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Effects of Air Temperature and Relative Humidity on UHF Free Space Optical Communication in Foggy Weather

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ABSTRACT

Theoretically, free space optical communication has been proved to be viable and capable of providing high data rates, secured and license-free transmission but it is seriously susceptible to atmospheric conditions/turbulence majorly fog and other primary weather parameters. In this work, the effects of temperature and relative humidity on ultra-high frequency (UHF) optical communication during fog have been investigated using an optical instrumentation system capable of measuring signal strengths and concurrently measured the temperature and relative humidity at two unlicensed frequencies (900 and 1800 MHz). Temperature shows high level negative correlation with signal attenuation between -0.6060 and -0.8599 while relative humidity shows positive correlation coefficient with signal attenuation between 0.5737 and 0.7551 for the frequencies 900 and 1800 MHz respectively. This implies that the relationship between the optical signal attenuation, temperature and relative humidity are higher, stronger and statistically significant. In addition, empirical models for predicting the variations of temperature and relative humidity on UHF optical signal attenuation during fog were developed.
Keywords : Fog, Optical Communication, Relative Humidity, Temperature, UHF

I. INTRODUCTION

Free space optical communication, FSOC is a new communication technology that uses LASER beam to transmit high quality audio signals through the atmosphere from the transmitter to receiver. LASER [1, 2] transmits high quality audio with the link virtually impossible for anyone else to tap into. Also, it cannot be detected with the use of spectrum analyzers and RF meters. It is immune to electromagnetic interference (EMI) and highly secure with low probability of interception and low probability of detection (LPI/LPD) properties [3]. Hence, it can be used for diverse applications including financial, medical and military. However, FSOC has some disadvantages which have hampered its wide deployment. It has low availability due to its susceptibility to atmospheric weather conditions. The primary atmospheric processes that affect optical signal propagation are atmospheric absorption, scattering and refractive index of turbulence (Scintillation). 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 [4]. Again, optical radiation through the atmosphere is attenuated by scattering caused by gas molecules and aerosols such as fog, haze, snow, mist and rainfall. Scattering causes changes in the direction of propagation of the optical wave. The beam spreads wider than the receiver aperture, thus leading to significant loss of optical power. Fog causes the most detrimental effects with attenuation measurement of 480 dB/km [5, 6, 7, 8]. 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 in fog. 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, temperature and humidity on UHF free space optical signal propagation in low latitude region using a developed optical instrumentation system.

II. METHODS AND MATERIAL

The work was based on the measurement of signal strength at UHF band during foggy weather. The measurement was carried out using a developed optical transmitter and receiver. For the purpose of measuring the effects of local weather condition, the nodes of the optical receiver was integrated with a sensor DHT11 and this was used to measure concurrently the temperatures and relative humidity every 120 seconds during fog.

III. RESULTS AND DISCUSSION

3.1 Variation of temperature and attenuation profile

Figures 1 and 2 shows the variations of temperature and attenuation profile for the fog event at 900 and 1800 MHz frequencies respectively. Since fog is formed whenever there is a temperature difference between the ground and the air, that is, when the air temperature is the same as the dew point temperature. Hence, temperature changes affect the formation of fog which is equally affects the optical signal strengths during fog. It was discovered that fog dispersed when there was a rise in temperature and the optical signal absorption (attenuation) equally reduced. Generally, optical signal attenuation increase as the temperature decreases because of the presence of huge water vapour in the atmosphere. This increase is attributed to Tropospheric ducting of UHF Optical signal which leads to the changes in the refractive index of the Troposphere of the boundary between air masses of different temperatures and relative humidity. As the optical signal propagates from less dense to dense medium, there was a change in the direction of the signal (Refraction). Hence, part of the Optical signal transmitted deviated away from the line-of-sight before reaching the receiver and this leads to loss in the strengths of the optical signal. Obviously, in figures 1 and 2, there was a clear relationship between temperature and signal attenuation in fog with respect to time. The rise in temperature leads to decrease in optical signal attenuation indicates negative correlation (dependence) between temperature and signal attenuation at the frequencies considered. For frequency 900 MHz (R^2 = 0.3680, r = -0.6066) which indicates a rise of 6.066 dBm in signal attenuation to a rise in temperature by 10%.

