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Pathloss Prediction for a typical mobile communication system in Nigeria using empirical models

Akpado K.A
Department of Electronics and Computer Engineering
Nnamdi Azikiwe University, PMB 5025Awka, Nigeria

Abe Adewale
Department of Electronics and Computer Engineering
University of Essex, United Kingdom

Oguejiofor O.S
Department of Electronics and Computer Engineering
Nnamdi Azikiwe University, PMB 5025Awka, Nigeria

Ejiofor A. C
Department of Industrial and Production Engineering
Nnamdi Azikiwe University, PMB 5025 Awka, Nigeria

Abstract—: **In wireless networks, propagation path loss has a strong impact on the quality of service. Its accurate determination leads to development of efficient design and operation of quality networks. Several researches have been carried out in many countries in the past and are still ongoing to determine or validate the values of propagation path loss of an existing network in their own environment. The propagation path loss which is a major limiting factor to coverage prediction is derived from all losses encountered by the signal in its propagation from base station (BS) tower to the mobile user or mobile station (MS). In this study MATLAB simulation tools were used to predict the attenuation the signal experienced on its propagation from point A to point B separated by several kilometers in a cell using empirical propagation model.**

Keywords-Basestation, Cellular mobile system, Mobile station ,Path loss and Received signal strength,.

I. INTRODUCTION

All has been observed that dropped calls; no service or no network, network busy, number not reachable are the fact of life in today's cellular mobile networks. They are usually the result of poor coverage, limited capacity and problems in propagation of radio waves (which is how the waves get from Point A to Point B and back again). Lots can happen between those two points, and if the signal is damaged or otherwise fades to such a low level that the receiver cannot detect and use (demodulate) it, it becomes a problem.

This creates room for network operators to be confused as how will these problems be eliminated to ensure good quality of service to cellular mobile subscribers. The quality of coverage of any wireless network design depends on the accuracy of the propagation prediction models. For accurate designs, the propagation models are estimated from signal strength measurements taken in the service area. Even though it is known that modelling error is unavoidable during signal strength measurements. In this paper, we predict network coverage based on the established empirical propagation models

II. RADIO PROPAGATION ENVIRONMENT

Generally, radio wave propagation consists of three main attributes: Reflection, diffraction and scattering see Fig 1.

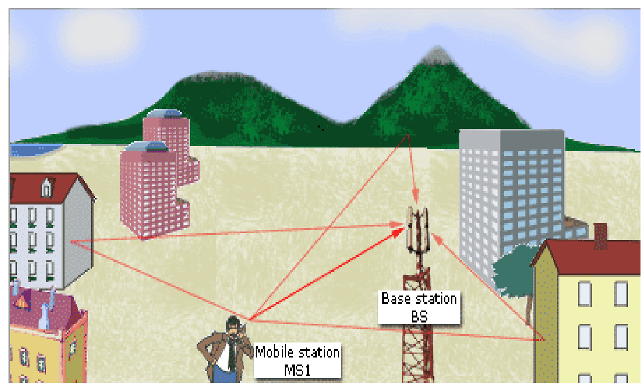

Figure1. Propagation Mechanisms

- Reflection occurs when radio wave propagating in one medium impinges upon another medium with different electromagnetic properties. The amplitude and phase of the reflected wave are strongly related to the medium's intrinsic impedance, incident angle, and electric field polarization. Part of the radio wave energy may be absorbed or propagated through the reflecting medium, resulting in a reflected wave that is attenuated.
- Diffraction is a phenomenon by which propagating radio waves bend or deviate in the neighbourhood of obstacles. Diffraction results from the propagation of wavelets into a shadowy region caused by obstructions such as walls, buildings, mountains, and so on.
- Scattering occurs when a radio signal hits a rough surface or an object having a size much smaller than or on the order of the signal wavelength. This causes the signal energy to spread out in all directions. Scattering can be viewed at the receiver as another

radio wave source. Typical scattering objects are furniture, lamp posts, street signs, and foliage [1-4].

