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Performance Evaluation of Path Loss in Mobile Channel for Karada District in Baghdad City

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ABSTRACT

In this work Hata, Lee, Walfisch-Ikegami and Free Space Loss models have been compared with practical path loss based on series of measurements in Karada district in Baghdad for GSM900 downlink band. Hata model showed the closest path loss predictions with mean square error = 10.8 dB, but these results are far from good prediction results and need enhancement. Hata model was optimized using Least Squares method based on measured received signal power. The optimized Hata model showed much better results from the original Hata with mean square error = 6.96 dB. The simulation and calculations were implemented using MATLAB R2009b. The measurements were done using Field Test Display (FTD) with a compatible hand phone to measure signal strength. A Ground Positioning System (GPS) was used to measure the distance from transmitter.

Keywords: Path Loss Models, Model Optimization, GSM 900, Suburban Outdoor Coverage

تقييم أداء خسائر المسار لقناة المحمول لمنطقة الكرادة في مدينة بغداد

الخلاصـــة

تم في هذا العمل المقارنة بين نماذج هاتا ، لي ،ولفش- ايكيجامي (Walfisch-Ikegami) و نموذج خسارة الفضاء الحر (Free Space path loss) مع نتائج عملية لخسائر المسار و تم الحصول عليها بعد سلسلة من القياسات في منطقة الكرادة في بغداد ضمن حزمة الترددات الهابطة (downlink) لنظام الاتصالات GSM900. أظهر نموذج هاتا أقرب التنبؤات لخسائر المسار مع معدل مربع الخطأ = 10.8 ديسيبل ، و كانت النتائج بعيدة كل البعد عن النتائج الجيدة و تحتاج الى تحسين .تم التحسين على نموذج هاتا بإستخدام طريقة المربعات الأقل بالاعتماد على قياس قدرة الإشارة المستلمة .أظهر نموذج هاتا المحسن نتائج أفضل بكثير من نموذج هاتا الأصلي مع معدل مربع الخطأ = 6.96 ديسيبل. تم في هذا العمل أجراء عمليات المحاكاة والحسابات باستخدام MATLAB R2009b ، و أجريت القياسات الميدانية باستخدام Field Test Display مع هاتف محمول متوافق لقياس قوة الإشارة حيث تم استخدام نظام تحديد المواقع الأرضية لقياس المسافة بين جهازي الارسال والاستلام.

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INTRODUCTION

Path loss refers to electromagnetic wave attenuation between transmitter and receiver in the communication system. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, scattering and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas [1].

The prediction of path loss in channel is very important step in planning a mobile radio system, and accurate prediction methods are needed to determine the parameters of a radio system which will provide efficient and reliable coverage of a specified service area [2].

PATH LOSS MODELS

Free Space Path Loss Model

Free Space Path Loss (FSPL) provides a means to predict the received signal power when there is no object obstructing the Line Of Site (LOS) path between the Transmitter and the receiver [3].

The model for path loss in a LOS environment is straightforward. The received power P_r is related to the transmitted power P_t *via* the Friis transmission formula [3]:

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

Where

- $EIRP$ is the effective isotropic radiated power = $P_t G_t$
- G_t is the transmitter antenna gain.
- G_r is the receiver antenna gain.
- d is the separation between transmitter and receiver.
- A_e is the receiver antenna effective aperture = $\frac{G_r \lambda^2}{4\pi}$
- λ is the signal wavelength.

The path loss for free space model in dB is:

$$PL\,(dB) = 10\log_{10}\left(\frac{P_t}{P_r}\right) = -10\log_{10}\frac{G_t G_r \lambda^2}{(4\pi d)^2} \quad \ldots (2)$$

Hata Model

Hata [4] empirical mathematical relationships to describe the graphical information given by Okumura. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain. The mathematical expression and their ranges of applicability are as follows:

For Urban areas

$$PL_{Hata}\,(DB) = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_b) - a(h_m) + (44.9 - 6.55 \log_{10}(h_b)) \log_{10}(d) \quad \ldots (3)$$

Where

- Carrier Frequency: 150 MHz ≤ f_c ≤ 1500 MHz.
- BTS Antenna Height: 30 m ≤ hb ≤ 200 m.
- MS Antenna Height: 1 m ≤ h_m ≤ 10 m.
- Transmission Distance: 1 km ≤ d ≤ 20 km.
- $a(h_m)$ is the correction factor of MS antenna height and computed as shown in equations (4), (5) and (6):

