International Journal of Information and Communication Sciences
2016; 1(3): 59-62
http://www.sciencepublishinggroup.com/j/ijics
doi: 10.11648/j.ijics.20160103.15

Determination and Comparative Analysis of Refractivity Profile and Fade Depth for Microwave Links in Lagos

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To cite this article:
Udofia Kufre. M., Ogungbemi Emmanuel Oluropo, Etokebe Iniobong Jackson. Determination and Comparative Analysis of Refractivity Profile and Fade Depth for Microwave Links in Lagos. *International Journal of Information and Communication Sciences.* Vol. 1, No. 3, 2016, pp. 59-62. doi: 10.11648/j.ijics.20160103.15

Received: October 17, 2016; **Accepted**: December 28, 2016; **Published**: January 16, 2017

Abstract: The concept of radio link design and planning remain very vital to a radio link engineer and so the need to have a clear information outlook of the refractivity profile and fade depth of that location. In this study, radiosonde data from 2012 to 2014 was used to estimate the point refractivity gradient and fade depth for Lagos located 6.4531° N, 3.3958°E South West of Nigeria. The refractivity gradient for Lagos from the distribution table showed the highest occurrence in December with dN1 of -56.4268.1N units and February with the lowest dN1 having -398.5034N units while the fade depth for the different models also showed monthly and seasonal variations, with fade depth of 142.03 dB for the ITU-R P.530-9 model, 132.051 dB for the ITU-R P.530-14 model and 156.861 dB for the ITU-R P.530-16 model.

Keywords: Refractivity, Refractivity Index, Refractivity Gradient, Fade Depth, Radiosonde Data, Geoclimatic Factor

1. Introduction

According to research findings, microwave radio propagation is in greater extent affected by meteorological and terrain conditions [1, 2, 3]. Particularly, the refractive index of the atmosphere which is the key medium of propagation varies with atmospheric height [4, 5] The the refractive index affects the magnitude of the multipath fade depth that microwave signal can experience in a given terrain [6, 7]. Also, terrain elevation profiles and other site specific feature affect the multipath fade depth. Consequently, radio communication equipment designed specifically for the tropic region may not be suitable for the temperate region due to the significant disparity in the characteristics of the troposphere which is the medium of propagation. [8]. It is therefore important to have a good understanding of the atmospheric variation in refractive index especially in the aspect of equipment design and usage during radio propagation planning.

Notably, available data for multipath fading is usually based on data obtained from coastal areas because the effects occur predominantly in higher humid areas. This might not be entirely true since tropospheric refractive index has a distinct dependence on variations on weather parameters, namely; air temperature, air pressure and relative humidity [9]. Moreover, spatial distribution of the refractive index of the air, especially its vertical profiles, affects the propagation of electromagnetic waves in the atmosphere [10]. Consequently, in this study, radiosonde atmospheric parameter data from 2012 to 2014 are used to estimate the point refractivity gradient and fade depth for Lagos located 6.4531° N, 3.3958°E South West of Nigeria.

2. Theory

The determination of refractivity gradient is very important in estimating some key link parameters that are useful in the prediction of microwave link coverage and performances. Consequently, International Telecommunication Union (ITU) has outlined in their recommendation; Rec. ITU-R F 1093-1, the various methods used to calculate outage probabilities such as [11];

i. Ray models (multiple echo model, general three ray model, etc
ii. Polynomial models in the frequency domain (complex polynomials, real polynomials of amplitude and group delay)
iii. Parametric models (two point method with fixed frequency spacing

The impact of this kind of multipath on terrestrial point-to-point microwave links was studied by Bell laboratories in the 1960s and 1970s [6]. Over the years, different models have been developed for predicting the multiple propagation effects on terrestrial links. Some of the multiple propagation models are Morita model used in Japan, Barnett-Vigant models widely used in the United States, Sogal model used in Canada and ITU-R models used worldwide [12]. The ITU-R model has over the years gone through several evaluations which have brought continuous improvement in the propagating prediction model. The ITU-R model considers the analysis of the atmospheric refractivity index in clear air in order to predict outage probability. The radio refractivity index is the ratio of velocity in a specified medium to the velocity in free space [5, 13]. At standard atmospheric environments, close to the earth's surface, the radio refractivity index, n, has a value of about 1.000312. Its value is always greater than unity but by a small fraction [14]. However, a more convenient parameter, the atmospheric refractivity, N (N-units) is usually applied, and it can be determined using the following expression [15].

