

Review Paper

A Review Investigation on outdoor and indoor propagation models

Abstract: *Path loss exponent has become one of the major challenges that are been faced with telecommunication industries in the world with Nigeria inclusive. There is a great need to critically take a look at the different methods and mathematical methods that have been developed by many researchers of which are used in the calculation of signal loss in telecom. In this article, over forty (40) journals were reviewed and it was observed that, all the methods are accurate depending on the condition(s) or factors governing the methods. It was therefore concluded that the method that is applied to a particular situation depends on the surrounding environments.*

Keyword: path loss, propagation, models, signal strength

1. Introduction

Path loss or path attenuation is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system. The term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. Path loss is also influenced by terrain, contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of the antennas [1-5].

Path loss normally includes propagation losses caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), absorption losses (sometimes called penetration losses), when the signal passes through media not transparent to electromagnetic waves, diffraction losses when part of the radio wave front is obstructed by an opaque obstacle, and losses caused by other phenomena. [6].

The signal radiated by a transmitter may also travel along many different paths to a receiver simultaneously; this effect is called multipath. Multipath waves combine at the receiver antenna, resulting in a received signal that may vary widely, depending on the distribution of the intensity and relative propagation time of the waves and bandwidth of the transmitted signal. The total power of interfering waves in a Rayleigh fading scenario varies quickly as a function of space (which is known as a small-scale fading). Small-scale fading refers to the rapid changes in radio signal amplitude in a short period of time or travel distance.

2. Path Loss Experiment

In wireless communication studies, path loss is represented by the path loss exponent, whose value is normally in the range of 2 to 4, where 2 is for propagation in free space, 4 is for relatively lossy environments and for the case of full specula reflection from the earth surface referred to as the flat earth model. In some environments, the path loss exponent can reach values in the range of 4 to 6. On the other hand, a tunnel may act as a waveguide, resulting in a path loss exponent less than 2.

Path loss is usually expressed in dB. In its simplest form, the path loss can be calculated using the formula.

$$L = 10 n \log_{10}(d) + C \quad (1)$$

Where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which account for system losses.

The value of C usually varies and is normally dependent on the type of modeling under consideration. A list of typical path loss exponents obtained in various mobile environments is shown in Table 1.

Table 1: Path Loss Exponents for Different Environments [7-11]

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

3. Path Loss Prediction Techniques

Calculation of the path loss is usually called prediction. Exact prediction is possible only for simpler cases, such as the above mentioned free space propagation or the flat-earth model. For practical cases the path loss is calculated using a variety of approximations.

Statistical methods (also called stochastic or empirical) are based on measured and averaged losses along typical classes of radio links. Among the most commonly used such methods are Hata, Okumura-Hata, the COST Hata model, W.C.Y.Lee etc. These are also known as radio wave propagation models and are typically used in the design of cellular networks and public

land mobile networks (PLMN). For wireless communications in the very high frequency (VHF) and ultra-high frequency (UHF) frequency band (the bands used by walkie-talkies, police, taxis and cellular phones), one of the most commonly used methods is that of Okumura-Hata as refined by the COST-231 project.

Other well-known models are those of Walfisch-Ikegami, W.C.Y Lee, and Erceg. For FM radio and the TV broadcasting the pathloss is most commonly predicted using the ITU model as described in ITU-R P.1546 recommendation.

Deterministic methods based on the physical laws of wave propagation are also used; ray tracing is one such method. These methods are expected to produce more accurate and reliable predictions of the path loss than the empirical methods; however, they are significantly more expensive in computational effort and depend on the detailed and accurate description of all objects in the propagation space, such as buildings, roofs, windows, doors and walls. For these reasons they are used predominantly for short propagation paths. Among the most commonly used methods in the design of radio equipment such as antennas and feeds is the finite-difference time-domain method.

