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Evaluation and Performance of Path Profile Characteristics in Communication System

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ABSTRACT

This study presents the evaluation and performance of path profile characteristics in communication system, to determine the path profile characteristics such as margin fade (dB), receiver power (dBm), 2-ray propagation model (dB), free space propagation model (dB), LOS_{MAX} (km) and critical distance (km). Data were obtained from Network 'A', using three different links within a geographical location in Edo State. Receiver power is mathematic model, the sensitivity of the receiver, which depends on the bandwidth (data rate) (dBm) of antennas were considered in this analysis. All the path profile characteristics were determined, it was observed, that increase in path length distance of microwave line of sight, will necessitate the increase in transmitter power in decibel. The Path length distance and margin fade of the three basic mobile propagation links were determined. It was observed that path length distance characteristic as such the length of distance, obstacle, reflection, diffraction from ground, water bodies and atmosphere resulted to the pattern of radio margin fade signal obtained in receiver antenna. The margin fade determined are 28.83 dB, 12.95 dB and 21.24 dB for the three different links considered from Network 'A' in Auchi, Nigeria.

1. Introduction

In wireless communication systems, line-of-sight (LOS) communication is a form of communication used when the signal, such as microwave, travel in a straight line using directional antennas (Fig. 1). When signals travel directly from the transmitting antenna to the receiving antenna, this is referred to as line-of-sight propagation [1]. Microwaves are widely used for point-to-point communications, because of their small wavelength associated with it and leading to use of sizeable antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna. This allows nearby microwave equipment to use the same frequencies without interfering with each other [2].

Naturally, radio wave did not follow the natural curvature of the earth. Earth's curvature is a direct block to line-of sight communication. When enough distance separates the two radio stations so that their antennas fall behind the curvature, the earth itself blocks the transmitted signals from the receiver [1]. Therefore, the transmitter and receiver antennas are raised and aligned to each other above the surrounding obstructions in the signal path. In order to determine the minimum antenna height for clear line-of-sight, certain terrain and network parameters are considered; namely, the terrain elevation profile, the earth bulge, the obstruction height, the signal frequency, radius of the Fresnel zone, among others [3].

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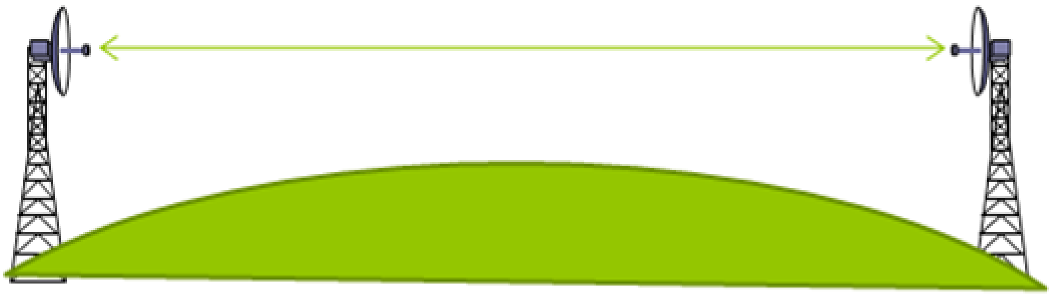

Fig. 1 Mobile Communication Propagation LOS.

The Electromagnetic (EM) wave must be propagating through non homogeneous 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 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 which impact propagation in a mobile communication system. Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave. Reflections occur from the surface of the earth and from buildings and walls. 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 ($\theta_{\text{diff}} < \pm 90^0$). 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 ($\theta_{\text{diff}} > \pm 90^0$). The phase difference of 180° and a small difference in amplitude, the wavefronts will cancel out, resulting in a null in the received signal level. Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surfaces and even behind the obstacle, it gives rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction. Scattering occurs when the medium through which the wave travels consist of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel.

