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CHARACTERIZATION OF THE INFLUENCE OF RADIO WAVE REFRACTIVITY IN SOUTH SOUTH NIGERIA

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Abstract: **This study clarifies the impact of radio wave refractivity on wireless communication systems with a focus on South-South Nigeria. Using a thorough methodology that combines computer models with empirical observations, the study looks into fluctuations in atmospheric conditions and how they affect radio signal transmission. The results highlight how important it is to take refractivity dynamics into consideration while building reliable communication infrastructures that are appropriate for the unique climate of this area. These abstracts are meant to capture the substance of your study, emphasizing that it is primarily concerned with characterizing the impact of radio wave refractivity on South-South Nigerian communication systems.**

Keywords; **Radio Waves, Mobile Networks, Communications, Radio Frequencies.**

1. INTRODUCTION

A carrier for wireless, or over-the-air, communication is atmosphere. All wireless communication technologies, such as Bluetooth, cellular communication, GPS, radio frequency identification, satellite communication, radar communication, and wireless fidelity (Wi-Fi), rely on the atmosphere. (Alam et al., 2016: Amajama, 2016: Sabri et al., 2018: Ukhurebor and Azi, 2018: Voznak and Rozhon, 2012) The weather has an impact on the atmospheric channel. The state of the atmosphere at a specific location and time, including its cloud cover, heat, dryness, wind, sunshine, and rain, is called the weather.

Generally, the parameters that affect the weather of a place are:

1. temperature
2. Pressure,
3. Wind and Relative humidity

(Emmanuel and Adebayo, 2013: Jacobson, 1999: Oluwole, 2013: Ukhurebor and Umukoro, 2018)

The characteristics of the atmosphere as a medium for communication and the ongoing radio wave propagation are impacted by the discrepancy of the four meteorological factors mentioned above (Eichie et al., 2017: Isikwe et al., 2013: Joseph, 2016a: Joseph, 2016b: Joseph, 2016c: Michael, 2013: Valma et al., 2010). The density of the atmosphere is one of the significant characteristics that changes as the weather does (Okeke et al., 2019). The characteristics of propagating electromagnetic waves, including radio waves, may be affected by changes in the atmosphere's density, particularly its refraction (Adediji and Ajewole, 2008: Agbo et al., 2013: Oyedum et al., 2010: Willoughby et al., 2003). Refraction is the simple process by which a wave changes direction while propagating due to variations in the density of the medium or media it passes through. Because of variations in the weather that alter the densities with vertical position in the atmosphere, radio waves refract as they travel through the atmospheric channel (Ekpe et al., 2010: lgwe and Adimula, 2009: Isaakidis & Xenos, 2004: Owolabi and Williams, 1970: Zilinskas et al., 2011).

1.1. Refractive Index In Relation To Meteorological or Weather Factors

“Radio refractivity and its meteorological components: mathematical correlations with a new linear mathematical equation to calculate radio refractivity " was published by Amajama (2015a) in Calabar, Cross River. The following findings were obtained from half-hourly measurements conducted over the course of 48 hours in the Calabar Metropolis, Nigeria: radio refractivity is directly correlated with atmospheric temperature, atmospheric pressure, and relative humidity; provided that any of these parameters is met, other parameters, such as wind direction and speed, remain constant. There were 0.99, 0.91, and 0.99 correlations, respectively, between radio refractivity and atmospheric temperature, atmospheric pressure, and relative humidity. The following mathematical expression in equation (1) was proposed based on study as well. The observed error was around 5%. Any climatic zone may employ the aforementioned recipe.

N = KP2T1/2H1/3

Where, K = Constant = 0.01064097915 P = Atmospheric pressure in inHg

T = Atmospheric temperature in F

H = Relative humidity in %

N = Radio refractivity

Additionally, the “Ukhuerebor et al. (2018) conducted study on "Influence of weather variables on atmospheric refractivity over Auchi Town, Edo State, Nigeria." The measurements of the many atmospheric weather variables utilized in this research were performed using a low-cost, portable weather monitoring device that the author constructed. The micro Secure Digital (SD) card is used to store the atmospheric weather variables that were measured by the weather monitoring equipment. In order to continuously measure the air temperature, atmospheric pressure, relative humidity, and light intensity at the Edo University Iyamho administrative building block in Auchi, Edo State, Nigeria, a fixed measuring method involving positioning the weather monitoring system on a 50-meter platform above ground level was used. Next, the micro SD card with the measured weather variables was transferred from the weather monitoring device to the PC. A year's worth of atmospheric variable measurements were conducted (from January to December, 2017). The meteorological variables were gathered, and the recordings span twenty-four hours a day, at one-hour intervals, from 0:00 to 23:00. Based on the study's findings, an inferential conclusion was drawn that, while measured air temperature had a significant impact on calculated atmospheric refractivity throughout 2017, measured air temperature also had a significant influence during the months with higher rainfall (the wet season). Together, these factors significantly influenced calculated atmospheric refractivity throughout 2017.

