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Characteristics of VHF Line-Of-Sight Propagation for Point-To-Area Network in A Tropical Atmosphere

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Abstract: This paper investigates the degree of influence of weather and the environment on radio signal propagation between a Very High Frequency (VHF) band transmitter and a receiver in the North Central region of Nigeria. Signal strength measurements were made from a Frequency Modulation (FM) station broadcasting at 100.5 MHz using a digital signal level meter. The results obtained showed that received signal strength (RSS) values were higher during the wet season with average values ranging between 41 dBµV and 50 dBµV as compared to lower values of between 36 dBµV and 48 dBµV recorded during the dry season. The computed radio refractivity revealed similar trend of low dry season values in the range of 291 N-units to 345 N-units and high wet season values ranging between 350 N-units and 363 N-units. Also, the cumulative frequency distribution of the signal level computed showed that 50 dBµV had the highest number of samples, while 60 dBµV and 70 dBµV recorded the lowest number of samples. In addition, dry season values of attenuation deduced ranged between 1.6 dB and 2.8 dB, while average wet season attenuation values vary from 1.4 dB to 2.3 dB. Finally, the RSS was modeled using ITU-R P.526-12 to predict losses due to diffraction over the earth's curvature, and the results obtained revealed that the model underestimated the RSS for the radio link.

Keywords: Diffraction model, radio refractivity, received signal strength, VHF band

1. Introduction

The major determinant factor for the propagation of VHF and HF (Higher Frequency) radiowaves in the troposphere is weather. This is because the various components that make up weather interfere with Radio Frequencies (RF) in one way or the other (Zhenzhong et al., 2011; Luomala & Hakala, 2015; Segun et al., 2015; Amajama et al., 2016; Suleman et al., 2017). Factors such as reflection, scattering, absorption and diffraction are responsible for the attenuation of these RF signals during propagation from one point to another (Gomes et al., 2018). Although data collected on a radio path during a given period of time may be very different from data collected over a similar path at the same time interval, it is a known fact that when such data are collected over longer periods, they give general statistics that assist radio engineers in designing excellent systems with almost zero interference. For this to be achieved, it is necessary to apply statistical data with an understanding of how they were derived and a good assessment of the influences of various meteorological and terrain conditions on radiowaves (Hall, 1979).

Weather conditions have significant effects on radio wave propagation in the atmosphere because variations of meteorological parameters of pressure, temperature and water vapour result to variation in the radio refractive index, which in turn is responsible for the refraction and scattering of electromagnetic waves propagating through the troposphere (Adediji & Ajewole, 2010). Hence, the strength of radio signals at VHF and HF bands generally varies in the troposphere and these variations show diurnal, seasonal and climatic trends. Also, it is not possible to install a

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communication link without encountering interference from the environment. Obstacles such as hills or large buildings obstruct part of the field from the transmitting antenna, thereby restricting its arrival at the receiving terminal.

A radio broadcast service is usually planned at the VHF band so that a satisfactory service would be provided within a defined coverage zone. Such intended coverage zone might be a town and its immediate surroundings. A service that is termed 'satisfactory' may be defined by specifying the received field strength to be equal to or greater than a certain value at a given percentage of locations within the intended coverage area and for a specified percentage of time. The service area of an FM station, from the transmitter to the receiver, depends on space wave propagation. Space waves are reflected off, and diffracted around mountains, buildings and other objects as they propagate through the atmosphere. Areas with unobstructed line-of-sight signals from transmitter to receiver have very reliable and predictable propagation but when obstructions lie along the path, the FM signal strength is attenuated below the expected level that would exist for a line-of-sight path of the same distance. By using simple physical models based on diffraction theory, the amount of attenuation can be calculated (Anderson, 2014; Aboaba, 2015).

Although propagation curves and models are very useful in estimating the extent of nominal coverage of VHF-FM and Television (TV) services and also calculating the likely effects of potential sources of interference, some limitations still exist in the tropics because the propagation curves used here were developed from statistical analyses of experimental data from temperate climates. So, significant variations between predicted and actual field strength values arise from time to time and from location to location. Also, allocation and deployment of frequencies for national and international communication services have always depended on local propagation characteristics provided by various countries. The current trends in information and communication technology, and the increasing need for every country to be a part of the evolving global village has made this situation become very vital (Oyedum, 2005). In addition, there is need for continuous upgrade of received signal strength prediction models and simplification of link design procedures to enhance optimisation of performance predictions, minimisation of interference problems and more reliable communication circuits. In particular, it is important to have local propagation data for terrestrial links to enhance preliminary design of such links in most tropical regions. Hence, the need for the present study at various local levels.

2. Background

2.1 Free Space Propagation

In order to assess and compare radio wave propagation under different conditions, it is simpler to establish a reference standard. The theoretically calculated free space loss for propagating waves between two idealised antennas is conventionally considered as a standard. The easiest case to examine this is the emitted radiation from an isotropic source, that is, an ideal antenna that radiates energy with uniform intensity in all directions. The intensity of the energy is inversely proportional to the squared distance from the source (the inverse square law).