The path loss in other frequency bands (medium wave (MW), short wave (SW or HF), micro wave (SHF)) is predicted with similar methods, though the concrete algorithms and formulas may be very different from those for VHF/UHF. Reliable prediction of the path loss in the SW/HF band is particularly difficult, and its accuracy is comparable to weather predictions [12]. Easy approximations for calculating the path loss over distances significantly shorter than the distance to the radio horizon:

In free space the path loss increases with 20dB per decade (one decade is when the distance between the transmitter and the receiver increases ten times) or 6dB per octave (one octave is when the distance between the transmitter and the receiver doubles). This can be used as a very rough first order approximation for (microwave) communication links. For signals in the UHF/VHF band propagating over the surface of the Earth the path loss increases with roughly 35-40 dB per decade (10-12 dB per octave). This can be used in cellular networks as a first guess.

In cellular networks, such as UMTS and GSM, which operate in the UHF band, the value of the path loss in built up areas can reach 110-140 dB for the first kilometer of the link between the base transmitter station (BTS) and the mobile. The path loss for the first ten kilometers may be 150-190 dB. These values are very approximate and are given here only as an illustration of the range in which the numbers used to express the path loss values can eventually be; these are not definitive or binding figures. Studies have shown that the path

loss may be very different for the same distance along two different paths and it can be different even along the same path if measured at different times.

In radio wave environment for mobile antennas is close to the ground. Line-of-sight propagation (LOS) models are highly modified. The signal path from the BTS antenna normally elevated above the roof tops is refracted down into the local physical environment (hills, trees, houses) and the LOS signal seldom reaches the antenna. The environment will produce several deflections of the direct signal unto the antenna, where typically 2-5 deflected signal components will be vectorially added.

These refraction and deflection processes cause loss of signal strength, which changes when the mobile antenna moves (Raleigh fading), causing instantaneous variations of up to 20db. The network is therefore designed to provide an excess of signal strength compared to LOS of 8-25 db depending on the nature of the physical environment, and another 10db to avoid the fading due to movement. [12]

4. Propagation Models

A radio propagation model, also known as the Radio Wave Propagation Model or the Radio Frequency Propagation Model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other conditions. A single model is usually developed to predict the behavior of propagation for all similar links under similar constraints. Created with the goal of formalizing the way radio waves are propagated from one place to another, such models typically predict the path loss along a link or the effective coverage area of a transmitter.

As the path loss encountered along any radio link serves as the dominant factor for characterization of propagation for the link, radio propagation models typically focus on realization of the path loss with the auxiliary task of predicting the area of coverage for a transmitter or modeling the distribution of signals over different regions. Because each individual telecommunication link has to encounter different terrain, path, obstructions, atmospheric conditions and other phenomena, it is intractable to formulate the exact loss for all telecommunication systems in a single mathematical equation. As a result, different models exist for different types of radio links under different conditions. The models rely on computing the median path loss for a link under a certain probability that the considered conditions will occur.

Radio propagation models are empirical in nature, which means they are developed based on large collections of data collected for the specific scenario. For any model, the collected data has to be sufficiently large to provide enough likeliness (or enough scope) to all kind of

situations that can happen in that specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a link, rather, they predict the most likely behavior the link may exhibit under the specified conditions.

Different models have been developed to meet the needs of realizing the propagation behavior in different condition. Types of models for radio propagation include the under listed:

- (i) Models for indoor applications
- (ii) Models for outdoor applications
- (iii) Ground wave propagation models
- (iv) Sky-Wave propagation models
- (v) Environmental Attenuation models
- (vi) Point-to-Point propagation models
- (vii) Terrain models
- (viii) City models

5. Models For Outdoor Attenuations

Model for outdoor attenuations are generally sub divided into four groups namely, Near-earth propagation models, Terrain models, City models and Band-specific models.

5.1. Near-Earth Propagation Models

Under this model, there are two distinct groups namely, Foliage and updated ITU model.

1. Foliage models

Foliage models are sub divided into Weissberger's modified exponential decay model and Early ITU model.

(a) Weissberger's Modified Exponential Decay Model

Weissberger's modified exponential decay model, or simply, Weissberger's model is a radio wave propagation model that estimates the path loss due to the presence of one or more trees in a point-to-point telecommunication link. This model belongs to the category of Foliage or Vegetation models with depth of foliage of up to 400m, for the cases of line of sight propagation as used in microwave transmission. This model is only applicable when there is an obstruction made by some foliage in the link i.e. in between the transmitter and receiver.

It is ideal for application in the situation where the LOS path is blocked by dense, dry and leafy trees. It is suitable for application in the frequency range of 230 MHz to 95 GHz [13].