Adedayo (2016) conducted the following study: "Statistical analysis of the effects of relative humidity and temperature on radio refractivity over Nigeria using satellite data" . The Department of Satellite Application Facility on Climate Monitoring (CM-SAF), DWD Germany, repository provided data on average monthly temperature and relative humidity for five different atmospheric pressure levels (925, 775, 600, 400, and 250 mbar) between 2004 and 2007. For this study, data from 26 sites inside the Nigerian troposphere were categorized into four climatic areas according to Olaniran and Sumner (1989). These areas are classified as sahelian (SH), midland (ML), coastal (CT), and guinea savannah (GS). Refractivity was computed using the suggested formula by the ITU-R from the raw data collected. The obtained data demonstrated the seasonal change in the region's temperature, relative humidity, and refractivity, particularly at low and mid-levels. When measured against temperature and refractivity, the coefficient of determination is low, but for relative humidity and refractivity, it is high in both locations. This confirms that at lower and intermediate levels, variations in relative humidity have a greater impact on refractivity than temperature.

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Okoro and Agbo (2012) investigated "The effect of variation of meteorological parameters on the tropospheric radio refractivity for Minna, Nigeria's Niger State". The Center for Basic Space Center (CBSS) supplied the meteorological data (pressure, temperature, relative humidity) needed to compute radio refractivity for Minna. All of the months of 2008 were used for the study, but the findings of the months of February and August were chosen to symbolize Nigeria's wet and dry seasons. For both the wet and dry seasons in Minna, the hourly fluctuations of the meteorological parameters were recorded for each day at five-minute intervals. From the collected data, the average variance for each hour of the day was computed. The study revealed that seasonal fluctuations in the troposphere's weather, particularly in its lowermost regions, are responsible for the influence of meteorological factors on the tropospheric radio refractivity in Minna (below sea level). Due to an increase in tropospheric temperature and humidity, which translate to very high radio refractivity at that time, it was noticed that this weather variation was more significant during Minna's wet season than during its dry one.

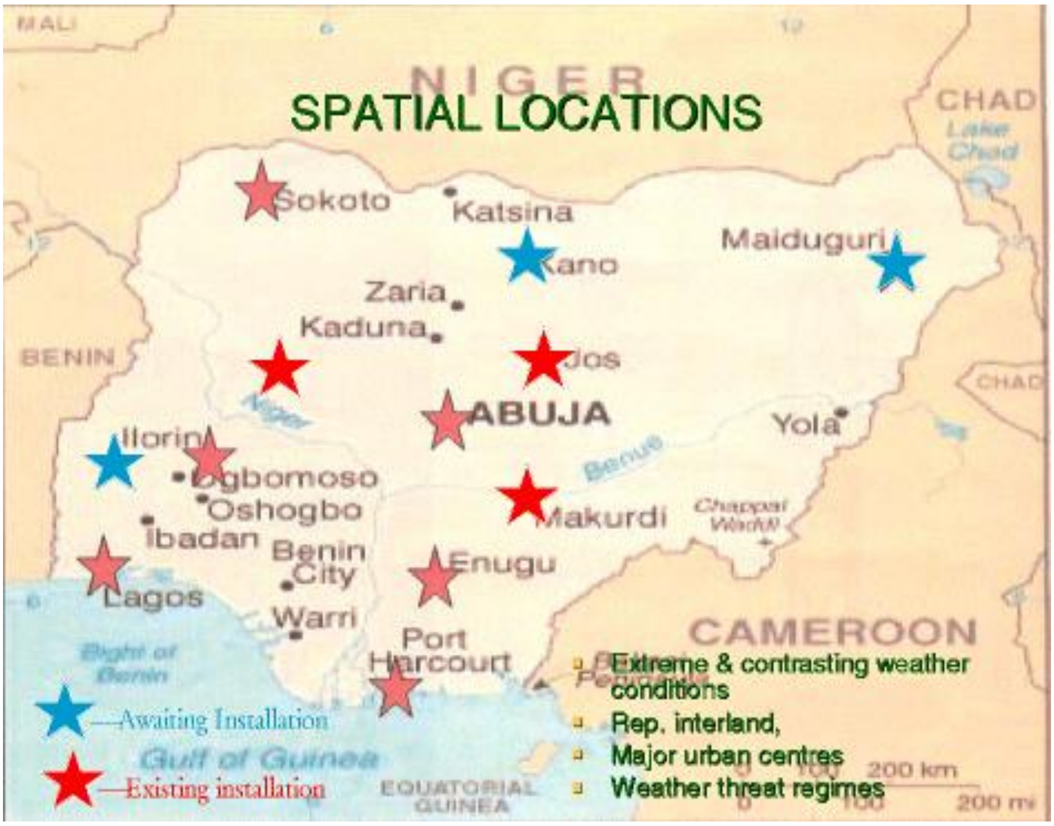
“Variation in weather conditions and how it affects the air's refractive index over Lagos, Nigeria " was the subject of a 2017 study by Bawa et al.

