A New Method of Realistic GSM Network planning for Rural Indian Terrains

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Summary
This paper discusses a new method of generating rural radio network plan for GSM based on ASSET3G parameter tuning and identification of uncovered areas. The network planning has been carried out using digital clutter, terrain and vector data as input to ASSET3G whose default parameters have been fine tuned using measurement data of plane and rolling hill terrains. The ASSET3G parameters have been tuned to achieve the closest matching plot between the measured and ASSET3G generated values of path loss at 320 MHz. It is shown that the upper bound of mean error, standard deviation and path loss exponents for plane and hilly terrains are 5, 6 & 2.40 and 9, 11 and 3.13 respectively, which is below their respective acceptable limits. ASSET3G output along with boundary and census data is provided to MapInfo Professional to determine the tower position. The radio network plan for entire rural India has been generated, however as an illustrative example the coverage map generated for Manipur (India), a difficult rural hilly terrain, is presented.

Key Words
Digital terrain data, Radio network planning, Path loss, Path loss exponent, GSM

1. Introduction

Realistic radio planning for wireless mobile communication in remote rural areas has been a difficult task due to difficulty in conducting experiments. Although the network coverage map can be theoretically generated using professional radio network planning tool such as ASSET3G along with digital GIS software tool and terrain data [1-6] but it greatly differs from the actual path loss values due to wide variations of terrain types and their topologies. This is because the network planning tool parameters do not match with the actual terrain conditions such as hills, dense forest, rivers and coastal areas. Therefore investigation of the effect of specific terrain conditions on the network planning tool parameters so as to achieve realistic generation of path loss data using existing software tools becomes an interesting research problem. The necessasity of such studies is further reinforced due to unavailability of backbone network and poor economical viability because of sparse population of remote rural areas. However as connectivity has emerged as basic need of remotely rural population in India, the efforts are being made to provide wireless connectivity by generating optimum location of mobile base station towers and their coverage map using simulation tools in UHF band. In addition telecommunication professionals like Siemens and Lucent are also focusing on UHF band for extending broadband wireless connectivity to rural areas.

This paper describes the generation of radio network plan for entire rural India using ASSET3G radio network planning tool. The parameters of the tool have been fine tuned considering plane and rolling hill terrains and using propagation path loss measurement data to achieve location and coverage map of the base station towers closer to their actual values. It is shown that the upper bound of mean error and standard deviation between the experimental and tool generated path loss values are within acceptable limits. Further the path loss exponent has been determined experimentally as well as using ASSET3G and they have been compared to validate fine tuning of the tool parameters. As an illustrative example the radio network plan indicating location and coverage of base station towers for Manipur (India) is presented.

Section 2 describes ASSET3G parameters for path loss estimation and their relevance in path loss estimation followed by generation of radio network plan for Manipur (India) is given in section 3. Section 4 presents experimental data of path loss measurements along rail roads in northern and western India [7-14] which have been utilized for fine tuning of the ASSET3G parameters and determination of path loss exponent. The conclusion of the work is given in section 5.

2. Simulation Tools

ASSET3G provides coverage map for signal strength [4] based on BTS parameters and GIS digital data i.e. clutter, elevation and vector [5]. The path loss expression for estimating signal strength using ASSET3G is given by [4],[15]:

$$PL = K_1 + K_2 \log_{10}(d) + K_3 H_{ms} + K_4 \log_{10} H_{ms}$$

$$+ K_5 \log_{10} H_{eff} + K_6 \log_{10}(H_{eff}) \log_{10}(d) + K_7 + CL \quad (1)$$

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where PL and CL are the path and clutter losses respectively in dB, d is the distance between mobile and base station in kilometers, H_{ms} is mobile station height above ground in meters and H_{eff} is the base station antenna height in meters. The constant K_1 is an offset parameter and K_2, K_3, K_4, K_5, K_6 determine the path loss where as K_7 accounts for diffraction loss.

Referring table 1 [4] [15] it is evident that except parameter K_1 the remaining parameters $K_2 - K_7$ remain fairly constant at specific spot frequency. Therefore the path loss express by equation 1 is primarily governed by the parameter K_1 which varies with the frequency and K_2 which has got the next highest value parameter. The ASSET3G provides default values of the parameters K_1 - K_7 only at spot frequency, however, as K_2 is constant for the band 450 to 2000 MHz , we have selected K_2 = 44.9 for path loss simulation and it's comparison with experimentally measured values at 320 MHz. The values of K_1 for ASSET3G corresponding to 320 MHz has been obtained by extrapolating the plot of K_1 vs. frequency as shown by dotted line in Fig 1.

