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Statistical Tuning of the Best suited Prediction Model for Measurements made in Hyderabad City of Southern India

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Abstract— **The demand for increased mobile phone subscribers requires an efficient radio network planning that involves an accurate prediction of path loss. Although various empirical path loss models are in use, they are suitable for a particular environment or a specific cell radius. In this paper, GSM 900 MHz mobile signals that are recorded experimentally, for five base stations in Hyderabad city, are considered for path loss analysis. The measured path loss is determined from the collected field strength data. Three standard prediction models namely, Cost-231 Hata model, ECC-33 model and SUI model are implemented. Based on the comparison of measured and predicted path loss exponents, Cost-231 Hata model is identified as the best suited model. In order to improve the prediction accuracy, this model is statistically tuned using Least Square algorithm. The initial offset parameter and slope of the model curve in Cost-231 Hata model are considered for tuning and new model parameters are estimated. The performance of the tuned model is evaluated using mean square error, root mean square error, standard deviation and relative error. The error statistics are estimated for the tuned model as well as the prediction models. The tuned model gives a mean error of 1.294, root mean square error of 4.764, standard deviation of 4.29 and a relative error of 12.75%. The results show that the errors are least for the tuned Cost-231 Hata model, compared to the implemented empirical models. This successfully validates the tuning methodology and suggests that the tuned model is more accurate for the specified environment.**

Index Terms— **path loss model, path loss exponent, least square tuning algorithm, mean square error, relative error.**

I. INTRODUCTION

In mobile radio systems the obstacles between the base station and the mobile station significantly influences the strength of the mobile signal. The attenuation of the radio signal is referred as path loss. The path loss prediction models have a major role in the radio frequency coverage optimization, interference analysis and efficient utilization of the available network resources [1]. It is required to accurately estimate the channel characteristics in order to maintain the interference at a minimum level. Since the terrain conditions vary to a large extent, the path loss prediction models cannot be generalized. This drawback can be overcome by adjusting or tuning the model parameters to suit the desired environment. In this paper, the data collected experimentally at 900 MHz band for five base stations, located in the sub urban region of Hyderabad city (Southern India) are used for path loss analysis. The measured path loss exponent obtained from Linear Least Square regression fit is compared with the theoretical values predicted from the empirical models. Based on the relative error of the path loss exponents, Cost-231 Hata model is found to be the best suited path loss prediction model. The accuracy of this model is enhanced by tuning its parameters, in order to achieve minimum error between the predicted and the measured values. Although various tuning methods are available, a statistical tuning approach using Least Square (LS) algorithm is used to fit the Cost-231 Hata model parameters to the measured data [2,3]. Since the propagation environment where the measurements are taken, is fairly homogeneous, the statistical tuning method gives good prediction results. A comparative assessment of various errors between the tuned model and three standard empirical models, namely Cost-231 Hata model, ECC-33 model and SUI model are presented.

II. DATA COLLECTION AND PATH LOSS ANALYSIS

The experimental drive test was done over a radius of 2.5 Km, within the coverage area of the base stations. It is assumed that automatic handover occurs at adjacent base stations, when the signal strength is weak. The propagation medium around this region is categorized as sub urban, since it is scattered with trees, medium size buildings and few obstacles, without too much congestion [4].

A. Data collection

The data was collected while driving a car, having the experimental setup. It consists of GSM modem (Wavecom WM01-G900), a hand held (Global Positioning System) GPS receiver (ML250), a receiving antenna, and a laptop with a suitable interface. The car was driven within the coverage area of the base stations, while continuously recording the received signal strength. At all instants of the collected field strengths, the GPS data is also simultaneously recorded. The base station's information such as transmit or receive frequency, transmitted power, and antenna heights are obtained from Bharat Sanchar Nigam Limited (BSNL) for analysis purpose. With the help of GPS data, and

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knowing the location of base stations, the radial distances from the base station to any point on the route can be computed. The positions of the base stations are shown in Fig 1.

