Mobile Radio Link Design Using Path Loss Model

Oguejiofor O.S, Oleka C.V, Ejiofor H.C, Okumbor N.A

Abstract*— This paper presents the design of mobile radio link using path loss models. Measurements were carried out over a distance to determine various received power levels from a fixed Code Division Multiple Access (CDMA) Base Transceiver Station (BTS) Transmitter; these values were applied to some path loss model equations to obtain the mobile radio design parameters such as the path loss exponent (n) and the standard deviation (σ). The results obtained show that path loss exponent was 3.16 while the standard deviation was 5.79dB. Hence the log-normal shadowing model for the design of a mobile radio link in the test bed area is PL(dB) = 85.79 + 31.6 log (d)

***Index Terms*— Base Transceiver Station (BTS), CDMA, model, Path Loss.**

I. INTRODUCTION

The mobile radio systems in the world today are classified into five categories and they are: Cellular telephone system; cordless telephone systems; Personal communication system; paging systems and specialized mobile radio system. The cellular telephone system is subdivided into the conventional (land-based) cellular radio system and the satellite (spaced-based) cellular radio system. The different types of land-based cellular telephone technology in use are: Analog cellular radio telephony and Digital cellular radio system. The digital technology allows greater sharing of the radio hardware in the base station among the multiple users; it also provides large capacity to support more users for a base station per MH_3 of spectrum as compared to analog systems [1].

Signal propagation in the land mobile cellular communication is affected by phenomena such as free space loss, scattering, refraction and diffraction of the radiated energy. These phenomena give rise to path loss and fading. Fading normally is divided into slow fading also known as Log-normal fading or shadowing, and fast fading also called multipath fading [2]. The performance of the current and future generation mobile communication system depends critically on accurate prediction of the propagation characteristics. To solve this problem, this paper discusses the practical path loss measurements in obstructed environment such as Enugu urban city of Nigeria; we find out that fading of signals in this area is mostly caused by obstructions of high rise building between the transmitter and receiver, hence it calls for designing of a mobile radio link which can easily proffer solution to this aforementioned problem.

Manuscript received August22, 2013.

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II. MOBILE RADIO LINK DESIGN

Communication Engineers are generally concern 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 exponent (*n*) and the standard deviation (σ). The Path loss exponent indicates the rate at which a signal depreciates with increase in distance while the standard deviation accounts for the random shadowing effects which occur over a large number of measurement locations which have the same transmitter-receiver separation, but have different levels of clutter on the propagation path. The aim of this paper is on the determination of mobile radio link design which entails the mobile link parameters for a given propagation environment.

A. Mobile radio path loss models

Path loss is define as the difference in decibel (dB) 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 [3]. We have different kind of path loss models associated with areas, they are:

- Path loss model for mega cellular areas: Mega cellular areas are those areas where communication is over extremely large cells spanning hundreds of kilometers. These areas are served mostly by mobile satellites. The path loss is usually the same as that of free space, but fading characteristics are somewhat different.
- Path loss model for macro cellular Areas: Macro cellular areas span a few kilometers to tens of kilometers depending on the location. The frequency of operation is most around 900MHz though the emergence of personal communication system has resulted in frequencies around 1800 to 1900MHz for each cell. In fact the path loss model for macro cellular areas is the one that is applicable to this research paper and therefore applied.
- Path loss model for micro cellular Areas: Microcells are cells that span hundreds of meters to a kilometer and are usually supported by below rooftop level base station antenna mounted on lamp posts and utility poles.
- Path loss model for Pico cellular indoor areas: Pico cells correspond to radio cells covering a building or parts of a building. The span of Pico cell is between 30m and 100m. Pico cells are usually employed for WLAN, Wireless PBX systems and PCS operating in indoor area.

