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# A Review of Path Loss Models for UHFRADIOWaves Propagation: Trends andAssessment.

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**Abstract:** Wave propagation models are essential and very important tools for determining the wave propagation characteristics for a particular environment. Path loss predictions are therefore required for the coverage planning, determination of multipath effects as well as interference and cell calculations. These calculations lead to high level network planning. The planning process includes the prediction of the received power which determines the parameter of the base station transceiver. In wireless broad band services, delay spread, angular speed and impulse response of the mobile channel have become more and more important for the planning process. This paper outlines the trends in the development of various path loss models and assessing these models.
**Keywords:** coverage planning macro cell, multipath, path loss radio, wave propagation,

## I. INTRODUCTION

Since the evolution of wireless technologies in the 1980s the need for faster and better communication systems has increased tremendously. This unexpected growth rate is attributed to the newly introduced notion of terminal, service and user mobility. Technological advancements are tending towards more increase in wireless applications. Wireless communication is therefore expected to become the dominant mode of data access technology in the future. Propagation models are used for conducting feasibility studies and initial deployment.

These days' propagation models are tailored toward specific terrains and environment in order to get better coverage and performance by Global System for Mobile Communication (GSM) service providers. As the number of subscribers in cities is continuously increasing this has led to the development of techniques to increase system capacity. One of this is the decrease in cell sizes and this leads to a multilayer network. Another technique is the extension of GSM to the 1800MHz band, when possible thereby allowing the use of more frequencies.All these have led to development of good propagation models, in order to predict the correct signal strength. It also permits the prediction of areas where the signal strength is minimal as well as those areaswhere interference may appear, leading to an efficient and reliable coverage of the desired service area.

Radio waves start from a certain point, typically the transmitting antenna, and love a certain level of energy. If the antenna radiates power equally in all directions i.e. it is omini directional and assuming that all conditions for its operation are Ideal, then the radio waves propagates in an ever-expanding circle.Since the energy is finite, at any distance from the transmitter, the original energy spreads out over a larger area with diminishing energy. In this case the signal is said to be attenuated. The receiver cannot correctly receive the information if the signal is too weak.

Various methods for realizing fading processes were shown by [1, 2]. The models of superposition of finite number of waves were proposed in [3]. The method for realizing a general fading processusing Rice's sum of sinusoids method was developed in [4].The methods[3] require the generation of a complex Guassian process thus making simulation more efficient

It was found out that in wireless communication, the Rayleigh fading process was usually used to describe the fluctuation of the amplitude of the radio signal over short period of time or travel distance, assuming the multipath delay was much less than the signal period.[5]

Large-scale fading represents the average signal power attenuation or path loss due to motion over large areas. A GSM channel is highly frequency selective in a hilly terrain environment where delay spreads can reach 10 to 15µs. Also the large angle spread causes variations of the channel from antenna to antenna. The channel variation in time depends upon the Doppler spread. GSM uses a short time slot; therefore the channel variation during the time slot is negligible.[3 ]

In cellular networks, the base station which is located at the centre of a cell directs telephone calls to and from the wireless terminals within the cell throughout the duration of the call. This network system is connection oriented. It was originally developed for voice transmission but now it is equally applicable for data transmission.

GSM systems standard of Europe stipulates that rural channels are often characterized by strong direct line-of-sight path and quick exponential decay of responses.[1 ] It assumes that in a rural environment there are no distant largescatterers such as large buildings and mountains. In this class of channels, the multipath is mainly due to scattering objects such as trees and that streets are within the proximity of the mobile receiver and the span of arrival times is short. Whereas in urban areas it is typically assumed that the mobile would be surrounded by many reflective and diffracting objects like buildings which are a sizeable distance away from the receiver. This leads to disguisable multipath arrivals in addition to the small scale scatters in its proximity.[5]

A rigorous mathematical treatment of the subject of channel characterization was done by [6] and provides more complete characterization of digital cellular radio channels. [7]Also did an in depth characterization of the mobile radio communications channel and also provides a good summary of fading on land mobile channels.

