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Evaluation of Fade Margin in Telecommunication Network in Auchi, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Fading is a concept that is associated with communications, be it digital or analogue. This work deals with the careful analysis, performance, and evaluation of fade margin on a particular mobile network in Nigeria, using Auchi as a case study. With the careful analysis that was carried out on three (3) different links using some collated data such as latitude, height of tower, power, antenna gain and model, frequency, path length and distance etc. It was discovered that the said mobile network fade margin across the three different links was within the acceptable range of 10db to 30db. Also, it was discovered that the longer the pathlength, the higher the fade margin value, as confirmed in the results. Thus, the major characteristics needed to determine the fade margin and evaluation process were effective and realizable.

Keywords: Fade margin; line of sight; path length; path profile; sensitivity; point to point.

1. INTRODUCTION

Line of Sight (LOS) communication is a type of wireless communication system communication in which the signal, such as a microwave, travels in a straight line using directional antennas. Line-of-sight propagation occurs when signals travel directly from the transmitting antenna to the

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receiving antenna [1]. Because of their small wavelength, microwaves are widely used for point-to-point communications because they can be directed in narrow beams that can be pointed directly at the receiving antenna using conveniently sized antennas. This allows microwave equipment in close proximity to use the same frequencies without interfering with one another [2].
Radio waves, by definition, do not follow the curvature of the earth. The curvature of the Earth is a direct impediment to line-of-sight communication. When there is enough distance between the two radio stations that their antennas fall behind the curvature of the earth, the earth itself blocks the transmitted signals from the receiver [1]. In that case, the transmitter and receiver antennas are raised and aligned with each other above the signal path's surrounding obstructions. Certain terrain and network parameters, such as the terrain elevation profile, the earth bulge, the obstruction height, the signal frequency, and the radius of the Fresnel zone, are taken into account when determining the minimum antenna height for clear line-of-sight [3].

The electromagnetic (EM) wave must travel through a non-homogeneous atmosphere, often over mixed terrain and uneven terrain. Furthermore, system design constraints may necessitate the establishment of a link over a path that contains unavoidable man-made or natural obstructions. Many of these non-free-space elements in the physical environment can cause the propagating wavefront to be absorbed, scattered, refracted, reflected, or diffracted. Reflection, diffraction, and scattering are the three basic propagation mechanisms that impact propagation in a mobile communication system. When a propagating electromagnetic wave strikes an object with very large dimensions in comparison to the wavelength of the propagating wave, reflection occurs. Reflections occur from the earth's surface as well as from buildings and walls. The primary source of reflections for an unobstructed LOS path over relatively flat terrain is the earth's surface. The effect of the ground reflected wavefront on the received signal is largely determined by the distance between the transmitting and receiving antennas, their relative heights, and the earth's surface's reflective properties.

This research work outlines the recommended methods used by Communication Infrastructure Corporation for conducting a thorough path survey, as well as key items to consider when hiring a company to install your network. Fidelis [3] presents a method for the determination of the minimum antenna mast height for line-of-sight wireless communications link with nonzero path inclination and with known height of one antenna that is above the maximum obstruction height of the antennas. This study aims to evaluate the performance of fade margin characteristics in communication systems using three different propagation links located in Auchi, Edo State, Nigeria.

Fig. 1. Mobile communication propagation Line of Sight (LOS)

2. LITERATURE REVIEW

Line of Site (LOS) communication is a type of communication used in wireless communication systems when the signal, such as microwave, can travel in a straight line. In that case, the transmitter and receiver antennas are raised and aligned with each other above the signal path's surrounding obstructions. Line-of-sight propagation occurs when signals travel directly from the transmitting antenna to the receiving antenna. In order to determine the minimum antenna height for a clear line-of-sight, certain terrain and network parameters are considered, namely, the terrain elevation profile, the earth`s bulge, the obstruction height, the signal frequency, and the radius of the Fresnel zone, among others [4].

Microwave radio communications necessitate a clear path between parabolic antennas, a condition known as line-of-sight (LOS). When there is a direct path between two points and no obstacles (e.g., buildings, trees, hills, or mountains) between them, there is LOS. Microwave radio waves are a type of electromagnetic radiation with wavelengths longer than infrared light in the electromagnetic spectrum. Radio waves have frequencies as high as 300 gigahertz (GHz) and as low as 30 hertz (Hz). At 300 GHz, the corresponding wavelength.

A major difference in propagation through the real atmosphere versus free space is that there is air present. The two absorption peaks present in the frequency range of commercial radio links are located around 23 GHz for water molecules and 60 GHz for oxygen molecules.

2.1 Related Works

In a study on communication links between a satellite and the Earth Station (ES), Aderemi [5] observed a lot of impairments such as noise, rain, and atmospheric attenuations. It is also prone to losses such as misalignment and polarization. It is therefore crucial to design for all possible attenuation scenarios before the satellite is deployed. Gemechu [2], presents a thesis which aims at providing microwave radio links operating at microwave frequencies between Jimma main and Agaro campuses with a minimum objective reliability of 99.999%. Geo context-profiler is used for path profile analysis, Feko suite 5.5 for rectangular waveguide design and a link budget calculator is used to create the designed link. Free space loss calculations, path profile analysis, fade margin, frequency planning, attenuation, rain fading predictions, reflection point calculations, tower heights, Signal to Noise Ratio, Fresnel zone, and link budget calculation are among the parameters considered in the analysis. Fresnel zone clearance was considered at least 60% of the first Fresnel zone Volkan [6] presents a study on optimally performing microwave communication networks that starts with a properly conducted path survey that analyses the microwave path's characteristics in order to identify and mitigate all potential signal obstructions. Finally, a thorough path survey can shorten outages and save money on costly repair or reinstallation costs. As the demand for point-to-point microwave transmission technology increases, the need for a properly designed and installed network becomes imperative. This paper outlines the recommended methods used by Communication Infrastructure Corporation for conducting a thorough path survey, as well as key items to consider when hiring a company to install your network. Fidelis [3] shows a method for the determination of the minimum antenna mast height for line-of-sight wireless communication links with nonzero path inclination and a known height of one antenna that is above the maximum obstruction height of the antennas. This study is aimed at the evaluation and performance of fade margin characteristics in communication systems using three different propagation links located at Auchi, Edo State, Nigeria.