Table 1: Default values of $K_1 - K_7$ provided in ASSET3G

Parameter	450 MHz	900 MHz	1800 MHz	2000 MHz
K_1	142.30	150.60	160.90	162.50
K_2	44.90	44.90	44.90	44.90
K_3	-2.60	-2.55	-2.55	-2.55
K_4	-0.80	0.00	0.00	0.00
K_5	-11.70	-13.82	-13.82	-13.82
K_6	-4.30	-6.55	-6.55	-6.55
K_7	0.40	0.70	0.80	0.80

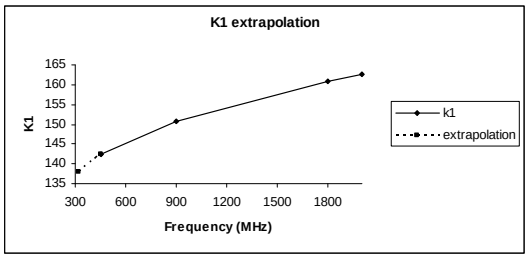

Fig. 1 Variation K_1 with frequency

The clutter loss CL values have been taken based on the radio measurements over the Indian rural zones as given in table 2.

Table 2: Clutter Losses

S.No.	Clutter Type	Losses (dB)
1	Low density urban	2 dB
2	Village/ Low density vegetation	1 dB
3	Medium density vegetation	2 dB
4	High density vegetation	4 dB
5	Agriculture	0 dB
6	Open/quasi open area	-5 dB
7	Water bodies	-10 dB
8	River, Sea	-15 dB

ASSET3G provides signal strength coverage map based on selected K parameters, clutter loss and BTS parameters which can be used as input to MapInfo Professional tool [3] which provides optimal base station location by considering administrative boundary [1] and census data [6]. Therefore tuning of ASSET3G K_1 parameter and selection of clutter loss for specific terrain can be used to generate realistic signal strength map and this can be utilized by MapInfo Professional for generating radio network plan.

3. Tower Prediction for Remote Rural Areas

The prediction of tower location using MapInfo Professional requires a priori knowledge of parameter K_1 of ASSET3G which can be fine tuned for the rural regions whose experimental path loss data is available else the default value of K_1 can be taken for simulation. As an illustrative example the radio map generated for typical hilly state Manipur (India) considering the parameter K_1 =138, clutter losses due to terrains in table 2, base station height 35 meter, effective radiated power 37 dBm and diffraction loss model (as per knife edge diffraction model (Epstein-Peterson model) for steep high mountains and ITU-R diffraction model [16] for rolling hills), have been generated as shown in Fig 2. The generated coverage map indicating the tower locations excludes the areas which are already covered (yellow color in Fig 2) or those which have very little population density. The generated radio network plan of Fig 2 indicates a minimum requirement of 95 GSM towers covering 695 villages consisting of nearly 1 million populations. The existing population of number of households (NO_HH) is indicated in the Fig 2 with varying shades of blue color.

