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A novel geospatial approach for identifying optimal sites for setting-up of mobile telecom towers strategically

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Abstract: This paper conveys the effective utilization of geospatial technology for identification of optimal sites for setting-up of new telecom towers strategically. Both proximity and viewshed analysis have been adopted to identify the uncovered villages by the existing telecom towers. Multi-criteria spatial modeling using fuzzy membership based overlay function has been utilized for selection of suitable sites. Overlapping coverage zone (OCZ) based on the intersection of radial coverage of telecom towers is proposed to optimize the locations with the least number of telecom towers to cover uncovered villages. A case study on West Khasi Hills district of Meghalaya, India has been demonstrated and reported here.

Keywords: Geospatial technology, Optimal sites, Spatial modeling, Telecom towers

1. Introduction

India has witnessed an exceptional expansion in the availability of economical telecom services. Over the last decade, significant developments have taken place in the telecom sector. These changes have been in the arena of institutional reforms as well as technological advances. The growth in information technology, which has enabled the growth of the telecom sector, has, at least to some extent, relieved the constraints on growth imposed by inadequate and expensive transport facilities. People from all parts of the population are now using cellular telephone phone and accessing the internet for viewing/retrieval of information and e-mail. The impact of communication networks will surely benefit in improving the living conditions in the world today. Nevertheless, among the various states of India, it is considered that there is a significant interruption in the provinces of North Eastern Region (NER) of India in terms of tele-density. As the whole country is moving towards next generation network and data oriented services, however, a large number of villages in NER do not have 2G coverage. The primary operations in the telecom network industry may include site identification and planning, measurements of signal strength with coverage estimation for the expansion of the system. In general, the reason for low tele-density and gap in telecom coverage in NER are due to the lack of necessary infrastructures for the establishment of telecom network and tough terrain. Hence, establishing the telecom towers to cover all the uncovered villages of NER is now high priority. Effective utilization of geospatial technology can be adapted for locating the uncovered villages of the region and to identify the optimal sites for setting-up of new telecom mobile towers to connect all the uncovered villages with the rest of the country.

1.1 Geospatial technology for optimal site selections

A number of studies have been reported for selection of optimal sites for development of infrastructure and other natural resources applications using geospatial techniques. Multi-criteria spatial modeling enabled by spatial analysis is one of the most effective tools for the growth of a spatial decision support system (SDSS). It not only improves the management, analysis and presentation of any SDSS, but also supports spatial analysis and modeling within the geographic and the other spatially defined data (Oledzki, 2004). Election Management System (EMS) proposed by Chutia (2011) using multi-criteria modeling was found in getting to more practical policies while conducting the election processes viz. in examining the numbers of electors in polling stations, location of emergency services, preparing the transportation budget, manpower deployment, etc. Rahmaniati and Yusrin (2014) developed a descriptive method using GIS for improving infrastructure services of the city public health. However, the model requires spatial modelling based on statistical data to improve the monitoring and planning of health services. Baidya et al. (2014) proposed an effective fuzzy overlay function for multi-criteria spatial modeling for preparation of the land resources map and very effective for planning agricultural activities.

Guan et al. (2016) developed a spatial fuzzy multi-criteria evaluation model to determine agricultural feasibility in China based on physical variables (accumulated temperature, sunshine, precipitation, hydrology, elevation and soil properties). GIS-based Analytical Hierarchy Process (AHP) was used as a multi-criteria decision making model for evaluation of land suitability for urban land-use planning (Ullah and Mansourian,2016). Multi-criteria analysis was carried out by Suryabhagavan et al. (2015) for identification of potential ecotourism sites in Hawassa town and its surroundings, Ethiopia. Weight and score were given to each of the parameters depending upon its importance in eco-tourism suitability.

1.2 Contributions

The study has been carried out with the following contributions.