The power flux per unit area P_a (W/m^2) at a distance r (m) from a loss free isotropic antenna radiating a power P_T (W) is given by (Freeman, 1997):

$$P_a = {}^{P_T}/_{4\pi r^2} \qquad (1)$$

where $4\pi r^2$ is the surface area of a sphere at a distance d (m) from the source.
The power at the receiver is given by:

$$P_R = P_T \left(\frac{\lambda}{4\pi r^2}\right)^2 \qquad (2)$$

The free space loss, L_{FSL} between a transmitting and a receiving antenna is defined by:

$$L_{FSL}(dB) = 10Log(\frac{P_T}{P_R}) \qquad (3)$$

Combining equations (2) and (3), the free space loss is given as:

$$L_{FSL}(dB) = 20Log(\frac{4\pi r}{\lambda}) \qquad (4)$$

Equation (4) is restated more conveniently as

$$L_{FSL}(dB) = 32.45 + 20Log(r_{km}) + 20Log(F_{MHz}) \qquad (5)$$

Or as (ITU-R, 2009):

$$L_{FSL}(dB) = 139.3 - E + 20Log(F_{MHz}) \qquad (6)$$

and the free space field strength, E_{FS} for 1 kW e.r.p (effective radiative power) is given by:

$$E_{FS}(dB\mu V/m) = 106.9 - 20Log(r_{km}) \quad (7)$$

For a non free-space environment, the field strength can be related to the basic free space loss by (Barringer and Springer, 1999):

$$L_{FSL}(dB) = 137 + 20Log(F_{MHz}) + P_T + G_T - E(dB\mu V/m) \quad (8)$$

Also, the field strength can be expressed as a function of received voltage, received antenna gain and frequency when applied to an antenna whose impedance is 50 Ohms. This is given as:

$$E(dB\mu V/m) = E(dB\mu V) - G_r(dBi) + 20Log(F_{MHz}) - 29.8 \quad (9)$$

For received voltage calculation, this equation becomes:

$$E(dB\mu V) = E(dB\mu V/m) + G_r(dBi) - 20Log(F_{MHz}) + 29.8 \quad (10)$$

where G_r is the isotropic gain of the receiving antenna.

2.2 Attenuation of Radio Signals

Attenuation is directly proportional to frequency. That means the higher the frequency, the higher the attenuation and the lower the frequency, the lesser the effect of attenuation. Some attenuation (signal loss) occur in the transmitter as well as in the receiver block but the major attenuation occurs in the transmission medium, between the transmitting and receiving antennas of two stations (Gurung & Zhao, 2011). The attenuation equation is given as:

$$A_{dB} = 10Log\frac{P_{out}}{P_{in}} \quad (11)$$

where P_{out} and P_{in} are the power at the transmitter and receiver respectively.

2.3 Refractivity Effects

The radio refractive index, n, of a parcel of air is defined as the ratio of the propagation velocity of an electromagnetic radiation in vacuum to that in air. At the earth surface, radio refractive index is usually between 1.00025 and 1.00035. In order to have an easier number to handle, the radio refractivity, N is defined by Smith and Weintraub (1953) as:

$$N = (n-1)\, X\, 10^6 \quad (12)$$

N is generally given by:

$$N = \frac{77.6}{T}\left(P + \frac{4810e}{T}\right) \quad (13)$$

where P is the atmospheric pressure in hectoPascal (hPa), e is the water vapour pressure in mb and T is the absolute temperature in Kelvin. Equation (13) is rewritten as:

$$N = \frac{77.6P}{T} + \frac{3.73\ x\ 10^5 e}{T^2} \quad (14)$$

where the first and second terms represent the dry (N_{dry}) and wet (N_{wet}) components of refractivity respectively. The dry term contributes about 70% to the total value of N, while the wet term is responsible for a major part of the variation in N at a given location in the atmosphere.

The vapour pressure, e is calculated from (Hall, 1979):

$$e = (R.H\ x\ e_s)/100 \quad (15)$$

where $R.H$ is the relative humidity and e_s is the saturated vapour pressure. e_s is calculated from:

$$e_S = 6.11\ exp\ [(19.7t)/(t+273)] \quad (16)$$

t is the temperature in ^oC.

2.4 Analysis of Field Strength Model using Diffraction Formula

The diffraction field strength, E, relative to the free-space field strength, E_o, is given by (ITU-R, 2012):

$$20\ log\frac{E}{E_0} = F(X) + G(Y_1) + G(Y_2)\ dB \tag{17}$$

where X is the normalised length of the path between the antennas at normalised heights Y_1 and Y_2 (and where $20\ log\frac{E}{E_0}$ is generally negative). The remaining steps of the modeling is outlined in recommendation ITU-R P. 526.

3. Materials and Methods

3.1 Measurement of Signal Strength

The signal strength was measured from a transmitting FM station (Power FM) broadcasting at a frequency of 100.5 MHz and at 8.5 kW power. It is located at Bida town, at a distance of approximately 83 km from the receiver which is situated at the Mini Campus (Bosso) of Federal University of Technology, Minna, Nigeria. The measurements were carried out during three dry season months (January-March) and three wet season months (May-July).

Geberit digital signal level meter, GE-5499 was used to measure the received signal strength (RSS). Its measurement properties are: frequency range of 45 MHz - 860 MHz, bandwidth > 300 kHz, signal strength range of 30-120 dBμV, resolution of 0.1 dBμV and accuracy level of ±1. Fig. 1 shows the Geberit digital signal meter with antenna.

