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DETERMINATION OF OPTIMAL LOCATION FOR SETTING UP CELL PHONE TOWER IN CITY ENVIRONMENT USING LiDAR DATA

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ABSTRACT:

Cell phones have become an inherent part of human life and have grown rapidly in the last decade. In India, there are nearly 120 crore cell phone users which require setting up of cell phone tower at an appropriate location to transmit the signals. A signal strength that is measured in (dBm) keeps on varying from one location to another. Over the decades, there has been a great deal of concern about placing a cell phone tower to manage adequate signal strength for an area. During transmission, the signals get affected by the position of building, ground and the distances the signals need to travel before reaching any receiver or user location. Existing researches focus on the requirement of a suitable number of cell phone towers for a big area in a GIS environment. Depending on the building and other infrastructure present in an area an optimal location can be determined for setting up the cell phone tower. However, the detailed 3D data is required for it. In this paper, a LiDAR-based technique is attempted. Using the point cloud data of the RGIPT campus, features like building, ground, obstruction points, etc are extracted. To determine the transmission paths for the signal, building/object boundary(es), etc. coming in the path(s) between the cell phone tower and the receiver location are determined. Once the detailed paths for the signal transmission i.e, direct path, or path after diffraction (around the buildings), and/or reflection (from the wall and ground) are determined, terrain parameters (distance, path difference, attenuation, etc) are ascertained. These are then used to model and determine the relative signal strength for any receiver location. The position of cell phone tower is then tested for optimal XY, and Z position to ascertain the best location for setting up the cell phone tower. The method is verified against various path determination algorithms. A centroid and viewshed based approach is adopted here. The technique is generic, novel and essentially work with LiDAR point data without needing DEM and can be applied for any terrain condition.

1. INTRODUCTION

Cell phone has become essential in social life. There has been unparalleled growth in the cell phone industry during the last decade in India. However, the cost of erecting, managing, and maintaining network infrastructure has become higher. Cell phone tower, in the network, plays an important role as it provides signals to Cell phones. Placing cell phone towers at an optimal location to manage adequate signal strength for a built-up area is a challenge. A signal strength keeps on varying from a location to another. Signal strength coming from any cell phone tower is measured in terms of decibel-milliwatts (dBm). Sometimes the cell phone user has high reception of the signal at a point, while low reception on the other nearby side at the same time, which is called the dead zone. The cell phone signal operates on very low power (typically at less than 1 milliwatt). The strength of the signal at large parts of areas come in the range of negative dBm. The places closer to cell phone tower records 0 dBm with stronger signal strength. In India -50 dBm is considered the excellent signal strength for an area. People are facing issues due to inadequate signal strength mainly due to improper locations of cell phone towers. In an urban environment when it is required to provide adequate strength of the signal to every location then there is a need to place a cell phone tower at an optimal location and suitable height. Incidentally, the optimal location is a function of positions of the buildings, terrain points, ground points, and other objects in the area. Hence, the transmission of the signal depends on the positions of the tower and the paths through which the signal passes before reaching the end of any receiving point. A signal can follow a direct or indirect a path starting from the source (i.e., the position of cell phone tower) before reaching any receiver. The signal can propagate via diffraction (around the building), reflection (from a wall or by the ground) in the indirect path. The manner of signal propagation involves attenuation in the strength of the signal due to distance, diffraction, reflection, etc. Determination of suitable location required terrain data in 3D. Terrain data is usually expressed as a collection of points with x, y, z values. Raster, Vector, or Point cloud form of terrain data offer its challenge to process the data to extract the terrain features. Research is done by (Deane et al., 2009) suggests an effective algorithm to identify the tower locations by providing a three-way solution (first by greedy approach, then by ratio heuristics and finally by a genetic algorithm). (Kiema & Munene, 2014) suggests the spatial analysis approach, which minimizes the costs of wireless network planning. It has been proved that an existing cellular network can be optimized using optimization tools and fine parameter tuning (Rahman et al., 2012). Existing researches primarily work on GIS environment to determine the requirement of several cell phone towers for a very large area, without focusing the optimal location of cell phone tower(s) or how the signal can reach any receiver location maintaining optimal strength (AL-Hamami & Hashem, 2011; Babar & Kaur, 2013; George, 2013; Kashyap et al., 2015; Tayal et al., 2017). In the present paper, an effort is made to determine the optimal location of setting up the cell phone tower for an area. As determination of transmission paths from source, i.e., cell phone tower to receiver points play a very important role towards determination of path loss and strength of the signal, efforts are made here to determine them and then use those to ascertain the optimal location for setting up the cell phone tower for an area. Terrain data are managed through LiDAR data (Iordan &

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Popescu, 2015) because of its precision and high quality in 3D. Instead of the raster, vector, or DEM, the extraction of paths was attempted using LiDAR point cloud data.

