Investigating the Applicability of Okumura-Hata Model for GSM 900 Networks of Yola Suburbs in Nigeria

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Accurate radio propagation models are a dire need for efficient and reliable coverage predictions and good network planning in mobile wireless communication systems. The existing empirical models are developed based on measurements made specifically for an intended communication system or spectrum allocation which may not generalize for all environments. This work presents a comparison between the measured and predicted signal strength using the commonly used Okumura-Hata propagation model. The study was carried out for the suburban area of Yola-Jimeta in Nigeria for GSM 900 MHz band. The Root Mean Square Error (RMSE) was calculated between measured path loss values and those predicated on the basis of Okumura-Hata model for an open area. An improved model was then developed and tested on a different data. The result supports the improved model for future system design or system expansion in Yola suburbs and provides reference for other environments with similar features.

Keywords: Okumura-Hata, Radio propagation, Propagation models, RMSE

Introduction

Recent enabling technologies which permit wider deployment of mobile communication networks resulted in the fastest growth-period in history. The cellular concept employed in these systems came as a major breakthrough in solving the problem of spectral congestion and user's capacity. This offered high capacity with a limited spectrum allocation without any major technological change. The concept is a system level idea in which a single, high power transmitter is replaced with many low power transmitters each covering a cell (Rappaport, 2002).

A cell describes a small portion of the entire coverage area serviced by the low powered transmitter, also called a base station. Base stations close to one another are assigned different groups of channels so that all the available channels are assigned to a relatively small number of neighboring base stations subject to certain

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interference constraints. The design process of selecting and allocating channel groups for all the cellular Base Station (BS) within a system is called frequency reuse or frequency planning (Rappaport, 2002; and Nadir and Muhammad, 2010).

With the increasing demand for mobile services, the number of base stations is increased through techniques such as cell splitting, sectorization and coverage zone approaches. This results in additional capacity for the unit coverage without any increase in radio spectrum. Hence, it is possible to serve a wider number of subscribers distributed over an unlimited area, using only a limited number of channels through efficient channel reuse scheme (Rappaport, 2002; and Nadir and Muhammad, 2010).

However, the radio propagation characteristics influence the effectiveness of all of these methods in an actual system. Radio propagation path loss model is an important tool that characterizes the quality of mobile communication and determines effective radio coverage as well as network optimization (Alotaibi *et al*., 2006). The power loss involved in transmission between the BS and the Mobile Station (MS) known as the path loss basically depends on the antenna height, carrier frequency and BS-MS separation distance.

Path loss models predict a high level of accuracy, the true signal strength reliability of the network and the quality of coverage (Emagbetere and Edeko, 2009). Imprecise propagation models lead to networks with high channel interference and a waste of power. Unfortunately, radio propagation modeling has historically been one of the most difficult parts of mobile radio system design, and is typically done in a statistical fashion based on the measurements made specifically for an intended communication system or spectrum allocation in a given environment.

Therefore, in this work, to study radio wave propagation in a typical Yola environment in Nigeria, radio wave propagation measurements in an existing GSM mobile radio network was used to investigate the applicability of the commonly used Okumura-Hata model for radio planning.

Existing Radio Propagation Models

The mechanisms behind electromagnetic wave propagation are diverse, but can generally be attributed to reflection, diffraction and scattering. Thus, aside the losses in signal strength as the distance between the transmitter and receiver increases, these mechanisms result in shadowing and multipath fading. Propagation models have traditionally focused on predicting the average receive signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location. The theoretical free space propagation and ground reflection (2-ray) models as well as the commonly used Okumura-Hata model are discussed here.

Free Space Propagation Model

The free space propagation model is used to predict receive signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them (Rappaport, 2002).

The model assumes ideal signal propagation, i.e., equal radiation in all directions from the radiating source and propagation to an infinite distance without any loss. Attenuation however sets in as a result of spreading of the transmitted power over greater areas.

The free space power received by a receiver antenna which is separated from a transmitter antenna by a distance d, is given by the Friis free space equation,

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad ...(1)$$

where P_t is the transmitted power, $P_r(d)$ is the received power which is a function of the Transmitter-Receiver (T-R) separation distance d. G_t is the transmitter antenna gain, G_r is the receiver antenna gain, L is the system loss factor not related to propagation $(L \leq 1)$, and λ is the wavelength in m.