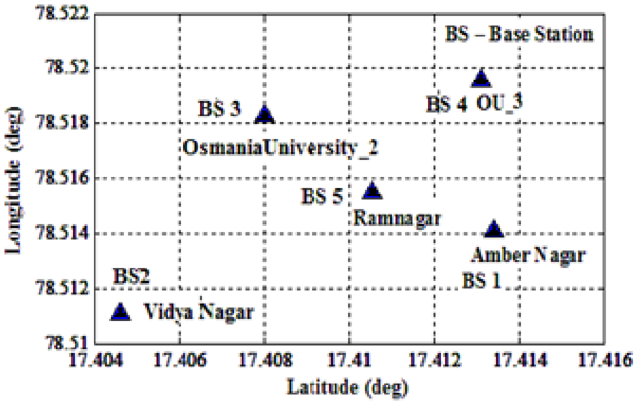

Fig 1 Locations of the base stations

B. *Determination of Measured Path Loss*

The average received signal strength obtained from GSM data sheets is used to determine the path loss. The measured path loss at any distance's' is given as

$$PL(d) = EIRP + G_m - MSS \tag{1}$$

$$EIRP = P_T + G_b - L_c \tag{2}$$

where $EIRP$ is the effective isotropic radiated power of the base station, G_m is the gain of the mobile station, MSS is the measured signal strength, P_T is the transmitted power of the base station, G_b is the gain of the base station and L_c is the antenna cable loss.

Least Square (LS) regression method is implemented on the collected data, so that the difference between the measured and predicted path loss is minimized in a mean square error sense. According to this method, the path loss at a given location with respect to path loss at a reference distance d_0 is given as [5],

$$\mathrm{PL(d) = PL(d0) + 10n\, log10(d/d0) + s} \tag{3}$$

where n is the measured path loss exponent, do is the reference distance (100 meters), s is the shadow fading term which ranges from 8.2 db and 10.6 db, and PL(do) is the free space path loss at reference distance do. It is given as

$$\mathrm{PL(do)} = 20\log 10\left(\frac{4\pi \mathrm{do}}{\lambda}\right) \tag{4}$$

The path loss exponent (n) is obtained from the slope of the measured path loss using Least Square fit. This value of path loss exponent is substituted in (3) and a least square regression curve is plotted. The Least Square curve indicates the measured path loss and is taken as the reference to evaluate the performance of the empirical models.

III. PATH LOSS PREDICTION MODELS

Three path loss propagation models are evaluated. They are Cost-231 Hata model, SUI channel model and ECC-33 model. These prediction models are selected, since they can easily fit into urban, sub urban or rural environment, by applying desired correction factors.

A. *Cost- 231 Hata model*

Hata-Okumura model developed by Hata is extended as Cost-231 Hata model [6]. Cost- 231 Hata model is given as,

$$PL(dB) = 46.3 + 33.9\, log_{10}(f) - 13.82\, log_{10}(\, log_{10}(h_b) - ah_m + \left(44.9 - 6.55(\, log_{10}(h_b)\right) log_{10}(d) + c_m \tag{5}$$

where f is the frequency in MHz, d *is* the distance between the base station and mobile station in Km, h_b is the antenna height of the base station in meters. The correction parameter ah_m is defined for urban and suburban environments as per (6) and (7).

$$ah_m = 3.2\,(log_{10}(\,11.75\ h_r\,))^2 - 4.97 \tag{6}$$

$$ah_m = (\,1.11\, log_{10}(f) - 0.7)h_r - (\,1.56\, log_{10}(f) - 0.8) \tag{7}$$

where h_r is the height of the mobile station antenna in meters
The correction parameter c_m is given as $c_{m\,(urban)} = 3$db and $c_{m\,(suburban)} = 0$ db.

$$n_{cost-231\,Hata} = \left(44.9 - 6.55\, log_{10}(\,h_b\,)\right)/10 \tag{8}$$

The theoretical path loss exponent for Cost-231 Hata model is given in (8). In this paper the feasibility of Cost-231 Hata model is checked for 900 MHz frequency band, for the sub urban region, with receiving antenna height of 1.5 meters.