Formulated in 1982, this model is a development of the ITU Model for Exponential Decay (MED). Weissberger's model is formally expressed as:

$$L = \begin{cases} 1.33f^{0.284}d^{0.588}, & \text{if } 14 < d \leq 400 \\ 0.45f^{0.284}d, & \text{if } 0 < d \leq 14 \end{cases} \quad (2)$$

where,

L = The loss due to foliage in decibels (dB).

f = The transmission frequency in gigahertz (GHz).

d = The depth of foliage along the path in meters (m).

Unfortunately, this model has the following limitations.

(i) The equation is scaled for frequency specified in GHz range.

(ii) Depth of foliage must be specified in meters (m).

(iii) It is significant for frequency range of 230 MHz to 95 GHz only, as pointed out by Blaunstein [13]

(iv) The model does not define the operation if the depth of vegetation is more than 400m.

(v) The model predicts the loss due to foliage; hence the path loss must be calculated with inclusion of the free space loss [13]

(b) Early ITU Model

The ITU vegetation model is a radio propagation model that estimates the path loss encountered due to the presence of one or more trees inside a point to point telecommunication link. The predictions found from this model is congruent to those found from Weissberger's modified exponential decay model in low frequencies. It was subsequently adopted late 1986.

The model is applicable on the situations where the telecommunication link has some obstructions made by trees along its way; it is therefore suitable for point-to-point microwave links that has vegetation in their path. Typical application of this model is to predict the path loss for microwave links.

The model is formulated as:

$$L = 0.2 f^{0.3} d^{0.6} \quad (3)$$

where

L = The path loss in decibels (dB).

f = The frequency of transmission in megahertz (MHz).

d = The depth of foliage along the link in meters (m).

Equation (2.3) is scaled for frequency specified in megahertz (MHz) only while the depth of foliage must be in the units of meter. Unfortunately, the result of this model gets impractical at high frequencies [14-20]

194

2. Updated ITU Model

The Early ITU model described above was updated in early 2002; this gave rise to two other models described below.

1. One Woodland Terminal Model

The ITU terrestrial model for one terminal in woodland is a ratio propagation model belonging to the class of foliage models. This model is a successor of the early ITU model. It is applicable to the scenario where one terminal of a link is inside foliage and the other end is free. It is very useful for frequencies below 5 GHz. The mathematical formulation of the model is:

$$A_V = A \left[1 - e^{-\frac{d\gamma}{A}} \right] \quad (4)$$

where

A_V = Attenuation due to vegetation in decibel (dB)

A = Maximum attenuation for one terminal caused by a certain foliage in decibel (dB)

d = Depth of foliage along the path in meter (m)

γ = Specific attenuation for short vegetations in decibel/meter (dB/m).

The value of γ is dependent on frequency and is an empirical constant. The model assumes that exactly one of the terminals is located inside some forest or plantation and the term depth applies to the distance from the terminal inside the plantation to the end of plantation along the link. It is also suitable for frequencies below 5 GHz [21-26]

2. Single Vegetative Obstructive Model

The ITU Single Vegetative Obstructive Model is a Radio propagation model that quantitatively approximates the attenuation due to the vegetation in the middle of a telecommunication link. The model is applicable to scenarios where no end of the link is completely inside foliage, but a single plant or tree stands in the middle of the link. It is found useful in the frequency range below 3GHz and over 5GHz. The single vegetative obstruction model is formally expressed as:

$$A = \begin{cases} \delta\gamma, & \text{frequency} < 3\text{GHz} \\ R_f d + k \left[1 - e^{\frac{(R_f - R_i) d}{k}} \right], & \text{frequency} > 5\text{GHz} \end{cases} \quad (5)$$

where

A = The Attenuation due to vegetation in decibel (dB)

d = Depth of foliage in meter (m)

γ = Specific attenuation for short vegetations in decibel/meter (dB/m).

