Hata-Okumura Model Computer Analysis for Path Loss Determination at 900MHz for Maiduguri, Nigeria

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Abstract

Empirical propagation models are used extensively for coverage prediction during the design and planning of wireless networks. Some of the most widely used empirical models include the COST 231 Hata Model (COST 231 1999, Saunders 2000, COST 231 revision 2), COST 231-Walfisch-Ikegami Model (COST 231 1999), etc. These models, however, are not universally applicable due differences in terrain clutter. Thus, when planning a wireless communication network it is necessary to determine radio propagation characteristics optimal to the terrain in question. In this paper, the applicability of the COST 231 Hata Model to the metropolis of Maiduguri, Nigeria, is tested by computing variations between the COST 231 Hata predictions and predictions based on the Least Squares function, being the best fit curve through measured data points. This was achieved with the help of a software system comprising of Visual Basic as Front End and Microsoft Excel as Back End. The Root Mean Square Error (RMSE) was found to be 5.33dB, which is acceptable, the acceptable maximum being 6dB. Further statistical proof testifies to the acceptability of the COST 231 Hata Model for path loss prediction across the metropolis of Maiduguri, Nigeria.

Keywords: COST 231 Hata, Hata-Okumura Model, COST 231-Walfisch-Ikegami Model, Root Mean Square Error, , Mean Prediction Error

1. Introduction

Cellular radio communication technology has been undergoing rapid evolution over the past couple of decades, and is still growing rapidly. Recently, wireless networks provide users with a wide range of network services. In order to ensure quality delivery of service, a sound network design is of paramount importance (Wagen & Rizk 2003). The most important practical results for telecommunications are predictions of the transmission impairment characteristics (loss, fading, interference, dispersion, distortion, etc.) of radio links (Frederiksen et al. 2000, Parsons 2000). One of the most important problems in the design phase of a cellular radio network is where to locate and how to configure base stations (Mathar & Niessen 2000).

Radio propagation characteristics to a large extent, vary from one type of environment to the other. This stems from the fact that a terrain is characterized by the types of obstacles that perturb radio propagation. Thus, accurate attenuation estimation plays a crucial role in wireless network planning. The prediction accuracy of a propagation model also depends on its suitability for that environment.

2. The Hata-Okumura Model

The Hata-Okumura Model (Hata 1981 & Neskovic et al. 2000), incorporates the graphical information from the Okumura Model (Okumura et al. 1968). The Hata Model for Urban Areas (also known as the Okumura-Hata model), is a widely used propagation model for predicting path loss in urban areas. This model takes into account the effects of diffraction, reflection and scattering caused by city structures. The model also has formulations for predicting path loss in Suburban and Open Areas.

The Hata Model for Urban Areas has the following parameters:

- *Frequency Range:* 150 MHz to 1500 MHz
- *Transmitter Height:* 30 m to 200 m
- *Link distance:* 1 km to 20 km
- *Mobile Station (MS) height:* 1 m to 10 m

Hata Model for Urban Areas is formulated as:

$$L_U = 69.55 + 26.16logf - 13.82logh_B - C_H + (44.9 - 6.55logh_B)logd \quad (1)$$

For small or medium sized cities (where the mobile antenna height is not more than 10 meters),

$$C_H = 0.8 + (1.1logf - 0.7)h_M - 1.56logf$$

For large cities,

$$C_H = \begin{cases} 8.29(\log(1.54h_M))^2 - 1.1, & for\ 150MHz \leq f \leq 200MHz \\ 3.2(\log(11.75h_M))^2 - 4.97, & for\ 200MHz \leq f \leq 1500MHz \end{cases}$$

Where,

- L_U= *Path loss in Urban Areas*
- h_B= *Height of base station antenna in meters (m)*
- h_M= *Height of mobile station antenna in meters (m)*
- *f= Frequency of Transmission in megahertz (MHz).*
- C_H= *Antenna height correction factor*
- *d= Distance between the base and mobile stations in kilometers (km).*