The miscellaneous losses L $(L \leq 1)$ are usually due to transmission line attenuation, filter losses, and antenna losses in the communication system. A value of $L = 1$ indicates no loss in the system hardware. The path loss which represents signal attenuation as a positive quantity measured in dB is defined as the difference between the effective transmitted power and the received power, and may or may not include the effect of the antenna gains. The path loss in dB for free space model when antenna gains are included is given by:

$$PL(dB) = 32.44 + 20\log(d) + 20\log(f) = (G_t + G_r) \quad ...(2)$$

where,

G_t is the transmitted antenna gain in dB;

G_r is the received antenna gain in dB;

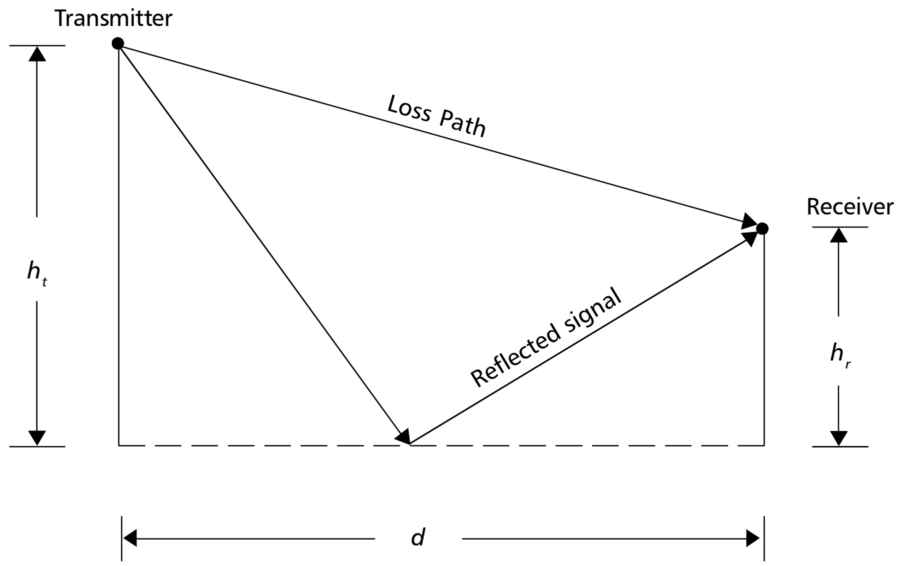
d is the T-R separation distance in km; and

f is the frequency in MHz.

Ground Reflection (2-Ray) Model

The free space propagation model of Equation (2) is in most cases inaccurate when used alone for mobile radio channel modeling. This is because a single direct path between the base station and a mobile is seldom the only physical means for propagation, and hence the effect of propagation over ground needed to be factored in. The 2-ray ground reflection model shown in Figure 1 is a useful propagation model that is based on geometric optics, and considers both the direct path and a ground reflected propagation path between transmitter and receiver.

Figure 1: 2-Ray Ground Reflection Model



This model has been found to be reasonably accurate for predicting the large-scale signal strength over distances of several kilometers for mobile radio systems that use tall towers (heights which exceed 50 m), as well as for line-of-sight microcell channels in urban environments (Rappaport, 2002).

The received power at a distance *d* from the transmitter can be expressed as:

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \quad \text{...(3)}$$

The path loss for the 2-ray model (with antenna gains) can be expressed in dB as:

$$PL(dB) = 40\log(d) - (10\log G_t + 10\log G_r + 20\log(h_t) + 20\log(h_r)) \quad \text{...(4)}$$

where *d* represents the path length in m and h_t and h_r are the antenna heights of the base station and the mobile station, respectively. The 2-ray model is also not appropriate for mobile GSM systems as it neglects the reflections from buildings, multiple propagation or diffraction effects. Also, as the mobile height changes, the predicted path loss will also be changed. Hence one appropriate way of accounting for the complex effects of reflection, diffractions and scattering is via an empirical modeling. Unfortunately, the existing empirical models are developed based on the data taken in a specific environment, and this makes it imperative to modify the model for application in a different environment. Okumura-Hata model is one of such models which are commonly used for network planning.

The Okumura-Hata Model

The Okumura-Hata (O-H) model is an empirical formula for graphical path loss data provided by Yoshihisa Okumura and is valid from 150 MHz to 1500 MHz. The Hata model is a set of equations based on measurements and extrapolations from curves derived by Okumura (Hata, 1980). Hata presented the urban area propagation loss as a standard formula, along with additional correction factors for application in other situations such as suburban and open areas. The computation time is short and only four parameters are required in Hata model.