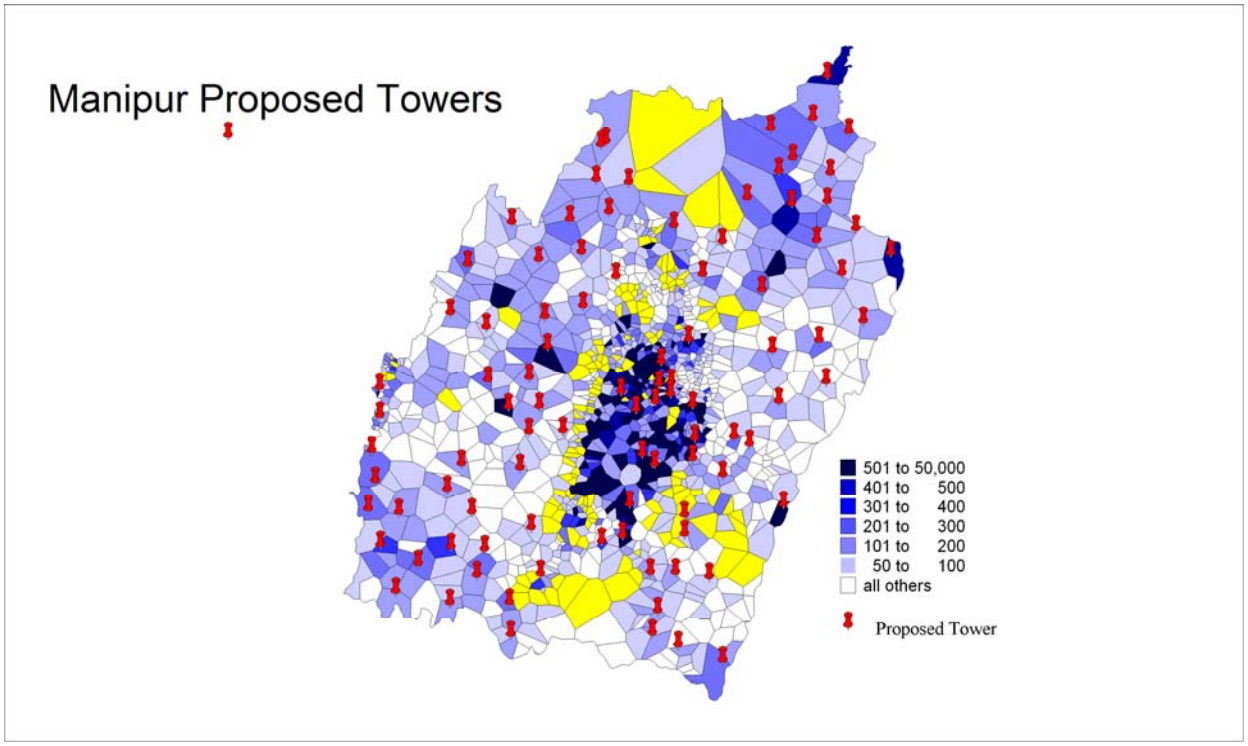

Fig.2 Proposed towers at Manipur obtained with the help of ASSET3G and MapInfo Professional

4. K_1 Parameter Tuning

4.1. Experimental Measurement

In the present study a comparison of tool based prediction method used for land mobile radio in rural/sub-urban areas with experimental path loss values have been carried out utilizing UHF band (320 MHz) train mobile radio measurements conducted in the northern and western regions of the country. The track side base stations utilized in the study are 1. Ghaziabad (latitude: 28.65, longitude: 77.43) 2. Meerut (latitude: 28.97, longitude: 77.67) located in northern India 1. Kalyan (latitude: 19.23, longitude: 77.13) 2. Vangani (latitude: 19.13, longitude: 73.26) situated in western India. The base stations in northern India are located at 40m above ground level and those in western India are situated at 49m and 26m above ground level. The effective radiated powers of the base stations are Ghaziabad, Meerut, Kalyan and Vangani are + 37 dBm. The checking of transmitter power, frequency, VSWR, supply voltage was done regularly to monitor the deviations and the values of the parameters reported in the paper are correct to the best of our knowledge.

At the time of measurements Indian railways were allocated frequency range from 314 to 322.6 MHz. Train radio network occupies a bandwidth of 2x 850kHz, in the range from 314 to 314.85 MHz and 321.0 to 321.85 MHz. Base stations located along the track continuously transmit the carrier at 320 MHz. In this carrier band the bandwidth is 850 kHz. A test coach is equipped with a calibrated receiver and computerized data logger. Also a chart recorder was used to record the carrier levels. To relate path loss values with locations, a counter of wheel rotations was necessary to drive the paper chart in a fixed linear relation to the train speed as well as having the option of storing samples at selectable intervals. The receiver sensitivity shall be better than 0.5 μ v (-93 dBm) for 20 dB S/N ratio measured at an RF signal modulated with 1000 Hz at 60 % of the peak deviation into the duplexer antenna input. The dynamic adjacent channel selectivity shall be 70 dB or better. A low profile omni directional antenna was used for reception at the roof of the coach. Slight directing antenna radiation patterns have been used for reduction of radiation in unwanted direction and obtain moderate antenna gain of 5 dB. Slightly directional- antennas have been employed when the track has minimum number of turns. Track is broad gauge type with width of 1.676m. However in the present case a slightly directional antenna, the beam width corresponded to 88^0 in horizontal direction and 30^0 in vertical direction has been used.

Antennas are vertically polarized, 50 ohms impedance. VSWR is less than 1.5:1 across the frequency band with antenna gain of 5 dB, branching & feeder loss of

transmitter cable is 3 dB, receiving antenna gain is 0 dB and omni directional, branching & feeder loss of receiver cable is 1 dB.

Coverage objectives for mobile radio systems utilized by railways are prescribed in technical regulations of International Union of railways (UIC code leaflet no.751-3). [17]. According to this, satisfactory coverage of an entire line is achieved if a minimum reception signal can be attained over 95 % of the track distance and for 95 % of the time. To estimate this coverage (which is not part of this paper) 100 m has been chosen as the statistic determined over portion of the path. A train traveling at 60 km/ hr will pass this gap within 6 sec. This will keep the communication link up right. In the present study the interest is to investigate the median path loss and not the fast fading.

