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Measurement Validation of Hata-Like Models for Radio Propagation Path Loss in Rural Environment at 1.8 GHz

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Abstract: In this study, we present a measurement-based model for path loss prediction in two GSM service areas at 1800 MHz. Simple hata-like models for rural/suburban environments were derived in this study on the basis of path loss measurements. The models developed predicted with reasonable accuracy the path loss of radio networks investigated with a root mean square error of <6 dB, a maximum standard normal deviation of less ±11 dB, mean prediction error of less than ±0.4 dB and standard deviation of error of less than ±8 dB. The developed model can be useful in network planning and optimisation for the environments taken as case study for the investigation, as well as any macrocellular environment, which is similar to the environment considered in this research.

Key words: Radio, propagation path loss, macrocellular networks, empirical models, radio coverage, hata-like models

INTRODUCTION

Radio propagation path loss model is an important tool that characterizes the quality of mobile communication, determines effective radio coverage, as well as network optimization. The path loss models also predict to a high level of accuracy the true signal strength reliability of the network and the quality of coverage (Anderson, 2006; Neskovic *et al*., 2000; Bachir and Saunder, 2004). With appropriate propagation path loss model, the coverage area of a mobile communication system, the signal-to-noise ratio, as well as the carrier-to-interference ratio can be easily determined (Lee, 1993; Tiong *et al*., 2004).

In developed communities, radio mobile communication has been in existence since, the early eighties of the 19th century, as a result investigation like the one discussed in this study have already been carried out and different propagation models as well as model performance established in those countries. Hence, this study may seem superficial to the developed world.

Nevertheless, in Nigeria where this study was carried out, the advent of modern radio mobile communication such as the Global System for Mobile communication (GSM) began its commercial operation in 2001. This makes this study new to our environment and will be of interest to the Nigerian community.

The vision for the introduction of this technology by the Nigerian government was to expand the country's teledensity, which was as low as about 450,000 land lines for a population of well over 120 million people as at 2001 and also make communication cheap, available, reliable and accessible to the average residents.

Although, this technology has transformed the face of telecommunication in Nigeria, the consumers satisfaction in some part of the country is not yet there. A lot of complains such as poor quality of service, frequent call drops, echo during radio conversation, poor interconnectivity to and from other licensed networks, distortions and network congestions among other factors are disturbing issues that need to be solved.

It is however, a known fact that the quality of radio coverage of any wireless network designed depends on the accuracy of the propagation model on which, the network was built. The accuracy of the model can be predicted from real-time measurement exhaustively taken from the service area, in which the network design will be deployed. Thus, the true signal strength reliability of a radio network depends on real-time measurement in the service area and the accuracy of the radio propagation model (Kanagalu, 1999; Beresnev, 2002; ETSISMG, 1999; Bachir and Saunder, 2004; ATIS-050001, 2004; Neskovic *et al*., 2000; Anderson, 2006).

It is against, this background that we looked at this topic with a view to present a radio propagation path loss model based on the measurements taken from two rural areas that are GSM services areas in southern part of Nigeria.

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MATERIALS AND METHODS

In this research, two locations (sites) were chosen for this investigation: NIFOR, Edo State and Oghara, Delta State, described as site 1 and 2, respectively. Site 1 is an area with terrain features such as dense vegetation mostly of Palm trees and few residential buildings. It lies within Lat 6°56'00.783"N and Long 5°37'20.820"E. Site 2 is a settlement characterised with lots of scattered small residential buildings, bushes and few rubber trees around. It lies within 5°56'02.220"N and Long 5°39'38.040"E. There were two functional base stations in site 1, each belong to a different operator. In site 2, there were three functional base stations, each for different operator. For legal reasons we refer to the network operators in site 1 as operator A and B, while in site 2, as operators A, B and C.