For the frequency 1800 MHz (R^2 = 0.7377, r = -0.8589) which indicates a rise of 8.589 dBm in signal attenuation to a rise in temperature by 10%. This shows that relationship between the optical signal attenuation and temperature is higher, strong and statistically significant (Cohen, 1998) [5]

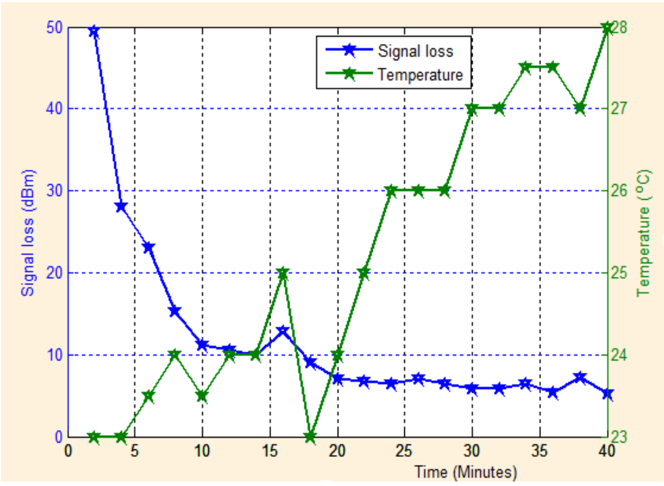

Figure 1: Temperature and attenuation profile for a fog event at 900 MHz.

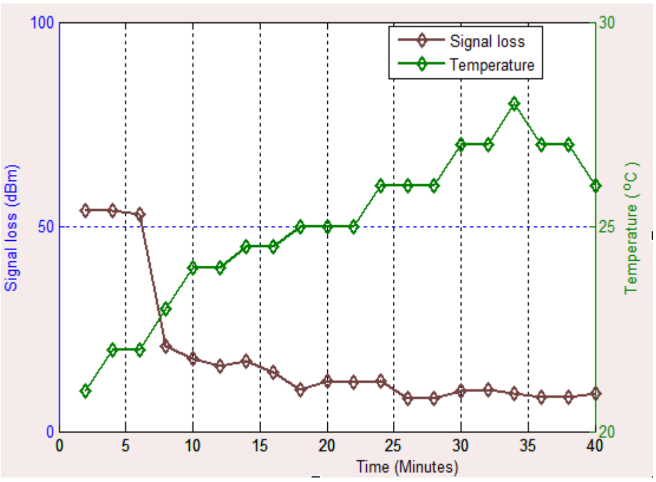

Figure 2 : Temperature and attenuation profile for a Fog event at 1800 MHz

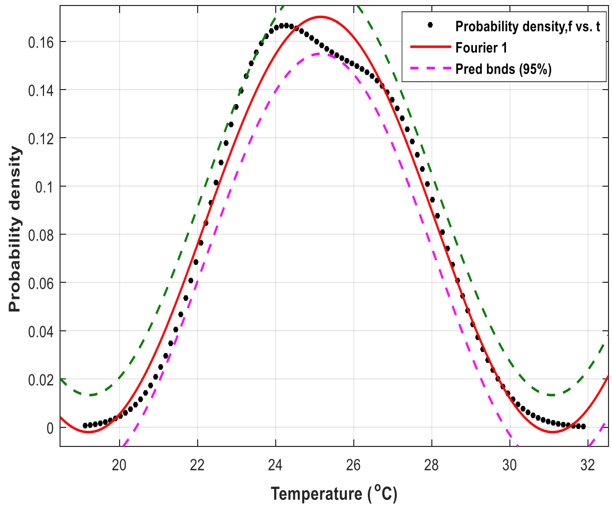

Figure 3 : probability density function against temperature.