R_i = The initial slope of the attenuation curve
 R_f = The final slope of the attenuation curve
 f = The frequency of operations in gigahertz (GHz)
 k = Empirical constant

The calculation of slopes

For the calculation of slopes, the initial slope is calculated as:

$$R_i = a^f \quad (6)$$

And the final slope as:

$$R_f = bf^c \quad (7)$$

where a, b and c are empirical constants given in Table 2

Calculation of k

For the calculation of k, it is computed as:

$$k = k_0 - 10 \log \left[1 - e^{\frac{-A_i}{A_0}} \right] [1 - e^{R_f f}] \quad (8)$$

where,

k_0 = Empirical constant given in Table 2
 R_f = Empirical constant for frequency dependent attenuation
 A_0 = Empirical attenuation constant given in the Table 2
 A_i = Illumination area

Calculation of A_i

A_i is calculated in using any of the equations 2.9 and 2.10, noting that, the terms h , h_T , h_R , w , w_T and w_R are defined perpendicular to the assumed horizontal line joining the transmitter and receiver. The first three terms are measured vertically and the other three are measured horizontally [27-30]

$$A = \min(w_T w_R w) \times \min(h_T h_R h) \quad (9)$$

$$A_i = \min \left(2d_T \tan \frac{\alpha_T}{2}, 2d_R \tan \frac{\alpha_R}{2}, w \right) \times \min \left(2d_T \tan \frac{\theta_T}{2}, 2d_R \tan \frac{\theta_R}{2}, h \right) \quad (10)$$

where,

w_T = Width of illuminated area as seen from the transmitter in meter (m).
 w_R = Width of illuminated area as seen from the receiver in meter (m).
 w = Width of the vegetation in meter (m).
 h_T = Height of illuminated area as seen from the transmitter in meter (m).
 h_R = Height of illuminated area as seen from the receiver in meter (m).
 h = Height of vegetation in meter (m).

α_T = Azimuth beam width of the transmitter in degree or radian.

α_R = Azimuth beam width of the receiver in degree or radian.

e_T = Elevation beam width of the transmitter in degree or radian.

e_R = Elevation beam width of the receiver in degree or radian.

d_T = Distance of the vegetation from transmitter in meter (m).

d_R = Distance of the vegetation from receiver in meter (m).

The empirical constants a , b , c , k_0 , R_f and A_0 are used as tabulated in Table 2.

Table 2: Empirical constants a , b , c , k_0 , R_f and A_0 used for Single Vegetation Obstruction

Model [31]

Parameter	Inside Leaves	Out of Leaves
A	0.20	0.16
B	1.27	2.59
C	0.63	0.85
k_0	6.57	12.6
R_f	0.002	2.1
A_0	10	10

Unfortunately, the model predicts the explicit path loss due to the existence of vegetation along the link. The total path loss includes other factors like free space loss which is not included in this model. Over 5 GHz and below 3 GHz, the equations suddenly become extremely complex in consideration of the equations. Also, this model does not work for frequency between 3 GHz and 5 GHz.

5.2. Terrain Models

Terrain models may be generally subdivided into three main models, namely Egli Model, Longley-Rice Model and ITU terrain loss model.

1. Egli Model

The Egli model is a terrain model for radio frequency propagation. The model was derived from real world data on UHF and VHF television transmission in several large cities. It predicts the total path loss for a point to point link. The model is typically used for outdoor line of sight transmission and it provides the path loss as a single quantity. It is typically suitable for cellular communication scenarios where one antenna is fixed and another is

mobile. The model is also applicable to scenarios where the transmission has to go over an irregular terrain. Unfortunately, the model has two major limitations:

- (a) It does not take into account travel through some vegetative obstruction, such as trees or shrubbery [32-36]
- (b) It predicts the path loss as a whole and does not subdivide the loss into free space loss and other losses.

The Egli model is formally expressed as:

$$P_R = G_B G_M \left[\frac{h_B h_M}{d^2} \right]^2 \left[\frac{40}{f} \right]^2 P_T \quad (11)$$

where,

P_{R50} = 50th percentile receive power (W).

P_T = Transmit power (W).

G_B = Absolute gain of base station antenna.

G_M = Absolute gain of mobile station antenna.

h_B = Height of the base station antenna (m).

h_M = Height of the mobile station antenna (m).

d = distance from the base station antenna (m).

f = frequency of transmission (MHz).

