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Pathloss Models For Vegetational Areas In Lagos Environs

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ABSTRACT

This paper presents the path loss models for vegetational areas of Lagos environs. Model equations were used for the major areas considered. In order to determine various path loss associated with different locations within the state. The obtained analytical results have been used to evaluate some parameters such as path loss and total path loss. .Hence, the total path loss results obtained therefore range between 132.85≤ 171.4 dB at frequencies between 7.7 GHz and 19 GHz with negligible errors in conformity with the existing models.

The model developed can also help in planning and improving better network for rural and suburban areas in Nigeria in as much as the investigated areas have the same characteristics.

Keywords: Vegetational areas, signal strength, path loss, model, propagation and foliage distance.

1. Introduction

The physical appearance of obstacles such as thick forest, high risers,,trees,and mountains creates loss between the path of the transmitting antenna and receiving antenna called path loss which enables line of sight impossible to be located.However,the foliage loss or vegetative distance is a very difficult subject that has so many parameters to be put in place before the analysis can be done. One of these parameters is the foliage distance which for different areas, has a lot of variations in it. In this paper, the frequencies of propagation used for this study ranges between 7.7 GHz and 19 GHz and the foliage distance is between 20m to 100m.As a result, it is important to understand the reasons adduced for mobile and radio path loss vis-à-vis investigated areas in order to determine the level of signal loss as the wave propagates for a given area at particular distance and frequency. Since the inception and advent of Global System for Mobile communication the demand for its services has geometrically increased day by day and the service rendered becomes worrisome to the subscribers of the service. A lot of complaints had been lodged such as incessant call drop, cross- talk, poor reception of signal and many more. This may be associated with poor quality of service experienced by the subscribers and the need to improve the quality has been a source of worry to operators of the service. The purpose of this study is to develop and analyze a model that may aid in network planning and optimization in order to reduce these persistent problems.

2. Theoretical Propagation Model

This work introduces the basic theoretical propagation models which are initially put into consideration and are now being classified into free space model, smooth plane earth propagation, Cost – 231, Hata, Okumura – Hata Model, Exponential decay model, the ITU-R (maximum alternation) model.

(a) Free Space Propagation Model Analysis

Free space transmission is the primary consideration in all wireless communication system. In propagation model in free space begins when a wave is not reflected or absorbed through the normal propagation.It connotes that equal radiation of signals in all directions from the radiating source and propagate to an infinite distance with no reduction of signal strength. Hence, free space attenuation other words, every communication system takes into consideration free space loss. The path loss increases as the frequency of propagation increases. For a particular unit of distance, this happens in the sense that higher frequencies definitely have smaller wavelengths in order to cover a specific distance.

Analysis of the Free Space Model

Consider the figure below in which the radiated power at a some distance from a transmitting antenna is inversely proportional to the square of the distance from the transmitting antenna antenna is inversely proportional to the square of the distance from the transmitting antenna.

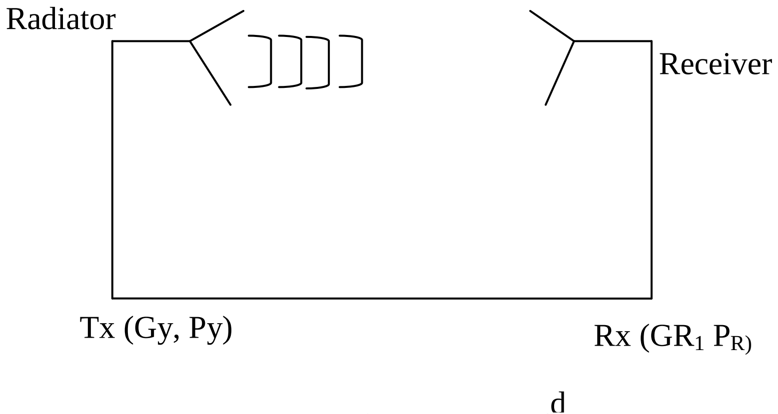


Figure 1: Free Space Model Diagram

Therefore, the power density at the receiver in watt/m^2 is given as

$$\text{Power density} = \frac{Transmitter}{Surface\ Area} \quad (1)$$

Where the surface area is tangent to the measurement point with the antenna at the centre. Mathematically, it can be expressed as