- Identification of uncovered villages by existing telecom towers using proximity and viewshed analysis.
- Selection of suitable sites for construction of proposed telecom towers using fuzzy overlay and proximity analysis.
- To define the optimal sites for proposed telecom towers using the minimum overlapping zone concept

2. Materials and methods

2.1 Study areas

West Khasi Hills district is one of the 11 districts of Meghalaya, India; lies between 25˚ 17' 40.45" N to 25˚ 51' 35.746" N latitude and 90˚ 44' 29.544" E to 91˚ 49' 42.092" longitude. West Khasi Hills district of Meghalaya covers an area of 828.74 km^2 with a total population of 45,262 as per 2011 census. Fig. 1 shows the Cartosat-1 image of the West Khasi Hills district. Nongstoin is the district headquarter located at an altitude of 1409m above sea level and 96km away from the state capital, Shillong by National Highway 44 East (NH44E). Meghalaya has great broadband internet connectivity.

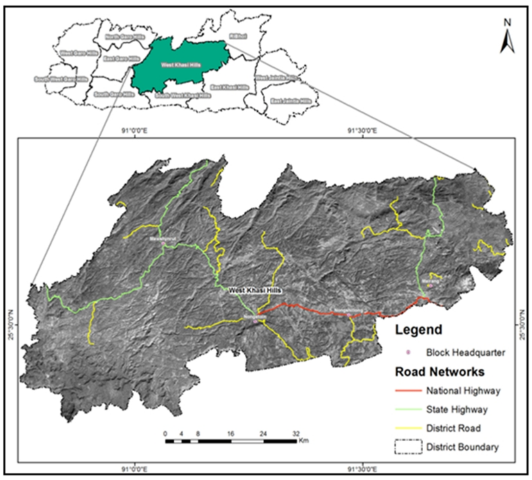

Figure 1: Cartosat-1 image of West Khasi Hills district of Meghalaya

Poor cellular connectivity in various regions of Meghalaya continues to bring endless inconvenience to the occupants of such areas that generally lie along the international border with Bangladesh. Adding to the woes of the people is the alleged indifference of private telecommunication companies which refuse to venture into such areas. A major portion of the West Khasi Hills district like Ranikor and other places is totally disconnected from the mainland. Nevertheless, those situations are easily covered by Bangladeshi telecommunication companies like BD link and Grameen phone. Coverage of existing telecom towers in West Khasi Hills district is depicted in the Fig. 2.

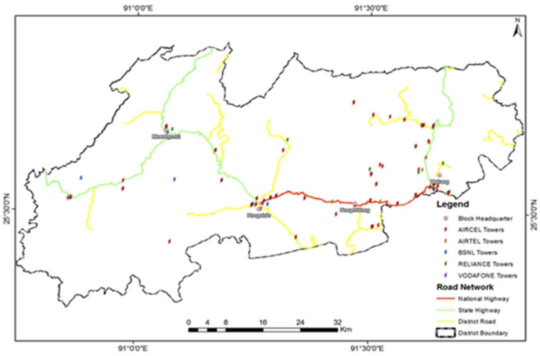

Figure 2: Coverage of existing towers in West Khasi Hills district (source: DoT)

2.2 Datasets used

Stereo pair datasets (2010-2011) of the Cartosat-1 sensor were used for the generation of digital elevation model (DEM). Fused images of ortho-rectified Cartosat-1 sensor with a spatial resolution of 2.5m and the multispectral Linear Imaging Self Scanner (LISS) IV sensor with a spatial resolution of 5.8m were utilized for preparation of essential geospatial layers like land use land cover (LULC), road network and settlements at 1:10,000 scale. Survey of India (SOI) topomaps (1:50,000 scale), other legacy and ancillary datasets like Census 2011 and field survey data have been utilized for updating attributes of geospatial layers.

