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EMPIRICAL CHARACTERIZATION AND MODELING OF FADE DEPTH DUE TO MULTIPATH PROPAGATION AT MICROWAVE BAND

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ABSTRACT: In communication system, signal propagates from the base station to the receiver as multitude of partial waves from different directions known as multipath propagation. This effect gives rise to fading of radio signal as the received signal strength decreases. In this work, fade depth, at microwave band signals is estimated and modeled based on the effect of secondary radio parameters such as geoclimatic factor, tropospheric radio reflectivity and refractivity gradient in the year 2017 in Ibadan, south western, Nigeria. The secondary radio parameters were obtained from temperature, relative humidity and atmospheric pressure. The values of point refractivity gradient obtained were used to figure out the geoclimatic factor, *K*. The results obtained shows monthly and seasonal radio refractivity gradient and geoclimatic factor *K* and the results affirmed that the geoclimatic factor *K* is region based. The percentage of time at a given fade depth is exceeded as a single frequency increases rapidly with increasing path length. Based on the geoclimatic factor obtained, the work proposes a general model power1 multipath fading adapted to a link distance at fixed frequency 12.5 GHz and multipath fading model as a function of frequencies at a fixed link distance.

Key words: Fade depth, Frequency, Geoclimatic factor, Link distance, Radio refractivity, Signal strengths.

1.0 INTRODUCTION

In wireless communication, fading is the variation or the attenuation of a signal with various communication variables. These variables include time, geographical position, and radio frequency. Fading is often modeled as a random process. A fading channel is a communication channel that experiences fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, weather (particularly rain), or shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading [1].

The presence of reflectors in the environment surrounding make a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signals, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power captured at the receiver. Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal to noise ratio. Since the atmosphere over the earth is a dynamic medium, its properties changes with primary radio climatic variables such as; temperature, relative humidity and atmospheric pressure. [2][3].

Loss in signal strength due to diffraction fading, fading due to multipath, atmospheric gases and precipitations have their own characteristics as a function of path length, frequency and geographical location [4]. Since fading is also a function of geographical location, hence, there is need to determine fade depth on different environment.

Many scholars have worked on fade depth measurement [5] [6]. This study concentrates attention on estimation of secondary radio climatic variables in Ibadan, south western, Nigeria. The study also discourses the employment of these variables to the design of radio link line-of-sight.

2.0 DETERMINATION OF SECONDARY RADIO CLIMATIC VARIABLES.

The changing in nature of the troposphere causes the refractive index to change with altitude and the refractive index of air, *n*, is measured by refractivity, N, and the two parameters are related as [7]

$$N = (n-1) \times 10^6 \tag{1}$$

The radio refractivity is derived in terms of the primary weather parameters (Temperature, water vapour pressure and atmospheric pressure) using the relation [7] [8]

$$N_{(T,P,e)} = N_{dry} + N_{wet} \tag{2}$$

where

$$N_{dry} = \frac{77.6P}{T} \tag{3}$$

$$N_{wet} = 3.732 \times 10^5 \frac{e}{T^2} \tag{4}$$

$$N_{(T,P,e)} = \frac{77.6P}{T} + 3.732 \times 10^5 \frac{e}{T^2} \tag{5}$$

Equation (5) was used to determine radio refractivity up to the frequencies of 100 GHz with error less than 0.5%. The water vapour pressure, e, is given as

$$e = \frac{H_g e_s}{100} \tag{6}$$

where Hg is the relative humidity, e_s is the saturation vapour pressure (hpa) at a given temperature, T. The e_s in equation (6) is given as

$$e_s = a \exp\left(\frac{bt}{t+c}\right) \tag{7}$$

where a, b and c are constant coefficient with values 6.1121 hpa, 17.502 and 240.97 °C respectively [9][10]

From the equation (5), the radio refractivity, N, is given as [11]

$$N(h) = N_s \exp\left(\frac{-h}{H}\right) \tag{8}$$

where N is the radio refractivity at height, h (km) above the sea level, H is the applicable scale height at average mid-latitude, Ns and H are 315 and 7.35 km respectively. Therefore, N as a function of height is given as [12]

$$N(h) = 315 \exp -0.136h \tag{9}$$

The refractivity gradient, dN/dh is obtained by differentiating equation (8) with respect to height, h.