B. *Stanford University Interim Path Loss Model*

Stanford University Interim (SUI) channel model is developed for IEEE 802.16 broadband wireless access working group based on research results of Stanford University [6]. This model covers three common terrain categories. Category A is the maximum path-loss category, which represents a hilly terrain with moderate to heavy tree densities. Category B is the intermediate path-loss category suitable for flat terrains. The minimum path-loss category for flat terrains with less tree densities is Category C. The basic path loss equation for SUI model with correction factors is given in [5], [6] as,

$$L = A + 10\gamma \log\left(d / d_o\right) + \Delta L_f + \Delta L_h \tag{9}$$

d is the distance between the base station and mobile station (m), d_o=100m, γ is the path-loss exponent, ΔL_f is the correction factor for the frequency, ΔL_h is the correction factor for the receiver antenna height and s is the log normally distributed shadow factor due to the trees and other obstacles, having a value between 8.2 dB and 10.6 dB [6]. The term A, the path loss exponent and the correction factors in the above equation are given as

$$A = 20\log\left(4\pi d_o / \lambda\right) \tag{10}$$

$$\gamma = a - bh_b + c / h_b \tag{11}$$

$$\Delta L_f = 6\log(\,f / 2000\,) \tag{12}$$

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$$\Delta L_h = \begin{cases} -10.8\log(h_r/2), & \text{Categories A,B} \\ -20\log(h_r/2), & \text{Category C} \end{cases} \quad (13)$$

where λ is the wavelength (m), f is the frequency (MHz), h_b is the height (m) of the base station h_r is the height (m) of the receiving antenna. The parameters a, b and c are standard values that depend on the type of terrain. Since the terrain is categorized as suburban, an intermediate path loss (Category B) is chosen for analysis.

C. ECC-33 Model or Hata-Okumura extended model

ECC-33 path loss model, developed by Electronic Communication Committee (ECC), extrapolated the original measurements by Okumura and modified its assumptions [7]. In this model path loss equation is defined as

$$PL = A_{fs} + A_{bm} - G_b - G_r \quad (14)$$

where A_{fs} is the free space attenuation, A_{bm} is the basic median path loss, G_b is the transmitter antenna height gain factor and G_r is the receiver antenna height gain factor[7,8]. These factors are given as

$$A_{fs} = 92.4 + 20log_{10}(d) + 20log_{10}(f) \quad (15)$$

$$A_{bm} = 20.41 + 9.83\, log_{10}(d) + 7.894\, log_{10}(f) + 9.56\ [log_{10}(f)]^2 \quad (16)$$

$$G_b = log_{10}\left(\frac{h_b}{200}\right)(13.958 + 5.8[log_{10}(d)]\, 2) \quad (17)$$

For medium city environment we have

$$G_r = [42.57 + 13.7\, log_{10}(f)]\,[log_{10}(h_r) - 0.585] \quad (18)$$

where, h_b is the height of the base station in meters, f is the frequency in GHz, h_r is the height of receiving antenna in meters and 'd' is the distance between transmitter and receiver in Km. The path loss exponent for the ECC model, is evaluated by taking the path loss gradient at 2 Km [9].

IV. LEAST SQUARE TUNING OF THE BEST SUITED PREDICTION MODEL

The tuning of a model is a process in which the parameters of the theoretical propagation model are adjusted with the help of measured values obtained from the experimental data. In this process several model parameters can be changed. The objective of tuning is to obtain the values of the predicted model parameters to have a closest match with the experimentally measured data [10]. This paper implements the linear Least Square method to fit the measurement data with Cost- 231 Hata model.

A. Least Square Tuning of Cost-231 Hata model

The Least Square method is a statistical tuning approach, in which all the environmental influences are implicitly considered. The Cost-231 Hata model as given in (5) consists of three basic elements [11]. This can be written as (19), (20) and (21).

