A Simple Model for Determination of GSM Mobile Towers Distribution

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Abstract

In this paper, a simple model for determination of initial geographic distribution of the base stations belong to a Mobile Communications (GSM) network is introduced. A SW tool based on the model is developed, it aims to assess the locations of a number of base stations required to make full coverage for certain geographic area. The proposed mathematical model is based on using the highest possible signal path loss criterion that could occurred for the signal traveled between a tower and GSM mobile transceivers. The determined locations of towers are pointed on a geographic map using simple mathematical manipulation (i.e., affain transform). Also, in this model the nature of the geographic area (i.e., urban/ non-urban areas) is taken into consideration. Baghdad city was selected to test the developed tool.

Keywords: Modeling, GSM, Cell, Path Loss, Hata Model.

1. Introduction

Cellular mobile network planning is necessary to provide highly efficient services [1]. It has become part of day to day life, even for an average person. Global System for Mobile Communications (GSM) is a digital wireless network standard designed by standardization committees from major European telecommunications operators and manufacturers [2]. It allows several users to share the same frequency channel by dividing the signal into different timeslots [3]. Patterns of cells have two types:

A. Square shape for the area coverage of cells. A matrix of square cells would be the simplest layout to define, as seen in Figure (1). However, this geometry is not ideal. If the width of a square cell is (d), then a cell has four neighbors at a distance (d) and four- neighbors at a distance ($\sqrt{2}d$) [4].

B. Hexagonal shape of cell’s area coverage, as shown in Figure (2). It is the most commonly used network topology because the hexagon tessellation provides coverage for larger areas with using the smaller number of cells [5].

2. GSM Locations

Two main kinds of criteria are used to determine the network distribution. The first one depends on classification of geographic area according to urban nature. The second one depends on path loss models. The total path loss at the radio horizon is about 25 decibels (dB units) greater than the path loss over the same distance in free space (absence of ground). This additional loss results from some energy being reflected from the ground, which acts as a canceling part of the direct wave energy. This is unavoidable in almost every practical case. The total path loss for any line of sight path above average terrain varies with the following factors: (i) total path loss between transmitting and receiving antenna terminals, (ii) frequency, (iii) distance, (iv) transmitter antenna gain and (v) receiver antenna gain [6].

2. Path Loss Models

Path loss depends on frequency, antenna height, receiver-transmitter line of sight relative to obstacles,
reflections, link distance, and many other factors. Usually, a statistical path loss model (or prediction program) is used to estimate the median propagation loss unit in dB. The National Institute of Standards and Technology (NIST) had done an excellent job in documenting and comparing several realistic empirical propagation loss models. Based on the NIST study, the following loss models were investigated [7]:

A. Free Space Model Transmission

In real environments the communication channel is contaminated by additive white Gaussian noise, and attenuated through propagation in free space. In practical situations, signals undergo additional attenuation. Therefore, Friis’s equation (1) cannot be used in real environments [7]. Free space path loss at a distance \( d \) from transmit antenna is defined as the ratio between transmitted and the received power:

\[
P_L = P_T / P_R
\]

Where, \( P_R \) is the received power and \( P_T \) is the transmitted power.

B. Okumura Model

The Okumura model is used for urban areas, it is a radio propagation model that is used for signal prediction. The frequency coverage of this model is in the range of 200 MHz to 1900 MHz, and distances of 1 Km to 100 Km. It can be applicable for base station with antenna heights \( h \) ranging from 30 m to 1000 m. The Okumura model is a well known classical empirical model to measure the radio signal strength in urban areas. This model is perfect for using in the cities having dense and tall structure [8, 9].

