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A Review on the Effects of Radio Refractivity and Atmospheric Parameters on Signal Quality at Ultra High Frequency (UHF)

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ABSTRACT

Refractivity is an important factor in predicting the performance of radio link. The structures of the refractive index of the troposphere are responsible for many complicated mechanisms such as, multipath effects, absorption, scattering of radio signals, etc. and these mechanisms can cause a lot of propagation impairment such as, loss of signal for mobile communication, the accuracy of tracking radio source (such as stars) with radio telescopes, radar system etc. Understanding the effects of the weather on radio wave propagation will help to improve the quality of radio signals, as the Weather variables are useful ingredients in the predictions of refractivity distributions and the anomalous radio wave propagation conditions of the atmosphere. This study contends that refractivity variations significantly affects received signal strength at Ultra High Frequency (UHF) and gave a brief theoretical background on Electromagnetic wave, Atmospheric effects on radio propagation anomalous propagation condition and the mathematical expression for refractive index and refractivity of the troposphere. Also, the paper review related articles in the following area; refractive index and refractivity of the troposphere, effects of weather variables and refractivity of troposphere. The analysis of the review articles submits that, refractivity reveals seasonal variations with high value in rainy season and low values in dry season. Also observed from the review articles, is that the diurnal variations are influenced by three atmospheric parameters; water vapour has the greatest effect on refractivity variations followed by temperature and pressure. Furthermore, the Refractivity is function of local meteorological parameters. Eventually, the study suggests that, the effect of Atmospheric parameters and consequently the Radio Refractivity should be compensated for when designing wireless *communication links in an environment*.

Keywords: Weather parameters, Refractivity, Electromagnetic wave, Ultra High Frequency

1.0 INTRODUCTION

1.1 Background

Increased dependence on radio communication in Nigeria through the use of communication technologies such as laptops, smartphones and computers in our day to day life ease the way of doing businesses and social activities such as mobile banking, e-businesses, access to news and usage of social media (Oladimeji and Folayan, 2018). According to the Director General, Nigeria Communication Commission (NCC), the Commission's statistics continue to show positive movement in the provision of services with internet and mobile phone penetrations, standing at over 100 million and 147 million subscribers respectively in

January 2018 (NCC, 2018). Despite all these advantages and prospects, users are vulnerable to poor network services which interrupt their social and business activities. In another survey by NCC, 30 % and 44 % of the respondents rated the mobile and internet services respectively as very poor (NCC, 2012). This may be connected to so many factors such as antenna height and overcrowding. However, tropospheric conditions may play an important role (Mat, *et al.*, 2018).

The performance of radio communication systems depends mainly on the propagating medium between the transmitter and the receiver. Unlike wired channels (fiber optic, coaxial cable, etc.) that are

stationary and predictable, the atmosphere is difficult to predict, because they depend on the physical characteristics of the atmosphere such as pressure, temperature, humidity, hydrometeors, suspended particles and atmospheric constituents (Margarita, 2005). The integrity of the information received at the receiver depends on how much the signal is distorted in the medium, however, the interference that occurs in radio signal transmission in many communication technologies are attributed to weather variations as well as other environmental factors (Mat., *et al*, 2018). The need to have adequate and comprehensive knowledge of the variation of the refractive index in tropical region has arouse, due to fact that the radio communication equipment design for use in the temperate region may not be very suitable in the tropical region because the characteristics of the troposphere as a media of propagation differ appreciably (Agunlejika and Raji, 2010). Adewumi (2013), established that the structures of the refractive index of the troposphere are responsible for many complicated mechanisms such as, multipath effects, absorption, scattering of radio signals, etc and these mechanisms can cause a lot of propagation impairment such as, loss of signal for mobile communication, the accuracy of tracking radio source (such as stars) with radio telescopes, tracking of satellites (such as GPS satellite), missile range, radar system etc.

The effect of Atmospheric parameters of pressure, temperature, and relative humidity on radio wave propagation at ultra-high frequency (UHF) can be analyzed from the study of radio refractive index derived from the aforementioned parameters. Since these variables vary considerably daily and seasonally, especially in the tropics, quantitative knowledge of refractivity variations is required in order to be able to design reliable and efficient radio communication system (Igwe and Adimula, 2009).

This review is intended to give details on the recent experimental and modeling of tropospheric radio propagation and the extent of atmospheric parameters and refractivity variation effects on signal quality at UHF.

