Computer Analysis of the COST 231 Hata Model and Least Squares Approximation for Path Loss Estimation at 900MHz on the Mountain Terrains of the Jos-Plateau, Nigeria

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Abstract

The determination of radio propagation characteristics for a given terrain is a key consideration in wireless network planning. For this purpose radio propagation models are quite useful. Some of the most widely used models are the Empirical Propagation Models. The suitability of any propagation model depends on terrain clutter and other constraints. Some extensively used Empirical Models include the COST 231 Hata Model (COST 231 1999, Saunders 2000, COST 231 revision 2, 1991), COST 231-Walfisch-Ikegami Model (COST 231 1999), etc. In this paper, the suitability of the COST 231 Hata Model for network coverage prediction across the mountain terrains of the Jos-Plateau Nigeria is tested. With a RMSE of 10.25dB the model is found unacceptable, the acceptable maximum being 6dB. An optimized propagation model built on the basis of the COST 231 Hata Model and backed up by statistical proof of acceptability is subsequently proposed.

Keywords: Empirical Propagation Models, COST 231 Hata Model, Hata-Okumura Model, COST 231-Walfisch-Ikegami Model

1. Introduction

Wireless telecommunication networks have become highly popular, providing a wide variety of services to a growing number of subscribers across various geographical locations all over the world. It has therefore become quite critical to provide quality service across various terrain types ranging from built-up to rural/open areas. Thus, accurate attenuation estimation plays a crucial role in wireless network planning. Empirical propagation models are widely used in determining network coverage. The prediction accuracy of a propagation model also depends on its suitability for that environment. Attenuation of radio signals between transmitter and receiver is dependent on terrain clutter characteristics. For this reason an accurate and flexible coverage prediction methodology with ease of implementation is required (Casaravilla et al 2009). 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).

2. The COST 231 Hata Model

The COST 231 Hata Model is a widely used radio propagation model. The model was built in Europe for coverage prediction across various European terrains. The model is also known as the *Hata Model PCS Extension,* being an extension of the Hata Model (Hata 1981), which in turn is based on the Okumura Model (Neskovic et al. 2000, Okumura et al. 1968). However, The COST 231 Hata model covers a wider range of frequencies. Moreover, its simplicity and availability of correction factors make it applicable to urban, suburban and rural areas. The COST 231 Hata Model has the following parameters:

- *Frequency Range:* 500 MHz to 2000 MHz
- *Transmitter Height:* 30 m to 100 m
- *Link distance:* up to 20 km
- *Mobile Station (MS) height:* 1 m to 10 m

The path loss equation for the COST 231 Hata Model is formulated as follows:

$$L = 46.3 + 33.9logf - 13.82logh_B - a(h_R) + (44.9 - 6.55logh_B)logd + C \quad (1)$$

Where,

- *C=0 for medium cities and suburban areas*
- *C=3 for metropolitan areas*
- *L = Median path loss in Decibels (dB)*
- *f = Frequency of Transmission in Megahertz (MHz)*
- h_B *= Base Station Antenna effective height in Meters (m)*
- *d = Link distance in Kilometers (km)*
- h_R *= Mobile Station Antenna effective height in Meters (m)*
- $a(h_R)$ *= Mobile station Antenna height correction factor as described in the Hata Model for Urban Areas.*
- *For urban areas,* $a(h_R) = 3.20(log10(11.75hr))2-4.97$*, for f > 400 MHz*
- *For sub-urban and rural areas,* $a(h_R) = (1.1log(f) - 0.7)h_R - 1.56log(f) -0.8$

3.0 Methodology

3.1 Description of the Area under Investigation

The region under investigation is a mountainous terrain situated on the Jos-Plateau, which lies within the Guinea savannah vegetation belt of Nigeria. The terrain in question shown in figure 1 is situated along the Rukuba road axis and is characterized by scattered trees, shrubs and houses. The mountains constitute obstacles of irregular shape, and form diffraction paths. The average mountain height is about 20 meters.

3.2 Measurement Procedure

Measurements were taken from 5 different Base Stations of a mobile network service provider (Mobile Telecommunications Network (MTN), Nigeria), 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.

