

Efficient Pathloss Model for determining Mobile Radio Link Design

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ABSTRACT

The focus of this paper is on efficient pathloss model for determining mobile radio link design. A fixed 3G BTS transmitter was also used to generate the data. Log-normal shadowing model was used to analyse the data. The calculated data were compared using path loss exponent and standard deviation. They were found to be within the specified range for urban area cellular radio environment like Enugu urban. The result is a provision of a link design network with an adequate coverage and quality of service.

Keywords: Efficient Pathloss Model, Radio Propagation Mechanisms, Propagation Path Loss Models, Free Space Propagation Model, Two-Ray Model, Mobile Radio

I. INTRODUCTION

Radio wave is a type of electromagnetic radiation (these are nothing but oscillations which propagate with the velocity of light. Approx. $=3 \times 10^8 \text{m/s}$) in free space.[1] Other forms of electromagnetic waves include infrared, visible light, ultra-violet, X-rays and gamma rays [2]. Mobile radio communication systems such as cordless telephone, hand held walkie talkie, cellular and pager telephones rely on the propagation of radio waves through air and space for their operation. These radio waves travel along transmission line and waveguides to and from antennas.

The mobile radio link places fundamental limitations on the performance of wireless communication system according to wireless communication [3] The antenna at a mobile terminal is very small, so obstacles and reflecting surfaces in vicinity and path of antenna have a substantial influence on the characteristics of the propagation path between the base station transmitting antenna and the mobile antenna. The transmission path between the transmitter and the receiver may vary from direct line-of-sight (LOS) to one that is heavily obstructed by buildings and topology. This is because obstacles and reflecting objects in a mobile radio environment greatly reduce the average signal strength received by a mobile system.

II. METHODS AND MATERIAL

2. The radio propagation mechanisms

The radio propagation mechanisms which impact propagation in a mobile communication system are:

- i. Reflection
- ii. Diffraction
- iii. Scattering

Mobile communication conditions operation is quit severe; the reason is that most cellular radio systems which operate in urban area operate with no direct Line-of-sight (LOS) path between the transmitter and the receiver. The presence of high building creates severe diffraction loss.

The path loss is generally the most important parameter predicted by propagation models based on the physics of reflection, diffraction and scattering.

Reflection occurs when electromagnetic waves impinges on obstacles with larger wavelength.

Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp edges. The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle given rise to bending of waves around the obstacle, even in the absence of line-of-sight path between the transmitter and receiver.

Diffraction therefore, remains an important phenomenon where signal transmission through buildings is virtually impossible.

Scattering occurs when objects are of dimensions that are in the order of a wavelength or less of the electromagnetic waves. Scattered waves are produced by irregular objects such as walls with rough surface, furniture, foliage etc.

2.1 Propagation path loss models

Path loss is defined as the difference in decibel between the effective transmitted power and the received power and perhaps includes the effect of antenna gains. It represents signal attenuation as a positive quantity measured in dB [4]. Some of these models are discussed in this section.

A. Free Space Propagation Model

Free space propagation environment is a region that is free of all obstacles and objects that might absorb or reflect radio frequency energy. Free space propagation model assumes an ideal propagation with an isotropic antenna radiating its energy equally in all directions to an infinite distance. If the radiating element is generating a fixed power to an ever expanding sphere, the power density on this hypothetical sphere at a distance d from the source is given by equation 1 below:

$$P(d) = \frac{G_t P_t}{4\pi d^2} \quad (1)$$

Where :

P_t is the transmitted power

G_t is the transmitting antenna gain

d is distance from the source.

If a receiving antenna with gain G_r is placed at this distance, d , the power extracted by the antenna can be calculated using equations (2)

$$P_r = P(d) \times A_e$$

(2)

Where ,

P_r is the received power

A_e is the effective area of an isotropic antenna

$$A_e = \frac{\lambda^2}{4\pi} \quad (3)$$

$$P_r = P(d) \times A_e = G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2 P_t$$

The free space transmission loss or propagation loss equations for Omni directional transmit and receive unity gain antennas separated by d meters is obtained as:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2$$

For Omni directional and unity gain antenna, free space path loss is given in equation (6) which is also known as Friis equation.