1.2 Electromagnetic Wave

Electric field is produced by stationary charges, while moving charge produces both electric and magnetic field. Regular repetitive motion of these fields produces electromagnetic wave. It transports energy from one point to another and propagate through space with a speed equivalent to that of light ($2.997 \times 10^8 \text{ m s}^{-1}$ or about 186,000 miles per second) (Mason, 2010).

Considering electromagnetic wave propagating at a given frequency in terms of oscillation per seconds, with an associated wave length in meters and speed of light in term of distance per second, we can deduce that, (Mason, 2010);

$$\text{Frequency} = \frac{\text{Speed of light}}{\text{Wavelength}} \quad 1.1$$

In the atmosphere, electromagnetic wave moves slightly slow due to its interaction with atmospheric parameters. Radiation is often specified by its wavelength, λ , which is the distance between crests of the electric or magnetic fields.

The standard description of a plane wave electric field is

$$E(k, R) = \frac{e^{ikR}}{kR} \quad 1.2$$

With,

$$K = 2\pi/\lambda \quad 1.3$$

and is called the wave number. R is the scalar distance between the transmitted and received signal. The power transmitted by the electric field is given by:

$$P = |E|^2 \quad 1.4$$

Putting equation (1) into (2) we have:

$$P = \left| \frac{e^{ikR}}{kR} \right|^2 \quad 1.5$$

The wavelength is related to the frequency by the speed of the signal, which in this case is the speed of light.

The range of all types of electromagnetic radiation is termed as the electromagnetic spectrum. The classification in terms of their frequencies is given below as suggested by (NASA, 2018).

- VLF – Very Low Frequencies 3-30 KHz
- LF –Low Frequencies 30-300 KHz
- MF –Medium Frequencies 300-3000 KHz.

- HF –High Frequencies 3MHz –30 MHz
- VHF –Very High Frequencies 30MHz –300 MHz
- UHF –Ultra High Frequencies 300 MHz –3 GHz
- SHF –Super High Frequencies 3 GHz –30 GHz
- EHF –Extra High Frequencies 30 GHz –300 GHz

Generally, when dealing with signals from Transmission to Reception takes three forms (Line of Site (LOS), Ground Wave and Sky Wave), but for VHF and UHF propagation LOS is very useful. Global System for Mobile (GSM) networks used UHF cellular frequencies (Ayatunji, *et al.*, 2018).

1.3 Atmospheric Effects on Radio Propagation

An electromagnetic signal propagating through a medium consisting of atoms and molecules (i.e., not a vacuum), will interact with that medium through various processes, among them are absorption and scattering. The efficiency of the interaction is related to the amount of signal absorption. Changes in propagation velocity due to this interaction result in a change in the wave's direction called refraction

and is described by its refractive index (n) (Mansion, 2010).

The Snell's Law is used to describe the relationship between the angles of incidence and angle of reflectance of a rays passing through a boundary between two different isotropic media:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \quad 1.6$$

where θ_1 , θ_2 are the angles of incidence and reflectance respectively, and n_1 , n_2 are the refractive indices of the two isotropic materials, and represent the factor by which a wave's speed decreases when traveling through a refractive medium (Medwin, 2005). Snell's law quantifies these speed changes in the form of angular change, thus, the degree of "bending" of the ray is one component which affects signal strength, in addition, by knowing the refractive index in the atmosphere at each level one can predict the direction by which the EM waves will follow (Mason, 2010). See Figure 1.

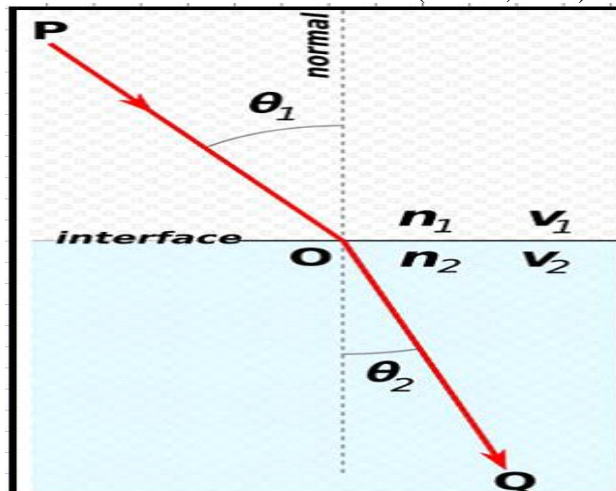


Figure 1.0 Refraction via Snell's Law

1.4 Anomalous Propagation

The slope of refractivity with altitude determines how microwaves propagate and is also used to characterize microwave propagation as **sub-refraction, normal refraction, super refraction or ducting**. The curvature of the earth's surface must be taken into account in order determine these propagation conditions. This is accomplished by using the modified refractivity M , given as (Bech, *et al.*, 2002)

$$M = N + \frac{z}{10^{-6}r_e} \approx N + 0.157z \quad 1.7$$

1.5 The Mathematical Expression for Refractive Index of the Troposphere

The refractive index of the atmosphere depends on the following three factors: humidity (water vapor), temperature and pressure.

