EVALUATION OF CELLULAR PREDICTION MODELS USING 900 MHz OUTDOOR MEASUREMENTS AND TUNING OF LEE MODEL OVER INDIAN URBAN & SUBURBAN REGIONS

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Abstract:

The present study reports the field strength measurements of some GSM transmitters in the 900 MHz band located in the urban and suburban regions of Delhi in India. The measured signal levels converted into path loss values have been compared with the losses predicted from models like Hata, Lee and COST 231 Walfisch & Ikegami. The prediction errors and standard deviations of the predictions errors have been deduced. Based on these results, Lee prediction method has been tuned and new model parameters have been derived. The model comparison is done in terms of statistical parameters like, root mean square error, coefficient of determination and average hit rate error.

Key words: 900 MHz measurements, path loss modeling, Lee model tuning

1 Introduction

Due to the rapid developments in cellular communication over this country and the pace with which the cellular data base is increasing, the standard 900 and 1800 MHz spectral bands are becoming increasingly congested with the demands of more frequency allocation by many operators. An efficient spectral allocation requires the testing of

various prediction methods. The evaluation of the prediction methods also helps to determine the interference levels and help in electromagnetic interference and compatibility studies. The 3G communication systems ready to be launched at any time in the country also require good field trials and identification of coverage prediction methods. In the past measurements in the 800/900 MHz band have been reported by workers [1] and they tried to explain the extensive field results through theoretical analysis and modeling of the physical phenomena. Some of the well known mobile operators utilized calibrated statistical models for coverage and planning purposes derived from Okumara-Hata model [2-3]. Vieira et al [4] extensively discussed the re-farming of 900 MHz band into HSPA and LTE and stressed the importance of this band for rural mobile broadband applications. The Lee propagation model has been recognized by the wireless industry as one of the most accurate propagation model in the 900 MHz band [5] wherein the authors Lee & Lee discussed several innovative and revolutionary approaches that can better handle issues created by rough terrain sampling data.

The special feature in Delhi urban environment is most of the buildings are non uniformly spaced and results reported elsewhere might not be totally applicable to this type of environment. With this background and to evaluate the suitability of the existing models, field strength measurements were conducted in the 900 MHz band utilizing the following GSM base stations situated in national capital region of Delhi. They are 1.Paschimvihar (PVR) 2. University Area (UA) 3. Nandanagari -1 (NN-1).   4. Nandanagari- 2 (NN-2)   5. Satyaniketan (SNT) 6. Faridabad (FBD) 7. Vinayak Hospital (VKH) and three suburban base stations namely 1. Tradex tower (TXT), 2. Meethapur (MPR) 3. Gurgaon (GRN). All the base stations shown on google earth map

are in figure 1 and figures 2a-2c show the map depicting the measurement route for three base stations. These have been incorporated to get a feel of the environment for the reader. The measured values of signal strength have been compared with the following prediction methods 1. Hata [4] 2. Lee [5-6] 3. COST 231 Walfisch & Ikegami [7]. The models have been chosen so that they are applicable to the environments where measurements were conducted. An attempt is also made to tune the Lee method based on the measured values. This type of work is the first of its kind from this region of the world.

2 Environmental descriptions

Both the NN-1 and NN-2 base stations are surrounded by dense urban areas on three sides and medium urban environment on the other side. The average building height is around 6 to 9 m. PVR base station is surrounded by medium urban environment with slight open areas in between. Far away from the base station on the left side low tree density is seen. On the southern side of the base station a small water canal flows. UA base station is surrounded by medium urban environment and from east to south of the base station a thick patch of tree density is seen. At distances 2 km away from the base station dense urban environment prevails on the southern side of the base station. MPR base station is surrounded by low density urban area (mainly suburban) and small patches of green vegetation in between. SNT base station is surrounded by medium urban environment and small patches of greenery in between denoting some kind of low urban residential environment. Clutter features of NN-1 and UA base station are shown in figures 3 and 4 to get a glimpse of measurement sites.

3 Experimental details

The specifications are shown in Table 1. In table 1 after the base station acronyms, the transmitting power in dBm and transmitting antenna gain in dBi are shown in brackets. H_b denotes the height of the base station antenna above ground. The receiver is standard Nokia equipment used in drive in tools for field trials. The position of the mobile is determined from the GPS receiver and this information with the co-ordinates of the base station was utilized to deduce the distance traveled by the mobile from the base station. The signal strength information recorded in dBm was converted into path loss values utilizing the gains of the antenna. Field strength samples recorded along a route must be properly managed to obtain statistics that represent accurate mean values of received field strength level. The Lee method [10-11] is the reference technique to determine the local mean values of the signal measured in movement. This technique is recommended by International organizations ITU-R[12] and CEPT[13]. A generalized method for a wider use was defined in [14]. Both methods define three parameters to be considered for an accurate estimation of field strength mean values along a route: the minimum number of equally-spaced samples that must be considered in the average, the minimum distance between uncorrelated samples and the appropriate distance that must be used in the sample averaging. The data was recorded with 512 samples in one second on a laptop and the number of samples collected in the present study varied from 1×10^5 to 2×10^5 . Hence all the samples provide representative field strength mean value. Measured r.m.s. error is 1.5 dB. Data was averaged over conventional figure of 40λ.

4 Methodology of study

In the present study observed field strength values have been converted into path loss values as a function of distance and compared with various empirical models like Hata, Lee and COST 231 Walfisch & Ikegami. The comparison is shown in figures for some typical base stations in the

section on results. From this comparison deviation of the models have been deduced. Also from

the observed values of path loss values, path loss exponents have been deduced as a function of

distance. From the prediction errors statistical parameters like RMSE, R^2 and AHRE have been

deduced to evaluate the suitability of the models. These are described in detail in the subsequent

sections. Based on these results an attempt is made to tune the Lee method and methodology of

tuning along with the discussion of tuned results has been presented. The statistical parameters of

tuned Lee method have been compared with Hata and COST 231 Walfisch-Ikegami methods.