In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system [4, 5]. Path loss is the principal contributor to loss in the link budget. It is the sum of free space loss plus additional losses induced by the interaction of the EM wavefront with the terrain and/or obstructions along the path of propagation [4]. Fading is defined as the variation of the strength of a received radio carrier signal due to atmospheric changes due to ground and water reflections in the propagation path. Fading types normally considered when planning microwave point-to-point paths are as follows: multipath fading, which is divided into Flat fading, Frequency-selective fading, Rain fading and Refraction-diffraction fading (k-type fading), all fading types are strongly dependent on the path length and are estimated as the probability of exceeding a given (calculated) fade margin. Design of microwave link involve free space loss calculation, path profile analysis, fade margin, frequency planning, attenuation, rain fading predictions, reflection points calculation, tower heights, Signal to Noise Ratio, Fresnel zone and link budget calculation [6,7].

The optical horizon derives from an optical LOS, which is a straight, direct path of slant-range distance from the antenna (or eyeball) to a point tangent to the earth's surface. A radio frequency LOS follows a curved path that is initially parallel to the earth's surface but is progressively bent toward the surface due to the refractive properties of the atmosphere. Therefore, the distance to the RF horizon will be somewhat (≈ 7%) greater than the distance to the optical horizon. For a 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 [8, 9].

Sensitivity of the receiver antenna, which depends on the bandwidth (data rate) (dBm), Receiver sensitivity is a measure of the ability of a receiver to demodulate and get information from a weak signal. In digital systems, receive signal quality is measured by calculating the ratio of bits received that are wrong to the total number of bits received. This is called bit error rate (BER) [5, 10, 11].

Dengia et al. [2], presented an article, which aims at providing microwave radio link operating at microwave frequencies Jimma main and Agaro campuses, with the minimum objective reliability 99.999%. The designed link depends on Geo context-profiler for path profile analysis, Feko suite 5.5 for rectangular waveguide design, and link budget calculator. In the analysis, there are parameters, which are significant in design of microwave link establishment: free space loss calculations, path profile analysis, fade margin, frequency planning, attenuation, rain fading predictions, reflection point's calculation, tower heights, signal to noise ratio, Fresnel zone and link budget calculation. Fresnel zone clearance was considered at least at 60% of the first Fresnel zone.

Nwaduwa et al. [3], showed a method for the determination of the minimum antenna mast height for line-of-sight wireless communication link with nonzero path inclination and with known height of one antenna that is above the maximum obstruction height of the antennas is presented. Atayero et al. [6], presented a study on communication link between a satellite and the Earth station (ES). The authors observed a lot of impairments such as noise, rain and atmospheric attenuations. It is also prone to loss such as misalignment and polarization. It is therefore crucial to design for all possible attenuation scenarios before the satellite is deployed.

Aydın et al. [12], presented a study on optimally performing microwave communication network, which begins with a properly conducted with path survey that analyzes the microwave path's characteristics to identify and mitigate all potential signal obstructions. Ultimately, a detailed path survey can reduce outage time and save money on costly repair or reinstallation bills. 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.

This study is aimed at evaluation and performance of path profile characteristics in communication system using three different propagation links located at Auchi, Edo State, Nigeria.

2. Methodology

This study is aimed at evaluating and determining the performance of fade margin characteristics in mobile communication network in Nigeria. The network "A" is considered, using three different mobile links. 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 transmitter is SC 2-W100A (TR) and the receiver is SC 2-W100A (TR) respectively. In addition, R_X sensitivity of the antenna is given as -94 dBm from [13]. The sites' locations in Auchi, Edo State, Nigeria shown in Fig. 2, are three mobile propagation links are considered.

Fig. 2 Site Map.

2.1. Analysis of Margin Fade Characteristics

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 (Fig. 3). However, it provides a margin of safety in the event of a temporary attenuation or fading of the received signal power. 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. Network 'A' parameters from link one; Location: Auchi; Link One, Point of location from EDO681 to EDO375.