In Okumura model, many factors have been added to equation (1); such as free space loss, \( A_{\text{uf}}(f,d) \) between points of interest, which were added to \( A_{\text{uf}}(f,d) \) beside to some correction factors relevant to terrain, therefore the formula becomes [8]:

\[
L_{50}(dB) = L_F + A_{\text{uf}}(f,d) - G(h_c) - G(h_r) - G_{\text{AREA}}
\]

Where,

- \( L_{50} \) is the half (i.e., 50%) of the value of propagation path loss (i.e., the median).
- \( L_F \) is the free space propagation loss.
- \( A_{\text{uf}}(f,d) \) is the median attenuation relative to free space.
- \( G(h_c) \) is the base station antenna height gain factor.
- \( G(h_r) \) is the mobile antenna height gain factor.
- \( G_{\text{AREA}} \) is the gain due to environment.

C. Hata Model \((L_h)\)

Hata model is empirically derived using the experimental data collected in Tokyo. It was intended to be used in Japanese suburban landscapes. Some published studies indicated that Hata model performs poorly over North American suburban terrain. Today, this model is one of the most widely used models, it belongs to the class of models for the prediction of the median field strength in urban areas, and it was introduced by Okumura [10, 11, 12]. The path loss according to Hata’s model formula is given by:

\[
L_P(dB) = \begin{cases} 
S & \text{for urban area} \\
S - C & \text{for suburban area} \\
S - D & \text{for open area} 
\end{cases}
\]

Where,

\[
S = 69.35 + 26.16 \log_{10}(f) - \log_{10}(h_b) - 13.82 \log_{10}(h_b) + B \log_{10}(d)
\]

and

\[
B = 44.9 - 6.55 \log_{10}(h_b)
\]

\[
C = 5.4 - 2(\log_{10}(f/28))^2
\]

\[
D = 40.49 + 4.78(\log_{10}(f))^2 - 18.33 \log_{10}(f)
\]

D. CCIR Model \((L_{\text{ccir}})\)

\[
L_{\text{ccir}} = \begin{cases} 
0.11 \log_{10}(f) - 0.7 & \text{for median and small city} \\
1.56 \log_{10}(f) - 0.8 & \text{for large city & } f \leq 300 \text{ MHz} \\
3.2(\log_{10}(11.75h_m))^2 - 4.97 & \text{for large city & } f \geq 300 \text{ MHz} 
\end{cases}
\]

Where,

- \( f \) is the carrier frequency (100 \( \leq f_{\text{MHz}} \leq 1500)\)
- \( h_b \) is the BS antenna height (30 m \( \leq h_b \leq 200 \text{ m)\)
- \( h_m \) is the MS antenna height (1 m \( \leq h_m \leq 10 \text{ m)\)
- \( d \) is the transmission distance (1 km \( \leq d \leq 20 \text{ km)\)
An empirical formula for the combined effects of free-space path loss and terrain induced path loss was published by the international radio consultative committee (CCIR) [12]. The CCIR formula is given by:

\[
L_{ccir} = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_1) + \alpha(h_2) + K
\]

........................................(9)

**Table (1) Hata model parameters (a & K factor)**

<table>
<thead>
<tr>
<th>Type of area</th>
<th>a(h2)</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>2.52h2−3.77</td>
<td>28.26</td>
</tr>
<tr>
<td>Suburban</td>
<td>9.79</td>
<td></td>
</tr>
<tr>
<td>Medium-small city</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Large city (f_{Hz}&gt;300)</td>
<td>3.2(\log_{10}(11.75h_{2})^2−4.97)</td>
<td></td>
</tr>
<tr>
<td>Large city (f_{Hz}&lt;300)</td>
<td>8.29(\log_{10}(1.54h_{2})^2−1.1)</td>
<td></td>
</tr>
</tbody>
</table>

Where,

- \(h_1\) is antenna height BS (in meters), its range [30,200].
- \(h_2\) is antenna height MS (in meters), its range [1,10].
- \(d\) is the link distance (in km), its range [1,20].
- \(f\) is the center frequency (in MHz), its range [150,1500].
- \(a(h_2)\) is an antenna height-gain correction factor that depends upon the environment, it equals zero for \(h_2=0\).
- \(K\) is a factor used to correct the formula for small city suburban and open areas.

