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Modeling and Mitigation of the Effect of Free Space Optical Attenuation during Fog at UHF Band

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ABSTRACT

Free space optical communication (FSOC) is a new communication technology that uses LASER beam to transmit high quality signals through the atmosphere with more data security. In this work, field measurement of signal strengths at five unlicensed ultra-high frequencies (900, 1200, 1400, 1600 and 1800 MHz) at various visibility during fog has been carried out. The measurement was carried out using a developed optical transmitter and receiver capable of transmitting and receiving optical signal strength within UHF band. The experimental data analyzed based on the best fit curve shows that, generally, the optical signal attenuation in fog decreases with increasing visibility. The lower frequency (900 MHz) suffered less attenuation (11.90 dBm) while the higher frequency (1800 MHz) suffered more attenuation (19.19 dBm). Hence, applying frequency diversity by telecommunication industry will mitigate the effects of FSO attenuation during fog. Furthermore, the results obtained were compared with ITU-R frequency dependent attenuation model and the root mean square error obtained was 16.81, a new model for predicting optical signal attenuation during fog weather at UHF band was developed. The value of R^2 obtained was 0.9538 which indicates that the model developed is considered to better fit the measured data. The correlation coefficient, r, between the optical signal attenuation and the frequencies is 0.9797 which indicates a rise of 9.98 dBm in signal attenuation to a rise in frequency by 10%.

Key words: Fog, Optical Instruments, Optical Signal, Ultra High Frequency, Visibility.

I. INTRODUCTION

Due to increasing demand for wireless broadband communication and congestion on bandwidth of radio frequency spectrum, FSOC has received considerable attention in the communication world. It has widespread use because of its advantages such as high modulation bandwidth, enhanced security and low power, it is also immune to electromagnetic interference (EMI) with low probability of interception properties [1]. However, FSOC has some disadvantages which have hampered its wide deployment. It has low availability due to its susceptibility to atmospheric weather conditions. The major challenge to FSO communications is fog. Rain and snow have little effect on FSO, but fog is different. Fog is vapor composed of water droplets, which are only a few hundred microns in diameter but can modify light characteristics or completely hinder the passage of light through a combination of absorption, scattering and reflection. The primary way to counter fog when deploying FSO is through a network design that shortens FSO link distances and adds network redundancies

. For an optical radiation traversing the atmosphere, absorption occurs when some of the photons are extinguished by molecular constituents of the atmosphere and their energy converted into heat energy leading to loss of optical power [2]. Again, optical radiation through the atmosphere is attenuated by scattering caused by gas molecules and aerosols. Scattering causes changes in the direction of propagation of the optical wave from the line of sight (LOS) in which the beam spreads wider than the receiver aperture, thus leading to significant loss of optical power. Hence, fog causes the most detrimental effects with attenuation measurement of 480 dB/km [3]. The presence of fog may completely prevent the passage of the optical beam that leads to a no operational communications. Other weather conditions particularly temperature and humidity also have a significant impact on UHF optical communication system. There can be spatial variation in weather, which can affect optical signal strengths. While these changes in weather conditions are inevitable and may have significant effects on optical signal variation in fog, they are usually measurable and could be mitigated based on experimental measurements. Hence, this work seeks to investigate the effects of fog and its mitigation on UHF free space optical signal propagation.

II. RELATED STUDIES

The attenuation effects of fog on microwave channels (dB km^{-1}) are well known and can be described by the following relation [4]

$$\gamma_F = LWC \times \kappa\,(T, F) \tag{1}$$

where γ_F is the fog-induced attenuation, a function of the liquid water content, LWC (g m^{-3}) and the expression κ (dB km^{-1}) (g m^{-3})$^{-1}$, which is dependent on the temperature T(K) and the link frequency.[5]. Equation (1) describes the attenuation as a function of microwave frequencies induced by fog ranging between 0.01 and 0.4 gm-3

Frequency dependent attenuation on the propagation of radio signal and free space optical communication (FSOC) has been studied by several researchers and it has been shown that both radio signal and FSOC attenuation are frequency dependent. The frequency diversity in reduction of signal fading on wireless communication network in Nigeria have been investigated [4]. It was noted that, fading vary with time, geographical position and radio frequency. The results also revealed that, frequency diversity technique was adopted and has been found to be suitable for reducing signal fading but had to do to the extent of about 90% in digital communication.