3.3 Base Station Parameters obtained from Network Provider (MTN)

i) Mean Transmitter Height, H_T= 34 meters
ii) Mean Effective Isotropic Radiated Power, EIRP = 47 dBm
iii) Transmitting Frequency, f_c = 900MHz

3.5 Received Power Data Obtained

Received power values were recorded at various distances from each of the seven Base Stations named BST1, BST2, .., BST5, as shown in Table 1. For every received power value, the corresponding path loss was computed using the formula:

$$L_p = EIRP - P_R \quad (2)$$

Where,

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

4.0 Results and Discussions

Figure 2 is a flowchart for computing the Mean Prediction Errors (MPE) and the Root Mean Square Errors (RMSE) for the Standard and the Modified COST 231 Hata Models. The computer program was written in

Visual basic, with an Excel Spreadsheet containing measured propagation data and other input parameters, as Back End.

Figure 3 shows a graphical comparison of the COST 231 Hata Model with the Least Squares Approximation Technique. The Least Squares function represents the best fit curve through mean measured path loss points. It can be seen that the COST 231 Hata Model overestimates the path loss, obviously due to differences in terrain clutter and other geographical features from the COST 231 Hata Model European environment.

Figure 4 shows the Mean Prediction Error (MPE) and the Root Mean Square Error (RMSE) between the COST 231 Hata and Least Squares predictions. The Least squares equation was formulated based on mean measurements obtained from the 5 Base Stations, using the system of normal equations (3) to determine the coefficients a_0, a_1, a_2:

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

The Least squares parabolic equation was found to be

$$LS = 98.92 + 14.65d - 0.25d^2 \quad (4)$$

Where,

LS – Least Squares Path Loss function

d - Receiver-Transmitter separation in kilometers.

N- Number of mean measured values

The Mean Prediction Error (MPE) of the COST 231 Hata model prediction relative to the Least Squares prediction was computed using the formula:

$$MPE = \frac{1}{N}\sum_{i=1}^{N}(PP_i - LS_i) \quad (5)$$

Where,

PP – COST 231 Hata 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:

$$RMSE = \sqrt{\sum_{i=1}^{N}\frac{(PP_i - LS_i)^2}{N-1}} \quad (6)$$

As shown in Figure 4, the COST 231 Hata MPE and RMSE for the environment were found to be 8.86dB and 10.25dB respectively. According to (Wu & Yuan 1998), any RMSE up to 6dB is acceptable. It therefore, implies that the COST 231 Hata Model is not acceptable for path loss prediction across the terrain in question. However, by subtracting the RMSE from the COST 231 Hata Model equation and substituting C with zero, the modified equation becomes

$$L = 36.05 + 33.9 logf - 13.82 logh_B - a(h_R) + (44.9 - 6.55 logh_B) logd \quad (7)$$

Figure 5 shows that the modified COST 231 Hata Model performs better than the Standard version. It also shows that variations between the Least Squares and the modified COST 231 Hata Model are acceptable. A further proof of this is buttressed by the statistical analysis shown in shown Figure 4. The figure shows that the modified COST 231 Hata RMSE for the environment was found to be 5.1dB, which is acceptable according to (Wu & Yuan 1998).

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

$$r = \frac{N\sum_{i=1}^{N} LS_i CH_i - \sum_{i=1}^{N} LS_i . \sum_{i=1}^{N} CH_i}{\sqrt{\left(N\sum_{i=1}^{N} LS_i^2 - \left(\sum_{i=1}^{N} LS_i\right)^2\right)\left(N\sum_{i=1}^{N} CH_i^2 - \left(\sum_{i=1}^{N} CH_i\right)^2\right)}} \quad (8)$$

Where,

- *LS – Least Squares path loss function*
- *CH – COST 231 Hata predicted path loss*
- *N – Number of paired values*

It was found to be 0.91, which indicates a high positive correlation between the Least Squares and the Modified COST 231 Hata model. A test for correlation significance was performed to ensure acceptability of the correlation as follows:

The Null Hypothesis $\boldsymbol{H_0 : r = 0}$, stating that there is no significant correlation between the Least Squares function and the modified COST 231 Hata model, is tested against the alternative hypothesis $\boldsymbol{H_a : r \neq 0}$, stating that there is a significant correlation between these methods. The t-value for correlation significance was computed using the formula:

$$t_{comp} = r.\sqrt{\frac{N-2}{1-r^2}} \quad (9)$$

It was found to be 8.47, which is significantly greater than the t-table value of 2.145, obtained under the level of significance α=0.025, with the degree of freedom ν = N-2=16-2=14. As a result, the Null Hypothesis is rejected.