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d} \right)^2$$

$$\frac{P_r}{P_t} = \left(\frac{c}{4\pi f d} \right)^2$$

In terms of pathloss in dB,

$$PL[dB] = 10 \log \left(\frac{P_t}{P_r} \right)$$

Where,

P_L is Path loss in [dB]

P_t is the transmitted power

P_r is the received power

The free space path loss equation is now:

$$P_L[dB] = 32.44 + 20 \log f \text{ [MHz]} + 20 \log d \text{ [km]} \quad (8)$$

B. Two-Ray Model

The two-ray model is used when a single ground reflection dominates the multipath effect, as illustrated in Figure1. The received signal consists of two components: the LOS component or ray, which is just the transmitted signal propagating through free space, and a reflected component or ray, which is the transmitted signal reflected off the ground.

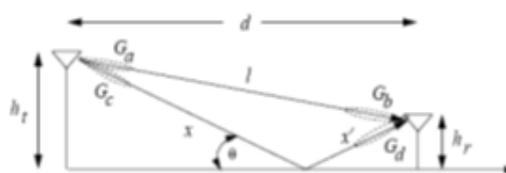


Figure 1: Two-Ray Model.

C. Mobile Radio Link

Communication engineers are generally concerned with the application of two main radio channel links. These channel links are the mobile radio link parameters and time dispersion nature of the channel.

The mobile radio link parameters consist of the path loss exponents (n) or path loss rate and the standard deviation (σ) about its mean value. The path loss exponent indicates the rate at which propagation (path) loss increases with distance, while the standard deviation accounts for the random shadowing effects which occur over a large number of measurement locations which have same transmitter-receiver separation, but have different levels of clutter on the propagation path [5].

The emphasis of this research is on the determination of mobile radio link design for a given propagation environment using path loss model. These parameters are used in link budget design to determine fundamental quantities such as transmit power requirements, coverage areas, battery life and the analysis of path losses in any mobile radio environment.

The time dispersive parameters of a multipath channel are the mean excess delay, rms delay spread and the maximum excess delay spread [6]. The time dispersive nature of the channel determines the maximum data rate that can be transmitted without equalization.

2.2 Practical link budget determination using the path loss models

Most radio propagation models are derived using a combination of analytical and empirical methods. The empirical approach is based on fitting curves or analytical expressions that recreate a set of measured data. This has the advantage of implicitly taking into account all propagation factors, both known and unknown, through actual field measurements. However, the validity of empirical models at transmission frequencies or environments other than those used to derive the model can only be established by additional measured data in the new environment at the required frequency. Over time, some classical empirical models have emerged, which are now used to predict both large-

scale and medium-scale coverage for mobile communication system design. The two practical mobile radio link design techniques are:

- i. The log-distance path loss model.
- ii. The log-normal path loss model.

(i) The log-distance path loss model

Both theoretical and measurement based propagation models indicate that the coverage received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. The average large-scale path loss for an arbitrary transmit-receiver (T-R) separation is expressed as a function of distance by using path loss exponent (n) as

$$PL(d) \propto (d / d_0)^n$$

Or

$$PL(dB) = PL(d_0) + 10n \log(d / d_0)$$

Where n is the path loss exponent, d_0 is the closed-in reference distance which is determined from measurements closed to transmitter and d is the T-R separation distance. The value of n depends on the specific propagation environment. For example if free space is 2 and when obstructions are present, n will have a larger value as shown in table 1 [7]

It is important to select a *close in* reference distance that is appropriate for the propagation environment. In large coverage cellular systems, 1km reference distance is commonly used, whereas in microcellular systems smaller distance such as 100m is commonly used. The reference distance should always be in the far field of the antenna so that near field effect does not alter the reference path loss. The reference path loss $PL(d_0)$ is calculated using free space path loss formula given equation (1) or through field measurement at distance (d_0). Table 1 list path loss exponents obtained in mobile radio environment