1. For a small or medium sized city,
2.

$$a(h_m) = (1.1\,log_{10}(f_c) - 0.7)\,h_m - (1.56\,log_{10}(f_c) - 0.8) \qquad \text{... (4)}$$

3. For large city,
   a) For $f_c \leq 200$ MHz

$$a(h_m) = 8.29\,(log_{10}(1.54\,h_m)^2 - 1.1 \qquad \text{... (5)}$$

   b) For $f_c \geq 400$ MHz

$$a(h_m) = 3.2\,(log_{10}(11.75\,h_m)^2 - 4.9 \qquad \text{... (6)}$$

The Hata model for open areas is a function of the Hata model for urban areas plus a series of correction factors that reduce the loss based on logarithmic degrees of the transmission frequency and a constant which will always result in the open area loss being at least 40 dB less than the calculated urban area loss [5].

$$L_{open} = L_{50} - 4.78(log_{10}(f_c))^2 + 18.33\,log_{10}(f_c) - 40.94 \qquad \text{... (7)}$$

The suburban Hata Model is a function of the urban Hata model plus a correction factor that reduces the degree of loss based on a logarithmic factor of frequency plus a constant value that is only a small percentage of the constant applied to the open area model [5].

$$L_{suburban} = L_{50} - 2\left[log_{10}\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \qquad \text{... (8)}$$

The COST-Walficsh-Ikegami model

This model is combination of J. Walfisch and F. Ikegami model. Now it is known as a COST 231 Walfisch-Ikegami (W-I) model. This model can be used in cases when the BTS (Base Transceiver Station) antenna is placed either above or below roof line in urban or suburban areas [6].

This model is most suitable for flat suburban and urban areas that have uniform building height. The W-I model gives more precise path loss predictions among other models like the Hata. This is a result of the additional parameters introduced which characterized the different environments. The additional parameters are [7]:

- Average heights of buildings (h_r).
- Average width of roads (w).
- Average building separation (b).
- Road orientation with respect to the LOS (φ).

This model is restricted to the following range of parameters:

- f_c = 800 to 2000 MHz
- h_b = 4 to 50 m
- h_m = 1 to 3 m
- d = 0.02 to 5 km

This model distinguishes between LOS and non-LOS paths as follows.

1. For LOS paths the equation is as below:

$$L_{LOS} = 42.6 + 26\,log_{10}(d) + 20\,log_{10}(f_c) \quad \ldots(9)$$

Where

- f_c in MHz
- d in Km and $d \geq 20$ m.

2. For non-LOS the equation is as below:

$$L_{NLOS} = \begin{cases} PL_{FSPL} + L_{rts} + L_{msd} \\ \\ PL_{FSPL} \end{cases} \quad \ldots(10)$$

Where:

- L_{rts} is the rooftop-to-street diffraction and scatter-loss.
- L_{msd} is the multiscreen diffraction loss.
-

$$L_{rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f_c) + 20\log_{10}(h_r - h_m) + L_{ori} \quad \ldots(11)$$

Where L_{ori} is the orientation loss and can be found using Eq. (12).

$$L_{ori} = \begin{cases} -10 + 0.354\,\varphi & 0^o \leq \varphi \leq 35^o \\ 2.5 + 0.075\,(\varphi - 35) & 35^o \leq \varphi \leq 90^o \\ 4 - 0.114\,(\varphi - 55) & 55^o \leq \varphi \leq 90^o \end{cases} \quad \ldots(12)$$

$$L_{msd} = L_{bsh} + k_a + k_d\,log_{10}(d) + k_f\,log_{10}(f_c) - 9\,log_{10}(b) \quad \ldots(13)$$

Where:

- L_{bsh} is the shadowing loss and given as shown below.

$$L_{bsh} = \begin{cases} -18\,log_{10}[1 + (h_b - h_r) & h_b > h_r \\ 0 & h_b \leq h_r \end{cases} \quad \ldots(14)$$

k_a, k_d and k_f are correction factors and given as shown below.