**E. LHata Model (L_{Hata})**

The category of “large city” used by Hata implies building height greater than 15m. At the cellular frequency of 850 MHz, the antenna height-gain \(a(h_2)\) & the correction factor (K) is shown in table (2). The formula of \(L_{Hata}\) becomes:

\[
L_{Hata} = (4.49−6.55\log_{10}(h_1))\log_{10}(d)−\alpha(h_2)−13.82\log_{10}(h_1)−K+146.18
\]

........................................(10)

**F. COST 231 Extended Hata Model**

COST 231 Extended Hata Model is considered as the first model used up to date. Sometimes, it is called Hata Model Personal Communication System (PCS) Extension. This model extends the Okumura-Hata model to a cover wider range of frequencies [16], and is used for medium to small cities to cover the 1500 to 2000 MHz band. For urban PCS applications at 1.5-2 GHz, the European study committee (COST 231) found that Hata model consistently underestimates path loss, and for this reason they developed the “extended Hata model” to correct the situation. According to extended Hata model the basic formula for the median propagation loss (in dB) is given as [17,18, 19]:

\[
L_{xHata} = 46.33+33.9\log_{10}(f)−\alpha(h_2)−13.82\log_{10}(h_1)−\alpha(h_2)+K+146.18
\]

........................................(13)

Where,

\[
C=\begin{cases} 
0 & \text{for medium & suburban city} \\
3 & \text{for urban centers}
\end{cases}
\]

........................................(14)

The ranges of parameters for which this model is considered valid are the following:
(i) \( f = [1500, 2000] \text{ MHz} \),
(ii) \( h_b = [30, 200] \text{ m} \),
(iii) \( d_{mb} = [1, 10] \text{ km} \),
(iv) \( h_s = [1, 10] \text{ m} \).

G. Hata-Davidson Model

Hata and Hata/Davidson ignore some of the adjustment factors included in Okumura, such as the slope of the terrain, street orientation, and correction for location on hills. The Hata-Davidson model provides an extension of the basic Hata model up to base station heights of 2500 meters [18]. The main factors included in Hata/Davidson are the area types: Urban, Suburban, Quasi-open and Open, as well as corrections for the receiver antenna height.

The modification consists of the addition of correction terms to the Hata model [18]:

\[
L_{HD} = L_{HATA} + A(h_1,d) - S_2(h_1,d) - S_3(f) - S_4(f,d)
\]

Where,

- \( A \) & \( S_1 \) are the distance \((d)\) correction factors extending the range to 300 km, see table (3).
- \( S_2 \) is a base station antenna height correction factor extending the range of \( h_1 \) values \([300, 2500]\) m.
- \( S_3 \) & \( S_4 \) are frequency correction factors extending frequency to 1500 MHz.

Table (3) Hata-Davidson’s Model parameters \((A \ & \ S_1)\) correction factors

<table>
<thead>
<tr>
<th>Distance</th>
<th>( A(h_1,d) )</th>
<th>( S_1(d) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d &lt; 20 \text{ km} )</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( 20 \leq d &lt; 64.38 \text{ km} )</td>
<td>( 0.0932(10^{0.1950d-20}) )</td>
<td>0</td>
</tr>
<tr>
<td>( 64.38 \leq d &lt; 300 \text{ km} )</td>
<td>( \log_{10}(121.92) )</td>
<td>( 0.174 )</td>
</tr>
</tbody>
</table>

3. Georeferencing

Georeferencing is applied as a process assigned to transform the non-metrical maps (usually the early maps) to a ‘metric reference’. When the metric reference is related to the system of earth coordinates or their map-projection counterparts, it is called georeference [21]. The steps involved in georeferencing a digital map image depends, mainly, on map image specifications [22].