General model Fourier 1 is given as

$$F_{(T)} = 0.08404 + 0.06453\cos(0.5284T) + 0.057\sin 0.5284T \quad (1)$$

Goodness of fit with 95% prediction bounds

SSE = 0.00549, R^2 = 0.9862, adjusted R^2 = 0.9858 and RMSE = 0.007563.

3.2 Empirical Relationship between temperature and Optical signal attenuation

Figure 4 shows the relationship between the Optical signal attenuation and the temperature of the day during fog. Obviously, the optical signal attenuation decreases with increase in temperature, that is, temperature plays an important role in the formation of fog and optical signal attenuation. An empirical relationship between temperature and optical signal attenuation is proposed. This relationship is developed using standard curve fitting technique by employing General model power 1 with non-linear least square method at Off robust with algorithm in the trust region. The model equation is given by

$$\boldsymbol{A_{(T)} = 2.296 \times 10^{20} \times T^{-13.83}} \quad (2)$$

Coefficients (with 95% confidence bounds):

where A(T) is the optical signal attenuation as a function of temperature in dBm, T is the temperature in °C.

Goodness of fit is given by following parameters; SSE = 210.600, R-Squared = 0.9031, Adjusted R^2 = 0.8978, RMSE = 3.420.

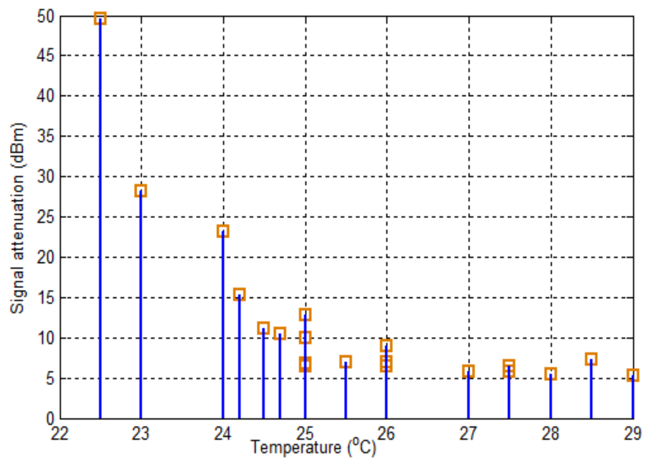

Figure 4 : Relationship between Optical signal attenuation and temperature during fog

3.3 Variation of relative humidity and attenuation profile

Generally, as the time of the day increases, the relative humidity and signal loss decreases in fog weather and this indicates a positive correlation as shown in figures 5 and 6 for the two frequencies considered. The increase in optical signal attenuation when the relative humidity increases in fog weather was attributed to Tropospheric ducting effect. Tropospheric ducting is a type of radio/optical propagation that tends to happen in anticyclonic weather when the radio/optical signal encounter a rise in relative humidity.

During fog event, the refractive index of the Troposphere changes and the signal propagates from the medium of different refractive indices and this lead to changes in the direction of the optical signal and deviate from line-of-sight which eventually leads to signal attenuation. Besides the effect of Tropospheric ducting, when the relative humidity is higher, the atmosphere is mostly dominated by moisture which lead to absorption of the optical signal there by lead to increase in optical signal attenuation in fog. Generally, as the time of the day increases, the relative humidity and signal loss decreases in fog weather and this indicates a positive correlation. The increase in relative humidity which leads to increase in optical signal attenuation indicates positive correlation (dependence) between relative humidity and signal attenuation at the frequencies considered. For frequency 900 MHz (R^2 = 0.3291, r = 0.5731) which indicates a rise of 5.731 dBm in signal attenuation to a rise in temperature by 10%. For frequency 1800 MHz (R^2 = 0.5701, r = 0.7551) which indicates a rise of 7.551 dBm in signal attenuation to a rise in temperature by 10%.

