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Signal Strength Measurements and Coverage Estimation of Mobile Communication Network Using IRS-IC Multispectral and CARTOSAT-1 Stereo Images

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The rapid growth of wireless communications requires efficient network planning of cellular mobile communication. The primary operations in the telecommunication network industry include network site identification and planning, signal strength measurements with coverage estimation for the expansion of system. There are many models developed by electrical engineers in the past decades to analyze telecom site deployment and design for cellular networks. But out of these models none of them provides a final solution because each technique has some particular limitation in its application. The generic radio wave propagation prediction algorithms based on computer databases or empirical results give only approximate coverage, which are not suitable for detailed network design. The efficiency of radio wave propagation prediction system can be improved greatly, with powerful capability of handling geo-spatial data through Remote Sensing and GIS techniques. Signal strength predicted by integration of NDVI methodology and watershed analysis taken into account for factors like terrain height, building height and distance from tower which will be compared with field measurements for validation of the model. The variation in signal strength depends upon many factors, such as the type of trees, trunks, leaves, branches, their densities, and their heights relative to the antenna heights. When the signal strikes the surface of a building, it may be diffracted or absorbed. This is an important consideration in the coverage planning of a radio network. Foliage loss is caused by propagation of the radio signal over vegetation, principally forests. Foliage loss depends on the signal frequency and varies according to the season. According to this quantitative analysis, RS/GIS oriented signal strength prediction method using NDVI found significantly improve the prediction

quality compared to the theoretical free space model which does not take into account any local terrain feature effects. The multi spectral and stereo satellite data in conjunction with GIS/GPS techniques can be utilised to formulate suitable plans and strategies for an effective telecom planning and development.

1. Introduction:

Digital mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. High-resolution space-borne remote sensing image data show a high level of detail and provide opportunities to be integrated into mapping applications. The demand for accurate and up-to-date spatial information is increasing and its availability is becoming more important for a variety of tasks. The successful launch of IRS-1C satellite with the availability of high spatial resolution data in 5.8m in single panchromatic band (0.5-0.75 μ m) and 23m (LISS) resolution data in four multispectral bands along with stereo and revisit capability of days, it would now be possible to explore its potential either singularly or in combination in different areas of telecom survey and planning, wireless radio coverage, landscape design, base map preparation etc.

The primary operations in the telecommunication network industry include network site identification and planning, signal strength measurements with coverage estimation for the expansion of system. In the past decades electrical engineers developed many models to analyze telecom site deployment and design for cellular networks. But out of these models none of them provides a final solution because each technique has some particular limitation in its application. The quality of the mobile service relies on the signal strength available at the user's location. The signal originates from a network of antennas sited at strategic locations across the landscape. However, trying to work out the best network of antennas over a large area is difficult and is dependent on numerous factors, which include land cover, terrain undulations, building heights, composition and morphology. Remote Sensing technology and Geographic Information System (GIS) can be incorporated into this procedure because most of the factors in radio wave propagation are geographic features. This modeling enables field engineers to conduct wave propagation studies, and identify the optimal tower location, height, and signal strength. Therefore Remote sensing and GIS modeling has become a critical component in developing our wireless networks around us and the better data models we are provide to our field engineers, the more reliable our wireless services. It is necessary to assess the influence of vegetation on the quality of radio communication, especially for radio communication in forested terrains. The generic radio wave propagation prediction algorithms based on computer databases or empirical results give only approximate coverage, which are not suitable for detailed network design. The efficiency of radio wave propagation prediction system can be improved greatly, with powerful capability of handling geo-spatial data through Remote Sensing and GIS techniques.



2. Study Area:

The coastal district Udupi of Karnataka state falls along the west coast of peninsular India and is separated from the rest of peninsula by towering high Western Ghats. The district lies between $13^{\circ} 04'$ and $13^{\circ} 59'$ North latitude and $74^{\circ} 35'$ and $75^{\circ} 12'$ East longitude covering an area of 3575 sq km. It is about 88 km in length and about 80 km in widest part and is bounded by Uttara Kannada district in the North, by Shimoga and Chikamagalur district in the East and by Dakshina Kannada district in the South as shown in Fig.1.

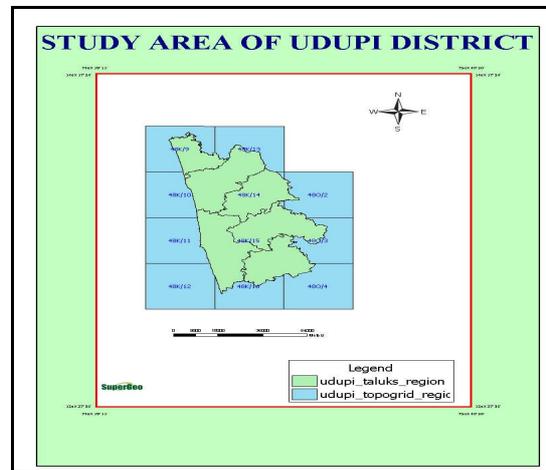


Fig.1 Study area of Udupi District, Karnataka state.