Measurement of propagation loss were conducted in the range 300 MHz to 3 GHz [5]. The measurement were done with a signal generator sweeping slowly across the band and a spectrum analyzer making fast sweeps uncorrelated to the signal generator sweep in peak detector mode. The results obtained shows that above 1.5 GHz the signal was attenuated 5 – 10 dB more than free space path loss and the attenuation increases with increasing frequencies.

The attenuation by fog for UHF and microwave has been determined using a simple ITU-R recommendation model. The model was adopted in 2009 for the dielectric permittivity of water based on the total liquid water content. When the Rayleigh scattering approximation is valid, the specific attenuation within fog can be written as [6] [7].

$$\gamma_c = K_l w \tag{2}$$

$$K_l = \frac{0.819F}{\varepsilon''(1+\eta^2)} \tag{3}$$

$$\eta = \frac{2+\varepsilon'}{\varepsilon''} \tag{4}$$

where γ_c is the specific attenuation in dB/km in the fog, K_l is specific attenuation coefficient in $dBkm^{-1}g^{-1}m^3$. The liquid water density in fog is typically about 0.05 g/m^3 for medium fog (visibility of the order of

300 m) and 0.5 g/m³ for thick fog (visibility of the order of 50 m) [6]. In the above equation F is the frequency, ε' and $\varepsilon''$are the real and image part of the complex dielectric permittivity of water which can be computed with ITU-R model (ITU-R, 2007).

$$\varepsilon''(F) = \frac{F(\varepsilon_o - \varepsilon_1)}{F_p\left[1 + \left({F}/{F_p}\right)^2\right]} + \frac{F(\varepsilon_1 - \varepsilon_2)}{F_s\left[1 + \left({F}/{F_s}\right)^2\right]} \quad (5)$$

$$\varepsilon'(F) = \frac{\varepsilon_o - \varepsilon_1}{F_p\left[1 + \left({F}/{F_p}\right)^2\right]} + \frac{\varepsilon_1 - \varepsilon_2}{F_s\left[1 + \left({F}/{F_s}\right)^2\right]} + \varepsilon_2 \quad (6)$$

With three permittivity constants given as;

$$\varepsilon_o(T) = 77.6 + 103.3(\theta - 1) \quad (7)$$

$$\varepsilon_1 = 5.48 \;\; and \;\; \varepsilon_2 = 3.51$$

III. MEASUREMENT CAMPAIGN

The investigation study area where the line-of-sight link was set up is in LAUTECH area, Ogbomoso, Oyo state, Nigeria. The measurement campaign area is on the geographical coordinate (8.13°N, 4.25°E).

A. METHODOLOGY

The measurements was carried out by placing an existing optical transmitter developed in the weather plagued by fog and the optical receiver was placed directly opposite of the transmitter at a direct line of sight (LOS). The distance between the transmitter and receiver as well as visibility was noted and recorded using a digital measuring wheel and transmissometer respectively. The signal was transmitted via microphone, the signal generator LM555 timer generated various frequencies at UHF band starting from 900 MHz; the signal is conditioned and modulated using an adaptive differential amplitude pulse position modulation (DAPPM) digital technique. LASER diode was used to transmit the optical signal and the amount of signal transmitted was noted and recorded on LCD. At the other end, the incoming signal is made to falls on the optical detector coupled with the optical receiver. The detector converts the optical pulses into electrical equivalent pulses and the exact replica but reduced magnitude was obtained. The signal is made to pass through conditioning processes in the optical receiver circuit and the values of signal strength received were display on LCD and recorded. The difference between the signal values sent and received gives the signal attenuation at that particular frequency of operation at a known visibility. The procedure was repeated at 10 m visibility interval up to 200 m. The entire procedure was repeated by varying the transmitting frequency to 1200 MHz, 1400 MHz, 1600 MHz and 1800 MHz, the respective optical signal transmitted and optical signal received were noted and recorded.

IV. RESULTS AND DISCUSSIONS

In this section, the results obtained from the measurement campaign for five unlicensed frequencies are presented. Measured optical signal attenuation as a function of visibility in fog weather are given, the variations of optical signal in clear weather at various distances are presented. Comparison between the measured optical signal attenuation and the simulated ITU-R model is presented. Finally, a model which can be used to predict free space optical attenuation at all the frequencies within UHF band was developed.

Figures 1 show the measured signal losses as a function of visibilities at different frequencies. Generally, the results show that the signal strength during fog decreases with increase in visibility. This occurs since the density of fog is a function of visibility, the thick fog (low visibility) has a higher density which attenuates the optical signal strengths during fog. For the frequency band considered in this work, 900-1800 MHz, the lower frequency suffered less attenuation while the upper frequency suffered more attenuation. This was due to the fact that low frequency signals are of larger wavelength than that of high frequency waves and they travel longer, for the same power. Frequency actually has various characteristics for sky and ground wave; in general, high frequency has lower wave length so it is disturbed due to more vibration but low frequency has greater wavelength so it is not disturbed easily by molecules. Hence, low frequency can travel further.