4. Geometric Transformation

The most common and simple geometric transformation is of linear type (usually called affine transformation); it takes a point/vector and maps it into another point/vector using linear equations. Affine transformations are commonly used for handling the georeferencing and registration tasks; specifically when the geographic coverage of the map (or image) is small. According to affine transformation the coordinates can be converted using linear expressions plus a translation term.

Affine mappings conserve co-linearity (i.e., 3 points lying on a common line before the transformation also lies on a common line afterwards), and proportionality of distances along a straight line (i.e., the relative relations of distances on a line are preserved). Affine transformation includes the geometrical primitive processes (i.e., translation, scaling, reflection, rotation and shearing). Simply, it can be a combination of these basic (primitive) transformations [23].

5. The Proposed Model

The proposed model is developed to be used for determination of the initial geographic distribution of the base stations of a GSM network. The used criteria are: (i) smallest possible number of base stations, with hexagon coverage area, and (ii) the path loss doesn’t exceed the allowed maximum value for parts of the coverage area. The latest criterion was fulfilled by making a constraint on the path loss value for the points located at farthest distance from their base stations.

In our proposal system we have concentrated on processing satellite images to extract the projection of base stations hexagon map. As shown in figure (3), the proposed model encompasses of seven modules; each module is designed to perform specific tasks. These modules are illustrated in the following sections.
5.1 Geographic Allocation of GSM Network

As a first step the geographic area (i.e., ROI) is allocated, then its boundary is determined. Also, its nature parameters are assigned (e.g., Urban/Non-Urban; Small City/Large City ...).

From the coordinates \((\text{Lon}=\lambda, \text{Lat}=\theta)\) of 4 boundary corners (i.e., \((\lambda_1, \theta_1), (\lambda_2, \theta_2), (\lambda_3, \theta_3), (\lambda_4, \theta_4)\)) the following steps are used to determine the parameters required to make a conversion from spheroid coordinate system \((\lambda, \theta)\) to flat coordinate system \((x_f, y_f)\):

(i) Determine the latitude and longitude average values \((\theta_{avg}, \lambda_{avg})\) using:

\[ \theta_{avg} = \frac{1}{4} \sum_{i=1}^{4} \theta_i \] ...............................(16)

(ii) Determine the effective radius \((R_{ef})\) value using spheroid equation:

\[ R_{ef} = \sqrt{\left( a \cos(\theta_{avg}) \right)^2 + b \sin(\theta_{avg})^2 } \] .................................(17)

Where \(a\) and \(b\) are the semi-major and semi-minor are radii of the Earth spheroid model (in the established program the WGS84 geodetic model was adopted, so the value of \(a\) is set 6378.137 km and for \(b\) is 6356.7523 km.

(iii) Determine the approximate separating distance \((S_\theta)\) between two parallels (latitude circles) separated by 1 degree:

\[ S_\theta = \frac{2\pi R_{ef}}{360} \] .................................(18)

(iv) Determine the approximate separating distance \((S_\lambda)\) between two meridians (longitude circles) separated by 1 degree (and within the ROI):

\[ S_\lambda = S_\theta \cos(\theta_{avg}) \] .................................(19)

(v) The mapping from geodetic coordinates \((\lambda, \theta)\) to flat coordinates \((x_f, y_f)\) is done using the following equations:

\[ x_f = (\lambda - \lambda_{avg}) \] .................................(20)

\[ y_f = (\theta - \theta_{avg}) \] .................................(20)

5.2 Georeferencing the Map

In this stage, at least three reference control points on the map image are allocated. Then the image coordinates and the corresponding geographic coordinates for these points are determined.

The image coordinates for three chosen control points are collected from the map image using an image editor, and their geographic coordinates are allocated using any map browser (like, Google mapper). The associated flat coordinates \((x_m, y_m)\) are computed using equations (20).