3. Materials and Methods:

The study mainly involves the applications of Remote Sensing and GIS techniques. A major part of the work has been carried out by making use of the satellite data (both hard copies and digital data), SOI topographical maps, Google maps and other maps. The satellite data taken for this study are the multispectral Linear Imaging Self Scanning-III (LISS-III) sensor data of the Indian Remote Sensing satellite IRS-1C acquired on 1st March 2000. These data primarily has been used for clutter analysis and for data integration with PAN, and for the extraction of road networks. This information derived from the satellite data was integrated with raster GIS modeling. High-resolution panchromatic data (PAN) of the Indian Remote Sensing satellite CARTOSAT-1 was used for this study. The PAN sensor was primarily chosen for its stereo capability. The stereo pair data were acquired on 24th November 2007, selected due to good overlap and a fairly good base to height ratio of 0.68. These data were used to generate the DEM of the study area. In particular, this study addresses how to develop a surface model using IRS-1C LISS-III and CARTOSAT-1 stereo pair.

The research work for DEM generation and stereo processing is created in Lieca Photogrammetry Suite (LPS) S/W and the CARTOSAT-1 stereo images were imported.



The interior orientation has been computed for both fore and aft camera images (Band A & Band F) using RPC. 15 GCPs have been identified on both the images for exterior orientation computation. Image matching has been performed between the fore and aft images. A total number of 6326 match points called as Tie points have been generated at more than 0.80 correlation coefficients. Triangulation has been performed with RPC at 2nd order polynomial refinement. The regular DEM has been generated at 1-5m grid interval. Finally Ortho-image is generated and features have been extracted in 2D mode by on screen digitization. The same model has also been used for 3D feature extraction. All the man made structures (buildings, fence etc.) and Trees have been captured in 3D environment in stereo mode. The accuracy achieved for DEM and orthoimage is better than 5m. Finally using SuperGIS 3D analyst, 3D modeling will be generated using GIS environment by which various 3D analysis have been used.

4. Results and Discussion:

The larger number of users, especially mobile users, has resulted in network planners increasing system capacity by locating transmission antennas at heights lower than surrounding trees and buildings. Propagation algorithms that determine path loss and signal coverage are critical for successful wireless network planning and deployment. Trees singly or in a group can be found in cells of land mobile systems as well as in fixed access systems. The trees act as obstacles in the radio path causing both absorption and scatter of radio signals. The scattering and absorption need to be accounted for in radio planning tools to improve their accuracy, with improved co-ordination of radio links and optimum use of the radio spectrum. Depolarisation of the incident signal arises when it encounters a scattering medium such as vegetation. Models are available for predicting depolarization from backscattered signals such as those encountered in remote sensing. Prevalence of mobile radio systems requires studies of spectral characteristics of electromagnetic wave attenuation by vegetative media in wide frequency range.

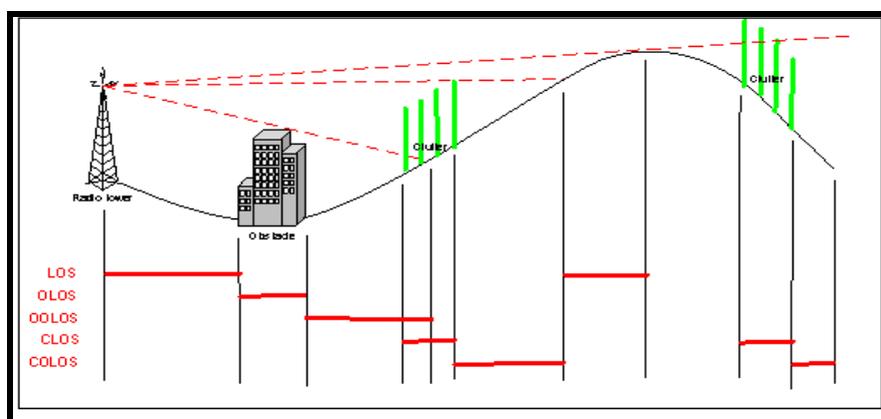


Fig.2 Showing the line of sight by terrain features



4 a) NDVI Method:

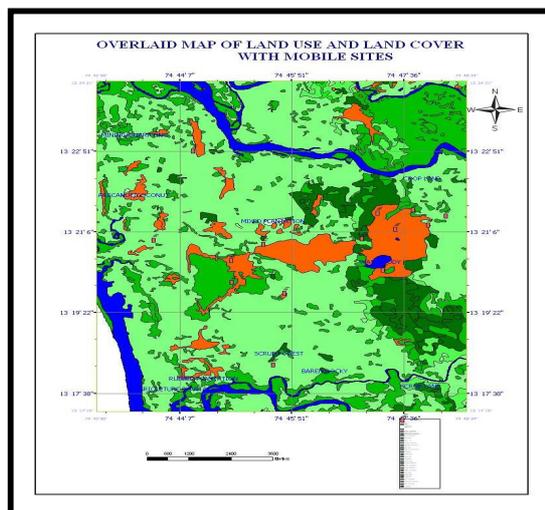
NDVI is an index of vegetation health and density. Clouds, water, and snow have larger reflectance's in the visible than in the near infrared while the difference is almost zero for rock and bare soil. Vegetation NDVI typically ranges from 0.1 up to 0.6, with higher values associated with greater density and greenness of the plant canopy. Surrounding soil and rock values are close to zero while the differential for water bodies such as rivers and dams have the opposite trend to vegetation and the index is negative. λ_{NIR} and λ_{red} are the reflectance in the near infrared and red bands respectively in the case of IRS-IC LISS III data.