2. RADIO PROPAGATION AND THE ATMOSPHERE

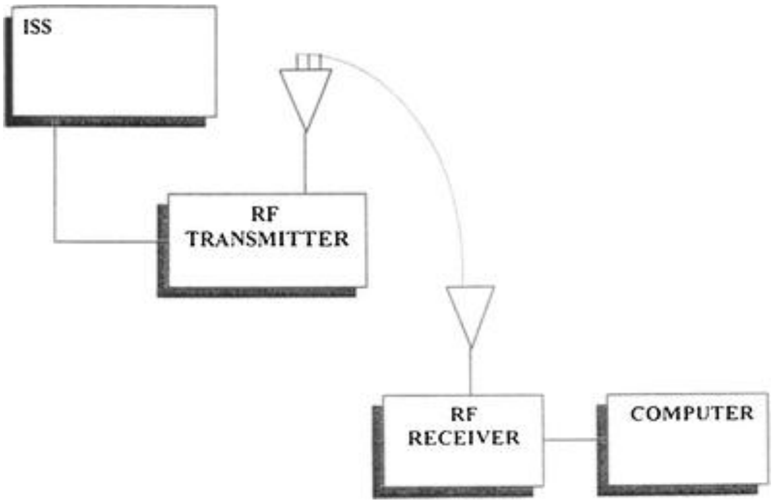
2.1 Radio Propagation

When constructing radio systems or communications networks, the remarkable method that radio waves flow from the transmitter to the receiver is crucial. The signals are mostly controlled by the places in the atmosphere through which they pass. Without the atmosphere acting as a medium or channel, radio frequency waves and communications will not be able to travel across the globe on "short wave bands" or beyond the "line-of-sight" dimension at high frequencies (Seybold, 2005).

In actuality, the environment offers several advantages to anybody involved in radio communication. It is impossible to overstate how much the atmosphere influences radio transmission, whether it is one-way or two-way between the transmitter and the receiver.



Map of Nigeria showing the locations of NECOP stations



The block diagram of the equipment set-up.

Source: Falodun, S.E., Okeke, P.N. (2013) Radiowave propagation measurements in Nigeria (preliminary reports). Theor Appl Climatol 113, 127–135 (2013). https://doi.org/10.1007/s00704-012-0766-z

2.2. Layers of the atmosphere

This part discusses the benefits of the atmosphere for radio communications, including a synopsis of its composition. various scientific universes have various perspectives on the unique characteristics of the atmospheric strata. From a different angle, every layer has more than one definition. The several levels may be divided based on their characteristics. The lowest layer, the troposphere, rises to a height of ten kilometers. Between 10 and 50 kilometers above this tropospheric height is where the stratosphere is located. The stratosphere, which is located around 20 kilometers above sea level, contains the ozone layer. Following the layer stated earlier is the mesosphere, which has a height range of 50 to 80 km. The thermosphere is located finally following the mesosphere. The temperature has dramatically increased here (Sharp, 2017).