Table (4) lists the coordinate of 3 reference points extracted from Map image for Baghdad City (see figure 5).
5.3 Affine Transformation

Here, affine transformation is used to represent the mapping process between the image coordinates and their corresponding geographic coordinates. Instead of direct use of (Lat, Lon) geodetic coordinate system their corresponding flat coordinates \((x, y)\) is used; this is useful to get better coordinates approximation accuracy. When the ROI covers a small area on the Globe, then, linear affine transformation is enough to do the mapping process:

(i) For forward mapping:
\[
x = a_1 x_m + a_2 y_m + a_3 \\
y = b_1 x_m + b_2 y_m + b_3
\]

(ii) For inverse mapping:
\[
x_m = c_1 x + c_2 y + c_3 \\
y_m = d_1 x + d_2 y + d_3
\]

The set of transform coefficients \(\{c(i), d(j)\}\) could be determined from the set \(\{a(i), a(j)\}\) using the following equations:

\[
c_1 = b_2 / (a_1 b_2 - a_2 b_1) \\
c_2 = a_2 / (a_1 b_2 - a_2 b_1) \\
c_3 = (a_2 b_3 - a_3 b_2) / (a_1 b_2 - a_2 b_1) \\
d_1 = b_1 / (a_1 b_2 - a_2 b_1) \\
d_2 = a_1 / (a_1 b_2 - a_2 b_1) \\
d_3 = (a_1 b_3 - a_3 b_1) / (a_1 b_2 - a_2 b_1)
\]

The values of the set \(\{a(i), b(j)\}\) are determined by: first substituting the coordinates of reference points (e.g., those listed in table) in equations (22) to get two sets of simultaneous linear equations and second solving these two sets of equations. Table (5) presents the calculated values of affine transform coefficients \(\{a(i), b(j)\}, c(i), d(j)\} \) when the reference coordinates tabulated in Table (4) are used.

<table>
<thead>
<tr>
<th>Point #</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Image</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>57</td>
</tr>
<tr>
<td>2</td>
<td>609</td>
</tr>
<tr>
<td>3</td>
<td>905</td>
</tr>
</tbody>
</table>

| Table (4): The coordinates list of reference points |

5.4 Selection of Reference Base Station

The geographic coordinates of reference base station are calculated by applying selection the site position on the map image, then the image coordinates \((x, y)\) are mapped using the affine transform equations (eq. 22). Then, the calculated flat coordinates \((x, y)\) are used to determine the geodetic coordinates \((\lambda, \theta)\) using equations (20). In the example shown in this paper the base station coordinates is taken \((\lambda = 44°40', \theta = 33°42')\).

| Table (5) Affine transform coefficients |

<table>
<thead>
<tr>
<th>Forward transform</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(b_1)</th>
<th>(b_2)</th>
<th>(b_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10835</td>
<td>-9192.1</td>
<td>-173680</td>
<td>96042</td>
<td>-14716</td>
<td>448870</td>
</tr>
<tr>
<td>Inverse transform</td>
<td>(c_1)</td>
<td>(c_2)</td>
<td>(c_3)</td>
<td>(d_1)</td>
<td>(d_2)</td>
<td>(d_3)</td>
</tr>
<tr>
<td></td>
<td>977060</td>
<td>-610320</td>
<td>44365</td>
<td>6376800</td>
<td>719390</td>
<td>33398</td>
</tr>
</tbody>
</table>

5.5 Assignment of Network Coverage

As a next step after the assignment of base station location, the geographic coverage of the GSM network should assigned (using a map image editor).

For example, assume the corner coordinates of the map image \{(0,0), (1000,0), (0,613), & (1000,613)\} represent the required coverage of GSM network. Then, the geographic coordinates of the coverage area are calculated using the inverse affine coefficients. So, the minimum and maximum latitude and longitude values are found:

\[
\lambda_{\text{min}} = 44^\circ 32.8' ; \quad \lambda_{\text{max}} = 44^\circ 46.3' \\
\theta_{\text{min}} = 33^\circ 35.43' ; \quad \theta_{\text{max}} = 33^\circ 39'
\]

5.6 GSM Network Determination

The GSM network parameters are required to determine the required net of hexagon coverage of the base stations. Among the network parameters are:

A. Base Station Transmitting Power

The required output power of the base stations depends mainly on: (i) the size of the coverage area they serve, (ii) the number of users and on (iii) the mobile’s generations. After a long review of the
published papers, we have noticed that the base station transmission power values ranges from 5 to 40 Watts.