NDVI is calculated and applied for each pixel of sample areas of study area as per the equation $NDVI = (B3 - B2) / (B3 + B2)$. The DN values of NIR band (B-3 band) in built up areas shows 50-100 ranges whereas in Red Band (B-2) in same built up areas shows range from 45-95. Hence NDVI for built-up areas becomes 0.1 to 0.35 and Fig.3 showing the thematic GIS map for the same built-up area overlaid with mobile site for investigation. The DN values of NIR band (B-3 band) in water areas shows 25-35 ranges whereas in Red Band (B-2) in same built up areas shows 15-20 by which NDVI for built-up areas becomes negative values. Fig.4 showing the thematic GIS map for the same areas nearby with mobile sites for investigation. The DN values of NIR band (B-3 band) in vegetation/forest/park areas shows 25-35 ranges whereas in Red Band (B-2) in vegetation areas shows 85-135 by which NDVI for vegetation areas becomes 0.1-0.7 values. Fig.5 showing the thematic GIS map for the same area of covering vegetation nearby with mobile sites for investigation. Hence the NDVI of built up areas will become positive values ranging from 0.1- 0.2 and signal strength in these regions measured with the help of GPS/RF Signal db meter and found excellent values ranging from -40 to -70dB. In the same way NDVI in water regions shows negative values and signal strength ranging from -20dB to -40dB observed. But in the case of Vegetation NDVI typically

ranges from 0.1 up to 0.6, with higher values associated with greater density and greenness of the canopy. Hence the measured filed strength values decreases from - to -110dB values as NDVI increases.

plant

70dB





ImageInfo (naveennndvi.img)

File Edit View Help

Layer 1

General Projection Histogram Pixel data

Row	559	560	561	562	563
1510	000.165	000.258	000.298	000.288	000.281
1511	000.116	000.324	000.270	000.302	000.291
1512	000.086	000.405	000.306	000.278	000.328
1513	000.096	000.459	000.393	000.282	000.325
1514	000.110	000.453	000.427	000.281	000.341
1515	000.105	000.282	000.378	000.295	000.364
1516	000.127	000.188	000.263	000.281	000.353
1517	000.141	000.184	000.299	000.315	000.329
1518	000.141	000.189	000.276	000.248	000.259
1519	000.140	000.158	000.159	000.183	000.250
1520	000.140	000.136	000.151	000.266	000.301
1521	000.143	000.075	000.165	000.407	000.384
1522	000.158	000.039	000.099	000.248	000.365
1523	000.161	000.041	000.096	000.231	000.364
1524	000.143	000.056	000.144	000.270	000.411
1525	000.150	000.059	000.174	000.379	000.307
1526	000.147	000.056	000.158	000.403	000.307
1527	000.148	000.075	000.148	000.352	000.388
1528	000.176	000.107	000.138	000.240	000.341
1529	000.195	000.150	000.137	000.159	000.299

Fig.3 Thematic map showing built-up areas overlaid with mobile sites under investigation and NDVI closes to low positive values

ImageInfo (naveennndvi.img)

File Edit View Help

Layer 1

General Projection Histogram Pixel data

Row	88	89	90	91	92
0	000.390	000.386	000.391	000.368	000.373
1	000.455	000.385	000.377	000.382	000.389
2	000.423	000.364	000.381	000.382	000.369
3	000.363	000.389	000.416	000.399	000.410
4	000.307	000.408	000.418	000.407	000.412
5	000.241	000.371	000.378	000.357	000.409
6	000.237	000.339	000.390	000.353	000.441
7	000.200	000.328	000.393	000.371	000.405
8	000.038	000.232	000.299	000.333	000.361
9	-000.070	000.149	000.248	000.311	000.400
10	-000.125	000.051	000.146	000.276	000.409
11	-000.276	-000.164	-000.083	000.129	000.309
12	-000.310	-000.246	-000.213	000.013	000.253
13	-000.279	-000.233	-000.241	-000.056	000.187
14	-000.258	-000.298	-000.358	-000.175	000.040
15	-000.233	-000.309	-000.385	-000.220	-000.046
16	-000.207	-000.298	-000.333	-000.200	-000.129
17	-000.233	-000.322	-000.310	-000.220	-000.250
18	-000.279	-000.345	-000.288	-000.220	-000.296
19	-000.276	-000.357	-000.288	-000.233	-000.286