Table 1: Path loss exponents for different environments

Environment	Path loss Exponent, n
Free space	2

Urban cellular/PCS	2.7 to 4.0
Shadowed urban cellular/PCS	3 to 5
Indoor LoS	1.6 to 1.8
Obstructed Indoor	4 to 6
Obstructed in factories	2 to 3

(ii) **The log-normal shadowing model**

The log-distance path model does not consider the fact that the surrounding environmental clutter may be vastly different at two different locations having the same T-R separation. This leads to measured signals, which are vastly different from the average value predicted by (10).

The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but have different levels of clutter on the propagation path. This phenomenon is referred to as log-normal shadowing. Log-normal shadowing implies that measured signal level at a specific T-R separation have a Gaussian (normal) distribution about the distance-dependent mean of equation 10 where the mean signal levels have values in dB. The standard deviation of the Gaussian distribution that describes the shadowing also in dB.

Measurements have shown that at any value of d , the path loss $PL(d)$ at a particular location is random and distributed log-normally (normal in dB) about the mean distance dependent value. i.e.

$$PL(d)[dB] = PL(d_0) + x_\sigma$$

$$PL(d)[dB] = PL(d_0) + 10n \log\left(\frac{d}{d_0}\right) + x_\sigma \tag{12}$$

And,

$$Pr(d)[dBm] = Pt[dBm] - PL(d)[dB] \tag{13}$$

Where x_σ is a zero-mean Gaussian distributed random variable (dB) with standard deviation σ also in dB. The closed in reference distance (d_0), the path loss exponent (n), and the standard deviation (σ) statically describe the path loss model for an arbitrary location

having a specific T-R separation and this model may be used in computer simulation to provide received power levels for random locations in communication system design and analysis [8]

III. RESULTS AND DISCUSSION

The real time measurements were conducted using CDMA 2000 1x BTS located at Headquarter opposite Teachers House Enugu as the test transmitter location. The eight radial field measurements were carried along specific separation distances for North, West and East routes.

The field measurement were carried out using 3G CDMA technology rather than the GSM because of its advantages such as higher bandwidth capacity, high-speed packet data and multipath fading reduction.

(A) Data Gathering

The field measurement were carried out using a radio propagation simulator called debug access equipment global positioning system (GPS) and simulation of free space model equation.

The GPS indicates the T-R separation distances while the debug access equipment measured received power levels at various distances away from a CDMA 2000 1xBTS.

The simulation was also done to compare the received signal levels at the eight radial distances.

4.0 System Specification

The system design for the 3G CDMA BTS at various separation distances and the received power are specified as follows:

A. Base Transceiver Station

BTS transmit power	=	10w
BTS antenna gain	=	20dB
BTS transmitter frequency	=	881.25MHz
Height of BTS antenna	=	45m

B. Mobile Station (MS)

MS transmit power	=	300MW
MS Sensitivity less than	=	104dB
MS antenna gain	=	0dB
MS transmitter carrier		
Frequency	=	841.25MHz
Height of MS antenna	=	1.6m
Average cell radius	=	5km
The distance between BTS	=	9km

The eight received power measurement taken at various distances radially along North, West and East were designed as follows using (14) and (15)

$$P_i(d_0) = 10 \log \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_0^2}$$

$$P_i = P_i(d_0) - 10n \log \left(\frac{d}{d_0} \right)$$

where,

d = T-R separation distance.

d_0 = close in reference distance

X_σ = zero-mean Gaussian (normal) distributed random variable (dB) with standard deviation, σ (dB).