Also brief description of the models is shown below

4.1 Brief description of the prediction models: The three models used in this study are briefly

described. Complete details can be had from the references.

 Hata Method: Okumara's prediction of median path loss[8] are usually calculated using

Hata's approximations as follows[6].

$$L(dB) = A + B \log R - E \text{ for urban areas}$$

$$= A + B \log R - C \text{ for suburban areas} \qquad (1)$$

$$= A + B \log R - D \text{ for open areas}$$

Where $A = 69.55 + 26.16 \log f - 13.82 \log h_b$,

$B = 44.9 - 6.55 \log h_b$, $C = 2 (\log (f_c/28))^2 + 5.4$

$D = 4.78(\log f_c)^2 + 18.33 \log f_c + 40.94$

$E = 3.2 (\log(11.75 h_m))^2 - 4.97$ for large cities , $f_c \geq 300$ MHz

$E = 8.29 (\log (1.54 h_m))^2 - 1.1$ for large cities, $f_c < 300$ MHz

$E = (1.1 *\log(f_c)-0.7) h_m - (1.56*\log(f_c)-0.8)$ for medium to small cities

f= Operating frequency in MHz , h_b= Effective height of Transmitting antenna in meter h_m= Effective height of mobile antenna in meters, R = distance from transmitter in km. The model is used for distances starting from one km onwards.

Lee Method: The Lee area to area model is given by

$$L \text{ (dB)} = L_0 + \gamma \text{ Log (d)} - 10 \log (F_0) \qquad (2)$$

where L represents the   path loss value at a given distance, L_0 is a median path loss at 1 km distance, γ is the slope of the path loss curve and F_0 is the adjustment factor comprised of several factors, $F_0 = F_1 F_2 F_3 F_4 F_5$ which have been explained in the original Lee papers.

COST 231 WALFISCH-IKEGAMI METHOD

In the non-LOS case the basic transmission loss comprises the free space path loss L_B the multiple screen diffraction loss L_{msd} and the rooftop to street diffraction and scatter loss L_{rts} . Thus the path loss L_b in non LOS is defined as

$$L_b = \begin{cases} L_B + L_{rts} + L_{msd} & L_{rts} + L_{msd} > 0 \\ L_B & L_{rts} + L_{msd} < 0 \end{cases} \qquad (3)$$

The determination of L_{rts} is based on the principle given in the Ikegami model, but with a different street orientation function .The values of L_{rts} are as follows

$$L_{rts} = -16.9 - 10\log_{10} w + 10\log_{10} f_{MHz} + 20\log_{10}(h - h_m) + L_{ori} \quad (4)$$

where w, h and h_m are gap between buildings, height of building and height of mobile stations respectively.

$$L_{ori} = \begin{cases} -10 + 0.354\psi & 0^0 \le \psi < 35^0 \\ 2.5 + 0.075(\psi - 35) & 35^0 \le \psi < 55^0 \\ 4.0 - 0.114(\psi - 55) & 55^0 \le \psi < 90^0 \end{cases} \qquad (5)$$

where L_{ori} is a factor which has been estimated from only a small number of measurements, ψ is street orientation angle.

The multiple screen diffraction loss was estimated by Walfisch and Bertoni for the case when the base station antenna is above the rooftops i.e. $h_b > h$. This has also been extended by COST to the case when the antenna is below rooftop height, using an empirical function based on measurements.

5 Results & Discussion

The observed signal levels have been converted into path losses and compared with path losses predicted from Hata, Lee and COST 231 Walfisch & Ikegami methods. Some typical figures of path loss comparison with the above prediction methods along with variation of path loss exponents with distance are shown in figures 5-10 for NN-1 and UA and PVR base stations. Figures 5,7 and 9 show the comparison of observed path loss with the above prediction methods for NN-1, UA and PVR base stations and figures 6, 8 and 10 show the corresponding variation of path loss exponents. In figure 5 observed path loss at distances close to the transmitter varies from 80 to 130 dB and beyond 1km is confined between 120 and 140 dB. In figure 7 for UA base station at closer distances the variation of path loss is 80 to 120 dB and at larger distances the variation is 110 to 140 dB. Here the path loss is plotted up to distances of 2.5 km. In figure 9 the path loss at distances below 500m varies substantially and at later distances it is confined between 110 to 145 dB. Figure 6 shows the variation of path loss exponent with distance for NN-1 base station. At distances very close to the transmitter exponent of 8 is seen and falls steeply to a value of 2.5 at a distance of 200 m and then varies between 3.0 and 4.0 for the remaining distances of 1.6 km. In figure 8 also the exponent also falls from 8 to 2.5 at a distance of 400 m and then gets confined between 2.5 and 4.0 for the remaining distances. In figure 10 also the path loss exponent falls steeply from 8 to 3.5 around 300m and thereafter remains stable for the remaining distances.

The path loss exponent shown in figures 6 and 8 has been deduced based on the following methodology. Path loss exponents from the data have been deduced from the equation 1 shown below using the observed path losses for various distances and L_0 depicting the path loss at one meter distance.

$$L = L_0 + 10 \, n \, \log d \ + S \qquad\qquad (6)$$

Where L is the path loss deduced for various distances, L_0 is the path loss at one meter and d is the distance in meters; S is the shadow fading in dB. Using the approach given in reference [15] of Erceg et al., the path loss exponent n has been deduced. In the above equation $L_0 = 20 \log (4\prod d_0/\lambda)$ where λ is the wavelength corresponding to 900 MHz and d_0 is taken as one meter. S is the shadow fading variation and varies from location to another within given macrocell. It tends to be Gaussian in a given macro cell denoting shadow fading as lognormal. It can be expressed as $s = y \, \sigma$, where y is a zero mean Gaussian variable of unit standard deviation and σ the standard deviation of s is itself a Gaussian variable over macrocells. L is taken from the observed path loss values. Using this methodology the path loss exponent 'n' has been deduced.