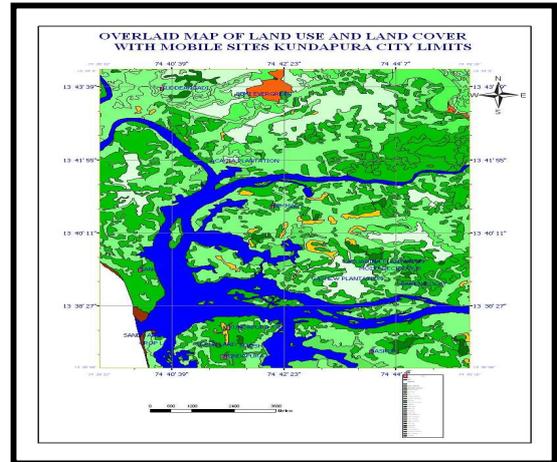


Fig.4 Thematic map showing water areas overlaid with mobile sites under investigation and NDVI closes to negative values

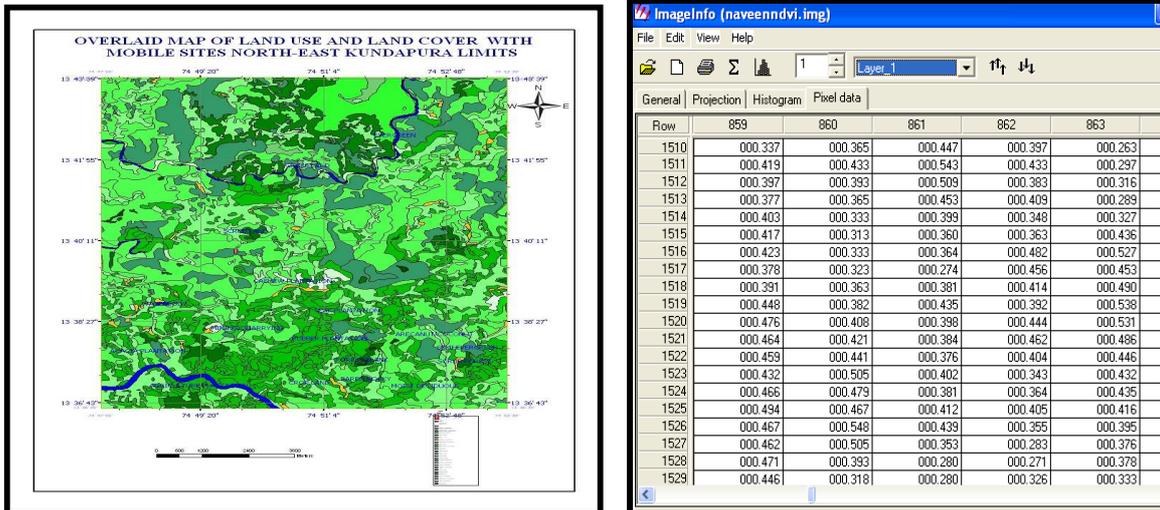


Fig.5 Thematic map showing vegetation areas overlaid with mobile sites under investigation and NDVI values close to high positive values

It can be shown that propagation prediction is a vital step in network design and has to be accurate to achieve effective network coverage. Hence signal strength measurement has been measured in several places by choosing urban areas at udupi, Manipal, Kundapura and highly vegetation places like Kemmannu, Hebri, Karkala and padubidri as shown in Fig.6.

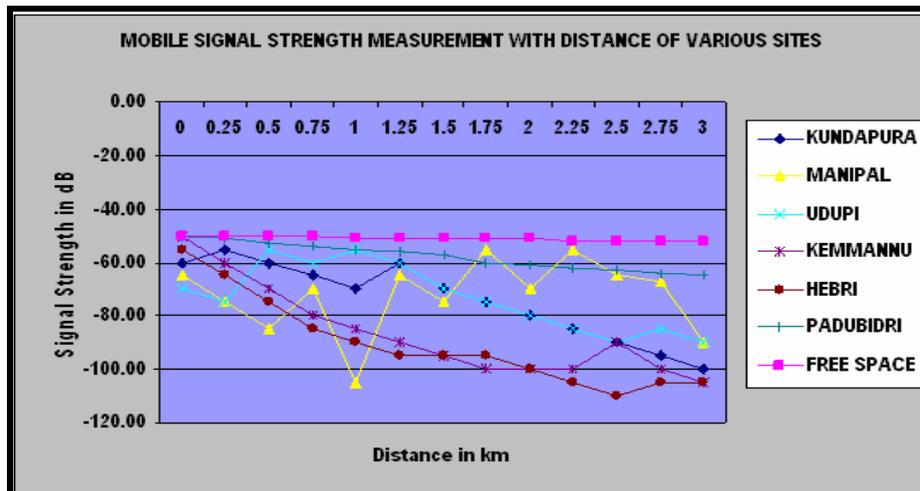


Fig.6 Mobile Signal Strength measurement with distance of various sites

These results were compared with the predicted values of signal measurement derived from NDVI and tabulated as shown in Table 1. The comparative chart of both the methods has been drawn as shown in Fig.7 and found that values remains almost similar



except lower values from the predicted values. The importance of tuning propagation prediction models is vital to achieve high levels of accuracy. Various approaches of tuning can be used depending on the type of propagation model used.