$$\frac{dN}{dh} = \frac{-N_s}{H} \exp\left(\frac{-h}{H}\right) \tag{10}$$

$$\frac{dN}{dh} = \frac{N_1 - N_2}{h_1 - h_2} \tag{11}$$

N_1 and N_2 are the refractivity at h_1 and h_2 respectively. The point refractivity, dN_1 is obtained from surface refractivity values, Ns and refractivity within 1000 m height above the ground. Since the data at exact heights are not available, the point refractivity gradient, dN_1 is determined using [12] [13][14]

$$dN_1 == \frac{N_s - N_1}{h_s - h_1} \qquad (12)$$

Tropospheric ducting occurs when the waves bend downwards with a curvature greater than that of the earth. The radio energy bent downwards can become trapped between a boundary in the troposphere and very strong signal strength can be obtained at very long range, this signal strength may exceed its free spaced value.

$$Ducting: \frac{dN}{dh} < -157$$

The k-factor can be used to characterize refractive conditions and it is given as [13][14]. . It is worth noting that, the value of k-factor is required in radio connections or link design to estimate the height of antenna needed and diffraction fade estimate.

$$k = \left[1 + \frac{\left(\frac{dN}{dh}\right)}{157}\right]^{-1} \qquad (13)$$

The geoclimatic factor, K which is a measure of the climatic and geographical condition of an area of land or the particular features of it was determined using the procedure given in ITU-R [15].

$$K = 10^{-4.2 - 0.0029 \times dN_1} \qquad (14)$$

2.1 Fade depth calculation

The path inclination, η is obtained based on ITU-R [15] as shown in equation (15)

$$|\eta| = \frac{h_t - h_r}{d} \qquad (15)$$

where h_t is transmitter height, h_r is the height of the receiver and *d* is the distance between the transmitter and the receiver. The percentage of time P_w that fade depth *A* in decibel is exceeded in the average worst month at frequency in GHz with at altitude h_L of the lower antenna is given as

$$P_w = Kd^{3.0}(1 + |\eta|)^{-1.29} 10^{-0.0033F - 0.001h_L - \frac{A}{10}} \qquad (16)$$

3.0 METHODOLOGY AND DATA PROCESSING

Radio-climatic data used in this study was obtained from Nigerian Meteorological Agency (NIMET), recorded over a period of twelve months in Ibadan South western, Nigeria. The raw data has primary parameters of temperature, pressure and relative humidity. Processing the primary data resulted in secondary parameters of: refractivity gradient, k-factor and Geo-climatic factors. From these parameters fade depth and outage probability are estimated using the following procedures; estimation of geoclimatic factor (K), estimating the path inclination (η) and computing the percentage of time that a fade depth (A) is exceeded in the average worst month, P_w.

4.0 RESULTS AND DISCUSSIONS

It was observed that multipath fading depends indirectly on primary atmospheric weather parameters such as temperature, relative humidity and pressure. From the measurement obtained, the mean value of temperature, relative humidity and atmospheric pressure at ground level and at 50 m altitude above the ground level using equation (5) and the radio refractivity was evaluated. Figure 1 shows the variation of average radio refractivity at 50 m for the period of twelve months understudied. Higher values of surface radio refractivity were obtained because it has been generally known that refractivity decreases with height [16]. The higher values of radio refractivity, Ns, were noticed during the wet season (April - September), Ns noticed ranges from 304 to 329 N-unit/km. The peak value (329 N-units/km) was obtained in the month of July, then there was a steady fall in the radio refractivity up till December. Gradual rise in monthly radio refractivity was noted from January, this was attributed to increase in water vapor reaching its highest value in the month of July which is associated with the rainy season.