$$k_a = \begin{cases} 54 & h_b > h_r \\ 540.8(h_b - h_r) & h_b \leq h_r \quad and\ d \geq 0.5\,km \\ 54 - 0.8(h_b - h_r) & h_b \leq h_r \quad and\ d < 0.5\,km \end{cases} \quad \ldots(15)$$

$$k_d = \begin{cases} 18 & h_b > h_r \\ 18 - 15\dfrac{(h_b - h_r)}{h_r} & h_b \leq h_r \end{cases} \quad \ldots(16)$$

$$k_f = \begin{cases} 0.7\left(\dfrac{f_c}{925} - 1\right) & for\ medium\ sized\ cities\ and\ suburban \\ & centers\ with\ medium\ tree\ density. \\ 1.5\left(\dfrac{f_c}{925} - 1\right) & for\ metropolitan\ centers \end{cases} \quad \ldots(17)$$

Lee Model

W.C.Y. Lee [6, 8] proposed a very simple signal propagation model originating from a series of measurements made in the USA at the carrier frequency f_c = 900 MHz. According to the Lee model, the path loss in suburban area is calculated as shown below:

$$L_{50} = 101.7 + 38.5\,log_{10}(d) + 10\,m\,log_{10}\left(\frac{f_c}{f_0}\right) - F_{o\,dB} \qquad \ldots(18)$$

Where:

- f_0 is the reference frequency f_0 = 900 MHz.
- m is an exponent varies with the frequency.

$$m = \begin{cases} 2 & for\ suburban\ and\ rural\ areas\ and\ f_c < 450 \\ 3 & for\ urban\ areas\ and\ f_c > 450 \end{cases} \qquad \ldots(19)$$

- F_o is the correction factor selected on the basis of a series of component factors according to Eq. (20)

$$F_o = \prod_{i=1}^{4} F_i \qquad \ldots(20)$$

Where the subsequent factors F_i are described by expressions below:

$$F_1 = \left(\frac{h_t}{30.5}\right)^2 \qquad \ldots(21)$$

$$F_2 = \left(\frac{h_m}{3}\right)^v \qquad \ldots(22)$$

The values of v are shown below:

$$v = \begin{cases} 1 & for\ \ h_m < 3 \\ 2 & for\ \ h_m < 10 \end{cases} \qquad \ldots(23)$$

$$F_3 = \frac{actual\ BTS\ antenna\ gain\ relative\ to\ a\ half\ wave\ dipole}{4} \qquad \ldots(24)$$

$$F_4 = actual\ MS\ antenna\ gain\ relative\ to\ a\ half\ wave\ dipole \qquad \ldots(25)$$

MEASUREMENT DATA

The received signal strengths were collected from four sectors, each sector illuminated by a directional antenna. The measurements were conducted in Karada, Baghdad Suburban areas. The streets widths were measured using Google-earth software. The mean building separation was calculated using the following equation [2].

$$b = \frac{w}{2} \qquad \ldots(26)$$

Where:

- B is the mean building seperation.
- W is the mean street width.

The mean buildings heights were calculated on the assumption that each buildings level is 3m height [2] as shown in table (1).

The measured data was collected with different roots and signal strength were recorded for the same distances at various locations in order to get averaging of signal strength for BTS1 and BTS2 as shown in Figures (1) , (3), (5) and (7). The field was examined as shown in Figures (2), (4), (6) and (8). The frequency band was in GSM 900 downlink (between 935 MHz and 960 MHz). The human body loss was imposed during testing when the mobile station was held by hand causes attenuation of 3dB through human body [9].

Due to building obstacles and high cochannel interference (because of frequency reuse), the measurements were only conducted for maximum radial distance of 1.25 km.

Path loss calculations

Path loss can be calculated via forward link (downlink), in which the transmission path is from the base transceiver station to the mobile station [10]:

$$PL(dB) = P_{TX} + G_{TX} - L_{TX} - P_{RX} + G_{RX} - L_{RX} - L_M \qquad \dots(27)$$

Where:

- PL is the path loss
- P_{RX} : is the received power.
- P_{TX} is the transmitter output power (dBm).
- G_{TX} : is the transmitter antenna gain = 16.5 dBi.
- L_{TX} : Are the transmitter losses = 5 dB.
- L_M : Are the miscellaneous losses (fading margin, body loss, other losses) = 3 dB.
- G_{RX} : is the receiver antenna gain = 0 dBi.
- L_{RX} : Are the receiver losses = 2 dB.

The calculated path loss were averaged every 100 m. The average path loss is drawn with distance as shown in Figures (9), (10), (11) and (12).

The path loss prediction models which are used here for comparison with the calculated path loss are Hata, Lee, W-I and FSPL. Figures (13), (14), (15) and (16) show the mean values of the calculated path loss and predicted path loss for different models against the distance between the BTS and the MS.