5.1 Discussion on statistical analysis parameters for all base stations

Instead of comparing individually the results of each base station with the predicted values statistical parameters like root mean square error(RMSE), coefficient of determination (R^2)[16], average hit rate error(AHRE) of prediction errors have been

deduced. The errors between measured data and predicted values for each location point

have been deduced and converted into RMSE, R^2 and AHRE.

The RMSE function of this prediction error is as follows

$$E\ (L_0, \gamma) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[e(di)]^2} \qquad\qquad (7)$$

Where, N is number of measured points, e (d_i) is the prediction error. L_0, γ are Lee

model parameters. L_0 is a median path loss at 1 km distance; γ is the slope of the path

loss curve. The second parameter i.e. coefficient of determination (R^2) is defined as the

square of the correlation between measured and predicted path losses. It is defined as

$$R^2 = 1 - \frac{\sum_{i=1}^{N}[e(d_i)]^2}{\sum_{i=1}^{N}[PL(di) - \overline{PL}]^2} \qquad\qquad (8)$$

Where $\overline{PL}$ is the mean path loss of the measured signal, PL (d_i) is the path loss observed

at various distances

5.2 Total Hit rate (THR) and Average Hit Rate Error (AHRE)

  Hit rate metrics were introduced by Owadally et al [17] to complement the first order

metrics for evaluating the prediction models. They have used location specific total hit

rate to evaluate the quality of prediction model. It is defined as the percentage of

locations at which the predictions and measurements agree for a particular path loss

threshold i.e. locations having state (1, 1) or (0, 0). It is defined as

$$\textbf{THR (L}_\textbf{T}\textbf{)} = \left[\frac{\sum_i U(m_i).U(p_i)}{N_T} + \frac{\sum_i \bar{U}(m_i).\bar{U}(p_i)}{N_T} \right] \qquad\qquad (9)$$

Where U (m_i) and U (p_i) denote step functions corresponding to measured and predicted values, N_T refers to the total number of points compared. The method is useful in assessing the validity of a model where coverage is determined simply by a threshold value of path loss. Ostlin et al [18] extended the concept by introducing the parameter average total hit rate error (AHRE) to compare different models. It is mean deviation from hundred percent THR and is expressed as

$$AHRE = \frac{1}{N_{LT}} \sum_{L_{T,min}}^{L_{Tmax}} 100\% - THR(L_T) \qquad (10)$$

Where L_T is the path loss threshold and N_{LT} is the number of THR points. L_{Tmin} and L_{Tmax} are taken from the observed path loss values and are between 80 and 150 dB. A model is said to perform well when it exhibits a lower value of AHRE. Ostlin et al [11] have interpreted AHRE as the area between the THR curve and 100%.

Initially RMSE and R^2 for all the above three models have been deduced for all the base stations utilized in this study. They are given in table 2. A perusal of the table showed that for Hata method in urban zones the RMSE values varied from 8.5 to 17.58, for Lee method they varied from 8.5 to 16.46, for COST 231 WI method the variation was between 8.42 to 14.68. Similarly R^2 varied from 0.2 to 0.7 for Hata method, 0.01 to 0.48 for Lee method, and 0.17 to 0.49 for COST 231 WI method. In the suburban region Hata's method exhibited RMSE of 8.12 to 15.16, Lee 9.39 to 16.88 and COST 231 WI method 9.72 to 13.95. All the three methods exhibited more or less similar values on the lower side of RMSE but on the higher side the values went up to 17 dB. Even R^2 which indicates the goodness of fit was not very high and turned out to be negative for TXT base station in suburban zone for all the three methods, and for CWI and Lee methods for GRN base station. Since both the statistical parameters were not presenting a clear

picture of agreement we have attempted to tune the prediction methods. The selection of the Lee model for tuning is based on simplicity, ease of tuning, applicability to the prevailing conditions under test, prediction accuracy and parameters involved. Since Lee model has been recognized by the wireless industry as one of the most accurate propagation model in the 900 MHz band it has been chosen for tuning. The following section gives brief outline of methodology of tuning.

5.3 Methodology of tuning the Lee model

The Lee area to area model is given by

$$L \text{ (dB)} = L_0 + \gamma \cdot \text{Log (d)} - 10 \log (F_0) \tag{11}$$

where L represents the path loss value at a given distance, L_0 is a median path loss at 1 km distance, γ is the slope of the path loss curve and F_0 is the adjustment factor comprised of several factors, $F_0 = F_1 F_2 F_3 F_4 F_5$ which have been explained in the original Lee papers. The first two terms represent the impact from man made structure and the third term represents terrain related parameter.

The importance of tuning comes in the fact that every region will have its own characteristic slope and intercept values due to the different man made constructions. The layout of buildings and the street widths in this part of our country especially Delhi are some what peculiar in some of these zones the buildings are not uniformly distributed with variable heights. This could be the main reason why the above prediction methods deviated largely. The parameters of Lee method were developed over western countries where construction of buildings and material used are very much different from that over Delhi region where measurements were made. Hence tuning of Lee model is necessary and important in the present context. Here an attempt is made to modify the L_0 and γ of Lee method based on these observed values. For tuning purposes the main criterion is to minimize RMSE function. It should be differentiated partially with respect to their

coefficients that achieve this minimization. To obtain Lee models parameters (L_0, γ) that optimize equation (1), N equations based on errors corresponding to N measured points should be solved.