2. METHODOLOGY

A method is planned for the determination of optimal location for setting up the cell phone tower to provide adequate signal strength in an area. Used LiDAR data comes as a 3D point cloud without any direct information on terrain features like building, ground, vegetation, etc. So, the processing of data required the extraction of the terrain points, which obstruct and/or control the transmission of a signal. The signal travels primarily from cell phone tower to receiver location directly (in case there is no obstruction between them). It can also travel indirectly after diffraction, reflection, etc., whenever there is/are obstruction(s) between them. Thus, to determine the signal strength at every receiver location, the determination of transmission path(s) is/are required. The determination of paths for a signal requires clear information about the boundary of building or edges and other obstructions that can come between the cell phone tower and receiver (i.e., cell phone user location). The methodology works on developing an algorithm to extract all-terrain features/terrain points from the LiDAR data without essentially transforming point data to DEM. A part of the 45-acre academic area of the RGIPT campus is chosen for the determination of the optimal location of the cell phone tower for the campus. LiDAR data has been acquired for the project site of the RGIPT campus. Corners and edges of buildings or obstructions are determined which are coming in the possible paths between the cell phone tower and cell phone user's location (or receiver location). A plane cutting technique is used for the determination of paths(Biswas & Lohani, 2008). The direct path is considered in case there is no obstruction between cell phone tower and receiver. In the indirect path of transmission, first, the path over the top of buildings or barriers are tried to be determined, then paths around the sides of the building or barriers are tried to be determined. The plane cutting technique considered a plane between cell phone tower (or source location) and receiver location and checked whether they are intervisible or not to determine the paths of transmission. The reflective paths are determined considering reflection from the ground as well as walls of barriers. The potential reflective surfaces are assumed to follow Snell's law. Once the detailed signal paths are determined the attenuations (loss of signal strengths) due to atmosphere, barrier, walls, etc. are tried to be determined. To determine the signal strengths (or relative loss of signals) at various ground positions an algorithm is created, which is planned to work iteratively for every pair of a cell phone tower and its surrounding receiver location. The process will determine the respective signal strength (or relative loss of signals) for different receiver (user) location. For a given terrain condition with specific locations of building, ground, tree, etc. once the boundary of the building, and other obstructions are determined, the algorithm will try to find various paths for transmission of signal, the relative loss of signals at various receiver/user locations, and would try to ascertain the optimal location to set up the cell phone tower. Positioning a cell phone tower at the optimal location will ensure adequate strength of the signal for all the surrounding cell phone users.

3. RESULTS AND DISCUSSION

The proposed methodology worked on different levels starting with LiDAR data acquisition, feature (terrain point) extraction, signal transmission path determination, the relative loss of signal strengths determination and finally determining the optimal location for setting up the cell phone tower. The Stepwise procedure is given below with performance: -.

3.1 LiDAR data Acquisition

An area of RGIPT native campus that consists of two Academic buildings that are Academic block 1 (AB1) and Academic block 2 (AB2) is taken into consideration are shown in Figure 1. LiDAR data for the selected area is chosen which is a point cloud of dense data containing x, y, z coordinates. Here the data acquisition is done by Terrestrial LiDAR for the project area. The LiDAR data for the project area is shown in Figure 2.

Figure 1. Project Area of RGIPT

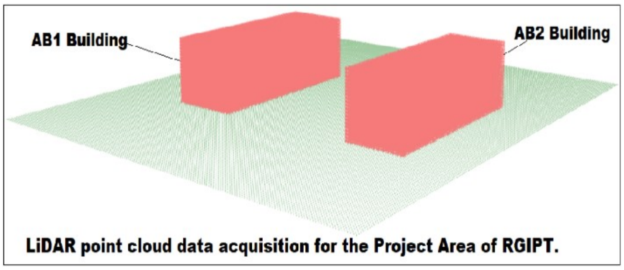

Figure 2. LiDAR data for the selected Project area

3.2 Building and Building edge extraction

Acquired LiDAR data comes as a 3D point cloud without any direct information of the building, ground, vegetation, etc. So, it is required to process the data to extract the above terrain features. For the processing of data to extract terrain features, a short algorithm is developed that takes LiDAR data as input, and at first, it extracts the over ground obstruction points by subtracting ground points from all points based on heights. The pink portion which is shown in Figure 3 is the elevated points of the building.

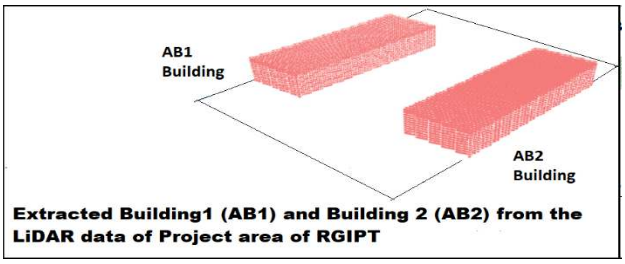

Figure 3. The subtracted output to calculate height-based point

After extracting the elevated features out from the LiDAR data. Next, the building corners are tried to be determined by estimation of the boundary of a cluster of the point cloud. This is done by the virtual division of the region found in Figure 3. Where it is divided into an equal number of rows denoted by (i) and columns denoted by (j). It is required to start moving in the divided region shown in Figure 4 from starting cell (i, j) where initially i=0 and j=0. Incrementing (i) row and (j) column and check whether it contains elevated point or not and if it contains the elevated point assign that point to an array naming building 1. Next, it is required to set a threshold for checking the distance between cells and differentiating elevated point of one building from another building by checking neighboring cells of that cell which contain the elevated point. If a neighboring cell contains the same elevated value then assign that elevated point to the same array, else assigned it to the new array. Continuously, checking cells till the end and finally making sets of arrays for different buildings. From the arrays of different building points, corners of the building are determined for each building and are stored separately in an array by using the criteria of minimum and maximum of x and y (min x, min y), (min x, max y), (max x, min y), (max x, max y).

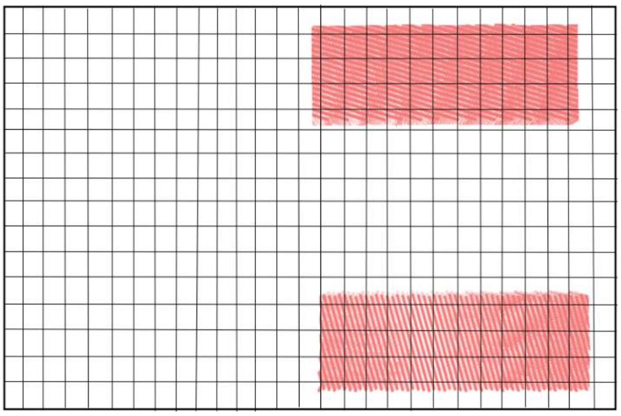

Figure 4. Division of the elevated area to find corners.

