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Terrestrial communication experiments over various regions of Indian subcontinent and tuning of Hata's model

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Abstract The development of various radio planning tools for the design of fixed and mobile communication systems requires radio channel measurements, comparison with various models, and the tuning of various parameters involved in the model. Based on the various land- and rail-based VHF/UHF measurements over northern, southern, western, and eastern parts of Indian subcontinent, the parameters of Okumura–Hata model are tuned, and modified parameters for the above regions have been deduced. These can be utilized for the design and development of future broadcast systems, mobile communication systems in this region of the world.

Keywords Path loss · Measurements · Model tuning · Hata's method

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1 Introduction

To provide better inputs for the design of future wireless communications, the communication group at National Physical Laboratory conducted various narrowband radio measurements on land-based and train-based platforms and compared number of existing radio propagation models with the measured results. The study showed that different models gave varying degrees of deviation in different regions[1–5]. It has been observed that out of all the models, the most popular model used by the cellular and other operators in their radio planning tools is the Okumura–Hata model, of course with some refinements. They generally conduct measurements in a small region of interest and attempt to fine-tune the Hata model to apply it to a larger region. This is a time-consuming procedure.

The objective of the work was to tune the parameters of this well-known model not only in a limited area but in larger parts of India to save valuable time and money on field trials for the design of new networks. Based on the experimental data collected in different contexts in VHF and UHF bands in the southern region (150 and 440 MHz) on land-based vehicles and in the UHF band in northern and western and eastern regions on train-based platforms(320 MHz), an attempt is made to fine-tune the Hata model for these respective regions following the approach of Medeisis and Kajackas [6]. The results of the present study can be utilized to design macrocellular and other related mobile systems where Okumura–Hata model is being used by system operators.

2 Experimental details

Radio measurements have been conducted over land-based vehicles in southern India at 150 and 440 MHz in urban, suburban, and open areas[4] and train-based measurements [1–2] in northern, western, and eastern India using various base stations. The observed results from these base stations have been utilized in the present study.

In the coastal regions of southern India(Andhra Pradesh State), field strength measurements were conducted radially from both the co-located transmitters with a radiated power of 5 W up to 30 km in different regions at 150 and 440 MHz. The whole region is a coastal zone with high humidity content. The measurements were carried out for a period of 30 days for different base station antenna heights of 16, 30, and 40 m with receiving antenna height of 3 m. The base station antenna was an omni directional monopole, and the receiving antenna was a yagi of gain 12 dBi, and antenna was oriented towards base station. The field strength was monitored with a field intensity meter RFT model SMV-8 from Germany. Both the frequencies were monitored with the same equipment mounted on a open jeep. The detailed specifications of system are given in Annexure A. Sampling rate was one measurement per minute. The averaged field strength value of ten samples in 10 min at a given distance was converted into a path loss value. The vehicle moved at constant speeds, and the yagi antenna is oriented towards the base station. Data points amounted to 300 for each frequency and each base station antenna height. Measurements were not repeated.

In the case of train mobile measurements in both northern and western India, the same equipment and methodology was adopted. Base stations situated along the track continuously transmit the carrier at 320 MHz. They are situated at different heights with telescopic masts, and some have utilized the track side microwave towers