Furthermore, the Null Hypothesis $\boldsymbol{H_0 : \mu_d = 0}$, stating that the mean of the paired differences between the Least Squares and the modified COST 231 Hata is not significantly different from zero, is tested against the alternative hypothesis $\boldsymbol{H_a : \mu_d \neq 0}$, 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:

$$t_{comp} = \frac{Mean\ of\ paired\ differences}{Standard\ Deviation} \quad (10)$$

It was found to be 0.273, which is less than the t-table value of 1.753, obtained under the level of significance α=0.05 with the degree of freedom ν = N-1 = 16-1=15. As a result the Null Hypothesis holds.

The above statistical analysis indicates that the Modified COST 231 Hata Model can be used in place of the Least Squares function, and is thus, valid for path loss prediction across the terrain in question.

5.0 Conclusion

Field measurements were obtained from Base Stations across the mountain terrains of the Jos-Plateau, 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 COST 231 Hata Model. It was discovered that the COST 231 Hata Model overestimates the path loss with a Root Mean Square Error of 10.25B, which is above the acceptable maximum of 6dB. However, by subtracting the RMSE from the COST 231 Hata Model equation, the modified model performs better with a RMSE of 5.1dB. The modified COST 231 Hata Model is therefore, recommended for path loss prediction across the region in question.

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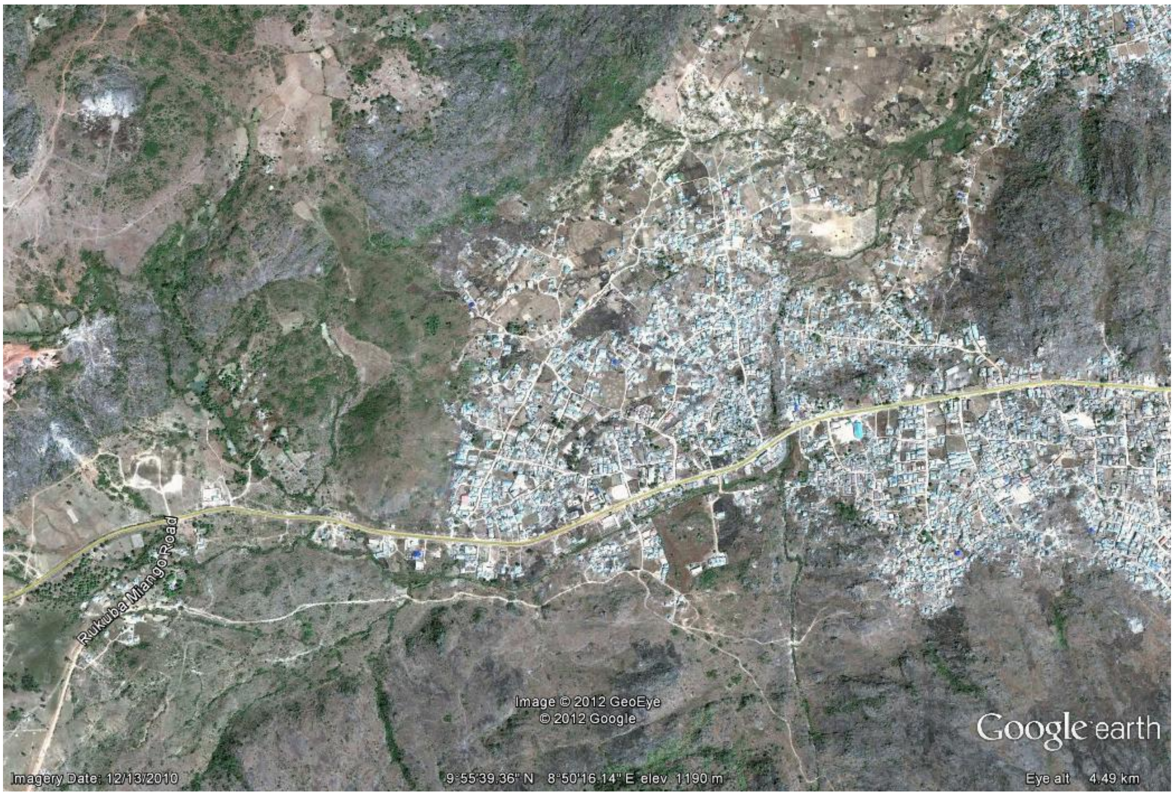