3.3 Path Determination

For understanding the signal strength at different locations from the cell phone tower, there is a need to understand the transmission manner of signal from one location to another. When propagating from one location to another signal follows direct transmission or indirect transmission (through diffraction, reflection). The different paths are as follow: -

3.3.1 Direct path: Direct path is the path which is estimated initially when there is no obstruction between the cell phone tower and cell phone user.

3.3.2 A path over the top of the building: Signal path over the top of the building is determined in the following steps: -

Step1- First thing is to check the building that is intersecting the plane formed between cell phone tower coordinate and cell phone user coordinate w.r.t Z-axis and out of all intersecting buildings, find out the tallest building, and the buildings that are on the right side of the tallest building are upward and on the left side, they are considered as downward which is shown in Figure 5.

Step2- First for upward, create a 3D line from the cell phone tower to the tallest building that is (building 4) and do check if any building intersects with the 3D line or not has shown in Figure 6. Stores the intersecting building in an array if exists. Pick the first element of an array if not empty and create a 3D line from cell phone tower point to the intersecting building exists as an array 1st element.

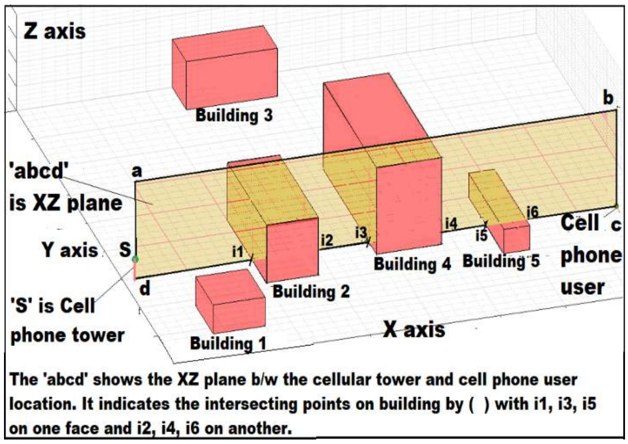

Figure 5. XZ plane intersecting with Building present

Step3- Now considering the first element of an array as Source and Repeat the step2 procedure with new source and the tallest building. If there exists any such intersecting building with a 3D line between step2 1st array element and the tallest building then update the array in step2. Else create a path from cell phone tower to building1 (1st element of an array in step2) to the tallest building and the path created is called upward way (S-j1-j3), where S is cell phone tower location has shown in Figure 6 by blue color.

Step4- Repeat the same procedure mentioned in above steps for the downward that contains the tallest building (building 4) and (building 5), the path created in step 4 is called downward way path that is (j3-j4- R) where R is cell phone user location has shown in Figure 6 by black color.

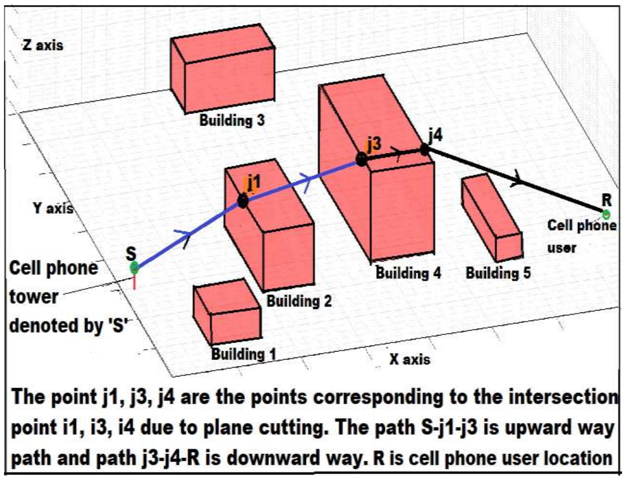

Figure 6. A signal path over the top of buildings

3.3.3 A path around the sides of the building: Signal path around the sides of building and obstruction is determined in the following steps: -

Step1- Set a buffer region to remove outliers' buildings, divide the whole region ABCD into two sides right and left in Figure 7. Start from the left side (ABRS), choose the max length building left side points and make a line between the cell phone tower and the max length point, store the intersecting points of buildings with the line in an array. Check it till the array become empty.

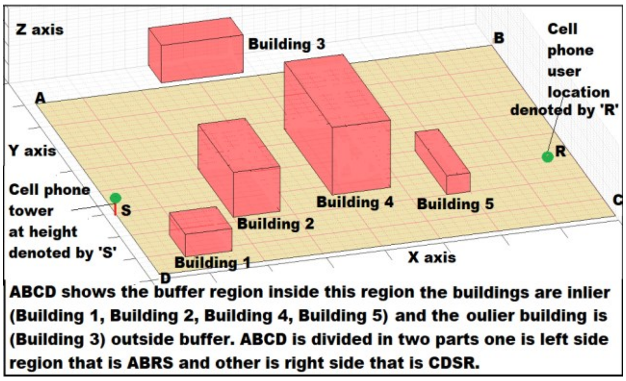

Figure 7. Set up for the path around the sides of the building

Step2- Find the maximum length point out of the non-intersecting building with a line between the cell phone tower location and receiver location line, repeat the above step 1 for this case. If there exists no such building on the left side continues with the maximum length of the building and repeat step 1 with changed source and receiver. Completing step 2 gives a complete left-side path is shown in Figure 8 and repeats the same procedure for the right side and the path formed is shown in Figure 9 where S is cell phone tower location and R is cell phone user location.