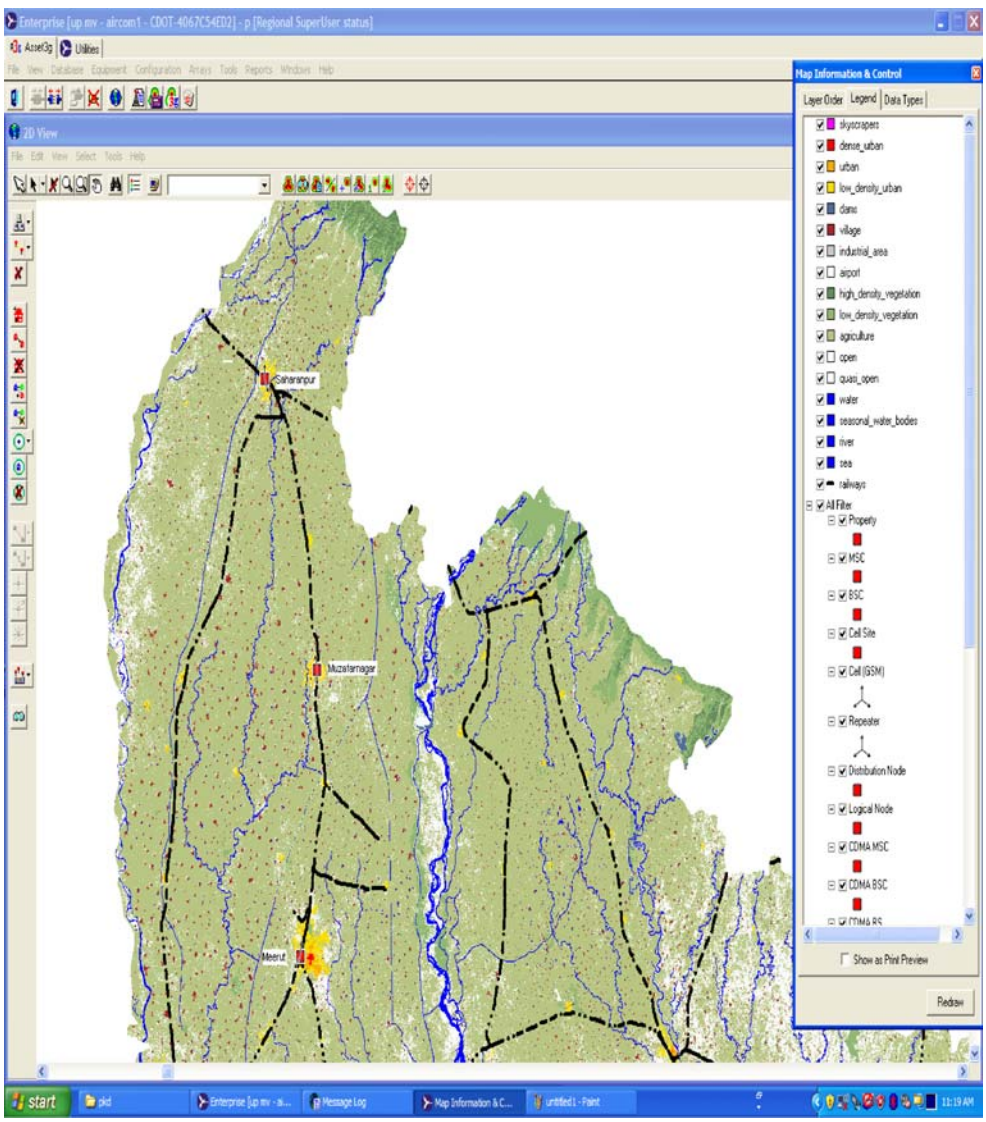

Fig. 1 Clutter map of north Indian base stations

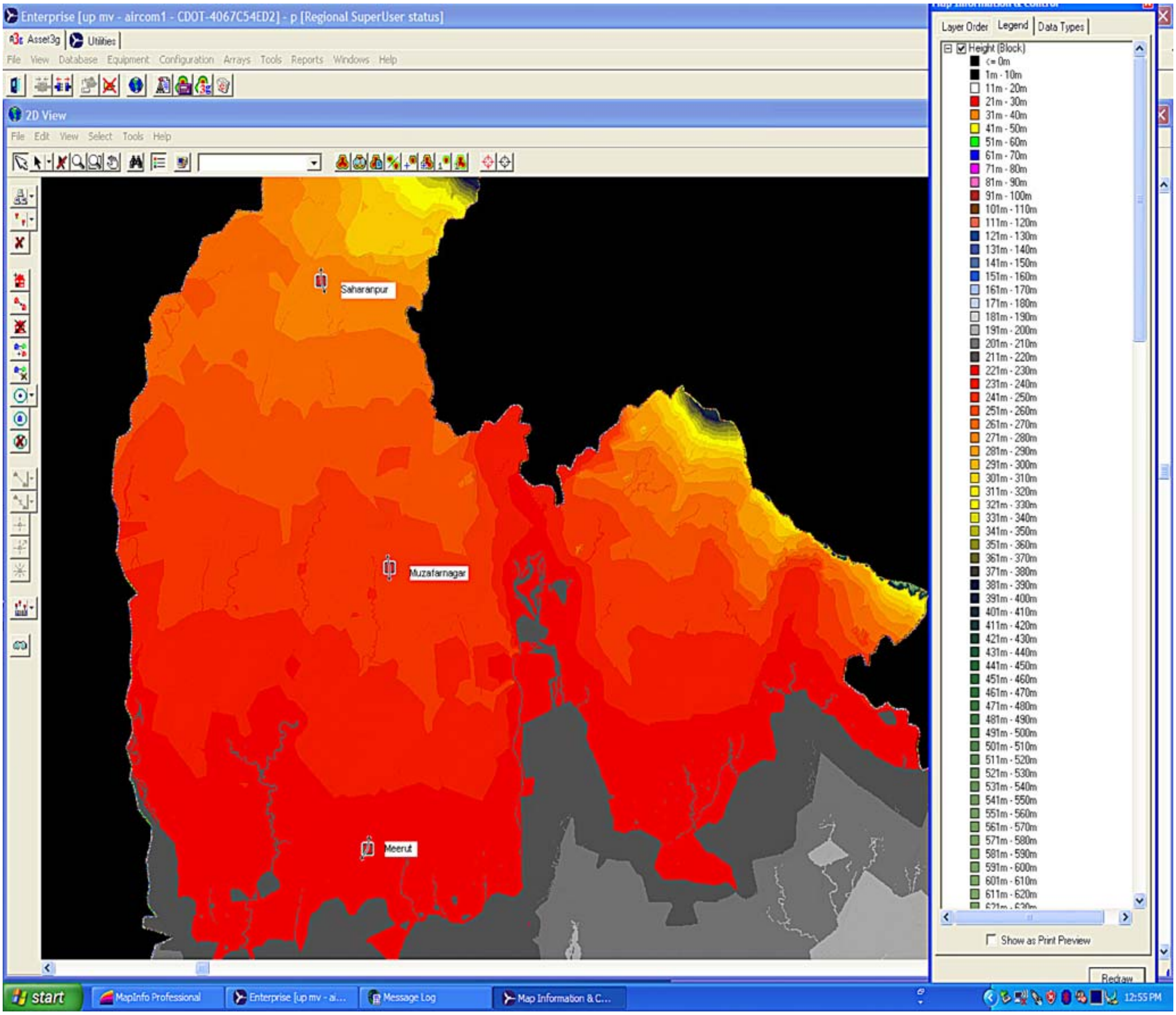

Fig. 2 Terrain variation of north Indian base stations

located at a height of 40 m. A test coach is equipped with a calibrated receiver and computerized data logger. In addition, a chart recorder was used to record the carrier level. To relate path loss values with location, 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. A low profile omnidirectional receiving antenna was used for reception outside the train on the roof of the coach. The recorded carrier level was averaged over every 100-m section. The receiver sensitivity shall be better than 0.5 μV for 20 dB S/N ratio measured at an radio frequency (RF) signal modulated with 1,000 Hz at 60% of the peak deviation into the duplexer antenna input. The dynamic adjacent channel selectivity shall be 70 dB or better.

Depending on the progress of the train, the base station signal is switched on. Using a signal generator, the receiver is calibrated before the start of the recording as well as after termination. The calibration curve is recorded on a PC and a chart recorder. The recording process begins when starting from or passing through a station. This point with exact kilometerage is important for synchronizing test equipment. When the signal level falls well below a useful level, the recording is terminated at the next station again with exact kilometerage. The mobile equipment in the coach worked with a petrol generator. One of the objectives of this measurement program is to determine the coverage area of the base station located along the railway track for designing future train mobile communication systems. According to the coverage objectives for mobile radio