Also, the height of the Base station antenna is important, and has effective effects on the network coverage.

B. Mobile Receiving Sensitivity

Mobile phones are one of the fastest growing technology-based industries in the world. Each type of mobile phones is characterized by specific set of specifications. One of these specifications is the receiving sensitivity. The typical range of the receiving sensitivity for GSM 900 is (-102) dB and for GSM 1800 is (-100) dB.

5.7 Path Loss Calculation

The path loss is assessed using different models. Table (6) lists the calculated path loss values using the models: Hata, L_{ccir}, L_{hata}, and L_{ITU}. The reason for adopting these 5 models is they are applicable for lands similar to Baghdad city. The path loss was calculated using equations (3, 9, 10 & 11). In all path loss calculations the following network parameters are adopted: \( f = 900 \text{ MHz} \); \( h_m = 30 \text{ m} \); \( h_w = 1.5 \text{ m} \).

The last column of table (6) lists the average path loss values using the predicted values of the 5 adopted models.

From figure (4), it is clear that Hata model predicts lower path loss values in comparison with predicted values by other loss models (such as, L_{ccir}, L_{hata}, and L_{ITU}).

Table (6) and figure (4) indicate that relationship between path loss and distance is monotonic. This monotonic behavior is similar for all path loss models. The contents of table (6) could be used as a look up table to do fast predictions for path loss values at any distance, and vice versa.

5.8 Determination of Base Station Coverage

The effective range of coverage of the each base station is determined using the following path loss equation:

\[
L(dB) = P_t - S_r - M \text{ (in dB)} \quad \text{.................................(25)}
\]

Table (6) Path losses versus distance (d) for the adopted models (the height of base station tower is set 30m)

