Propagation Model For the 900 MHz Almadar Aljadid Mobile Network at Tripoli Area Using Linear Regression Method

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ABSTRACT

The accuracy of the predicted Received Signal Strength (RSS) is the key issue in the mobile network design. In the last decades many models invented to predict the RSS in specific locations. One of the most famous models is Hata model, which is developed originally based on measurements done in Tokyo – Japan. The objective of this paper is to modify Hata model at frequency band 900 MHz to match the environments of Tripoli area, the capital of Libya. The modifications was based on real measurements of the RSS which were conducted in the concerned area. The modified model is expected to be used during the designing phase of the mobile networks in the future. The measurements is collected in five types of areas (Dense Urban, Urban, Dense Suburban, Suburban and Rural). The regression method is used to modify the Hata model parameters to match the real measured values of RSS within an acceptable range of accuracy. The RMSE (root mean square error) was calculated and used as an assessment factor for the modified module. The modified module gives 4.7 to 23.6 dB improvement in the accuracy of predicting the path loss, i.e. (46.5% to 66.4%) of Hata model values.

KEYWORDS


1 INTRODUCTION

In wireless communication the information transfers from transmitter to receiver through wireless channel, which likely be affected by interference, fading, scattering, reflection …etc from the surrounded obstacles like buildings, terrains, cars, threes ..etc , due to all these processes the signal decays with distance[1]. The difference between signal strength transmitted from TX and signal strength received at RX defined as a pathloss, which is the main limitation of the cell coverage. The path loss is changeable and depending on many factors. One of the main important factor is the area type. The area can be classified as one of five types; Dense urban, Urban, Dense suburban, Suburban and Rural. The classification is based on the population density, building type and building density. The accuracy of predicted RSS is valuable in mobile network design, which is effected by cell characteristics (location- Antenna height- Antenna type- frequency band- transmitted power etc).

Many works has been done to model this loss mathematically either in empirical or in theoretical ways. These models help engineers during the designing phase of the cellular networks. The empirical models is obtained from the measurement of the effect of environment conditions on the RSS, regardless the correlation between the environment parameters. This type of models is commonly used since it requires less executing time and much lower details of the environment conditions.

In this work the RSS were measured as function of distance in 10 locations in Tripoli, 2 locations for each type of areas. For every location the measured values were averaged every distance equal to 40 λ. These values were analyzed by linear regression method to
develop the modified propagation model which is suitable for Tripoli Area[2],[3].

The rest of this paper is organized as follows. Section 2 gives a brief idea about the most famous propagation models, where section 3 describes the regression methods, and how to use linear regression method to get a mathematical equation that fits certain data. The measurements methodology used in this work has been illustrated in section 4, before presenting the results and the discussion in section 5 and 6. Finally, the paper was concluded in section 7.

2 PROPAGATION MODELS

Propagation model is a mathematical tool to simulate the propagation loss that can be used by engineers and scientists in designing and optimizing the wireless networks. The main goal in the design phase of the wireless network is to predict the amount of the signal strength as a function of the separation distance between the transmitter and the receiver, which is affecting the cell coverage radius in cellular networks. It is also used to avoid the expected interference with the neighboring sites. Here are some examples of the propagation models.

2.1 Free Space Propagation Mode

The free space model is used to predict the RSS when the transmitter and the receiver have clear, unobstructed line of sight path between them. The free space model predicate the path loss as function of frequency and the separation distance between the transmitter and the receiver as per the following equation [4],[7];

\[ L_{dB} = 32.44 + 20 \log_{10}(f) + 20 \log_{10}(d_{km}) \]  

Where

- \( L_{dB} \) is the free space path loss in dB
- \( f \) is the operating frequency in MHz
- \( d_{km} \) is the separating distance in km.