3. MATERIALS AND METHODS

3.1 Materials

From the site location in Auchi, Nigeria, the data obtained were; link ID for transmitter and the receiver, latitude and longitude, Site location, Elevation (m), TX Power (dBm), Antenna gain (dBi), Antenna height (m), Frequency (MHz), Path length (km) Free space loss (dB), atmospheric absorption loss (dB) and antenna model for the transmitter are SC 2-W100A (TR) and the receiver is SC 2-W100A (TR), respectively. In addition, the R_X sensitivity of the antenna is given as -94dBm. As shown in Fig. 2.

Fig. 2. Auchi Map

The data obtained from three different locations from Network "A" are presented in Table 1 to Table 3 with the unique parameters deployed for analysis of Margin Fade characteristics [7-11].

Table 1. LOS Link Parameters for Point One

S/NO	LINK ID	EDO681(Transmitter)	EDO375(Receiver)
1.	Lat.	06 1553.64 N	06 16 40.19 N
2.	Long	005 42 30.24E	005 4102.40E
3.	Site location	Auchi	Auchi
4.	Circulator Branching Loss	0.50	0.50
5.	Elevation(m)	62.03	69.08
6.	TX Power (dBm)	24.00	24.00
7.	Antenna model	SC 2-W100A (TR)	SC 2-W100A (TR)
8.	Antenna gain (dBi)	34.50	34.50
9.	Antenna height (m)	30	35
10.	Net Path Loss (dB)	56.12	56.12
11.	Polarization	Vertical	
12.	Average Annual Temperature (^{0}C)	10^{0}C	
13.	Frequency (MHz)	11100.00	
14.	Path length (km)	3.06	
15.	Free space loss (dB)	123.07	
16.	Atmospheric Absorption Loss (dB)	0.05	

Table 2. LOS link parameters for point two

S/NO	Link ID	EDO682(Transmitter)	EDO502(Receiver)
1.	Lat.	06 23 06.36 N	06 23 06.14 N
2.	Long.	005 42 21.60E	005 42 49.73E
3.	Site location	Auchi	Auchi
4.	Circulator Branching Loss	0.50	0.50
5.	Elevation(m)	112.26	106.24
6.	TX Power (dBm)	14.00	14.00
7.	Antenna model	SB 1-220B (TR)	SB 1-220B (TR)
8.	Antenna gain (dBm)	35.60	35.60
9.	Antenna height (m)	25	25
10.	Net Path Loss (dB)	49.40	49.40
11.	Polarization	Vertical	

S/NO	Link ID	EDO682(Transmitter)	EDO502(Receiver)
12.	Average Annual Temperature (^{0}C)	10^{0}C	
13.	Frequency (MHz)	23000.00	
14.	Path length (km)	0.86	
15.	Free space loss (dB)	118.43	
16.	Atmospheric Absorption Loss (dB)	0.17	

Table 3. LOS link parameters for point two

S/NO	Link ID	EDO647(Transmitter)	EDO207(Receiver)
1.	Lat.	07 05 52.08 N	07 05 22.31 N
2.	Long.	006 18 21.24E	006 17 38.80E
3.	Site location	Auchi	Auchi
4.	Circulator Branching Loss	0.50	0.50
5.	Elevation(m)	298.40	315.78
6.	TX Power (dBm)	15.00	15.00
7.	Antenna model	SB 2-190A (TR)	SB 2-190A (TR)
8.	Antenna gain (dBm)	39.00	39.00
9.	Antenna height (m)	33	35
10.	Net Path Loss (dB)	46.09	46.09
11.	Polarization	Vertical	
12.	Average Annual Temperature (^{0}C)	10^{0}C	
13.	Frequency (MHz)	18782.00	
14.	Path length (km)	1.59	
15.	Free space loss (dB)	121.98	
16.	Atmospheric Absorption Loss (dB)	0.11	

3.2 Method

3.2.1 Analysis of margin fade

The level of received power in excess of that required for a specified minimum level of system performance is referred to as the “fade margin”. So-called because it provides a margin of safety in the event of a temporary attenuation or fading of the received signal power. The minimum required received power level used for the link budget can be totally arbitrary owing to the designer’s knowledge and experience, but is most often tied to the receiver’s sensitivity. Simply put, the receiver’s sensitivity specifies the minimum RF input power required to produce a useable output signal. Typical values for receiver sensitivity fall within the range of –90 to –120 dBm.

Note: the three different locations are identified by their latitude and longitude in the Auchi area, which are in the tables.

3.2.2 Point one analysis of margin fade characteristics

Parameters from Table 1;
Location: Auchi

Point of Location from EDO681 to EDO375

$$FadeMargin = P_{RX} - R_X Sensitivity \quad (3.1)$$

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{Path} + G_{RX} - L_{RX} \quad (3.2)$$

Where:

P_{TX}= the transmit power in dBm.
L_{TX}= the total system loss in dB at the transmitter.
G_{TX}= the antenna gains in dBi at the transmitter.
L_{PATH}= the total propagation losses in dB between the transmitter and the receiver antennas.
G_{RX}= the antenna gains in dBi at the receiver.
L_{RX}= the total system loss in dB at the receiver.
P_{RX}= the receive power in dBm.