<table>
<thead>
<tr>
<th>d(km)</th>
<th>Hata</th>
<th>L_{ccir}</th>
<th>L_{hata}</th>
<th>L_{ITU}</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>98.16</td>
<td>126.42</td>
<td>125.77</td>
<td>126.42</td>
<td>119.19</td>
</tr>
<tr>
<td>1.5</td>
<td>104.37</td>
<td>134.12</td>
<td>131.97</td>
<td>132.62</td>
<td>125.77</td>
</tr>
<tr>
<td>2</td>
<td>108.77</td>
<td>139.59</td>
<td>136.37</td>
<td>137.02</td>
<td>130.43</td>
</tr>
<tr>
<td>2.5</td>
<td>112.18</td>
<td>143.83</td>
<td>139.78</td>
<td>140.44</td>
<td>134.05</td>
</tr>
<tr>
<td>3</td>
<td>114.97</td>
<td>147.29</td>
<td>142.57</td>
<td>143.23</td>
<td>137.01</td>
</tr>
<tr>
<td>3.5</td>
<td>117.33</td>
<td>150.22</td>
<td>144.93</td>
<td>145.58</td>
<td>139.57</td>
</tr>
<tr>
<td>4</td>
<td>119.37</td>
<td>152.76</td>
<td>147.97</td>
<td>147.63</td>
<td>141.68</td>
</tr>
<tr>
<td>4.5</td>
<td>121.17</td>
<td>155.00</td>
<td>148.78</td>
<td>149.43</td>
<td>143.59</td>
</tr>
<tr>
<td>5</td>
<td>122.78</td>
<td>157.00</td>
<td>150.39</td>
<td>151.04</td>
<td>145.30</td>
</tr>
<tr>
<td>5.5</td>
<td>124.24</td>
<td>158.81</td>
<td>151.85</td>
<td>152.50</td>
<td>146.85</td>
</tr>
<tr>
<td>6</td>
<td>125.57</td>
<td>160.46</td>
<td>153.18</td>
<td>153.83</td>
<td>148.26</td>
</tr>
<tr>
<td>6.5</td>
<td>126.80</td>
<td>161.98</td>
<td>154.40</td>
<td>155.05</td>
<td>149.55</td>
</tr>
<tr>
<td>7</td>
<td>127.93</td>
<td>163.39</td>
<td>155.54</td>
<td>156.19</td>
<td>50.76</td>
</tr>
<tr>
<td>7.5</td>
<td>128.99</td>
<td>164.70</td>
<td>156.59</td>
<td>157.24</td>
<td>51.88</td>
</tr>
<tr>
<td>8</td>
<td>129.97</td>
<td>165.93</td>
<td>157.58</td>
<td>158.23</td>
<td>52.92</td>
</tr>
<tr>
<td>8.5</td>
<td>130.90</td>
<td>167.08</td>
<td>158.51</td>
<td>159.16</td>
<td>53.91</td>
</tr>
<tr>
<td>9</td>
<td>131.78</td>
<td>168.16</td>
<td>159.38</td>
<td>160.03</td>
<td>54.83</td>
</tr>
<tr>
<td>9.5</td>
<td>132.60</td>
<td>169.19</td>
<td>160.21</td>
<td>160.86</td>
<td>55.71</td>
</tr>
<tr>
<td>10</td>
<td>133.39</td>
<td>170.17</td>
<td>160.99</td>
<td>161.64</td>
<td>56.54</td>
</tr>
</tbody>
</table>

Where,

\( L \) is the allowed path loss margin (in dB).

\( P_t \) is the power (in Watt) of base station transmitted from its antenna.

\( S_r \) is the sensitivity (in dB) of mobile receiver.

\( M \) is the power margin value, its value depends on other kinds of natural and operations power losses, it is taken 1-3 dB.

Table 7 presents an example for the path loss (L) value (the transmission power value is taken 5 Watts, and the receiver sensitivity considered is taken -102dB). Then the effective radius value was asseesd (using table 6) to be 1.83 km.

Table (7) The distance value at path loss (107.48 dB)

<table>
<thead>
<tr>
<th>Mobile receiving sensitivity (dB)</th>
<th>Path loss (dB)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-102</td>
<td>107.48</td>
<td>1.83</td>
</tr>
</tbody>
</table>
6. Determination of the Required Base Stations Number

Since the area covered by each GSM base station has hexagonal shape, so the coverage area \( A \) is calculated using the following equation:

\[
A = \frac{3\sqrt{3}}{2} R^2 \quad \text{...........................................(26)}
\]

Where \( R \) is the coverage radius of the base station.

From the previous example shown in table (7), the radius of cell coverage is found (1.83km) for transmission power (5 Watts) and mobile receiving sensitivity (-102 dB), so the coverage for each base station is (8.4175km²).

The minimum number of required base stations is computed using then following equation:

\[
n_{bs} = \left\lceil \frac{A_g}{A} \right\rceil \quad \text{...........................................(27)}
\]

Where, \( A_g \) is whole geographic area need to be covered by GSM Network.

7. Results and Conclusions

Hata model is a suitable model for path loss determination, in this work, because most of Iraqi areas are semi-flat and classified as an open large city according to the population of buildings.

In the case of increasing the tower’s height, the path loss is decreased, and this will lead to an increase in separation distance between base stations.

The hexagons grid could be locally shifted automatically to avoid the forbidden area (such as; military and natural obstacles like rivers, lakes, …, etc.).

References


Appendix A

Figure (4) The assessed path loss using different propagation models (height base station is 30 m)

Figure (5) Selection of the model of path loss to show the grid of towers