III. PATH LOSS MODELS

In order to solve the problem of capacity and coverage in cellular mobile network, network operators develop propagation models in predicting receive signal strength in the world. Propagation models are mathematical attempts to model the real radio environment as closely as possible. The propagation path loss which is a major limiting factor to coverage prediction is derived from all losses encountered by the signal in its propagation from base station (BS) tower to the mobile user or mobile station (MS) [5, 6]. Propagation models are useful for predicting signal attenuation or path loss which is the reduction in power of an electromagnetic wave as it propagates through space. It is a major component in analysis and design of link budget of a communication system. It depends on frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance, among many other factors. These models can be broadly categorized into three types; empirical, deterministic and stochastic. Empirical models are those based on observations and measurements alone. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require a complete 3-D map of the propagation environment. Stochastic models, on the other hand, model the environment as a series of random variables. Macro cells are generally large, providing a coverage range in kilometers and used for outdoor communication [7]. Several empirical path loss models have been determined for macro cells. Among numerous propagation models, the following are the most significant ones, providing the foundation of mobile communication services. The empirical models are:

(a) Yoshihisa Hata Okumura model

The Hata-Okumura model is measurement provided by Yoshihisa Okumura, and is valid from 150 MHz to 1500 MHz; Hata presented the urban area propagation loss as a standard formula, along with additional correction factors for application in other situations such as suburban, rural among others. The computation time is short and only four parameters are required in Hata model.

However, the model neglects terrain profile between transmitter and receiver, i.e. hills or other obstacles between transmitter and receiver are not considered.

This is because both Hata and Okumura made the assumption that transmitter would normally be located on hills [8, 9, 10]. The path loss in dB for the various environments is given in equations below:

- For Urban Area

$$P_{L\,(URBAN)}\,(dB) = A + B \log(d) \quad (1)$$

Where;

$P_{L\,(URBAN)}$ (dB) = path loss for urban area in dB

d = distance between transmitter (Tx) and receiver (Rx) in kilometer,

'A' = represents a fixed loss that depends on frequency of the signal.

These parameters are given by the empirical formula:

$A = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m)$.

$B = 44.9 - 6.55 \log(h_b)$.

Where,

f = operation frequency measured in MHz,

h_b = height of the base station antenna in meters,

h_m = mobile antenna height in meters and

$a(h_m)$ = is correction factor in dB

For effective mobile antenna height $a(h_m)$ is given by:

- for small and medium size cities

$a[h_m] = [1.1 \log(f) - 0.7]\, h_m - [1.56\log(f) - 0.8]$,

- for large cities,

$a[h_m] = 8.29[\log 1.54 h_m]^2 - 11,\ f \leq 200MHz$

$a[h_m] = 3.2[\log 11.75 h_m]^2 - 4.97,\ f \geq 400MHz$

For Sub-Urban Area the path loss is given as:

$$P_{L\,(SUB\text{-}URBAN)}(dB) = P_{L\,(URBAN)} - 2[\log(f/28)^2 - 5.4]dB \quad (2)$$

For Rural Area the path loss is given as:

$$P_{L\,(RURAL)}\,(dB) = P_{L\,(URBAN)} - 4.78\log(f)^2 + 18.33\log f - 40.94dB \quad (3)$$

The range of value for validity of Hata model is

$150 \leq f \leq 1500MHz$

$30 \leq h_b \leq 200m$

$1 \leq h_m \leq 10m$

$1 \leq d \leq 20km$.

(b) European Cooperative for Scientific and Technical Research (COST-231) model

This is the extension of Hata-Okumura- model for communication system operating at 1800 to 2000MHz. This model is derived from Hata model and depends upon four parameters for prediction of propagation loss: frequency, height of received antenna, height of base station and distance between base station and received antenna [8].

The path loss using COST 231 model for signal strength prediction is given as:

- For Urban Area

$$P_L\,(dB) = 46.33 + 33.9 \log(f) - 13.82 \log(h_b) - a(h_m) + [44.9 - 6.55 \log(h_b)] \log(d) \quad (4)$$

Where;

$a[h_m] = [1.1 \log(f) - 0.7]\, h_m - [1.56\log(f) - 0.8]$,

(c) Electronic and Communication Committee (ECC-33) model

The ECC 33 path loss model is developed by Electronic Communication Committee (ECC) from original measurements by Okumura and modified its assumptions so that it more closely represents a fixed wireless access (FWA) system. The path loss using the model for prediction is defined as:

$$P_L\,(dB) = A_{fs} + A_{bm} - G_t - G_r \quad (5)$$

Where;

A_{fs} = free space attenuation,

A_{bm} = basic median path loss,

G_t = BS height gain factor and

G_r = received antenna height gain factor.