First Stage

Transmit power (P_{TX}) is given 24.00dBm

Second Stage

System loss

Surge kit loss = (–0.5), cable loss = (–1.7), connectors loss (–0.5), mismatch loss (–0.511) ≈ –3.2 dB
Circulation Branching loss (dB) = 0.50 dB, atmosphere absorption loss 0.05dB
L_{TX}= surge kit (–0.5) + cable (–1.7) + connectors (–0.5) + mismatch (–0.511) ≈ –3.2 dB + Circulation Branching loss and atmosphere absorption loss (-0.55) Net Path Loss (56.12) = -59.87 dB
L_{RX}= surge kit (–0.5) + cable (–0.85) + connectors (–0.5) + mismatch (–0.511) ≈ –2.35 dB+ Circulation Branching loss and atmosphere absorption loss (-0.55) + Net Path Loss (56.12) = -59.02 dB (3.3)

Third Stage

Antenna Gain (dBi) = 34.50
From Table 2

Fourth Stage

N0TE: standard atmosphere (standard refraction = *k* = 1.33) over a smooth earth, the distance to the RF horizon is related to the height of the antenna as follows;

$$d_{HOR} = 4.124\sqrt{h} \quad (3.4)$$

D_{HOR}= distance in kilometers to the RF horizon
h = the antenna height in meters above a smooth earth

$$d_{HOR} = 1.414\sqrt{h} \quad (3.5)$$

The maximum line-of-sight path distance is equal to the sum of the RF horizon distance for both the transmitting and receiving antennas:

$$LOS_{max} = 4.124\sqrt{h_{TX}} + 4.124\sqrt{h_{RX}} \quad (3.6)$$

Where:
LOS_{max} = the maximum line-of-sight path distance in kilometers
h_{TX}= height of the transmitting antenna in meters above a smooth earth= 30m
h_{RX}= height of the receiving antenna in meters above a smooth earth=35m

$$LOS_{max} = 4.124\sqrt{30} + 4.124\sqrt{35}$$
$$LOS_{max} = 22.588 + 24.398 = 46.986km$$
$$LOS_{max} = 47.0km$$

Note: For a link to be considered as having a line-of-sight path of propagation, the distance between the transmitting and receiving antennas must be equal to or less than the maximum line-of-sight path distance: $d_{PATH} \leq LOS_{max} = 3.06 \leq 47.0$

Note: 3.06 km distance path from Table (1) (the distance between the transmitting and receiving antennas) is less than the maximum allowable 47.0 km, this link qualifies as a LOS path of propagation.

3.3.1 Free space propagation model

As an EM wave propagates in free space, the power density per unit area decreases in proportion to the frequency and the square of the distance traveled.

These facts give rise to the classic free space loss equation:

$$FSL_{dB} = 32.45 + 20\log(d) + 20\log(f) \quad (3.7)$$

Where:

FSL (dB) = free space loss in dB
d = distance in kilometers
f = frequency in megahertz
Therefore, for a distance of 3.06 km and an operating frequency of 11100.00 MHz from table 4:

$$FSL_{dB} = 32.45 + 20\log(3.06) + 20\log(11100.00)$$
$$FSL_{dB} = 32.45 + 9.7144 + 80.906 = 123.071$$

While free space loss alone is often used in link budget calculations, it is important to understand that in this context, the term “free space” is meant literally; there is no atmosphere and no reflective surfaces or obstructions of any type. This does not represent a realistic environment for earth-based telemetry links, and for many path scenarios; the use of free space loss alone will not result in a realistic link budget.

3.3.2 2-Ray multipath propagation model

The EM wave must propagate through a nonhomogeneous atmosphere over a path of often mixed terrain and uneven topography. Additionally, system design constraints may require that a link be established over a path containing unavoidable manmade or natural obstructions. Many of these non-free-space elements in the physical environment can cause the propagating wavefront to be absorbed, scattered, refracted, reflected, or diffracted. For an unobstructed LOS path over relatively flat terrain, the primary source of reflections is the earth's surface. The effect of the ground reflected wavefront on the received signal is largely dependent on the distance between the transmitting and receiving antennas, the relative height of the antennas, and the reflective properties of the earth's surface.

The reflected wavefront will interfere with the direct wavefront either constructively or destructively. *Constructive interference* occurs when the wavefronts arrive more or less in phase ($\theta_{diff} < \pm 90^0$). A 0° phase shift with a small difference in amplitude can result in as much as a 6 dB gain in received signal strength relative to the direct wavefront alone. Conversely, *destructive interference* occurs when the wavefronts arrive more or less out of phase ($\theta_{diff} > \pm 90^0$). With a phase difference of 180° and a small difference in amplitude, the wavefronts will cancel out, resulting in a null in the received signal level.

When the path distance is equal to or greater than the critical distance, the relative antenna heights become very small compared to the path distance, and the angle of incidence will approach 0°. For this path geometry, the phase shift contributable to a difference in path lengths becomes very small, and the phase shift induced in the reflected wave approaches 180° for both vertical and horizontal polarization. Under these conditions, the power density per unit area will decrease in proportion to the fourth power of the distance, and the path loss can be calculated using the following equation:

$$PL_{2Ray} = 120 - 20\log(h_{TX}h_{rx}) + 40\log(d) \quad (3.7)$$

Where:
PL_{2Ray} = 2-ray path loss in dB
h_{TX}= height of the transmitting antenna in meters
h_{RX}= height of the receiving antenna in meters
d = distance between antennas in kilometers

The critical distance (d_c) is calculated as follows:

$$d_c = \frac{4\pi h_{TX}h_{RX}}{\lambda} \quad (3.8)$$

Where:
$d_c = critical distance in meters$

λ = wavelength of the propagating EM wave, 27.03 meters @ 11100.0 MHz

$$d_c = \frac{4\ x\pi x\ 30\ x\ 35}{27.03} = \frac{13{,}188}{27.03} = 487.9$$
$$d_c = 497.9\ meter$$
$$d_c = 0.4979\ kilometer$$

For d<d_c : calculate path loss using the free space propagation model, using Equation (3.7)

For d ≥ d_c : calculate path loss using the 2-ray propagation model, using Equation (3.7)

Because the distance between antennas is 3.06 kilometers, this requires the Free Space Propagation Model (FSL).