The *Hata Model for Suburban Areas* is widely used for path loss prediction in city outskirts and other rural areas where man-made structures are available but not as high and dense as in the cities. The model is based on the Hata Model for Urban Areas and uses the median path loss from urban areas. The Hata Model equation for Suburban Areas is formulated as

$$L_{SU} = L_U - 2(log\frac{f}{28})^2 - 5.4 \quad (2)$$

Where,

- L_{SU} = *Path loss in suburban areas in decibels (dB)*
- L_U = *Average Path loss in urban areas in decibels (dB)*
- *f = Frequency of Transmission in megahertz (MHz).*

The Hata Model for open areas predicts path loss in open areas where no obstructions block the transmission link. This model is suited for both point-to-point and broadcast transmissions. Hata model for open areas is formulated as,

$$L_O = L_U - 4.78(logf)^2 + 18.33logf - 40.94 \quad (3)$$

Where,

- L_O = *Path loss in open area. Unit: (dB)*
- L_U = *Path loss in urban area. Unit: decibel (dB)*
- *f = Frequency of transmission. Unit: (MHz)*

3. The Software Development Process

Software development usually involves a series of steps generally referred to as the Software Development Life Cycle (SDLC) (Systems Development 2000). The SDLC is an established framework used by software developers to develop software based on requirement analysis. The general phases in software development include Requirements analysis, Design, Coding, Testing/debugging and Documentation.

4. Methodology

4.1 Description of the Area under Investigation

Maiduguri is the capital and the largest city of Borno State in north-eastern Nigeria. The city is located within the Sudan savannah vegetation belt. Its terrain clutter is characterized by the availability of trees, houses mostly below 10 meters and an average road with of about 20 meters. Attenuation is caused by multiple reflections, absorption and multiple diffractions off roof tops, trees, cars etc. The concrete ground and tarred roads have very poor electrical conductivity, and therefore, cause attenuation by absorption. Ground reflected waves are blocked by buildings and trees. Sandy soil in certain parts of the city has very poor electrical conductivity and therefore basically causes attenuation by absorption.

4.2 Measurement Procedure

Measurements were taken from 7 different Base Stations of a mobile network service provider (Mobile Telecommunications Network (MTN)), situated within the terrain. The instrument used was a Cellular Mobile Network Analyser (SAGEM OT 290) capable of measuring signal strength in decibel milliwatts (dBm) (for instrument description visit http://www.ers.fr/Sagem/OT200.pdf). Readings were taken within the 900MHz frequency band at intervals of 0.2 kilometer, after an initial separation of 0.1kilometer away from the Base Station.

4.3 Base Station Parameters obtained from Network Provider (MTN)

i) Mean Transmitter Height, H_T= 40 meters
ii) Mean Effective Isotropically Radiated Power, EIRP = 46dBm
iii) Transmitting Frequency, f_c = 900MHz

4.5 Data Obtained

Received power values were recorded at various distances from each of the seven Base Stations named BST1, BST2, .., BST7, as shown in Table 1. For every received power value, the corresponding path loss was computed using the formula:

$$L_p = EIRP - P_R \quad (4)$$

Where,

- L_p = *Path loss*
- *EIRP = Effective Isotropically Radiated Power*
- P_R = *Received power*

4.6 Developing the Software

4.6.1 Software Architecture

The software system comprises of Visual Basic as Front End and a Microsoft Excel Spreadsheet as Back End. The spread sheet stores measured propagation data, relevant input parameters, and prediction errors.

4.6.2 Functional Diagram

The functional diagram basically shows how the software runs. The module for prediction error computation uses the available input parameters and measured propagation data stored in a spreadsheet application, to compute the Mean Prediction Error (MPE) and the Root Mean Square Error (RMSE). The modules for path loss computation and field strength computation are used for path loss and field strength analysis respectively.