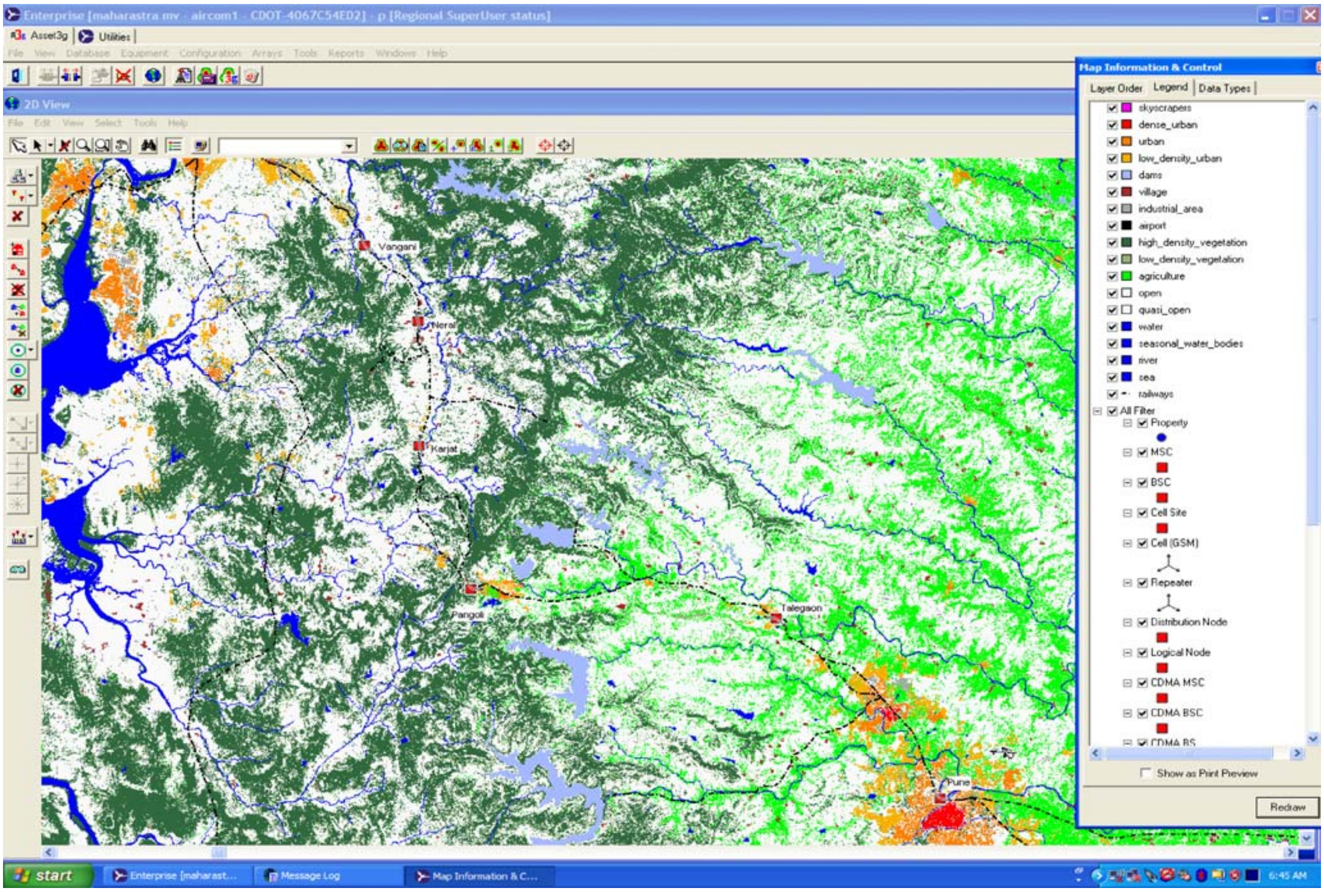

Fig. 3 Clutter map of west Indian base stations

systems utilized by railways as per the regulations of International Union of railways, satisfactory coverage of an entire line is achieved if a minimum reception signal can be attained more than 95% of the track distance and for 95% of the time. In the northern Indian plains, the total distance between base station Meerut and last base station Saharanpur was 160 km. Throughout this distance, measurements were conducted in the train in one go only. Similarly, in the western region, the total distance between base station Vangani and the last base station Pune was 136 km encompassing various types of environments ranging from urban to open.. In the case of Eastern India, the total length of the path was 100 km spanning nine base stations. The corresponding data points over northern India are 1600, western India 1360, eastern India 1000. In the case of train measurements, low profile omnidirectional antenna was used outside the train on top of the coach to avoid the shielding effects. Slightly directing antenna radiation patterns have been used for reduction of radiation in unwanted direction and obtaining moderate antenna gain of 5 dB. When the track has minimum number of turns, slightly directing antenna are used and when it is zigzag, omnidirectional antenna are used, and when it is straight, highly directing antenna can be used. Antenna are vertically polarized, with 50 Ω impedance.

Table 4 in Annexure B shows the details of base stations, their heights above the ground, transmitter power, etc.

3 Environmental description

3.1 Southern India environment

These measurements were conducted in the Andhra Pradesh region of southern India. The region consists of three storey buildings with street widths of order of 10 m. It is a medium urban region. Suburban region is characterized by low-density single storey dwelling units with some trees. Quasi-open area consists of terrain partly with agricultural lands, partly woods and trees. As it is a coastal area, a lot of greenery is present throughout the year and at some points, the region is crossed by water bodies. Open region consists of flat open areas with extensive agricultural rice fields and is sparsely populated. In the present study, measurements conducted in open regions are only included. The height above the mean sea level varies from 1 to 10 m, as it is close to the coast and contains water bodies also.

3.2 Northern India environment

The base stations utilized in the present study are Meerut, Muzzafarnagar, and Saharanpur base stations. Between Meerut and Saharanpur, the terrain is flat, having rolling plains and comes under the category of open region with agriculture fields and intermittent trees. The region can be taken as suburban category for the distances extending up to 1 km from the base stations.

3.3 Western India environment

The region around base stations starting from Vangani up to Pune is suburban, and the region between these base stations is open with green fields and agricultural lands. The last base station Pune is a small city with medium urban environment prevailing up to 2 km from the base station, and it is suburban region thereafter up to 4 km. Beyond this, it comes under open category. Part of the terrain in the present study is elevated with many ghat sections. The terrain is flat and passing through a broad valley interspersed with hills in between. The remaining part close to Pune base station is plateau area. Microwave towers located by the track side were utilized as base stations. The terrain irregularity in the plateau area is 50 m, which is an average value. The terrain encountered in the north Indian train radio measurements reported in [3] is different from the western Indian environment. There the terrain was open, flat with urban, suburban, and open demarcations. Hence, mobile radio propagation characteristics would be totally different in these regions.

3.4 Eastern India environment

The railway track from Chakradharpur to Rourkela runs through deep cuttings and a tunnel in between. Chakradharpur depicts medium urban near the base station, and as one moves away from the station, suburban and open type environment prevails. At Chakradharpur end, the terrain is situated at 220 m