From the parameter,

$$P_t = 10\text{w}$$

$$G_t = 20\text{dB} = 100$$

$$G_r = 0\text{dB} = 1$$

$$d_0 = 100\text{m}$$

$$f = 881.25 \times 10^6$$

$$\lambda = 0.34\text{m}$$

From equation 14

$$P_i(d_0) = 10 \log \left[\frac{10 \times 100 \times 1 (0.34)^2}{(4\pi)^2 \times (100)^2} \right]$$

$$P_i(d_0) = 41.36\text{dBm}$$

Then using field measurement at a close in reference distance (d_0) of 100m, $P_i(d_0) = -40\text{dBm}$.

So, recall equation (15) and substitute,

$$P_i = -40 - 10n \log \left(\frac{d}{100} \right)$$

Based on the field measurement the estimated received power for the specified distances were found using (15).

For 100m,

$$P_1 = -40 - 10n \log \left(\frac{100}{100} \right)$$

$$P_1 = -40$$

For 200m,

$$P_2 = -40 - 10n \log \left(\frac{200}{100} \right)$$

$$P_2 = -40 - 3n$$

For 500m,

$$P_3 = -40 - 10n \log \left(\frac{500}{100} \right)$$

$$P_3 = -40 - 7n \quad (14)$$

For 1000m,

$$P_4 = -40 - 10n \log \left(\frac{1000}{100} \right)$$

$$P_4 = -40 - 10n$$

For 2000m,

$$P_5 = -40 - 10n \log \left(\frac{2000}{100} \right)$$

$$P_5 = -40 - 13n$$

For 3000m,

$$P_6 = -40 - 10n \log \left(\frac{3000}{100} \right)$$

$$P_6 = -40 - 15n$$

For 4000m,

$$P_7 = -40 - 10n \log \left(\frac{4000}{100} \right)$$

$$P_7 = -40 - 16n$$

For 5000m,

$$P_8 = -40 - 10n \log \left(\frac{5000}{100} \right)$$

$$P_8 = -40 - 17n$$

The Table for the evaluation of MSE is shown in table 2

$d(m)$	$P_r(dBm)$	$p_r(dBm)$	$P_r(dBm)$	$P_i - p_i$	$(P_i - p_i)^2$
100	-40	-40	-40	0	0
200	-43	-43	$-40 - 3n$	$3n - 3$	$9n^2 - 18n - 9$
500	-54	-54	$-40 - 7n$	$7n - 14$	$49n^2 - 196n - 196$
1000	-67	-67	$-40 - 10n$	$10n - 27$	$100n^2 - 540n - 729$
2000	-76	-76	$-40 - 13n$	$13n - 36$	$169n^2 - 936n - 1296$
3000	-84	-84	$-40 - 15n$	$15n - 44$	$225n^2 - 1320n - 1936$
4000	-95	-95	$-40 - 16n$	$16n - 55$	$256n^2 - 1760n - 3025$
5000	-102	-102	$-40 - 17n$	$17n - 62$	$289n^2 - 2108n - 3844$
					$\Sigma = 1097n^2 - 6878n + 11035$

$$n = \frac{6878}{2194}$$

$$n = 3.13 \approx 3.1$$

The path loss exponent for the mobile radio link is 3.1

Table 3 : Received power measurement taken at various distances along North, West and East Routes

$d(m)$	Received power P_r (North)	Received power P_r (West)	Received power P_r (East)
100	-40	-41	-42
200	-43	-44	-43
500	-54	-56	-55
1000	-67	-66	-65
2000	-76	-75	-75
3000	-84	-87	-87
4000	-95	-96	-96
5000	-102	-100	-100

The plot of the received signal strength along the different routes is shown in Figure 2, Figure 3, Figure 4 and Figure 5