MODELS VALIDATION

The exact calculation for path loss is possible only for simple cases such as free space propagation [11]. For practical cases the path loss is calculated using variety of models and it is important to calculate which model serves better for the area of application. The Mean Squared Error [12] was calculated in order to estimate the better model for path loss prediction in Karada district and to decide the best model for optimization as shown below:

$$MSE = \sqrt{\frac{\sum (PL - P_{model})^2}{(N-1)}} \qquad \dots(28)$$

Where:

- *MSE* is the mean square error
- N Is the number of calculated data points.

Table (2) shows the MSE of each model prediction with the calculated oath loss. The MSE shows clearly that Hata model gives the smallest prediction error (MSE =10.46 dB) compared with other models, but the given results far inaccurate and need improvement. The reason of these differences is that each model was derived based on certain assumptions and these assumptions may change according to the area.

OPTIMIZATION PROCESS

From the presented results, it was conducted that certain corrections should be introduced into Hata model in order to improve its performance in Baghdad. It was suggested in [13] that the most appropriate tool for such optimization may be the well known statistical method of least squares.

The Hata model for suburban area equation may be written as shown below in Eq. (29) below:

$$PL_{Hata} = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_b) - C_H + [44.9 - 6.55 \log_{10}(h_b)] \log_{10}(d) \quad \ldots(29)$$

The Hata model as any other empirical prediction models contains three basic elements: initial offset parameter (E_o), initial system design (E_{sys}) and the parameter establishing the slope of model curve (β_{sys}) [13].

From Eq. (29) the three system parameters can be found by the following equations below:

1) E_o parameter is fixed for a given Hata model and expressed by Eq. (30) below:

$$E_o = 64.15 \quad \ldots(30)$$

2) E_{sys} parameter is dependent on system features. It is constant for a given system installation and expressed by Eq. (31).

$$E_{sys} = 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_b) - C_H - 2 [\log_{10}(\frac{fc}{28})]^2 \quad \ldots(31)$$

3) β_{sys} parameter is also a constant for a given system installation and expressed by Eq. (32)

$$\beta_{sys} = \beta[44.9 - 6.55 \log_{10}(h_b)] \quad \ldots(32)$$

For Hata the model optimization only two parameters might be relevant and sufficient: initial offset and slope of the curve. In the latter case, it would be most convenient way to adjust the overall slope parameter β in eq. (4.8), because of its appropriate placement in front of the expression [13].

Now the total path loss is given by Eq. (33):

$$PL_{Hata} = E_o + E_{sys} + \beta_{sys} \log_{10}(d) \quad \ldots(33)$$

The appropriate tool for optimization as it was mentioned is the statistical method of least squares (LS). The condition of best fit of theoretical curve with a given set of experimental points would be met if the function of sum of deviation squares is minimum [14].

$$P(a,b,c,\dots) = \sum_{i=1}^{N}[\,y_i - E_R\,(x_i,a,b,c,\dots)]^{\,2} \qquad \dots(34)$$

Where:

- y_i = measurement result at distance x_i .
- $E_R\,(x_i,a,b,c,\dots)$ = modeling result at the x_i based on optimization.
- a,b,c = Parameters of the model based on optimization.

For P to be minimum; the required conditions are:

$$\begin{cases} \frac{\partial P}{\partial a} = 0 \\ \frac{\partial P}{\partial b} = 0 \\ \frac{\partial P}{\partial c} = 0 \\ \dots \end{cases} \qquad \dots(35)$$

Solution of Eq. (35) can be simplified based on Equations (30), (31) and (32). Parameters of P function in Eq. (34) is expressed by Eqs. (36) and (37):

$$a = E_o + E_{sys} \qquad \dots(36),$$

$$b = \beta_{sys} \qquad \dots(37)$$

This would mean that the expression of Hata model in Eq. (29) transformed into:

$$PL_{Hata} = a + b\,log_{10}\,d \qquad \dots(38)$$

Further simplification may be achieved through the change of logarithmic base: $\log_{10} d = x$, then (38) becomes:

$$PL_{Hata} = a + b.\,x \qquad \dots(39)$$

From Eq. (38) both factors a and b are constants for a given system installation (transmitter and receiver), hence a and b are also constants for a given set of measurement. The solution of Eq. (35) may be expressed by:

$$\sum_{i=1}^{n}(\,y_i - E_R\,(x_i,a,b)).\frac{\partial E_R}{\partial a} = \sum(\,y_i - a - bx_i\,).1 = 0 \qquad \dots(40)$$

$$\sum_{i=1}^{n}(\,y_i - E_R\,(x_i,a,b)).\frac{\partial E_R}{\partial b} = \sum(\,y_i - a - bx_i\,).x_i = 0 \qquad \dots(41)$$