4.6.3 Flowchart for Prediction Error Computation

The flowchart for Mean Prediction Error and the Root Mean Square Error computation for the standard Hata-Okumura Model is shown in Figure 4.

5.0 Results and Discussions

A Graphical comparison of the Hata-Okumura Model with the Least Squares Method is shown in Figure 5. The Least Squares function represents the best fit curve through the mean measured path loss points. It can be seen that the variations between these two methods are within the limits of acceptability.

Figure 6 shows the Mean Prediction Error (MPE) and the Root Mean Square Error (RMSE) between the Hata-Okumura Model and Least Squares predictions. The Least squares equation was formulated based on mean measurements obtained from the 7 Base Stations, using the system of normal equations (5) to determine the coefficients a_0, a_1, a_2:

$$\left.\begin{aligned} \sum_{i=1}^{N} L_i &= N a_0 + a_1 \sum_{i=1}^{N} d_i + a_2 \sum_{i=1}^{N} {d_i}^2 \\ \sum_{i=1}^{N} d_i\, L_i &= a_0 \sum_{i=1}^{N} d_i + a_1 \sum_{i=1}^{N} {d_i}^2 + a_2 \sum_{i=1}^{N} {d_i}^3 \\ \sum_{i=1}^{N} {d_i}^2\, L_i &= a_0 \sum_{i=1}^{N} {d_i}^2 + a_1 \sum_{i=1}^{N} {d_i}^3 + a_2 \sum_{i=1}^{N} {d_i}^4 \end{aligned}\right\} \quad (5)$$

The Least squares parabolic equation was found to be

$$LS = 91.19 + 33.3d - 5.05d^2 \quad (6)$$

Where,

LS – Least Squares Path Loss function

d - Receiver-Transmitter separation in kilometers.

N- Number of values

The Mean Prediction Error (MPE) of the Hata-Okumura Model was computed using the formula:

$$MPE = \frac{1}{N} \sum_{i=1}^{N} (PP_i - LS_i) \quad (7)$$

Where,

PP – Hata Okumura Predicted Path loss
LS - Least Squares path loss function
N – Number of values considered

The Root Mean Square Error (RMSE) was computed using the formula

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(PP_i - LS_i)^2}{N-1}} \quad (8)$$

As shown in Figure 6, the Hata-Okumura MPE and RMSE for the environment were found to be -0.18dB and 3.15dB respectively. According to (Wu & Yuan 1998), any RMSE up to 6dB is acceptable. It therefore, implies that the Hata-Okumura Model is acceptable for path loss prediction across the terrain in question. A further proof of this is buttressed by the statistical analysis shown in Figure 6.

The Pearson's correlation coefficient was computed using the formula:

$$r = \frac{N\sum_{i=1}^{N} LS_i LH_i - \sum_{i=1}^{N} LS_i . \sum_{i=1}^{N} LH_i}{\sqrt{\left(N\sum_{i=1}^{N} {LS_i}^2 - \left(\sum_{i=1}^{N} LS_i\right)^2\right)\left(N\sum_{i=1}^{N} {LH_i}^2 - \left(\sum_{i=1}^{N} LH_i\right)^2\right)}} \quad (9)$$

Where,

- *LS – Least Squares path loss function*
- *LH – Hata-Okumura predicted path loss*
- *N – Number of paired values*

It was found to be 0.98649, which indicates a high positive correlation between the Least Squares and the Hata-Okumura model. A test for correlation significance was performed to ensure acceptability of the correlation as follows:

The Null Hypothesis $H_0 : r = 0$, stating that there is no significant correlation between the Least Squares and the Hata-Okumura model, is tested against the alternative hypothesis $H_a : r \neq 0$, stating that there is a significant correlation between these methods. The t-value for correlation significance was computed using the formula:

$$t_{comp} = r.\sqrt{\frac{N-2}{1-r^2}} \quad (10)$$

It was found to be 19.98, which is significantly greater than the t-table value of 2.201, obtained under the level of significance α=0.025, with the degree of freedom ν = N-2=13-2=11. As a result, the Null Hypothesis is rejected.