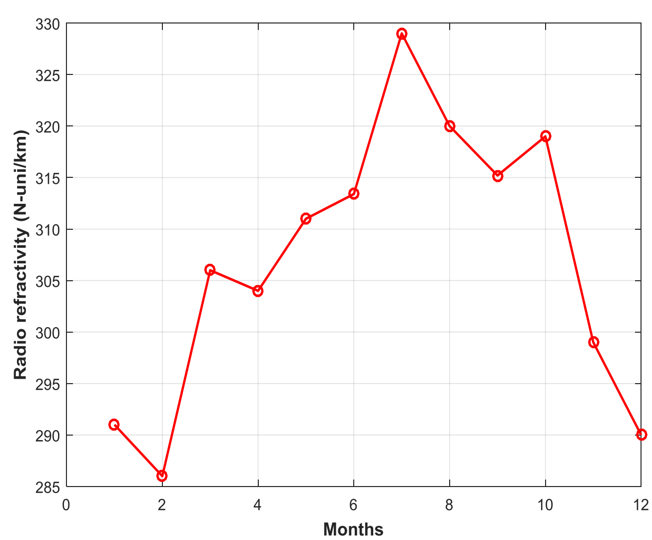

Figure 1: Variation of radio refractivity in Ibadan for 2017

The variations of refractivity gradient dN/dh was found to depend on primary radio climatic variables (temperature, relative humidity and atmospheric pressure), so also the effective earth radius (k-factor) also depends on refractivity gradient as shown by equation (13). Figure 2 shows the graphical representation of k-factor for the year 2017. It was observed that the monthly k-factor was generally high during the wet season, with July having a maximum value of 1.89. The months of October, November, December, January and February shows the reduced values of k-factor with the lowest value (1.22) observed during the month of January which corresponds to dry season. The average value of monthly k-factor computed for the year was 1.49; this value is greater than ITU-R recommended value, 1.33. Hence, the value of k-factor obtained in this region should be used to compute the value of transmitter and receiver height required for clear line-of-sight (LOS). It was also observed that, the behavior of the k-factor is relatively similar to that of the surface refractivity in that it exhibited a maximum value at the month of July in 2017 and also showed a minimum at the months of January and February.

The geo-climatic factor, K, for the average worst month was estimated from fading data for Ibadan south western, Nigeria using the link equation (14). The months of June, July, August, September and October have the higher K-factor but the highest was experienced in the month of July. It was also noticed that multipath fading is a random phenomenon. Equation (16) was used to predict the percentage of time that fade depth, A, in decibel, which exceeded in the average worst month (July). The values of K-factor was also used for prediction of the percentage of time, Pw, that fade depth, A, is exceeded using a transmitter height 105 m and receiver height 52 m. The link distance between the transmitter and receiver was 2 km.

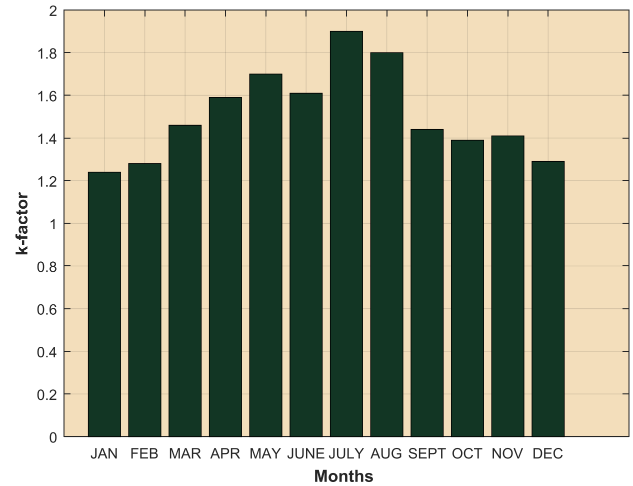

Figure 2: Monthly variation of effective earth radius (k-factor)

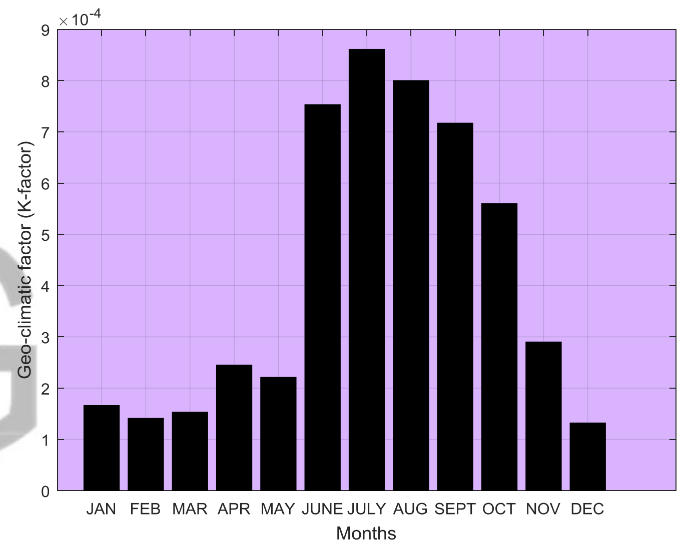

Figure 3:Monthly variations of Geoclimatic factor (K-factor)

Figure 4 shows the variation of fade depth (in log scale) exceeded for 0.01% of the time with link distance at a fixed frequency (12.5 GHz). It was discovered that, the fade depth increases with increasing link distance, longer link distance suffered higher fade depth because as the link distance increases, multipath fading is more articulated due to multiple reflections and diffraction which leads to multipath of radio signal. With varying frequency at a fixed link distance, the fade depth (dB) increases with frequency as shown in figure 5. It was noted that, higher frequency suffered more fade while the lower frequency experienced a low fade. Equations (17) and (18) show the models developed for the fade depth variations with link distance and frequency respectively

$$A_{(d)} = 3.871\, ln\, (d^{0.7272}) \qquad (17)$$

$$A_{(f)} = 34.43\, ln\, (f^{0.1428}) \qquad (18)$$

where *d* is the link distance and *f* is the frequency in GHz. Table 1 shows the statistical analysis of the fade depth obtained with link distance and frequency.