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

If the value of ground refractivity index is substituted into equation 1, then the atmospheric refractivity value of 312 (N-unit) is obtained. The International Telecommunication Union Recommendation ITU-R P.453-11 outlines a general model to obtain the atmospheric refractivity along with atmospheric water vapour pressure as follows [11]:

$$\mathrm{N} = \frac{77.6}{\mathrm{T}}\left(\mathrm{p} + 4810\left(\frac{\mathrm{e}}{\mathrm{T}}\right)\right) \tag{2}$$

$$\mathrm{e} = \frac{6.112\,\mathrm{H}}{100}\exp\left(\frac{17.5\,\mathrm{t}}{\mathrm{t}+240.98}\right) \tag{3}$$

where: T is the absolute temperature
p is the atmospheric pressure
e is the water vapour pressure
H is the relative humidity
t is the atmospheric temperature (Celsius)

The refractivity changes with height and so refractivity gradient, specifies how radio refractivity index varies with height in the atmosphere. Refractivity gradient in the lowest 65m from ground is computed as follows [1, 5, 16,17]:

$$\mathrm{dN_1} = \left(\frac{\mathrm{N_2}-\mathrm{N_1}}{\mathrm{h_2}-\mathrm{h_1}}\right) \tag{4}$$

Where N_2 is the refractivity at 65m
N_1 is the refractivity at ground level
h_2 = 65m
h_1 = ground level

3. Methodology

In this work, three years (from 2012 to 2014) radiosonde data on air temperature, air pressure and relative humidity are obtained from the Nigerian Meteorological Agency (NIMET). The radiosonde data are obtained in clear air (that is, in the absence of rain, fog or snow) at every six (6) seconds from ground level to eight hundred metres (800m) in altitude. The measurements are taken in Lagos located at 6.4531° N, 3.3958°E South West of Nigeria. At each altitude level, the monthly mean refractivity value is computed using the measured atmospheric parameters (i.e. temperature, pressure and relative humidity) [17]. For those altitudes and corresponding parameters not fully captured, the inverse distance weighting interpolation technique is used to estimate the missing data. Equation 3 and then equation 2 are used to compute the atmospheric water vapour pressure and the refractivity (N) respectively. Then, equation 4 is used to determine the point refractivity gradient ($\mathrm{dN_1}$). Next, the geoclimatic factor is then determined for each of the three ITU multipath fade models considered. For for quick planning applications in the ITU-R P.530-16 model, the geoclimatic factor, K given as [11]

$$K = 10^{(-4.6-0.0027dN_1)} \tag{5}$$

where, f is frequency in GHz, h_L is altitude of the lower antenna (i.e. the smaller of h_e and h_r).

Also, the percentage of time p_w that fade depth A (dB) is exceeded in the average worst month can be estimated as follows in the detailed design applications using ITU-R P.530-16 model [11];

$$P_w = K(d^{3.4})\left(1 + |\varepsilon_p|\right)^{-1.03}(f^{0.8})10^{\left(-0.0076h_L-\left(\frac{A}{10}\right)\right)}\ \% \tag{6}$$

K is given in equation (5).

Also, the percentage of time p_w that fade depth A (dB) is exceeded in the average worst month can be estimated as follows for the detailed design applications using ITU-R P.530-14 model [11]:

$$P_w = K(d^{3.0})\left(1 + |\varepsilon_p|\right)^{-1.2}10^{\left(0.033f-0.001h_L-\frac{A}{10}\right)}\% \tag{7}$$

K is also given in equation (5).

Likewise, for quick planning applications in the ITU-R P.530-9, the geoclimatic factor, K is given as [11]:

$$K = 10^{(-4.2-0.0029dN_1)} \tag{8}$$

Once more, the percentage of time p_w that fade depth A (dB) is exceeded in the average worst month can be estimated as follows for detailed design applications using ITU-R P.530-9 model [11]:

$$P_w = K(d^{3.2})\left(1 + |\varepsilon_p|\right)^{-0.97}10^{\left(0.032f-0.0085h_L-\frac{A}{10}\right)}\ \% \tag{9}$$

In this case, K is given in equation (8).