Figure 1: A Section of the Mountain Terrain Settlement along Rukuba Road, Jos (courtesy of Google earth)

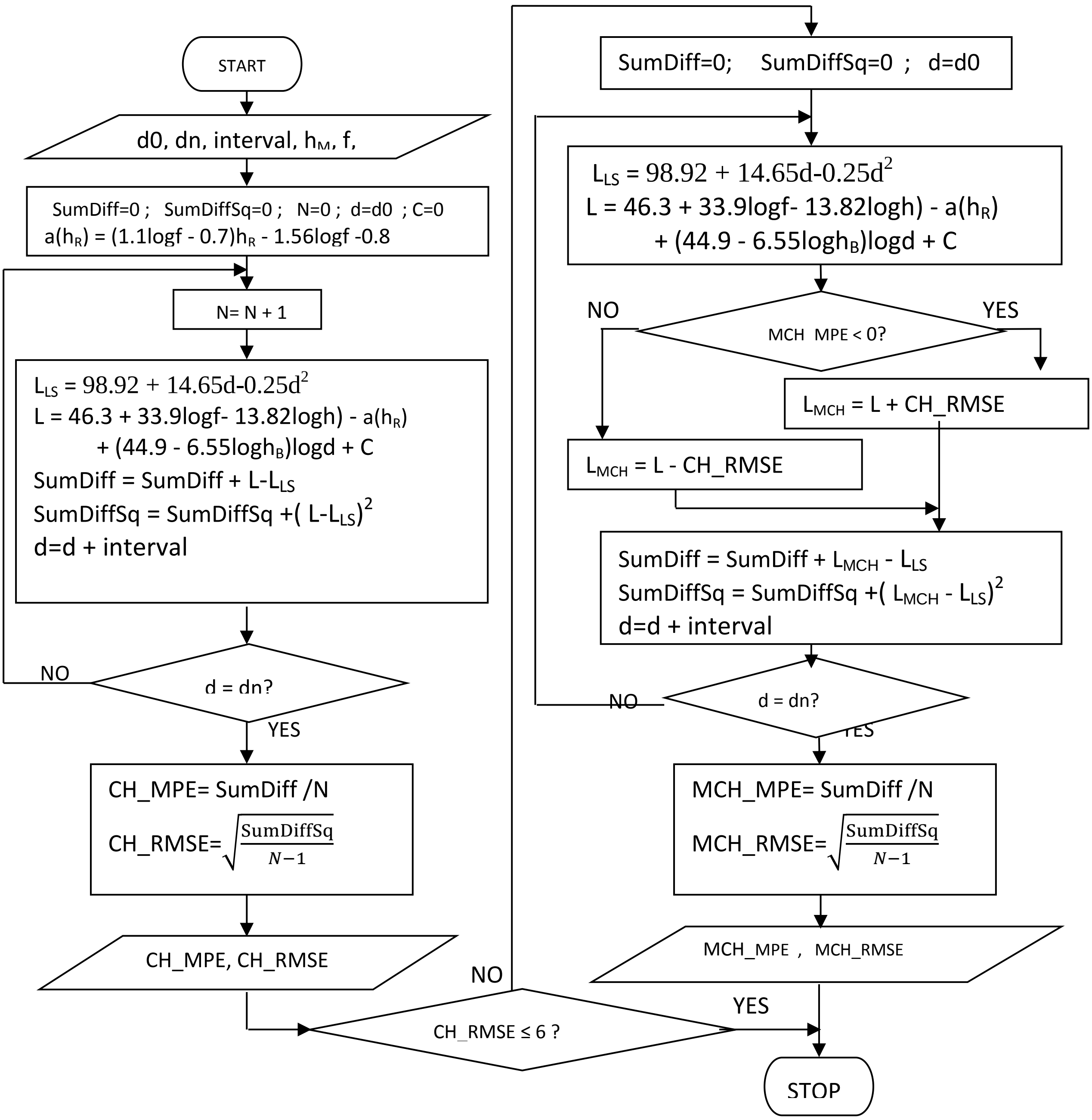

Figure 2: Prediction Error Computation

Where,

- *d0 – initial separation (km)*
- *dn – final separation(distance after which received power is negligible) (km)*
- *N – number of values considered*
- *SumDiff – Sum of differences between Least squares and COST 231 Hata predictions*
- *SumDiffSq – Sum of squares of differences between Least squares and COST 231 Hata predictions*
- *CH_MPE – COST 231 Hata Model Mean Prediction Error*
- *CH_RMSE – COST 231 Hata Model Root Mean Square Error*
- *MCH_MPE – Modified COST 231 Hata Model Mean Prediction Error*
- *MCH_RMSE – Modified COST 231 Hata Model Root Mean Square Error*

- *L_{LS} - Least Squares Path Loss Prediction*
- *L –COST 231 Hata Path Loss Prediction*