$$S_R = S_T \frac{1}{4\pi d^2} \quad (.2)$$

Then, the effective power density =Power density * gain

$$S_{RE} = \frac{S_T G_T}{4\pi d^2} \quad (3)$$

The antenna gain

$$(G_T) = \frac{4\pi A_T \eta_T}{\lambda^2} \quad (4)$$

Where A_T is transmitting antenna $Area$ and η_T is antenna efficiency

The receiver would also be of the same type as the transmitter so that the receiver's $Area\ A_R$ and the receiver's efficiency η_R diminish the receiver's power by the factor $A_R \eta_R$.

$$S_R = S_T G_T\ A_R \eta_R \frac{1}{4\pi d^2} \quad (5)$$

Noting that the receiver gain is also given as ;

$$G_R \lambda^2 \frac{1}{4\pi} = A_R \eta_R \quad (6)$$

Substitute equation (5) into equation (6)

$$S_R = \frac{S_T G_T G_R}{\left(\frac{4^2 \pi^2 d^2}{\lambda^2}\right)} \qquad (7)$$

Equation (7) can equally be expressed in decibel (dB) as follows

$$10 \log_{10} S_R = 10 \log_{10} S_T + 10 \log_{10} G_T + 10 \log_{10} G_R - 20 \log_{10} \left(\frac{4\pi d}{\lambda}\right)$$

(8)

Equation (8) is called Transmitter- Receiver Formula.

Therefore, in an isotropic medium, antenna transmits signals evenly and equally in all directions. Hence, for basic transmission free space path loss denoted as L, is defined as the reciprocal of equation (10) which is the ratio of transmitted power to the received power usually expressed in decibel. For transmission between isotropic antennas, the gain of the receiver and transmitter assumes the value of unity(1).

$$L = (S_T / S_R) = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (9)$$

Expressing equation (3.12) in decibel (dB)

$$L(dB) = S_T - S_R = 20 \log_{10} \left(\frac{4\pi d}{\lambda}\right) \qquad (10)$$

Note: A path loss is a gain that is viewed as a loss.

(b)Plane Earth Loss:

The free space propagation model consideration in the previous paragraph does not take into account the effects of propagation over ground. If we now consider the effect of the earth surface, the expression of the received signal becomes more complicated. For (theoretical) isotropic antenna above a plane earth, the received electric field strength is given as

$$E = E_0(1 + R_c e^{j\Delta} + (1 - R_c)F. e^{j\Delta} \qquad (11)$$

Where R_c is the reflection and E_0 is the field strength for propagation in free space. This expression can be interpreted as the complex sum of a direct line of sight wave, a ground reflected wave and a surface wave.

For a horizontally polarized wave incident on the surface of a perfectly smooth earth, the reflection coefficient R_c is given as

$$R_c = \frac{\sin\varphi - \sqrt{(E_r - jX) - \cos^2\varphi}}{\sin\varphi + \sqrt{(E_r - jX) - \cos^2\varphi}} \qquad (12)$$

Where E_r is the reflection dielectric constant of the earth,φ is the angle of incidence(between the radio ray and the earth surface) and X is given as

$$X = \frac{s}{2\pi f c e_0} \qquad (13)$$

With s being the conductivity of the ground and e_0 is the dielectric constant of the vacuum.

For vertical polarization, R_c is given as

$$R_c = \frac{(E_r - jX)\sin\varphi - \sqrt{(E_r - jX) - \cos^2\varphi}}{(E_r - jX)\sin\varphi - \sqrt{(E_r - jX) - \cos^2\varphi}} \qquad (14)$$

Therefore, the relative amplitude F(.) of the surface wave is very small for most cases of mobile UHF communication (F(.) $\ll 1$).Its contribution is relevant only a few wavelength above the ground.

