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ANALYSIS OF ATMOSPHERIC TURBULENCE EFFECT ON FREE SPACE OPTICAL COMMUNICATIONS IN ILORIN, KWARA STATE, NIGERIA

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ABSTRACT

This work seeks to statistically analyze the effect of wavelength transmission in free space over Ilorin, Kwara State, Nigeria using existing atmospheric data for wind velocity from Nigeria Meteorological Agency (NiMET). Scintillation attenuation was calculated based on Rytov approximation for wavelengths of 780nm, 850nm, 1250nm and 1550nm.The signal to noise ratio (SNR) for all the wavelengths considered were also analyzed and it was found that wavelength 1550nm is less attenuated and also has a good SNR as compared with the others. Therefore to improve the efficiency of transmission of FSO, the wavelength of 1550 nm must be used.

KEYWORDS: Wavelength Transmission, Scintillation Attenuation, Rytov Approximation, Signal to Noise Ratio

1. INTRODUCTION

Free Space Optical (FSO) communication is a wireless, fibreless and a line of site (LOS) technology that transmits data through atmospheric channel as opposed to fiber optic cables which appears to be more reliable but the cost of digging and laying down the fiber cable are huge and highly difficult to relocate once it is deployed (Ramasarma, 2002).

FSO communication system have been gaining popularity consistently over the years because of its increased power efficiency for practically longer distances (Raj, 2015). FSO communication system is useful in areas where physical connections are not feasible as a result of topography, cost implication, and other considerations. Other merits of this method of communication include license free operation, ease of deployment and installation, immunities to electromagnetic interference, high bit rate and no fresnel zone necessary (Liu et al., 2014). FSO also finds applications in communication between buildings in cities and industrial parks and also between ships or aircraft particular for military applications because of their high security of transmission. The major limitation to FSO communication system is bad weather conditions such as fog, haze, dust, rain and turbulence are capable of causing fluctuations in the received signal level which in turn results in bit error increase in a digital communication link (Alkholidi and Altowij, 2012) and (Heba Yuksel, 2005). Hence, the weather conditions of the location of interest must be studied in detail before adopting FSO communication technique. Some of the major factors considered for the selection of wavelength for FSO communication systems are availability of components, transmission distance, price and eye safety (Willebrand and Ghuman, 2002).

Hemani and Georges, (2015) defined Atmospheric turbulence as a random phenomenon which is caused by the variation of temperature and pressure of the atmosphere along the propagation path. Eye safety is one of the most important restrictions to the optical power level emitted by a wireless Infrared (IR) transmitter. Lasers of higher power can be used more safely with 1550 nm systems than with 850nm and 780nm systems this is because wavelengths less than about 1400nm focused by the human cornea into a concentrated spot falling on the retina can cause eye damage (Alkholidi and Altowij, 2012). However the allowable safe laser power is about 50 times higher at 1550nm (Zaatari, 2003), (Hemani and Georges, 2015).

A lot of works have been done in the area of FSO communication some of which includes Ali, 2013 who studied atmospheric turbulence effect on free space optical communication and concluded that of the various wavelengths considered, the wavelength of 1550 nm has the best signal to noise ratio. In Motlagh et al., 2008 studied the effect of atmospheric turbulence on the performance of free space optical communications, they opined that the bit error rate (BER) deteriorated with higher values of refractive structure index coefficient C_n^2. Also, (Ali, 2016) studied the impact of atmospheric turbulence on the performance of FSO link using L-PPM technique, in their opinion, link distance has an inverse relation with SNR. Furthermore, in 2018, Sawhil and Priyanka studied the effect of atmospheric turbulence and pointing on OOK (on-off keying) in free space optics and concluded that bit error rate is a function of both atmospheric turbulence and pointing error. Alkholidi and Altowij, 2010 studied the effects of clear atmospheric turbulence on quality of free space optical communications in Yemen, the authors focused on the effects of scintillation on the performance of FSO link, they concluded that FSO may be applied in Yemen efficiently under turbulent atmospheric conditions and that using a wavelength of 1550 nm reduce the level of atmospheric turbulence effects on FSO system and that the power allowable is higher compared to smaller wavelengths.

The present paper seeks to statistically analyze the effect of wavelength transmission in free space over Ilorin, Kwara State, Nigeria.

2. METHODOLOGY

2.1. Model Adopted for the Study

Though various empirical models had been developed to estimate the refractive index structure parameter but the Hufnagel Valley Boundary (HVB) model was adopted for the present work because it gives a better result compared with other models (Tyson, 2000) and. Fig. 1 shows the transmitter and receiver for the model selected.

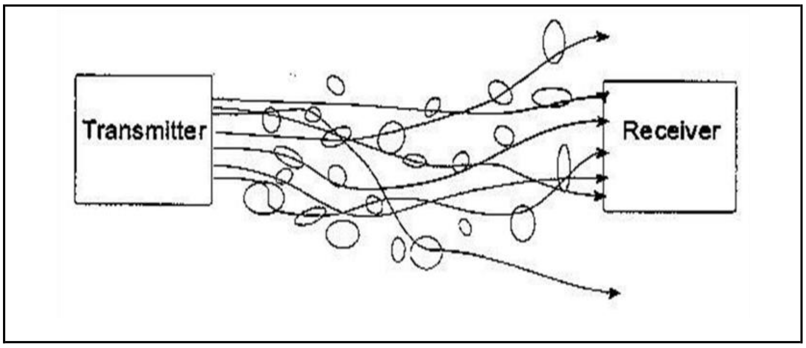

Fig. 1. Atmospheric Transmission Turbulence with Transmission Source (Source: Ali , 2016).