The Refractivity, N , is related to the refractive index of air (ITU-R 453-11, 2015) as follows;

$$N = (n - 1) \times 10^{-6} \quad 1.8$$

Where N is radio refractivity expressed by $N = 77.6 \frac{P_d}{T} + 72 \frac{e}{T} 3.73 \times 10^5 \frac{e}{T^2}$ 1.9

Introducing total pressure $P = P_d + e$, equation 1.8 can be written as:

$$N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \quad 2.0$$

with the 'dry term' of radio refractivity given by:

$$N_{dry} = 77. \quad 2.1$$

and the 'wet term' given by

$$N_{wet} = 3.732 \times 10^5 \frac{e}{T^2} \quad 2.2$$

where P is atmospheric pressure (hpa)

e is a water vapor pressure (hpa) and

T is the absolute temperature (K)

The expression in 1.9 may be used for all radio frequencies (for frequencies up to 100GHz; the error is less than 0.5%) for representative profiles of temperature, pressure and water vapour pressure. The water vapour pressure, e , can be calculated from relative humidity as;

$$e = \frac{He_s}{100} \quad 2.3$$

Where e_s is defined as

$$e_s = EF.a.exp\left\{\frac{(b-\frac{t}{c})}{t+c}\right\} \quad 2.4$$

And

$$EF = 1 + 10^{-4}[7.2P(0.00320 + 5.9 \times 10^{-7} \times t^2)] \quad 2.5$$

Where e_s is the water vapour partial pressure, t is temperature in Celsius, H is the humidity, and constants for water are $a = 6.1121$, $b = 18.678$, $c = 257.14$ and $d = 234.5$ (ITU-R, 2015)

$$dN = 77.6 \frac{dN}{T} - \left(77.6 \frac{P}{T^2} + 7.46 \times 10^5 \frac{e}{T^3}\right) dT + 3.73 \times 10^5 \frac{e}{T^2} \quad 2.6$$

For normal atmospheric condition; $P = 1000$ hpa, $RH = 60\%$, $T = 290$ k and $e = 13.7$ hpa

$$dN = 0.268dp - 1.289dT + 4.435de \quad 2.7$$

This clearly indicates that the contribution of ' e ' is large relative to ' T ' and ' p ' in the gradient of ' N '.

The reason behind this is the fact that water vapour polarizes on interaction with the radio signal; this effect causes the dielectric constant of the water vapour to rise, resulting in a relatively larger contribution of relative humidity in Refractivity

2.0 REVIEW OF RELEVANT LITERATURE

2.1 Introduction

Research indicates that several studies have been carried out in Nigeria and around the globe on Electromagnetic wave medium interaction processes and the propagation implications (Adediji, *et al.* 2013). The review studies were divided into sub-sections for better comprehension of the study.

2.2 Refractive Index and Refractivity of the Troposphere

Refractivity variation in the very near surface environment is critical in the planning and design of radio links/systems for achieving optimal performance. Many researchers in Nigeria and around the globe have contributed immensely in this field. For instance, several studies show that during rainy season, the values of refractivity is high while in low values of refractivity is observed during dry season, and that refractivity values vary with climatic zones, also depends on the local meteorological parameters. The researchers further established that, among the three meteorological parameters affecting refractivity, atmospheric humidity has the greatest effects, followed by atmospheric temperature and pressure (Tankoet *al.*, 2019; Kingsley and Samuel 2019; Chimaat *el.*, 2019; Sayoet *al.*, 2017; Adediji *et al.*, 2011, 2013; Kaissassou *et al.*, 2013; Foladun and Okeke, 2012; Okoro and Agbo 2012; Ayatunjiet *al.*, 2011; Ali *et al.*, 2011; Falodun and Ajewole 2005). These results can be theoretically confirmed by differentiating equation (1.9);

(Ayatunji *et al.*, 2019). Higher values observed in the rainy months were due to the fact that the atmosphere is mostly dominated by moist content of water vapour which eventually increases the humidity in the atmosphere and consequently the surface radio refractivity. While low values of surface radio refractivity were due to the low atmospheric humidity which in turn led to the

reduction in atmospheric water vapour and consequently the surface radio refractivity.

