CHAPTER 3
OBJECTIVES AND CONSTRAINTS OF BS PLACEMENT

3.1 BS PLACEMENT IN LOCATION AREA

A typical outcome of network planning process is a set of base stations, a list of antenna in each site, the coverage of each antenna where needed and the allocation of frequencies to the different cells. A base station can communicate with mobiles as long as they are within its operating range. The installation of BS consists of cell tower with the desired antenna in the cell structure. The height of the antenna also plays an important role in achieving the maximum coverage.

Out of three recommended cell structure namely triangular, rectangular and hexagonal, hexagon has been universally adopted, since the design permits easy and manageable analysis of a cellular system. If geometric shapes are considered which cover an entire region without overlap and with equal area where as hexagon has the largest area considering the distance between the center of a polygon and its farthest perimeter points.

A site consists of one or more BS. This site is represented by (x, y, h) where (x, y) represents the Cartesian coordinates and h represents the height of base station from the ground level. The variations in the calculations of field strength measurements and path loss are based on the height of the base station and the distance between base station and mobile. Every BS situated in the location has the following parameters.

$BS_{tp}$ - Base Station transmitting power (in dBm)
$BS_{ant}$ - different types of base station antenna available (Directional, Omni)
\( BS_{\text{lt}} \) - tilt angle of an antenna (range: \(-15^\circ\) to \(0^\circ\))
\( BS_{\text{az}} \) - Azimuth angle of an antenna (range: \(0^\circ\) to \(360^\circ\))

### 3.1.1 Representation of Users

For the simulation purposes, users are represented as testing points in the discretized area where the BSs are need to be installed. Different types of testing points are represented as follows.

Let \( R \) be a set consists of total number of Receiving Testing Points (RTP) in an area. Each RTP is represented by the \((x, y)\) coordinates with equal distance between each other RTP and are distributed in the selected simulation area. \( N_R \) is the total number of RTP represented in the Equation (3.1).

\[
R = \{1, 2, 3, \ldots, N_R \mid N_R \in \text{RTP}\} \tag{3.1}
\]

Service Testing Points (STP) (which have service threshold \( S_q \) equal or greater than \(-90\text{dBm}\)) are selected from the group of RTP. Traffic Testing Points (TTP) are identified based on the traffic demand from STP. TTP is measured in Erlang. Assume that \( T \) is a set consists of \( N_T \) number of TTPs which are randomly selected from the set \( R \) as shown in the Equation (3.2)

\[
T = \{1, 2, 3, \ldots, N_T \mid T \subseteq R\} \tag{3.2}
\]

BS consists of cell tower with the desired antenna in the cell structure. Hexagonal cell structure is preferred since it covers large area with no ambiguous region. Field Strength Matrix (FSM) is calculated for each RTP with respect to each BS. Path Loss Matrix (PLM) and Angle of Incident Matrix (AIM) are calculated for each BS to RTP.
### 3.1.2 Selection of an Antenna

A choice between an omni directional radiation patterns versus a directional radiation pattern is usually made first, and is dependent on the shape of the coverage area and the number of users expected. Three types of antennas namely Omni directional, small panel directive and large panel directive are mainly considered for the installation of BS. Omni-directional antenna radiates and receives equally in all directions in azimuth.

Directional Antenna radiates and receives most of the signal power in one direction. The types of antennas (Theodore, S.R 2001) are classified based on the parameters shown in Table 3.1. Antenna gain $G_{\text{ant}}$ and antenna loss $L_{\text{ant}}$ are expressed in db. BS$_{\text{\ell.Z}}$ and BS$_{\text{\ell.t}}$ in between STP and antenna, determines two types of Antenna Diagram Losses (ADL) namely, Antenna Horizontal Diagram losses (AHDL) and antenna vertical diagram losses (AVDL) respectively.

#### Table 3.1 Antenna parameters

<table>
<thead>
<tr>
<th>Types</th>
<th>Power range (watts)</th>
<th>$G_{\text{ant}} / L_{\text{ant}}$ (dB)</th>
<th>BS$<em>{\text{\ell.Z}}$ / BS$</em>{\text{\ell.t}}$</th>
<th>No of ant / BS</th>
<th>ADL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni Directional</td>
<td>0.3 to 316</td>
<td>11.15 / 7.00</td>
<td>(-15° to 0°) Tilt only</td>
<td>1</td>
<td>AVDL</td>
</tr>
<tr>
<td>Large panel Directive</td>
<td>0.3 to 316</td>
<td>15.65 / 7.00</td>
<td>(0° to 360°) / (-15° to 0°)</td>
<td>3</td>
<td>AHDL and AVDL</td>
</tr>
<tr>
<td>Small Panel Directive</td>
<td>0.3 to 316</td>
<td>17.15 / 7.00</td>
<td>(0° to 360°) / (-15° to 0°)</td>
<td>3</td>
<td>AHDL and AVDL</td>
</tr>
</tbody>
</table>