$$E_o = 46.3 - ah_m + c_m \quad (19)$$

$$E_{sys} = 33.9\, log_{10}(f) - 13.82\, log_{10}(\, log_{10}(h_b)) \quad (20)$$

$$\beta_{sys} = (44.9 - 6.55(\, log_{10}(h_b))\, log_{10}(d) \quad (21)$$

where E_0 is the initial offset parameter, β_{sys} is the slope of the model curve and Esys is the initial system design parameter. The total path loss given in (5) is written as

$$PL(dB) = E_o + E_{sys} + \beta_{sys} \quad (22)$$

Equation (22) may be expressed as

$$a = Eo + E_{sys}\ ;\ b = \beta_{sys} \quad (23)$$

The expression of the Cost-231 Hata model in (5) is rewritten as

$$P_r = a + b\,.log\, R$$

Simplified logarithm base log R = x then the above equation becomes

$$P_r = a + b\,.x \quad (24)$$

P_r is the model predicted path loss in decibels. The parameters 'a' and 'b' are constant for a given set of measured values. Tuning of Cost-231 Hata model is done by considering the parameters E_o, E_{sys} and β_{sys}. As per the least square algorithm, the condition for the best fit of a theoretical model curve with a given set of experimental data is satisfied, if the function of sum of deviation squares is minimum as given below.

$$E(a, b, c \dots) = \sum_{i=1}^{n}[y_i - P_{R,i}\,(x_i a, b, c, \dots)]^2 = \min \quad (25)$$

y_i = experimentally measured values of path loss at the distance x_i;
$P_{R,i}\,(x_i a, b, c, \dots)$ = model predicted path loss values at distance x_i based on tuning;
a, b, c ,= parameters of the model based on tuning.
n = number of experiment data set.
The error function $E(a, b, c \dots)$ must be least. To ensure this all partial differential of the E function should be equal to zeros.

$\partial E/\partial a = 0$;
$\partial E/\partial b = 0$;
$\partial E/\partial c = 0$; (26)

The solution of (26) may be expressed as

$$\left(\sum_{i=1}^{n}\left(y_i - P_R(x_i, a, b, c)\right)\frac{\partial P_R}{\partial a}\right) = \sum(y_i - a - bx_i)\,.1 = 0$$

$$\left(\sum_{i=1}^{n}\left(y_i - P_R(x_i, a, b, c)\right)\frac{\partial P_R}{\partial b}\right) = \sum(y_i - a - bx_i)\,.\,x_i = 0$$

By re-positioning the elements in the above equations, it results in the following expressions

$$n\,.a + b\sum x_i = \sum y_i; \quad (27)$$

$$a\sum x_i + b\sum x_i^2 = \sum(x_i\,.y_i); \quad (28)$$

By substituting the variables *a* and *b* into (27) and (28), the tuned statistical estimates of parameters *a* and b are given as

$$\tilde{a} = \frac{\sum x_i^2\,.\,\sum y_i - \sum x_i\,.\sum x_i y_i}{n\,.\sum x_i^2 - (\sum x_i)^2}\ ;\ \tilde{b} = \frac{n\,.\sum x_i y_i - \sum x_i.\sum y_i}{n\,.\sum x_i^2 - (\sum x_i)^2} \quad (29)$$

The tuned statistical estimates $\tilde{a}$ and $\tilde{b}$ are substituted in the equations of the original Cost-231 Hata model and the tuned values of initial offset parameter and slope of the model curve are obtained as per (30) [12]

$$E_{0\,new} = \tilde{a} - E_{sys}; \quad \beta_{\text{sys new}} = \frac{\tilde{b}}{44.9 - 6.55\,.log\, h_{te}} \qquad (30)$$

By substituting the measurement data using (29) and (30) the values $E_{0\,new}$ and $\beta_{\text{sys new}}$ are computed for five base stations, and the values are tabulated in Table IV. This statistical tuning approach has a good computational efficiency and gives fairly good prediction results for homogeneous environments [13].

B. Performance metrics to validate the tuned results

The performance of the optimized model is evaluated by error analysis. The four error metrics employed are, Mean Square Error (MSE) ρ, Root Mean Square Error (RMSE), standard deviation of error 'σ' and relative error 'δ' [14]. They are defined as follows: The mean square error ρ, is the difference between the measured path loss (y_i) at a distance i and the model predicted path loss ($P_{R,i}$) and is given by

$$\rho = \frac{1}{n} \sum_{i=1}^{n} |y_i - P_{R,i}| \qquad (31)$$

'n' indicates the number of data samples.
The root mean square error is given as

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (|y_i - P_{R,i}|)^2} \qquad (32)$$

The standard deviation of error is

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (|y_i - P_{R,i}| - \text{Prediction error})^2} \qquad (33)$$

The relative error in percentage is defined as

$$\delta = [(PL_{measured} - PL_{model}) / PL_{measured}]100 \quad (34)$$

where $PL_{measured}$ is the measured path loss obtained from LS and PL_{model} is the path loss predicted from the empirical models. The measured path losses are compared with the prediction models and tuned Cost-231 Hata model.