Studies by Adewumi, *et al.*, (2018), Paul and Ayegba (2018), Bawa *et al.* (2015), Adediji *et al.*, (2013), Ayatunji and Okeke (2011), indicate that annual radio refractivity decreases with increase latitude across Nigeria, that is, from arid region in the north to the coastal region in Southern Nigeria. These studies could enhance accurate and efficient radio refractivity links across Nigeria, by providing a clue on the expected antenna height for efficient transmission and reception across the earth and radio horizons of the climatic zones under study. Hence, terrain nature and variations in antenna height play a significant role in signal transmission and reception in the troposphere (Adewumi, *et al.*, 2018, Mason, 2010).

The knowledge of the refractivity gradient and statistical distribution of k -factor is very important in the planning of radio communication especially from radio conservation point of view which is sometimes referred to as frequency reuse, this is a situation where nearly-same frequency or same frequency is assigned to different services within a particular location provided the area of coverage of the different services does not overlap (Theodore, 2002).

Studies by Igwe and Adimula (2009), entitled the variation of surface radio refractivity and radio refractive index gradient in sub-sahel Nigeria, evaluates the variation of refractive index near the ground and seasonal variation of refractivity with height using five years' meteorological data over Minna (1979 to 1983) and Ilorin (2000 to 2004). The result reveals value of refractivity gradient of the atmosphere over Minna to be sub-refractive during the dry season and super-refractive during the wet season periods of the year.

The analysis from Refractive Gradient and Effective Earth Radius Factor (K -Factor) over Sokoto, Ikeja and Lokoja Nigeria using the meteorological data of temperature, pressure and relative humidity by Paul and Ayegba (2018), shows that propagation of radio wave in the three regions (Ikeja, Lokoja and Sokoto) is mostly super-refractive. Also, Emmanuel *et al.*,

(2017), Foladu and Okeke (2012), also, reports the occurrence of abnormal propagation such as super refractive, sub refractive and ducting across Nigeria.

The above studies on refractivity gradient indicates the occurrence probability of abnormal propagation condition such as super refraction, sub refraction and ducting depend on the location as well as the local time. The application and validity of these studies will provide valuable information about the propagation of radio waves over Nigeria, which will assist the radio engineer in their planning and designing of radio circuitry.

2.3 Effects of Atmospheric Parameters, Refractivity Variation on Ultra High Frequency Signals Strength

Weather variables such temperature, pressure and relative humidity significantly affects electromagnetic wave mostly propagated in the troposphere (Agbo, *et al.*, 2020). The effects of variable troposphere in the tropical region, in which Nigeria is not an exception, have been comprehensively investigated by many researchers using theoretical, experimental and statistical approaches.

A number of studies have reported correlation between atmospheric parameters and UHF signal strength (Ayatunjiet *al.*, 2018; Chima and Udegbe 2018; Mat, R. *et.al* (2018); Ukhurebor and Umukoro, 2018; Felix *at.el.* 2017; Roshidah, *et al.*, 2016; Abraham, *et al.*, 2015; Adewumi, *et al.*, 2013; Jari and Ismo 2015; Joseph, A., 2010).

The investigation in to the Influence of Air Temperature, Relative Humidity and Atmospheric Moisture on UHF Radio Propagation in South Western Nigeria (coastal region) by (Adewumi, *et al.*, 2013) involved measuring UHF Received Signal Strength (RSS) over the available frequency band of 900 – 960 MHz and specifically at individual service providers operating frequency simultaneously with the variable atmospheric parameters. The result shows that as the air temperature increases, relative humidity decreases, hence a proportional decrease in UHF path loss while the RSS shows a proportional increase.

Joseph, (2016) has carried out an experiment to characterize the propagation of radio signals through the atmosphere by the force of weather parameter, in Calaba, South-South (coastal) Nigeria. The Results indicated that radio signal strength is inversely proportional to atmospheric humidity with a correlation factor of -0.94.

Similar study by Jari and Ismo (2015) over Benin, South-South (coastal region), Nigeria to ascertain the influence of meteorological variables on the UHF signal strength for a period of one year (2017). The results show that the UHF signal strength having inverse relationship with the air temperature, atmospheric pressure and the relative humidity with a negative correlation values of -0.94, -0.92 and -0.96 respectively.