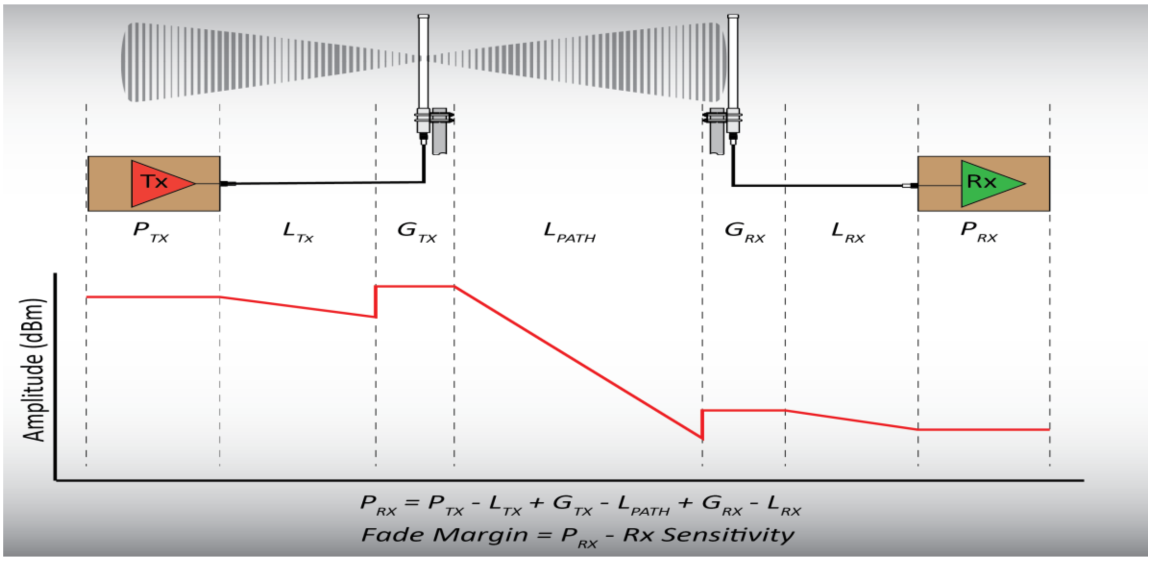

Fig. 3 Fade Margin Profile for a Link Budget.

$$Fade\ Margin = P_{RX} - R_X Sensitivity \quad (1)$$

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{Path} + G_{RX} - L_{RX} \quad (2)$$

Where, P_{TX} is the transmit power in dBm, L_{TX} is the total system loss in dB at the transmitter, G_{TX} is the antenna gain in dBi at the transmitter, L_{PATH} is the total propagation losses in dB between the transmitter and receiver antennas, G_{RX} is the antenna gain in dBi at the receiver, L_{RX} is the total system loss in dB at the receiver, and P_{RX} is the receive power in dBm. The transmit power (P_{TX}) is given as 24.00dBm, obtained from field data.

System loss is the sum of the total insertion loss in the transmission line plus any loss due to an impedance mismatch with the antenna. Except for the case where an antenna is mated directly to a transceiver's antenna connector, there will likely exist some combination of coaxial cables, surge suppressors, and possibly even band pass filters used to connect the transceiver to the antenna. Collectively, these devices comprise what is termed the transmission line. Surge kit loss (–0.5), cable loss (–1.7), connectors loss (–0.5), mismatch loss (–0.511≈ –3.2 dB), Circulation Branching loss (0.50 dB), and atmosphere absorption loss (0.05dB).

L_{TX} = surge kit (–0.5) + cable (–1.7) + connectors (–0.5) + mismatch (–0.511) + 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) + circulation branching loss and atmosphere absorption loss (-0.55) + net path loss (-56.12)

≈ –59.02 dB

Antenna Gain (dBi) = 34.50, obtained from field data.

Path loss is the principal contributor to loss in the link budget. It is the sum of free space loss plus additional losses induced by the interaction of the EM (electromagnetic) wavefront with the terrain and/or obstructions along the path of propagation. NOTE: standard atmosphere (standard refraction = k = 1.33) over a smooth earth, the distance (kilometers) to the RF horizon is related to the height of the antenna as follows;

$$d_{HOR} = 4.124\sqrt{h} \tag{3}$$

Where, h is the antenna height in meters above a smooth earth; else,

$$d_{HOR} = 1.414\sqrt{h} \tag{4}$$

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

$$LOS_{max} = 4.124\sqrt{h_{TX}} + 4.124\sqrt{h_{RX}} \tag{5}$$

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

$$LOS_{max} = 4.124\sqrt{30} + 4.124\sqrt{35}$$

$$LOS_{max} = 22.588 + 24.398 = 46.986km$$

$$LOS_{max} = 47.0km$$

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:

$$d_{PATH} \leq LOS_{max} = 3.06 \leq 47.0 \tag{6}$$

Note: 3.06 km distance path from link one, (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. Thus, equation (6) becomes d = distance between antennas in kilometers = 3.06 km. The critical distance (d_c) is calculated as follows:

$$d_c = \frac{4\pi h_{TX} h_{RX}}{\lambda} \tag{7}$$

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

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

$$d_c = 497.9\ m\ = 0.4979\ km$$

For d < d_c, calculate path loss using the free space propagation model, using equation (8). Because the distance between antennas is 3.06 kilometers, this requires the free space propagation model (FLS). Therefore, for d < d_c:

$$FLS_{dB} = 32.45 + 20\log(d) + 20\log(f) \tag{8}$$

Where, *FSL (dB)* is the free space loss in dB, d is the distance in kilometers (=3.06), and f is the frequency in megahertz (= 11100.0 MHz).

$$FLS_{dB} = 32.45 + 9.7144 + 80.906 = 123.071$$

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

$$L_{PATH} = 123.071$$

For d ≥ d_c; calculate path loss using the 2-ray propagation model, using equation (9). Recall equation of the 2-Ray multipath propagation model:

$$PL_{2Ray} = 120 - 20\log(h_{TX}h_{rx}) + 40\log(d) \tag{9}$$

Where, PL_{2Ray} is the 2-ray path loss in dB, h_{TX} is the height of the transmitting antenna in meters (=30), h_{RX} is the height of the receiving antenna in meters (=35), and d is the distance between antennas in kilometers (=3.06). Therefore,

$$PL_{2Ray} = 120 - 20\log(30\ x\ 35) + 40\log(3.06)$$

$$PL_{2Ray} = 120 - 20\log(1050) + 40\log(3.06)$$

$$PL_{2Ray} = 120 - 60.42 + 19.43 = 120 - 79.85 = 40.15dB \tag{10}$$

2.2. Received Signal Level

With all the input parameters to the link budget, the power level arriving at the receiver's input can be calculated using equation (2) with following parameters: P_{TX} (24.00dBm), L_{TX} (59.87dB), G_{TX} (34.50 dBi), L_{PATH} (123.071dB), G_{RX} (34.50 dBi), and L_{RX} (59.02dB), thus:

$$P_{RX} = 24.00\text{dBm} - (59.87\text{dB}) + 34.50\text{dBi} - 123.071dB + 34.50\text{dBi} - (59.02\text{dB}) = -148.96dBm \tag{11}$$

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 required to:

(a) limit the number of errors in the received digital data stream to a maximum BER; A typical specification would be: –103 dBm for 1 x 10^{-4} BER, meaning, one bit error for every ten thousand bits received; and

(b) produce a minimum SINAD (signal to noise and distortion) 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 would 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), equation (12) can be used to convert volts to power in dBm:

$$P_{dBm} = 10\log\left[\frac{(V\ x\ 10^{-6})^2}{50}\right] + 30 \tag{12}$$

Where, *PdBm* is the power in dBm, and *V* is the rms voltage in microvolts. *Rx Sensitivity* at 0.25 uV for 12 dB SINAD is expressed as:

$$R_x\ Senitivity\ (P_{dBm}) = 10\log\left[\frac{(0.25\ x\ 10^{-6})^2}{50}\right] + 30 \tag{13}$$

$$R_x\ Senitivity\ (P_{dBm}) = -119dBm$$

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. Note that the receiver antenna used is SC 2-W100A (TR) with receiver sensitivity given as -94 dBm [13]. Therefore,

$$R_X Sensitivity = -94dBm$$

$$Fade\ Margin = P_{RX} - R_X Sensitivity$$

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

L_{PATH} = the total propagation losses in dB between the transmit and receive antennas = $40.15dB$

Using the 2-Ray multipath propagation model:

$$P_{RX} = 24.0\text{dBm} - (59.87\text{dB}) + 34.50\text{dBi} - 40.15dB + 34.50\text{dBi} - (59.02\text{dB}) = -65.17dBm$$

$$Margin = P_{RX} - R_X Sensitivity = (-65.17) - (-94dBM) = -28.83\ dB$$

3. Results and Discussion

The 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 1. The comparison between total system loss in decibel at the transmitter (L_{TX}) and total system loss in decibel at the receiver is shown in Fig. 3 whereas, the relationship between transmitter power and path length distance is compared in Fig. 4.