The values of AHDL and AVDL for the respective angles are provided by the manufacturers. Each transmitting device has the traffic handling capacity expressed in terms of Erlang. Based on the number of TRX, the maximum traffic handling capacity is fixed as given in Table 3.2.
Table 3.2 Capacity per transmitters (TRX)

<table>
<thead>
<tr>
<th>No. of TRX</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (Erlang)</td>
<td>2.9</td>
<td>8.2</td>
<td>15</td>
<td>22</td>
<td>28</td>
<td>35.5</td>
<td>43</td>
<td>58</td>
</tr>
</tbody>
</table>

3.2 SIGNAL STRENGTH MEASUREMENTS

The propagation of radio frequency signals in the service area has a major impact on the design. The propagation models are used to predict the signal strengths at various locations for both coverage and interference studies. Earlier researchers have studied the radio frequency propagation and published empirical formulas for calculating the path loss at various frequencies for different morphologies. These results are limited to approximate path loss calculations and morphology classification. To obtain a more precise propagation model, actual signal strength measurements with their corresponding locations must be taken in the desired service area. In addition, the measurement of true signal strength reliability of the network mainly depends on the accuracy of the propagation model.

Obtaining these signal strength measurements can be a tedious task and in many areas, due to physical limitations, only a small number of the measurements can be taken. The important parameters, which determine the received signal strength are transmitting power, antenna diagram losses and path loss calculations.

3.2.1 Antenna Diagram Losses

Antenna azimuth and tilt are two important optimization parameters in mobile telecommunications system networks. Optimization of these two parameters can significantly improve the system performance. Furthermore, inconsistencies in setting these parameters during installation vary the network coverage and capacity.
The azimuth and tilt angle in between mobile device and antenna determine the horizontal and vertical Antenna Diagram Losses (ADL). The values of AHDL and AVDL for the respective angles are provided by the manufacturers and every antenna has its own fixed gain and loss measured in db. The different types of mobile antenna used by mobile service provider-BSNL, Madurai, its associated antenna diagram losses and tilt are shown in the Table 3.3. The frequency range used is 880-960 MHz.

<table>
<thead>
<tr>
<th>Antenna parameters</th>
<th>Types of antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Omni directional</td>
</tr>
<tr>
<td></td>
<td>Type No: 736349</td>
</tr>
<tr>
<td></td>
<td>Large panel directive</td>
</tr>
<tr>
<td></td>
<td>Type No: 739684</td>
</tr>
<tr>
<td></td>
<td>Small panel directive</td>
</tr>
<tr>
<td></td>
<td>Type No: 735727</td>
</tr>
<tr>
<td>Antenna Diagram Losses</td>
<td>AVDL only</td>
</tr>
<tr>
<td>Electrical tilt</td>
<td>5°</td>
</tr>
<tr>
<td>Half-power beam width</td>
<td>Horizontal: 11°</td>
</tr>
<tr>
<td></td>
<td>Horizontal: 65°</td>
</tr>
<tr>
<td></td>
<td>Horizontal: 33°</td>
</tr>
<tr>
<td>Gain</td>
<td>10.5dBi</td>
</tr>
<tr>
<td></td>
<td>15 dBi</td>
</tr>
<tr>
<td></td>
<td>16.5 dBi</td>
</tr>
</tbody>
</table>

3.2.2 Path Loss Estimation Models

Path loss is reduction in power density of an electromagnetic wave as it propagates through space. This plays a very vital role in link budget calculation of telecommunication systems. Path loss normally includes propagation loss, absorption losses and diffraction losses.

A set of mathematical expressions, diagrams and algorithms are used to find propagation losses. In general, three kinds of models are available to find out the propagation losses namely empirical, deterministic and semi-deterministic. Empirical path loss models are very simple and based on the measurement data which use statistical properties. But empirical models are not so accurate.
Deterministic models are site specific and accurate. These models require enormous number of geometry information about the environment and high computational effort. The semi-deterministic models are the combination of both deterministic and empirical models. The calculation of path loss is very important to calculate the link budget, cell size and frequency planning.