2. Longley-Rice Model

The Longley-Rice model (LR) is a radio propagation model: a method for predicting the attenuation of radio signals for a telecommunication link in the frequency range of 20MHz to 20 GHz (Seybold, 2005). Longley-Rice is also known as the irregular terrain model (ITM). It was created for the needs of frequency planning in television broadcasting in the United States in the 1960s and was extensively used for preparing the tables of channel allocations for VHF/UHF broadcasting there.

Longley-Rice has two parts: a model for predictions over an area and a model for point to point link predictions. The Longley-Rice model was proposed for frequencies between 20 MHz and 40 GHz for different scenarios and different heights of transmitting and receiving antennas. The model presents a generalization of the received signal power without a detailed characterization of the channel, which depends on the variables of each scenario and environment.

The variation of the signal is determined by the prediction model according to the atmospheric changes, topographic profile and free space. These variations are described with the help of statistical estimates which have deviations that contribute to the total attenuation of the signal.

The statistical estimates or attenuation variables of this prediction model are: i) Situation variability (Y_S); II) Location variability (Y_L). The reference attenuation (W) is determined as a function of the distance, attenuation variables and an urban factor for an area or point-to-point. Because of this variability, there could be deviations (δ) more or less significant to the attenuation of the transmitted signal. The received signal (W) is obtained signal level attenuated in free space (W_0) attenuated by the sum of the attenuated formed by random variables. If transmitter and receiver are at known points, the location variable has a value of zero.

The reference attenuation defined as a function of distance also features 3 ranges for prediction: i) line-of-sight; ii) diffraction; iii) scatter. For each of these ranges, there are attenuation coefficients defined according to link geometry. These variables also consider the topography that is defined as terrain irregularly parameter $\Delta h(d)$ for a reference distance (D_0). Several applications use the Longley-Rice Model. Examples are CRC-COVWEB, SPLAT!, Radio Mobile, QRadioPredict, Pathloss5 [37-38]

3. ITU Terrain Loss Model

The ITU terrain loss model is a radio propagation model that provides a method to predict the median path loss for a telecommunication link. The model was developed on the basis of diffraction theory and it predicts the path loss as a function of the height of path blockage and the First Fresnel zone for the transmission link (Seybold, 2005). The model accounts for obstructions in the middle of the telecommunication link. It is therefore suitable to be used inside cities as well as in open fields. The model has the advantage of being suitable for use in any terrain and any frequency. The model is mathematically formulated as:

$$A = 10 - 20 C_N \quad (12)$$

Where,

A = Additional loss (in excess of free-space loss) due to diffraction (dB)

$C_N = \frac{h}{F_1} = \text{Normalized terrain clearance}$

$h = h_L - h_0$

$F_1 = 17.3 \sqrt{\frac{d_1 d_2}{f d}}$

5.3. City Models

City models include Young Model, Okumura Model, Hata Model for Urban Areas, Hata Models for Suburban Areas, Hata Model for Open Areas, COST Hata Model, Area to Area

Lee Model and Point to Point Lee Model. Some of these models that are close to the area under study are selected for presentation in this section.

1. Young Model

Young model is a ratio propagation model that was built on the data collected on New York City in 1952. It typically models the behavior of cellular communications in cities. It is ideal for modeling the behavior of cellular communications in large cities with tall structures. The model provides a useful tool in the frequency range of 150 MHz to 3700 MHz. The Mathematical formulation for Young model is given as:

$$G_B G_M \left(\frac{h_B h_M}{d^2} \right)^2 \beta \quad (13)$$

where,

L = Path loss in decibel (dB)

G_B = Gain of base transmitter in decibel (dB)

G_M = Gain of mobile transmitter in decibel (dB)

h_B = Height of base station antenna in meter (m).

h_M = Height of mobile station antenna in meter (m).

d = Link distance in kilometer (km).