The above N equations are solved using a Mat lab program to get L_0, and γ.

5.4 Discussion of Tuned results

 The values of Tuned Lee path loss model parameters L_0, γ were computed and tabulated in table 2. It shows that L_0, γ values for urban areas are high compared with suburban areas. In the present study tuned Lee parameter L_0 varied from 107 to 117 in urban regions and 98 to 105 in suburban regions. The parameter γ varied from 31 to 43 over urban regions and 27 to 31 over suburban regions. The average value of γ over urban region is 36.78 and over suburban region are 29.0. The original value of L_0 proposed by Lee varied from 104 in Newark, 110 in Philadelphia and 124 in Tokyo and in suburban regions it is 101.7. The parameter γ varied from 36.8 to 30.5 in urban areas it is 38.5. Paiboon et al. in Bangkok city [19] reported L_0 of 111 dB and γ of 36. The corresponding values reported over Taipei are [20] are 121 dB and 38, over Dhaka [21] are 126 and 30. Compared with the values reported in literature L_0 values in the present study match with those reported in the literature whereas the γ values are slightly higher than those reported in literature.

The main difference between tuned values in the present study and original Lee parameters is with reference to the parameter γ. We feel present set of γ values are more representative of urban regions prevailing over Delhi. Out of the two parameters γ is more important as it represents the rate of fall of signal level/path loss and these values can be used by cellular operators in models while using radio planning tools over this

region and similar regions. Ali [22] over the urban desert regions of Saudi Arabia made an attempt to tune the values of Lee method on the basis of Tetra measurements in the 400 MHz band. They observed values of γ ranging from 23.47 to 33.8. These values probably could be due to the different nature of urban environment and frequency used in this study is 400 MHz. The L_0 values reported are 2 to 48. The value 2 appears to be on the lower side. In this study the standard deviation (RMSE) varied from 3 to 4 in urban and suburban areas with average RMSE of 3.961 and R^2 varied from 0.54 to 0.78. In the present study after tuning RMSE varied from 5 to 9 and R^2 showed variations from 0.29 to 0.79 in urban regions. In suburban regions the corresponding variations are 5.8-10 for RMSE and 0.29-0.39 for R^2. The tuned values of RMSE and R^2 are shown in table 1. The average RMSE for tuned Lee method in urban and suburban zones is found to be 7.69 and 7.68 respectively.

From the table 2, comparison of tuned values of Lee method with other models showed that the RMSE and R^2 values of tuned Lee model performed better than the traditional models like Hata and COST 231 WI methods. The averaged RMSE value for all the base stations for the tuned Lee model is 7.69 dB and average RMSE value for Hata and COST 231 WI models are 11.03, 11.39 respectively for urban regions. Overall tuned Lee model performed well. In the case of COST 231 WI model the parameters used are, separation between buildings b=10m, average height of the buildings hr=6m.The average RMSE value of tuned Lee model is less compared to Hata and COST 231 WI. The R^2 value of tuned Lee model is better compared to Hata and COST 231 WI models. In suburban environments COST 231 WI model over estimated the path loss

values. Hence RMSE and R^2 values are not given for TXT tower MPR and GRN base stations.

Table 3 denotes the AHRE values for all the base stations for the three prediction methods. In the case of urban region for Hata's method AHRE varied from 8 to 20.8, 8.16to 19.31 for CWI method, 5 to 15.69 for tuned Lee method. For PVR base station all the three methods exhibited lowest values ranging from 5.7 for tuned Lee, 8.16 for CWI and 11.13 for Hata's method. Highest values were observed for NN 2 base station. For suburban regions, AHRE varied from 12 to 21.6 for Hata's method, 15 to 21.2 for CWI method, 9 to 10 for tuned Lee method. Urban zones exhibited better values than suburban values. The highlight of the study is the lowest values (improved model performance) exhibited by tuned Lee method compared with Hata and COST 231 WI for all the base stations. The average AHRE in urban region for all the base stations are Hata =14.16, COST 231 WI method = 12.7, tuned Lee method = 10.26. In the case of suburban region the corresponding values are 16.27, 17.6 & 10.4.These tuned value of Lee method can also be applied to the similar type of medium urban environment prevailing over various parts of India and other countries.

6 Conclusions

 Signal level measurements were conducted utilizing 7 urban and 4 suburban GSM base stations in the national capital region of Delhi in the 900 MHz band and the observed path losses were compared with prediction models like Hata, COST 231 WI and Lee methods. The comparison of predictions with observed values have been given in terms of RMSE, R^2 and AHRE. Based on the observed path losses the parameters of Lee method were tuned and new values of parameters L_0 and γ were deduced for these

regions. The values of L_0 deduced vary from 104 to 117 in urban regions and 98 to 114 in

suburban regions. The parameter γ varied from 14 to 26 over urban regions and 13 to 16

over suburban regions. The statistical metrics of tuned Lee method were seen to

outperform the Hata and COST 231 WI methods significantly.