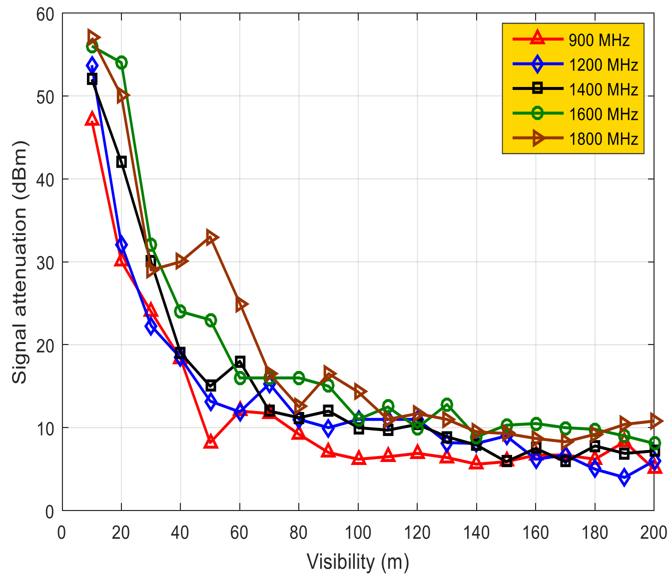

Figure 1: Measured signal attenuation against visibility at various frequencies within UHF band

Figure 2 shows the variation of signal attenuation with distance at different frequencies in a clear weather. As the separation distance between the optical transmitter and receiver increase, the optical signal attenuation also increases. It was also discovered that, loss of optical signal strength was a function of frequencies because the higher frequency suffered more attenuation when compared to lower frequencies. There was a significant difference between optical signal attenuation during fog and clear weather as shown in Table 1, this shows that optical signal is susceptible to fog weather condition and reduces the strength of the signal there by resulting to optical signal attenuation, the results also indicates that optical signal attenuation due to fog is directly proportional to frequency.

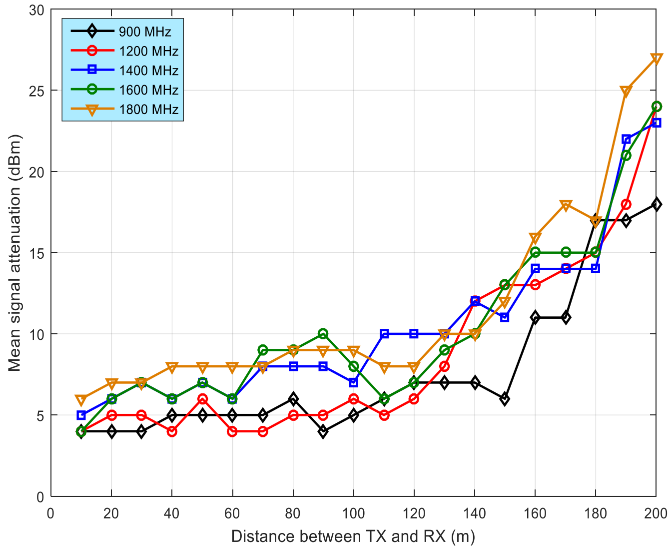

Figure 2: Variation of signal losses with distance as a function of frequency in clear weather.

Table 1: Mean attenuation at various frequencies in clear weather and during fog

Frequency (MHz)	Mean signal attenuation in clear weather (dBm)	Mean signal attenuation during fog weather (dBm)
900.00	7.70	11.96
1200.00	8.80	13.57
1400.00	10.40	15.17
1600.00	10.50	18.04
1800.00	11.50	18.50

A. Developed model

It has been established in table 1 that lower frequency suffers less attenuation during fog weather while higher frequencies suffered more attenuation during fog. Hence, the UHF optical attenuation due to fog is directly proportional to frequency. Equation (2) was used to compute optical signal attenuation as a function frequencies and the results computed was compared with experimental measured optical attenuation obtained in the field as shown in figure 3.