(a) (b)

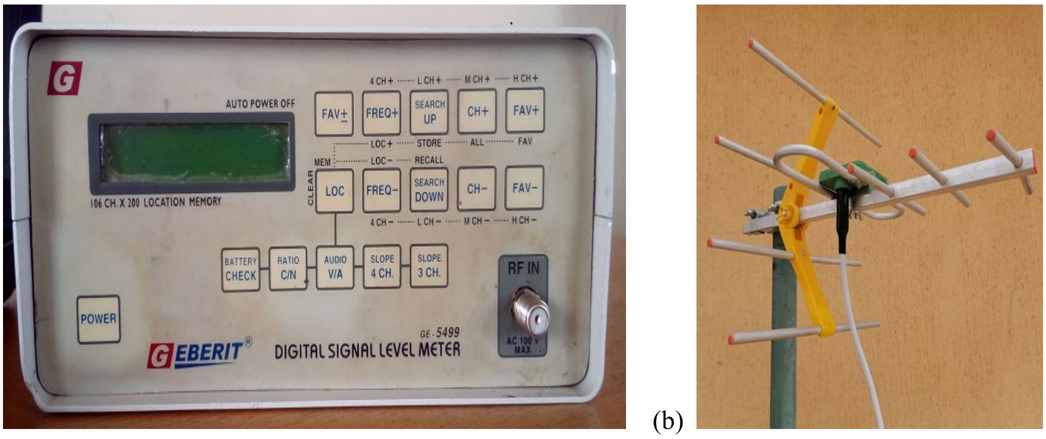


Fig. 1 - (a) Geberit digital signal meter; (b) antenna

3.2 Measurement of Atmospheric Parameters

The meteorological variables of temperature, pressure, relative humidity, rainfall, wind speed and wind direction were measured at 5-minutes intervals at the Tropospheric Data Acquisition Network (TRODAN) situated in Federal University of Technology, Bosso Campus, Minna (Fig. 2). The instrument employed for these measurements is the Campbell CR-1000 data logger.

Fig. 2 - TRODAN weather station with Campbell CR-1000 data logger inset

Fig. 3 shows the map of the transmitting station and the measurement site.

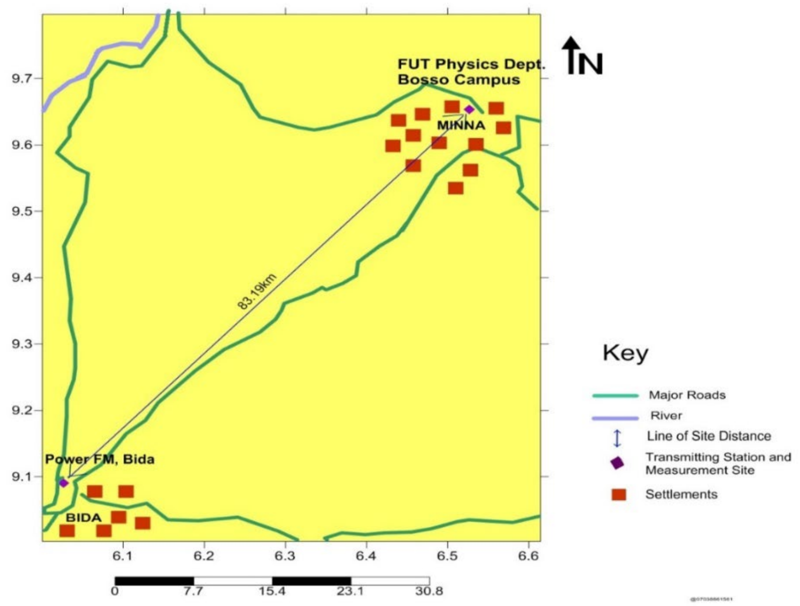


Fig. 3 - Map of transmitting station and measurement site

The signal strength from the broadcasting station was measured and logged simultaneously during broadcast periods at one-hour interval using the Geberit digital signal level meter. The measured signal strength, received as values of voltages were converted to values of electric field strength using equation (9). The converted electric field strength values were modeled using diffraction formulae according to ITU-R recommendation P. 526. The block diagram showing the stage-by-stage implementation of this phase of research is shown in Fig. 4.

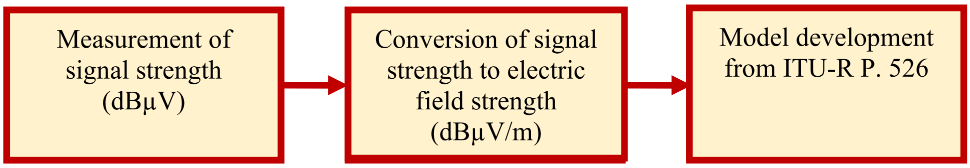


Fig. 4 - Block diagram of model development of electric field strength

Considering the fact that there is need to provide information for calculating field strength over diffraction paths, the ITU-R P. 526 recommendation presents different models that are applicable to different obstacle types and to various path geometries, so as to evaluate the effect of diffraction on the received field strength. The degree of terrain irregularity was defined using ITU-R recommendation P. 310-9 (ITU-R, 1994). After careful analysis of the parameters used, a 'smooth terrain' was considered appropriate for the links used in this work; thus, the prediction model adopted was based on diffraction over spherical earth. Hence, the method of numerical calculation as outlined in the model was adopted, which involves calculating a normalised factor for surface admittance and determining the extent to which the electrical characteristics of the earth's surface influence the diffraction loss. The flow chart used in the modelling of the received field strength is given in Fig. 5. The flow diagram is a general guide provided by ITU-R P.526 for the evaluation of diffraction loss.