Table 1 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., Long.	06 1553.64 N, 005 42 30.24E	06 16 40.19 N, 005 4102.40E	06 23 06.36 N, 005 42 21.60E	06 23 06.14 N, 005 42 49.73E	07 05 52.08 N, 006 18 21.24E	07 05 22.31 N, 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 FLS (dBm)	123.07		118.43		121.98	
Calculated 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	

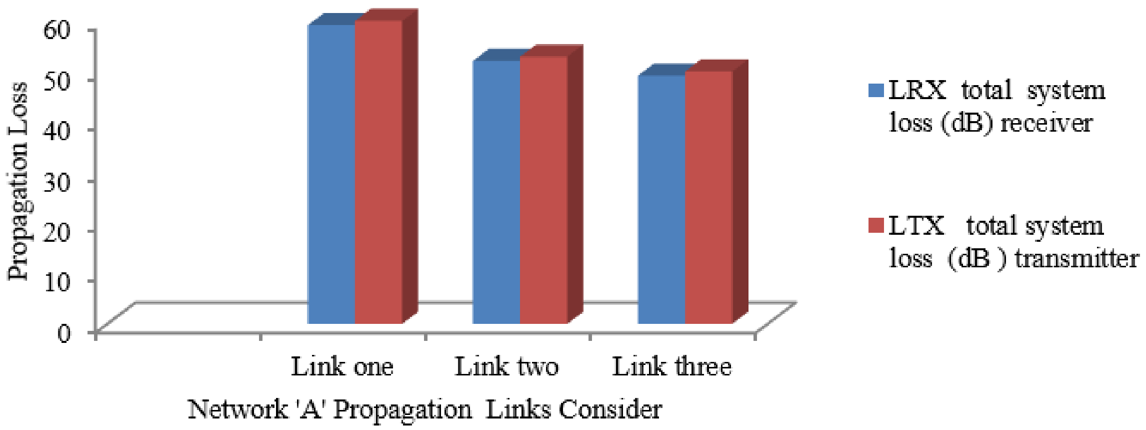

Fig. 3 Comparative between Transmitter and Receiver losses in dB from three different links.

It was observed (Fig. 3) 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.

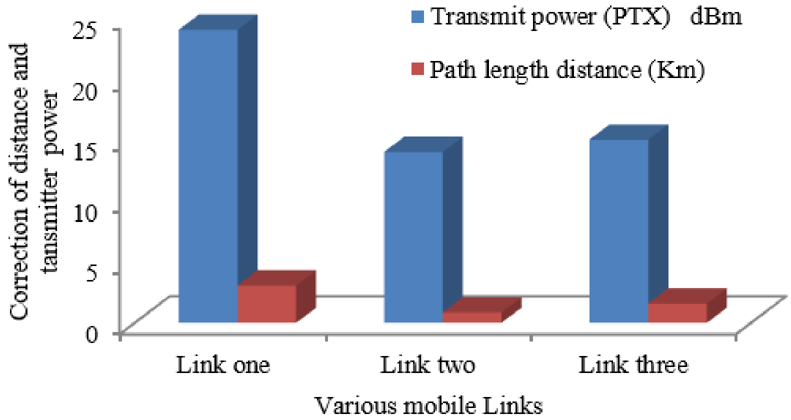

Fig. 4 Relationship between Transmitter Power and Path Length Distance.

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.

The critical distance (Fig. 5) 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.

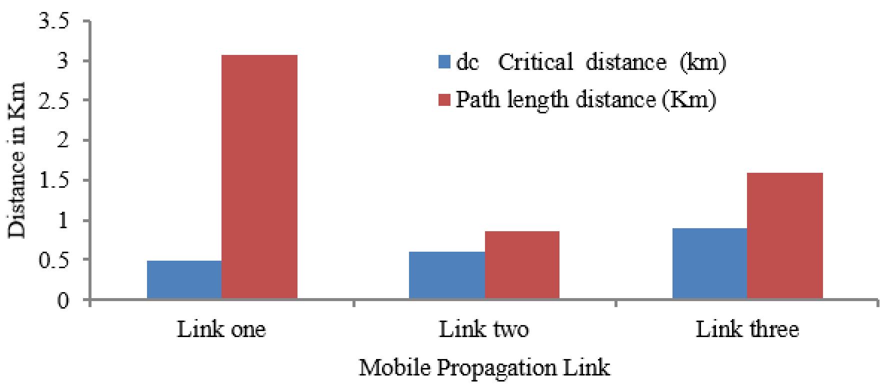

Fig. 5 Critical Distance and Path Length Distance.