Sl. No	Latitude	Longitude	Elevation in meter	Measured Signal strength (Field Survey) in dB	Predicted Signal Strength (NDVI Method) in dB
1	13° 2' 28"	74° 46' 50"	69.12	-89.23	-98.18
2	13° 23' 39"	74° 42' 44"	18.24	-77.61	-98.67
3	13° 11' 14"	74° 47' 30"	34.23	-84.41	-84.42
4	13° 20' 80"	74° 47' 16"	27.41	-56.47	-74.95
5	13° 07' 51"	74° 46' 82"	16.34	-79.56	-82.69
6	13° 02' 19"	74° 48' 12"	06.21	-73.05	-83.22
7	13° 00' 46"	74° 51' 10"	51.08	-79.65	-81.8
8	13° 19' 55"	74° 44' 29"	27.12	-68.57	-83.26
9	13° 17' 27"	74° 55' 34"	47.01	-79.77	-87.51
10	13° 11' 55"	74° 44' 37"	09.08	-69.72	-78.12
11	13° 11' 45"	74° 51' 08"	75.02	-74.94	-92.6
12	13° 15' 13"	74° 50' 51"	47.23	-92.93	-92.05
13	13° 20' 19"	74° 50' 17"	42.43	-82.66	-93.53
14	13° 33' 06"	74° 44' 40"	22.04	-74.29	-84.28
15	13° 34' 00"	74° 43' 53"	26.74	-79.05	-83.16
16	13° 31' 38"	74 48' 05"	30.03	-79.91	-88.31
17	13° 34' 18"	74° 44' 17"	26.12	-73.79	-92.87
18	13° 34' 55"	74° 41' 08"	05.04	-76.52	-80.57
19	13° 19' 34"	74° 43' 50"	06 34	-64.3	-77.42
20	13° 42' 02"	74° 38' 45"	02.07	-77.7	-83.43
21	13° 42' 20"	74° 40' 07"	27.06	-79.47	-91.84
22	13° 19' 34"	74° 43' 50"	06.04	-52.48	-77.58
23	13° 12' 07"	74° 45' 25"	12.31	-53.13	-80.45
24	13° 19' 56"	74° 42' 46"	01.24	-21.34	-50.26
25	13° 05' 15"	74° 46' 53"	05.33	-38.73	-55.79
26	13° 11' 55"	74° 44' 37"	09.02	-57.01	-62.82
27	13° 22' 05"	74° 51' 08"	15.65	-25.16	-59.5
28	13° 36' 28	74° 40' 41"	05.08	-30.56	-65.65
29	13° 43' 39"	74° 41' 46"	32.05	-89.23	-98.18
30	13° 44' 21"	74° 38' 34"	12.08	-77.61	-98.67
31	13° 41' 14"	74° 46' 37"	67.03	-84.41	-84.42
32	13° 25' 06"	74° 45' 47"	18.03	-56.47	-74.95
33	13° 36' 08"	74° 46' 18"	28.04	-89.23	-98.18
34	13° 32' 56"	74° 45' 44"	29.01	-77.61	-98.67
35	13° 17' 36"	74° 56' 01"	89.09	-84.41	-84.42
36	13° 41' 23"	74° 40' 10"	30.06	-56.47	-74.95
37	13° 21' 00"	74° 47' 09"	97.00	-89.23	-98.18
38	13° 40' 29"	74° 39' 02"	10.03	-57.61	-68.67

Table 1 Comparison of signal strength measurement by field and NDVI method



It is found that predicted and measured values of signal measurements of all this approach, the information rich radio-wave tuning approach emphasizes accuracy since it considers a small section of the network allowing for detailed modelling of the physical environment. This detailed modelling of the environment improves the propagation model to closely approximate the real field strength as shown in this study.

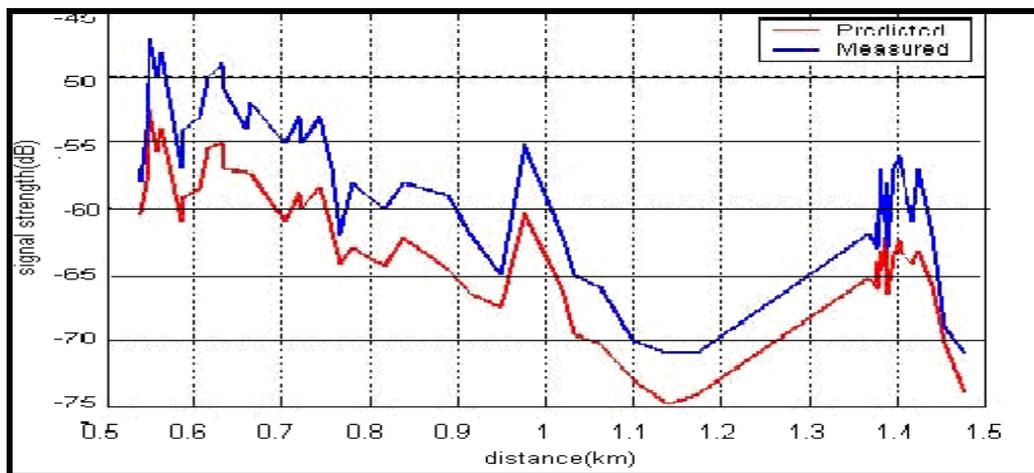


Fig.7 Comparison of signal strength measurement by field and NDVI method with observed slight difference as factors like terrain height, building height and distance from tower not applied

4 b) Terrain Modelling and Viewshed Analysis:

As the NDVI method not considered factors for the elevation, terrain height and building heights, it is very essential for the study of 3D model of the terrain for studying these factors. Environment modelling involves determining the effects of the terrain features between the BTS and the specific position within the cell. Modelling of the environment includes the signal reduction due to the distance from the BTS as well as diffraction losses caused by buildings or other terrain features between the BTS and specific points within the cell. Furthermore, since radio propagation conditions vary significantly in typical operating environments, signal path loss models normally account for the statistical variability of the received signal by incorporating suitable power margins for the purpose of cell.