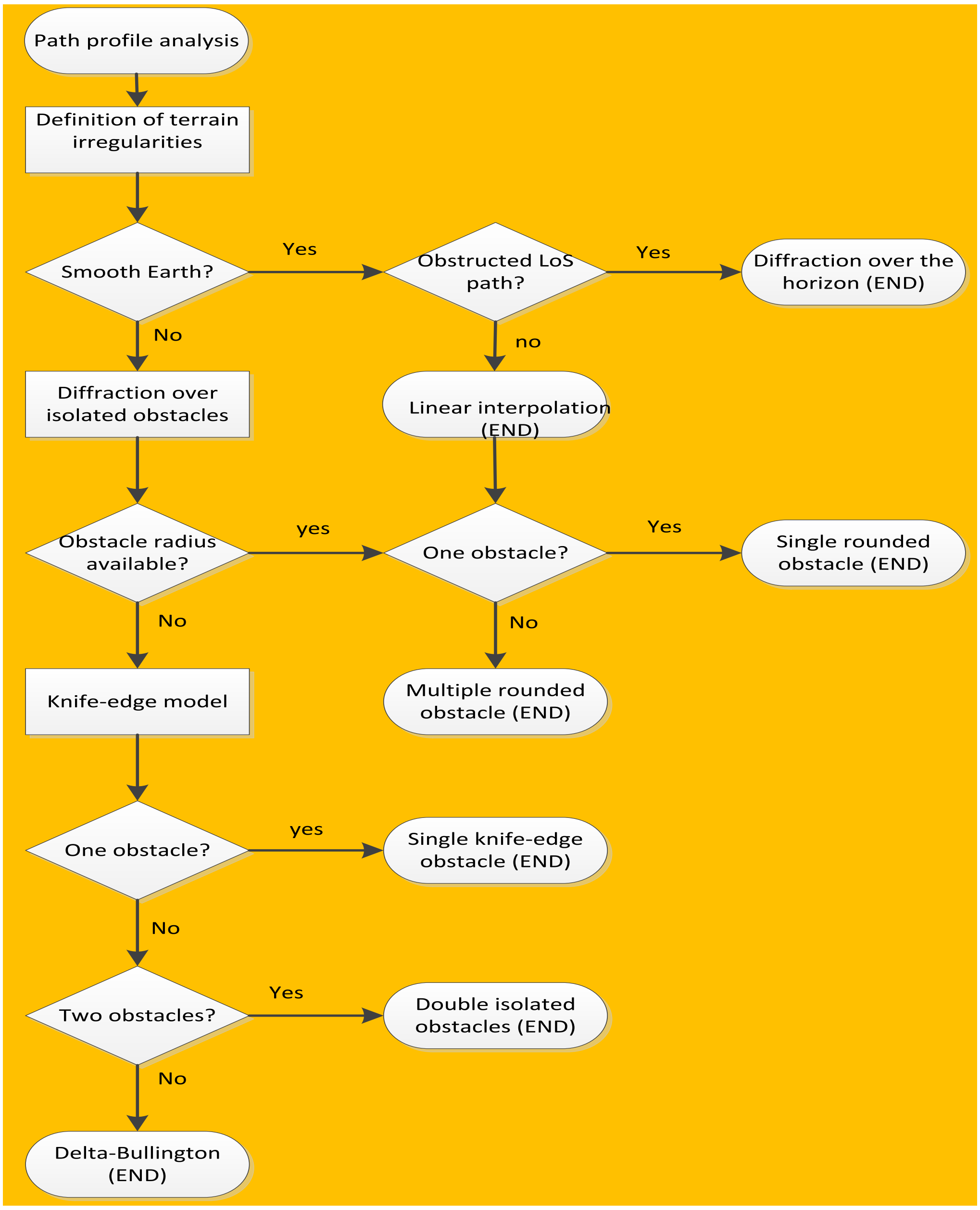


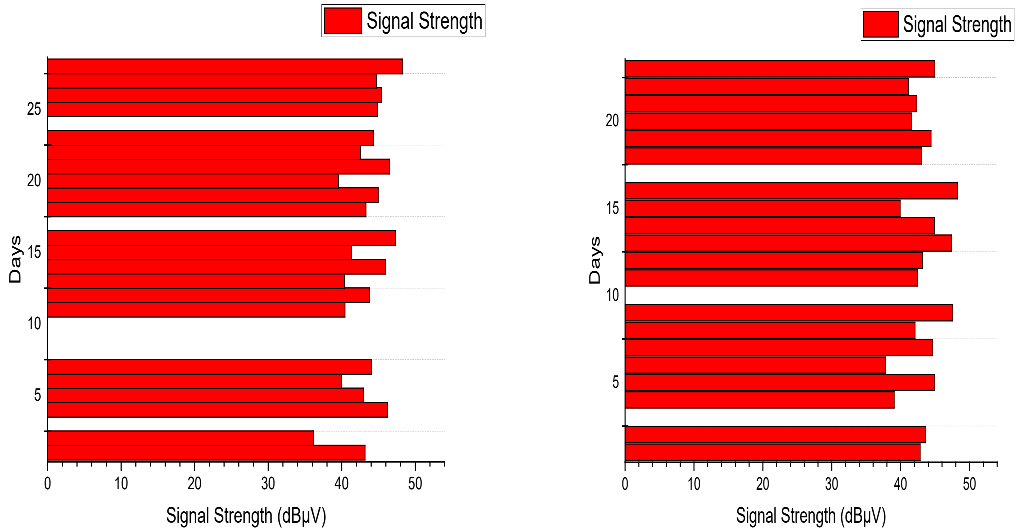
Fig. 5 - Guide to propagation by diffraction (ITU-R, 2012)

4. Results and Discussion

The signal level measured along the link was recorded and analysed over a period of six (6) months. The mean signal levels for each month were then determined. These are the non-rainy signals also referred to as clear-air and the rainy signals.