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 (8) possess a close correlation and attribute shown in Fig. 6.

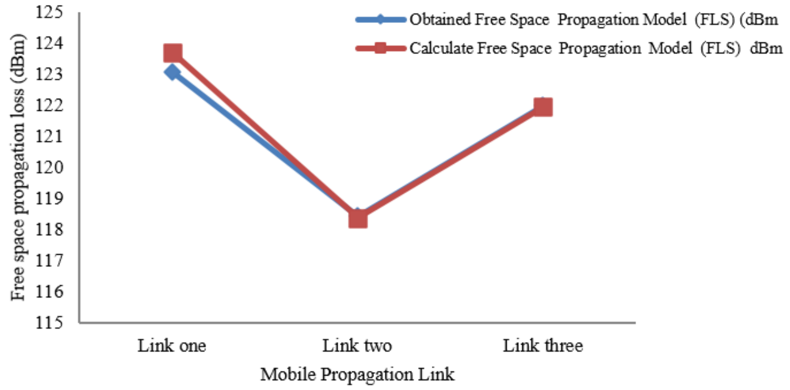

Fig. 6 Correlation between Obtained and Calculated Free Space Propagation Model (FLS).

Path length distance and margin fade of the three basic mobile operator's propagation links were considered (Fig. 7). It was observed that path length distance characteristic is affected due to 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.

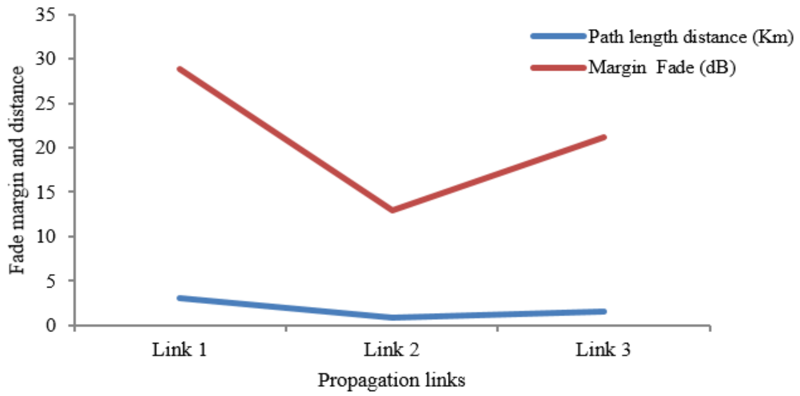

Fig. 7 Propagation Link for both Fade Margin and Path Length Distance.

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. RF telemetry link is required; the design 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:

(a) Use an antenna with a higher gain specification on one or both ends of the link.
(b) 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.
(c) Add a repeater site to the path. By far, the largest factor in a link budget is path loss.
(d) In mobile communication radio links, slight variation receiver signal values in decibels could result in increase in BER and affect the allover performance. So, a good rule of thumb is to stay way below the maximum allowed receiver signal for at least 5 dB and preferably even more

The primary disadvantage of LOS technique is their vulnerability to atmospheric effects such as attenuation and scintillation, which can reduce link availability. While the advantage of microwave link are as follows:

(a) microwave communication is a cost-effective;
(b) it can be rapidly installed;
(c) it can cross complicated terrains;
(d) efficient means to connect two or more wireless points together over a variety of terrains and space; and
(e) where continuous runs of cable or fiber type transmission lines would not be practical or even possible.

4. Conclusion

Mobile communication has become a major travelling force of economic development of many countries. Therefore, the mobile communication operators are saddle with efficient service delivery, especially long-distance communication. The microwave technology using Line of Sight became paramount in mobile communication Network, which leads to the determination of fade margin of the LOS. The various fade margin characteristic parameters were determined, using existing mathematical models. Data were obtained from network "A" mobile communication network in Nigeria, three different mobile propagation links were considered. The obtained data are link ID, latitude and longitude, 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 such as 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.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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