Furthermore, the Null Hypothesis $H_0 : \mu_d = 0$, stating that the mean of the paired differences between the Least Squares and the Hata-Okumura is not significantly different from zero, is tested against the alternative hypothesis $H_a : \mu_d \neq 0$, stating that the mean of the paired differences between these methods is significantly different from zero. The computed t for paired values was obtained using the formula

$$t_{comp} = \frac{Mean\ of\ paired\ differences}{Standard\ Deviation} \quad (11)$$

It was found to be 0.057, which is less than the t-table value of 1.782, obtained under the level of significance α=0.05 with the degree of freedom ν = N-1 = 13-1=12. As a result the Null Hypothesis holds.

The above statistical analysis indicates that the Hata-Okumura Model can be used in place of the Least Squares method, and is thus, valid for path loss prediction across the terrain in question.

6.0 Conclusion

Field measurements were obtained from Base Stations across situated within the metropolis of Maiduguri, Nigeria, and the best fit function through the mean measurements was obtained using the Least Squares Approximation technique. Comparisons were made between the obtained Least Squares function and the Hata-Okumura Model. It was discovered that the Hata-Okumura Model has an acceptable Root Mean Square Error of 3.15B, the acceptable maximum being 6dB. Further statistical proof shows that the Hata-Okumura Model for urban areas is acceptable for path loss prediction across the terrain in question.

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Figure 1: An Arial view of Maiduguri (courtesy of Google earth)