2.2. Formulation of the Governing Equations

A number models have been used to describe the refractive index structure parameter, C_n^2 profile. One of the models that is frequently being used is the Hufnagel-Valley model. It is given by equation (1a) as expressed by (Valley, 1980).

$$C_n^2(h) = 0.00594\left(\frac{v}{27}\right)^2 (10^{-5}h)^{10}\ e^{-\frac{h}{1000}} + 2.7\ \times 10^{-16}e^{-\frac{h}{1500}} + A_o e^{-\frac{h}{100}} \quad \text{1a}$$

Where: A_o is the turbulent strength at the ground level.

$$A_o = \ 1.7 \text{ x } 10^{-14}\ \text{m}^{-2/3} \quad \text{1b}$$

Andrews (2004), defined the measure of scintillation magnitude (Rytov variance) for weak turbulence in the case of plane waves as:

$$\sigma_i^2 = 1.23C_n^2 k^{7/6}L^{11/6} \quad 2$$

Where the optical wave number, k is expressed as:

$$k = \frac{2\pi}{\lambda} \quad 3$$

For a plane wave having weak and symmetrical atmospheric turbulence, the log irradiance variance is given by (Xu et al., 2004).

The log irradiance variance $< \chi >$ is given by:

$$< \chi^2 > = 0.31C_n^2\, k^{7/6}L^{11/6} \quad \text{4a}$$

Similarly

$$< \chi >= \ln(1+\varepsilon) \quad \text{4b}$$

For weak turbulence, ε is very small and equation (4b) becomes (Xu et al., 2004)

$$< \chi > \approx\ \varepsilon \quad \text{4c}$$

Following (Motlagh et al., 2008) and (Zhu and Kahn, 2002):

$$SNR = [< \varepsilon^2 >]^{-1} \quad \text{4d}$$

The signal-to-noise ratio (SNR) which tells the dependability of the link between the transmitter and the receiver is defined as the ratio of the desired signal power to the noise power (Pandey et al., 2013). Based on the approximation made above, from equations (4a, 4c & 4d) SNR according to Ali, 2013 is given as follows:

$$SNR = [< \chi >]^{-1} = \left(0.31C_n^2 k^{\frac{7}{6}}L^{\frac{11}{6}}\right)^{-1} \quad 5$$

2.3. Solution Technique

A yearly average data of wind velocity for the year 2016 over Ilorin, Kwara State, Nigeria was obtained from Nigeria Meteorological Agency (NiMet). This data was used for the estimation of refractive index structure C_n^2. The result was plugged into Rytov variance equation for plane wave (Eq.1) for wavelengths (780, 850, 1250, and 1550) nm, all simulations were run in Matlab.

3. RESULTS AND DISCUSSION

The data was taken from the Nigeria Meteorological Agency (NiMET).The work entails the analysis of these data; the import is to calculate SNR, Rytov variance and log irradiance variance for some selected range of wavelengths. From the results presented in Fig. 2, it can be observed that as the propagation distance increases, Rytov variance also increases. Also at a propagation distance of 1000 m for example, the variance for the wavelength 780 nm is about 0.53146, 850 nm is about 0.50561 dB and 0.35614 dB for the wavelength 1550 nm which implies that, the scintillation attenuation for Rytov approximation at 780 nm is more compared to 1550 nm wavelength. These results reveal that the use of 1550 nm wavelength is capable of reducing the variance, atmospheric turbulence effects on the FSO system.

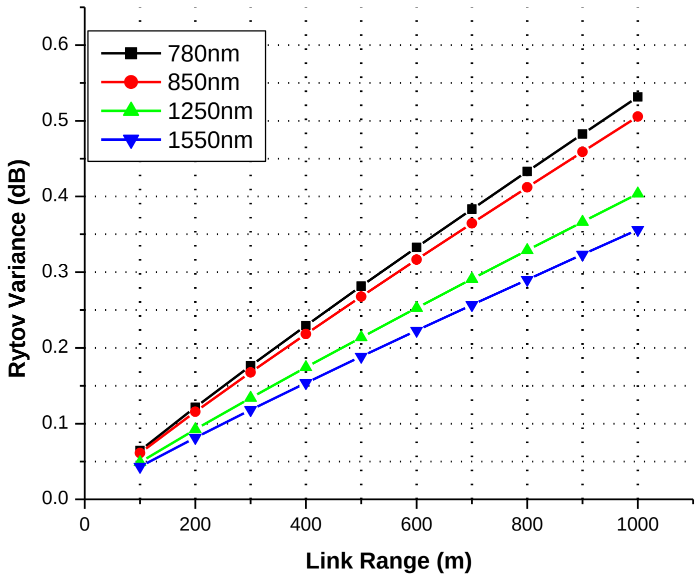

Fig. 2. Rytov Variance versus Link Range for plane waves for varying wavelengths.