Analysis of Plane Earth Loss

The phase difference (Δ) between the direct and the ground- reflected wave can be found from two-ray approximation considering only a line of sight and a ground reflection. By denoting the transmit and receive antenna Heights as h_T and h_R respectively, the phase difference can be expressed as

$$\Delta = \frac{2\pi}{\lambda}\left[\left(\sqrt{d^2 + (h_T + h_R)^2}\right) - \left(\sqrt{d^2 + (h_T - h_R)^2}\right)\right] \quad (15)$$

For d $\gg 5$, one finds using the expression below

For large d (d $\gg 5h_T\ h_R$), the reflection coefficient tends to $R_C = 1$ so the received signal(S_R) is given

$$S_R = \frac{\lambda^2}{4\pi d^2}\left(2\sin\left(\frac{2\pi h_T\ h_R}{\lambda d}\right)^2\right)G_T G_R \quad (16)$$

For propagation distance substantially beyond the turn over point i.e. d= $\frac{h_R h_T}{\lambda}$ this tends to the fourth power distance law.

Hence, the plane earth path loss is given as

$$L_{PEL} = 40\log_{10} d - 20\log_{10} h_T \quad (17)$$

Experiments confirm that in macro-cellular links over smooth, plane terrain, the received signal power(expressed in dB) decreases with" $40\log_{10} d$".

In contrast to the theoretical plane earth loss, Egli measured a significant increase of the path loss with the carrier frequency (f_c).He further proposed the semi- empirical model to be

$$S_R = \left(\left(\frac{40MHz}{fc}\right)^2\right) \left(\left(\frac{h_T\ h_R}{d^2}\right)^2\right) S_T G_T G_R$$

(18)

In addition, Egli introduced a frequency dependent empirical correction for ranges 1$< d < 50\ km$ and carrier frequencies 30MHz $< fc <$ 1GHz.

Propagation model Types

The path loss propagation can usually be modelled in three different ways namely empirical model approach, deterministic model approach and stochastic model approach.

The empirical models are usually based on observation and measurements taken alone in the site which are normally used to forecast the path loss. Deterministic model uses a form of law governing the electromagnetic wave propagation to compute the receive signal power at a particular location,while stochastic model requires a complete and comprehensive details usually in 3-D map form of the propagation environment.

The deterministic and stochastic models are often used with least accuracy but require the least information pertaining to the environment.

However, for the determination of path loss at each distance, empirical method was chosen because of its applicability with the investigated environment and it has merits over the other models such as high level of accuracy, simplicity and clarity. The aforediscussed theoretical propagation models above such as free space, plane earth loss may require critical details of the site location, dimension, and constitutive parameters of every foliage..There are many forms of empirical prediction among which are Okumura-Hata model, COST-231 model, Weissberger model, Early ITU model and Updated ITU-R model. All these models may actually proffers solution to the poor quality of network service by telecommunications outfits and as well may address the problem drop calls experienced by GSM subscribers in Lagos State but Weissberger model and Updated ITU-R model are suitable for this study because of the features the investigated environment posseses.

(a)Early ITU-R Vegetation Model

Although, it has been superceded by another ITU model but it's still useful to compute the path loss where the frequency of propagation is in Megahertz.Mathematically,it can be expressed as

$$L(dB) = 0.2F^{0.3}\, d^{0.6} \qquad (19)$$

Hence, the performance of the above model can be investigated against the measured data obtained on site.

(b) Updated ITU Model

This model is fairly specific and does not cover all possible scenarios. One key element of this model is that the total losses obtained by the foliage or vegetation are limited. The reason why it's preferable is that it assumes there is always a diffraction path as depicted in the figure below.

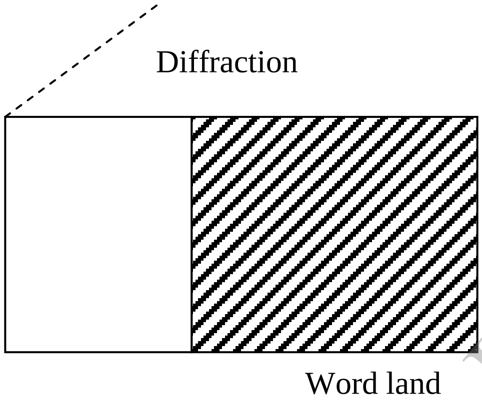


Figure 3.4: Updated ITU - Model

There are two approached to this kind of model.

Case One

The first scenario is when the first terminal (antenna) is at wildlife in the forest (thick bushes). The figure below shows this.