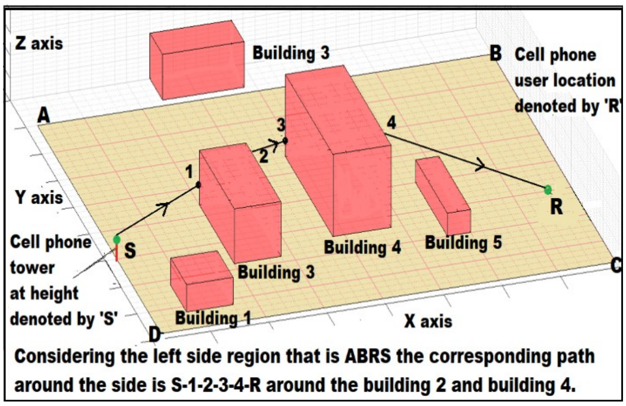

Figure 8. A signal path around the left side of the building

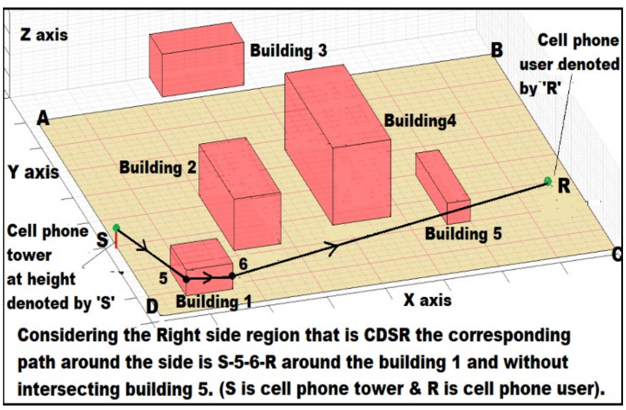

Figure 9. A signal path around the right side of the building

3.3.4 Path due to reflection: Signal during propagation reflects from ground and wall of buildings forms the reflection path of the signal. These paths are determined by the following steps: -

Step1- Initially for the Reflection, consider the source and over the 3D environment along with the area. Create a line between cell phone tower S (x1, y1, 0) and the cell phone user location R (x2, y2, 0), it is required to calculate the distance between the two-point S and R by using where S is cell phone tower location and R is cell phone user location.

$$D = \sqrt[2]{((x2 - x1)^2 + (y2 - y1)^2 + (z2 - z1)^2)} \quad (1)$$

where D = Distance
x1, y1, z1 = coordinate of cell phone tower
x2, y2, z2= coordinate of cell phone user location

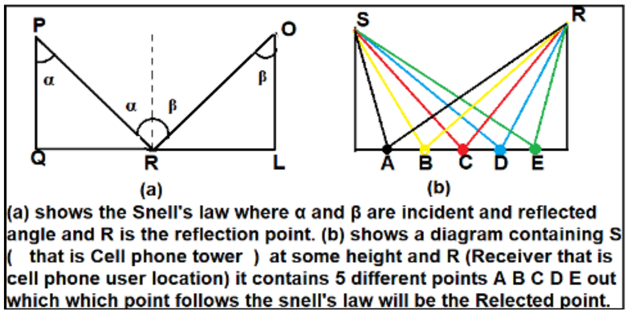

Figure 10. Snell's law description

Snell's law for reflection states that the incident angle is equal to the reflected angle as shown in Figure 10.

$$sin(\alpha) = sin(\beta) \quad (2)$$

$$(\alpha) = cos - 1(QR/PR) \quad (3)$$

$$(\beta) = cos - 1(RL/OR) \quad (4)$$

$$d = |sin(\alpha) - sin(\beta)| \quad (5)$$

where α = Incident angle
β = Reflected angle
d = difference if angles

Step2- According to Snell's law for reflection, the angle made by the incident ray is equal to the reflected ray that is sin(i) = sin(r). Different points are found on the XY plane between cell phone tower and cell phone user location are A, B, C, D, E has shown in Figure 10 (b) (Gaol, 2013). Now for each point say 'A', the angle from S and angle from R are measured. After calculating angles from S and R, the angle difference (d) is calculated. This is repeated for all the points, to find the best point of reflection. After finding the angle difference for each point the likely reflection point is determined by the least value of d shown in Figure 11.

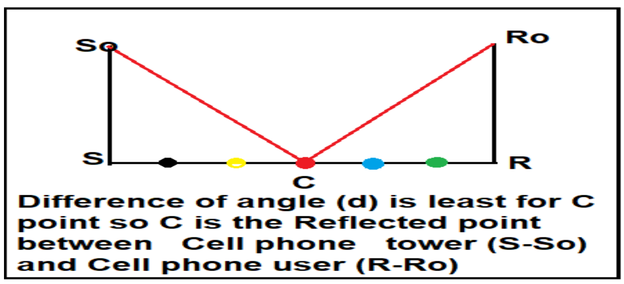

Figure 11. Reflected point found by Difference of angle

Step3- There is one example of reflection path creation for ground reflection and wall reflection with a path over the top and path around the sides of the building is shown in Figure 12

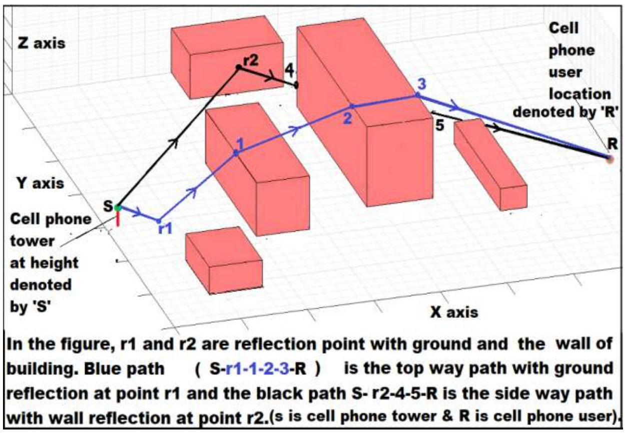

Figure 12. Signal path due to reflection

3.4 Determination of Terrain parameters

Determination of terrain parameters is required for signal strength calculation the main parameters are path difference, distance attenuation, barrier attenuation, etc.