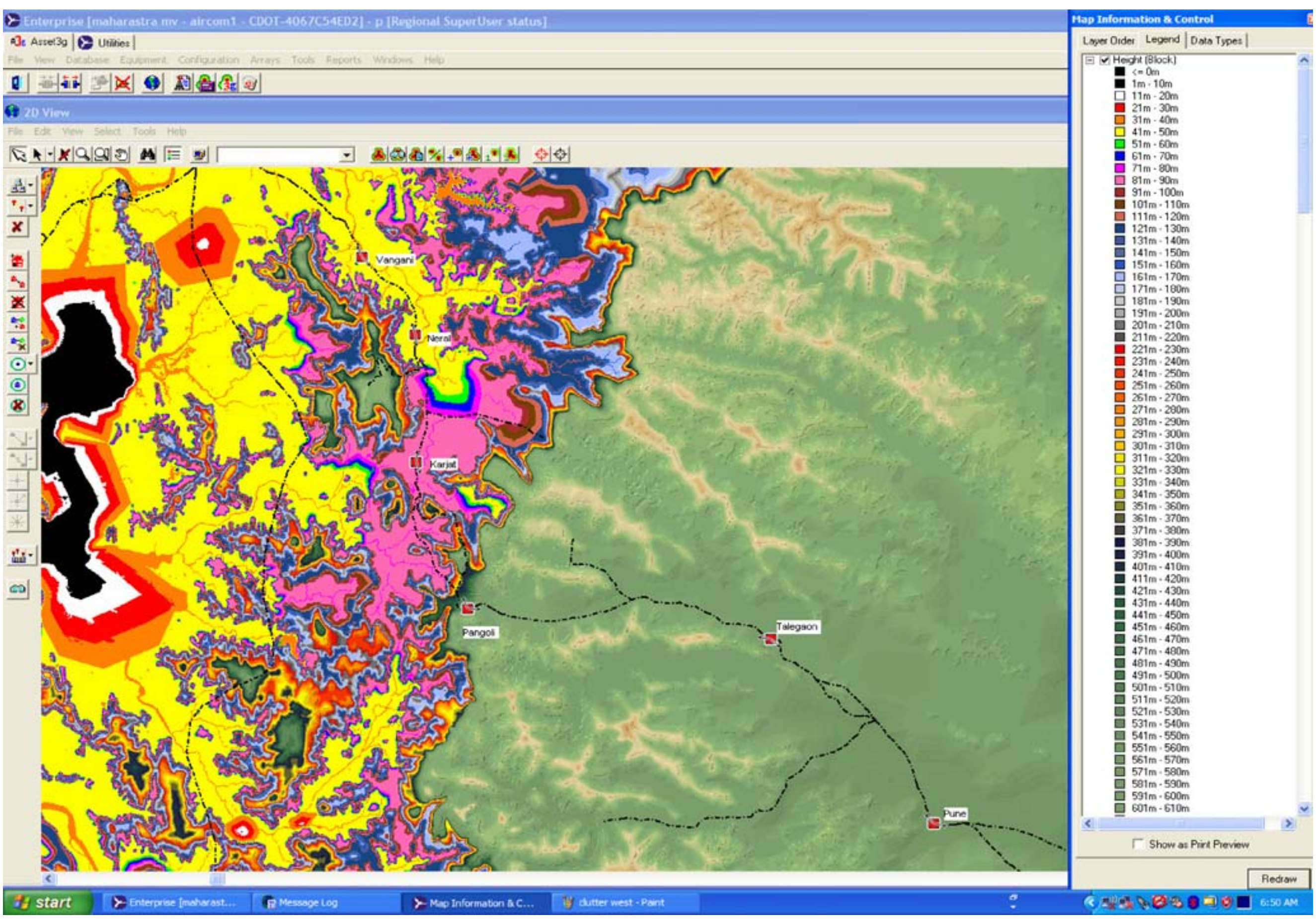

Fig. 4 Terrain variation of west Indian base stations

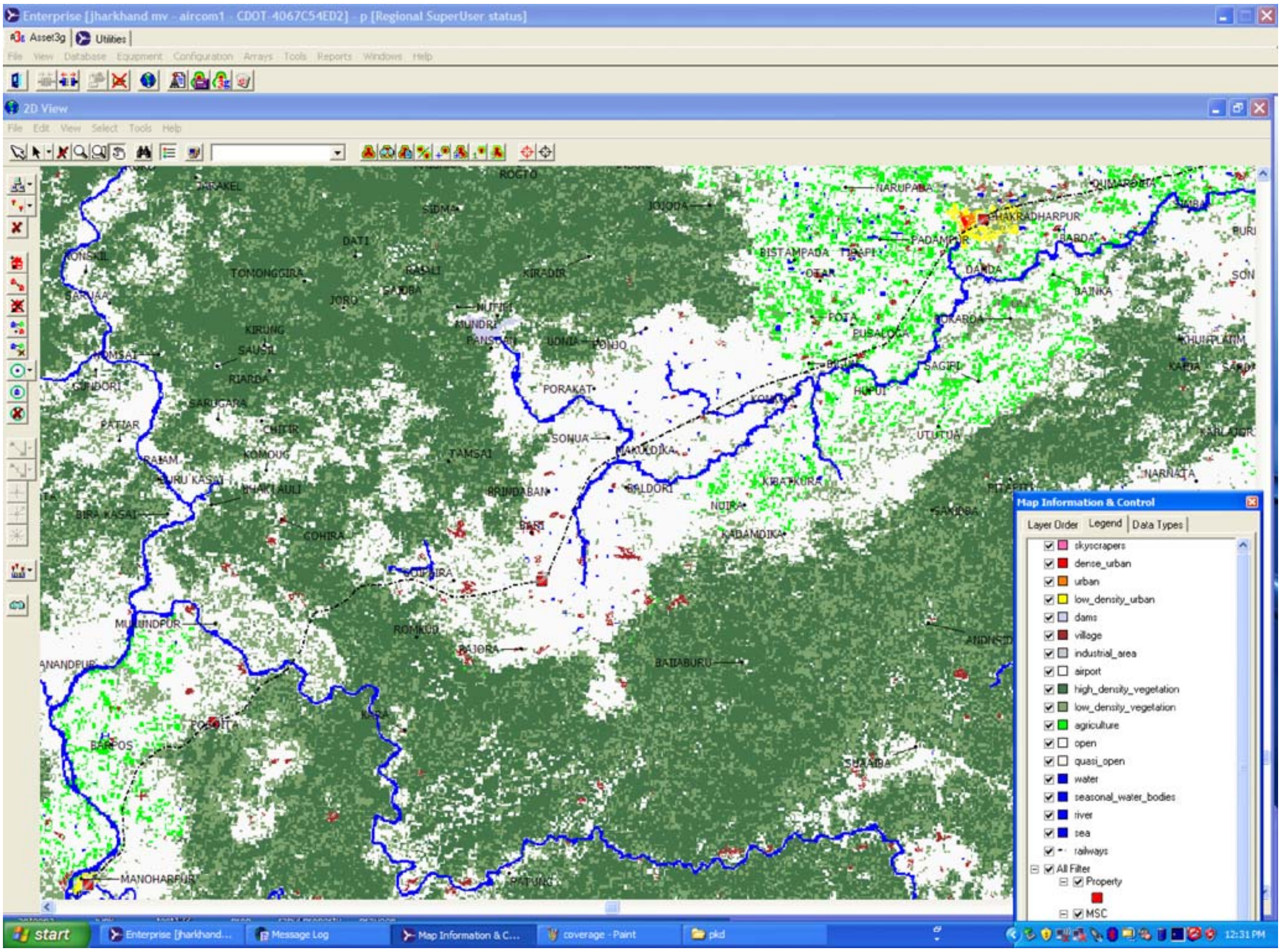

Fig. 5 Clutter map of east Indian base stations

above mean sea level (msl), and this increases to 330 m above msl as one moves towards Goilkera. In between, at 6 km distance from Goilkera base station, the terrain levels is 290 m. The terrain is sloping upwards as one moves from Chakradharpur to Goilkera. Near Goilkera station, suburban environment prevails. From Goilkera to Mahadevsal, open environment with few trees and bushes is seen. At Posoita, which is the next base station, the terrain level comes down to 280 m, and at 3 km distance from Posoita base station, the terrain level comes to 242 m, and a hill is seen at a distance of 6 km touching a height of 363 m. At 6.38 km distance from Posoita base station, the terrain height comes to 300 m and remains at 320 m height for the remaining part of the distance. Along the track, some agricultural fields are seen. Between Posoita and Manoharpur, the environment is considered to be open except for the suburban nature near the base stations. At Manoharpur base station, the terrain level is 219 m, and the terrain remains flat up to a distance of 4 km from Manoharpur base station. Terrain reaches 240 m at 5 km distance and remains at that level till Posoita base station end. Between Manoharpur and Jaraikela, the environment is also open with small roadside bushes and agricultural fields in between. At Jaraikela, the terrain level is 224 m above mean sea level, and at 2 km distance, the terrain reaches 240 m, and from 3 km distance, it drops down to 220 m. Between Jaraikela and Bondamunda, the same kind of open environment exists. At Bondamunda base station, the terrain levels above msl is 200 m, and beyond 5.5 km, the terrain starts sloping up and reaches 240 m, and at 7 km, it remains the same up to 9.53 km, i.e., up to Jaraikela. Between Bondamunda and Rourkela, the environment near the Rourkela base station is medium urban up to 2 km from Rourkela base station, and the remaining environment is open type. Rourkela is an industrialized town.