β = Clutter factor

2. Hata Model for Urban Areas

The Hata model for urban areas, also known as the Okumura-Hata model for being a development version of the Okumura model, is the most widely used radio frequency propagation model for predicting the behavior of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in suburban areas and open areas [39]

This particular version of the Hata model is applicable to the radio propagation within urban areas. It is suited for both point-to-point and broadcast transmissions and it is based on extensive empirical measurements taken. It is well suited to be applied in the frequency range of 150 MHz to 1500 MHz. The model was developed for Mobile Station Antenna Height of between 1 to 10km, and Base Station Antenna Height of range 30 to 200 meters [39]

The Hata model for urban areas is formulated as shown in equation 2.19.

$$L = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_B - C_H + [44.9 - 6.55 \log_{10} h_B] \log_{10} d \quad (14)$$

For small or medium sized city,

$$C_H = 0.8 + 1.1 \log_{10} f - 0.7 h_M - 1.56 \log_{10} f \quad (15)$$

And for large cities

$$C_H = \begin{cases} 8.29(\log_{10}(1.54h_M))^2 - 1.1, & \text{if } 150 \leq f \leq 200 \\ 3.2(\log_{10}(11.75h_M))^2 - 4.97, & \text{if } 200 \leq f \leq 1500 \end{cases} \quad (16)$$

where,

L = Path loss in urban areas in decibel (dB).

h_B = Height of base station antenna in meter (m).

h_M = Height of mobile station antenna in meter (m).

f = Frequency of transmission in Megahertz (MHz).

Though based on Okumura model, the Hata model does not provide coverage to the whole range of frequencies covered by Okumura model. Hata model does not go beyond 1500 MHz while Okumura provides support for up to 1920 MHz.

3. Hata Model for Suburban Areas

The Hata model for suburban areas, also known as the Okumura-Hata model for being a developed version of the Okumura model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions in city outskirts and other rural areas. This model incorporates the graphical information from Okumura model and develops it further to better suit the need. This model also has two more varieties for transmission in urban areas and open areas; these are not reviewed in this work.

The Hata model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications, and is a function of transmission frequency and the average path loss in urban areas. The Hata model for suburban areas, also known as the Okumura –Hata model, for being a developed version of the Okumura model is the most widely used in radio frequency propagation for predicting the behavior of cellular transmission in city outskirts and other rural areas. This model incorporates the graphical information from Okumura model and develops it further to better suite the need. It also has two more varieties for transmission in urban areas and open areas.

The Hata model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. It also serve as a function of transmission frequency and the average path loss in urban areas. Hata model for suburban areas is formulated as, [38]

$$L_{SU} = L_U - 2 \left[\log_{10} \frac{f}{28} \right]^2 - 5.4 \quad (7)$$

where,

L_{SU} = Path loss in suburban areas in decibel (dB)

L_U = Average path loss in urban areas for small sized city in decibel (dB)

f = Frequency of transmission in Megahertz (MHz)

5.4. Models For Indoor Attenuations

In indoor radio channels, the propagation is strongly influenced by the layout of buildings, construction materials and building type, e.g. type of partitions, soft or hard partitions and multi-floor buildings. In general, it is difficult to predict the exact model for indoor environments where penetration from outside is involved. For this reason, a generalization is usually made, e.g. the signal strength received inside building increases with height, due to urban cluster effect [39-40]

1. ITU Model for Indoor Attenuation

The ITU indoor propagation model, also known as ITU model for indoor attenuation, is a radio propagation model that estimates the path loss inside a room or a closed area inside a building delimited by walls of any form. Suitable for appliance designed for indoor use, this model approximates the total path loss an indoor link may experience. The model is applicable to only the indoor environments. Typically, such appliances use the lower microwave bands around 2.4 GHz. However, the model applies to a much wider range, with better results between the frequencies of 900 MHz to 5.2 GHz. [16-18]

The model is also found suitable for multi floor attenuation predictions when the number of floors less than or equal to 3 (ITU-R, 2001). The ITU indoor path loss model is formally expressed as (ITU-R, 2001):

$$L = 20 \log f + N \log d + L_f(n) - 28 \quad (17)$$

where,

L = The total path loss in decibel (dB)

f = Frequency of transmission in megahertz (MHz)

d = Distance between base station and portable terminal in meter (m).

N = The distance power loss coefficient

n = Number of floors between the transmitter and portable terminal ($n \geq 0$), $L_f = 0$ dB for $n = 0$

$L_f(n)$ = The floor loss penetration factor

6. Conclusion

From these models analysis both the outdoor and indoor, it was observed that all models can perform better depending on the condition(s) that is involved. That is, the type of model used

in analysis depends on the area where the experiment is to be carried out and as such, model A could perform better than model B, etc. Therefore, it is highly recommended that before a mathematical model can be chosen for any experiment, the surrounding environment have to be considered.