From the perspective of radio communications, two main areas pique our interest. The troposphere is the first factor that usually affects radio frequencies higher than 30 MHz. Second, there is the ionosphere, a sphere that crosses the boundary between the meteorological spheres at an altitude of around 60 to 700 km (Sharp, 2017). Here, the ionization of the air results in the production of ions and free electrons. Free electrons and ions have an impact on radio communications and transmissions at certain frequencies, usually those lower than 30 MHz (Seybold, 2005). Signals are often bent or returned to Earth in order to be received at great distances worldwide. In this experiment, the troposphere—which controls our weather—was examined for its influence on radio waves and signals in relation to temperature, pressure, and humidity in the atmosphere.

2.2.1 An overview of radio communications and the troposphere

The lowest part of the atmosphere is called the troposphere. This extends from sea level to a height of ten kilometers. This sphere is where the forces that govern our weather reside (Sharp, 2017). It is found that middle level clouds develop to a height of approximately 4 km, whereas low clouds originate at a height of about 2 km. The tallest clouds are found up to a height of 10 kilometers. Modern aircraft can reach heights of up to 15 km beyond this.

In general, the temperature of the troposphere regularly decreases with height. As a result, some "radio propagation modes" and radiocommunications that occur in this domain are clearly affected. The troposphere's temperature continuously drops until the "tropopause" is reached. The temperature gradient levels off at this point when the temperature begins to climb. At this stage, the mercury is around 500C (Seybold, 2005).

Applications of radio communications that make advantage of "tropospheric radio wave propagation" benefit from the troposphere's air refractivity. Temperature, pressure, and humidity all affect refractivity. Radiocommunications transmissions are often impacted at heights of up to 2 km (Seybold, 2005). The influence of tropospheric, or lower atmospheric, temperature, pressure, and humidity on radio signal or wave propagation is the main emphasis of this study.

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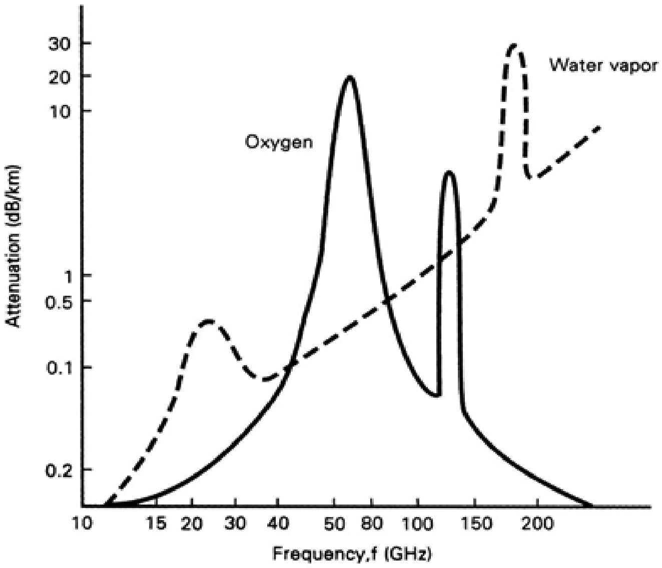

2.2.2 Tropospheric ducting

Tropospheric ducting often takes place under "stable anticyclonic weather" conditions. It is a kind of troposphere-based radio propagation. Here, instead of the usual reduction that occurs anytime the signal meets a temperature rise (also called a temperature inversion) in the troposphere, the greater refractivity index of the atmosphere will force the signal to bend into space (The Editors of Encyclopaedia Britannica, 2015). Tropospheric ducting affects radio waves and transmissions at all frequencies. Signals that are stimulated by this event often travel up to 1,300 kilometers. Still, "tropo" has been received at distances greater than 1,600 kilometers. When the atmosphere's refractivity is very high, it is typical to receive strong, steady signals from distances of 800+ kilometers ("Tropospheric propagation," 2015).

During the summer and fall, tropospheric ducting signals are more prevalent. Tropospheric ducting is the term used to describe the alteration in the atmosphere's refractivity at the interface of air masses with different temperatures and humidity. According to an analogy, the propagating wave is thought to curve downward because the heavier ground level air somewhat retards radio signals more than the seldom lighter upper air ("Tropospheric propagation," 2015).

When warm air crosses over cold air of a big quantity, ducting occurs on a very wide scale. The phenomena is known as a "Temperature inversion" in scientific parlance, and a standing weather front may allow the interface between the aforementioned twin volumes of air to extend for up to 1,600 kilometers. ("Tropospheric propagation," 2015).