They are individually defined as:

$A_{fs} = 92.4 + 20 \log (d) + \log (f)$

$A_{bm} = 20.41 + 9.83\log d + 7.894\log f + 9.56[\log (f)]^2$

$G_t = \log (h_b/200)\ [13.958 + 5.8 \log d]^2$ for medium city environments,

$G_r = [42.57 + 13.7 \log (f)][\log (h_m) - 0.585]$

Where,

f = operating frequency in GHz,

- **Free Space Model**

In free space there are no obstacles. The propagated wave radiates freely to an infinite distance without being absorbed or reflected.

In radio wave propagation models, the free space model predicts that received power decays as a function of T-R separation distance [1 7]. The path loss in dB for free space model when antenna gains are included is given by

$$P_L (dB) = -G_t - G_r + 32.44 + 20\log (d) + 20 \log (f) \qquad (6)$$

Where;

G_t = transmitter antenna gain in dB,

G_r = receiver antenna gain in dB,

d = T-R separation distance in kilometers and

f = operating frequency in MHz

IV. PROBLEM EVALUATION AND PERFORMANCE ANALYSIS

In general, the path loss the signal experienced as it propagate from point A to B separated by several kilometers are compared for the various empirical propagation model with distance as shown in the table 1.0; the qualitative values for the path loss showcased by the various propagation models are gotten through a MATLAB script developed using equations (1) for Hata Okumura, equation (4) for cost-231, equation (5) for ECE-33 and simulation parameters showcased at table 2.0. Figures 2.0 and 3.0 shows the path losses for the various empirical models against distance using plots and bar chart.

Table 1.0 Path Loss Comparison for the Empirical Models

Distance (km)	Hata Okumura L_p (dB)	COST-231 L_p (dB)	ECC-33 L_p (dB)
1	115.78	115.43	133.64
2	124.76	124.41	142.62
3	130.01	129.66	147.87
4	133.74	133.39	151.60
5	136.63	136.28	154.49
6	138.99	138.64	156.85
7	140.99	140.64	158.85
8	142.72	142.37	160.58
9	144.24	143.89	162.10
10	145.61	145.26	163.47

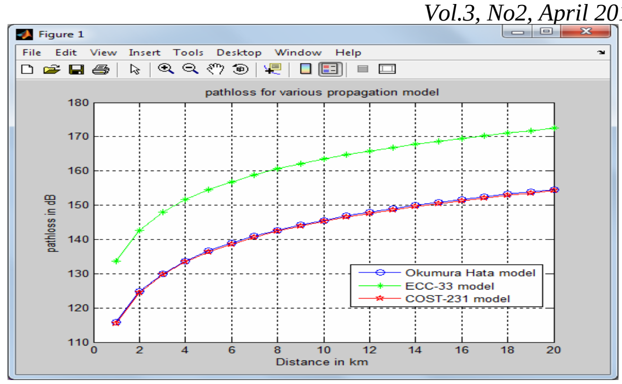

Fig. 2: Plot showing path loss for the various empirical Models against distance

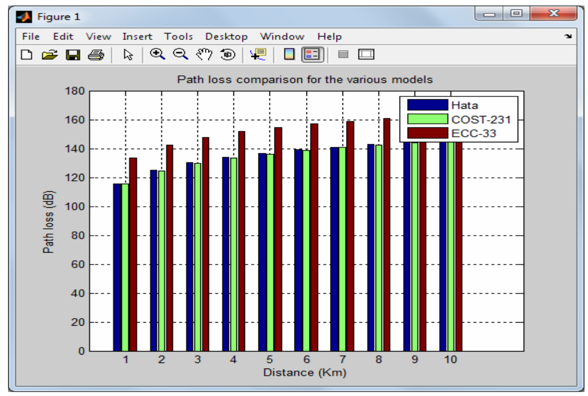

Fig. 3: Path loss for the various empirical models against distance

V. RECEIVED SIGNAL STRENGHT PREDICTION

In mobile communication, received signal strength is a measurement of power present in a received radio signal. Signal strength between base station and mobile subscriber must be greater than threshold value to maintain signal quality at receiver. Simultaneously signal strength must not be too strong to create more co-channel interference with channels in another cell using same frequency band. Handoff decision is based on received signal strength from current base station to neighboring base stations [9].