The region extending from Ghaziabad to Meerut can be classified as open area with intermittent trees and small villages and towns in between. The region extending from Kalyan to Vangani, in western India is also open with agricultural lands and the region around the base station is of sub urban in nature. Over all both the northern and western regions represent typical rural Indian scenario. Microwave towers located by the track side were utilized as base stations. In the northern region the terrain is flat and open whereas in the western region where measurements were conducted the terrain is rough with some hilly(ghat) sections in between. Photographs of environments, clutter where measurements were conducted are shown in figures 3-6 and are described under the radio planning tool section. These are given to get a feel of the environment.

Using the digital terrain data with a resolution of 50 m and Aircom's ASSET3G tool [4]clutter, terrain and environmental photographs, signal coverage plots for different base stations have been generated. Clutter maps, terrain maps for entire northern and western base stations are shown in figures 3-6. Figure 3 shows the clutter map of north Indian base stations Ghaziabad and Meerut base stations along the track. Ghaziabad and Meerut base stations are surrounded by low density urban environment. As one moves along the track from Ghaziabad to Meerut base station agricultural lands

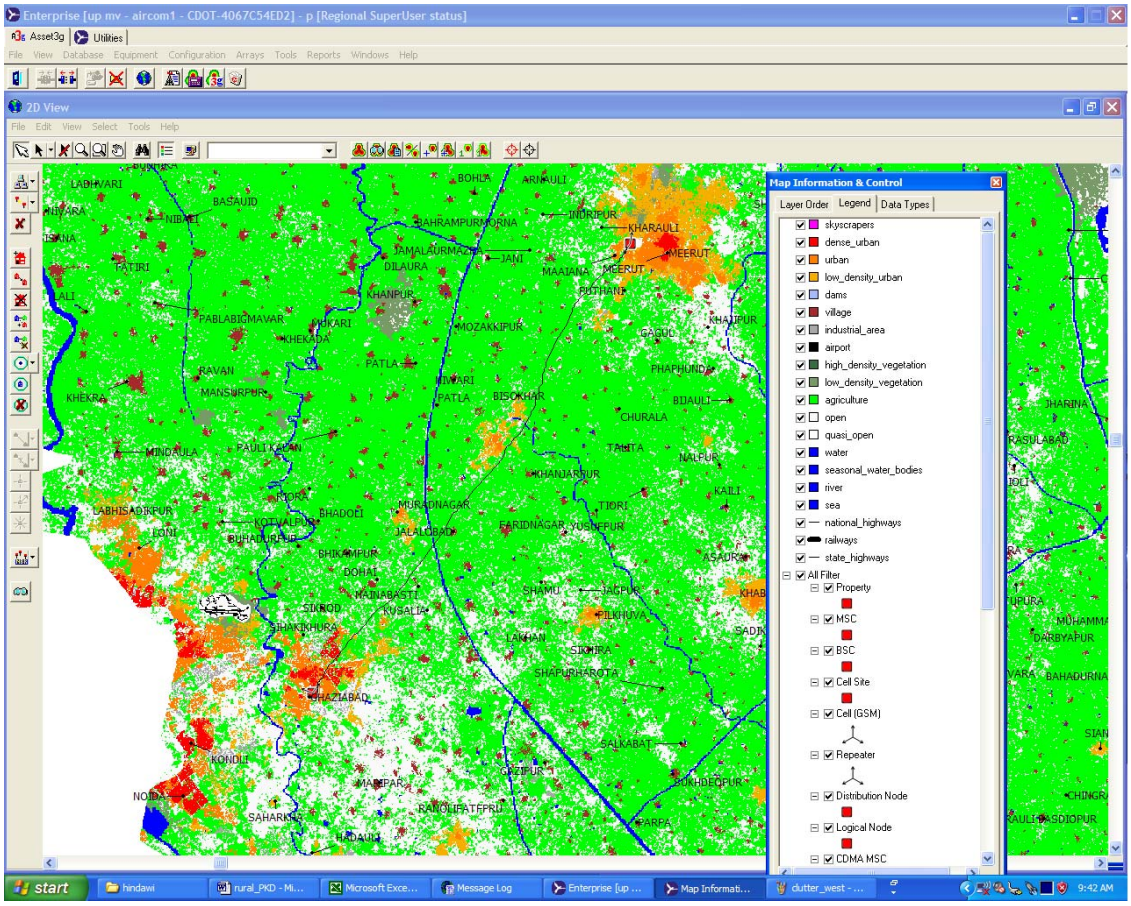

Fig 3 Clutter map of Ghaziabad and Meerut base stations (North India)