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Table1. Base station specifications along with tuned Lee model parameters for urban regions of Delhi

Urban region	Hb(m)	Lat	Long	Tuned Lee L_0	Tuned Lee γ
PVR(43.8dBm, 2dBi)	13	28.6738	77.08882	108.20	33.50
UA (43.8dBm, 2dBi)	24	28.69655	77.21367	110.27	36.12
NN1(43.8dBm, 2dBi)	14	28.66912	77.36256	117.70	38.16
NN2(43.8dBm, 2dBi)	12	28.68908	77.3026	114.50	43.35
SNT(43.8dBm, 2dBi)	18	28.58845	77.16848	115.40	38.46
FBD(43.8dBm, 2dBi)	10	28.38071	77.29720	107.30	36.30
VKH(43.8dBm, 2dBi)	13	28.57132	77.32809	108.70	31.60
Suburban region					
TXT(43.8dBm, 2dBi)	43	28.47266	77.51447	98.54	28.20
MPR(43.8dBm, 2dBi)	12	28.49434	77.32450	104.70	31.23
GRN(43.8dBm, 8dBi)	20	28.4753	77.08445	105.20	27.82
	Hm=1.5				

Table 2. Comparison of prediction methods used in the present study based on
RMSE and R^2

Urban region	Hata RMSE	CWI RMSE	Lee RMSE	Tuned Lee RMSE	Hata R^2	CWI R^2	Lee R^2	Tuned Lee R^2
PVR	12.14	8.42	9.47	5.52.	0.335	0.488	0.014	0.766
UA	10.50	8.99	8.50	8.06	0.239	0.443	0.493	0.552
NN- 1	8.60	13.68	12.45	6.83	0.681	0.177	0.317	0.794
NN- 2	8.54	12.8	16.46	9.28	0.753	0.29	-1.22	0.293
SNT	8.46	8.79	10.2	6.62	0.493	0.494	0.318	0.691
FBD	11.42	9.96	13.05	7.61	0.304	0.317	-0.230	0.579
VKH	17.58	14.68	10.50	9.96	0.433	0.241	0.488	0.540
Suburban region								
TXT	15.16	13.95	15.5	6.47	-0.746	-0.776	-0.11	0.395
MPR	9.79	12.92	16.88	10.78	0.652	0.056	-0.567	0.295
GRN	8.12	9.72	9.39	5.80	0.256	-0.747	-0.682	0.355

Table 3. Average hit rate error for all the base stations

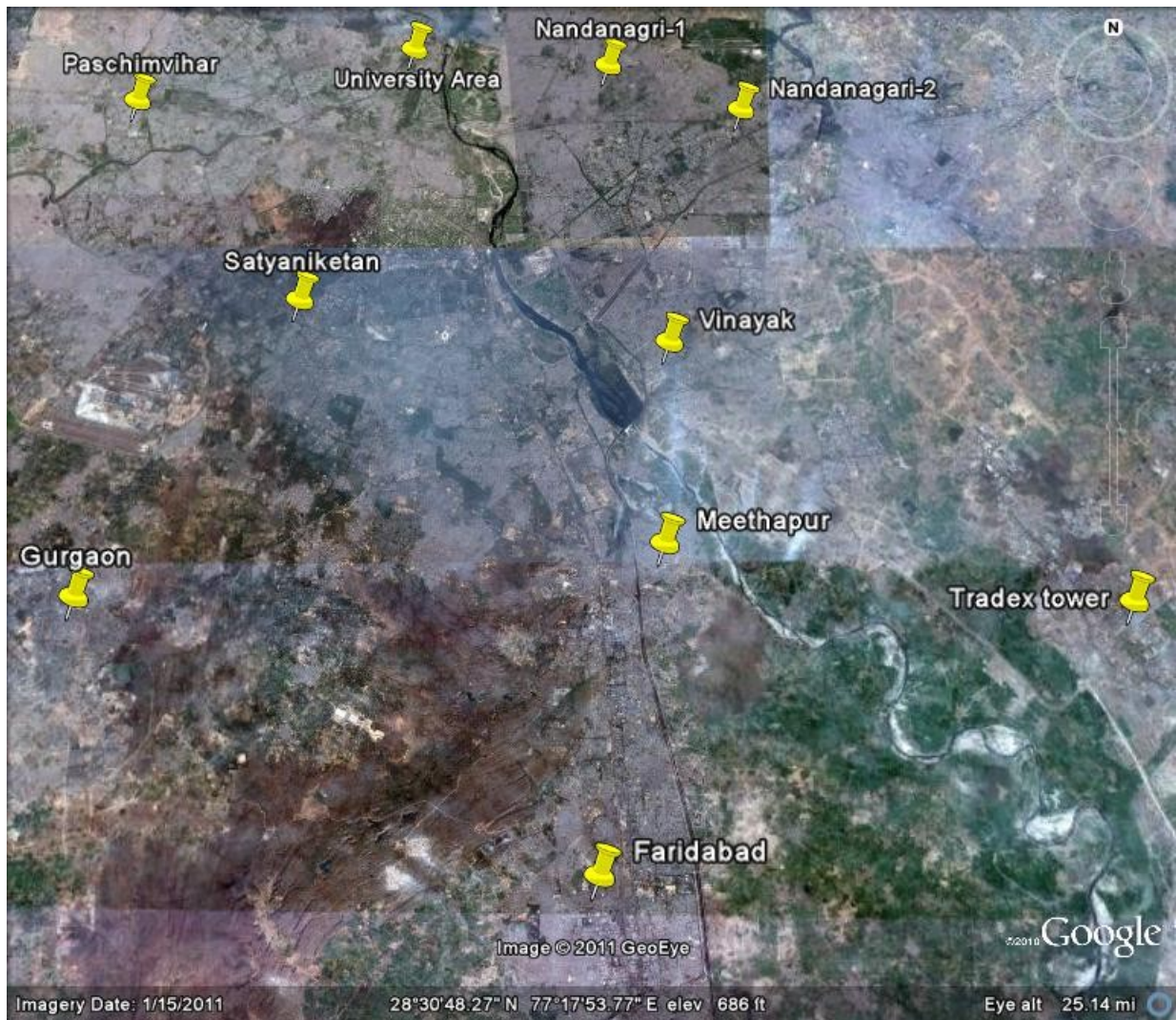| Urban region	Hata	CWI	Tuned Lee
PVR	11.13	8.16	5.70
UA	12.68	10.33	10.32
NN- 1	8.06	12.11	6.84
NN- 2	15.44	13.53	12.908
SNT	17.06	19.31	15.69
FBD	13.97	9.50	7.48
VKH	20.8	16.34	12.90
Average	14.16	12.70	10.26
Suburban region			
TXT	21.6	21.12	10.03
MPR	12.9	15.57	12.19
GRN	14.33	16.31	9.11
Average	16.27	17.60	10.4