B. Practical link budget determination using path loss models

Most radio propagation models are derived using a combination of analytical and empirical methods. The empirical approach is based on curve fittings whereas analytical is based on a set of measured data. However, the validity of an empirical model at transmission frequencies or environment other than those used to derive the model can only be established by additional measured data in the new environment at the required frequency. The two practical mobile radio link design estimation techniques are: The log-distance path loss model and the log-normal shadowing model [4].

- The Log-distance path loss model- This model indicates that the average receive signal power decreases logarithmically with distance; the average large-scale path loss for an arbitrary Transmitter-Receiver(T-R) separation is expressed as a function of distance(d) by using a path loss exponent(n) as:

$$PL\,(d)\ \alpha \left(\frac{d}{d_0}\right)^n \qquad (1)$$

$$PL(dB) = PL(d_0) + 10n \log (d/d_0) \qquad (2)$$

Where n: path loss exponent

d_0: close-in reference distance

d: T-R separation distance

Table 1.0 shows path loss exponents obtained in mobile radio environments.

Table 1.0 Path loss exponents for different environment

Environment	**Path Loss Exponent**
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

- The log-normal shadowing model -The log-distance path loss model does not consider the fact that the surrounding environmental clutter may be vastly different at two difference locations having the same T-R separation. This leads to measured signals, which are vastly different from the average value predicted by equation (2).The log-normal distribution describe 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 levels at a specific T-R separation have a Gaussian (normal) distribution about the distance-dependent mean of equation (2); where the measured signal levels have values in dB units. The standard deviation of the Gaussian distribution that describes the shadowing also has units in dB.

Measurement 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. That is:

$$PL\,(d)\,[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n \log (d/d_0) + X_\sigma \qquad (3)$$

And

$$Pr(d)[dBm] = Pt[dBm] – PL(d)[dB] \qquad (4)$$

Where X_σ is a zero-mean Gaussian distributed variable (in dB) with standard deviation σ also in dB. The close-in reference distance (d_0), the path loss exponent (n), and the standard deviation (σ) statistically 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 [4].

III. DATA COLLECTION

The received power levels of the transmitting Base Transceiver Station (BTS) used for this experimentation were obtained from a CDMA2001X network located in Enugu; one of the urban cities of Nigeria and the base station was designated as Zoom HQS BTS. The received power levels at various distances away from BTS were measured and analyzed using the debug access equipment which is a radio propagation simulator. The base station under consideration is of height 45m and has a carrier frequency of 881.25MHz. The base station from where the transmitted signals emanate is regarded as the network under consideration and it belong to Zoom mobile network. The received power levels were measured at intervals of 100meters up to 500meters and intervals of 1000m up to 5000m from the transmitting base station (BTS1). The distances of these measurements points from the reference point of the base station were recorded using the global positioning system (GPS). The GPS showed the T-R separation distances. The GPS was first switched on at the foot of the BTS tower; before the ENTER button was pressed. We moved away from the reference BTS, and when the radial distance on the GPS becomes equal to the desired close-in reference distance, the radio propagation simulator was switched on. Its debug access code (101101) was keyed in and the debug screen appeared. We then scrolled down the screen to find the received power level in dBm and clicked on it. The received power level of the transmitting BTS at the location was displayed automatically. The above procedure was repeated at the other locations along the specified route as shown in fig 1.0. Until all the readings were recorded. The received signal power at specified route and distances along North, west and east were presented in tables.