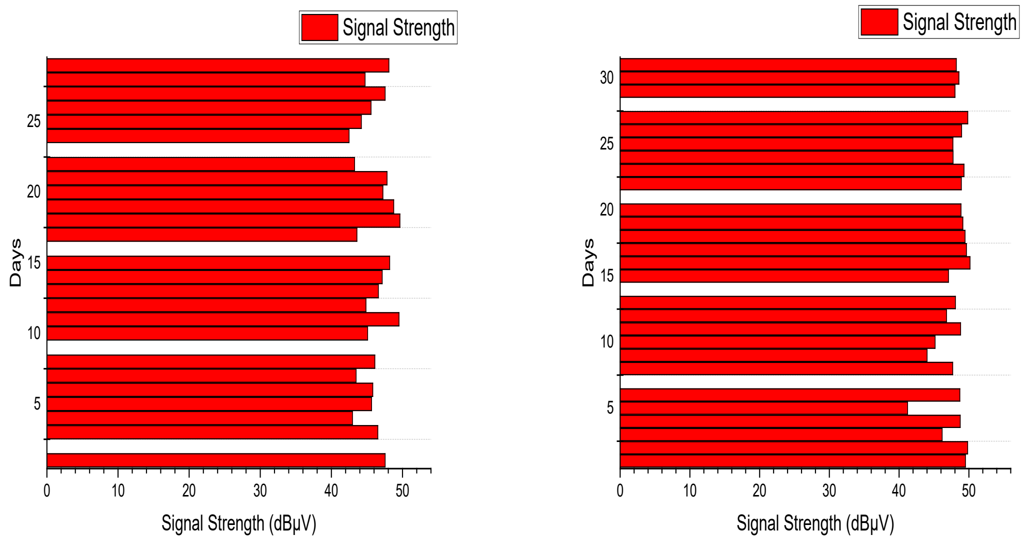
4.1 Seasonal Variation of Received Signal Strength

Fig. 6 and 7 show the mean monthly variation of signal strength for two typical dry months (February and March) and two typical wet months (June and July) respectively. Table 1 also depicts the seasonal signal level range for the VHF link.



(a) February (b) March

Fig. 6 - Mean daily signal strength variation for dry months



(c) June (d) July

Fig. 7 - Mean daily signal strength variation for wet months

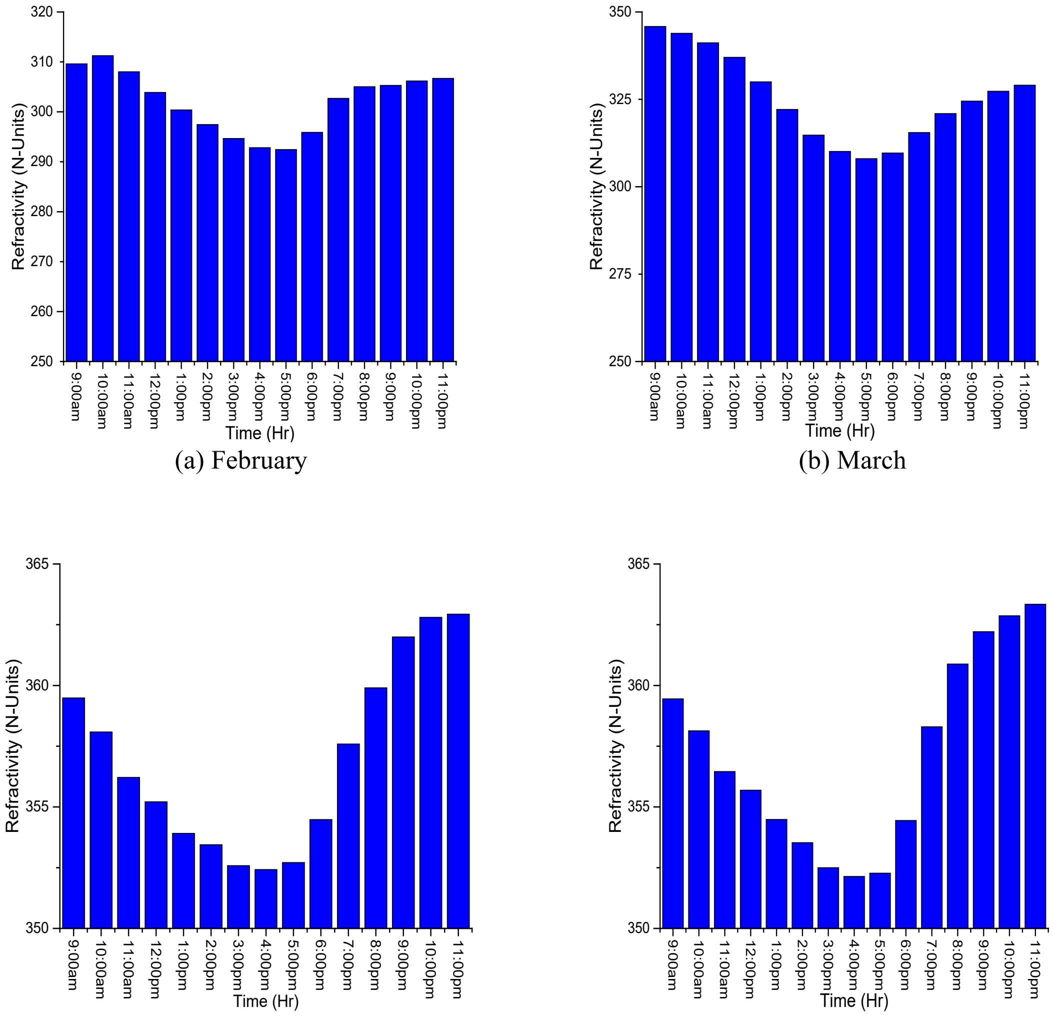
Table 1 - Seasonal signal level range for the link