The signal gets weaker as mobile subscriber moves far away from base station and gets stronger as it gets closer.

The received signal strength for various path loss models like Hata Okumura model, Cost 231 model, and ECC-33 model are calculated as:

$$P_r = P_t + G_t + G_r - PL - A \qquad (7)$$

Where,

P_r = is Received signal strength in dBm,

P_t = is transmitted power in dBm,

G_t = is transmitted antenna gain in dB,

G_r = is received antenna gain in dB,

PL = is total path loss in dB and

A = is connector and cable loss in dB.

Having known the values for the total path loss (PL) for the various empirical models as showcased in table 1.0, together with the simulation parameters showcased in table 2.0, a

MATLAB script was developed using equation (7) to give rise to table 3.0

Table 2.0: Simulation parameters and their Specifications

Parameters	Values
Operating Frequency(f)	900MHz
Base Station Transmission power	43dBm
Mobile Transmission power	30dBm
Base Station antenna height	38m
Mobile station antenna height	1.5m
Transmitter antenna gain	17.5dB
Distance between transmitter and Receiver	1-10(km)
BS threshold level	-110dBm

The table 3.0 shows the received signal for the various empirical propagation models as a function of distance.

Table 3.0: Received signal strength comparison for the empirical models

Distance (km)	Hata Okumura R_{xd} (dBm)	COST-231 R_{xd} (dBm)	ECC-33 R_{xd} (dBm)
1	-123.56	-123.21	-164.04
2	-139.26	-138.91	-185.96
3	-148.80	-148.44	-199.49
4	-155.72	-155.36	-209.40
5	-161.18	-160.83	-217.27
6	-165.70	-165.34	-223.82
7	-169.56	-169.21	-229.44
8	-172.94	-172.58	-234.37
9	-175.94	-175.58	-238.76
10	-178.64	-178.29	-242.73

Figures 4.0 shows the received signal for the various empirical models against distance.

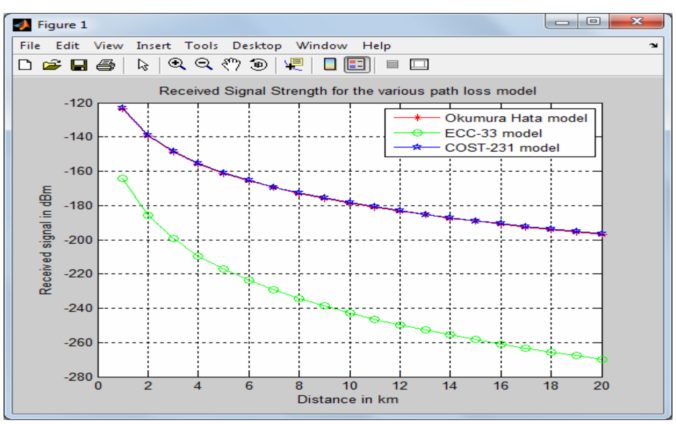

Fig. 4: Received signal for the various empirical models against distance

VI. Result Analysis

Clearly, from fig.2; as the distance increases the path loss for the various models also increases; the path loss using Hata-Okumura and COST 231 model are less than the threshold value (which was assumed to be 162.5dB for both uplink and downlink in this work) and ECC 33 model exceed the threshold value at 11km; also from fig. 4. The received signal strength using ECC 33 model is higher than the mobile receiver sensitivity whereas the received signal strength using COST 231 and Hata-Okumura models are less than the sensitivity threshold of mobile

VII. Conclusion

The propagation path loss has been predicted using the empirical propagation models. As seen from the analysis, the received signal strength using COST 231 and Hata- Okumura models are less than the mobile sensitivity threshold. Hence these two models are preferred for maximum coverage area and reduce the number of handoff.

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AUTHORS PROFILE

Oguejiofor O.S is a lecturer in the department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria. His research interest lies within areas such as wireless sensor networks, wireless communications, radar and microwave engineering e.t.c. He is a member of IAENG, IACSIT and current IEEE counselor for unizik student branch.

AUTHORS PROFILE

Akpado K.A is a senior lecturer in the department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria. He has published various papers on wireless communications; computer and control systems e.t.c He is currently a member of the following organizations; IEEE, IAENG and IACSIT.

Abe Adewale is a lecturer with Ekiti state University, department of Electrical and Electronic Engineering but presently a PhD student in the University of Essex, United Kingdom