Based on the cell type, cell size and location like indoor and outdoor, the path loss models are recommended. By and large, service providers mostly concentrate on two types of models namely empirical based Hata and semi-deterministic based Walfish-Ikegami model.

3.2.2.1 Hata - Okumura model

Hata-Okumura model is widely used in mobile wireless system for predicting path loss in the frequency band from 500 MHz to 1500 MHz (Hata M 1980). It also contains corrections factors for urban, suburban and rural (flat) environments. Its simplicity and availability of correction factors have made it to use widely for path loss prediction at this frequency band. We have adopted the basic equation for path loss in dB is by using Equations (3.3) and (3.4).

\[
PL(\text{dB}) = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_{bs}) - a(h_m) + [44.9 - 6.55 \log(h_{bs})] \log(d)
\]

(3.3)

\[
a(h_m) = 3.2(\log(11.75 \times h_m))^2 - 4.97
\]

(3.4)

where \(a(h_m)\) is correction factor, \(h_{bs}\) is height of BS measured in m, \(d\) is the distance between BS and STP measured in km and \(f_c\) is carrier frequency measured in MHz.
3.2.2.2 Walfish-Ikegami model

Walfish-Ikegami path loss model (Walsh J and Betroni H 1988), which is empirical and semi-deterministic in nature, covers the frequency range of 800-2000 MHz. This model gives particular attention to propagation over roof-tops and leads to higher accuracy in dense urban areas. The real city structures like street width, building separation, height of the building and road orientation are included in the path loss calculations. Out of the two cases recommended by this model namely Line of Sight LoS and Non-Line of Sight NLoS, the proposed work considers NLoS, since it is calculated based on free space propagation path loss $L_O$, rooftop-to-street diffraction, scatter-loss $L_{rts}$ and the multiscreen diffraction loss $L_{MSD}$ as given in Equations (3.5),(3.6),(3.7) and (3.8).

$$L_{NLOS} = L_O + L_{rts} + L_{msd} \quad (3.5)$$

$$L_O = 32.4 + 20 \log_{10} d + 20 \log_{10} f \quad (3.6)$$

$$L_{rts} = -16.9 - 10 \log w + 10 \log f + 20 \log (h_r - h_m) + L_{ori} \text{ for } h_r > h_m \quad (3.7)$$

$$L_{ori} = 4.0 - 0.114(\Phi - 55) \quad (3.8)$$

where $f$ is the carrier frequency, $w$ is width of the road, $h_r$ is the height of roof building, $h_m$ is the height of the mobile and $\Phi$ is the road orientation and $L_{MSD}$ is derived using Equation (3.9).

$$L_{msd} = L_{bsr} + k_a \log d + k_d \log f - 9 \log b \quad (3.9)$$

where $b$ is the building separation distance, correction factors $k_a = 54$, $k_d=18$, and $k_f$ can be found out using Equation (3.10).

$$k_f = -4 + 0.7 \left( \frac{f}{925-1} \right) \quad (3.10)$$
3.3 FIELD STRENGTH CALCULATIONS

The Field Strength (FS) of any point \((x, y)\) in the grid can be calculated using the following Equation (3.11).

\[
FS(x,y) = P_i + G_{ant} - L_{ant} - PLM(x,y) - AVDL(AIM\theta_{\angle} - BS\theta) + M_G - M_L \tag{3.11}
\]

Here, the mobile gain and the mobile loss are assumed as \(M_G = M_L\). For omni directional antenna, AVDL only is considered. AIM is determined with the help of Figure 3.1 and using Equation (3.12).

![Figure 3.1 Angle of incidence calculation between BS and RTP](image)

\[
\theta_{\angle} = \frac{\tan^{-1}(h_m - h_m)}{d} \quad \tag{3.12}
\]

3.4 OBJECTIVES AND CONSTRAINTS

In BS placement, the optimal locations of mobile antenna are to be found out. The objective of the BS placement which is to determine \((x, y)\) coordinates of mobile antenna and to maximize the coverage in the area taking into account of the radio propagation characteristics of the area. This issue is known as NP-hard since the complexity of the problem increases exponentially to the number of variables and consists of mixed integer decision variables with multiple nonlinear objectives and constraints. The objectives and constraints of BS placement are discussed below.
3.4.1 Objectives

Coverage and cost are considered as multiple conflicting objectives of BS placement.