Railway environment is different from the traditional road environment. A 25-kV line runs along the track generating harmonics of radio waves causing electromagnetic interference.

The height of coach is at a higher elevation compared with the traditional road-based vehicle height. This may improve signal levels due to height gain characteristics of antenna. The propagation environment consists of plane earth, sidewalls, terrain cuttings, over bridges, masts, wires, tunnels, crossing trains, etc. [7]. Propagation paths in this environment is complicated due to different propagation mechanisms like reflection, diffraction, scattering, etc. Railway environments are first divided into between stations or station yards. In station yard, as there are some railway structures, multiple interference occurs. In between the stations, environment is divided into traditional classification like urban, suburban, or open. This has been described in the above paragraphs.

To get a feel of the environment, clutter maps and terrain variation of north Indian, west Indian, east Indian, and south Indian regions are shown in Figs. 1, 2, 3, 4, 5, 6, 7, and 8. These have been generated based on digital terrain data with a resolution of 50 m using asset tool of aircom. The figures are depicted in the end.

4 Methodology

(a) Initially, the mean error and standard deviation of prediction errors obtained for all the paths from Hata's method are given in Table 5 shown in Annexure B.

In the case of 440 and& 150 MHz measurements, 40, 30, and 16 m refer to the positions of base station antenna heights. In all the cases, prediction was calculated as the difference between observed loss and predicted loss. The negative sign before the mean error shows that prediction method is overestimating the path loss. Standard deviations observed over northern India are in the range of 3–5 dB,