Fig. 3 illustrates the log irradiance variance versus the propagation distance for 1550 nm, 1250 nm, 850 nm and 780 nm wavelenghts. As the link range increases, the variance (scintillation) also increases. For a 500 m link range, the variances are about 0.01998, 0.0181, 0.011523 and 0.00897 for wavelengths 780 nm, 850 nm, 1250 nm and 1550 nm respectively.

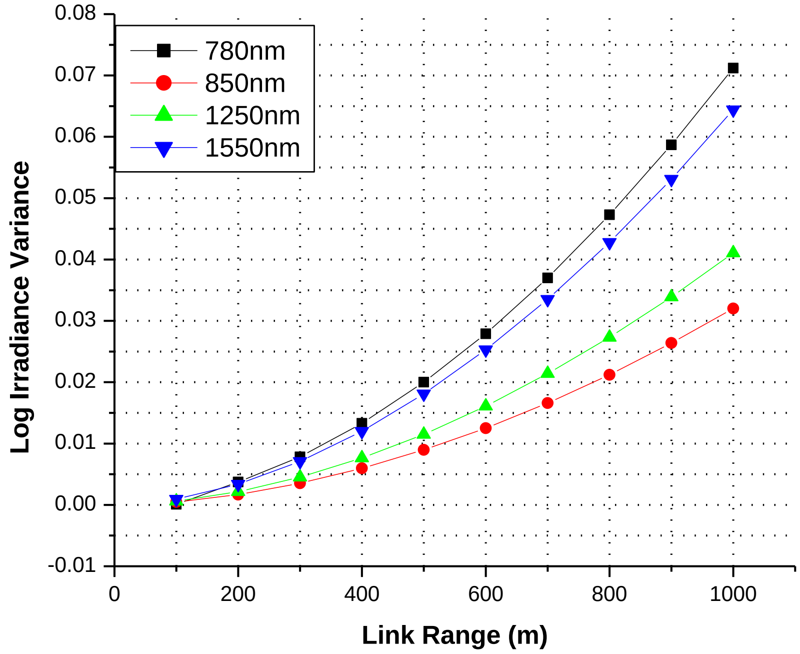

Fig. 3. Variation of Log Irradiance Variance with Link Range for plane wave for different wavelenghts.

Fig. 4 indicates the comparison between the SNR on a propagation distance for varying wavelengths**.** As the link range between the transmitter and receiver increases, the SNR decreases. This implies that link range increment is capable of increasing the quality of transmission and FSO system efficiency. For a 100 m link range, the values of SNR are high while at propagation distances between 800m and 1000m, SNRs values are approximately the same. Meanwhile, the SNR for wavelength 1550 nm is less attenuated (large SNR) compared to the 850nm wavelength.

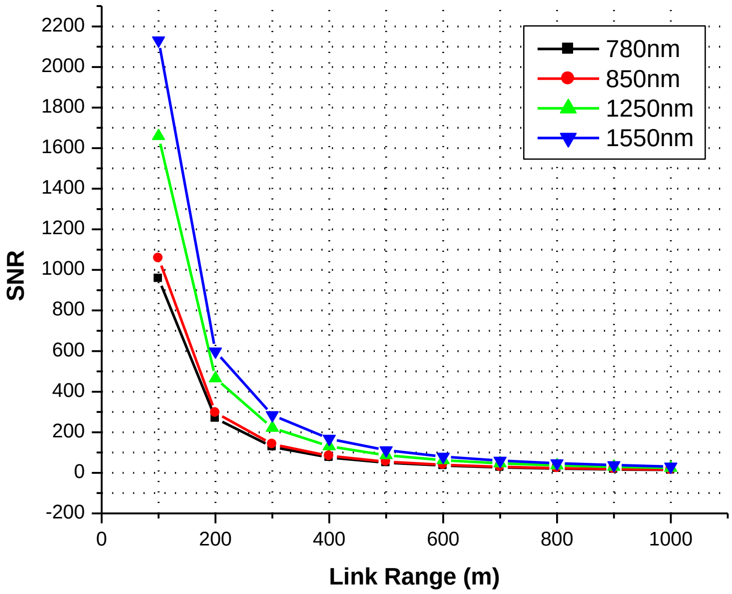

Fig. 4. SNR versus Propagation distance for different wavelengths.

4. CONCLUSION

In this article, the scintillation effects on the performance of FSO system was investigated. The analysis was done for the Rytov variance, log irradiance variance and signal-to-noise ratio. Scintillation for the Ilorin environment is a function of wavelength and distance. It is worthy of note that the wavelength of 1550 nm is less sensitive to atmospheric turbulence and does not pose any treat to the human eye. From the results presented above, to improve the efficiency of transmission of FSO, the wavelength of 1550 nm must be made use and also the distance between the transmitter and the receiver has to be reduced. The results of the present study align with the trend followed by the results of Alkholidi and Altowij, (2012).

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