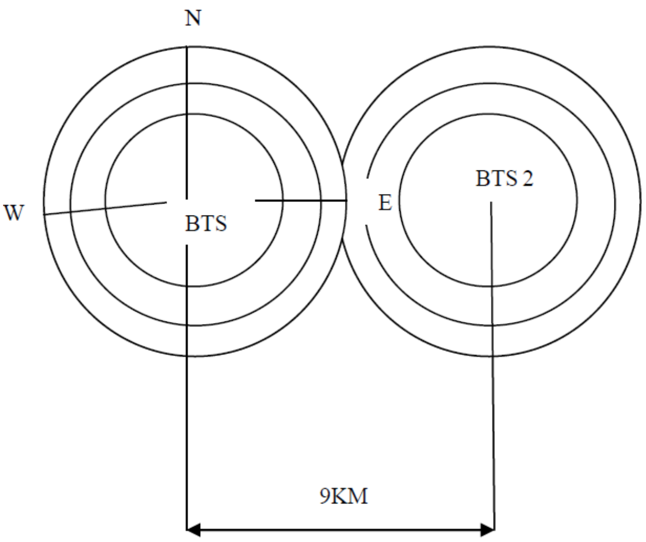

Figure 1.0: Received Power Measurement along three routes

IV. DATA PRESENTATION

Results of the field measurement of received power for the various distances along the north, east and west directions are shown in tables 2.0, where as table 3.0 shows the average received power over the same distances.

Table 2.0: Received power measurement at various distances along the north (N), West (W), East (E)

T-R separation distance(d)	Received power (Pr) along north (N)	Received power(Pr) along West(W)	Received Power (Pr) along East (E)
100m	-40dBm	-41dBm	-39dBm
200m	-43dBm	-44dBm	-42dBm
500m	-55dBm	-56dBm	-54dBm
1000m	-66dBm	-67dBm	-65dBm
2000m	-76dBm	-75dBm	-74dBm
3000m	-84dBm	-85dBm	-86dBm
4000m	-95dBm	-96dBm	-97dBm
5000m	-102dBm	-103dBm	-101dBm

Table 3.0: Average Received power measurement at various distances along the north (N), West (W), East (E)

T-R separation distance(d)	Average Received Power(Pr) along N,W,E
100m	-40dBm
200m	-43dBm
500m	-55dBm
1000m	-66dBm
2000m	-75dBm
3000m	-85dBm
4000m	-96dBm
5000m	-102dBm

Parameters of the Base Transceiver Station (BTS) are:

- BTS transmitting power (Pt) = 10w
- BTS Antenna gain = 20dB = 100w
- BTS transmitting Frequency = 881.25MHz
- Height of BTS antenna = 45m

V. DATA ANALYSIS

Having known that the close-in reference distance (d_0), the path loss exponent(n), and the standard deviation (σ) statistically describe the path loss model of an arbitrary location; to truly characterize propagation path loss for the environment (location), values should be establish for these parameters PL, n, $d_{0,}$ and σ. The path loss exponent n which characterizes the propagation environment is obtained from the measured data by the method of linear regression (LR) analysis [5]. In the LR analysis the difference between the measured and predicted path loss values are minimized in a mean square sense, the sum of the squared errors is given by [5].

$$e(n) = \sum_{i=1}^{k}\left(PL - \overline{PL}\right) \qquad (5)$$

Where PL is the measured path loss and $\overline{PL}$ is the modeled path loss obtained using equation (2). The value of n which minimizes the mean square error e (n) is obtained by equating the derivative of equation (5) to zero and solving for n. Table 3.0 shows the measured path loss values while Table 4.0 summarizes the mean square error obtained.

Table 3.0: Measures path loss at various distances

T-R separation distance(d)	Average Received Power(Pr)	Power Transmitted(Pt)	Path loss PL=Pt -Pr
100m	-40dBm	10w = 40dBm	80dB
200m	-43dBm	10w = 40dBm	83dB
500m	-55dBm	10w = 40dBm	95dB
1000m	-66dBm	10w = 40dBm	106dB
2000m	-75dBm	10w = 40dBm	115dB
3000m	-85dBm	10w = 40dBm	125dB
4000m	-96dBm	10w = 40dBm	136dB
5000m	-102dBm	10w = 40dBm	142dB