[8] have expressed various mathematical models to analyze and design physical transmission media. The models differ depending on the medium (wired or wireless) and transmission type (analogue or digital). These differences are to reflect the most important characterization of the channel. These models are very important as they serve as the basis for the design of recorder and modulator at the transmitter and the demodulator and decoder at the receiver.

[9, 10,] at different times devised ways to carry out impulse response measurements using channel sounders. Even though the most realistic deterministic models are based on direct channel measurement results, it is important to know how these measurements were done and their limitations.

The parameters of a channel for example path loss, delay spread etc are functions of key properties of the environment and the system under consideration. It was found out that the delay and angular spread in an urban environment are significantly different from those in rural environments. Sub divisions like typical urban and bad urban are widely in use.[11]

Shadowing and delay spreads are sometimes reported to increase and sometimes decrease with carrier frequency when these parameters vary with carrier frequency. When these parameters are measured severally and the average values are found, it is observed that the average path loss shows distinct frequency dependence.

[12-14] variously investigated the frequency dependence of the narrow band parameters and delay spread. While investigations on the frequency dependence of the angular spread were conducted by [15].[16,17] observed that the height of the Base Station (BS) with respect to the surrounding buildings had a strong influence on the propagation parameters. These led to the basic classifications namely,macrocell (BS above rooftop), microcell (BS below rooftop) and Pico cell (BS indoor).

In any system planning, the first thing to do is to determine the average narrow band power. The values are the average of both small scale fading and shadowing effect measurements. Okumura-Hata model is the most preferred for rural as well as urban environments. [18]had extended and modified this model to cover higher frequencies and had made it more suitable for urban environments.

Transmission losses, environmental losses, shadowing as power margins to account for multipath fading are parameters taken into consideration before a particular path loss model is accepted. The propagation model must be accurately celebrated to represent the specific cell site.

After carrying out extensive drive test measurements with various range of clutter type, frequency, transmitter height and transmitter power in Tokyo, Japan, [19] concluded that signal strength decreases at much greater rate with distance than that predicted by free space loss.

[20,21] have extensively studied the behaviour of propagating electromagnetic waves through forests and thick woods. And they variously suggested a simple model that used ray trace techniques for mixed paths in forest environments. This model makes use of diffraction and /or reflection on abrupt discontinuities caused by the presence of a road inside a forest environment. [22 ]observed that the path loss models can be used to mainly predict rain fade and multipath.

Some calibration processes to be used in modifying the model parameters to accurately approximate the relevant measured data were proposed by [23]. This work was an extension of the work earlier done by [22.[24]did a comprehensive set of propagation measurements at 3.5GHz in Cambridge, United Kingdom. They compared three methods namely COST 231 Hata model, Stanford University interim (SUI) and ECC-33 models. Their results showed that in general SUI and COST 231 Hata models over predicted the path loss in all environments studied. The ECC-33 model showed the best result, especially in urban area.

The effects of rainfall rates on propagation along line-of-sight (LOS) for wireless access paths was investigated by [25].Their findings revealed that higher rainfall rates lead to higher distortion of signals and therefore larger paths of propagation. [26]determined the path loss using Okumura-Hata for Oman. This study was carried out in the urban areas of Oman using measurements from Oman mobile. He compared with the theoretical simulation using Okumura-Hata with the experimental data. Using piecewise spline interpolation he was able to find the missing experiment data for Oman.

It is common to model large scale fading effects using a path loss model that obeys some sort of power law [27]. Large scale fading represents the average signal power attenuation or the path loss caused by the motion of the mobile device over large areas. This phenomenon occurs when the receiver is shadowed by the presence of prominent terrain contours e.g. buildings, trees, bill boards etc [27].

## II. PATH LOSS MODELS

There are different ways of modeling path loss depending on the propagation environment. Some of the these models include (a) Free space loss model (b) Okumura – Hata model (c) Stanford University Interim (SUI) model (d) COST-231 Hata model (e) ECC-33 path loss model (f) COST 231 Walfisch-Ikegami model. These models depend on location, frequency range and clutter type such as urban, sub-urban and countryside.