7. References

- [1] Ajakaye, T.A (2005) "Telecommunication Business in Nigeria" University of Lagos, Vol. 1, pp. 37-51.
- [2] Ajay Mishra (2007) "Advance Cellular Network Planning and Optimization" John Wiley and Sons, Vol. 28, pp. 402-411.
- [3] Amitay, N. (1992) "Modeling and Computer Simulation of Wave Propagation in Lineal Line-of Sight Microcell" IEEE Trans. Veh.Tech; pp. 337-342.
- [4] Anderson J.B, Rappaport T.S, and Yoshida S. (1995) "Propagation Measurements and Models for Wireless Communication Channels," IEEE Communication Magazine, January, pp. 42-49.
- [5] Anderson, H.R (2001) "A Ray-Tracing Propagation Model for Digital Broadcast Systems in Urban Area," IEEE Trans. Broadcasting, Vol. 39, pp. 309-317.
- [6] Andrea Goldsmiths (2005) "Wireless Communications," Cambridge University Press, Vol. 7, pp. 43-67
- [7] Andrea, G (2005) "Wireless Communications," Cambridge University Press.
- [8] Anyasi, F.I. and Yesufu, A.K., (2007) "Indoor propagation modeling in brick, zinc and wood buildings in Ekpoma". Journal of engineering and Applied Sciences. Vol. 2(9): 1408-1413. Medwell journals, ANSINET building, Pakistan.
- [9] Anyasi, F.I., Yesufu, A.K., Akpaida, V.O.A., Evbogbai, M.J.E. and Erua, J.B., (2007) "Indoor modeling for determination of G. S. M. signal penetration level". A case study of mud, block, and steel building materials in Ekpoma. Journal of engineering and Applied Sciences. Vol. 2(9): 1443-1449. Medwell journals, ANSINET building, Pakistan.
- [10] Armogum. V, Soyjaudah K.M.S, Fogarty T and Mohamudally N. (2007) "Comparative Study of Path loss using existing models for Digital Television Broadcasting for Summer, Mauritius Vol. 4, pp 34-38, May Season in the north of Mauritius", Proceeding of Third Advanced IEEE International Conference on Telecommunication.
- [11] Baccelli F, Blaszcyszyn B, and Mühlethaler P. (2006) "An Aloha Protocol for Multihop Mobile Wireless Networks" IEEE Transactions on Information Theory, Vol. 52. No. 2, pp. 421-436.
- [12] Bettstetter C. (2004) "On the Connectivity of Ad Hoc Networks" The Computer Journal, Special Issue on Mobile and Pervasive Computing, Vol 47. No. 4, pp. 432-447.
- [13] Carlson A.B, Crilly P.B, Rutledge, J.C. (2002) "Communication Systems, An Introduction to Signal and Noise in Electrical Communication," 4th Edition, McGraw-Hill, 2002.
- [14] Clint Smith, Daniel Collins (2000) "3G Wireless Network" page 136.
- [15] Domazetovic A, Greenstein L.J, Mandayan N, Seskar I. (2002) "A Modeling Approach 50 for Wireless Channels with Predictable Path Geometrics," IEEE Beh.Tech.Conf.
- [16] Durgin G.D. Rappaport T.S and Xu H. (1998) "Measurements and Models for Radio Path Loss and Penetration Loss in and Around Homes and Trees at 5.85 GHz" IEEE Transactions on Communications. Vol 46, No. 11, November, pp. 1484-1496.