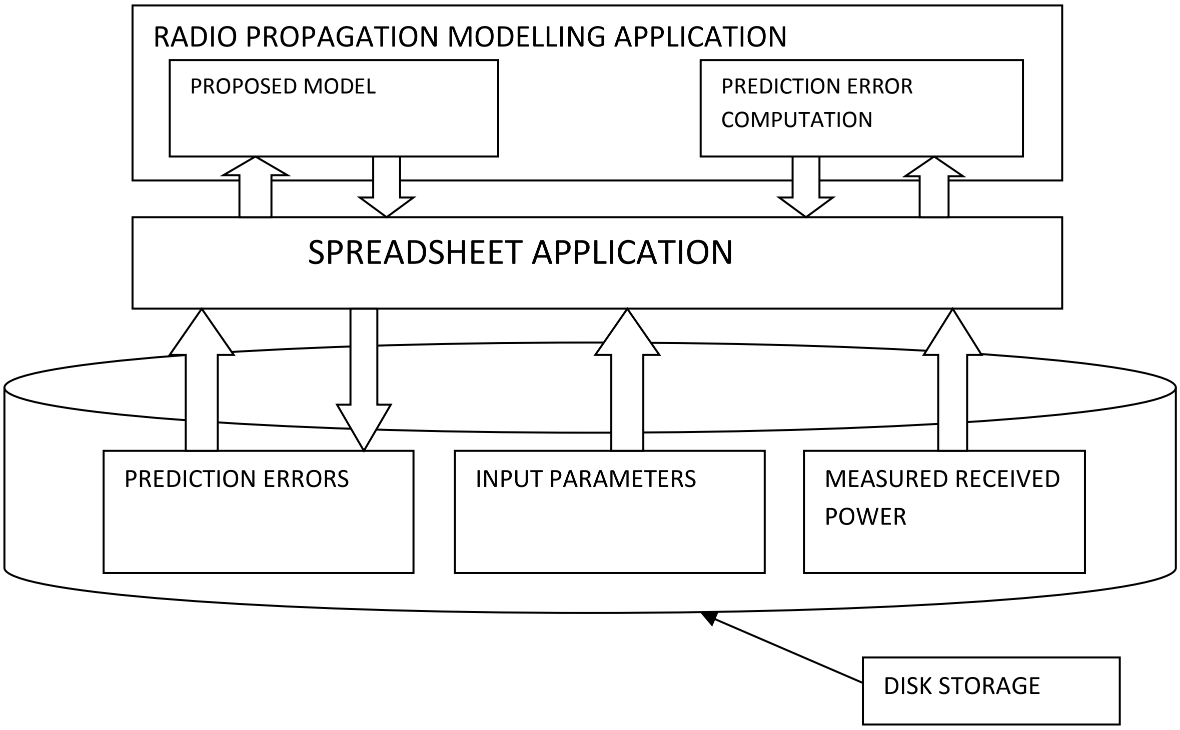

Figure 2: Software Architecture

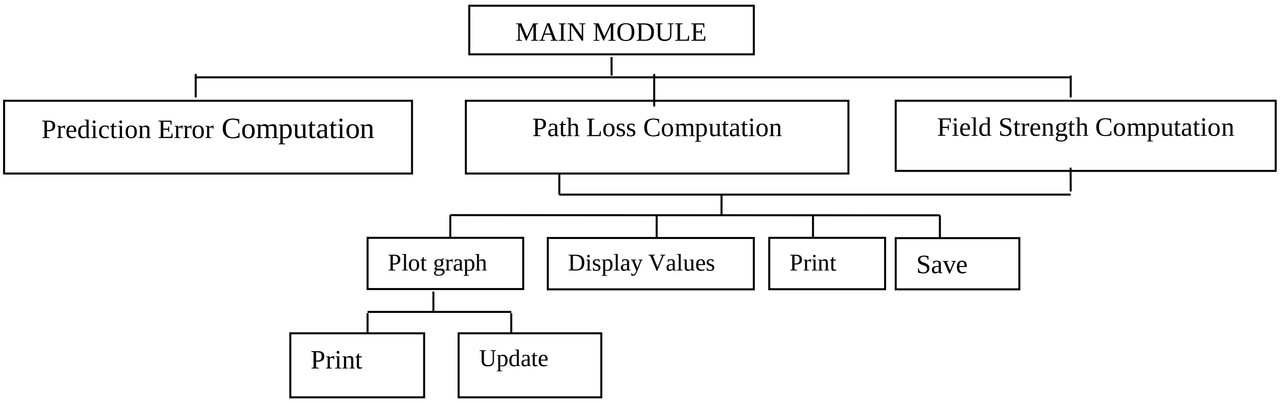

Figure 3: Functional Diagram

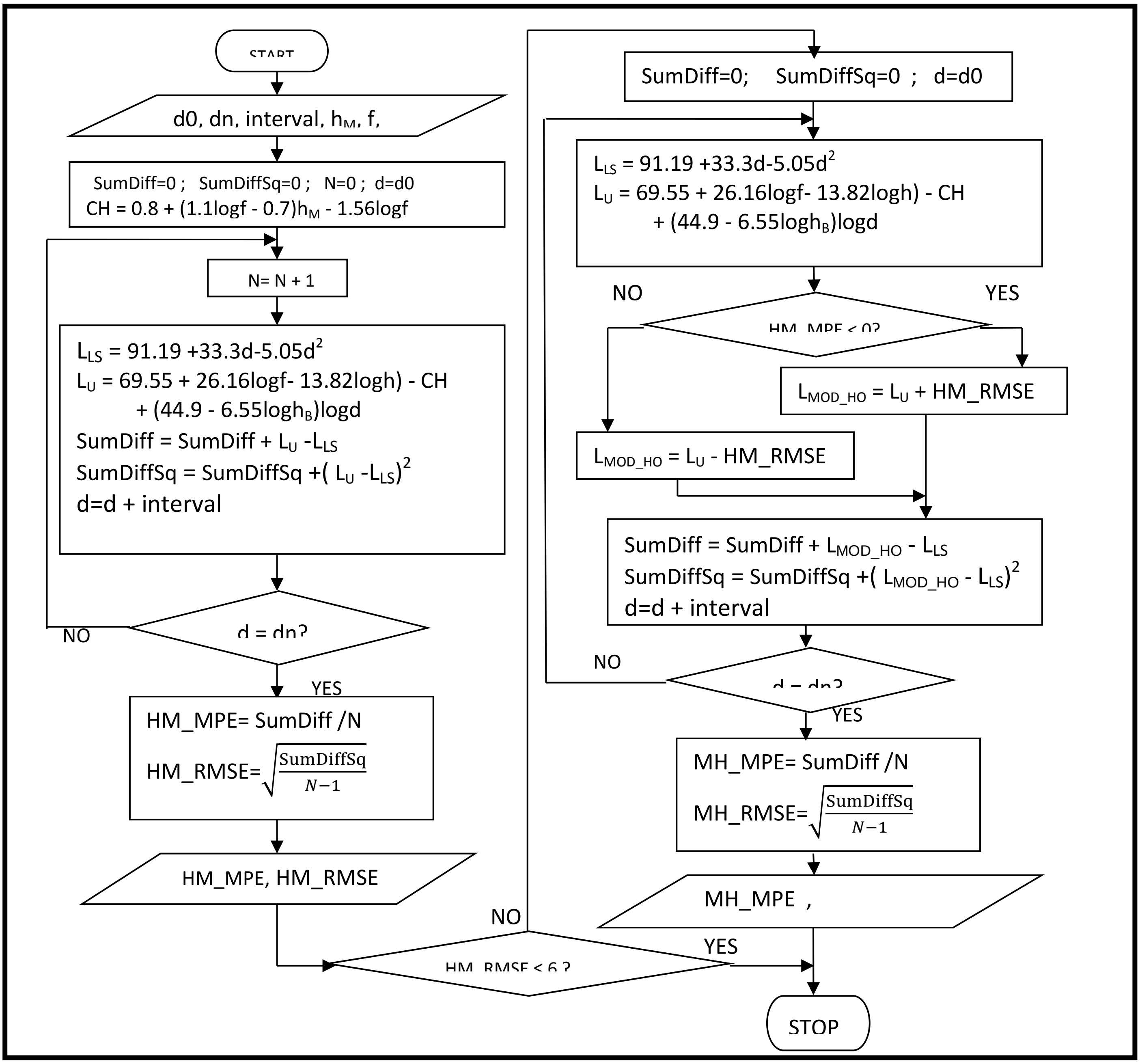

Figure 4: Prediction Error Computation

Where,

- *d0 – initial separation (km)*
- *dn – final separation (km)*
- *N – number of values considered*
- *SumDiff – Sum of differences between Least squares and Hata-Okumura predictions*
- *SumDiffSq – Sum of squares of differences between Least squares and Hata-Okumura predictions*
- *HM_MPE – Hata-Okumura Model Mean Prediction Error*
- *HM_RMSE – Hata-Okumura Model Root Mean Square Error*
- L_{LS} *- Least Squares Path Loss Prediction*
- L_U *–Hata-Okumura Model Urban Path Loss Prediction*
- L_{MOD_HO} *– Modified Hata-Okumura Model Path Loss Prediction*
- *MH_MPE – Modified Hata-Okumura Model Mean Prediction Error*