Figure 3.5: Updated ITU – Model When one of the Antennas is Outside the Foliage

The attenuation due to particular vegetation specifically is given as

$$A_{er} = A_m\left(1 - e^{\frac{dr}{A_m}}\right) \qquad (20)$$

Where Am = maximum attenuation for one terminal between a specific type and depth of vegetation.

A_{er}=Attenuation due specifically to a particular vegetation.

d=distance

y=specific attenuation for very short vegetation path.

Case Two

The second approach is when a single type of vegetation of obstruction where foliage or vegetation is between the two antennas.

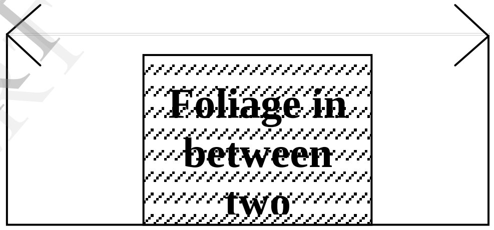


Figure 3.6: Updated ITU – Model (the Foliage is in between Two Antennas)

When the frequency of propagation is at or less than 3GHz, the vegetation loss model is simplified as A_{er} = dy where d and y have the same interpretations as the first approach.

It should be noted that d is the length of path within trees in meters, y is the specific attenuation for very short vegetation paths in decibel per metre. A_m is the maximum attenuation for one terminal within a specific type and depth of vegetation in decibel. It depends on the types and density of the vegetation, plus the antenna pattern of the terminal within the vegetation and the vertical distance between the antenna and the top of the vegetation.

A frequency dependence of A_m (dB) is of the form given below.

$$A_m = A_1 f^{\alpha} \quad (21)$$

Where f is the frequency, A and α are the constants.

In addition, the path loss (net) for this kind of foliage is computed as

$$L = L_{fs}\,(dB) + L_{wm}(dB) \quad (22)$$

Where L_{fs}=free space path loss

L_{wm}=Weissberger model attenuation loss

(c) Weissberger Model:

This is one of the models used in a vegetation area in which losses are due to foliage where the signals fall exponentially. In a point to point communication link, a lot do happen. For instance, a scenario can be created in which both transmitter and are fixed. In cellular telecommunication system, the cells are fixed but subscribers change position. A good example of this is a moving car and a fixed base station .Moreso,both can be moving e.g. a mobile NTA station trying to broadcast from a street.Mathematically,Weissberger model equation can be expressed as;

$$L_d = 1.33F^{0.288} d_f^{0.588} \quad 14\text{m} \leq d_f \leq 400m$$

(23)

$$L_d = 1.33F^{0.288} d_f^{0.588} \quad 0 \leq d_f \leq 14m \quad (23)$$

Where F is frequency in GHz, d_f is depth of the foliage along the line of sight(LOS).This model is used when the propagation path is blocked, by a dense, dry and leafy trees. The frequency ranges from 230MHz to 95GHz.

3. Study Area/Investigation Area

Lagos falls within the western part of Nigeria vegetation zone. This investigation was carried out in different locations within Lagos State, southwest of Nigeria. Lagos State is 6^0 35'N and 3^0 45'E on the chart with total distance of 3,475.1km^2 and population of 18 million and above. A goggle map of these areas was taking along with BTS mast antenna.

4.Path loss Computations

In the path loss cases consider, various frequencies ranging from 7,700MHz to 19GHz were used for the computation. The respective distances of transmitter to the foliage were varied from 20m to 100m while their corresponding path losses were calculated.

Case 1:

Path length=3120m,F=18GHz, d_f=20m

Using Weissberger model of eqn (23)

$$L_d = 1.33F^{0.288} d_f^{0.588}$$

$$L_d = 17.59 \text{ dB}$$

$$L_{fs} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

$$L_{fs} = 127.43 \text{ dB}$$

The total path loss =L_d+L_{fs} =145.02 dB

When d_f=40m, F= 18GHz

L_d =26.45 dB

The total path loss $=L_d+L_{fs}$

=153.88 dB

Tables 1 and 2: Results at 7.7GHz

	Elevation(m)	d_f (m)	path length (km)	Path loss (dB)	Total path loss (dB)
1	2	20	0.560	13.82	132.93
2	4	40	1.120	20.78	139.89
3	6	60	1.680	26.37	145.48
4	8	80	2.240	31.23	150.34
5	10	100	2.80	35.61	154.72