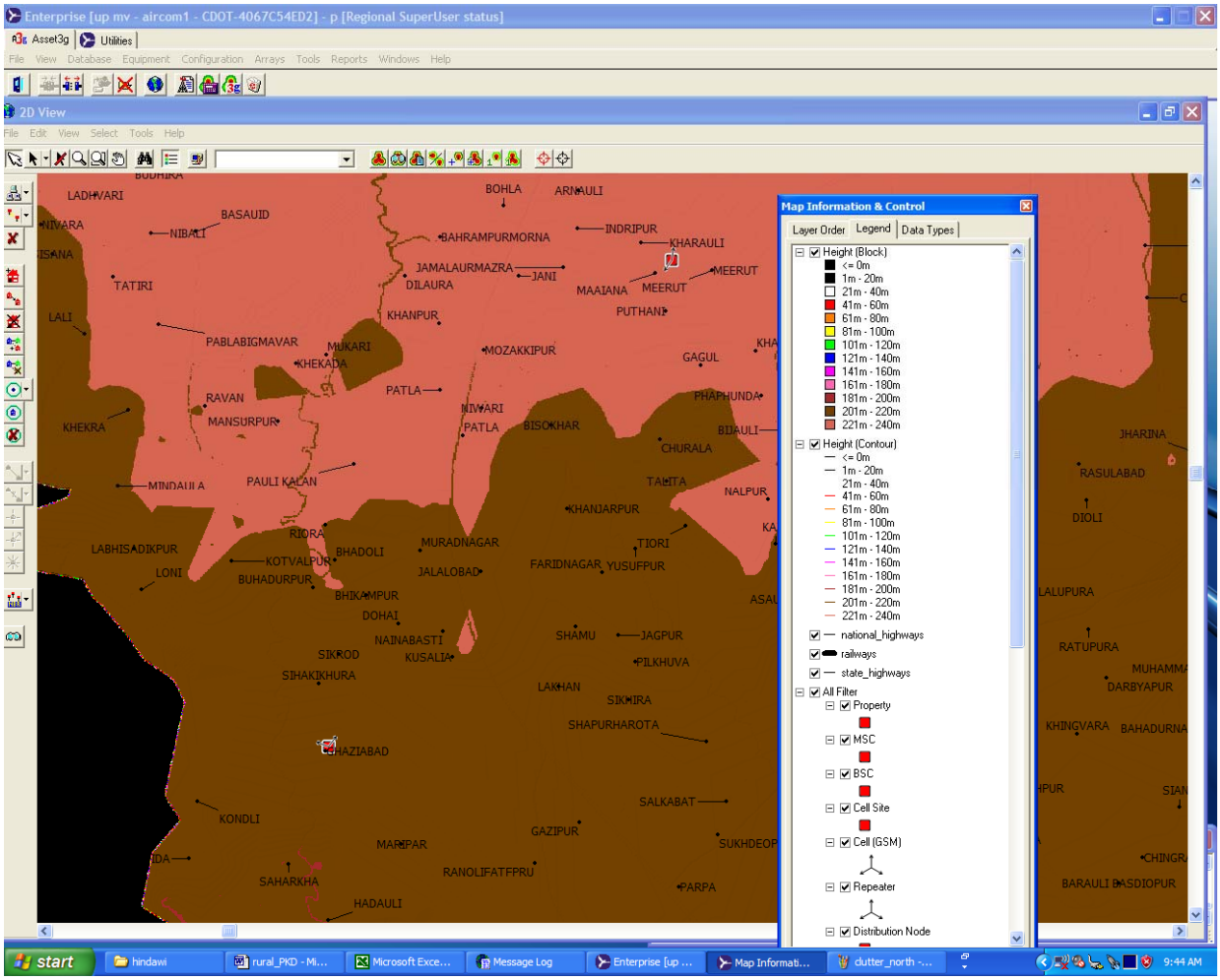

Fig 4 Terrain variation of Ghaziabad and Meerut base station of north India

and very low density vegetation are seen. At intermittent distances rural villages are located. All the base stations are surrounded by low density urban environment up to small distances. Figure 4 depicts the terrain variation of these north Indian base stations. Ghaziabad and Meerut base stations are situated at mean sea level height of 211m and 225m respectively. As one progresses the terrain is rising and there is a gradual upward slope.

The clutter map of west Indian base stations Kalyan to Vangani ia shown in figure 5. From Kalyan to Vangani open regions with low density vegetation are seen along the track. From Kalyan to Vangani open area with low height vegetation is seen. This is not tall enough to block out radio waves and apply foliage losses. The railway track in this section lies in the hilly terrain. Figure 6 shows the terrain variation of all these west Indian base stations. Kalyan and Vangani are situated at mean sea level height of 11m and 40m respectively.