2.3 Methodology

The component of overall methodology is depicted in the Fig. 3. A detailed illustration on each of the components is presented in the subsequent sections.

a) *Identification of uncovered villages by the existing telecom towers:* If the geographical location of existing telecom towers are known along with their respective tower coverage (*see* Table 1), then the location of uncovered villages can be identified simply using proximity buffer analysis on those locations. However, this analysis does not run in the hilly terrain. For example, all village locations are found within the range of

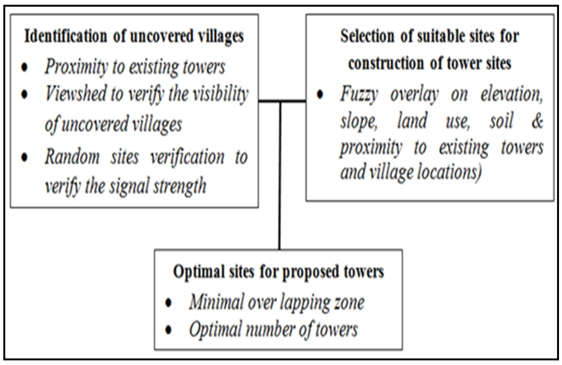

Figure 3: Overall methodology chart of proposed approach

telecom tower using the proximity buffer analysis do not have the actual Line of Sight (LoS) visibility from the existing telecom towers.Four different types of towers based on the tower heights and estimated range values are considered for the study (See Table 1). Each of the tower types has different tower height and range of coverage as defined by the Department of Telecom (DoT), Government of India.

Table 1: Specifications of various telecom towers (source: DoT)

Sl. No.	Tower type	Tower height (m)	Tower coverage radius range (m)
1	A1	20	1000
2	A2	20	2000
3	B	30	2000 - 4000
4	C	40	4000 - 6000

The next steps are adopted to identify the location of uncovered villages:

- Proximity analysis using buffer has been applied to the each of the points pertaining to the location of the existing telecom tower, where the output is a region that surrounds and encompasses the range of the tower.
- If the village (as per Census 2011 record) locations are not spatially within the range of the towers, then they are treated as uncovered villages; where remaining villagers are considered to be within the range of towers.
- A viewshed analysis (ESRI white paper, 2014) has been adopted to verify the visibility of villages (i.e. villages within the ranges as per proximity analysis) by any one of the existing telecom towers based on the 'offsets' or canopy height of towers (i.e. summation of elevation of the tower and tower height) and corresponding coverage range radius.

Both LoS and Viewshed have been widely used for visibility analysis in many application areas. LoS determines the visibility of sight lines over obstructions consisting of a surface and an optional multipatch dataset. Only the endpoints of the input line are applied to define the observer and target. It is more appropriate for the telecom applications where telecom towers are proposed based on the LoS visibility. On the other hand, viewshed is a multi-layer function that analyzes visibility based on terrain elevation. It requires a grid terrain layer and a point layer and produces a visibility grid layer that tells about visibility of every cell from the point feature(s). A viewshed identifies the location of villages (i.e. cells in an input raster) that can be seen from one or more tower locations. Each cell in the output raster receives a value that indicates how many tower locations can be seen from each location. Viewshed has been found more appropriate in our work where suitable sites for new telecom towers are offered based on the signal coverage (Sangeetha et al., 2014) as defined in the Table 1.

An example of viewshed analysis carried out to identify the uncovered village locations which are not visible by any existing telecom tower is pictured in the Fig. 4. Out of 811 villages of the West Khasi Hills district, total 327 village locations were found uncovered by the existing telecom towers. Field survey has been carried out randomly for 25 locations of the proposed sites of new telecom towers with a set of GPS-enabled smart phones using the SIM cards of all the existing mobile phone service providers to check the radio coverage. Randomization of 25 locations has been done using a simple random procedure based on the spatial distribution of points. Location of randomly surveyed points is depicted in the Fig. 4.

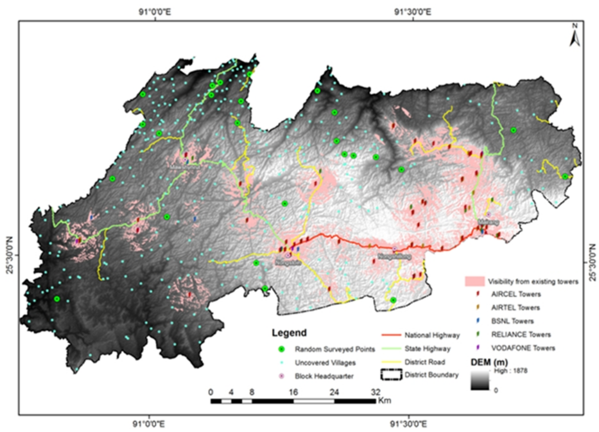

Figure 4: Viewshed analysis - locations of uncovered villages overlaid with existing telecom towers and road network. Twentyfive randomly selected surveyed points are also shown in the figure.