When d_f=60m, F= 18GHz

L_d =33.57 dB

The total path loss $=L_d+L_{fs}$

=160.10 dB

Tables 1 and 2:Result at 7.7GHz

When d_f=80m, F= 18GHz

L_d =39.75 dB

Total path loss $=L_d+L_{fs}$ =167.18 dB

When d_f=100m, F= 18GHz

L_d =45.33 dB

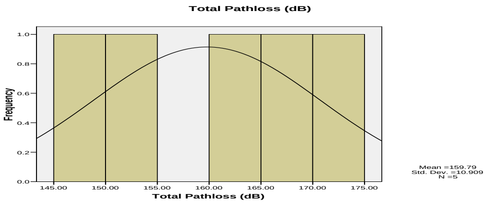
The total path loss $=L_d+L_{fs}$

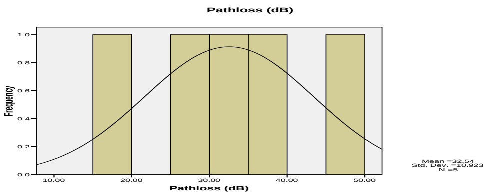
=172.76 dB

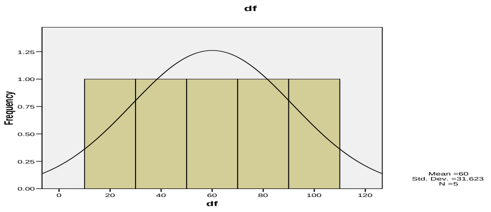
4. Results and Discussion

Using Weissberger model of eqn(23),the table and graphs below obtained are

	Elevation (m)	d_f (m)	path length(km)	Path loss (dB)	Total path loss (dB)
1	5	28	0.624	17.59	145.02
2	10	40	1.249	26.45	153.88
3	15	60	1.249	33.57	160.10
4	20	80	1.250	39.75	167.18
5	25	100	3.120	45.33	172.76

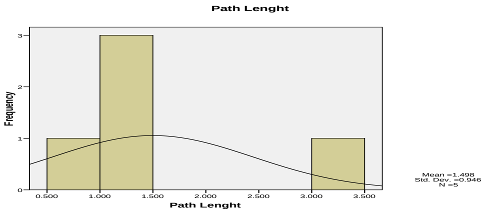


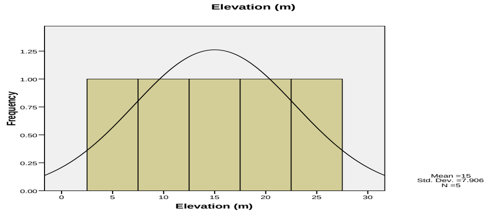


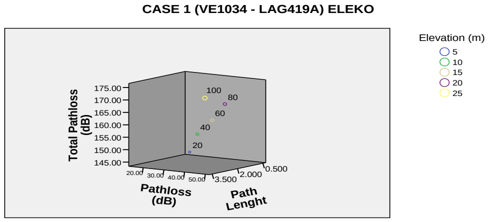


considered followed the same trend due the fact that an increase in path loss, frequency of propagation, foliage distance, elevation and so on, would definitely bring about increase in the other The graphs plotted for various cases parameters considered and vice versa.

However, in the analysis of the different cases considered in different locations of Lagos State, it can be inferred that the mean, mean deviation, standard deviation and variance of each case differ because of the difference in their frequency of propagation and path length.Hence,it does conform with the expected results theoretically.







The test results were in coherence and agreement with that which were expected theoretically as demonstrated and shown through various graphs of different parameters. In comparison to the existing models for analyzing vegetational areas carried out in different States or countries

Conclusion

This work shows that the total path loss increased only substantially and appreciably with an increase in path-length, foliage distance, and reduction in the transmitted frequency. Nevertheless, of the various possible ways of analyzing and improving quality of network service in vegetation areas, using Weissberger model appears to be the most efficient, cheap and appreciable owing to the fact that the foliage distance considered in this thesis.

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