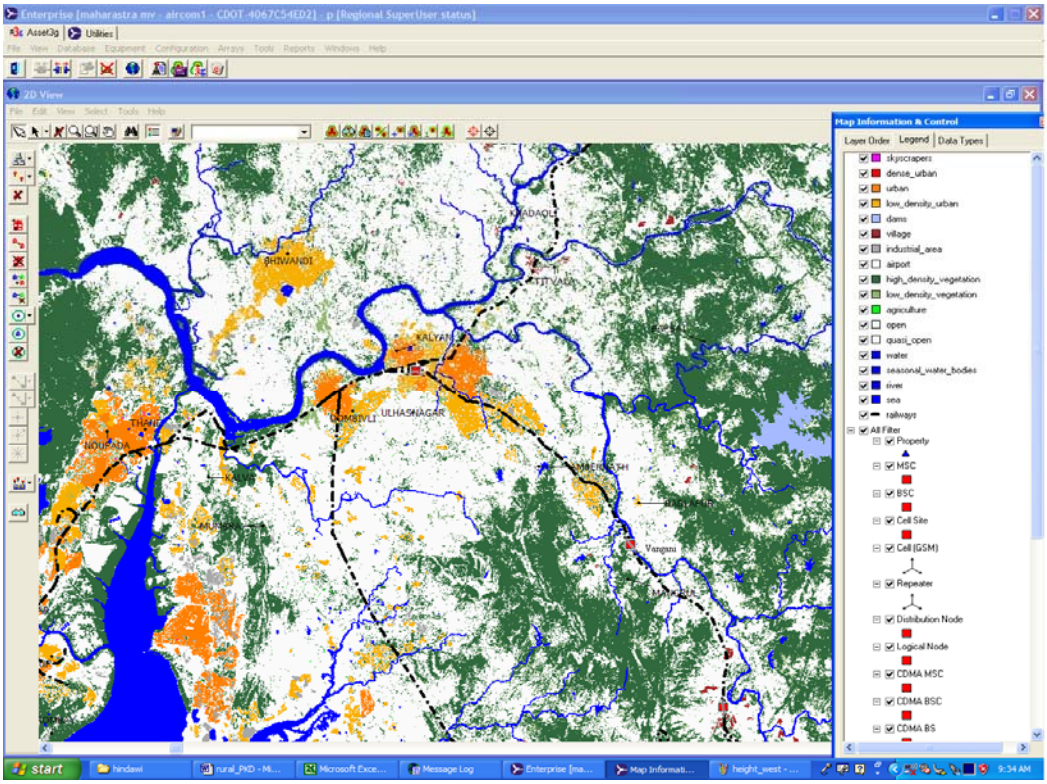

Fig 5 Clutter map of Kalyan and Vangani base stations of western India

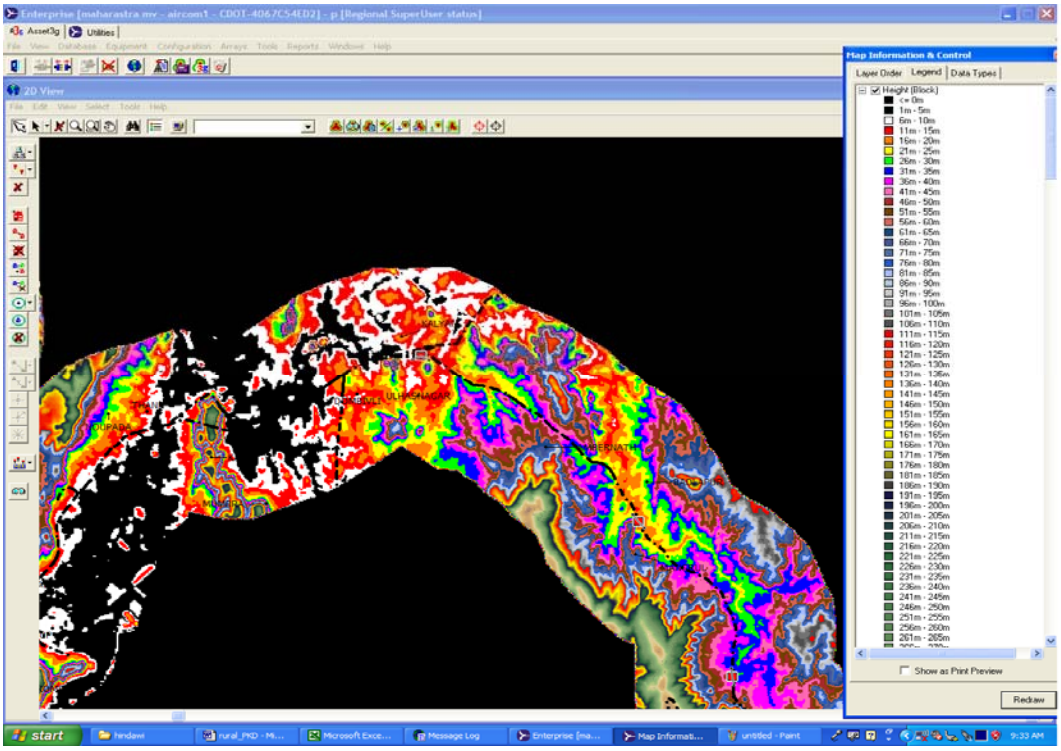

Fig 6 Terrain variation of Kalyan and Vangani base stations in western India

4.2. Path Loss Comparison

The default values of the most dominating ASSET3G simulation parameters for estimating path loss PL with the help of (1) have been identified as $K_1 = 138$ at the typical working frequency 320 MHz (Section 2), it would be of interest to validate the values of PL obtained by simulation against those obtained by measurement [7-14]. We have presented, typically, four selected plots for the validation of simulation against measurement [8] at tailored values of K_1, for two typical places of different terrain conditions, respectively — a plane terrain at Ghaziabad and Meerut in Northern India (Fig. 7 and Fig 8), and a mixed terrain comprising both plane and hilly areas at Kalyan and Vangani, in Western India (Fig. 9 and Fig 10). Measured data on PL, in general, have deviated from the corresponding ASSET3G simulation data of the concerned region. However, in ASSET3G simulation, we have tailored the value of K_1 around its default value 138 at the operating frequency of 320 MHz (Section 2) such that the simulated PL would agree with the available measurement data on PL of the concerned region , taking care to minimize the standard deviation in the values of PL obtained by ASSET3G simulation and measurement. The measurement data on path loss, typically at the operating frequency 320 MHz, are collected [7-14]. The positive and the negative values of d in the plots refer to the distances of the mobile station (on train) towards the right and the left of the base-station tower (as seen from the mobile station on railway track), respectively. The value $K_1 = 110$ yields a close agreement between the simulation and the measurement on PL for both the negative values of d at Ghaziabad (Fig 7), however at positive side $K_1 = 110$ holds vaid up to 22 km, beyond that $K_1 = 115$ yields