Distance(m)	PL(dB)	$\overline{PL}$(dB)	PL-$\overline{PL}$	$(PL-\overline{PL})^2$
100	80	80	0	0
200	83	80 + 3.01n	3 - 3.01n	9 - 18n + 9n²
500	95	80 + 6.98n	15 - 6.98n	225 - 209n + 49n²
1000	106	80 + 10n	26 -10n	676 - 520n + 100n²
2000	115	80 + 13.01n	35 -13.01n	1225 - 911n +169n²
3000	125	80 + 14.77n	45 - 14.77n	2025- 1329n +218n²
4000	136	80 + 16.02n	56 -16.02n	3136 - 1794n +257n²
5000	142	80 + 16.99n	62 -16.99n	3844 - 2107n +289n²

Therefore the value of the mean square error from the table gives:

$$\sum_{i=1}^{k}\left(PL - \overline{PL}\right) = 11140 - 6888n + 1091n^2 \qquad (6)$$

Differentiating equation (6) and equating it to zero gives the value for n.

$$\frac{d\,e(n)}{dn} = \frac{d(1091n^2 - 6888n + 11140)}{dn} = 0 \qquad (7)$$

$$n = 3.16$$

The standard deviation σ (dB) of random shadowing effect is computed using the relationship below [6]:

$$\sigma(dB) = \sqrt{\sum_{i=1}^{k}\left(PL - \overline{PL}\right)^2 / k} \qquad (8)$$

But n=3.16 and k=8, therefore substituting these values in equation (8) gives $\sigma(dB) = 5.79$

Substituting the above calculated path loss exponent n and the standard deviation σ into the log-normal shadowing model in equation (3) gives the model that describes the design parameters of a mobile link in that location.

PL(dB) = 80 + 10(3.16) log (d) +5.79

PL(dB) = 85.79 +31.6log (d) (9)

The equation (9) models the radio propagation channel/link for the mobile system in the location the research was carried out. This model can also be used in computer simulation to provide received power levels for random locations in mobile communication system design and analysis. Fig 2.0 shows the relationship between Path loss and distance; as the distance increases the signals fading (path loss) increases.

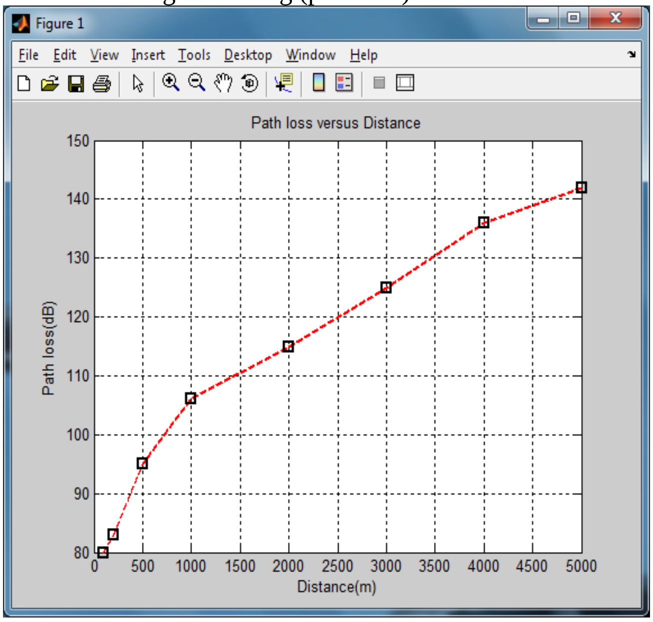

Figure 2.0:Relationship between path loss and distance

VI. CONCLUSION

The mobile radio design parameters were obtained using the log normal shadowing model and it reveals that the channel path loss exponent and the standard deviation are 3.16 and 5.79dB respectively. The path loss exponent value is accurate and good, because it falls within the path loss exponent for urban area cellular radio environment which theoretically ranges from 2.7 to 3.5 as shows in Table 1.0. Furthermore, the standard deviation of value 5.79dB is due to the presence of many buildings or infrastructure along the communication link.

Summarily, 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 mobile wireless system design.

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