In both sites, the BTS transmitting antenna were dual band antennas; the antennas have inbuilt features, which enables them radiate at 900/1800 MHz. The antenna were sectored 120°. In site 1, the height of the transmitting antennas for operator A and B about 34 and 35 m above sea level. In site 2, for operator A-C, the base antenna heights were about 25, 30 and 25 m. An approximate height of 1.5 m was used as mobile receiver height in both sites. All transmitting stations were fixed, while the receiving stations were mobile. Due to the characteristic features of the environment investigated as discussed, measurement was obtained in both Lines of Sight (LOS) and Non-Line of Sight (NLOS) scenarios.

In both locations, a straight path was marked-out, at different radial directions to the BTSs. On each of these paths, test points manually measured 200 m intervals, with the BTS as the source point, were marked with the aid of a measuring tape (liner) and a monitoring signal strength meter, to monitor the signal until the signal fade, or other hindrances on the path that could not permit further measurement. In site 1 and 2, a measurement path length of 2600 and 4000 m were successfully marked-out.

The testing tool used for the measurement was Nokia 3310 handsets programmed to the NetMonitor mode. The NetMonitor is software compatible with some Nokia phones, with the capability of giving information on a BTS over the air interface. Thus, the signal strength information sent over the air interface between the BTS and the Mobile Station (MS) were read. The software comprises a scale, which is calibrated in power terms (dBm) (Rappaport, 2003; Beresnev, 2002; Hata, 1980). With the mobile handsets running on the software mode, calls were initiated at each test point until it is established. Received signal strength level recorded was on the downlink information within the air interface. The values of the signal strength level measured were converted into path losses using the expression in Eq. 1 (Rappaport *et al*., 1997). All measurements were taken in the mobile active mode and in different radial directions from the BTS:

$$P_L(\text{dB}) = P_t(\text{dB}) - P_r(\text{dB}) \qquad (1)$$

At each test point 45 sampled measured data of received signal strength were recorded at each 200 m marked point. Each call lasted for about 3 min. In each site, measurement were taken twice a day between 9:00 am and 12:00 noon and 2:00 pm and 6:00 pm. The investigation was carried out for a period of 12 months in both sites; from June 2006 to May 2007 in site 1 and from August 2006 to July 2007 in site 2.

For the period investigated, a minimum number of 770 calls month^{-1} were initiated, with a total of 9240 calls year^{-1} and an average sample size of 415,800 samples was recorded in site 1. For site 2, a minimum number of 726 calls month^{-1} were also initiated, with a total of 8712 calls year^{-1} and an average sample size of 392,040 was recorded in site 2.

RESULTS AND DISCUSSION

Data presentation: Measured data of path loss (in dB) against their corresponding receive-transmit separation distance average over the period of the investigation are presented as in Table 1 and 2.

Data analysis: According to Seidel and Rappaport (1992) and Christoph (2001), a propagation path loss model based on measurement, increases logarithmically as a function of distance. This is mathematically expressed as (Rappaport *et al*., 1997):

$$P_L\,(d)\ \alpha\ d^n$$

This expression can be simplified as:

$$P_L(\text{dB}) = P_L(d_0) + 10n\log D \qquad (2)$$

Where:

$P_L\,(d)$ = The mean path loss relative to reference distance (dB).

$P_L\,(d_0)$ = The propagation intercept (dB) (free space loss)

D = The transmit-receive separation distance (m)

The model in Eq. 2 is a simple Hata-like model. Based on this concept in Eq. 2, we developed a logarithmic regression propagation path loss models

Table 1: Measured data for path loss (dB) for site 1

	Path loss (dB)	
Distance (km)	Operator A	Operator B
0.2	102.35	121.08
0.4	101.69	117.25
0.6	109.54	119.99
0.8	115.55	124.78
1.0	118.17	127.82
1.2	123.42	130.20
1.4	125.00	131.23
1.6	130.54	133.61
1.8	128.89	134.46
2.0	125.42	132.81
2.2	125.48	131.15
2.4	129.51	132.97
2.6	144.33	145.29