Therefore

For d< d_c

$$FSL_{dB} = 32.45 + 9.7144 + 80.906 = 123.071$$
$$L_{PATH} = FSL_{dB} = 32.45 + 9.7144 + 80.906 = 123.071$$
$$L_{PATH} = 123.071$$

For d ≥ d_c :

Recall Equation (3.7) the 2-Ray Multipath Propagation Model

$$PL_{2Ray} = 120 - 20\log(h_{TX}h_{rx}) + 40\log(d)$$

Where:
PL_{2Ray} = 2-ray path loss in dB
h_{TX}= height of the transmitting antenna in meters =30
h_{RX}= height of the receiving antenna in meters =35
d = distance between antennas in kilometers =3.06

Therefore

$$PL_{2Ray} = 120 - 20\log(30\ x\ 35) + 40\log(3.06)$$
$$PL_{2Ray} = 120 - 20\log(1050) + 40\log(3.06)$$
$$PL_{2Ray} = 120 - 60.42 + 19.43 = 120 - 79.85 = 40.15dB$$

Fifth Stage

3.3.3 Received signal level

With all the input parameters to the link budget, the power level arriving at the receiver's input can be calculated.

Recall Equation (3.2)

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{Path} + G_{RX} - L_{RX}$$

Where:
P_{TX}= the transmit power in dBm = 24.00dBm
L_{TX}= the total system loss in dB at the transmitter=59.87dB
G_{TX}= the antenna gain in dBi at the transmitter = 34.50 dBi
L_{PATH}= the total propagation losses in dB between the transmit and receive antennas =123.071dB
G_{RX}= the antenna gain in dBi at the receiver = 34.50 dBi
L_{RX}= the total system loss in dB at the receiver =59.02dB
P_{RX}= the receive power in dBm =

$$P_{RX} = 24.00\text{dBm} - (59.87\text{dB}) + 34.50\text{dBi} - 123.071dB + 34.50\text{dBi} - (59.02\text{dB}) = -148.96dBm$$

Power received, using free space loss model.

Sixth Stage

3.3.4 Fade margin

Note that the receiver's sensitivity specifies the minimum RF input power required to produce a useable output signal.

Two common methods of specifying receiver sensitivity are:

- The minimum input signal level is required to limit the number of errors in the received digital data stream to a maximum Bit Error Rate (BER). A typical specification would be: –103 dBm for 1 x BER—meaning, one bit error for every ten thousand bits received.
- The minimum input signal level is required to produce a minimum SINAD ratio in the demodulated audio. SINAD is the ratio, in dB, of (Signal + Noise + Distortion) to (Noise + Distortion) and is an expression of audio quality for voice communications. A typical specification is assumed to be 0.28 μV for 12 dB SINAD. A somewhat subjective industry standard specifies a SINAD ratio of 12 dB as the minimum required for intelligible voice communications.

For link budget calculations, it is convenient to convert units of voltage to units of power. For a 50 Ω system (the standard for the telecommunications industry), the following equation can be used to convert volts to power in dBm:

Therefore

$$P_{dBm} = 10\log\left[\frac{(Vx10^{-6})^2}{50}\right] + 30 \quad (3.9)$$

Where:
P_{dBm} = power in dBm
V = rms voltage in microvolts
Rx Sensitivity at 0.25 uV for 12 dB SINAD

$$R_xSenitivity\ (P_{dBm}) = 10\log\left[\frac{(0.25\ x10^{-6})^2}{50}\right] + 30$$

$$R_xSenitivity\ (P_{dBm}) = -119dBm$$

Therefore, fade margin for the link can be deduced using Equation (1) based on transmit power in dBm (*P_{TX})* and R_X Sensitivity parameters

$$FadeMargin = P_{RX} - R_XSensitivity = (-148.96) - (-119dBM) = -29.96\ dB$$

A link budget provides a quick, simplistic assessment of a link's viability.

The goal should be for a minimum fade margin of 20 to 30 dB. If the link budget calculations or on-site measurements indicate a fade margin of less than 10 dB, one should exercise all possible options to improve upon this figure. Some possible options are:

Use an antenna with a higher gain specification on one or both ends of the link. One should be cognizant of any FCC regulations that may put limits on the maximum radiated power for given transmitter site.

- Increase the antenna elevation at one or both ends of the link. If path obstructions or multipath interference is suspected, even a small increase (or decrease) of one-half wavelength could make a significant difference in received signal level. Any increase in system losses due to a longer transmission line are usually more than offset by the decrease in path loss.
- Add a repeater site to the path. By far, the largest factor in a link budget is path loss.

Therefore

NOTE: The receiver antenna used is SC 2-W100A (TR) with receiver sensitivity given as -94dBm from: (https://media.digikey.com/pdf/Data%20Sheets/Linx%20Technologies%20PDFs/TR-xxx-SC-P.pdf)

$$R_X Sensitivity = -94dBm$$

$$FadeMargin = P_{RX} - R_X Sensitivity$$

$$FadeMargin = P_{RX} - R_X Sensitivity$$
$$= (-148.96) - (-94dBM)$$
$$= -54.96\ dB$$

Therefore

L_{PATH}= the total propagation losses in dB between the transmit and receive antennas =$40.15dB$dB
Using the 2-Ray Multipath Propagation Model

$$P_{RX} = 24.00\text{dBm} - (59.87\text{dB}) + 34.50\text{dBi} - 40.15dB + 34.50\text{dBi} - (59.02\text{dB}) = -65.17dBm$$
$$Margin = P_{RX} - R_X Sensitivity = (-65.17) - (-94dBM) = 28.83\ dB$$