Step1- Path difference is the difference between the direct path transmission and the indirect one that may be diffracted (over the top of the building, around the sides of the building), reflected, etc.

$$Path\ difference\ = D1 - D \qquad (6)$$

where D1= Indirect transmission path
D = Direct transmission path

Step2- Signal attenuation is based on distance and the barrier between the cell phone tower and the cell phone user location. This is calculated individually.

$$Distance\ Attenuation = 20\ LOG10(D) + 11 \qquad (7)$$

$$B.A\ = 5.65\ + 66N\ + 244N^2\ + 287N^3 \qquad (8)$$

$$N = \frac{Path\ difference}{\frac{\lambda}{2}} \qquad (9)$$

$$\lambda = \frac{c}{f} \qquad (10)$$

where D= Direct transmission path

B.A = Barrier attenuation

λ = wavelength

c = Speed of light

f = Frequency

N = Fresnel number

3.5 Determination of Optimal location of cell phone tower

After getting the Building and building edges, the requires signal propagation path is determined in the above steps. Now for the deployment of a cell phone tower in the project area of RGIPT campus containing buildings Academic block 1 (AB1) and Academic block 2 (AB2), there is a need to determine XY coordinate that defines the position and Z coordinate that defines the height of the cell phone tower. Determination of XY and Z gives the optimal location of a cell phone tower to manage adequate signal strength in a large area. The determination of the optimal location is done in the following steps.

3.5.1 Determination of optimum XY position for cell phone tower:

3.5.1 Determination of optimum XY position for cell phone tower: The steps for determination are defined below.

Step1- Before starting the XY determination, the first thing to do is taking the regular polygon of the RGIPT project area. For the area, LiDAR 3D point cloud data is in Figure 2 which is shown in the LiDAR data Acquisition step.

Step2- For X-Y the centroid is initially tried to be ascertained for the regular polygon area. The cell phone tower is now located at centroid initially at 0 height with 150 different Receiver points (cell phone users) around the AB1 and AB2 building. Now signal propagation path from cell phone tower location to every receiver is obtained that follows direct as well as indirect path. With the path determination, calculation of terrain parameters that are path difference, distance, barrier attenuation, etc. are done. These parameters are used to calculate signal strength at all receivers. And the signal strength map is calculated in ArcGIS software is shown in Figure 13.

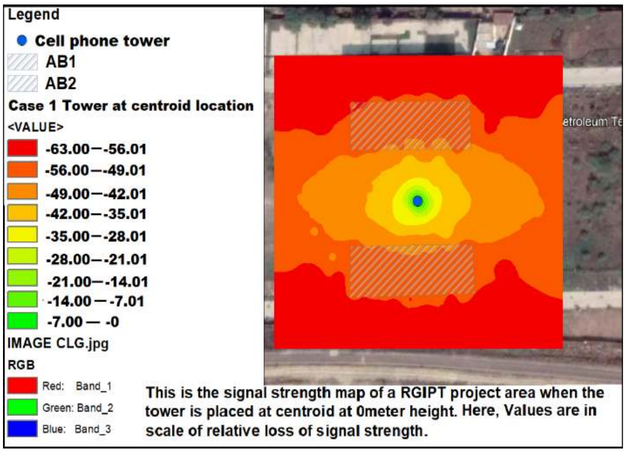

Figure 13. Cell phone tower at XY centroid

Step3- To validate the XY centroid location for the determination of position, a random XY coordinate is taken from the Project region, and the same procedure is followed. And the signal strength map is created in ArcGIS which is shown in Figure 14. After comparing the strength map and aggregate strength of each case, it is clear that choosing the centroid location is the best XY for placing a cell phone tower.

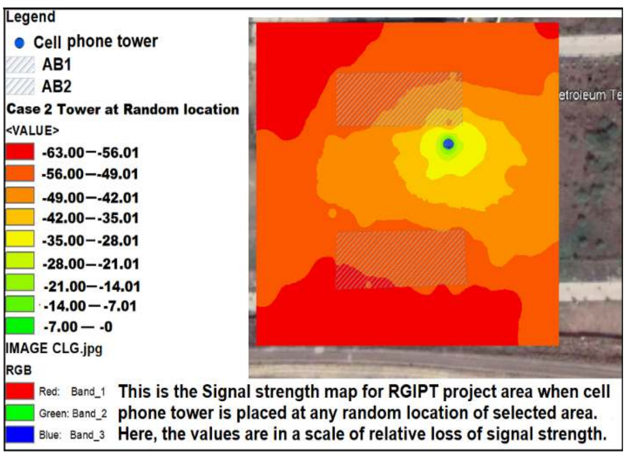

Figure 14. Cell phone tower at XY random location

3.5.2 Determination of Z (height) of cell phone tower: After validation of XY at the centroid, the Determination of the Z parameter is required to find the optimal height of the cell phone tower. For determining Z, XY is fixed at the centroid, and Z keeps on varying. The project area of RGIPT has two building mention previously as AB1 and AB2. They are of equal height of 20 meters. But for the more accuracy of results here two different cases are studied that are- 1) both AB1 and AB2 are at the same height and 2) both are at a different height.