Table 4.7: The interpretations of coefficient of correlation (Cohen, 1998) [9].

Coefficient of correlation (r)	Interpretation
0.10 to 0.29 or -0.10 to -0.29	Small
0.30 to 0.49 or -0.30 to -0.49	Medium
0.50 to 1.00 or -0.50 to -1.00	Large

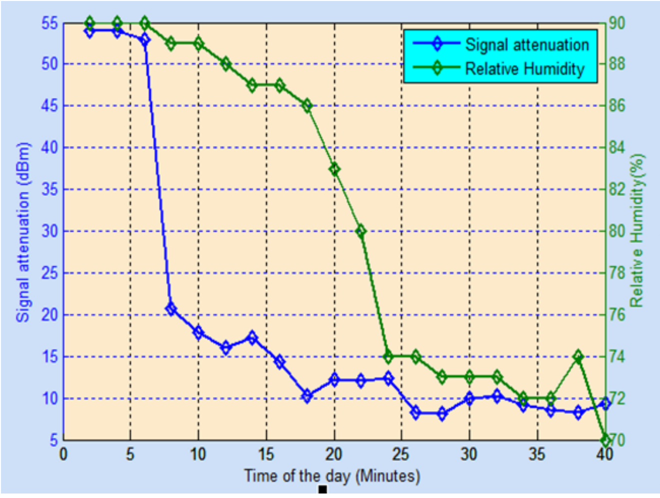

Figure 5 : Humidity and attenuation profile for fog event at 900 MHz

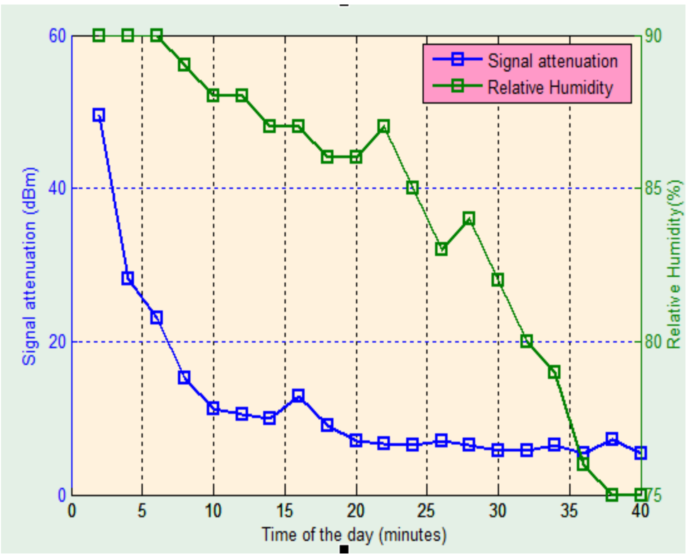

Figure 6 : Relative humidity and attenuation profile for fog event at 1800 MHz

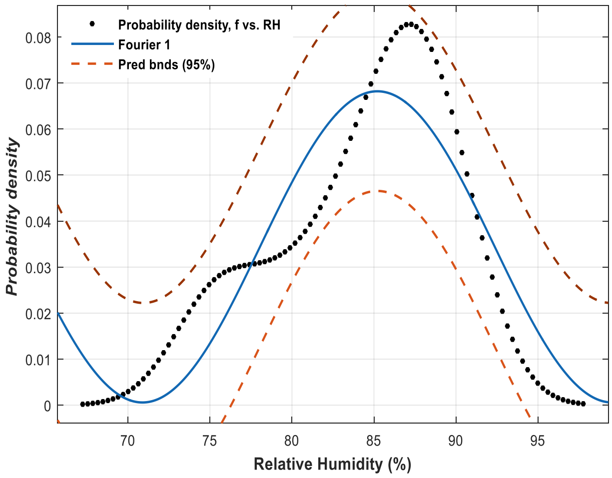

Figure 7 : probability density function against relative humidity.