V. RESULTS AND DISCUSSION

This paper estimates the path loss of the mobile signals for the suburban region in Hyderabad city, by analyzing the GSM 900 MHz signals recorded experimentally in kinematic mode. The path loss predictions are made using Cost-231 Hata model, SUI model and ECC-33 model. The measured path loss exponent is obtained using linear regression fit. By comparing the measured and theoretical path loss exponents, Cost-231 Hata model is found to be the best suited prediction model. In order to have better prediction accuracy, the parameters of this model are adjusted or tuned using Least Square tuning algorithm. Four error metrics are used to validate the tuned results.

A. Implementation of path loss models

The measured path loss is extracted from the received field strength obtained from the drive test. Fig 2 shows the scatter plot of the experimentally determined path loss. The straight line represents the least square linear regression fit. The slope of the linear line gives the measured path loss exponent as 3.12. This value justifies that the region considered for path loss analysis is a shadowed sub urban area. The statistics of the measured path loss are given in Table I.

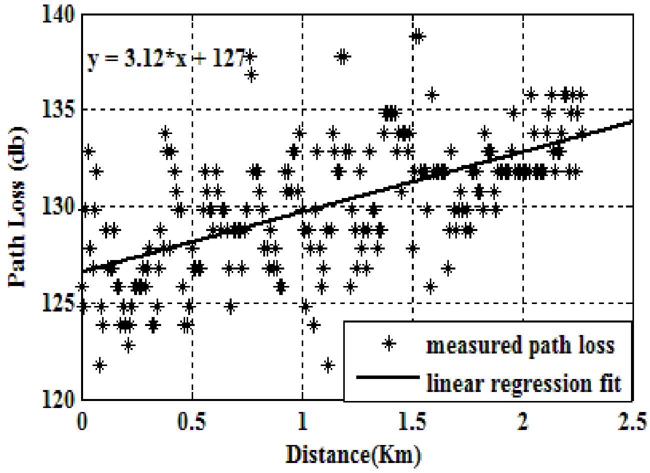

Fig.2 Scatter plot of the measured path loss with linear regression fit.

Table I
Statistics of experimentally measured path loss

min	max	mean	median	standard deviation
121	138	130	129.8	3.401

Knowing the measured path loss exponent, the least square method is implemented and path loss is plotted as a least square curve. This curve is used as a reference for comparison with prediction models. The measured path loss and predicted values are plotted against distance on the same graph. The reference distance is taken as 100 meters. Fig 3 shows the measured and predicted path loss curves for BS1.

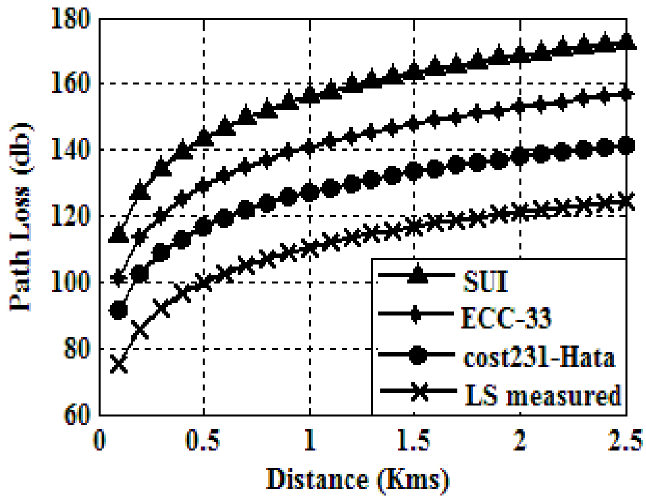

Fig 3 Comparison of measured and predicted path loss for BS1

It is observed that path loss estimated by Cost-231 Hata model matches with the measured path loss in a much better way, compared to other prediction models. The ECC-33 model and SUI model over estimate the path loss. Similar results are observed for other base stations.