In Geographic Information System environment, viewshed analysis is the result of a function that determines, given a terrain model, which areas on a map can be seen from a given point(s), line or area. In the communications industry, this function has been used to model radio wave coverage and to site transceiver towers for cellular phones. For wireless telecommunications providers, a GIS viewshed analysis has great potential to help plan network extensions by siting transmitter towers. A viewshed is the result of a function that determines which areas of a map can be seen from a given point, line, or



area. Wireless telecoms provide telecommunications access by using portions of the radio spectrum to transmit data. If the wavelength used is a Line-Of-Sight frequency, then a viewshed should show the regions that can receive a signal from a potential tower site. So, given the LOS properties of the wavelength, a viewshed would show the zones able to receive data, called a communications viewshed or 'commshed'. From that information, further viewshed analyses would aid in creating a chain of towers to cover a desired region. Next, building height data was recorded for the whole study area and about 1200 building sites are extracted from satellite data as shown in Fig.8. The building heights were added as a new column in the building layer of GIS.

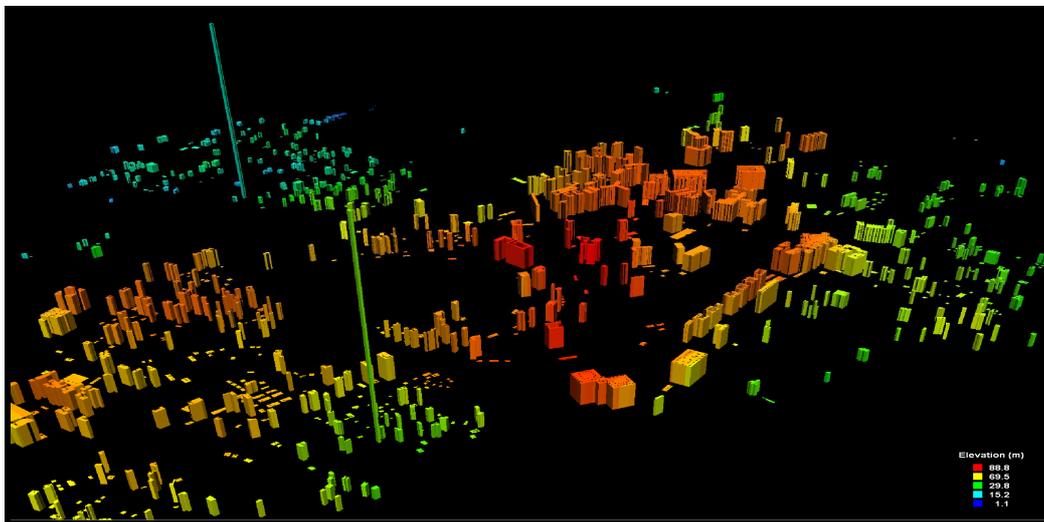


Fig.8 Representation of DSM as buildings with elevation and integrated with mobile sites

The GIS used in this study was SuperGIS (version 3.0 with Spatial Analyst and 3D Analyst extensions). GIS viewshed algorithm treats the targets and origin of the viewshed as points and uses linear interpolation between grid neighbors to infer elevations from the DEM. It also allows limitations to be put upon the viewshed. These limitations are elevation offsets for the origin (transmitter) and targets (receivers), vertical and horizontal constraints of the transmitter beam, and distances from the transmitter to begin and end the viewshed computation. In order to create a view shed that includes building heights in its analysis, the building elevations must be added to the ground elevations at the correct locations. The first step in this process was to convert the buildings layer to a grid with the elevations as the cell values; all non-building cells were assigned a value of zero. Next the building grid and the DEM were resampled from 10 meter resolution to 5 meter resolution to allow for a more accurate overlay of the building heights onto the terrain elevations. This resampling caused a significant increase in the number of cells to be processed, so as to reduce processing time; both grids were clipped to the study area. The roads layer was also clipped for display purposes. The fourth step was to create a new

elevation grid by adding the building grid to the terrain grid. A viewshed analysis was then performed using the buildings-Added DEM and the transmitter site as the origin. Fig.8 shows the effects of the buildings on the elevation model along with site locations for viewshed analysis. The red mark shows the higher elevation having higher signal strength whereas blue colour shows lowest elevation and these are not getting signal and treated as weak points.