b) Multi-criteria spatial analysis

Multi-criteria spatial model using fuzzy overlay function is adopted here. The primary ground for using fuzzy overlay function is that it can handle erroneous data, i.e. inaccuracies in the attribute and geometry of geospatial layers. Also, the input layers for multi-criteria analysis has not been derived from the same sources of data with the same resolution and scale. In weighted overlay and weighted sum, the values are on a ratio scale of preference, with the highest values being more favourable, unlike possibilities of membership as they are in fuzzy overlay. The fuzzy overlay function requires weightage of fuzzy membership value to determine the suitable regions. It is based on the fuzzy theoretic approach, where a set generally corresponds to a class. It reclassifies or transforms the data values to a common scale, but the transformed values represent the probability of belonging to a specified. Gaussian function is adopted for defining membership for an input raster layer. The membership value ranges from 0.01 to 1.

Multi-criteria spatial analysis was carried out using the fuzzy overlay function of ArcGIS (version 10.2) software. The flow chart of multi-criteria spatial modeling using fuzzy overlay function is given in the Fig. 5. Total five geospatial layers, slope (%) generated from Cartosat-1 DEM, land use, land cover (1:10K scale), soil (1:50K scale), raster distance from existing telecom towers (Dist_Towers) and raster distance from the village locations (Dist_Villages) have been integrated in the fuzzy overlay function. Proximity analysis has been applied to the road network (1:10K scale) with respect to the output of the fuzzy overlay function in order to select those sites which are well connected by the existing road network.

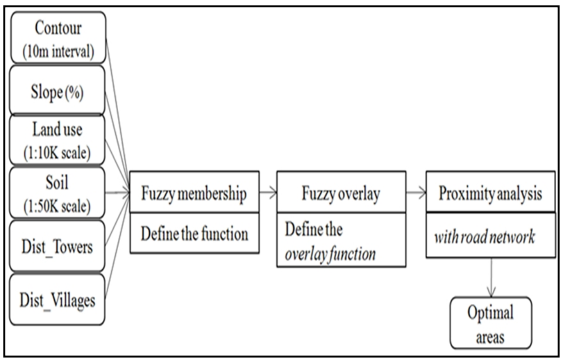

Figure 5: Flow chart of multi-criteria spatial modeling using fuzzy overlay function

The combining analysis step in the fuzzy overlay analysis quantifies each location's possibility of belonging to specified sets from various input rasters. Fuzzy overlay analysis quantifies the possibilities of each cell or location to a specified set based on membership value. We have used 'AND' overlay type which combines the minimum of the fuzzy memberships from the input fuzzy rasters. This type is best for finding the locations that meet all criteria. All the layers have been converted to raster format and fuzzified using Gaussian membership function. Now, each of the input raster layers contains the criteria values defined by the membership function. The fuzzification value of 0.5 is the crossover point. Any fuzzy value greater than 0.5 implies that the original criteria value may be a member of the set, or it is less likely that the original criteria value. Appropriate classes of each of the geospatial layers for the defining fuzzy overlay model is presented in the Table 2. The suitable sites for setting up of new telecom towers is depicted in the Fig. 6.

Table 2: Appropriate classes of geospatial layers for fuzzy overlay function

Sl. No.	Geospatial layers	Preferable classes
1	Slope (%)	0-20
2	Land use	Open areas, settlement mixed with tree clad areas, agricultural lands
3	Soil	Clay and silt
4	Dist_Towers	For tower types, i.e., A1: more than 1000 m, A2: more than 2000 m, B: more than 2000-4000 m and C: 4000-6000m away from exiting towers
5	Dist_Villages	Inside the buffer of 1000 m of existing small town locations