Hata model is valid for transmitter effective antenna height between 30 to 200 m, receiver effective antenna height between 1 to 10 m and link distance from 1 to 20 km. For an urban center, median path loss is given by Abhayawardhana *et al*., (2005); and John, (2005).

$$PL(dB)_{urban} = A + B\log(d) \quad \text{...(5)}$$

where,

d is the T-R distance in km,

A represents a fixed loss that depends on frequency of the propagating signal and is 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 is frequency measured in MHz;

h_b is height of the base station antenna in m;

h_m is mobile antenna height in m; and

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

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

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

The Hata path loss model for suburban is given by:

$$PL(dB)_{Open} = PL(dB)_{urban} - 2\left[\log(f/28)^2 - 5.4\right] \quad \text{...(6)}$$

$$PL(dB)_{Open} = PL(dB)_{urban} - \left[40.94 + 4.78[\log_{10}(f)]^2 - 18.33\log_{10}(f)\right] \quad \text{...(7)}$$

Materials and Methods

Signal strength level measurements for downlink on a live GSM network at coverage areas for a cell along Yola-Jimeta road in Nigeria, were obtained using TEMS drive test equipments. The transmitting antenna at the BS is a dual band 3-sectored antenna operating at 900/1800 MHz band frequencies. The height of the transmitting antenna was 38 m above sea level. The MS antenna height was approximately 1.5 m. Straight paths were marked out at 200 m intervals of varying radial directions to the BS. The network parameters and their values are shown in Table 1.

Table 1: Network Parameters

Parameter	Values
Base Station Transmitter Power	43 dBm
Transmitter Antenna Gain	15 dB
Mobile Antenna Gain	0 dB
Mobile Transmitter Power	33 dBm
Base Station Antenna Height	38 m
Mobile Antenna Height	1.5 m
Connector Loss	2 dB
Cable Loss	1.5 dB
Duplexer Loss	2 dB
$P_t+G_t+G_r-A$	53 dB
Frequency	955.8 MHz Down Link

From the measured signal strength, path loss is computed using:

$$PL(dB) = EIRP_t - P_r \quad ...(8)$$

where $EIRP_t$ is the Effective Isotropic Radiated Power and is given by:

$$EIRP_t = P_t + G_t + G_r - A$$

where,

P_r is the measured signal strength in dBm;

P_t is the transmitted power in dBm;

G_t is the transmitted antenna gain in dB;

G_r is the received antenna gain in dB;

PL is total path loss in dB; and

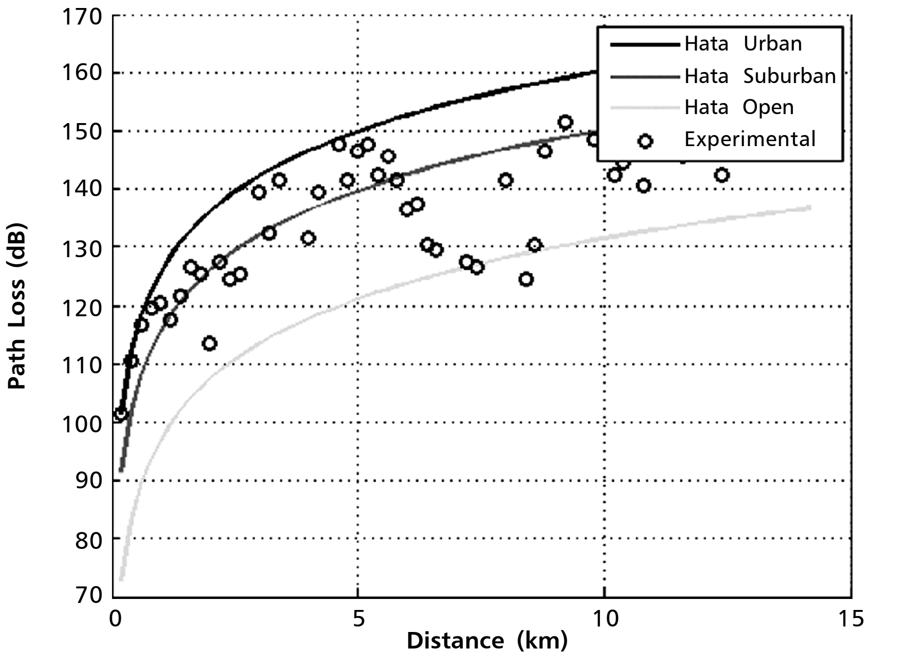
A is sum of connector, duplexer and cable losses in dB.