3.4 Point Two Analysis of Margin Fade Characteristics

Analysis for link 2 using Table 2 parameters

First Stage

Transmit power (P_{TX}) is given 14.00dBm

Second Stage

System loss

Circulation Branching loss (dB) = 0.50 dB, atmosphere absorption loss 0.17dB and Net Path Loss (49.40)

L_{TX}= surge kit (–0.5) + cable (–1.7) + connectors (–0.5) + mismatch (–0.511) ≈ –3.2 dB + Circulation Branching loss (0.50) + atmosphere absorption loss (=0.17)+ Net Path Loss (49.40) = -52.82 dB

L_{RX}= surge kit (–0.5) + cable (–0.85) + connectors (–0.5) + mismatch (–0.511) ≈ –2.35 dB+ Circulation Branching loss (0.50) + atmosphere absorption loss (=0.17)+ Net Path Loss (49.40) = **-51.97 dB**

Third Stage

From table 2
Antenna Gain (dBi) = 35.60

Fourth Stage

Path Loss $LOS_{max} = 4.124\sqrt{h_{TX}} + 4.124\sqrt{h_{RX}}$

Where:
LOS_{max} = the maximum line-of-sight path distance in kilometers
hTX= height of the transmitting antenna in meters above a smooth earth =25
hRX= height of the receiving antenna in meters above a smooth earth= 25

$$LOS_{max} = 4.124\sqrt{25} + 4.124\sqrt{25}$$
$$LOS_{max} = 20.62 + 20.62 = 41.24km$$
$$LOS_{max} = 41.0km$$

The critical distance (d_c) is calculated as follows:

$$d_c = \frac{4\pi h_{TX} x h_{RX}}{\lambda}$$

Where
d_c = Critical distance in meters
h_{TX}= height of the transmitting antenna in meters=25
h_{RX}= height of the receiving antenna in meters=25

λ = wavelength of the propagating EM wave, 13.04 meters @ 23000.00MHz

$$d_c = \frac{4\ x\pi x25\ x25}{13.04} = \frac{7850}{13.04} = 601.99$$

$$d_c = 601.99\ meter$$
$$d_c = 0.602\ kilometer$$

For d<d_c : calculate path loss using the free space propagation model, using above Equation

For d ≥ d_c : calculate path loss using the 2-ray propagation model, using above Equation(3.7)
Note d= 0.86

Therefore, the path loss will determine using the 2-ray propagation model, using Equation (3.7)

$$PL_{2Ray} = 120 - 20\log(h_{TX}h_{RX}) + 40\log(d)$$

Where:
PL2Ray = 2-ray path loss in dB
h_{TX}= height of the transmitting antenna in meters =25
h_{RX}= height of the receiving antenna in meters =25
d = distance between antennas in kilometers =0.86
Therefore,

$$PL_{2Ray} = 120 - 20\log(25\,x\,25) + 40\log(0.86)$$
$$PL_{2Ray} = 120 - 20\log(625) + 40\log(0.86)$$
$$PL_{2Ray} = 120 - 20(2.7958) + 40\log(0.86)$$
$$PL_{2Ray} = 120 - 55.92 + (-2.62) = 61.46$$
$$PL_{2Ray} = 61.46dB$$

Received Signal Level: With all the input parameters to the link budget, the power level arriving at the receiver's input can be calculated

Recall Equation (3.2)

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{Path} + G_{RX} - L_{RX}$$

Where:
P_{TX}= the transmit power in dBm = 14.00dBm
L_{TX}= the total system loss in dB at the transmitter=52.82 dB
G_{TX}= the antenna gain in dBi at the transmitter = 35.60
L_{PATH}= the total propagation losses in dB between the transmit and receive antennas =61.46 dB
G_{RX}= the antenna gain in dBi at the receiver = 35.60
L_{RX}= the total system loss in dB at the receiver =51.97 dB
P_{RX}= the receive power in dBm = $P_{RX} = 14.00dBm - (52.82dB) + 35.60dBi - 61.46dB + 35.60dBi - (51.97dB) = -81.05$

Recall equation

$$Fade\ margin = P_X - R_X sensitivity$$

Assuming,

$$R_X sensitivity = -94$$
$$Fade\ margin = P_X - R_X sensitivity = (-81.05) - (-94) = 12.95$$

3.5 Point Three Analysis of Margin Fade Characteristics

Analysis for link 3 using Table 3 parameters

First Stage

Transmit power (P_{TX}) is given 15.00dBm

Second Stage

System loss

Circulation Branching loss (dB) = 0.50 dB, atmosphere absorption loss 0.11dB and Net Path Loss (48.09)

L_{TX}= surge kit (–0.5) + cable (–1.7) + connectors (–0.5) + mismatch (–0.511) ≈ –3.2 dB + Circulation Branching loss (0.50) + atmosphere absorption loss (=0.11) + Net Path Loss (46.09) = -49.9 dB

L_{RX}= surge kit (–0.5) + cable (–0.85) + connectors (–0.5) + mismatch (–0.511) ≈ –2.35 dB+ Circulation Branching loss (0.50) + atmosphere absorption loss (=0.11) + Net Path Loss (46.09) = -49.05 dB

Third Stage

From Table 3
Antenna Gain (dBi) = 39.00

Fourth Stage

Path Loss

$$LOS_{max} = 4.124\sqrt{h_{TX}} + 4.124\sqrt{h_{rx}}$$

Where:
LOS_{max}= the maximum line-of-sight path distance in kilometers
h_{TX}= height of the transmitting antenna in meters above a smooth earth =33
h_{RX}= height of the receiving antenna in meters above a smooth earth= 35

$$LOS_{max} = 4.124\sqrt{33} + 4.124\sqrt{35}$$
$$LOS_{max} = 23.69 + 24.398 = 48.09\ km$$
$$LOS_{max} = 48.1km$$