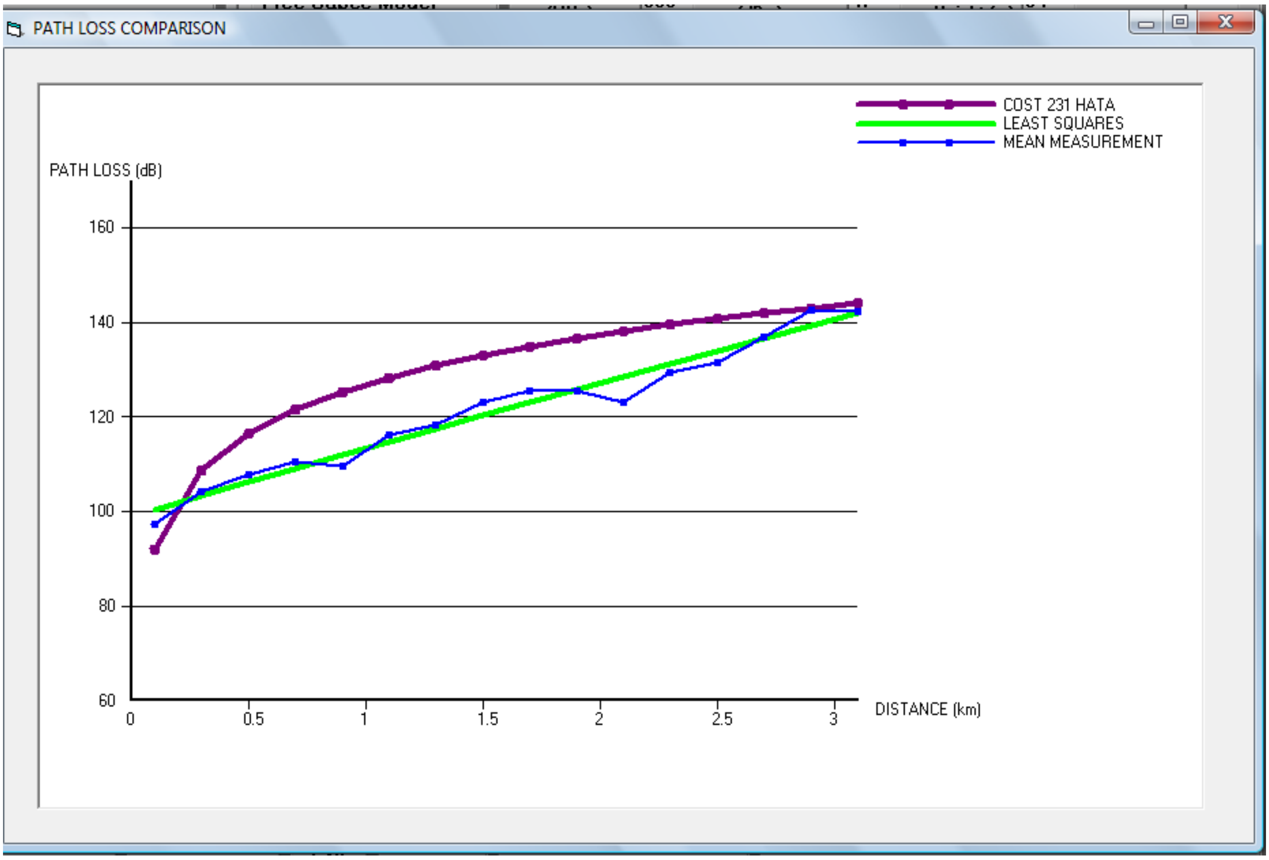

Figure 3: Graphical Comparison of the COST 231 Hata Model with the Least Squares Method