General model Fourier 1 is given as

$$F_{(H)} = 0.03439 + 0.03338\cos(0.2103H) - 0.005363\sin 0.2109H \quad (3)$$

Goodness of fit with 95% prediction bounds

SSE = 0.01103, R^2 = 0.8407, adjusted R^2 = 0.8358 and RMSE = 0.01072.

3.4 Empirical relationship between relative humidity and optical signal attenuation during fog

Figure 8 shows the relationship between optical signal attenuation and relative humidity in fog. It has been established from the measured value in the figures 6 and 7 that the amounts of water vapour in the atmosphere play an important part in the formation and dissipation of fog. Obviously, when the relative humidity is high, the optical signal attenuation is higher because the presence of huge amounts of water vapour absorbed and scattered the optical signal there by lead to losses or deviation from the line of sight (LOS). An empirical relationship is proposed between the optical signal attenuation and relative humidity in order to determine the influence and prediction of relative humidity on free space optical signal in fog weather. The data values of optical signal attenuation and relative humidity are first smoothed (averaged) and then non-linear least square General power 1 fit is applied at off robust with algorithm in the trust-region. The empirical relationship is given as shown in equation 4

Coefficients (with 95% confidence bounds):

$$\boldsymbol{A_{(H)} = 9.667 \times 10^{-51} \times H^{-26.30}} \quad (4)$$

where $A_{(H)}$ is the optical signal attenuation as a function of humidity in dBm, H is the Relative humidity (%).

The goodness of fit is given by the following parameters:

SSE = 287.20

R-Squared = 0.8679

Adjusted R^2 = 0.8605

RMSE = 3.995

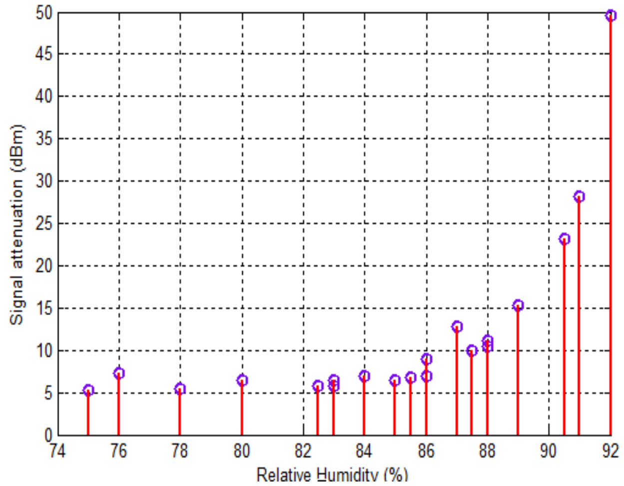

Figure 8 : Relationship between Optical signal attenuation and relative humidity in fog

IV. CONCLUSION

In this work, the effects of air temperature and relative humidity on optical signal strength of wireless communication system during fog weather has been explored. Experimental results show that changes in weather condition affects the received optical signal strength during fog. The optical signal attenuation decreases with increase in temperature (-0.6060 and -0.8599) for 900 and 1800 MHz, this implies that temperature plays an important role in the formation of fog and optical signal attenuation. An empirical model relationship between temperature and optical signal attenuation is developed. It has also been established from the measured values that the amounts of water vapour in the atmosphere (relative humidity) play an important part in the formation and dissipation of fog. Obviously, when the relative humidity is high, the optical signal attenuation is higher because the presence of huge amounts of water vapour absorbed and scattered the optical signal there by lead to losses or deviation from the line of sight (LOS). Hence, relative humidity has a positive correlation with the optical signal attenuation due to fog, the correlation was (0.5737 and 0.7551) for 900 and 1800 MHz respectively. An empirical model for predicting free space optical signal attenuation in foggy weather at different temperature and relative humidity has been developed.

Remarks

This investigation revealed that the relationship between the optical signal attenuation, temperature and relative humidity are higher, stronger and statistically significant.

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