The critical distance (d_c) is calculated as follows:

$$d_c = \frac{4\pi h_{TX}\,x\,h_{rx}}{\lambda}$$

Where:
d_c =Critical distance in meters
h_{TX}= height of the transmitting antenna in meters = 33
h_{RX}= height of the receiving antenna in meters = 35

λ = wavelength of the propagating EM wave, 15.97 meters @ 18782.00MHz

Table 4. Key performance indicators parameters

Location with lat. & long														
Transmitter	**Receiver**	**AntennasModel**	**Transmitpower (P_{TX}) dBm**	***Path length distance (Km)***	**L_{RX} total system loss (dB) receiver**	**L_{TX} total system loss (dB) transmitter**	**Antenna Gain (dBi)**	**LOS_{MAX}(Km)**	**d_c Critical distance (km)**	**Free Space Propagation Model(FLS) dBm**	**2-rayPropagation Model (dB)**	**P_{RX} receive power (dBm)**	**R_X Sensitivity(dBm)**	**Margin Fade (dB)**
EDO681 06 1553.64 N& 005 42 30.24E	EDO375 06 16 40.19 N &005 4102.40E	SC 2-W100A (TR)	24.00	3.06	59.02	59.87	34.5	47.0	0.498	123.71	40.15	65.17	-94	28.83
EDO682 06 23 06.36N & 005 42 21.60E	EDO502 06 23 06.14N & 005 42 49.73E	SB 1-220B (TR)	14.00	0.86	51.97	52.82	35.60	41.0	0.6O2		61.46	81.05	-119	12.95
EDO647 06 23 06.36N & 005 42 21.60E	EDO207 06 23 06.14N & 005 42 49.73E	SB 2-190A (TR)	15.00	1.59	49.05	49.9	39.00	48.1	0.909		66.81	72.76	-119	21.24

$$d_c = \frac{4\pi h_{TX} x\, h_{RX}}{\lambda} = \frac{14{,}520}{15.97} = 909.2$$

$$d_c = 909.2\ meter$$
$$d_c = 0.9092\ kilometer$$

For $d<d_c$: calculate path loss using the free space propagation model, using Equation

For $d \geq d_c$: calculate path loss using the 2-ray propagation model, using Equation

Path length d=1.59 and d_c =0.9092

Therefore, the path loss will determine using the 2-ray propagation model, using Equation ()

$$PL_{2Ray} = 120 - 20\log(h_{TX}\ x\ h_{rx}) + 40\log(d)$$

Where:
PL_{2ray}= 2-ray path loss in dB
h_{TX}= height of the transmitting antenna in meters =33
h_{RX}= height of the receiving antenna in meters =35
d = distance between antennas in kilometers =1.59

Therefore,
$$PL_{2Ray} = 120 - 20\log(33\ x\ 35) + 40\log(1.59)$$
$$PL_{2Ray} = 120 - 20\log(1155) + 40\log(1.59)$$
$$PL_{2Ray} = 120 - 20\ (3.06258) + 40\log(1.59)$$
$$PL_{2Ray} = 120 - 61.25 + (8.0559) = 66.8059$$
$$PL_{2Ray} = 66.81\ dB$$

Received Signal Level: With all the input parameters to the link budget, the power level arriving at the receiver's input can be calculated

Recall above Equation

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{Path} + G_{RX} - L_{RX}$$

Where:
P_{TX}= the transmit power in dBm = 15.00dBm
L_{TX}= the total system loss in dB at the transmitter=49.9 dB dB
G_{TX}= the antenna gains in dBi at the transmitter = 39.00
L_{PATH}= the total propagation losses in dB between the transmit and receive antennas = 66.81dB
G_{RX}= the antenna gains in dBi at the receiver = 39.00
L_{RX}= the total system loss in dB at the receiver = 49.05 dBdB
P_{RX}= the receive power in dBm = $P_{RX} = 15.00\text{dBm} - (49.9\text{ dB}) + 39.00\text{dBi} - 66.81dB + 39.00\text{dBi} - (49.05\text{ dB}) = 72.76$

Recall

Fade Margin = P_{RX} – R_XSensitivity

Assuming

R_X Sensitivity=-94dBm

$$Fade\ Margin = P_{RX} - R_X\ Sensitivity$$
$$= (+72.76) - (-94dBm)$$
$$= 21.24dB$$

The analysis of margin fades characteristics from Network "A" for the three links considered were presented in Table 4.

4. DISCUSSION AND RESULT ANALYSIS

This result obtained from network 'A' from three different Mobile links location at Auchi were considered. The basic parameters associated with mobile communication fade margin were determined and presented in Table 5.

The comparison between total system loss in decibel at the transmitter (L_{TX}) and total system loss in decibel at the receiver show in Fig 3, it was observed that both transmitter and receiver total system loss in decibel are in close correlation due to hardware devices such as antenna connector, combination of coaxial cables, surge suppressors, and possibly even band pass filters used to connect the transceiver to the antenna.

The transmitter power in decibel has great effects on the path length distance of microwave line of sight. Therefore, the three mobile links considered in Fig. 4, it was observed that increase in path length distance of microwave line of sight, will necessitate increase in transmitter power in decibel in microwave line of sight system.