Step1- In this step, the first case is taken when AB1 and AB2 are at the same height of (20 meters). For this setup, the cell phone tower is fixed at XY centroid and Z keeps on varying at height 0-meter, 6-meter, 12-meter, 18-meter, 20-meter, and 24-meter. For each height there are different paths for signal transmission, that may change the terrain parameters accordingly. A signal strength map is generated for each height. The signal strength map for cell phone tower height at 0-meter has shown in Figure 15. Further for height 6-meter, 12- meter, 18- meter, 20-meter, 24-meter has shown in Figure 16, Figure 17, Figure 18, Figure 19, and Figure 20.

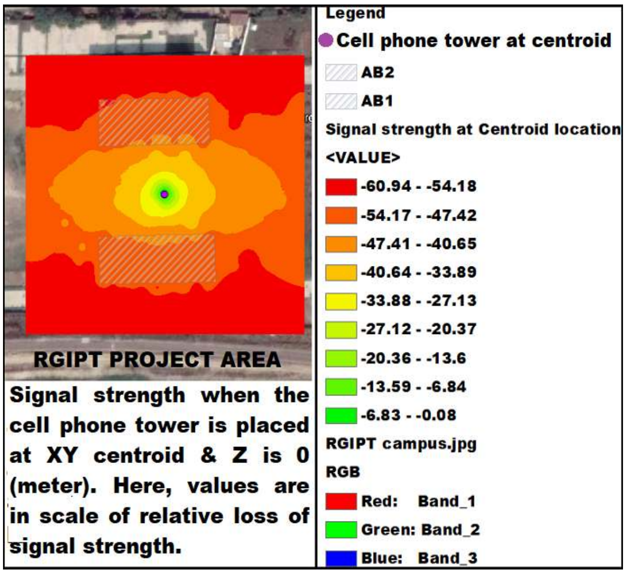

Figure 15. Cell phone tower at XY Centroid and Z at 0 meters

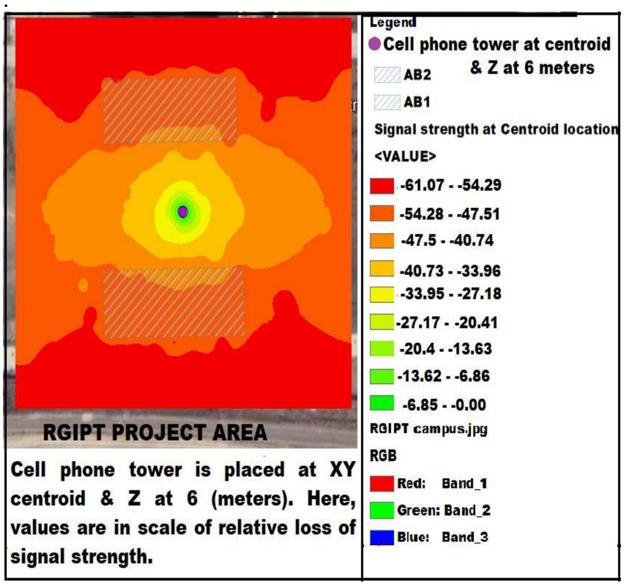

Figure 16. Cell phone tower at XY Centroid and Z at 6 meters

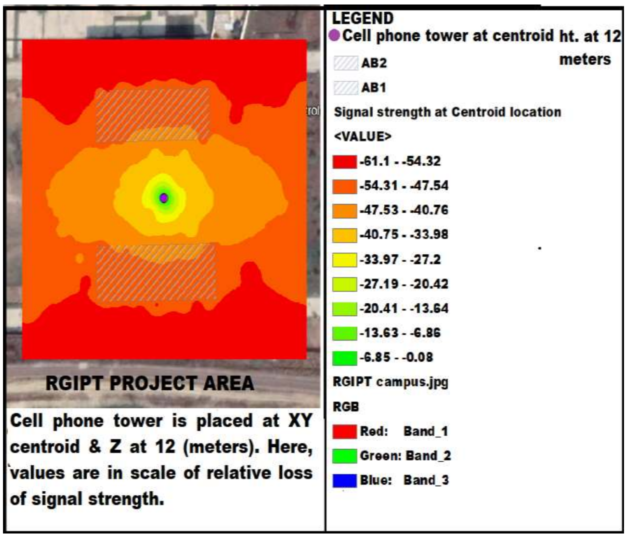

Figure 17. Cell phone tower at XY Centroid and Z at 12 meters

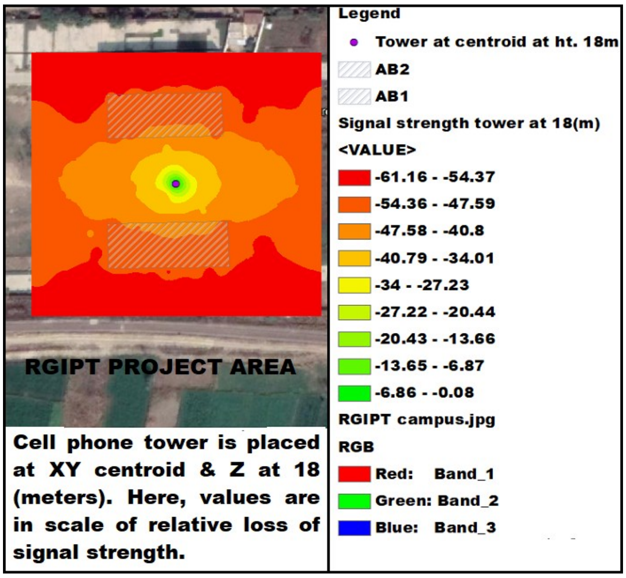

Figure 18. Cell phone tower at XY Centroid and Z at 18 meters.