Month	Jan	Feb	Mar	May	Jun	Jul
RSS (dBµV)	38-45	36-48	38-48	42-50	42-50	41-50

It is observed from Fig. 6 and 7 that higher signal levels were recorded during the wet season than the dry season for the link. This is also further illustrated in Table 1 where the signal level ranged from 36 dBµV to 48 dBµV in the dry season, while the wet season values ranged between 41 dBµV and 50 dBµV. This is attributed to the prevailing weather conditions pervading the area. The climatic conditions resulting from the North-South migration of the Inter Tropical Discontinuity (ITD) across Nigeria is responsible for the observed trend; and the meteorological boundary between the rainy season on its southern side of the boundary and the dry season on the northern side represents the surface position of this low-pressure zone.

4.2 Mean Diurnal Variation of Surface Refractivity

In order to investigate the effect of refractivity on signal strength, diurnal variation of radio refractivity during the same period of signal strength measurements was explored. The same characteristic diurnal variation of signal strength was also observed for the diurnal variation of surface refractivity. The mean diurnal variation of surface refractivity (N_s) during the measurement period is shown in Fig. 8.



(a) February (b) March

(c) June (d) July

Fig. 8 - Diurnal variation of surface refractivity

Fig. 8 shows that refractivity values were generally higher during the morning and evening/night hours, while lower values were recorded during the afternoon time. Using the month of February which is a typical dry month as an example, Peak value of 311 N-units occurs at 10.00 am after which it begins to decrease until a minimum value of 292 N-units is reached by 5.00 pm local time. Refractivity values begin to increase again towards the evening and night hours. This trend of morning/night peaks and afternoon minimum is observed in the remaining months. The minimum value recorded in the afternoon is due to the simultaneous effects of high temperatures and low humidity which reduces the moisture content of the atmosphere during this period, while the night and early morning peaks are as a result of increased water vapour content at night. Comparing results of dry months refractivity (February and March) with wet months refractivity (June and July), it is observed that refractivity values are higher during the wet months than the dry months. Average dry season values ranged from 300 N-units in January to 330 N-units in March, while average wet season values ranged from 357 N-units in May to 359 N-units in July. This same observation of measured low values during the dry season period and higher values in the wet season period was made for the radio signal strength measurements. Hence, this has shown that diurnal and seasonal characteristics of radio refractivity are in general agreement with diurnal and seasonal variation of VHF radio signal strength. These observations have been corroborated by earlier efforts (Oyedum and Ojeba, 1999; Gunashekar et al., 2005; Igwe et al., 2018).

4.3 Cumulative Frequency Distribution of Signal Strength

The cumulative frequency distribution of the received signal strength is presented in Fig. 9.

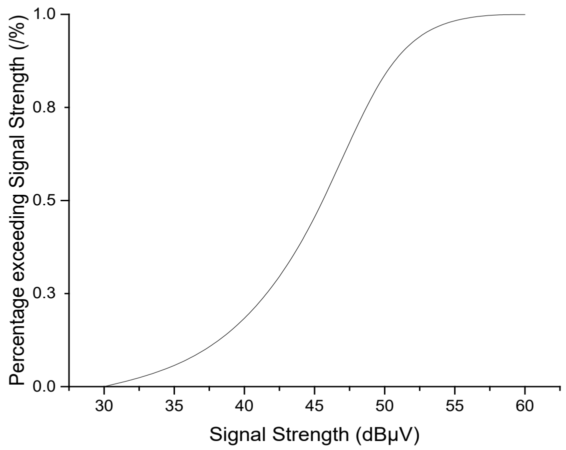


Fig. 9 - Cumulative frequency distribution of RSS for the link

The curve shown in Fig. 9 depicts the fraction of total time for which the received signal exceeded a specified power. The entire database consists of 1,738 signal strength values. The RSS value with the highest number of samples in the entire database is 50 dBµV. It occurred 841 times which represents 48.38% of time of measurement, while the RSS with the lowest number of samples in the database is 60 dBµV and 70 dBµV, both occurring once during measurement thus representing 0.06% of time. In addition, Figure 7 reveals that the RSS exceed 35 dBµV in 95.5% of the measurement time.

4.4 Attenuation of Received Signals

There is a certain power expected at the receiver end of a terrestrial link during transmission. For example, when a transmitting power of 8.5 kW is used, the RSS expected at the receiver end is 69.3 dB. However, because of signal attenuation due to atmospheric or environmental losses, the actual RSS fall below this level. The attenuation of the signal level was calculated and the effect is observed in the measured values of the RSS. The results for a typical dry month (February) and a typical wet month (July) are shown in Fig. 10 and 11.