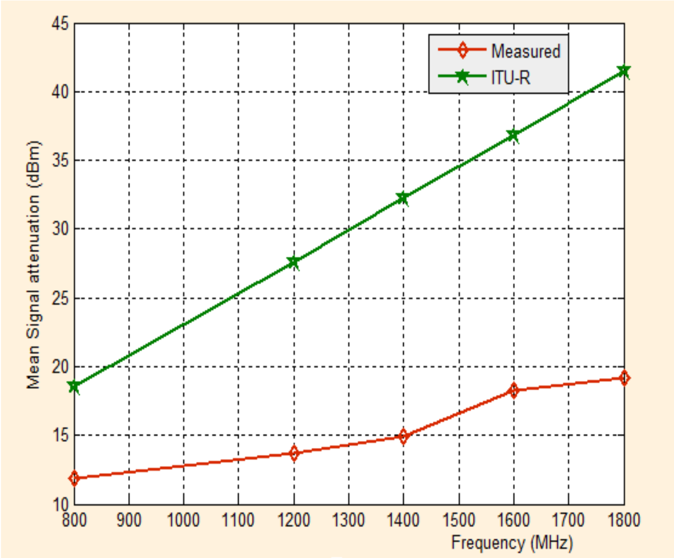

Figure 3: Comparison between measured attenuation and predicted ITU-R model.

The sum of square error, R-Squared, adjusted R-Squared and the root mean square error has been determined and a general model power 1 is developed. The value of goodness of fit is shown in Table 2 while equation (7) shows the developed frequency dependent optical attenuation model during fog at UHF band.

$$A_{(F)} = 0.0667 \times F^{0.755} \quad (7)$$

where $A_{(F)}$ is the signal attenuation in dBm, F is the frequency in MHz. The model developed at co-efficient (with 95% confidence bounds) has the goodness of fit shown in Table 2. Figure 4 shows the graphical representation of the simulation of optical signal attenuation against the UHF band for the ITU-R and developed model.

The value of R^2 obtained was 0.9538, this value is very close to 1 which indicates that the model is considered to better fit the measured data. The correlation coefficient, r, between the optical signal attenuation and the frequencies is 0.9797 which indicates a rise of 9.98 dBm in signal attenuation to a rise in frequency by 10%

Table 2: Goodness of fit for developed model.

Goodness of fit	Value
Sum of square error (SSE)	1.738
R^2	0.9538
Adjusted R-Square	0.9385
r	0.9979
Root mean square error (RMSE)	0.7611

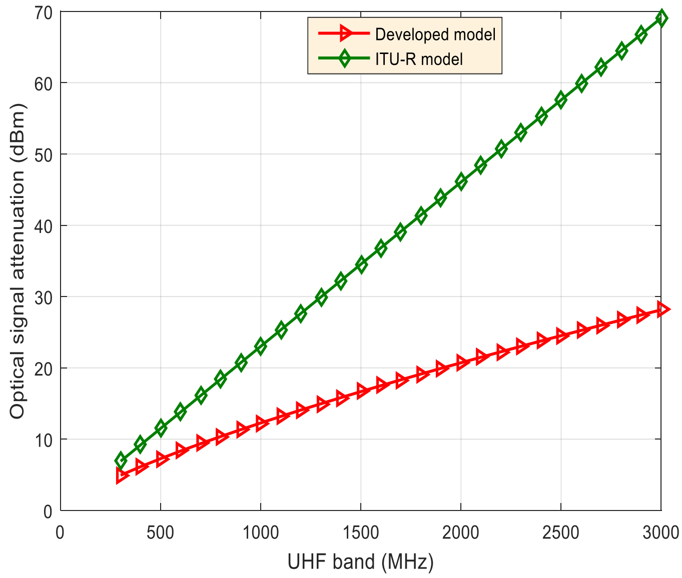

Figure 4: Simulation of ITU-R and developed model at UHF band.

V. CONCLUSION

In this study, modeling and mitigation of FSO attenuation during fog weather at UHF band has been investigated. The study revealed that, the free space optical attenuation decreases with increasing visibility, the lower frequency (900 MHz) suffered less attenuation (11.50 dBm) while the higher frequency (1800 MHz) suffered more attenuation (19.19 dBm). Hence, applying frequency diversity by telecommunication industry will mitigate the effects of FSO attenuation during fog. Furthermore, the results obtained were compared with ITU-R frequency dependent attenuation model and the root mean square error obtained was 16.81, a new model for predicting optical signal attenuation during fog weather at UHF band was developed. The value of R^2 obtained was 0.9538 which indicates that the model developed is considered to better fit the measured data. The correlation coefficient, r, between the optical signal attenuation and the frequencies is 0.9797 which indicates a rise of 9.98 dBm in signal attenuation to a rise in frequency by 10%.

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