"Temperature inversions" most often occur in coastal areas that are next to bodies of water. These result from the natural passage of cold, humid air over land just after sunset, when the temperature of the ground drops far faster than that of the upper troposphere's air layers. When the sun rises and heats the top layer air in the morning, a similar process could take place ("Tropospheric propagation," 2015).

Even at 40MHz, tropospheric ducting has seldom been seen or recognized, despite the signals often being quite weak. Beyond 90 MHz, transmissions often travel more favorably at higher frequencies ("Tropospheric propagation," 2015).

A "effective barrier" to "tropospheric signals" will be created between the transmitter and receiver by steep hilly regions and undulating terrain. Tropospheric ducting is suitable for a relatively flat land route between the transmitter and receiving antennas. Furthermore, marine routes often provide better outcomes ("Tropospheric propagation," 2015).

Particularly in the "Mediterranean Sea" and the "Persian Gulf," tropospheric ducting conditions may stabilize for a few months of the year to the point that watchers or listeners can consistently get high-quality receptions more than 1,600 kilometers. Conditions that are favorable to "tropo signals" are often present during very hot, calm summer weather ("Tropospheric propagation," 2015).

Ducting has produced UHF/VHF receptions ranging from 1,600 to 4,800 kilometers, especially across the oceans between Brazil and Africa, California and Hawaii, Australia and Indonesia, Australia and New Zealand, and Bahrain and Pakistan. In order to take advantage of a regular signal ducting from Southern Russia, the United States of America constructed a listening station in Ethiopia ("Tropospheric propagation," 2015).

The "tropospheric signals" do not degrade quickly and often produce strong signals that are adequate for noise-free stereo reception of "Radio Data System" (RDS) data, solid locks of "High Definition" (HD) radio strength on "Frequency Modulation" (FM), or noise-free visuals on "Color Television" (TV). Because almost all DTV stations transmit in the UHF band, tropospheric ducting causes almost every distant reception of "Digital Television" (DTV) ("Tropospheric propagation," 2015).

2.3 Keys to radio signal route loss

Broadly speaking, signal path loss is the weakening of a radio signal or wave as it passes through a certain area. Radio path losses may be caused by a wide range of factors. Here are some explanations for some of these causes.

2.3.1 Losses of free space

This kind of loss happens when a signal passes through a zone in space unaffected by external factors. The signal becomes weaker as it gets further away (Elechi and Otasomie, 2015). One approach to visualize the radio communications signal is as an expanding sphere that is raying away from the source. Because the signal has a broad region to cover, the principle of conservation of energy states that "the energy in any given area will reduce as the area covered becomes larger". This follows the inverse square rule as well.

2.3.2 Losses from absorption

This kind of loss occurs when radio waves hit materials such the ground (Ronald, 2000), walls and buildings (Elechi and Otasomie, 2015), plants (Meng et al., 2009), and air moisture (Dalip & Kumar, 2014) that are not completely transparent to the signal. It is comparable, on the other hand, to light passing through clear glass.

2.3.3 Losses from diffraction

Diffraction losses happen when an item or obstruction gets in the way of a radio wave. The signals scatter as they go around the obstruction, but the losses indicated before are the outcome. The bigger the loss, the more rounded the item. Sharp edges are often better for radio wave or signal diffraction (Elechi and Otasomie, 2015).

2.3.4 Multiple Path

A true terrestrial region is the consequence of several radio signal reflections. There are many ways for the signals to reach the receiver. The relative phases of the signals determine this; they may either add or subtract from one another. If the receiver is moved, it will be discovered that the whole signal received changes with location (Elechi and Otasomie, 2015). It is known as "Raleigh fading" effect. Mobile receivers, such as cellular telecommunications phones, exhibit it.

2.3.5 Terrain

Naturally, relief features like hills and mountains block the course of radio waves and greatly deteriorate them, which often results in poor or nonexistent reception. Therefore, a signal's or radio waves' propagation over a terrain will unavoidably have a significant influence on it (Famoriji and Olasoji, 2013). Furthermore, the earth's composition will have a big impact on radio waves or transmissions at low frequencies. As an example, it has been shown that signals travel more easily across more conductive terrain, such as moist, marshy, or marine routes on the long wave band. Sandy, arid terrains exhibit a greater degree of deterioration or attenuation.