By repositioning of Eqs. (40) and (41) would provide the following expression:

$$n.a + b\sum x_i = \sum y_i \qquad \text{... (42)}$$

$$a\sum x_i + b\sum x_i^2 = \sum(x_i.y_i) \qquad \text{...(43)}$$

The solution of Eqs. (34) and (35) may be found by applying variable substitution method in Eqs. (42) and (43).

This would give the statistical estimation of parameters a and b:

$$\tilde{a} = \frac{\sum(x_i)^2.\sum y_i - \sum x_i.\sum x_i y_i}{n.\sum(x_i)^2 - (\sum x_i)^2} \qquad \text{... (44)}$$

$$\tilde{b} = \frac{n.\sum x_i y_i - \sum x_i.\sum y_i}{n.\sum(x_i)^2 - (\sum x_i)^2} \qquad \text{... (45)}$$

Where $\tilde{a}, \tilde{b}, \tilde{E}_o$ and $\tilde{\beta}$ are the mean values of a, b, E_o and β respectively.

Eqs. (44) and (45) allows a simple calculation of parameters a and b of Hata model Eq. (38) for a given set of experimental measurements. This leads to the offset and slope parameter in the original Hata model may be calculated from Eqs. (32), (36) and (37).

$$\tilde{E}_o = \tilde{a} - E_{sys} \qquad \text{... (46)}$$

$$\tilde{\beta} = \frac{\tilde{b}}{44.9 - 6.55.\log_{10} h_t} \qquad \text{... (47)}$$

After substituting measured data using Eq. (44), Eq. (45), Eq. (46) and Eq. (47), E_o = 54.36 and β = 0.887. These values allows for accurate prediction of path loss using Hata model with the modified empirical parameters.

RESULTS AND DISCUSSION

The calculated path loss using optimized Hata was plotted in Figures (17), (18), (19) and (20) with the path loss prediction models (Hata, W-I, Lee and FSPL) of each sector against the distance. It can be noted that the optimized Hata gave very good path predictions in according to original Hata. In general, the optimized model gave good results for distances above 800 m which are very important for interference consideration and for cell coverage calculation, since the cell coverage in Baghdad does not exceed 1 km of distance separation between the BTS and MS.

The MSE of optimized Hata were calculated and shown in Table (3), in Table (3) the impact of enhancement is clearly shown with 3.84dB difference between the original and optimized Hata.

CONCLUSIONS

In this research, the received signal strength of mobile communication system (GSM 900 band) was measured in Baghdad suburban areas. The calculated path loss was compared with known models in terms of relative error and MSE. Generally the Hata path loss model gave the closest predictions (the average relative error = 8.74% and the average MSE =10.80dB).

The obtained results from Hata model still have a lot of divergence from the actual path loss. This model was optimized using least squares in order to obtain better results. The results are better from the original Hata (the average relative error = 5.6% and the average MSE = 6.96 dB). According to the obtained results the optimized Hata model can be used to predict the signal strength of mobile phone due to BTS in Baghdad suburban area compared with other models. This model is useful for Iraq telecommunication providers to improve their service for better capacity and better mobile user satisfaction with low drop in calls inside the cells and during handoff process.

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Table (1): W-I extended parameters.

Sector	Mean building Height in meter	Mean buildings Separation in meter	Street Width in meter
1	12	60	30
2	9	20	10
3	9	20	10
4	9	20	10
Average	10	30	15

Table (2): MSE of prediction models.

	Hata	W-I	Lee	FSPL
Sector 1	13.61 dB	12.75 dB	12.16 dB	26.40 dB
Sector 2	7.93 dB	10.70 dB	17.41 dB	31.49 dB
Sector 3	9.19 dB	11.21 dB	19.81 dB	36.05 dB
Sector 4	12.48 dB	15.26 dB	13.23 dB	27.63 dB
Average	10.80 dB	12.48 dB	15.65 dB	30.39 dB

Table (3): MSE of optimized Hata and prediction models.