Fig 1. Google map depicting all base stations

Fig 2.(a) Measured route for NN-1 base station

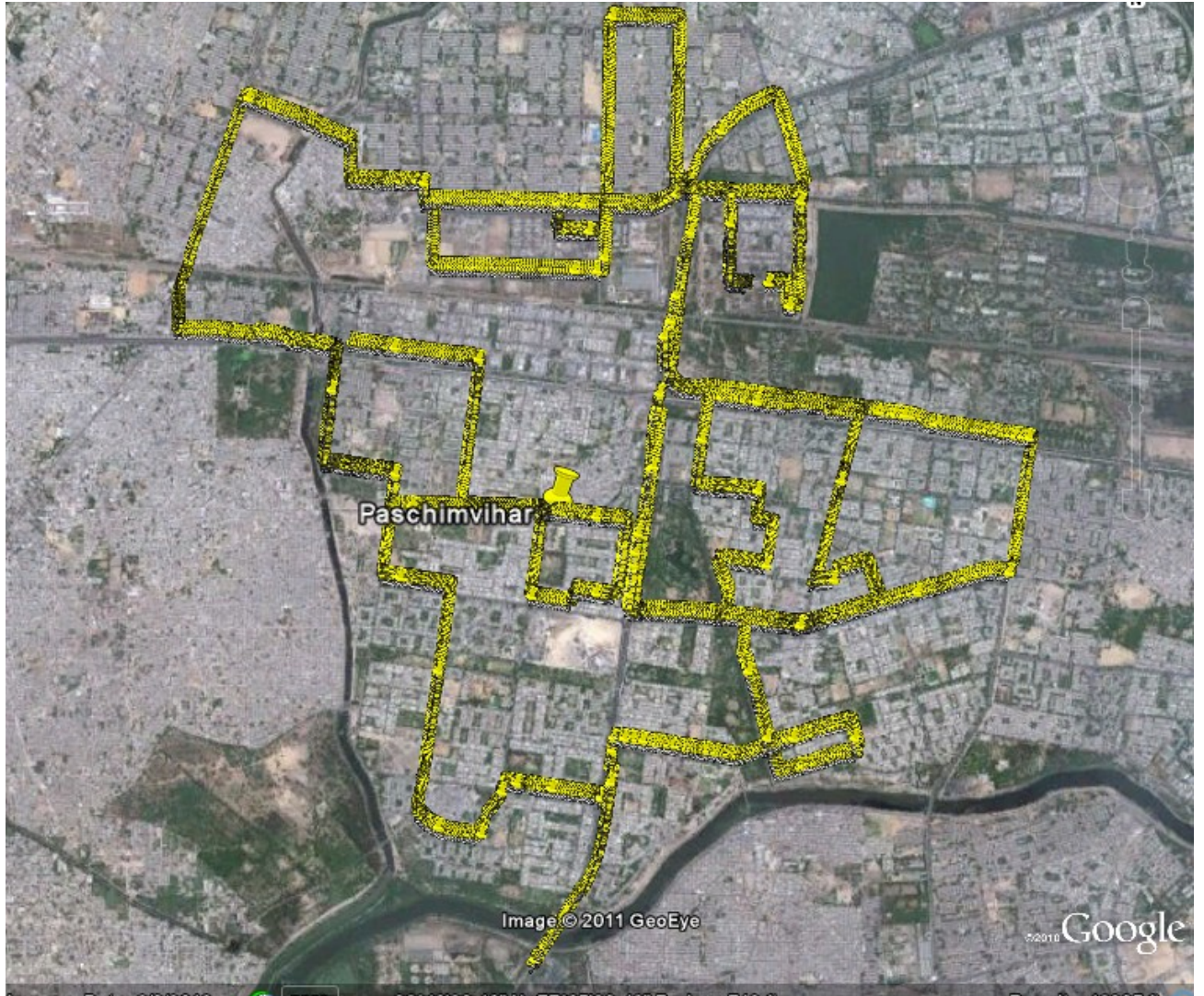Fig 2(b) Measured route for Paschim vihar base station