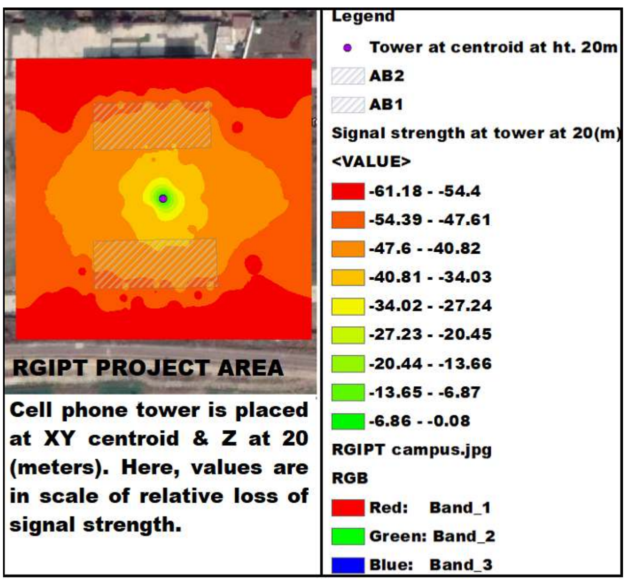

Figure 19. Cell phone tower at XY Centroid and Z at 20 meters.

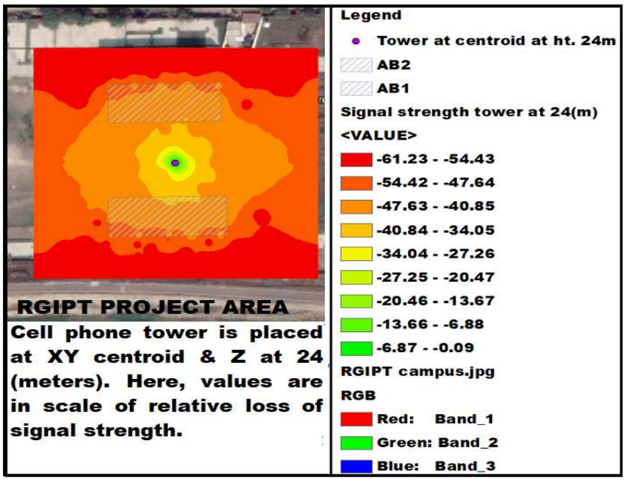

Figure 20. Cell phone tower at XY Centroid and Z at 24 meters.

Step2- In this step, the second case is taken when AB1 is at 20-meter height and AB2 is at 10-meter height. Now for this setup, the cell phone tower is placed at XY centroid and varying height at 0-meter, 10-meter, and 20-meter. The signal strength map is created for each height shown in Figure 20, Figure 21, Figure 22.

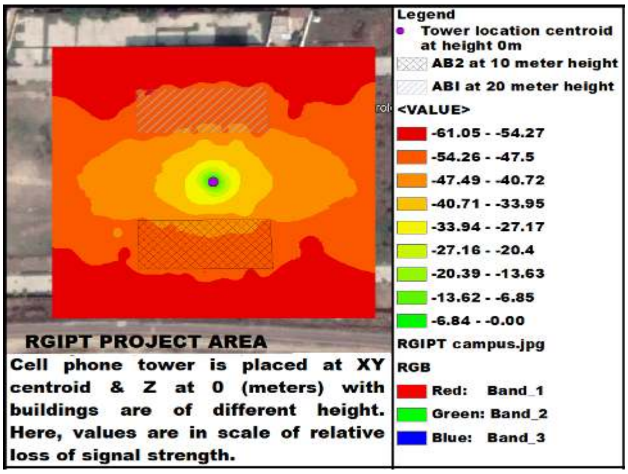

Figure 21. Cell phone tower at XY Centroid and Z at 0 meters when both building heights are different.

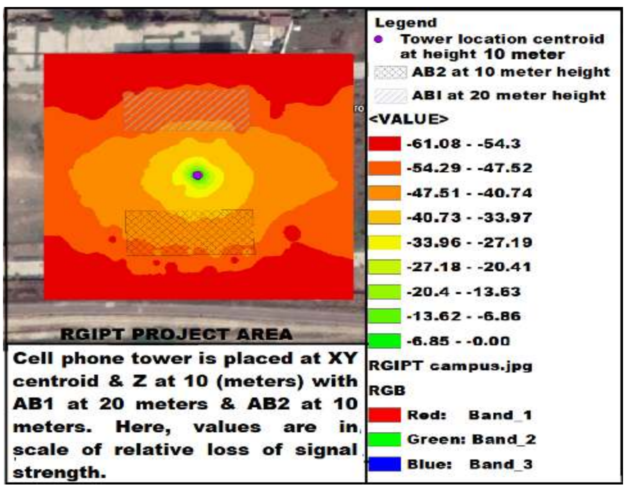

Figure 22. Cell phone tower at XY Centroid and Z at 10 meters when both building heights are different.

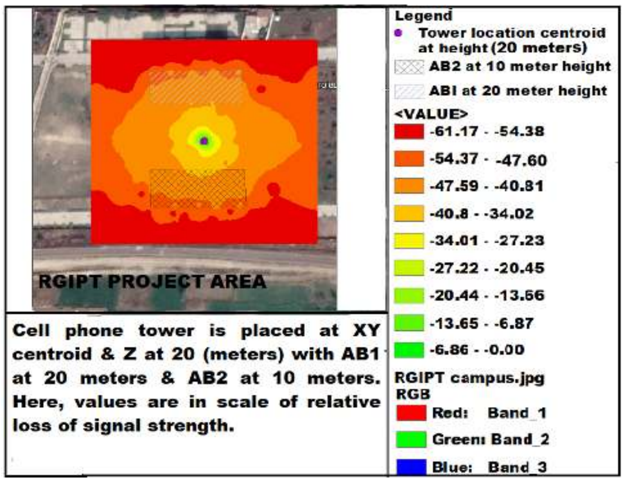

Figure 23. Cell phone tower at XY Centroid and Z at 20 meters when both building heights are different.