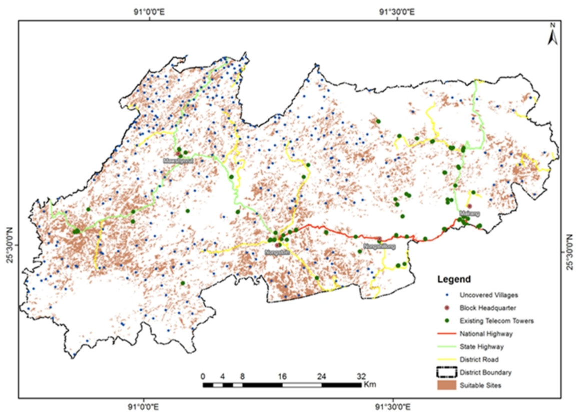

Figure 6: Suitable sites for construction of new telecom towers showing road connecting with the uncovered villages and existing telecom towers

c) Selection of optimal sites for new telecom towers

Once suitable areas for setting up of new telecom towers are defined (Fig. 6), it is now required to select the locations of telecom towers within the suitable areas in order to cover all the uncovered villages with optimized number (i.e. less number of) of telecom towers. The optimization model adopted here is based on the least possibility of conflicts (Shapira and Simcha, 2009; Javier, 2012) as a criterion for optimizing the location of telecom towers. The possibility of overlapping is presented utilizing the overlapping or intersected coverage zone (OCZ) of telecom towers with respect to radio coverage. Initially, the model assumes that each of the village locations is optimal for setting up of new telecom towers if it comes within the suitable areas (Fig. 6). Then the model optimizes the sites with minimum OCZ between each of the telecom towers. OCZ for a set of telecom towers can be defined as follows:

$$I_{OCZ} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(R_i \cap R_j) + \sum_{i=1}^{n}\sum_{j=1}^{n}(R_i \cap S_j)}{\sum_{i=1}^{n} R_i + \sum_{i=1}^{n}\sum_{j=1}^{n}(R_i \cap S_j)}$$

where R_i is the coverage zone of new telecom towers and S_i is the coverage zone of existing telecom towers. $R_i \cap R_j$ defines the OCZ between the new telecom towers and $R_i \cap S_j$ refers the OCZ between the new and the existing telecom towers.

OCZhas been computed for each of the tower types, A1, A2, B and C with the corresponding tower coverage (see Table 1). The main goal is to get minimal overlapping zone as defined by the OCZ. Minimal values of I_{OCZ} (> 0) represent the minimal overlapping zone, i.e. it requires minimal number of telecom towers.Optimal locations for new telecom towers in the study area are those locations with minimal range of OCZ, where the entire uncovered villages are covered by the optimized (i.e. least) number of telecom towers. Experimentally, it has been investigated to define the minimal ranges of OCZ (I_{OCZ}). The minimal range of I_{OCZ} computed for each of the tower types and the number of telecom towers required to cover the uncovered villages is presented in the Table 3. For example, value of I_{OCZ} ranges from 0.04 to 0.08 only in case of tower type C and entire uncovered villages can be covered by only 78 new telecom towers (see Table 3). Similarly, value of I_{OCZ} ranges from 0.11 to 0.14 in case of tower type B, 0.18 to 0.21 in case of tower type A2 and 0.29 to 0.33 in case of tower type A1 with optimal number of new telecom towers 78, 95, 115 and 121 respectively. Optimal locations for setting up of new telecom towers (i.e. tower type C) proposed in the suitable sites is given as an example in the Fig. 7.

Table 3: Minimal range of I_{OCZ} for each of the telecom tower types

Sl. No.	Tower type	OCZ(I_{OCZ})	Number of telecom towers required
1	A1	0.29-0.33	121
2	A2	0.18-0.21	115
3	B	0.11-0.14	95
4	C	0.04-0.08	78

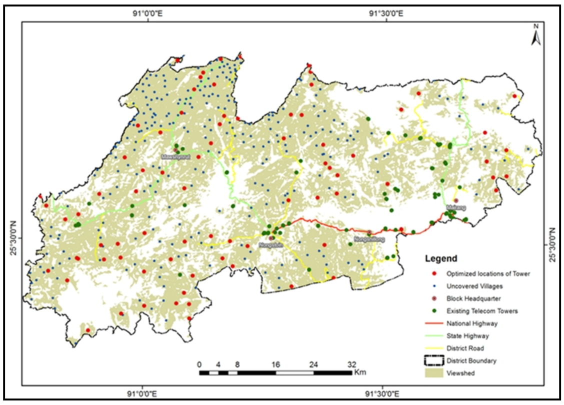

Figure 7: Optimal locations for setting up of new telecom towers (i.e. tower type C) overlaid on visibility layer (viewshed) along with the existing locations of telecom towers and locations of uncovered villages.