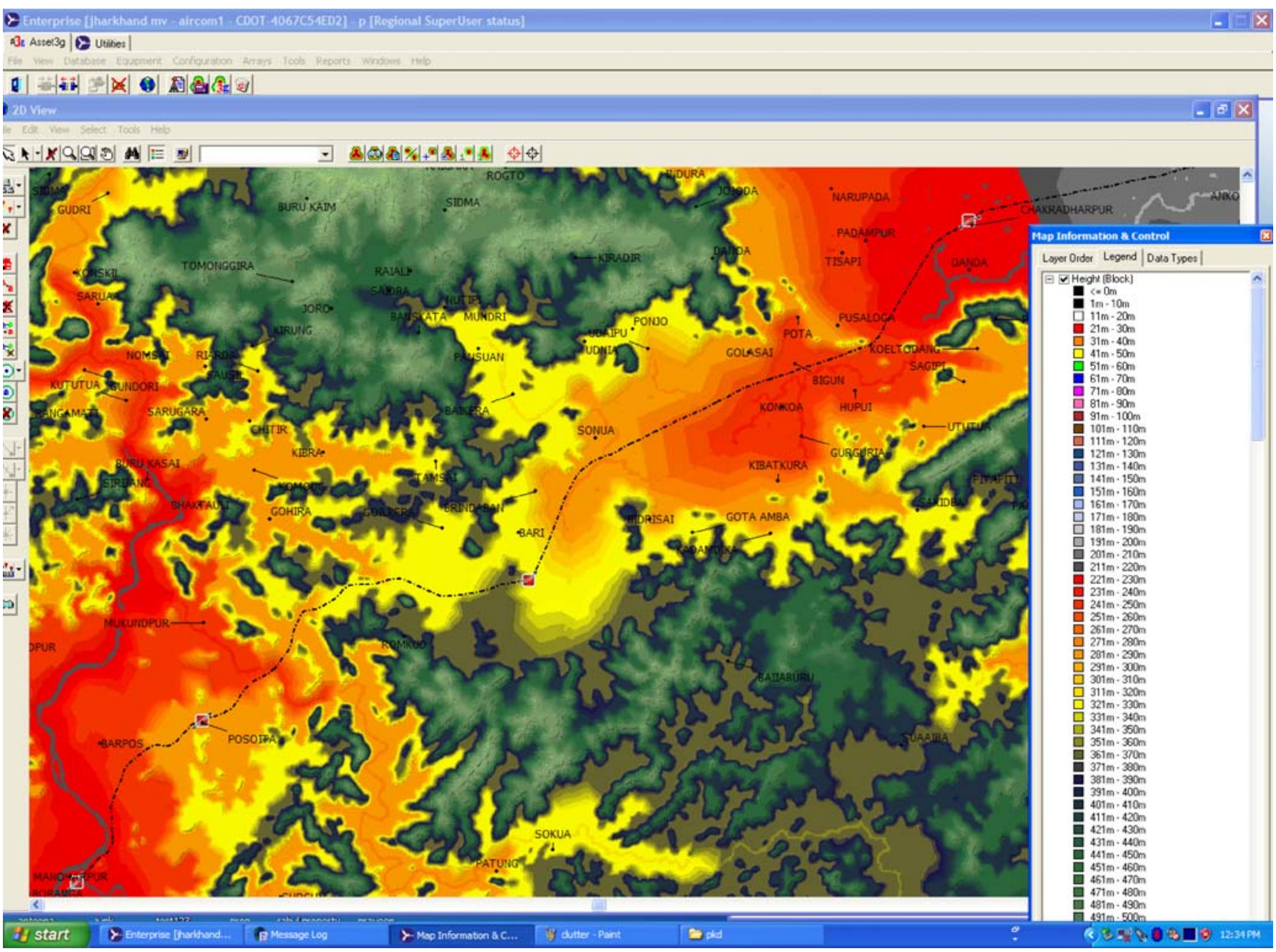

Fig. 6 Terrain variation of east Indian base stations

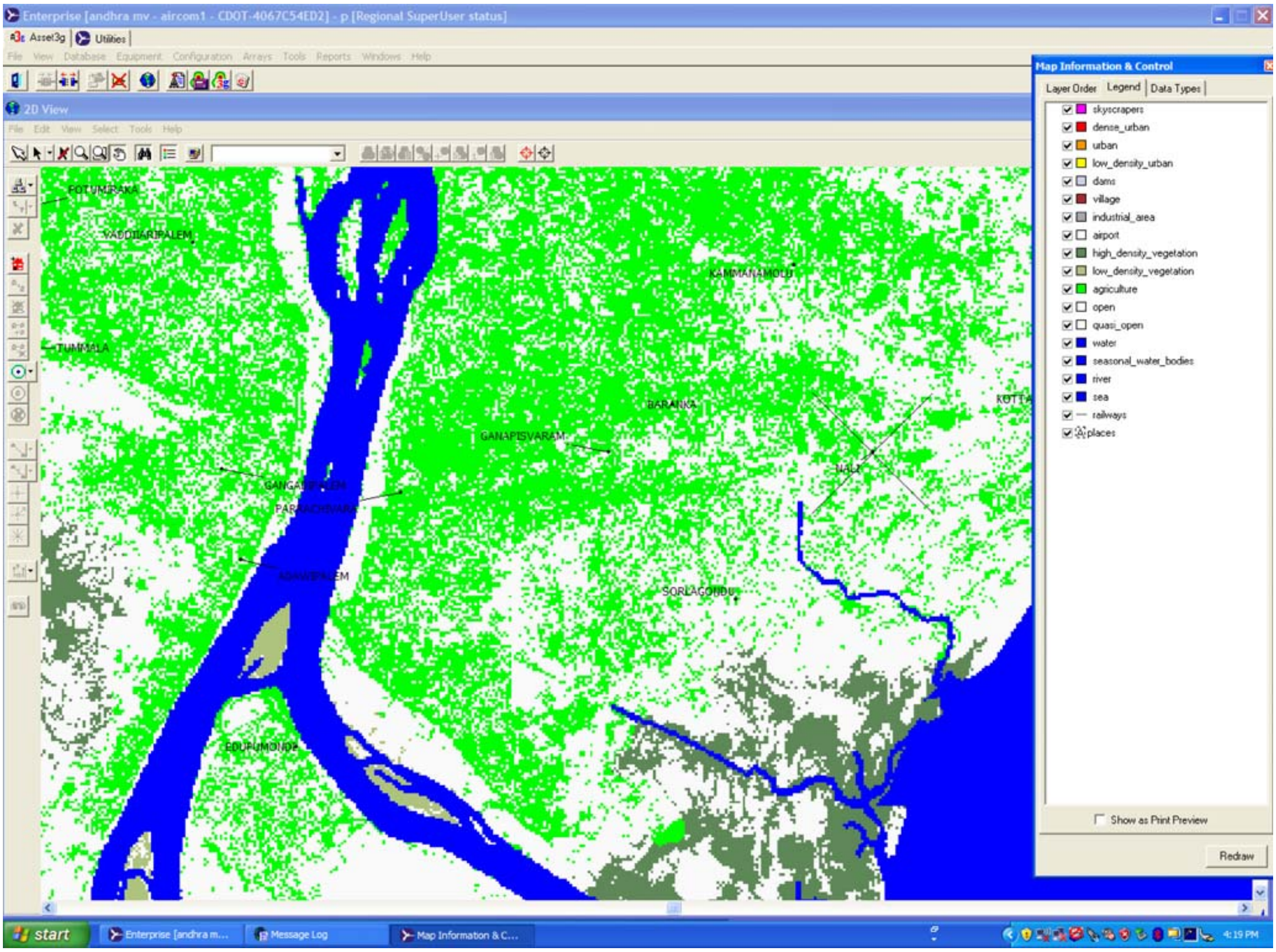

Fig. 7 Clutter map of south Indian base stations

and Hata method performed well here. Over western and eastern India, standard deviations ranged from 5 to 12 dB. Over southern India, the method exhibited minimum standard deviation. In view of the wide variability of the standard deviations, an attempt to tune the Hata's method was attempted.

(b) Tuning methodology:

Okumara's prediction of median path loss [8] are usually calculated using Hata's approximations as follows [9].

$$L = A + B \log R - (h_m) \quad (1)$$

where

A	$69.55 + 26.16 \log f - 13.82 \log h_b$,
B	$44.9 - 6.55 \log h_b$,
$a(h_m)$	$(1.1 * \log(f) - 0.7)h_m - (1.56 * \log(f) - 0.8)$
f	operating frequency MHz
h_b	effective height of transmitting antenna in meters
h_m	effective height of receiving antenna in meters
R	distance from transmitter (km)

The relation between field strength in dB μV/m, path loss is given in terms of transmitted power, antenna gain, frequency as

$$L(\mathrm{dB}) = 137 + 20 \log f + P_t + G_t - E \quad (2)$$

As P_t and G_t are known, E can be calculated from Eq. 2 by substituting for L from Eq. 1. Then, we get

$$E_R = 35.45 + P_t - 6.16 \log(f) + 13.82 \log(h_b) + a(h_m) - (44.9 - 6.55 \log(h_b)) \log R^{\gamma} \quad (3)$$

This is the equation obtained by Medesis and Kajackas [6].

E_R	received field strength in dB (μV/m)
P_t	radiated power, dBW
f	operating frequency (MHz)
h_b	Effective height of transmitting antenna in meters
h_m	effective height of receiving antenna in meters

$$a(h_m) = (1.1 * \log(f) - 0.7)h_m - (1.56 * \log(f) - 0.8) \quad (4)$$

R distance from transmitter (km)
γ 1 for $R \leq 20$ km

$$\gamma = 1 + \left(0.14 + 1.87{*}10^{-1}{*}f + 1.07{*}10^{-3}{*}h_b\right) \quad (5)$$
$$*(\log(R/20))^{0.8} \text{for } 20 \leq \text{R} \leq 100\,\text{km}$$

The three important parameters are initial offset parameter (E_0), initial system design parameter (E_s), and parameter establishing slope of the model curve (γ).

$$E_0 = 35.55\,\text{dB}(\mu\text{V/m})$$

$$E_{sys} = P_t - 6.16{*}\log(f) + 13.82{*}\log(h_b) + a(h_m) \quad (6)$$

$$\gamma sys = -\gamma(44.9 - 6.55{*}\log(h_b)) \quad (7)$$

Authors [6] have suggested that for the tuning of the model, only two parameters may be most relevant and sufficient, initial offset and slope of the curve γ. System design parameters should not be subjected to tuning. Authors approach is based on statistical method of least squares (details can be seen in the authors' paper). Based on this approach, E_0 and γ for different frequencies, environments have been deduced.

5 Results

Based on the above approach, E_0 and γ have been deduced for all the above base stations and are shown below for urban, rural, suburban zones (Table 1). In the case of land-based measurements at 150 MHz, the values of E_0 vary from 77.56 to 77.68 and γ from 0.99 to 1.002 for base station antenna heights of 16, 30, and 40 m. In the case of Lithuania, authors have obtained around 40 for rural area at 160 MHz. At 440 MHz, the corresponding values of E_0 range from 65.2 to 66.19, and γ varies from 0.99 to 1.01.