B. Selection of best path loss prediction model for Tuning

It is required to identify the best prediction model, so that this model can be tuned to achieve minimum error with the measured data. The path loss exponents computed for the prediction models of the five base stations are tabulated in Table II.

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Table II.
Computation of path loss exponents

Base stations	Cost 231 Hata model	ECC model	SUI model
BS1	3.53	4.11	4.31
BS2	3.58	3.97	4.31
BS3	3.52	3.93	4.11
BS4	3.53	4.10	4.29
BS5	3.65	4.16	4.55
Average	**3.56**	**4.05**	**4.31**

In order to estimate the best suited model, relative errors are computed between the measured and predicted path loss exponent. From the results of Table III it is observed that the average relative error for Cost-231 Hata model is the least, compared to other models. This indicates that path loss is best predicted by Cost-231 Hata model. Based on this result, Cost-231 Hata model is selected as the suitable model for tuning process.

Table III
Comparison of measured and theoretical path loss exponents

Path Loss models	**Path loss exponents**	**Average relative errors (δ_{error})**
LS regression (measured)	3.12	
COST – 231Hata model	3.56	14.10%
ECC-33 model	4.05	29.80%
SUI model	**4.31**	**38.14%**

C. Tuning of Cost-231 Hata model and its Validation

The initial offset parameter (E_0) and the slope (β_{sys}) parameters of the original Cost-231 Hata model are considered for the tuning process. With the help of the measured data, using Least Square tuning algorithm the optimized values of E_0 and β_{sys} are computed for the BCCH frequencies of different base stations. The tuned parameters are tabulated in Table IV. These parameters are substituted in the original Cost-231 Hata model and path loss is estimated for the tuned model. The tuned and predicted models for BS1 are shown in Fig 4.

Table IV
Tuned Parameters of Cost-231 Hata model

BS No	BCCH Frequency (MHz)	Trx antenna height (mts)	Tuned Parameters of Cost-231 Hata model	
			Eo_{new}	$\beta_{sys\ new}$
BS1	950.6	30	29.501	0.01582
BS2	949.8	24	29.708	0.01566
BS3	948.2	21	29.948	0.01555
BS4	951.0	30	29.948	0.01545
BS5	949.2	19	29.346	0.01594
Average			29.690	0.01572

D. Performance evaluation of the tuned model

The measured path losses are compared with tuned Cost-231 Hata model, original Cost-231 Hata model, ECC-33 model and SUI model. The metrics used for comparison are mean square error, root mean square error, standard deviation of error and relative error. The errors are computed for distances ranging from 100m to 2.5 Km for different base stations. The receiver antenna height is 1.5 meters. The measured data size is 200 samples. The results of error metrics are tabulated in Tables V, VI, VII, and VIII.

Table V
Comparison of mean square error

Base Stations	Tuned Cost 231 model	Cost 231 model	ECC model	SUI model
	MSE	MSE	MSE	MSE
BS1	1.3229	2.2002	2.3495	4.3608
BS2	1.2895	2.2598	2.3023	4.0353
BS3	1.2552	2.1600	2.4207	3.7020
BS4	1.2548	2.1600	2.4255	3.7013
BS5	1.3520	2.1192	2.4189	4.6401
Average	1.2949	2.1798	2.3834	4.0879

Table VI
Comparison of root mean square error

Base Stations	Tuned Cost 231 model	Cost 231 model	ECC model	SUI model
	RMSE	RMSE	RMSE	RMSE
BS1	4.7844	7.2417	7.8789	13.0556
BS2	4.7494	6.9774	8.0823	12.1055
BS3	4.7318	6.6771	8.3251	11.1276
BS4	4.7339	6.6771	8.3364	11.1255
BS5	4.8226	7.4421	7.7205	13.8434
Average	4.7644	7.0031	8.0686	12.2515