Fig.9 shows the effects of the buildings on the elevation model along with site locations for viewshed analysis in another direction overlaid with 1 meter and 5 meter contour data for the viewshed analysis. The low lying areas of the terrain clearly visible in this DSM as marked weak points of the area. Comparison of signal strength measurement by the combination of NDVI method and viewshed analysis, the prediction methodologies taken into account for factors like terrain height, building height and distance from tower with field measurements are recorded as per Table 2. The results are verified and found to be very similar as shown in Fig.10.

Sl. No	In View?	Obstruction	Signal Strength using NDVI method and Terrain Factors	Signal Strength measured in Field
1	YES	NONE	-26.66	-24.78
2	NO	BUILDING	-48.5	-47.5
3	YES	VEGETATION	-32.5	-30.4
4	NO	BUILDING	-71.5	-65.5
5	NO	BUILDING	-77.2	-75.2
6	NO	BOTH	-64.2	-60.1
7	YES	NONE	-38.6	-35.4
8	NO	BUILDING	-66.2	-63.8
9	NO	BUILDING	-75.9	-71.6
10	NO	BUILDIN	-59.9	-56.3
11	NO	BUILDIN	-61.88	-59.8
12	NO	BUILDIN	-56.98	-54.7
13	YES	VEGETATION	-54.48	-53.1
14	NO	BUILDIN	-66.91	-64.4
15	NO	BOTH	-74.17	-71.2
16	NO	BOTH	-70	-68.5
17	NO	BOTH	-86.94	-81.5
18	NO	BOTH	-65.68	-61.5
19	NO	BOTH	-72.62	-71.3
20	NO	BOTH	-60.45	-54.3
21	YES	VEGETATION	-44.85	-42.1
22	YES	NONE	-32.74	-30.9
23	NO	BOTH	-59	-54.6
24	NO	BOTH	-69.58	-67.5
25	NO	BOTH	-63	-60.5
25	NO	BUILDIN	-50.8	-47.5
26	NO	BUILDIN	-82.39	-80.6
27	NO	BUILDIN	-78.23	-74.45
28	NO	BOTH	-87.14	-85.32
29	NO	VEGETATION	-46.9	-43.5
31	YES	NONE	-32.62	-30.78
32	YES	NONE	-40.43	-38.78
33	NO	BUILDIN	-62.23	-60.15
33	NO	BOTH	-83.64	-79.57
34	NO	BUILDIN	-76.36	-73.54
35	NO	UNKNOWN	-67.02	-64.32
36	NO	BUILDIN	-101.86	-97.53
38	NO	BOTH	-40.17	-37.25
39	NO	BUILDING	-66.25	-63.25
40	NO	BUILDING	-67	-65

Table 2 Recorded signal strength data for all points

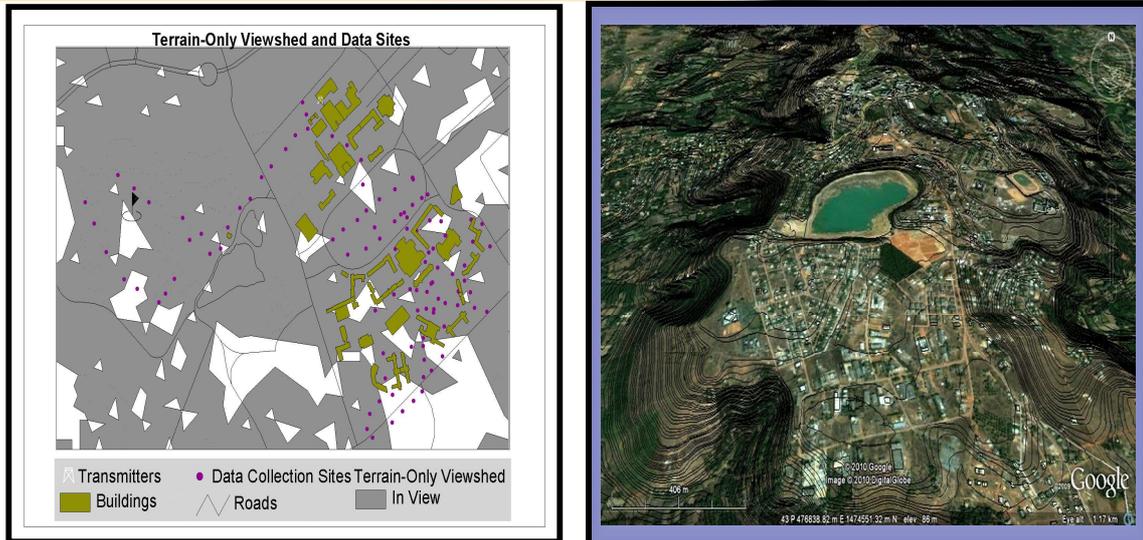


Fig.9 Representation of Terrain and Buildings in view as Line of Sight and Overlaid image of buildings contours of 1m and 5m of the same area over Google server.