2.4 Characterization of radio wave propagation and loss of free space paths

There are four main ways that radio waves or signals might propagate from a transmitter-antenna to a distant receiver-antenna, as diagrammatically shown in FIG. 3. These are the ground-reflected wave, the surface wave, the sky wave, and the director "line-of-sight" (LOS) wave. The direct or LOS wave is by far the most notable mode; yet, the other modes can reasonably affect the received resulting signal (Wayne, 2001)..

$$E = \frac{\sqrt{30 \cdot P_t \cdot G_t}}{d} \quad (5.1)$$

Where d is the distance, Gt is the antenna gain, and Pt is the transmitted power. E is volts per meter when Pt is in watts and d is in meters.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \quad (5.2)$$

The wavelength is represented by λ, and the transmitter and reception antenna gains are Gt and Gr.

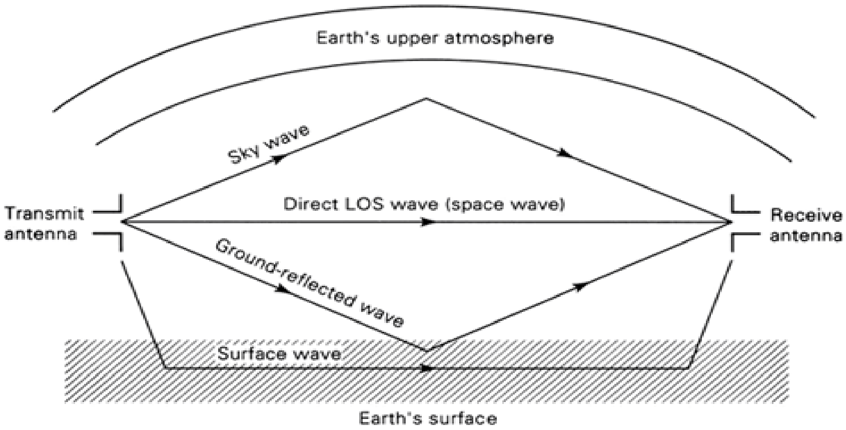

Fig. 1 Radio wave Propagation modes [Diagram].

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Four more phenomena are experienced by radio waves emanating from the transmitter-antenna, namely diffraction, reflection, refraction, and scattering (Freeman, 2007: Rappaport, 1996: Wayne, 2001). When the radio wave "bends" over obstructions or things like hilltops, it causes diffraction. Similar to how visible light reflects off things, reflection occurs when radio waves or signals bounce or ricochet off an item, such as the earth, water, or a structure. Refraction happens when a radio wave bends at the border between two medium with differing densities. This may happen when the atmosphere's density varies with altitude due to weather-related changes in the atmosphere. Lastly, scattering occurs when radio waves or signals hit things that are much smaller than the incoming radio waves' wavelength and cause the waves to disperse in several directions, as happens when a signal strikes trees, rough surfaces, etc. The broadcast radio wave or signal is impacted by the previously listed elements as it is "carried" to the distant receiver-antenna via the air channel (Rappaport, 1996: Seybold, 2005).

A "LINK-BUDGET" is often used to describe radio communications between two points—the transmitter and receiver radios, or vice versa, if the communications are two-way. The link budget accounts for all power gains and losses that occur between the transmitter and the receiver by allocating the available power (Wayne, 2001). Each receiver has a minimum threshold average power of signal that must be received in order for the broadcast signal to be appropriately demodulated and decoded at a performance level that is suitable. Below is an example link-budget between two radios, as shown in FIG. 4.

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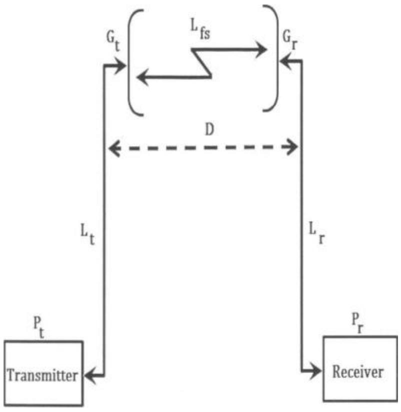

Fig.2 An exemplary link-budget between two radios [Diagram].

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This is how a basic link budget equation looks: Transmitted power (dBm) + gains (dB) - losses (dB) equals received power (dBm).

Prx=Ptx+Gtx–Ltx–Lfs–Lprop+Grx–Lrx, where

Prx is received power in dBm,

Ptx is transmitter power amplifier output power in dBm,

Gtx is transmitter antenna gain in dBi,

Ltx is transmitter losses (e.g., cable, connectors, radome) in dB,

Lfs is free space path loss in dB,

Lprop is other propagation losses (e.g., antenna mispointing, fading margin, polarization mismatch, interference, atmospheric environment) in dB,

Grx is receiver antenna gain in dBi, and

Lrx is receiver losses (e.g., cable, connectors, radome, demodulator loss) in dB.