3.4.1.1 Coverage

The area where the BS needs to be installed is conveniently discretized into smaller cells. Each cell has users and they are represented by RTP. If a RTP is said to be covered by a BS, it should have the Field Strength (FS) above the threshold level $S_q$. Normally $S_q$ is fixed as -90db. The aim is to achieve maximum coverage through covering maximum RTP. At the same time, it is not possible by a BS to cover all STP due to the restrictions in traffic handling capacity. Coverage maximization is recommended in this work after implementing suitable methods for handling the restrictions in traffic handling.

3.4.1.2 Cost

The role of an efficient algorithm is to select best location in order to maximize the coverage and to minimize the number of BSs and its associated cost. If coverage needs to be improved, it is an obvious choice to increase the number of antennas. The cost factor is directly proportional to the number of BS and its adopted transmitting power. They are as shown in Table 3.4 (Hurly 2002). The incurred cost of a cell plan is the total cost of all BS (represented by a value in between 1-2) with the utilization of minimum transmitting power other than zero.

<table>
<thead>
<tr>
<th>Transmitted power (Watts)</th>
<th>1000</th>
<th>501</th>
<th>251</th>
<th>125</th>
<th>63</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>2</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>
3.4.2 Constraints

BS suitable location identification is carried out to improve the coverage of users with minimum cost after satisfying inequality constraints. These constraints are conditions to be satisfied for achieving good coverage. Three inequality constraints namely traffic demand, overlap and handover are considered.

3.4.2.1 Traffic demand

According to the maximum traffic load handling capacity by a transmitter, one BS can handle up to 43 Erlang. This constraint should allow a TTP to attach with another BS based on the $S_q$ value. Normally, a mobile device which receives signals above $S_q$ should select only the strongest signal. By this analogy, BS calculates maximum traffic capacity after analyzing the TTP based on the strongest signal. Minimum number of BS can be calculated using Equation (3.13) which satisfies the traffic demand.

$$\text{Minimum antenna required} = \sum \frac{\text{Traffic demand of TTP}}{43}$$ (3.13)

Traffic demand created by each user is calculated either using the distance calculation between BS and user or allotted equal value to all users inside the locations.

3.4.2.2 Overlap

Whenever STP is covered by two BS, there is a possibility of the cell overlap. Overlap leads to the duplication of STP, increasing uncovered areas, restriction of transmitted power and interferences. The checking of overlap constraint is the best method of controlling interferences. This gives permission to have a minimum percentage of overlap $\alpha$ in between two cells
or BS. The \( \alpha \) constraint ensures the permissible transmitting power and installation of new cell in the desired area along with the existing cells. The mathematical expression (Hurly 2002) for \( \alpha \) in percentage is shown in the following Equation (3.14)

\[
\alpha = \sum_{j=1}^{n_b} \sum_{i=1}^{n_s} \mu_{ij}
\]

(3.14)

where \( \mu_{ij} = \begin{cases} 1 & \text{if } F_j(s_i) > R_s \\ 0 & \text{otherwise} \end{cases} \)

Here \( n_b \) is the number of base stations, \( n_s \) is the number of potential sites, \( F_j(s_i) \) is the field strength of sites \( s \) and \( R_s \) is the receiver sensitivity. If the commissioning of new cell violates the alpha constraint, the system will not allow the new cell in that particular location. It is possible to have alpha value from 5% to 90%. Minimum permissible alpha is necessary to have a seamless handover whereas maximum value will lead to excessive interferences. In this thesis, a detailed study is performed in overlap percentage and suitable recommendations are made to have a good \( \alpha \).

### 3.4.2.3 Handover

If one user moves away from one BS, its signal strength is automatically reduced below required sensitivity. At that time, user searches for the good quality signal from nearby BS and sends request to attach with them. User will be detached from the old BS due to realization of poor signal strength and attach to the new BS with good receiver sensitivity is termed as handover. The types of handover can be classified based on the signal connectivity, initiation and geographical location. The handover set \( \text{HAND}_j \) operates on the cell \( C_j \) which inclusive of site \( S \) and the base station \( B_i \) is defined as follows (Hurly 2002) in Equation (3.15).
\[ \text{HAND}_i = \{ s_i : s_i \in c_j \text{ and } \exists j' \neq j \text{ such that } |F_j(s_j) - F_{j'}(s_{j'})| \leq 7 \} \]

This thesis deals with rigid handover constraint to achieve the desired multiple objectives. Normally, the user must receive at least four good sensitive signals from BS. The necessary condition to achieve the handover constraint is, when the signal strength received by any one STP in each cell is above the threshold from four BSs and which is within 7 dB.