Step3- In this step, there is a case in which receiver (cell phone user) height is varying from height 0-meter to 3-meter, from 3-meter to 6-meter, to analyse the change in signal strength w.r.t the cell phone height at 0-meter, 10-meter, and 20-meter. The impact has shown in Figure 23, Figure 24, Figure 25.

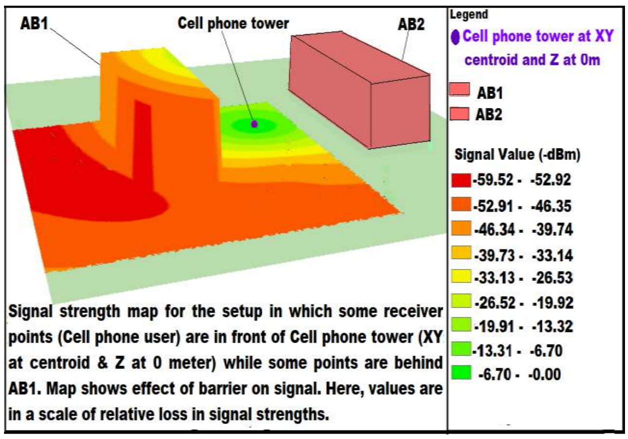

Figure 24. 3D signal strength map showing the effect of barrier on a signal when cell phone tower (XY at the centroid, Z at 0 meters).

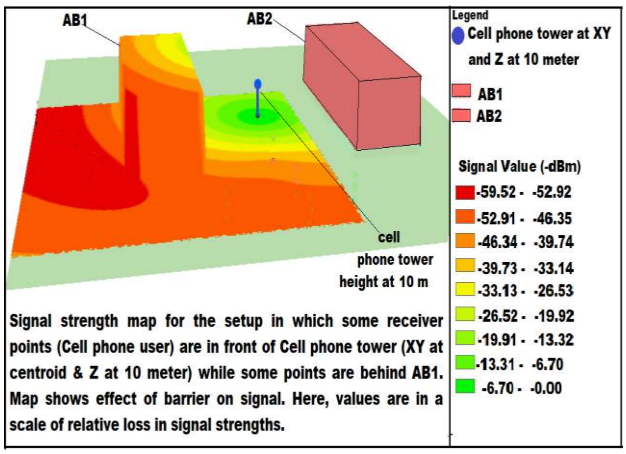

Figure 25. 3D signal strength map showing the effect of barrier on a signal when cell phone tower (XY at the centroid, Z at 10 meters).

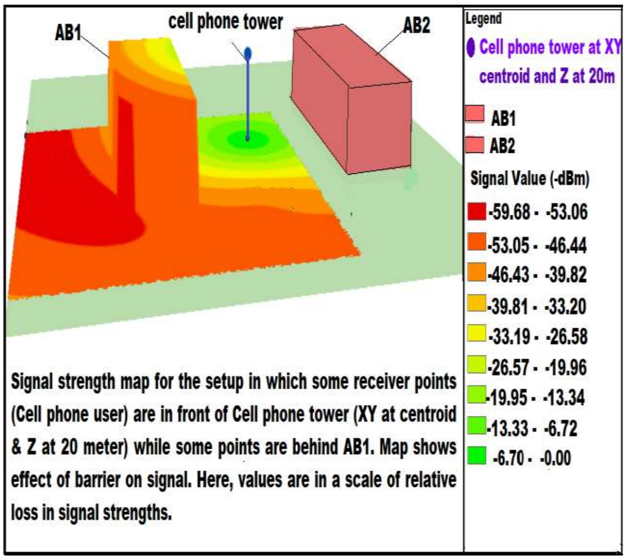

Figure 26. 3D signal strength map showing the effect of barrier on a signal when cell phone tower (XY at the centroid, Z at 20 meters).

The above Figure 24, Figure 25, Figure 26 shows that the effect of barrier on the signal strength calculated for different heights of a cell phone tower. These maps are plotted in Arc Scene by first creating a TIN structure for the LiDAR points of the project area of RGIPT. Then, the values of signals are interpolated accordingly concerning the height of the cell phone tower and cell phone user location.

4. VERIFICATION

The above-defined algorithm evolves on the shortest path, these paths automatically provides the best signal strength. The algorithm to determine these paths are already in publication and verified with results. Signal strength maps were created in the ArcGIS tool. Here in this paper, values are in a scale of the relative loss of signal strengths which is done to perform our algorithm to illustrate its simulated implementation, but in practical condition, relevant values can be taken to get accurate values.

5. CONCLUSION

The Analysis of signal strength at every cell phone user location (receiver's location) after determining the routes of signal transmission from the cell phone tower has been done. The shortest route automatically provides the best signal strength. A Novel point to point rigorous routing technique is discussed here using LiDAR data for working in 3D, specially made for the acoustic propagation principle (unlike well-known shortest path determination algorithms primarily used in 2D). The above-discussed methodology helps in deploying cell phone towers at an optimal location to provide adequate signal strength at every cell phone user location. In this work, the best possible height (Z) and best possible location (XY) of a cell phone tower are determined for the Project area of the RGIPT campus.

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