Table 5. Key performance indicators parameters

Number of links	Link One		Link Two		Link Three	
Link ID	EDO681 (Transmitter)	EDO375 (Receiver)	EDO682 (Transmitter)	EDO502 (Receiver)	EDO 647 (Transmitter)	EDO207 (Receiver)
Lat. and long,	06 1553.64 N and 005 42 30.24E	06 16 40.19 N and 005 4102.40E	06 23 06.36 N and 005 42 21.60E	06 23 06.14 N and 005 42 49.73E	07 05 52.08 N and 006 18 21.24E	07 05 22.31 N and 006 17 38.80E
Antennas Model	SC 2-W100A(TR)	SC 2-W100A(TR)	SB 1-220B (TR)	SB 1-220B (TR)	SB 2-190A (TR)	SB 2-190A (TR)
Site location	Auchi		Auchi		Auchi	
Path length distance (Km)	3.06		0.86		1.59	
L_{TX} total system loss (dB) transmitter	59.87		52.82		49.9	
Antenna Gain (dBi)	34.5		35.60		48.1	
LOS_{MAX} (Km)	47.0		41.0		48.1	
Critical distance (km)	0.498		0.602		0.909	
Obtained Free Space Propagation Model (FLS) (dBm)	123.07		118.43		121.98	
Calculate Free Space Propagation Model (FLS) dBm	123.71		118.37		121.95	
2-ray Propagation Model (dB)	40.15		61.46		66.81	
P_{RX} receiver power (dBm)	65.17		81.05		72.76	
Margin Fade (dB)	28.83		12.95		21.24	

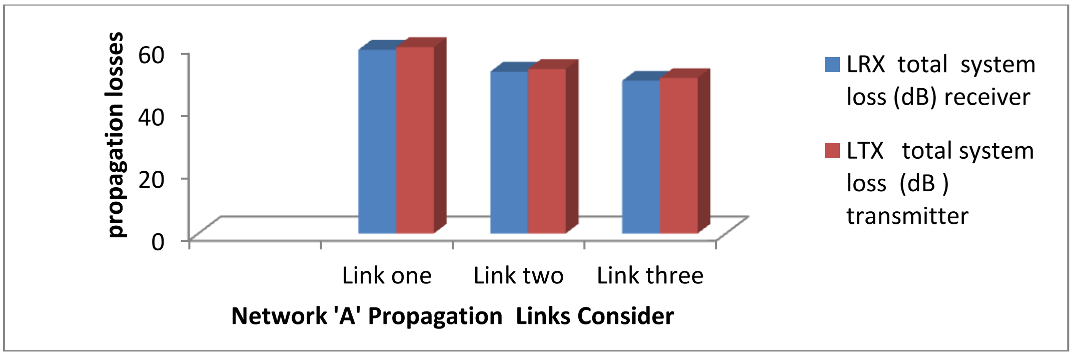

Fig. 3. Comparative between transmitter and receiver losses in db from three different links

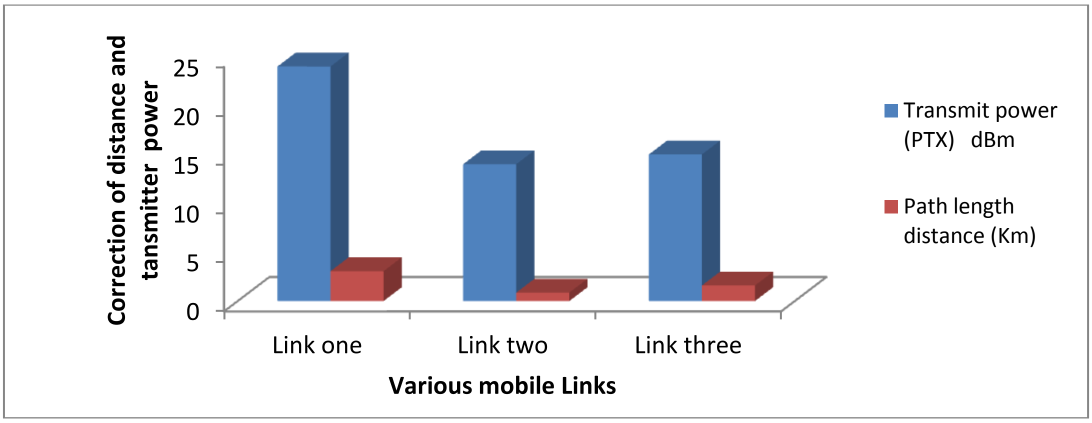

Fig. 4. Relationship between transmitter power and path length distance

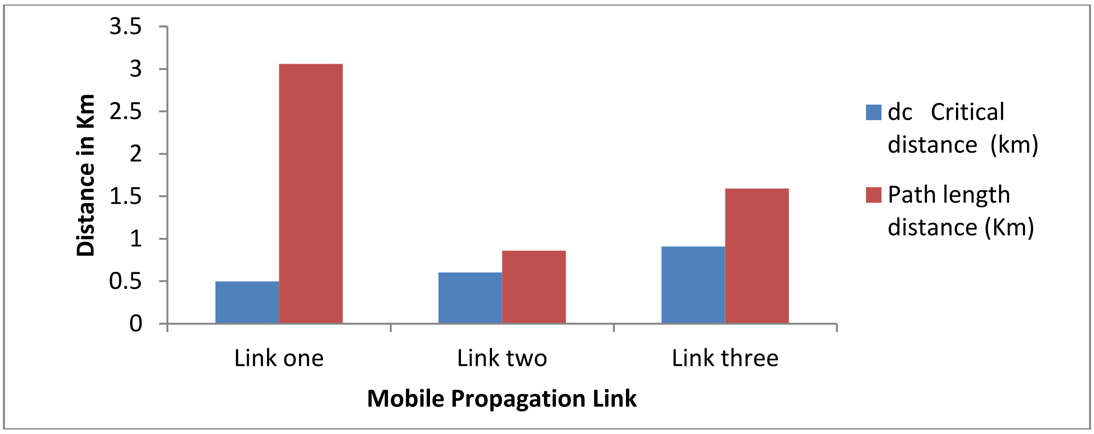

Fig. 5. Critical distance and path length distance

The critical distance is deduced due to environmental effect from reflection both from the ground, water body, cloud etc. The critical distance is major factor in deploying either free space propagation model or 2-Ray Multipath Propagation Model in determining the receive power in dBm.