Table 2: Measured data for path loss (dB) for site 2

	Path loss (dB)		
Distance (km)	Operator A	Operator B	Operator C
0.2	108.86	109.12	108.45
0.4	110.91	112.83	101.96
0.6	113.34	119.30	106.57
0.8	116.92	122.50	109.15
1.0	119.81	124.60	111.03
1.2	117.37	118.42	111.04
1.4	120.08	120.81	115.15
1.6	124.95	125.44	117.58
1.8	127.76	126.35	117.87
2.0	126.90	126.23	121.25
2.2	125.06	123.30	117.65
2.4	128.40	127.69	122.75
2.6	131.56	129.37	119.00
2.8	130.29	124.81	114.40
3.0	135.79	135.82	130.16
3.2	136.31	135.84	126.27
3.4	132.59	132.58	122.42
3.6	131.58	129.96	118.42
3.8	132.19	133.08	124.37
4.0	134.53	135.16	125.67

based on the performance of the investigated networks using Microsoft Excel tool. The regression model developed is referred to in this study as the JOEF model. Table 3 shows some of the standard parameters used in designing the JOEF model.

The JOEF model for the networks in investigated are;

In site 1:

$$\text{Operator A} \rightarrow P_L(\text{dB}) = 14.39\ln(x) + 96.57 \tag{3}$$

$$\text{Operator B} \rightarrow P_L(\text{dB}) = 8.26\ln(x) + 115.1 \tag{4}$$

In site 2:

$$\text{Operator A} \rightarrow P_L(\text{dB}) = 9.891\ln(x) + 104.32 \tag{5}$$

$$\text{Operator B} \rightarrow P_L(\text{dB}) = 8.18\ln(x) + 108.34 \tag{6}$$

$$\text{Operator C} \rightarrow P_L(\text{dB}) = 7.681\ln(x) + 100.8 \tag{7}$$

Table 3: Standard parameters used to design the JOEF model

Parameters	Standard condition
Transmit power (dBm)	45
Height of transmitting antenna (m)	34 for site 1 and 30 for site 2
Height of receiving antenna (m)	1.5
Reference distance d_0 (m)	200

The models expressed in Eq. 3-7 define a relationship between the link path loss and the separation distance between the base transceiver stations and the mobile terminal. Figure 1 and 2 shows the logarithmic regression plots of the path loss (dB) models for the different operators investigated in sites 1 and 2, respectively.

Model validation: The standard deviation and the Root Mean Square Error (RMSE) of the JOEF model from the actual measurement were parameters used to evaluate the quality of the model as a quantitative measure of its accuracy. In this investigation, the overall mean standard normal deviations in all networks investigated were less than ±11 dB for a measurement path distance of 2.6 km in site 1 and less than ±9 dB for a measurement path distance of 4 km in site 2. The RMSE of the models in site 1 for operator A and B were 0.8475 dB and 0.7307 dB and in site 2, the RMSE for operators A, B and C was 0.9099, 0.833 and 0.7205 dB, respectively. Thus, in all networks investigated in sites 1 and 2, the root mean square errors of the JOEF model were <1 dB. This is quite a satisfactory result.

We evaluated the accuracy and suitability of the JOEF models statistically by determining their prediction error with respect to the real-time data obtained from the networks. The predicted error was presented in terms of mean error, standard deviation of error and the variance of error. The standard deviation of error measures how much the error associated with individual observation of the received signal strength differs from the mean error. The variance of error indicates the variability of the sum of components or contributions, one from each of the random error terms (Kanagalu, 1999; Rappaport, 2003).

Thus, in Table 4 a summary of the prediction error of the JOEF model for the different networks obtained in this study is presented.

Although, the variance of error (dB) recorded in site 1 were high as shown in Table 4, the mean prediction error measured with the JOEF models were within reasonable accuracy, with an overall assessment of the prediction error; mean prediction error of less than ±0.4 dB and the standard deviation of error less than ±8 dB (Bachir and Saunder, 2004; Kanagalu, 1999; Christoph, 2001).

Note that a large prediction error for a given distance between the Base Station (BS) and Mobile Station (MS) makes a model not suitable for an environment (Fillipe *et al*., 2002).