a close agreement. $K_1 = 115$ yields a close agreement between the simulation and the measurement on PL for both the positive and negative values of d at Meerut and Kalyan (Fig 8 and Fig 9). However, at Vangani, such a close agreement has been obtained with the value $K_1 = 115$ for the negative values of d, and with the value $K_1 = 130$ for the positive values of d, corresponding to the left and the right sides of the base station, respectively (Fig 10). Interestingly, at Ghaziabadand and Meerut, both the left and the right sides of the base station (corresponding to the negative and the positive values of d, respectively) are the plane regions. However, at Vangani, the left side of the base station (corresponding to the negative values of d) is the plane region while the right side (corresponding to the positive values of d) is the rolling-hill region. Thus, the value of the simulation parameter $K_1 = 110$ to 115 for 'plane' region obtained based on comparison of simulation with measurement (carried out both at Ghaziabad, Meerut and Vangani) is significantly less than the default value $K_1 = 138$ of ASSET3G for the typical operating frequency 320 MHz chosen (see Section 2). Interestingly, however, the value of the simulation parameter $K_1 = 130$ for 'rolling-hill' region similarly arrived at by comparison with measurement (carried out at Vangani) is higher than the corresponding value for 'plane' region, being much closer to the default value ($K_1 = 138$) of ASSET3G. Clearly, then one has to give due attention to choosing the value of the simulation parameter K_1 in ASSET3G, on the basis of the minimum path loss criterion, depending on the terrain condition of the region to be covered under radio network planning for mobile communication.

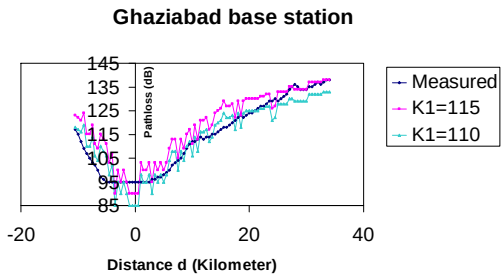

Fig 7 Comparison between measured and simulated path loss PL (dB) verses distance (km) for Ghaziabad

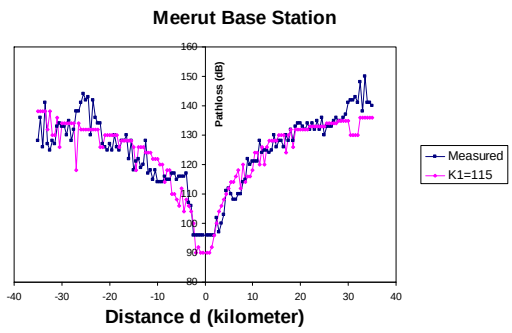

Fig 8 Comparison between measured and simulated path loss PL (dB) verses distance (km) for Meerut