Fig 2(c) Measured route for Tradex tower base station

Fig 3. Clutter features around NN-1 base station

Fig4. Clutter features around UA base station

Fig 5. Comparison of observed path losses with those deduced from various prediction methods for NN-1 base station
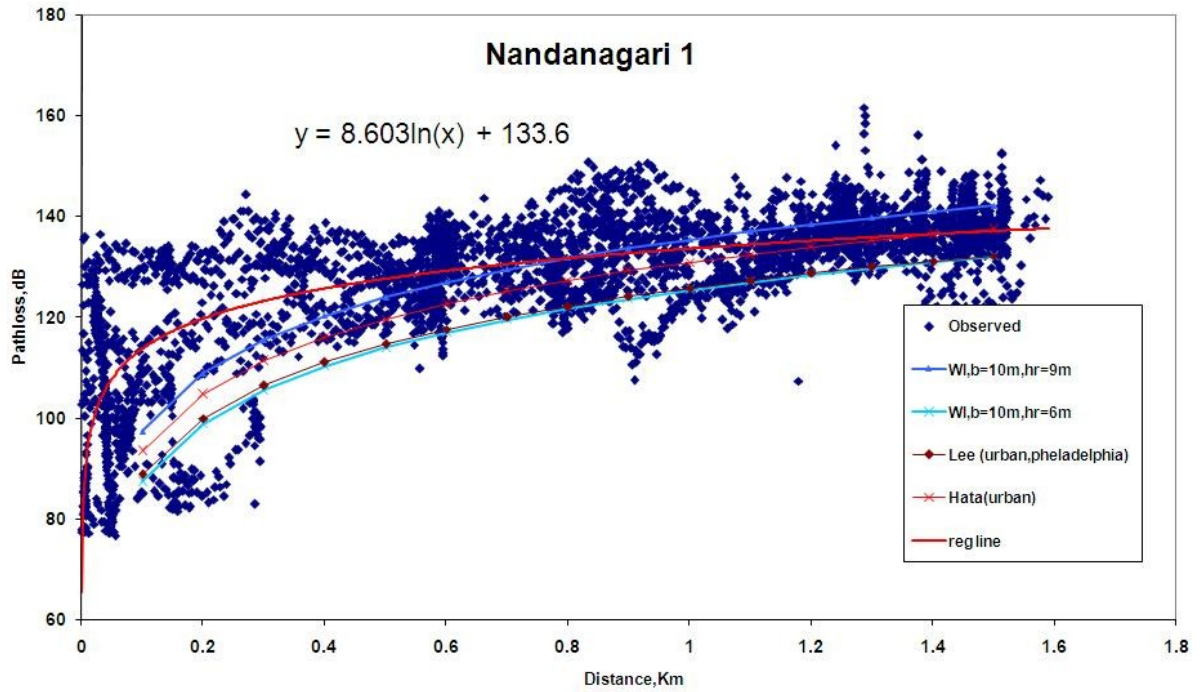

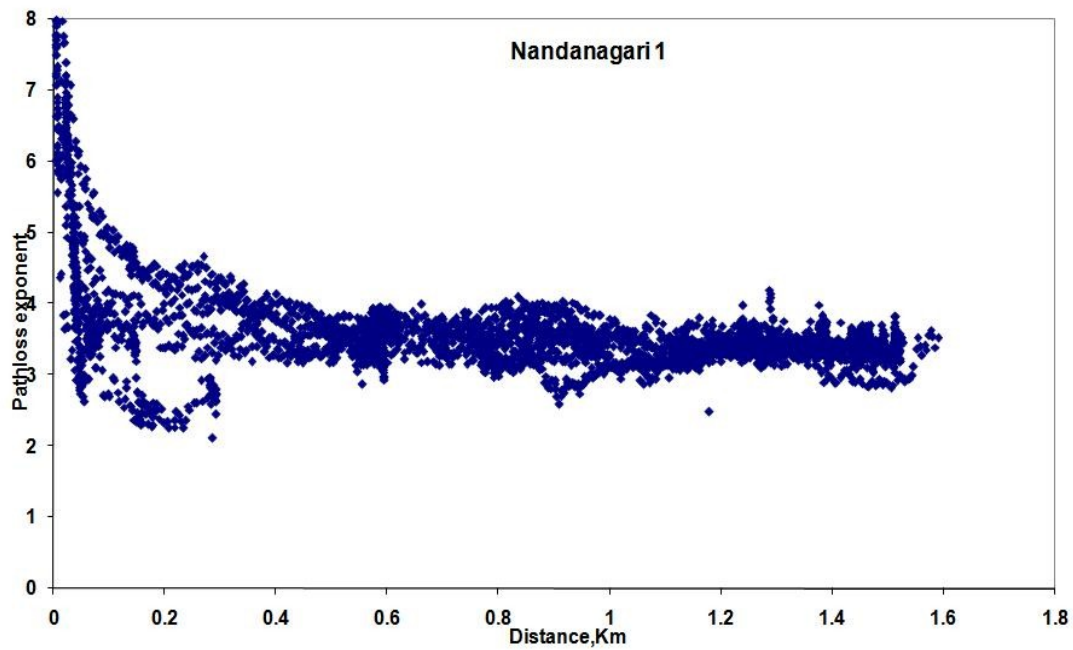Fig 6. Variation of path loss exponent as a function of distance for NN-1 base station

Fig 7. Comparison of observed path losses with those deduced from various prediction methods for UA base station
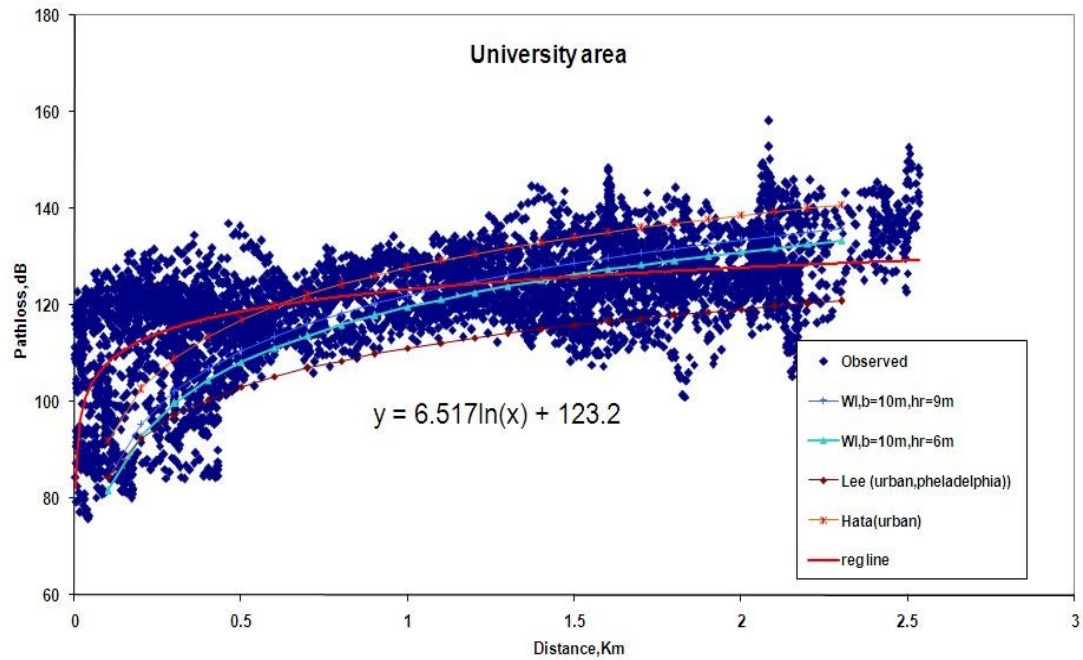