3. Discussion

West Khasi Hills district of Meghalaya has 811 villages as per 2011 Census. It has been observed that most of the telecom towers of BSNL, Reliance, Vodafone, Airtel and Aircell are concentrated in the district headquarter (i.e. Nognstoin) and in other block headquarters (Mawshynrut, Nongshillong and Mairang) only (*see* Fig. 2). Out of 811 villages, total 327 villages are identified in the study as uncovered villages (*see* Fig. 4). Identification of uncovered villages, selection of suitable sites for setting up of telecom towers and the optimized locations of new telecom tower are the three important issues regarding expansion of telecom network in the hilly region like North Eastern part of India. These issued are addressed very effectively in this study using geospatial technology. Both proximity and viewshed analysis have been carried out to identify the uncovered villages as per the criteria as mentioned in the earlier section. It has been observed that a large number of villages in the northwestern part of the district are not yet covered by any telecom network; similarly, there is very poor coverage of telecom network in the southern part of the district.

A number of parameters (*see*Fig. 4) have been modeled in spatial analysis using fuzzy overlay function to define the optimal sites for new telecom network towers. Suitable sites for setting up of new telecom towers overlaid on existing road network and uncovered villages is depicted in the Fig. 6. On the other hand, optimal locations for setting up of proposed telecom towers (for tower type C as an example) showing visibility (viewshed) from the uncovered villages is depicted in the Fig. 7. However, defining optimized locations of new telecom tower was found more challenging, as it needs consideration of many parameters as mentioned in the earlier section. In addition, it requires consideration of other parameters like population density, availability of infrastructures like buildings, electrical connectivity and radio signal coverage, minimum wind speed of the location etc. On the other hand, in most of the cases the effective tower height will depend along the tower construction site altitude with respect to the target area to be hatched.Towers are considered to be heavy weight narrow base and wide base Ground Base Tower (GBT) tower of length 20 meters, 30 meters and 40 meters. For hilly areas of NER erection of angular tower are time consuming and difficult job, hence such tower was recommended for only Type C category. Besides, it covers larger areas as compared to the other tower type; hence entire uncovered villages can be covered comparatively with less number of telecommunication towers. For example, total 78 C type telecom towers are required to cover entire uncovered villages in the district, whereas, requirement of A1 type telecom tower is highest (i.e. 121) (*see* Table 3). Requirement of the B type telecom tower is also less as compared to A1 and A2 type telecom towers.

It has been observed that the proposed locations of telecom towers are found scientifically and accurately networked with the entire uncovered villages. There are total 106 existing telecom towers which cover approximately 484 villages in the district. Nevertheless, most of the existing telecom towers are confined to the mainland of the territory. Proposed new 78 type C telecom towers can cover approximately 327 uncovered villages. The number of proposed locations can be further optimized considering the density of the population and the demand for the utilization.

4. Conclusion

Usage of telecom service is now creating a new vista in the societal applications. Increasing expectation of cell phone users and the usage of information and ICT enabled services via cell phone in the entire world now demand the service providers to expand their network coverage to all the places including rural hilly areas like West Khasi Hills district of Meghalaya. The strategic location of telecom towers can ensure efficient provision of telecom services in a cost efficient manner. The primary aim of this work is to demonstrate the effectiveness of advancement of geospatial technology for identifying optimized locations of new telecom towers strategically. The outcomes reported here is quite encouraging; where both multi-criteria spatial analysis and overlapping coverage analysis have been integrated effectively for identifying optimized locations of proposed towers strategically.

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