	Hata	W-I	Lee	FSPL	Optimized Hata
Sector 1	13.61 dB	12.75 dB	12.16 dB	26.40 dB	7.32 dB
Sector 2	7.93 dB	10.70 dB	17.41 dB	31.49 dB	4.70 dB
Sector 3	9.19 dB	11.21 dB	19.81 dB	36.05 dB	9.10 dB
Sector 4	12.48 dB	15.26 dB	13.23 dB	27.63 dB	6.73 dB
Average	10.80 dB	12.48 dB	15.65 dB	30.39 dB	6.96 dB

Figure (1): Sector 1 path measurements.

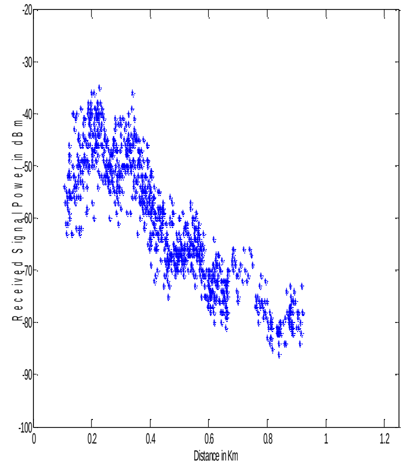

Figure (2): Practical measurements of received signal power at sector 1

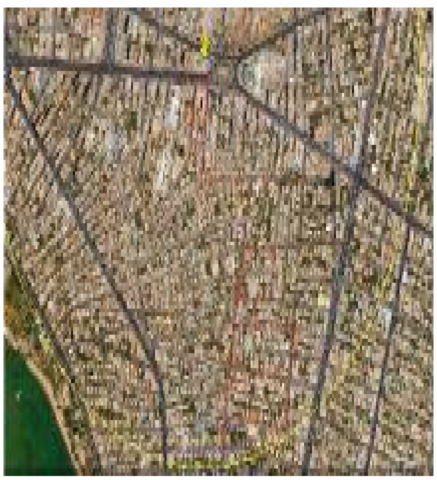

Figure (3): Sector 2 path measurements.

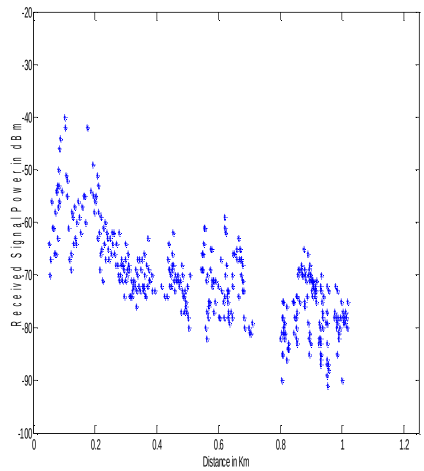

Figure (4): Practical measurements of received signal power at sector 2.

Figure (5): Sector 3 path measurements.

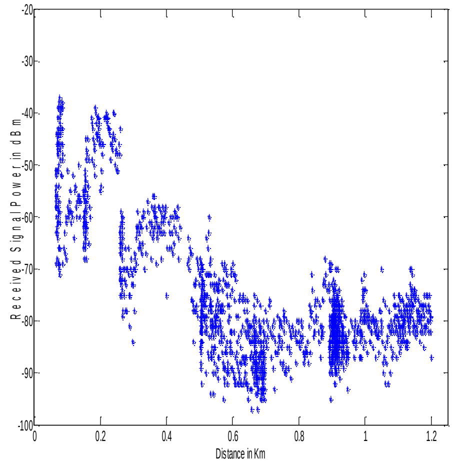

Figure (6): Practical measurements of received signal power at sector 3.

Figure (7): Sector 4 path measurements.

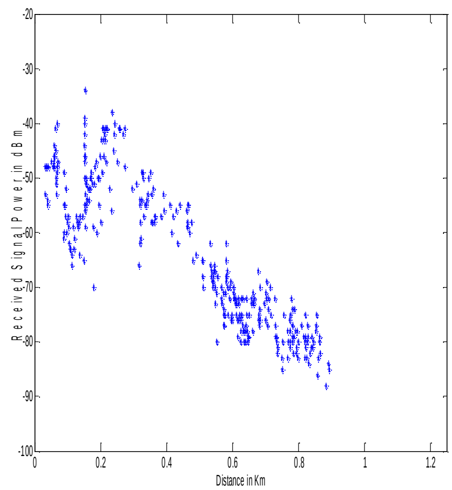

Figure (8): Practical measurements of received signal power at sector 4.