Table VII
Comparison of standard deviation of error

Base Stations	Tuned Cost 231 model	Cost 231 model	ECC Model	SUI model
	std	std	std	std
BS1	4.2981	6.8157	7.3062	12.6150
BS2	4.2801	6.5629	7.5057	11.6770
BS3	4.2807	6.2743	7.7440	10.7114
BS4	4.2831	6.2744	7.7549	10.7095
BS5	4.3216	7.0058	7.1508	13.3914
Average	4.2927	6.5866	7.4923	11.8209

Table VIII
Comparison of relative error

Base Stations	Tuned Cost 231 model	Cost 231 model	ECC model	SUI model
	(%)	(%)	(%)	(%)
BS1	12.81	13.02	23.55	38.06
BS2	12.78	13.62	23.52	36.58
BS3	12.82	14.32	23.49	35.12
BS4	12.81	14.35	23.52	35.14
BS5	12.54	12.81	23.55	39.29
Average	12.75	13.62	23.52	36.83

The results indicate that the error statistics are least for the tuned model compared to other predicted models. The average mean square error is 1.2949 for the tuned model, where as it is 2.1798 for Cost-231 Hata model, 2.3834 for ECC-33 model and 4.0879 for SUI model. The average standard deviation of error for the tuned Cost-231 model is 4.2927, which is lesser than standard Cost-231 model. As a result of tuning, the relative error is reduced than the best predicted model. From the above results it can be concluded that the tuned Cost-231 model gives the best performance, for the specified sub urban region.

VI. CONCLUSION

The highlight of this paper is to obtain the tuned parameters of the best suited path loss prediction model, for GSM 900 MHz signals recorded in the sub urban region of Hyderabad city (Southern India). The measured path loss is obtained from experimentally collected field strength data. Three existing path loss models, such as Cost-231 Hata model, ECC-33 model and SUI model are used to predict the path loss. The path loss and path loss exponents of the measured and predicted models are discussed. Based on the closest match with measured path loss exponent, Cost-231 Hata model is identified as the best suited model. The parameters of this model are tuned by implementing Least Square tuning algorithm. The tuned model is compared with original Cost-231 Hata model and other prediction models in terms of mean square error, $RMSE$, standard deviation of error and relative error. From the overall error analysis, it is observed that, the performance of the tuned model is the best, since it gives the least error. This indicates that the path loss predicted by the tuned model is more accurate, compared to Cost-231 Hata model and other implemented prediction models.

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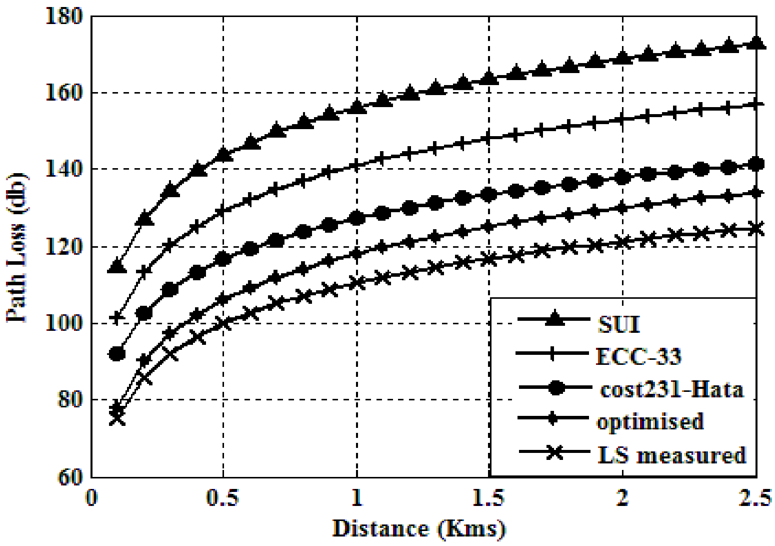

Fig.4 Optimized and predicted models for BS1

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Modified on 2013/10/3

ON THE SECOND PAGE OF THE FIRST COLUMN, AFTER EQUATION (2) AT THE FOURTH LINE, IT IS GIVEN AS " GB IS THE GAIN OF THE MOBILE STATION " . ONLY THE WORD MOBILE IS REPLACED WITH BASE.

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