### 2.1 Free Space Loss Model

The free space model involves direct line-of-sight (LOS) transmission between the transmitter and the receiver. From least square regression analysis, path loss (PL) at a distance d is given by:

$$PL(d) = PL(d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) \qquad (1)$$

where $d_o$ is the reference point at one kilometre and n is the path loss exponent. For free space loss, if n is equal to 2. The equation for free space loss then becomes:

$$PL(dB) = PL(d_o) + 20\log_{10}\left(\frac{d}{d_o}\right) \qquad (2)$$

When transmitted and received powers are put into consideration equation 2 becomes:

$$PL(dB) = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \qquad (3)$$

where $\lambda$ is the wave length of the received signal.Substituting $\lambda$ in kilometre and rationalising the equation produces the generic free space path loss formula which is :

$$PL\ (dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (4)$$

Other propagation models are developed on the basis of the free space propagation model.

### 2.2 Okumura – Hata Model

This model commonly used for urban and sub-urban areas is a modification of the Okumura model. This model is the most commonly used for macro-cell coverage planning.

Hata based his model on Okumura's free test results and predicted various equations for path loss with different types of clutter with a range of frequency, 150MHz to 1500MHz. The distance from the base station ranges from 1km to 20km while the range of the height of the mobile antenna is from 1m to 10m.

The model gives the path loss in dB for the urban environment to be [28]:

$$PL(urban) = 69.55 + 26.16(l0g_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log_{10}(h_b)]\log_{10}(d) \qquad (5)$$

Where,

$$a(h_m) = [1.1\log_{10}(f) - 0.7]h_m - [1.56\log_{10}(f) - 0.8]$$

Where d = distance in kilometre , $f$ is frequency measured in MHz
$h_b$ = height of the base station antenna in meters
$h_m$ = height of mobile antenna in meters
a ($h_m$) = correction factor in dB

Path loss model for highway without noise factor is [28] :

$$L_p(dB) - L_p(dB)_{urban} - 2\left[\log\left(\frac{f}{28}\right)^2 - 5.4\right] \qquad (6)$$

Path loss model for highway with noise factor is [28] :

$$L_p(dB) - L_p(dB)_{urban} - 2\left[\log\left(\frac{f}{28}\right)\right]^2 \qquad (7)$$

Okumura – Hata model is not suitable for micro-cell planning where antenna is below roof height. It is not valid for 1800MHz and 1900MHz systems.

**2.3 Stanford University Interim (Sui) Model**

This model was developed for fixed wave less access systems (FWA). It was developed for frequency bands below 11GHz. From its name, this model originated from Stanford University in USA and covers a frequency range of 2.5GHz to 2.7GHz.

The SUI models are divided into three different types namely, A (hilly terrains with moderate to heavy tree densities), B(hilly terrains with light tree densities) and C (flat terrains with light tree densities.

The basic path loss equations with correction factor are presented in [29, 30] :

$$PL(dB) - A + 10_{\gamma} \log_{10}(d/d_o) + X_f + X_u + S \;\; for\; .d > d_o \tag{8}$$

where d is the distance between the Access Points (AP) and the Customer Premises Equipment (CPE) antennas in meters, $d_o$ = 100m and $S$ is a log normally distributed factor used to account for the shadow fading due to trees and other clutter and has a value of 8.2dB and 10.6dB [31].

The other parameters are defined as :

$$A = 20\log_{10}\left[\frac{4\pi d_o}{\lambda}\right] \tag{9}$$

$$\gamma = a - bh_b - c/h_b \tag{10}$$

where$h_b$ is the base station height above ground in meters and should be between 10m and 80m and a, b and c are constants that vary with terrain.

**2.4 Cost 231 Hata Model**

COST stands for European Co-operative for Scientific and Technical research and this model is widely used for predicting path loss in mobile wireless systems. It is an extension of the Okumura – Hatamodel.The COST 231 Hata model is designed to be used in the frequency range 500MHz to 2000MHz and has correction for urban, suburban and rural (flat) environments.