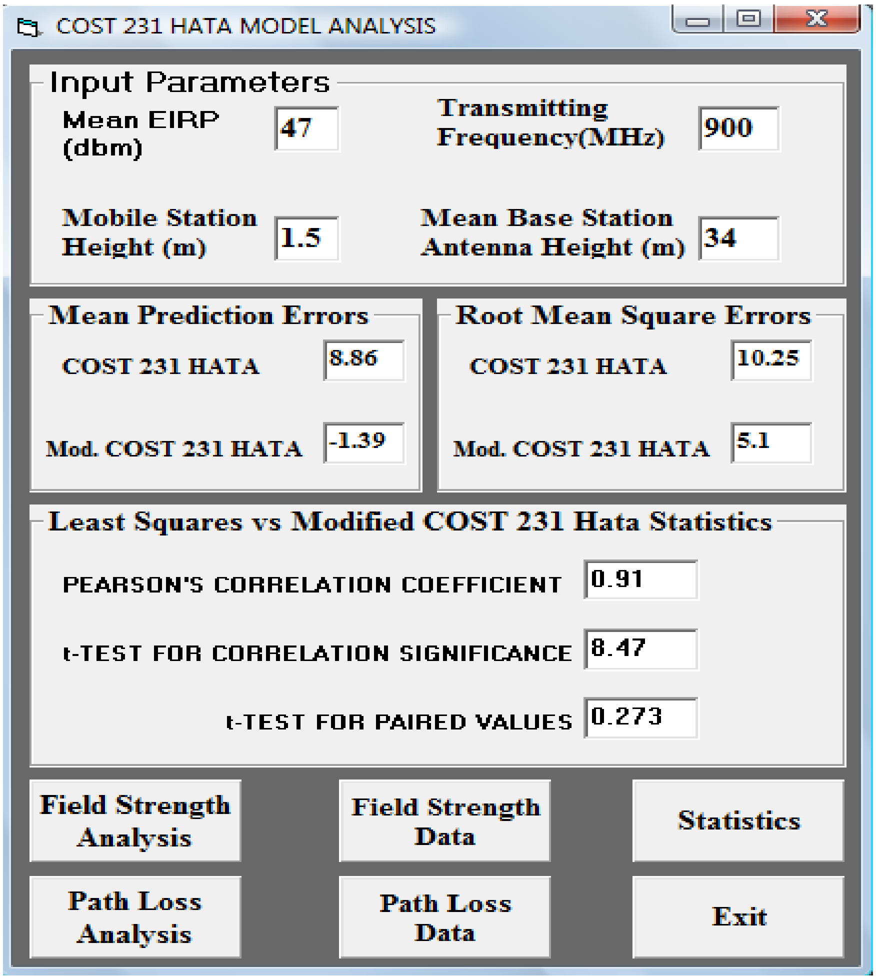

Figure 4: Modeling Application showing results of Statistical Analysis

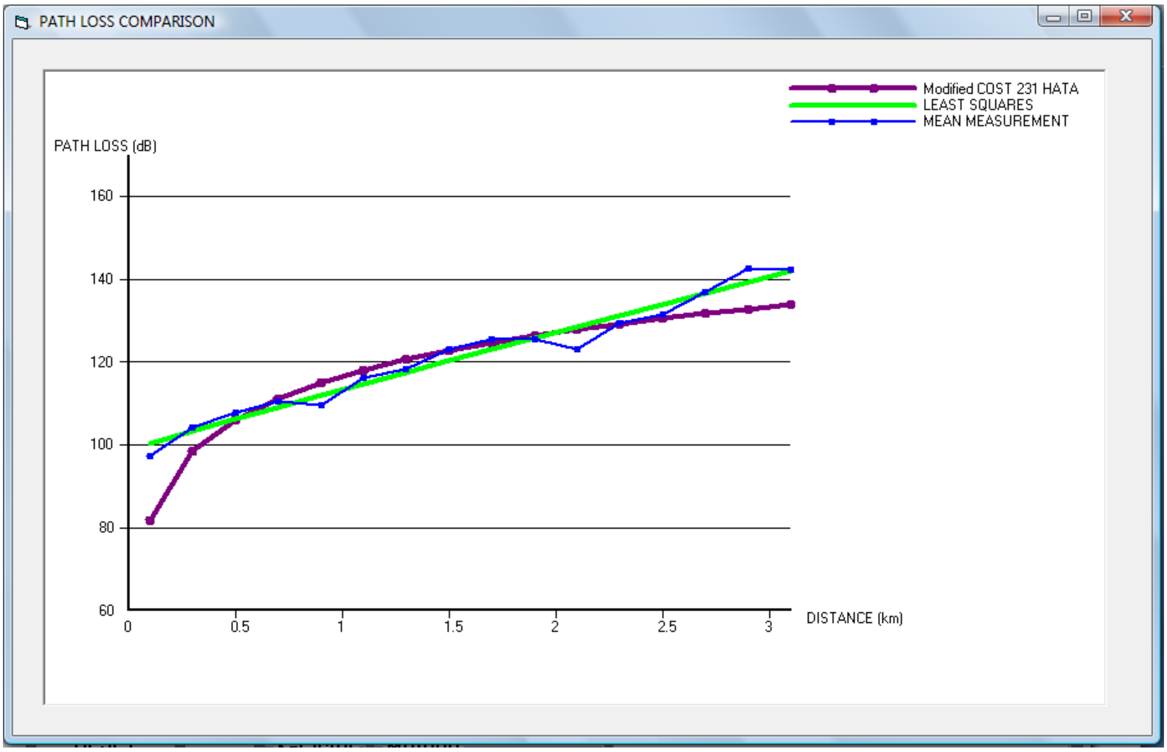

Figure 5: Graphical Comparison of the Modified COST 231 Hata Model with the Least Squares Method

Table 1: Received Power from Base Stations at various separations

	BST1	BST2	BST3	BST4	BST5	MEAN
Dist (km)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)	P_R (dBm)
0.10	-50	-48	-54	-51	-49	-50
0.30	-54	-63	-52	-59	-58	-57
0.50	-53	-61	-66	-62	-62	-61
0.70	-53	-69	-69	-63	-63	-63
0.90	-52	-68	-68	-65	-60	-63
1.10	-56	-68	-79	-72	-71	-69
1.30	-58	-78	-77	-69	-75	-71
1.50	-68	-79	-86	-75	-73	-76
1.70	-78	-71	-85	-77	-81	-78
1.90	-70	-87	-77	-82	-76	-78
2.10	-67	-77	-81	-78	-77	-76
2.30	-76	-83	-88	-82	-83	-82.4
2.50	-73	-85	-97	-87	-81	-84.6
2.70	-92	-85	-93	-91	-89	-90
2.90	-89	-94	-106	-95	-94	-95.6
3.10	-91	-94	-103	-96	-93	-95.4