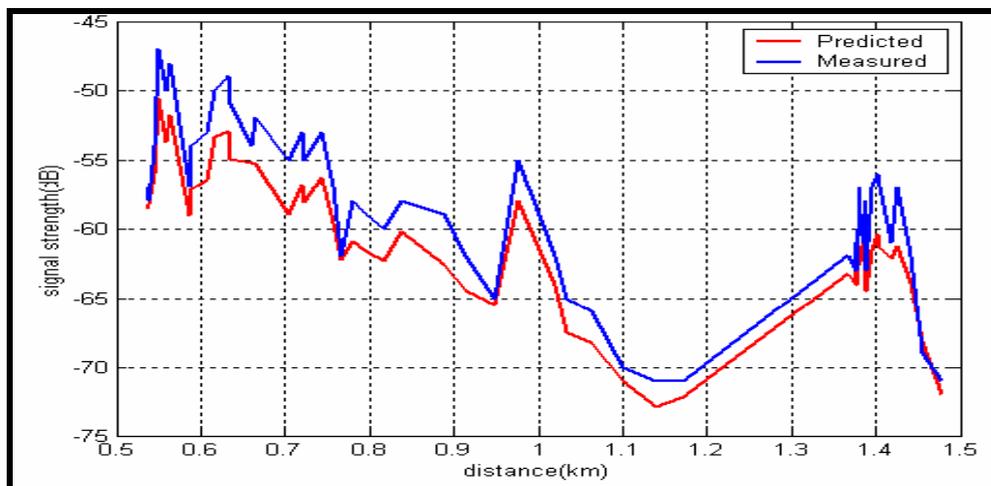


Fig.10 Comparison of signal strength measurement by field and NDVI method, observed similar as RS/GIS viewshed analysis employed for factors like Terrain height, building height and distance from tower

According to this quantitative analysis, RS/GIS oriented signal strength prediction method using NDVI found significantly improve the prediction quality compared to the theoretical free space model which does not take into account any local terrain feature effects. Because of the lack of building data in the NDVI, the accuracy of predicting a particular point's visibility is not very high. With building height data included in the viewshed model, the viewshed analysis along with NDVI method could be used to



predict the extent of a LOS area and produces a more precise analysis, thereby allowing a fine sketch of the coverage layout of transmitter towers can be made. The largest impediment to increasing the predictive accuracy of the viewshed appears to be input data resolution and accuracy. Secondary concerns are the addition of vegetation data and the radio frequency's variance from true line of sight activity (possible bends and bounces of the radio wave). Based upon the NDVI method of measuring signal strength of mobile sites with integrated with GPS, the coverage map of Minimal City mobile tower shown as Fig.11

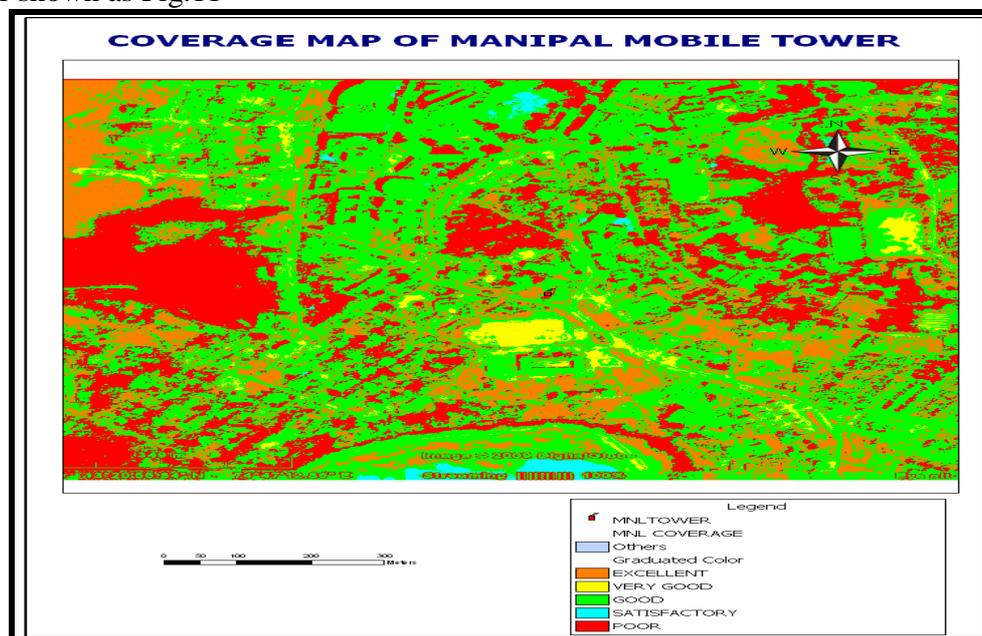


Fig.11 Coverage map of manipal mobile tower

7. Conclusions:

Theoretically it is possible to exactly predict the strength of the signal from any transmitter at any other location if all the elements of the propagation environment are correctly taken into account. In so called “free space” (actually a vacuum), there are no elements in the propagation environment and the signal strength at some distance from the transmitter can be exactly calculated. It is found that RS and GIS oriented signal strength prediction can significantly improve prediction quality compared to the theoretical free space model which does not take into account any local terrain feature effects. The study also suggested that future research in radio wave propagation modeling and analysis should be carried out in a more strategic way and field measurement should provide more even representation of land cover types in order to make the statistical analysis more efficient. The multi spectral for spatial analysis and stereo satellite data for obtaining terrain height information in conjunction with GIS/GPS solution have helped to

formulate and derive an algorithm for calculating signal strength and coverage estimation.

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