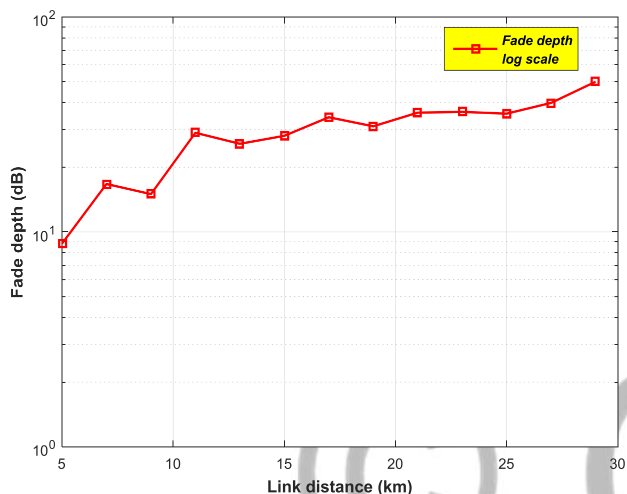

Figure 4: Variation of fade depth exceeded for 0.01 % of the time with link distance

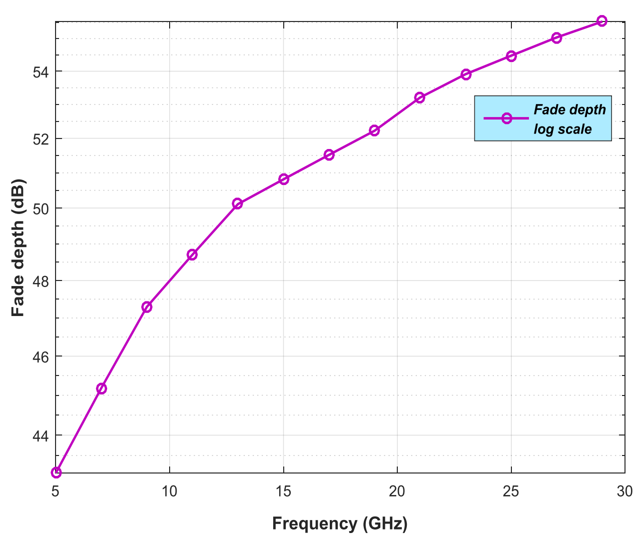

Figure 5: Variation of fade depth exceeded for 0.01 % of the time with frequency

Table 1: Statistical analysis of fade depth as a function of link distance and frequency

Statistical parameter	Fade depth as a function frequency	Fade depth as a function link distance
Model type	General model Power1	General model Power1
Developed model	$A_{(f)} = 34.43\, ln\, (f^{0.1428})$	$A_{(d)} = 3.871\, ln\, (d^{0.7272})$
Goodness of fit	95% confidence bound.	95% confidence bound.
SSE	0.5209	155.10
R^2	0.9971	0.8960
Adjusted R^2	0.9968	0.8865
RMSE	0.2176	3.7555

5.0 CONCLUSION

In this work, the values of point refractivity gradient obtained has been used to figure out the geo-climatic factor, *K* in Ibadan, South western, Nigeria. The results obtained shows monthly and seasonal radio refractivity gradient and geo-climatic factor *K* and the results affirmed that the geo-climatic factor *K* is region based. The percentage of time at a given fade depth was exceeded for a single frequency, as it increases rapidly with increasing path length. Based on the effective earth radius and geo-climatic factor obtained, the work proposes a general model power1 multipath fading adapted to a link distance at fixed frequency 12.5 GHz and multipath fading model as a function of frequencies at a fixed link distance. The work also shows that, the effect of multipath fading can be tackled by using diversity to transmit the signal over multiple channels that experience independent fading and coherently combining them at the receiver. The probability of experiencing a fade in this composite channel is then proportional to the probability that all the component channels simultaneously experience a fade.

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