- *MH_RMSE – Modified Hata-Okumura Model Root Mean Square Error*

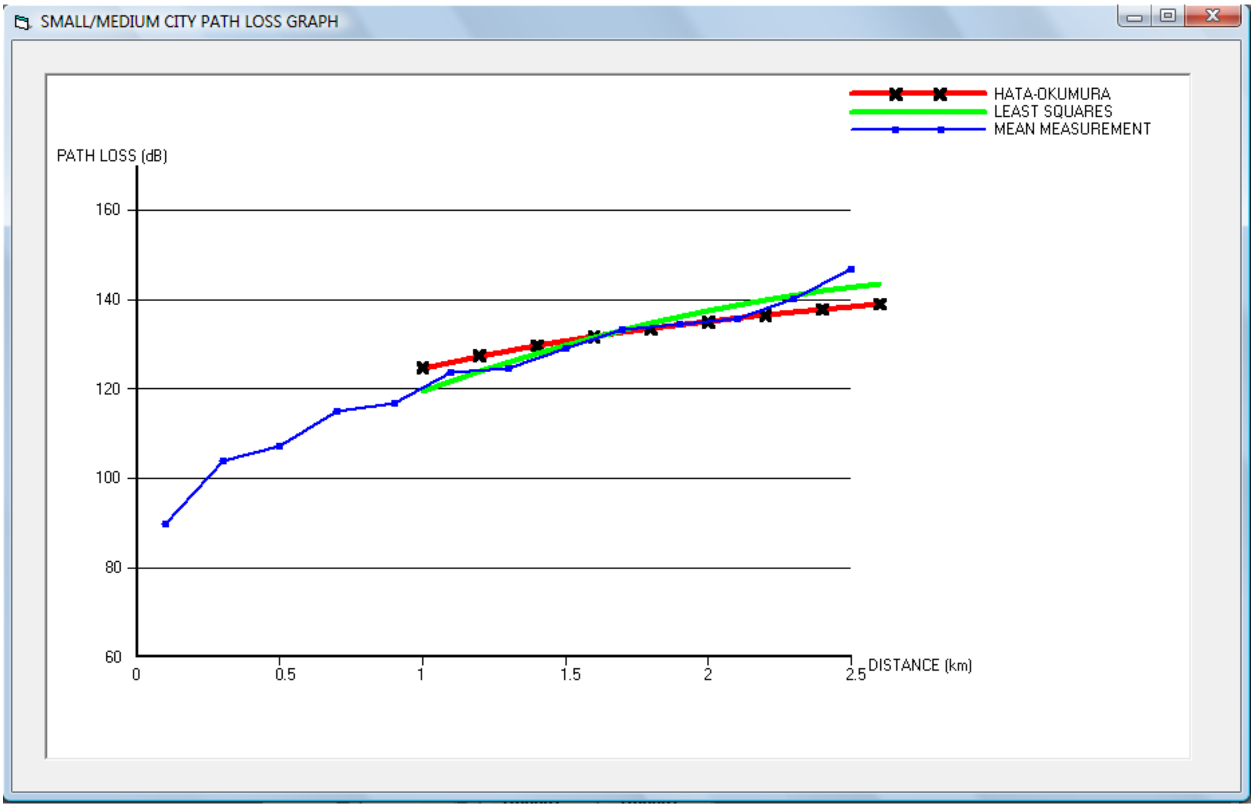

Figure 5: Graphical comparison of the Hata-Okumura Model with the Least Squares Method

Table 1: *Received Power values from Base Stations at various separations*

DISTANCE (Km)	BST 1	BST 2	BST 3	BST 4	BST 5	BST 6	BST 7	MEAN VALUES
	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R(dBm)
0.10	-43	-46	-41	-45	-46	-41	-44	-44
0.30	-55	-58	-61	-57	-57	-61	-57	-58
0.50	-59	-51	-65	-67	-69	-65	-53	-61
0.70	-68	-66	-64	-71	-75	-72	-67	-69
0.90	-67	-73	-68	-73	-72	-73	-70	-71
1.10	-64	-78	-82	-80	-84	-78	-78	-78
1.30	-68	-78	-83	-77	-85	-81	-78	-79
1.50	-69	-83	-89	-86	-88	-84	-83	-83
1.70	-76	-88	-91	-94	-87	-88	-88	-87
1.90	-76	-93	-90	-89	-90	-92	-89	-89
2.10	-83	-95	-89	-88	-91	-90	-92	-90
2.30	-91	-91	-109	-93	-91	-89	-94	-94
2.50	-104	-94	-106	-96	-94	-102	-110	-101