- [17] Erceg V and Greenstein L.J (1999) "An Empirically Path Loss Model for Wireless Channels in Suburban Environments" IEEE Journal on Selected Areas in Communication, Vol. 17, pp. 1205-1211.
- [18] Erceg V, Fortune S.J, Ling J, Rustako A.J Jr, Valenzuela (1997)"Comparisons of a Computer-Based Propagation Prediction Tool with Experimental Data Collected in Urban Microcellular Environments" IEEE Journal on Selected Areas in Communications, Vol 15, No. 4, May, pp. 677-684.
- [19] Erceg V, Greenstein L.J, Tjandra S.Y, Parkoff S.R, Gupta A, Kulic B, Julius Bianchi A.A. (1999) "An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments" IEEE Journal on Selected Areas in Communication, Vol. 17, pp. 1205-1211.
- [20] Hung HuyKhong, Bing W. Kwan, LeonardJ. Tung (2008) "A Physics-Based Path-Loss Model for UWB (Ultra-WideBand) Systems," Proc. International Conference on Wireless Networks (ICWN).
- [21] Idim, A. I. and Anyasi, F. I. (a) "Determination of Building Penetration Loss of GSM Signals, Using selected buildings in Orhuwhorun, Delta State, Nigeria As a Case Study. *Journal of Electronics and Communication Engineering*, 9(5): 1-5.
- [22] Idim, A. I. and Anyasi, F. I. (b) "Determination of Path Loss Exponent Using GSM in Orhuworun Environ, Delta State. *Journal of Electronics and Communication Engineering*, 9(5): 15-20.
- [23] International Engineering Consortium (2005). Global System for Mobile Communication (GSM), IEEE Vol 5, No 23 pp. 56-70.
- [24] Iskander M.F and Yun Z (2002) "Propagation Prediction Models for Wireless Communication Systems", IEEE Transaction on Microwave Theory and Techniques, Vol 50, No 3, March, pp. 662-673.
- [25] ITU (2009) "What Really is a Third Generation (3G) Mobile Technology" IEEE Vol 6, No 28, pp. 57-87.
- [26] Kagan, A.M, Linnik Y.V and Rao C.R. (1973) "Characterization Problems in Mathematical Statistics", Wiley.
- [27] King R.J. (1969) "Electromagnetic Wave Propagation over a Constant Impedance Plane", Radio Science, Vol 4, pp. 225-268.
- [28] Lee W.C.Y (1993) "Mobile Communications Fundamentals" Second Edition.
- [29] Lee W.C.Y (1998) "Mobile Communications Engineering" McGraw-Hill.
- [30] Leveque O and Tse D. (2007) "Hierarchical Cooperation Achieves Optimal Capacity Scaling in Ad Hoc Networks," IEEETransactions on Information Theory, Vol 53, No 10, pp. 3349-3572.
- [31] Li H.J, Chen C.C, Liu T.Y, Lin H.C. (2000) "Applicability of Ray-Tracing Techniques for Prediction of Outdoor Channel Characteristics", IEEE Trans. Veh. Tech, pp. 2336-2349.
- [32] Li R, (2000) "The Accuracy of Norton's Empirical Approximations for Ground Wave Attenuations", IEEE Trans. Ant. Prop. Vol31, pp. 624-628.
- [33] Lichun L. (2000) "IEEE Ant. Prop. Magazine", pp. 21-33.
- [34] Longley A.G (1998) "Radio Propagation in Urban Area" OT Report New York, pp 78-144.
- Propagation, Vol 42, No 2, February, pp. 137-144.
- [35] Schaubach, K.R, Davis IV, Rappaport T.S (1992) "A Ray Tracing Method for Predicting Path Loss and Delay Spread in Microcellular Environments", IEEE Veh. Trans. Tech, pp. 932-935.

- 541 [36] Seidel S.Y and Rappaport T.S (1992) “914MHz Path Loss Prediction Models for Indoor
542 Wireless Communications in Multifloored Buildings”, IEEE Transactions on
543 Antennas and Propagation, Vol 40, No 2, February, pp, 207-217.
- 544 [37] Sharma H.K, Sahu S and Sharma S (2011) “Enhanced Cost 231 W.I Propagation Model
545 in Wireless Network” International Journal of Computer Applications, Volume 19,
546 No 6.
- 547 [38] Sharma P.K (2013) International Journal of Engineering Science and Technology,
548 Volume 2(6), 2010,2008-2013.
- 549 [39] Skidmore R.R (1997) “A Comprehensive in Building and Microcellular Wireless
550 Communication System Design Tool”, M.S thesis, Dept. Elect. Eng, Virginia
551 Polytechnic Inst. And State University Blacksburg, V.A.
- 552 [40] Sommerfeld A.N (2000) “Propagation of Waves in Wireless Telegraphy II”, Ann. Phys.
553 Vol 81, pp. 1135-1153.