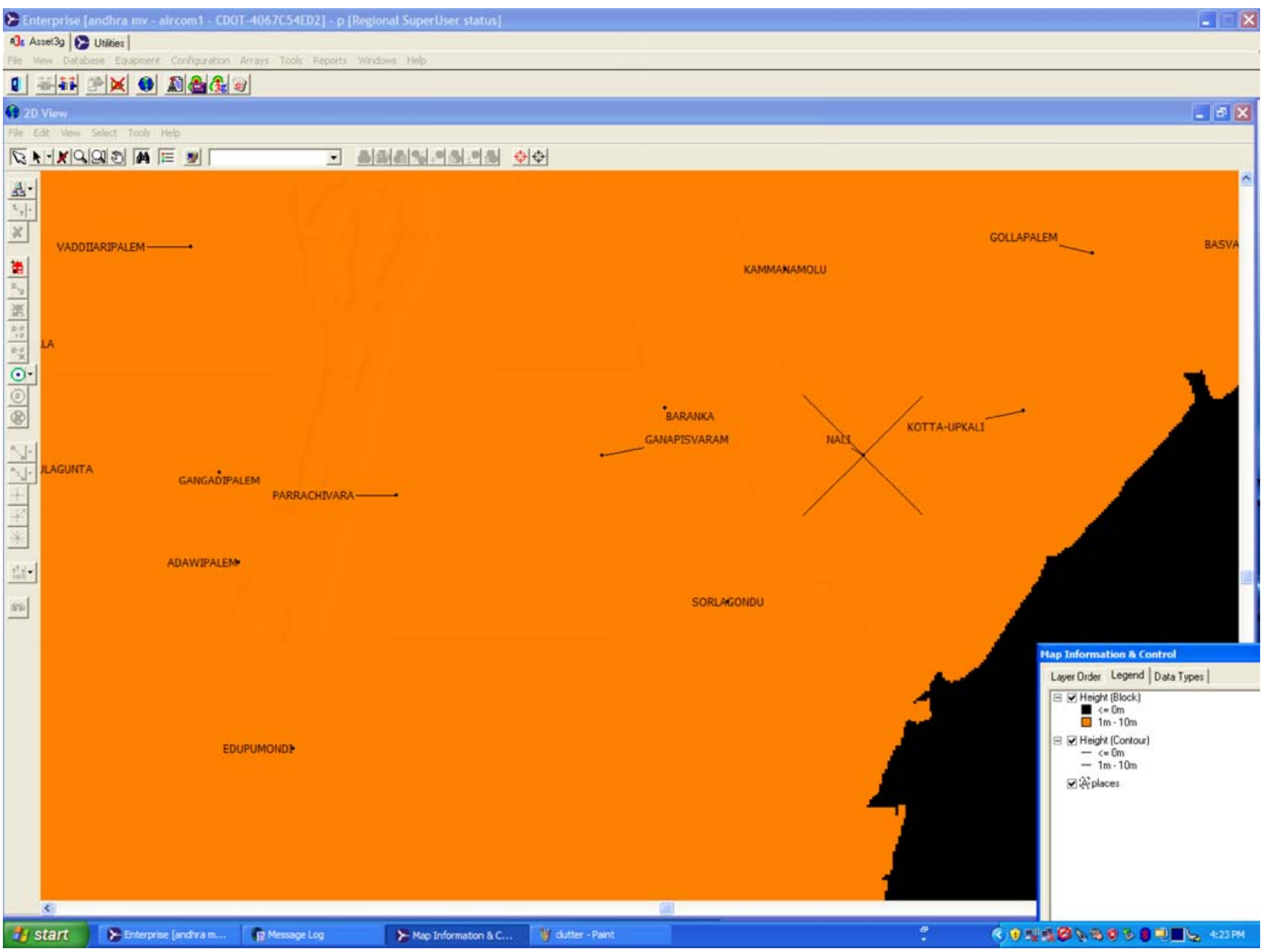

Fig. 8 Terrain variation of south Indian base stations

Table 1 Tuned values for different regions

Transmitting antenna height	320 MHz	E_0				γ			
		440 MHz	150 MHz	Left	Right	440 MHz	150 MHz	Left	Right
Southern region									
40 m		66.19	77.65			1.01	1.00		
30 m		65.23	77.78			0.99	1.002		
16 m		65.97	77.56			1.00	0.99		
Northern and western regions									
40 m	Meerut			50.85	42.22			1.17	0.95
40 m	Muzaffarnagar			55.4	52.71			1.15	1.29
40m	Saharanpur			39.26	–			0.88	–
26 m	Vangani			52.81	25.24			1.31	1.08
25 m	Neral			45.09	–			1.43	
46 m	Pangoli			55.25	–			0.948	–
115 m	Talegaon			59.65				1.8	
60 m	Pune			32.38	–			0.83	–
Eastern region									
37 m	Chakradarpur			–	50.47			–	1.01
37 m	Goilkera			52.35	42.25			1.77	0.939
50 m	Mahadevsal (T.T)			37	26.36			1.11	0.79
22 m	Mahadevsal			15.13	44.39			0.97	1.22
29 m	Posoita			32.38	28.04			0.97	0.89
31 m	Manoharpur			45.35	53.46			0.94	1.35
35 m	Bondamunda			–	52.04			–	1.00
200 m	Rourkela (P&T)			–	55.4			–	1.2
18 m	Jaraikela			43.74	41.34			1.16	0.92

They are almost constant. Russian authors reported 50 and 1.2 at 450 MHz. In the case of northern India rural zones at 320 MHz, values of E_0 varied from 39 to 55, and γ varied from 0.88 to 1.17. In the case of Western India, values of E_0 varied from 32 to 55 and γ from 0.83 to 1.43. In the eastern India, most of the base stations exhibited 40–50, and base stations like Goilkera, Mahadevsal, and Posoita exhibited still lower values. Here, the terrain is steeply changing with some kind of ghat sections and elevated type in between. These lead to high path losses and relatively lower values of E_0 compared with northern, western, and southern paths. Southern paths where measurements were conducted exhibited typical open environment with very smooth changes in terrain. Lowest values are seen in southern India, and highest values are observed in eastern part of India. This shows the widely changing environment of the subcontinent. The parameter E_0 depends on the environment, the frequency, and antenna heights. In a random environment, Blaunstein [10] advocates the general type of Hata equation which is valid for a macro-cell environment.

$$L = a_0 + a_f \log f_{\mathrm{MHZ}} + a_{\mathrm{d}} \log d_{\mathrm{km}} - 10 \log G_1 - 10 \log G_2 + L_{\mathrm{SF}} + L_{\mathrm{FF}} \tag{8}$$

where the parameter a_0 includes the offset and depends on the environment, the frequency, and antenna heights, and a typical value is around 45 dB. This is analogous to E_0 in the above methodology. The parameter a_{f} depends on the environment and additional diffraction losses and as such, typically has free space values between 25 and 30 instead of 20. The parameter a_{d} depends on the environments and has values between 30 and 40. This could be analogous to γ and not equal to it in magnitude. Antenna gains are frequency-dependent balancing out some of the propagation loss. For

Table 2 Route 1 measured in the open region of Indjija

	A_0^1	A_1^1	SD	RMS error	Mean error
LS	45.95	100.6	6.04	36.5	20.2
IRLS	47.91	101.0	6.04	38.0	18.4

Table 3 Route II measured in the sub-urban region of Indjija

	A_0^1	A_1^1	SD	RMS error	Mean error
LS	43.20	68.93	4.96	24.52	17.36
IRLS	44.17	80.55	4.96	27.1	14.56

large angular spreads, the antenna gains will tend to 0 dB independent of their original values.

Simi et al. [11] have proposed modified least square (LS) algorithm that decreases maximum error of predicted signal without influence on standard deviation compared to LS method in Ericsson's TEMS cellphone radio planning tool. Authors have performed RF field measurements carried out at many locations in Serbia. In the case of route 1 (Table 2) measured in the region of Indjija, coefficients A_0^1 and A_1^1 for LS are 45.95 and 100.6, and for iterative re-weighted LS algorithm (IRLS), the values are 47.31 and 101.0. Here, maximal error is decreased while r.m.s. error is increased.