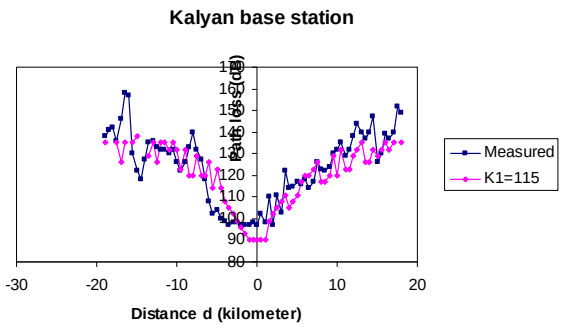

Fig 9 Comparison between measured and simulated path loss PL (dB) verses distance (km) for Kalyan

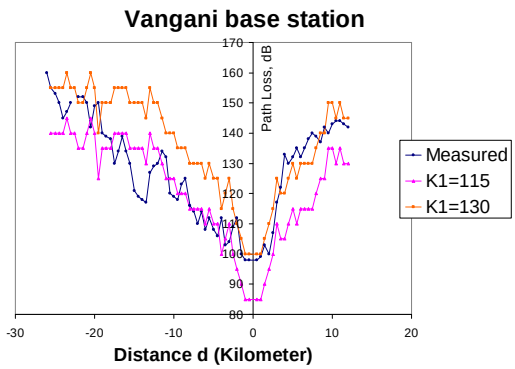

Fig 10 Comparison between measured and simulated path loss PL (dB) verses distance (km) for Vangani

Table 3: Standard deviation and Mean error

S.No.	Base Station	**Mean Error**			**Standard Deviation**		
		K_1 =110	K_1 =115	K_1 =130	K_1 =110	K_1 =115	K_1 =130
1	Ghaziabad	0.51	-4.46		5.09	5.14	
2	Meerut		0.75			5.76	
3	Kalyan		2.66			8.64	
4	Vangani		5.97	-8.98		10.53	10.66

4.3 Path Loss Exponent Determination

In designing mobile/cellular communication links it is established practice to use path loss exponents which are characteristic of the type of environment. Urban environment exhibits higher values and open environment has lower values. Suburban environment has values in between. In the present study path loss exponents deduced from observed values have been compared with the modeled values of Perez-vega and Zamanillo[18]. The single slope model is used to deduce observed values from the following equation

$$L_p(dB) = L_0 + 10n\log(d/d_0) \tag{2}$$

Here n is the path loss exponent and L_0 is the path loss at reference distance d_0 (taken as 1 km in present case). Typical urban and mobile radio channels have values of n which range from 2.2 to 4.35 when measured with a narrow band receiver[19].

The modeled values are obtained from the polynomial model of fourth degree of Perez-vega et.al [19] with the form

$$n = \sum_{i=0}^{4}\sum_{j=0}^{4} a_{ij} h^i d^j \tag{3}$$

where h is the height of transmitting antenna in meters and d is the distance in km. The coefficients of a are given for different order in the author's original paper.

Table 4: Observed and Model deduced path loss exponent

S.No.	Base Station	Observed path loss exponent	Model (Tool derived) Path loss exponent
1	Ghaziabad	1.83	2.81
2	Meerut	2.40	2.94
3	Kalyan	2.89	3.24
4	Vangani	3.13	3.97

5. Conclusion

A new method of generating realistic radio network coverage using K_1 parameter tuning of ASSET3G and considering clutter loss due to prominent rural terrains has been presented. The ASSET3G generated coverage map is used by MapInfo Professional tool to generate the optimal location of base station towers. The mean error and

standard deviation between measured and ASSET3G generated path loss values have been computed to determine the fine tuned values of K_1 for best matching between the experimental and simulated path loss values and it is shown that the upper bound of mean error and standard deviation are with in acceptable limits. This demonstrates that the tuning of K_1 parameters can be effectively utilized for predicting the network plan closer to the actual scenario. In addition to this path loss exponents have been determined experimentally as well as through simulation for validating the fine tuned model of ASSET3G. The radio network plan for plane and rolling hill terrains of part of rural India have been generated after tuning K_1 parameter of ASSET3G and as an illustrative example the network plan for Manipur state (India) based on default K_1 parameter of ASSET3G is presented. Therefore the proposed technique can find the potential application in generating realistic radio network plan based on fine tuning of K_1 parameter of ASSET3G for specific terrains. It is hoped that the present method for radio network planning to explore remote rural areas of difficult terrain conditions, though it is demonstrated here with typical Indian terrain conditions, could be used in other parts of the world as well.

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