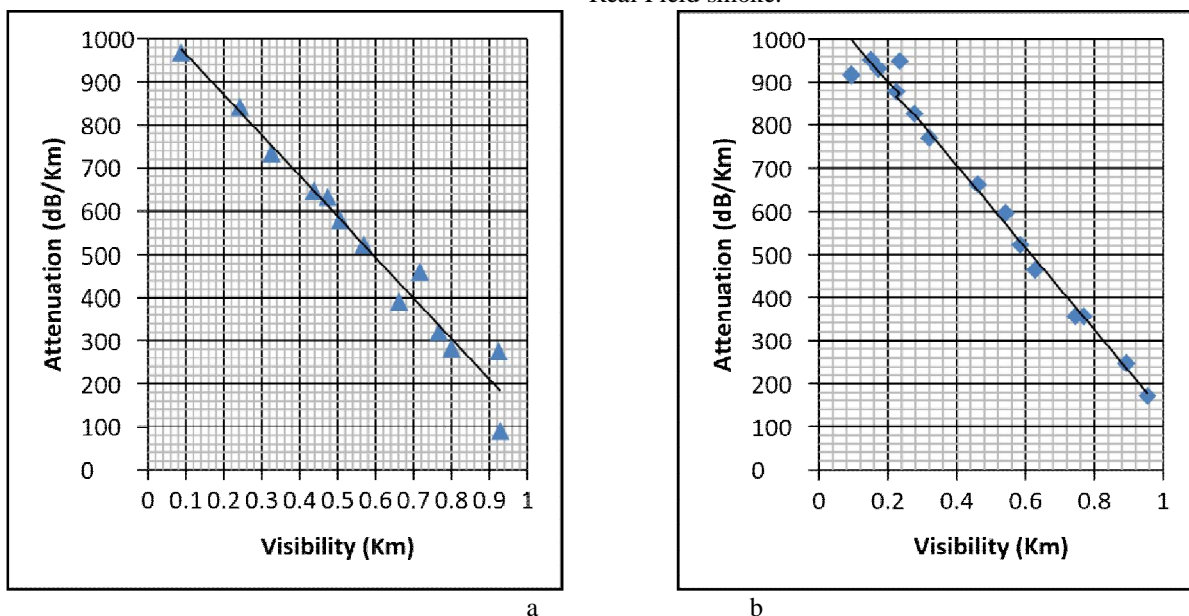


Figure 5: Smoke-Attenuation comparison versus visibility at different wavelengths a) 850nm, b) 650nm

The experimental result clearly demonstrates the dependency of the wavelength on the resultant smoke attenuation even if V is below 0.5 km. In general, the smoke attenuation difference is more than the fog attenuation.

VI. CONCLUSIONS

The impact of fog and smoke on the FSO link performance using the continuous wavelength spectrum of 850nm has been demonstrated. We have experimentally compared the continuous attenuation spectrum for the same fog and smoke conditions and found that the attenuation is almost decreasing for both cases. The proposed model is calibrated

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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for outdoor FSO links using Kim model, thus validating the laboratory-based empirical model. According to this results, the selection of higher wavelength range for moderate to the dense fog conditions where $V < 0.5$ km, is not a suitable solution in order to mitigate the fog attenuation for FSO communications.

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