University area

$y = 6.517\ln(x) + 123.2$

Pathloss, dB

Distance, Km

- Observed
- WI, b=10m, hr=9m
- WI, b=10m, hr=6m
- Lee (urban, pheladelphia))
- Hata(urban)
- reg line

Fig 8. Variation of path loss exponent as a function of distance for NN-1 base station
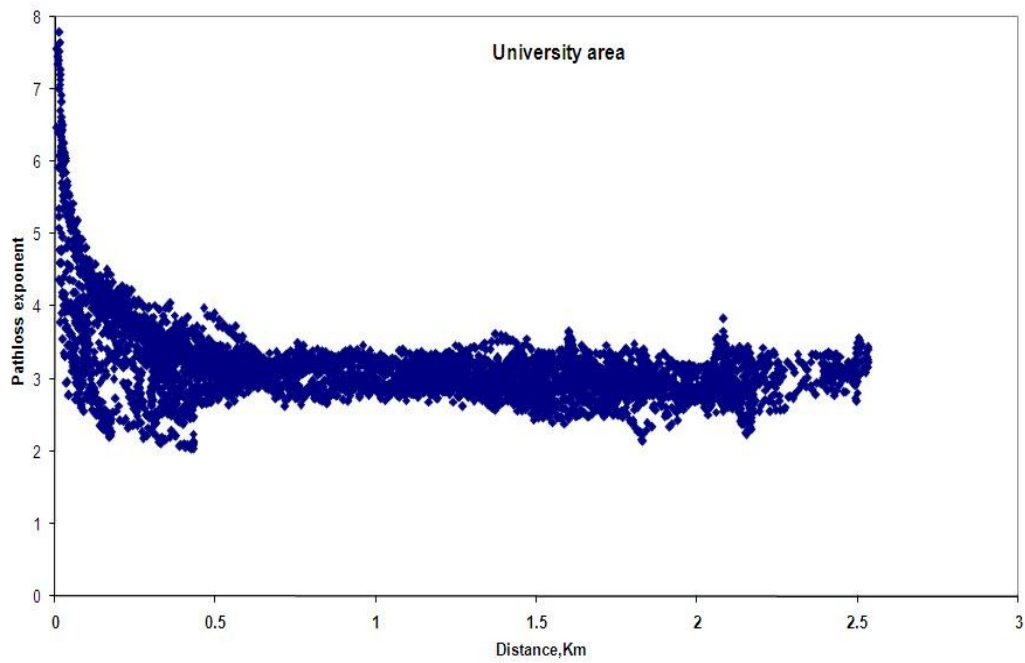

Fig 9. Comparison of observed path losses with those deduced from various prediction methods for PVR base station
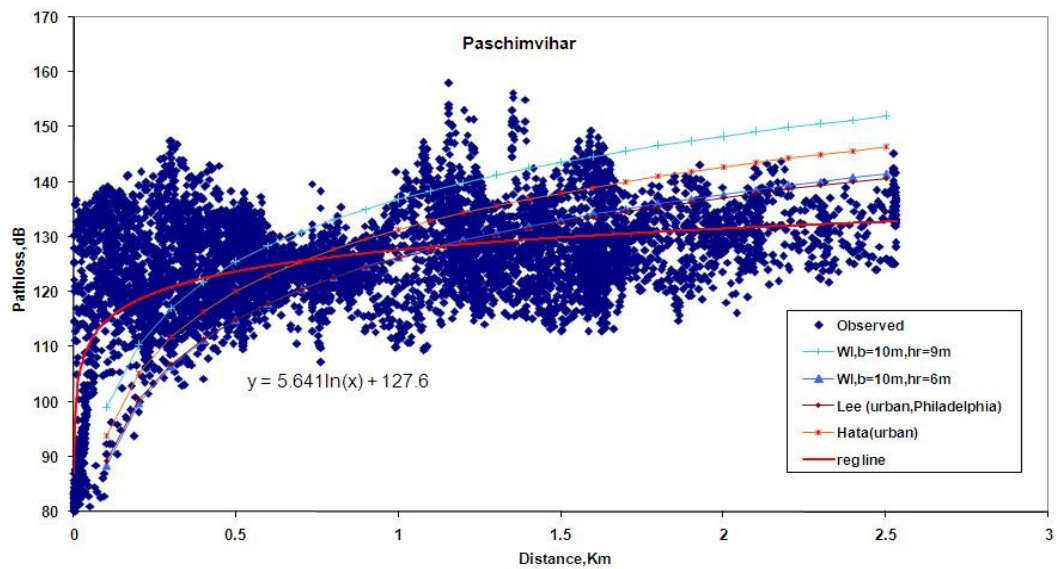
Fig10. Variation of path loss exponent as a function of distance for PVR base station