Ayatunjiet *al.*, (2018) conducted a research on atmospheric humidity and its implication on Ultra High Frequency (UHF) signal Strength over Gusau, North West (coastal region), Nigerian. In this research, regression analyses were employed using the data of atmospheric parameters and UHF signal strength measured at the very near surface of the atmosphere. The result shows that, there is strong relation between humidity and UHF signal strength. The regression analysis of the two parameters give a correlation of 0.418, 0.532, 0.728 and 0.639 for the month of May, June, August and September 2017 respectively.

Investigation in to the Influence of Atmospheric Temperature and Relative Humidity on FM Radio Signal Strength: A Case Study of FM Abuja North Central (Arid region) Nigeria by Felix *at.el.* (2017) affirmed that the signal strength directly varies with relatively humidity and inversely varies with the ambient temperature. The calculated correlation coefficients of the temperature and signal strength for two days were -0.42369 and -0.51878 while relative humidity and signal strength correlation coefficients are 0.29 and 0.39.

Abraham *et al.*, (2015) evaluates and establishes some atmospheric and environmental variables that have a dominating impact on temporal signal strength fluctuations that are experienced even on a fixed location over Bauchi, North-East (Arid region) Nigeria. Their result indicated that, the signal

strength is strongly correlated with locations among other factors across the different times of measurement. The results however suggest location as having a dominating impact on the received signal strength among other environmental factors such as weather and time of the day, since the correlation between the variables is as low as 0.091.

From the aforementioned studies, it can be seen that air temperature and relative humidity have significant influence on UHF signal propagation within the troposphere. Also observed is that, in the coastal region, the RSS increases with the increase in temperature and decrease in relative humidity. While in the arid region, RSS increases with an increase in relative humidity and decrease in temperature. Therefore, these results can be used to develop efficient link margin and budget for the region under study rather than using existing link margin developed from temperate region.

The variations in weather parameters cause changes in the refractive index of the atmosphere, which make the troposphere suitable region of the atmosphere for UHF and VHF propagation. Refractivity is an important factor in predicting the performance of radio link in an environment where it is to be situated.

Studies have been carried out in to the effects of refractivity on the signal quality at UHF band. Ayatunji, *et al.* (2019) investigated the impact of atmospheric parameters and consequently radio refractivity on UHF signal over Gusau North-West (Arid region) Nigeria for the year 2019. Regression analysis reveals a positive correlation between UHF signal strength and radio refractivity to be 0.530 and 0.864 for December and January, and 0.311 and 0.364 for August and September. These results indicate that the effect is more pronounced in the dry season months (December and January). More so, environmental factors have effects on signal quality.

Adegboyega (2013), Showcases the effect of vertical variation of radio refractivity in the troposphere on broadcast signal strength over Akure, South-West (Coastal region), Nigeria. Results obtained ascertained that each atmospheric parameter has a role to play in refractivity variation with humidity as

the major factor that is having more influence than other factors. In addition, the surface refractivity is also being influenced by the latitudinal and seasonal variations. Generally, radio refractivity and broadcast signal strength are inversely related with correlation factors of -0.81 and -0.97 for day and night respectively.

Joseph, (2015) conducted a research in the effects of Radio Refractivity on signal quality at UHF band. The result shows that signal strength varies partially inversely as the atmospheric radio wave refractivity with a negative correlation of are -0.62 and -0.43 respectively. Two mathematical formulas were deduced, relating refractivity with signal strength together with its meteorological components both at

3.0 CONCLUSION

Refractivity is an important factor in predicting the performance of radio link. The change in atmospheric condition leads to radio wave propagation. Generally, from the aforementioned contribution by different researchers based on actual, long term measurement and scientific interpretation, it has been observed that refractivity reveals seasonal variations with high value in rainy season and low values in dry season. The diurnal variations are influenced by three atmospheric parameters; water vapour - has the greatest effect on refractivity variations - followed by temperature and pressure. Furthermore, the Refractivity is function of local meteorological parameters. Also observed from the review articles, is that, the propagation of UHF and VHF are significantly affected by meteorological condition.

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constant wind speed and direction at initial and final conditions.

Mason, (2010) studied the effects of atmosphere on radio frequency (RF) wave propagation in humid, near-surface environment. The study analyzed the propagation loss taken from the near earth surface at 1768 MHz within few wave lengths of the surface. The result confirms a strong dependence of propagation loss on antenna height.

Therefore, the correlation between received signal strength and refractivity, increases with increase the decrease with in value of refractivity in the arid region, while decrease with increase in the value of refractivity.

Therefore, the effect of Atmospheric parameters and consequently the Radio Refractivity should be compensated for when designing wireless communication links in an environment. The research findings will benefit radio wave propagation research field which includes mobile communication, radio astronomy observations, space science, and wireless communication.

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