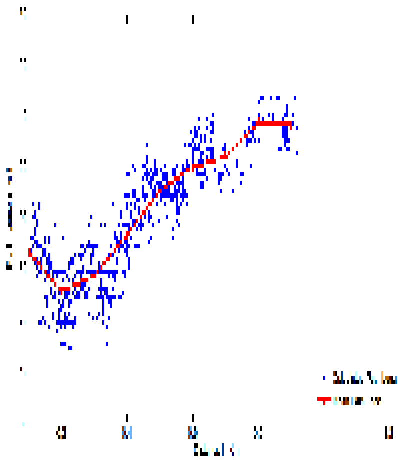

Figure (9): Calculation path loss of sector 1 according to practical received signal power.

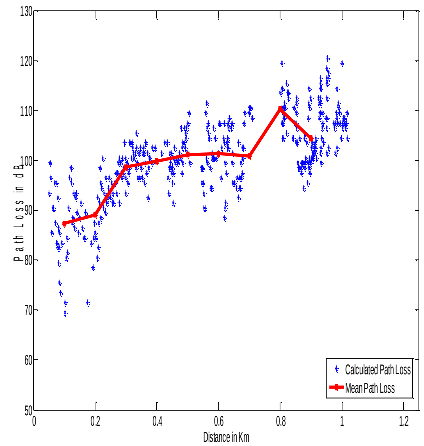

Figure (10): Calculation path loss of sector 2 according to practical received signal power.

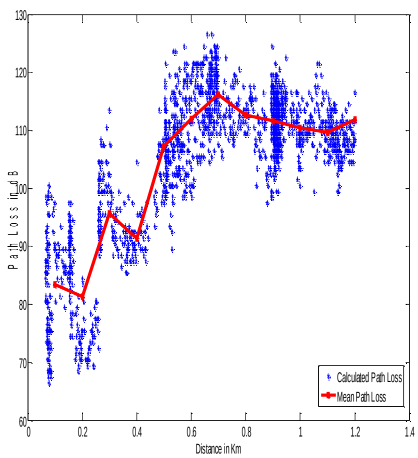

Figure (11): Calculation path loss of sector 3 according to practical received signal power.

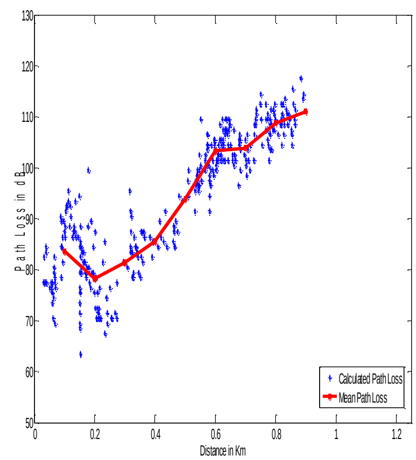

Figure (12): Calculation path loss of sector 4according to practical received signal power.

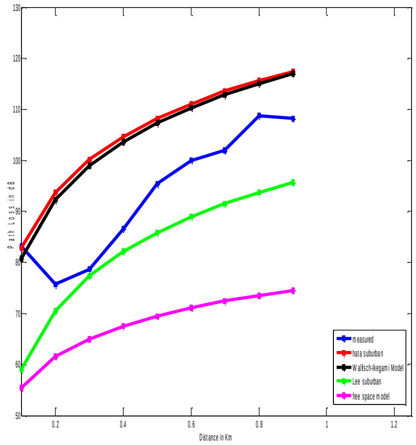

Figure (13): Mean path loss of Sector 1.

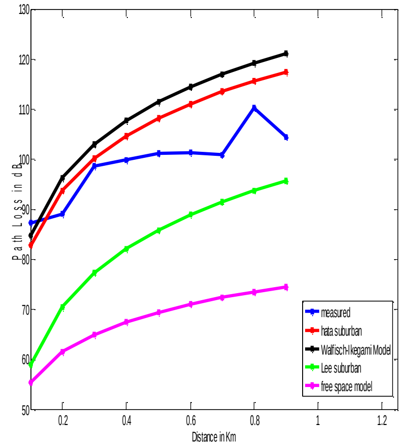

Figure (14): Mean path loss of Sector 2 .