The average power output of the transmitter, Pt, is available to the transmitting station. Lt indicates the transmitter power loss related to couplers, cabling, connections, etc. The transmitter-antenna's typical gain, or the antenna's input power less than the transmitter's output power, is Gt. The transmitter antenna's shape and the wavelength of the signals being sent determine GT. Additionally, the receiver-antenna has a gain, Gr, at the receiving end. Lr is the total of the various losses related to cabling coupling, etc. The signal received is funneled or transferred to the receiver itself for processing at the "front end," also known as the receiver end. It is essential that the received power level, Pr, be sufficient to satisfy the radio's performance requirements.

The transmitter-antenna may be considered a "Isotropic source" if it is seen as a point source of energy since radio waves will radiate from it in all directions equally. The antenna's energy will only disperse by free space dispersion. The energy of the signal will decrease as it radiates away from the antenna or as the radio waves scatter off of it (David, 2012: Freeman, 2007: Grabner and Kvicera, 2003: Wayne, 2001). The LFs indicate "FREE SPACE PATH LOSS" in this case.

When the signal is emitted and moves away from the antenna, this is the main cause of radio wave energy loss.

The free-space-path-loss depends on the spherical geometry of the area around the point-source antenna, the distance from the source antenna, and the frequency of the transmitted signal. Equation (2) illustrates the link that was seen above.

L_{fs}- (5 $= \left(\frac{c}{4TtfD}\right)^2$ .... (2)

LfS = Free-space path loss (Unit less)

D = Distance (meters)

f —Frequency (Hertz)

C = Speed of light in free space

This formula shows that the ratio of the received signal power to the power of transmitted signal is given by the mathematical expression in equation (3), (Wayne, 2001).

$$\frac{P_t}{P_r} = G_t G_r \left(\frac{\lambda}{4\pi D}\right)^2 \quad \text{………………………………………………………………………. (3)}$$

Friis expressions explicitly provide an overall relationship between the power transmitted (Pt) and received (Pr) that depends on the distance (D) between the two antennas and the wavelength (or frequency, f) of the transmitted signal. They do this by accounting for the free-space-path-loss and the gains of the transmitter and receiver antennas (Gt and Gr, respectively). The mathematical formula above makes the important assumption that there is a "direct line-of-sight" between the two antennas. The most remarkable channel that radio signals may travel over is the direct route between the two antennas (David, 2012; Freeman, 2007; Grabner & Kvicera, 2003). But the signal may go by a wide variety of additional routes or channels (Lavergnat and Sylvain, 2000: Parsons, 2000). Therefore, the resultant power of the received signal at the distant receiver may be found using the primary connection of Friis' formula between the sent signal power, the gains of the two antennas, and the remarkable "free-space-path-loss".

Logarithmic terminology may be used to express Friis' formula. Equation (4) illustrates how we translate the connection found in equation (3) into an explicit algebraic statement expressed in decibels.

Pr(dB) = Gt(dB) + Gr(dB) + 2010g10 C) + pt(dB)………………………………………..(4)

3. CONCLUSION

This study examined the effects of weather patterns on network performance and service quality provided by MTN, Glo, 9mobile, and Airtel network providers in the southern Nigerian states of Cross River, Bayelsa, Akwa Ibom, and Rivers State. Using the conventional Drive Test Method, radio frequency CRF/measurements were conducted at certain places in the aforementioned research regions. Key performance indicators (KPIs) were used to analyze the data and provide measurements for the quality of service. Each network provider's performance was assessed using these KPIs. The NCC threshold, which is established for all mobile network operators in Nigeria, was compared to the software MINITAB 17 that was used and the Time Series plots that were produced to ascertain the degree of variance of KPIs. In addition, a generic prediction equation was established for each, yt = B0 + B(t2 + But2), to forecast our data for the next 24 months.

In the days to come, this model 17 harness will guide GSM network operators in the research areas to monitor, boost capacity, and improve their quality of service. Analysis of Variance (ANOVA) was used to test whether there was a significant difference in the key performance indicators (KPIs) for MTN, Glo, 9mobile, and Airtel. Turkey conducted a post-HOC test.

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