The magnitude of the path inclination $|\varepsilon_p|$ (mrad) is calculated as follows:

$$|\varepsilon_p| = \frac{(h_r - h_e)}{d} \tag{10}$$

where d is the path length (km), h_e is the transmitter antenna height and h_r is the receiver antenna height;

4. Results and Discussion

In respect of ITU-R P.530-9 model in Table 1, the least fade depth occurrence is observed in June with a value of 138.325dB while the highest occurrence takes place in August with a value of 146.209dB. The fade depth becomes relatively high in the months of November, December, January and February.

Again for the ITU-R P.530-14 model in Table 1, the month of June has the least fade depth with a value of 128.371dB and the highest fade depth in August with a value of 135.955dB. Similarly, in the ITU-R P 530-16 model, June with fade depth of 153.1560dB has the least fade occurrence and August with fade depth of 161.04dB has the highest fade occurrence.

The refractivity gradient for Lagos from the distribution table shows the highest occurrence in December with values of -56.4268.1 Nunits and February dN1 values of -98.5034N units has the has the lowest refractivity gradient. The Yearly average refractivity gradient for Lagos is -210.11 Nunits.

Table 1. *Shows fade depth and refractivity gradient for different months in Lagos.*

	ITU-R P.530-9 (dB)	ITU-R P.530-14 (dB)	ITU-R P.530-16 (dB)	DN
Jan	144.345	134.391	159.176	-275.86
Feb	144.417	134.463	159.248	-398.5
Mar	145.362	135.408	160.193	-313.51
Apr	139.592	129.639	154.423	-99.823
May	139.318	129.364	154.149	-89.656
Jun	138.325	128.371	153.156	-172.88
Jul	141.174	131.221	156.006	-158.42
Aug	146.209	135.955	161.04	-344.88
Sep	143.102	133.148	157.933	-229.81
Oct	140.515	130.561	155.346	-134
Nov	143.581	133.628	158.413	-247.57
Dec	138.421	128.467	153.252	-56.427
Yearly Average	142.03	132.051	156.861	-210.11

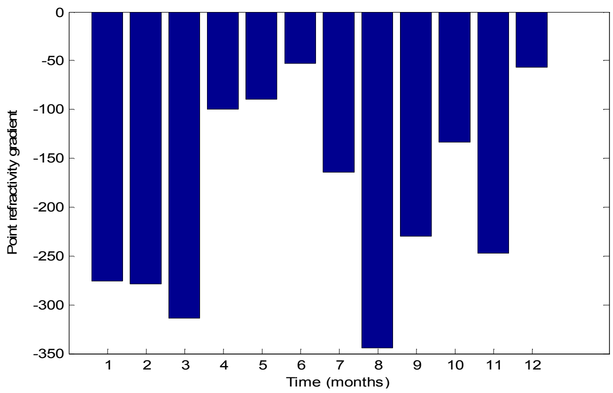

Figure 1. *Shows refractivity gradient for different months in Lagos.*

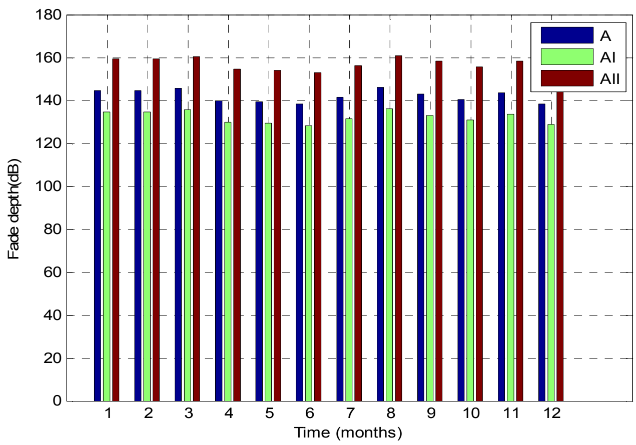

Figure 2. *Shows fade depth for different months in Lagos.*

5. Conclusion

In this paper, local radiosonde data made available by Nigerian Meteorological Agency have been used to calculate the point refractive gradient and fade depth in Lagos for the period between 2012 and 2014. Three versions of ITU models, namely; ITU-R P.530-9 model, ITU-R P.530-14 model and ITU-R P.530-16 model are used to compute the fade depth. In all models, the least fade depth occurred in the month of June whereas the highest fade depth occurred in the month of August. Similarly, the highest refractivity gradient occurred in December whereas the least refractivity gradient occurred in February.

Acknowledgement

The authors would like to express their heartfelt gratitude to Nigerian Meteorological Agency for providing meteorological data used for this work.

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