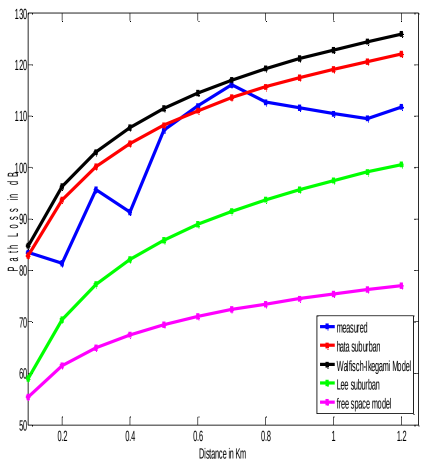

Figure (15): Mean path loss of Sector 3.

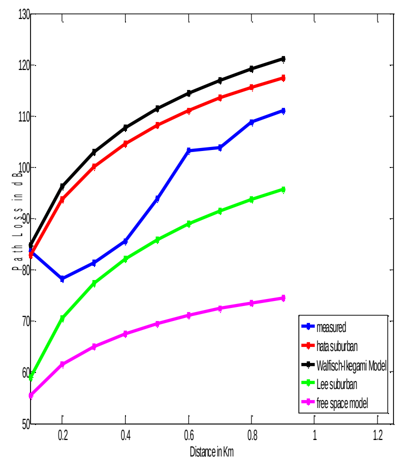

Figure (16): Mean path loss of Sector 4.

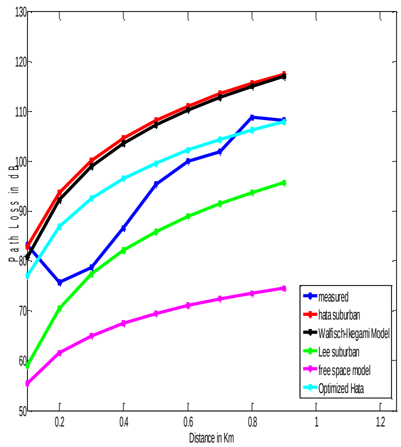

Figure (17): Sector 1 measure path loss VS prediction path loss by existing path loss models and optimized Hata path loss model.

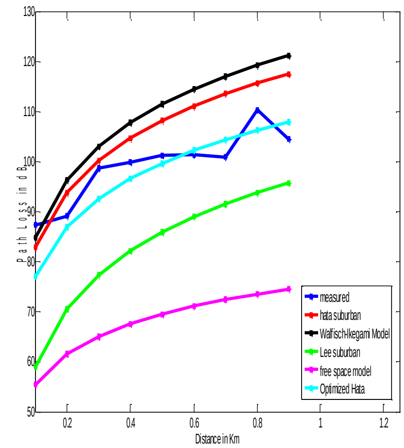

Figure (18): Sector 2 measure path loss VS prediction path loss by existing path loss models and optimized Hata path loss model.

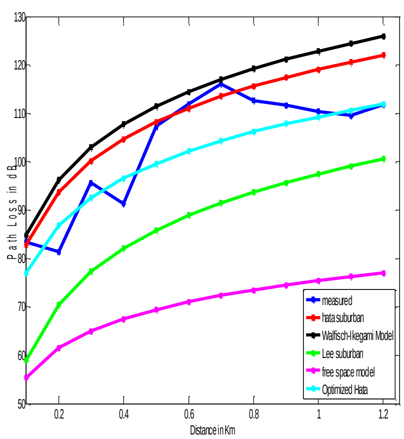

Figure (19): Sector 3 measure path loss VS prediction path loss by existing path loss models and optimized Hata path loss model.

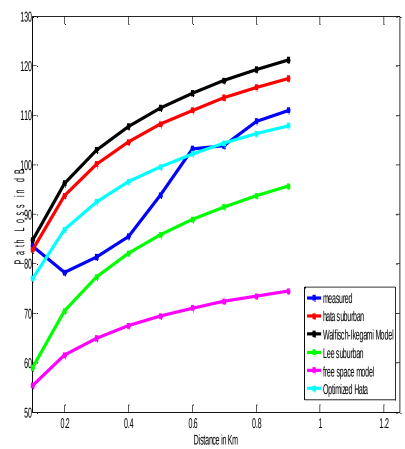

Figure (20): Sector 4 measure path loss VS prediction path loss by existing path loss models and optimized Hata path loss model.