Hata model for surburban gave the closest prediction to our data and therefore Equations (5) and (6) of the Okumura-Hata model were used to calculate the pathloss.

Results and Discussion

A comparison between the experimental path loss and the prediction by O-H model at the varying radial distances is shown in Figure 2. Hata surburban model gave the closet prediction when the Root Mean Square Error (*RMSE*) between the measured

Figure 2: Experimental Data Against Predictions by Hata Models



signal strength value and those predicted by Okumura-Hata model is obtained using the following equation:

$$RMSE = \sqrt{\left(\sum_{i=l}^{K} \left(P_i - \hat{P}_i \right)^2 \middle/ K \right)} \qquad ...(9)$$

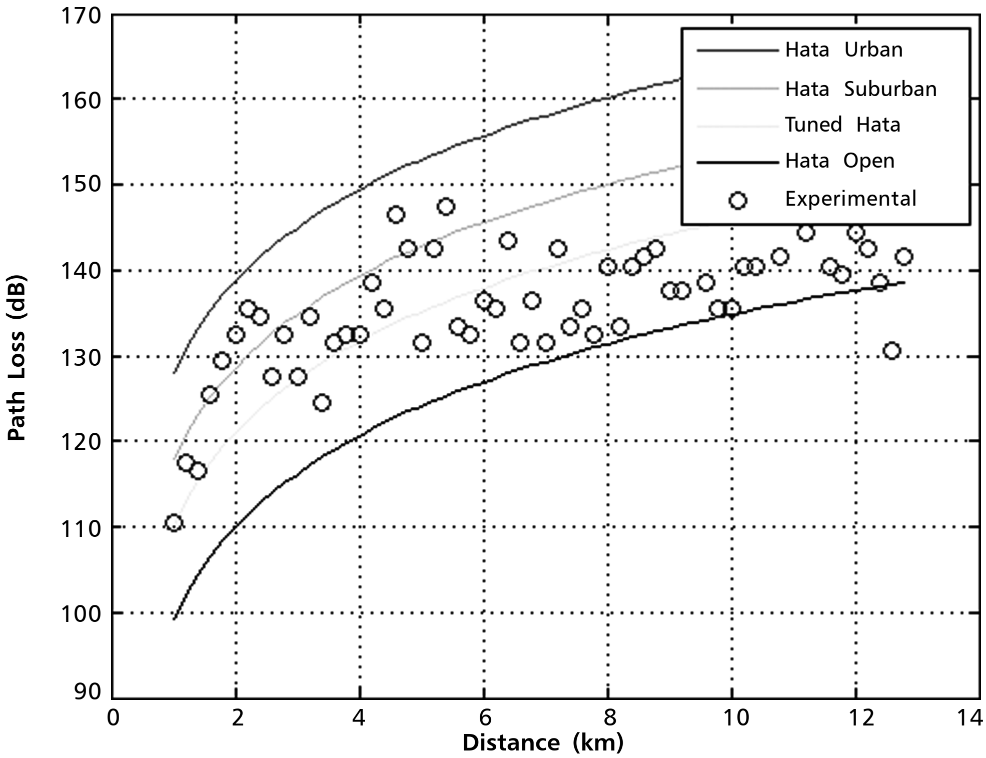
where P_i is the measured signal strength, $\hat{P}_i$ is the predicted, and K is the number of the sampled data points.

The RMSE value by the Hata suburban model is 7.67 dB, and so an improvement on the model is achieved by subtracting this value from the Hata suburban model of Equation (6). The improved model is thus given in Equation (10):

$$PL(dB)_{Open} = PL(dB)_{urban} - 2\left[\log(f/28)^2 - 5.4\right] - 7.67 \qquad ...(10)$$

This is then applied to a data from different route with similar features and gave an *RMSE* of 6.92 dB in comparison to the 11.21 dB by the original Hata suburban model (Figure 3).

Figure 3: Experimental Data Against Predictions by Hata Models and the Tuned Hata Model



Conclusion

Through our measurement taken in the suburban area of Yola, an improved Hata model has been developed which provides a closer prediction to the experimental data. The improved model, when tested on a data from a different drive test supports the model for future system design or system expansion in Yola suburbs and provides reference for other environments with similar features.

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Reference # 70J-2012-02-01-01