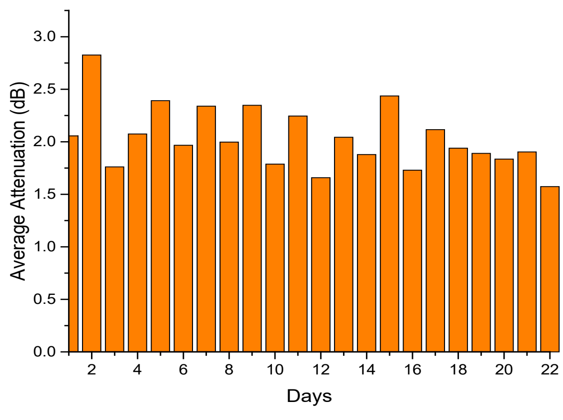


Fig. 10 - Clear air attenuation for a typical dry month (February)

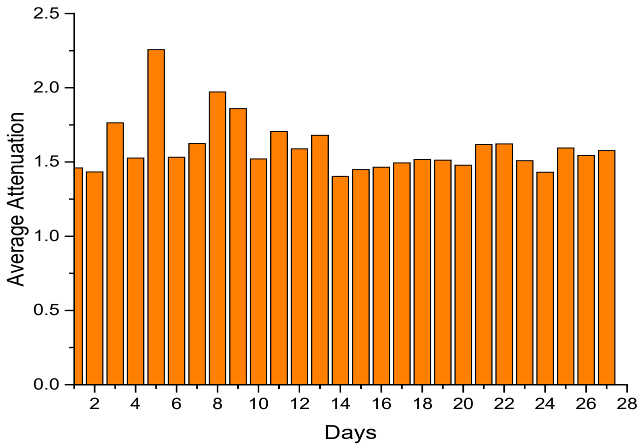


Fig. 11 - Attenuation for a typical wet month (July)

From Fig. 10, it is seen that the average clear-air attenuation for the link fluctuates between 1.6 dB and 2.8 dB for a typical dry month, while the average attenuation for a typical wet month as shown in Fig. 11 fluctuates between 1.4 dB and 2.3 dB. Generally, positive attenuation values imply that the signal strength is impeded, while negative attenuation values show enhanced signal strength. One of the factors that contribute to this clear-air attenuation is k-factor (effective-earth radius factor) fading. Diffraction or k-type fading in line-of-sight links result due to the variation of effective earth radius factor which also arises because of the time-varying nature of primary tropospheric parameters of temperature, pressure and relative humidity. These results are also in conformity with those obtained in Igwe et al. (2017a) and Igwe et al. (2017b).

4.5 Modeling of Received Field Strength using Diffraction Formulae

Diffraction of radio waves over the earth's surface is affected by terrain irregularities. The received signal strength was converted to field strength. Subsequently, the diffraction values were modeled using procedures in Recommendation ITU-R P.526-12. This recommendation uses antenna heights and range to predict path losses due to diffraction over the earth's curvature. Free space field strength for the link was also calculated and assuming free space loss along the path is classified as enhanced signals. Fig. 12 shows comparison between predicted field strength using ITU-R diffraction model, free space field strength model and measured field strength.

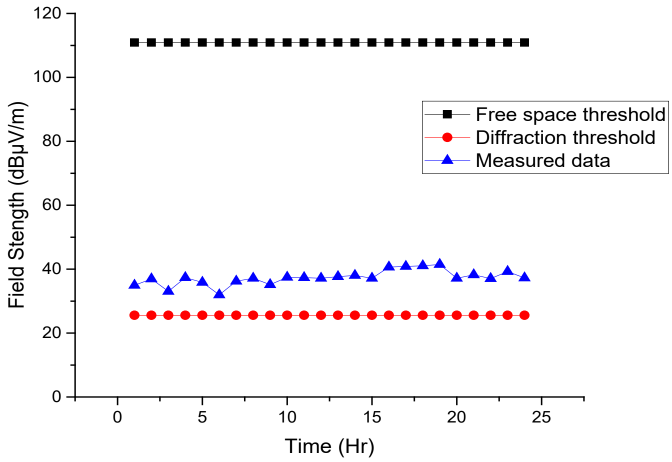


Fig. 12 - Comparison of measured, diffraction and free-space field strength models

From Fig. 12, it is observed that ITU-R diffraction model underestimated the received field strength values for the radio link. The differences between predicted and measured field strength values are in the range of 6-15 dBµV/m, hence no correlation exists between them. Also, the measured field strength is overestimated by the free space field strength model. Since the measured data lie between the free space and diffraction threshold values, it shows that it is possible to have enhanced field strength beyond the diffraction level as a result of refractive effects (atmospheric effects) but none of the field strength values measured for this link recorded any case of enhanced field strength.

5. Conclusion

Received signal strength have been measured for a VHF broadcasting station (Power FM) transmitting at a distance of 83.19 km from the measurement site in Niger State, North Central Nigeria. The analysis carried out reveal both diurnal and seasonal effects of weather on received signals as low values were recorded during the daytime and during the dry season period, while peak values were recorded at night time and during the wet season. The seasonal RSS variation showed that values ranged from 36-48 dBμV in the dry season, while higher values were recorded during the wet season with values ranging from 41-50 dBμV.

For the diurnal surface refractivity computed, peak values occurred at night and morning hours, while lower values occurred at afternoon hours. The seasonal variation of surface refractivity showed that refractivity values were higher during the wet season than the dry season period as dry season average values ranged from 300 N-units in January to 330 N-units in March, while average wet season values ranged from 357 N-units in May to 359 N-units in July.