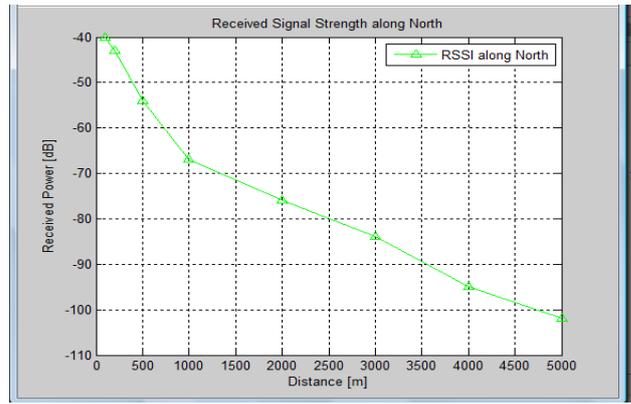


Figure 2: RSSI along North

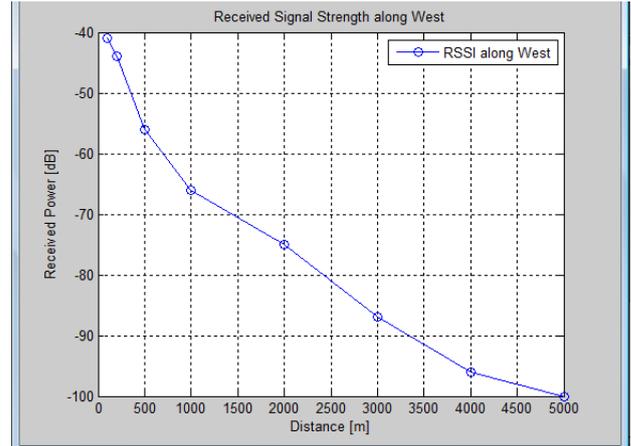


Figure 3: RSSI along West

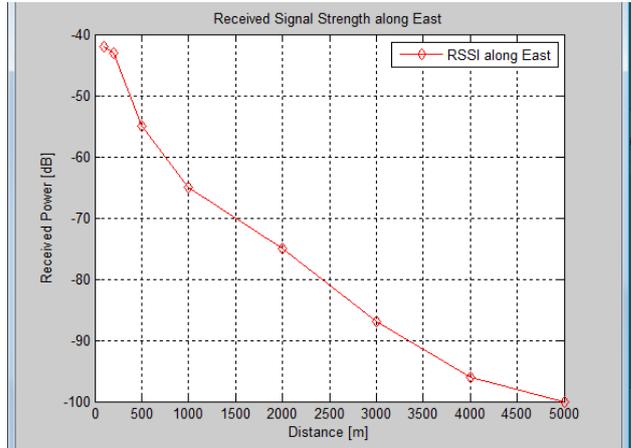


Figure 4: RSSI along East

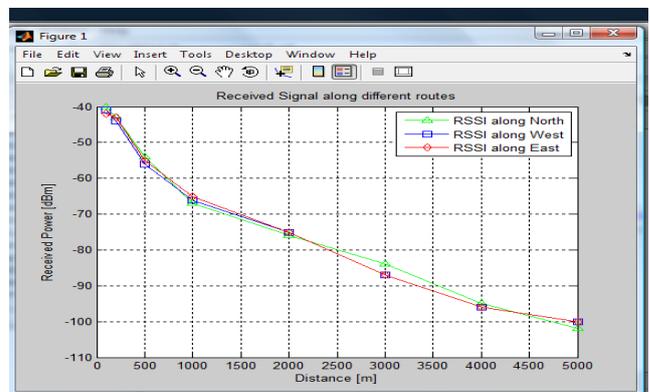


Figure 5: Plot of the Received Power along the specified route

IV. CONCLUSION

Mobile radio link design using path loss model can be easily designed using parameters of base transceiver station (BTS), mobile stations (MS) and the Log-normal shadowing pathloss model. In this paper, the path loss exponent and the standard deviation due to random shadowing in Enugu urban are 3.1 and 5.65dB respectively. These Mobile radio link designs were determined using the Log-normal shadowing path loss model. The path loss exponent value shows the rate at which the pathloss increases with distance in a CDMA2000 1x. This path loss model is very good for predicting distance dependant received power in obstructed environment. The accurate qualitative understanding of the radio propagation using path loss model as a function of distance from where the signal level could be predicted is essential for reliable wireless system design.

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