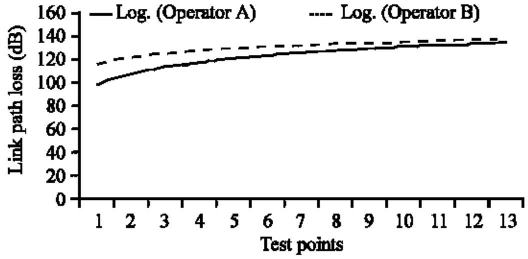

Fig. 1: Logarithmic regression plot for operators A and B in sites 1

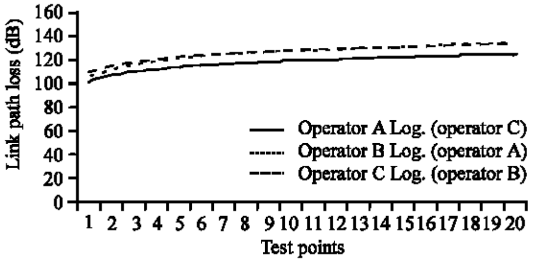

Fig. 2: Logarithmic regression plot for operators A, B and C in sites 2

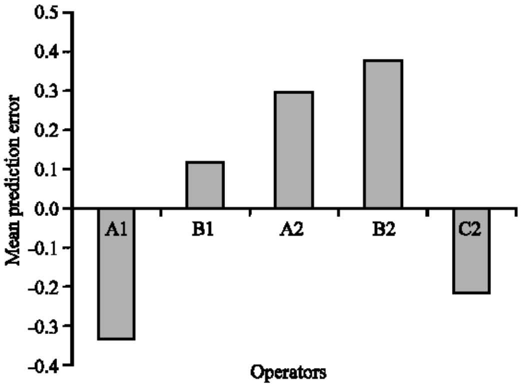

Fig. 3: The mean prediction error parameters for the different operators

Table 4: Prediction error statistics for JOEF models with respect to measured data

Operator	Site	Mean error	SD of error	Variance of error
A	1	-0.33	4.67	21.83
B	1	0.12	3.84	14.74
A	2	0.30	2.53	6.40
B	2	0.38	2.98	8.87
C	2	-0.21	3.89	15.12

The parameters of the prediction error statistics in Table 4 are graphically presented in Fig. 3 and 4. Figure 3 is a plot of the mean prediction error parameters for the different operators investigated in sites 1 and 2, while Fig. 4 is the plot of the behaviour of signal in terms of its standard deviation of error in decibel unit for each network investigated.

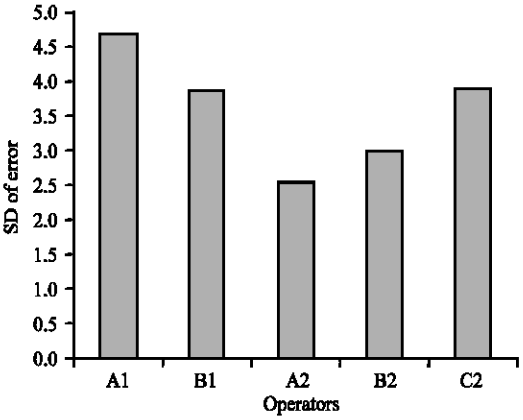

Fig. 4: The behaviour of signal in terms of its standard deviation of error

CONCLUSION

An empirical hata-like propagation path loss model was presented for GSM macrocellular networks at 1800 MHz in this study. The results have indicated that the path loss model increases logarithmically as a function of receive-transmit separation distance in all networks investigated. The JOEF models predicted the received signal behaviour within reasonable accuracy, a mean prediction error of less than ±0.4 dB and the standard deviation of error less than ±8 dB for all networks considered for this investigation. The Root Mean Square Error (RMSE) of the models in site 1 for operator A and B were 0.8475 and 0.7307 dB. In site 2, the RMSE for operators A-C was 0.9099, 0.833 and 0.7205 dB, respectively.

For radio network optimization, these models will provide a platform to aid in the system optimization process for improve performance. The model can be used to characterise the quality of radio coverage in the investigated environments. The model can also be applicable not only to site 1 and 2, but to any macrocellular environment, which is similar features to sites 1 and 2.

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