The Ericsson's modification of Okumura–Hata model is known as 9999 algorithm. It is without knife-edge and spherical earth loss contribution given by

$$L = A_0^1 + A_1^1 \log d + A_2 \log H_{\mathrm{eff}} + A_3 \log d \cdot \log H_{\mathrm{eff}} - 3.2[\log(11.75\, H_{\mathrm{m}})]^2 + g(f) \quad (9)$$

where $A_0^1 = A_0 + \mu_{\mathrm{mob}}$, and μ_{mob} is value in dB of land usage (clutter) type where mobile is located, d is the distance from base station antenna to mobile in kilometer. H_{eff} is the effective height of base station antenna, H_{m} is height of mobile antenna in meters, and $g(f)$=44.49 log f −4.78 (log f)^2 where f is frequency in MHz. A perusal of the above with the methodology shows that A_0^1 is analogous to parameter E_0 in our study, and A_1^1 is analogous to B in the Eq. 1 (original Hata equation). It is the coefficient in the distance dependence term.

Simi et al. tuned A_0^1, A_1^1, and their values for open area and suburban area have been presented in Tables 2 and 3. Their values of A_0^1, i.e., 45.95 and 47.31, are comparable to E_0 values of base station Neral under western India and Goilkera, Mahadevsal, and Jaraikela base stations under eastern India. The values of Simi et al. under suburban category in Table 3 also showed similar values for the open area.

In the case of route II (Table 3) measured in suburban area, maximal error is decreased by 2.8 dB, while RMS error is increased by 2.58 dB.

Authors conclude that not only r.m.s. error and standard deviation are important parameters for evaluation of the propagation model tuning process, maximal difference between predicted and measured values has to be also minimized.

6 Conclusions

An exhaustive measurements from various narrowband transmitters in open/rural regions of northern, western, southern, and eastern regions of India have been carried out in the VHF and UHF bands for various antenna heights. The observed signal levels of these measurements were utilized to tune the initial offset and slope of Okumura–Hata model. In the northern region, the offset values are confined between 40 and 55 and the slope (γ) between 0.95 and 1.29. In the western region, they lie in the range of 45–59 and γ values between 0.8 and 1.43. Only the base station Pune exhibited a lower value of 32. This could be due to suburban and medium urban nature of environment prevailing near the base station that dominated the measurements. This leads to an important conclusion that in most of the cases, in this study, medium urban and urban environments exhibit lower values of E_0, but the reciprocal assertion may not be true in all cases. If one has exhaustive measurement values, one can identify the type of environment through the E_0 values. In the eastern region spanning the states of Orissa and Jharkhand, E_0 values vary between 40 and 50 and γ values between 0.9 and 1.35. Only the base stations Goilkera, Mahadevsal, and Posoita exhibited lower values of 15, 26, and 32. This does not mean that the environment is medium urban or dense urban, but steep terrain changes and elevated terrain lead to high path loss values, and hence, small E_0 values. The whole study assumes importance in the context that for a country like India with widely varying environments, same values of E_0 and slope may not hold good, and the values deduced from the present study can be utilized for the design of future mobile communication systems in these regions.

Annexure A

The detailed specifications of receiver RFT SMV-8 are given below.

1. The frequency is subdivided into five ranges: 30–66 MHz, 66–142 MHz, 142–300 MHz, 300–600 MHz, 600–1,000 MHz.

   Error of the frequency scale after calibration onto the next frequency marker, $\pm 3\times10^{-3} f_{\mathrm{input}}$+200 kHz
2. Error with the measurement of voltage ratios.

   Error of the voltage divider within the frequency range 30–300 MHz, ±0.6 dB; 300–1,000 MHz, ±0.9 dB.
3. Input impedance=50 Ω, RF instrument connector series N
4. Selectivity properties

   4.1. Bandwidths 120, 20, 1 KHz (for sweep operation, the additional error of the voltage measurement is ±0.5 dB)

   4.2. IF selectivity

120 KHz bandwidth	Drop	6 dB	40 dB
	Bandwidth	120±20 KHz	<300 KHz
20 KHz bandwidth	Drop	3 dB	40 dB
	Bandwidth	20±5 KHz	<200 KHz

4.3. Image frequency rejection with in the frequency range 30–300 MHz, >80 dB; 300 MHz–1,000 MHz, >60 dB Amplitude and frequency demodulation facility available

5. Receiver sensitivity

12 dB or better for a level of −107 dBm (1 μV). Signal to noise ratio of 50 dB or better for RF level of −87 dBm of 10 μV at antenna port

6. Environmental conditions

Operational conditions class according to GDR standard, TGL 9200 B1.1, TII.

Extended ambient temperature range −30°C to +50°C. Instrument meets the environmental testing requirement according to USSR standard GOST 9763-67, group of instruments IV.

Transmitter was operating on amplitude modulation radiating output power of 5 W with a omnidirectional monopole antenna. Receiving antenna is a yagi with gain of 12 dBi.

Annexure B

Table 4 Details of paths and specifications of experimental measurements

Path	Tx.ant Height (m)	Rx.ant. Height (m)	Freq. (MHz)	Power (e.r.p) (W)
Southern region				
Coastal regions Andhra Pradesh	16, 30, 40	3	150,440	5
Northern region train measurements				
Meerut	40	3	320	5
Muzzafarnagar	40	3	320	5
Saharanpur	40	3	320	5
Western region train measurements				
Vangani	26	3	320	5
Neral	25	3	320	9
Pangoli	46	3	320	5
Talegaon	115	3	320	9
Pune	45	3	320	5
Eastern region train measurements				
Chakradharpur	37	3	320	5
Goilkera	37	3	320	9
Mahadevsal	22	3	320	9
Mahadevsal (tunnel top)	50	3	320	9
Posoita	29	3	320	9
Manoharpur	31	3	320	5
Jaraikela	18	3	320	9
Bondamunda	35	3	320	5
Rourkela (P&T)	200 (hilltop)	3	320	9

Table 5 Mean errors (ME) and standard deviations (SD) of Hata's prediction method (in dB)

Base station	Mean error (dB)	SD
Northern India		
Meerut	−1.36	3.23
Muzafarnagar	−2.57	5.55
Saharanpur	−1.81	3.12
Western India		
Vangani	−9.10	11.55
Neral	9.99	5.01
Pangoli	−16.17	11.83
Talegaon	−3.20	9.92
Pune	0.31	5.74
Eastern India		
Chakradharpur	−1.5	7.75
Goilkera	−13.1	10.70
Mahadevsal (tunnel top)	−18.0	7.39
Mahadevsal	−24.7	12.56
Posoita	−19.5	2.89
Manoharpur	−5.24	6.64
Bondamunda	0.75	6.28
Rourkela	−12.44	9.04
Jaraikela	−13.1	5.68
Southern India		
440 MHz, 40 m	−16.5	0.21
440 MHz, 30 m	−16.5	0.18
440 MHz, 16 m	−6.0	0.70
150 MHz, 40 m	−20.49	0.23
150 MHz, 30 m	−20.57	0.46
150 MHz, 16 m	−20.46	0.21

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