The path loss in urban area is given by :

$$P_L(dB) = [46.33 + 33.9\log(f)] - [13.82\log(h_b)] + [44.9 - 6.55\log(h_b)]\log(d) \tag{11}$$

where $a(h_m) = 1.1\log(f) - 0.7h_m - 1.56\log(f) - 0.8$ (12)

$h_b$ = height of base station antenna in meters

$h_m$= height of mobile antenna in meters

$a(h_m)$ = correction factor in dB

**2.5Ecc-33 Model**

This model was developed by Electronic Communication Committee (ECC). ECC extrapolated the original measurements by Okumura and modified its assumptions so that it more closely represents a Fixed Wireless Access (FWA) system. The path loss is defined as :

$$PL(dB) = A_{fs} + A_{bm} - G_t - G_r \tag{13}$$

where$A_{fs}$ is free space alternation , $A_{bm}$ is basic median path loss

$G_t$ is base station gain factor; $G_r$ is received antenna height gain factor :

$$A_{fs} = 92.4 + 20\log(d) + \log_{10}(f) \tag{14}$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log(f) + 9.56(\log(f))^2 \tag{15}$$

$$G_t \log\left[\frac{h_b}{200}\right] [13.958 + (5.8\log d)]^2 \tag{16}$$

For medium city environments :

$$G_r = [42.57 + 13.7\log(f)]\;[\log(h_m) - 0.585] \tag{17}$$

where f is frequency in GHz.

**2.6 Cost 231 Walfisch- Ikegami Model**

This model can be used for the frequency range 800–2000 MHz, for heights up to 50m (i.e. the height of building plus height of the BTS antenna) for a distance of up to 5 km. It takes the characteristics as heights of buildings, width of roads building separation and road orientation with respect to direct radio path into account. It has corrections for multi screen diffraction loss, approximation for the rooftop to street diffraction and losses as a result of scattering. It also has correction factors for antenna heights. This model is defined by the following equations and it talks about two conditions: line-of-sight (LOS) and no-line-of-sight (NLOS). The path loss formula for the LOS condition is:

$$P = 42.6 + 26 \log d + 20\log f \qquad (18)$$

For the NLOS condition, the path loss is given as:

$$P = 32.4 + 20 \log f + 20 \log d + L\text{rds} + L\text{ms}. \qquad (19)$$

where $L_{rds}$ is the rooftop to street diffraction and scatter loss and $L_{ms}$ is the multiscreen loss due to diffraction. [31] [32]

Okumura – Hatamodel is the commonly employed model for urban and sub-urban areas. This model is the most commonly used for macro-cell coverage planning. This is a combination of the work of Okumura and Hata. Okumura was able to carry out test measurements in Japan. These measurements had a range of clutter type, transmitter height, transmitter power and frequency. He found out that the signal strength decreases at a much greater rate with distance than the predicted space loss [33-35].

Hata based his model on Okumura's free test results and predicted various equations for path loss with different types of clutter. The ranges of tests were carried out from carrier frequency, 150MHz to 1500MHz. The distance from the base station ranged from 1km to 20km while the range of the height of the mobile antenna was from 1m to 10m.

Okumura – Hata model is not suitable for micro-cell planning where antenna is below roof height. It is not valid for 1800MHz and 1900MHz systems.

## III. DEVELOPING PROPAGATION MODELS

Various propagation models that specifically represent varying propagation environments and operating frequencies are widely known [36]. And a large number of propagation prediction models have been developed for various terrain irregularities, tunnels, urban streets and buildings, earth curvature etc [37, 38].

The degree of sophistication in the development of these models depends on how long the related technology is. Four different methods are usually used in developing propagation models. They are namely [39].

(a) Statistical method: In this method parameters are found through statistical analysis that bears a relationship to the quantity being predicted.
(b) Electromagnetic deterministic method: This method focuses on the physical laws governing the interaction of electromagnetic waves with the physical elements of the propagation environment under consideration.
(c) Empirical and measurement based method: Empirical and measurement based models are site and frequency specific and therefore lack generality.
(d) Ray tracing method: This is the most commonly used approach in the calculation of propagation models for terrestrial and urban environments. It is based on a ray launching and bouncing procedure. A combination of these methods is used to improve the accuracy, broaden the generality and greatly reduce computational time required. It improves curve fitting techniques and computation speed.