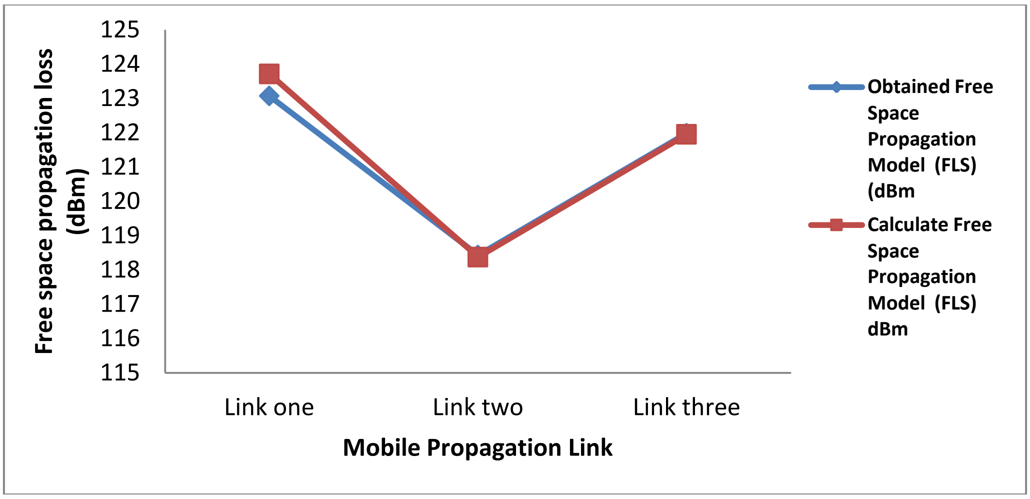

Fig. 6. Correlation between Obtained and Calculated Free Space Propagation Model (FLS)

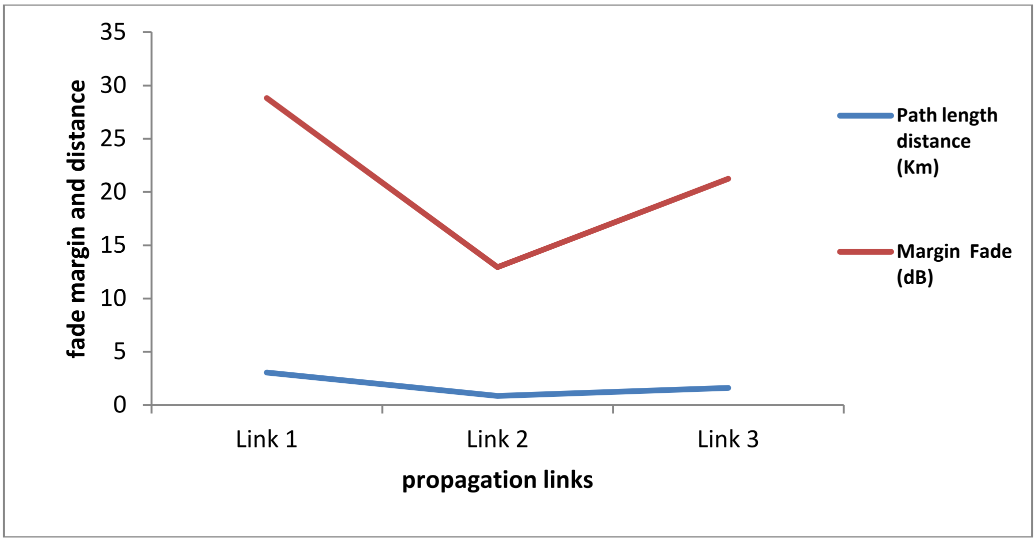

Fig. 7. Propagation link for both fade margin and path length distance

The comparison between the obtained and calculated free space propagation models presented in Fig. 6. It was observed that both obtained Free Space Propagation Model from the field and calculated free space propagation model using Equation 3.7 possess a close correlation and attribute shown in Fig. 6.

When the path length distance and margin fade of the three basic mobile operator's propagation links were considered, it was observed that the path length distance characteristic is affected due to the length of distance, obstacles, reflection, diffraction from ground, water bodies, and atmosphere, which results in the pattern of radio margin fade signal obtained in receiver antenna.

The maximum receiver signal is the highest value of the received signal that is safe and would not damage the receiver. A typical value is around 20 dBm. An RF telemetry link is required; the design goal should be to have a minimum fade margin of 20 to 30 dB. If the link budget calculations or on-site measurements indicate a fade margin of less than 10 dB, one should exercise all possible options to improve upon this figure. Some possible options are: using an antenna with a higher gain specification on one or both ends, increasing the antenna elevation at one or both ends of the link, adding a repeater site to the path, etc.

5. CONCLUSION

Mobile communication has become a major driving force in the economic development of many countries. Therefore, the mobile communication operators are saddled with efficient service delivery, especially for long-distance communication. The microwave technology using line-of-sight became paramount in mobile communication Networks, which led to the determination of the fade margin of the LOS. The various fade margin characteristic parameters were determined using existing mathematical models. Data was obtained from network "A" mobile communication network in Nigeria. Three different mobile propagation links were considered. The obtained data are link ID, Lat. & Long, Site location, Atmospheric Absorption Loss (dB), Elevation (m), TX Power (dBm), Antenna model, Antenna gain (dBi), Antenna height (m), Net Path Loss (dB), Polarization, Frequency (MHz) and Path length (km). Based on evaluation, the following parameters were obtained: margin fade (dB), receiver power (dBm), 2-ray propagation model (dB), free space propagation model (dB), LOS_{MAX} (Km), and critical distance (km) were determined. It was observed that path length distance characteristic such as the length of distance, obstacle, reflection, diffraction from ground, water bodies and atmosphere result to the pattern of radio margin fade signal obtained in receiver antenna. Thus, further work on more radio propagation links to other locations in Nigeria should be examined for proper validation.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is

absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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