The cumulative frequency distributions of the RSS values reveal that 1,738 signal strength values were recorded for the entire database. Of these, 50 dBμV had the highest number of occurrences. This occurred 841 times, which is equivalent to 48.38% of measurement time, while the lowest occurring samples in the data base were 60 dBμV and 70 dBμV, both occurring once during the measurement and this represented 0.06% of the time. Generally, the RSS exceeded 35 dBμV at 95.5% of the measurement time for the link.

The average clear-air attenuation values computed for a typical dry season month showed that attenuation ranged from 1.6 to 2.8 dB, while the attenuation for a typical wet season month varied from 1.4 to 2.3 dB. The field strength model from ITU-R P.526-12 showed that the model underestimated the received field strength for the radio link. Also, there was no correlation between field strength predicted by this diffraction model and actual field measurements.

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References

[1] Aboaba, O. A. (2015). Results of VHF radiowave propagation experiment in a tropical climate. American Association for Science and Technology Journal, 2(3), 123-131.

[2] Adediji, A.T. & Ajewole, M.O. (2010). Microwave anomalous propagation (AP) measurement over Akure South-Western Nigeria. Journal of Atmospheric and Solar-Terrestrial Physics, 72, 550–555.

[3] Amajama, J. (2016). Impact of Weather Components on (UHF) Radio Signal. International Journal of Engineering Research and General Science, 4 (3) 481-494.

[4] Anderson, H. R. (2014). Radio broadcasting. Consulting engineers, Eugene, Oregon: McGraw-Hill education, 63-67.

[5] Barringer, M. H., & Springer, K. D. (1999). Radio wave propagation. National association of broadcasters engineering handbook (9th ed.).

[6] Freeman R. L. (1997). Radio system design for telecommunications (2nd ed.). John Wiley & sons Incorporated.

[7] Gomes, I.R., Gomes, C.R., Gomes, H.S., Cavalcante, G.P.dS. (2018). Empirical radio propagation model for DTV applied to non-homogenous paths and different climates using machine learning techniques. PLoS ONE, 13 (3).

[8] Gunashekar, S. D., Siddle, D. R. & Warrington, E. M. (2005). The effect of weather conditions on transhorizon propagation of UHF radio waves in the British Channel Islands. Proceedings of the Loughborough Antennas and propagation conference, ISBN 0947974334.

[9] Gurung, S. & Zhao J. (2011). Attenuation of microwave signal and its impacts on communication system. Paper presented at the Dept. of Electrical Engineering, College of Engineering, University of North Texas. Retrieved on 9th April 2014 from http://www.tucfes.com/allfiles/documents/research_projects/

[10] Hall, M. P. M. (1979). Effects of the troposphere on radio communication. Peter Peregrinus Limited, U.K. & U.S, 13-181.

[11] Igwe, K. C., Oyedum, O. D., Ajewole, M. O. & Aibinu, A. M. (2017a). Measurements of VHF Signal Strength for Terrestrial Broadcast Service in Minna, North Central Nigeria. Journal of Science, Technology, Mathematics and Education (JOSTMED), 13(2), 63-71.

[12] Igwe, K. C., Oyedum, O. D., Ajewole, M. O. & Aibinu, A. M. (2017b). VHF Radiowave propagation measurements in Minna, North Central Nigeria. Proceedings of the 1st School of Physical Sciences Biennial International Conference, 320-328.

[13] Igwe, K. C., Oyedum, O. D. & Eichie, J. O. (2018). Effects of variation of some weather parameters on surface refractivity. Nigerian Journal of Physics (NJP), 27(2), pp. 62-70.
[14] ITU-R. (1994). Definitions of terms relating to propagation in non-ionized media. Recommendation P.310-9, ITU-R P Series, International Telecommunication Union, Geneva, 1-4.
[15] ITU-R. (2009). Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz. Recommendation P.1546-4, ITU-R P Series, International Telecommunication Union, Geneva, 50.
[16] ITU-R. (2012). Propagation by diffraction. Recommendation P.526-12, ITU-R P Series, International Telecommunication Union, Geneva, 1-36.
[17] Luomala, J. & Hakala, I. (2015). Effects of temperature and humidity on radio signal strength in outdoor wireless sensor networks Proceedings IEEE FedCSIS'15, 1247-1255.
[18] Oyedum, O. D., & Ojeba, E. B. (1999). Results of transhorizon VHF field strength measurement in Zaria. Journal of Science, Technology and Mathematics Education (JOSTMED), 2(1), 128-134.
[19] Oyedum, O. D. (2005). Seasonal variability of radio field strength and radio horizon in Nigeria. Proceedings of 1st Annual School of Science and Science Education Conference, Fedeal University of Technology, Minna, 1, 184-195.
[20] Segun, A. A., Olusope, A. M. & Kofoworola, A. H. (2015). Influence of air temperature, relative humidity and atmospheric moisture on UHF radio propagation in South Western Nigeria International Journal of Science and Research, 4, 588-592.
[21] Smith, E. K., & Weintraub, S. (1953). The constants in the equation for atmospheric refractive index at radio frequencies. Proceedings IRE, 41, 1035-1037.
[22] Suleman, K. O., Bello, I. T., Tijani, L. O., Ogunbode, A. O. & Olayiwola, W. A. (2017). Effect of Temperature and Ground Water on VHF Radio Wave Propagation in Tropical Climate International Journal of Science and Engineering Research, 8 (1), 1391-1396.
[23] Zhenzhong, L., Nezih, M., George, X., Yuu, O., Guocheng, L. & Dayan, B. (2011). Effects of temperature and humidity on UHF RFID performance. Proceedings CANSMART CINDE IZFP'11, 1.