The deterministic method was used to carry out measurement in seven urban areas in Nigeria and the generalized Okumura- Hata and COST 231 models were modified using simple interpolations.

## IV. TRENDS

Research works on the development of propagation models are ongoing in various countries particularly in Europe, America and Japan. Even though majority of the available models are based on computationally efficient statistical and empirical models, there is growing interest in using electromagnetic based deterministic models particularly in the USA [40]. Current areas of interest include [41]:

(a) Development of new models for microwave and millimeter wave wireless systems.
(b) Models for broadband wireless systems that take into consideration polarization diversity and effects of mobility.
(c) Computationally efficient deterministic/ quasi-deterministic models that maintain good accuracy and general applications.
(d) Development of integrated models that provide statistical parameters relevant to system and network simulations.
(e) Experimental measurements on scaled models or realistic channels to validate simulations and provide guidance for identifying the most important contributions to impairments and interference effects.

During the last couple of years, a number of new wave propagation models for outdoor predictions in urban areas have been proposed in various literatures such as[42-50]. Other supporting literaturesinclude [51-65].

Also works by[67-68] proposed models for some cities in Northern, Enugu and Port Harcourt in Southern Nigeria and Lagos respectively.

One of the trends in path loss modeling involves the modeling of the influence of vegetation and large-scale terrain variations as seen in the works of [69-87].

[88]did an exhaustive work on 914 MHz path loss prediction for indoor wireless in multi floored building. [89]proposed a simplified analytical model for predicting path loss in urban and sub-urban environments. [90]worked on measurements and models for radio path loss and penetration in and around homes and trees at 5.85 GHz.

[91]verified path loss and delay spread prediction of a 3D ray tracing propagation model in urban environment. A statistical path loss model for UWB channel was done by [92]. Comparison of empirical propagation path loss models for fixed wireless access systems was undertaken by[93]. [24]compared propagation accuracy for Wimax on 3.5 GHz. [95] proposed propagation models and characterization for under water communication channels.

## V. ASSESSMENT

Wave propagation models are very important and necessary tools for determining the radio wave propagation characteristics of a user environment or area. The model to use must be known before radio systems are installed. Path loss predictions are therefore required for the coverage planning, the determination of multipath effects, as well as for interference and cell calculations. These calculations are the basis for high level network planning process**.**

Therefore, for the cellular networks to effectively cover a terrain or environment, accurate prediction of the coverage of the radio frequency signal is highly needed. To improve the reception and accuracy of signal strength prediction, localised environmental features of the areaunder consideration have to be modeled to closely resemble the real environment.

As earlier stated there is a very high demand for new mobile communication services as networks play an important role in industry, medicine, environmental issues and other fields of human endeavor. There is much pressure on the networks to satisfy these demands and other user requirements. The need for a high quality of service (QoS) cannot be overemphasized. Since the spectral resources are finite, the only option for increasing the capacity of the networks is to reduce the size of the cells. This has led to an increase in the number of base stations however, thereby making the networks more complex. To solve this problem, the base station has to be well distributed within the cell and its optimal antenna height has to be estimated after taking into account the propagation conditions. This makes a good understanding of the wireless propagation channel essential for cell planning strategies.

## VI. CONCLUSION

The various models have been accepted in the electromagnetic wave propagation community, but they should not be applied without careful assessment of the conditions if the underlying experiences are similar to those of the propagation environment. One should keep in mind that the main objective of such empirical models is to provide estimates for a wide range of propagation conditions; but this objective if necessarily traded for reduced accuracy in specific propagation scenarios.

Due to great advancement in signal processing methods and rapid development in communication algorithms, future propagation modes are expected to play a critical role in the accurate measurement of mobility and the dynamic variation in the characterization of the propagation channels.

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