### 2.2 Lee propagation model

W. Lee proposed a very simple signal propagation model originating from a series of measurements made in the USA at 900 MHz carrier frequency. According to the Lee model, the mean power measured at distance “d” from the transmit station is determined by [1],[4],[10];

\[ l(d)(dB) = l_0 + 10 \log_{10}(d) + \alpha_c \]  

Where;

- \( L_0 \) is the loss at 1km.
- \( \nu \) is the loss parameter.
- \( \alpha_c \) is a correction factor.

The prediction were done for a carrier frequency of 900MHz, a base station (BS) antenna of height 30.5, and a receiving antenna or mobile station (MS) height of 3 m. The correction factor \( \alpha_c \) is included to account for any change in the standard parameters used in the model and can be expressed as

\[ \alpha_c = 10 \log_{10}(F_0) \]

\( F_0 \) is the correction factor selected on the basis of a series of component factors according to the formula.

\[ F_0 = \prod_{i=0}^{5} F_i \]  

where the subsequent factors \( F_i \) are described by expressions

\[ F_1 = \left( \frac{\text{Actual BS antenna height}[m]}{30.5[m]} \right)^2 \]  

\[ F_2 = \left( \frac{\text{Actual MS antenna height}[m]}{3[m]} \right)^\nu \]

The power \( \nu = 1 \) for the mobile station antenna height lower than 3m and \( \nu = 2 \) for the heights larger than 10m.

\[ F_3 = \left( \frac{\text{Actual power}}{10 \text{ W}} \right) \]

\[ F_4 = \left( \frac{\text{BS antenna gain}}{4} \right) \]

\[ F_5 = G_{MS} \]

Where;

- \( G_{MS} \) is the MS antenna gain.
2.3 Hata Model

The Hata model, also known as the Okumura–Hata model, is one of the most commonly used model for a macro cell environments to predict the radio signal attenuation. The model is considered as an empirical model, since it has been developed using field measurements data. The field measurements has been performed in Tokyo-Japan, and the obtained results was published in a graphical format and put into equations. The model is valid for quasi-smooth terrain in an urban area. For other terrain types correction factors are [5],[6],[7],[10],[11].

The ranges of the used parameters for this model are shown in table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>f</td>
<td>150–1500 MHz</td>
</tr>
<tr>
<td>Frequency Extension</td>
<td></td>
<td>1500–2000 MHz</td>
</tr>
<tr>
<td>Distance between MS and BTS</td>
<td>d</td>
<td>1–20 km</td>
</tr>
<tr>
<td>Transmitter antenna height</td>
<td>$H_b$</td>
<td>3–200 m</td>
</tr>
<tr>
<td>Receiver antenna height</td>
<td>$H_m$</td>
<td>1–10 m</td>
</tr>
</tbody>
</table>

The Okumura–Hata model for path loss prediction in Urban area can be written as

\[
L = A + B \log_{10}(f) - 13.82 \log_{10}(H_b) - a(H_m) + [44.9 - 6.55 \log_{10}(H_b)] \log_{10}(d) \tag{9}
\]

Where:
- \( f \) is the frequency (MHz).
- \( H_b \) is the base station antenna height (m).
- \( H_m \) is the MS antenna height (m).
- \( a(H_m) \) is the mobile antenna correction factor
- \( d \) is the distance between the BTS and MS (km).

The correction factor for the MS antenna height is represented as follows, for a small or medium sized city:

\[
a(H_m) = [1.1 \log_{10}(f) - 0.7] H_m - [1.56 \log_{10}(f) - 0.8] \tag{10}
\]

and for large city:

\[
a(H_m) = \begin{cases} 
8.29[\log_{10}(1.54H_m)]^2 - 1.1 & f \geq 200 MHz \\
3.2[\log_{10}(11.75H_m)]^2 - 4.97 & f \geq 400 MHz 
\end{cases} \tag{11}
\]

The parameters A and B are dependent on the frequency as follows [1-4-5]:

\[
A = \begin{cases} 
69.55, & 150 < f < 1500 MHz \\
46.30, & 1500 < f < 2000 MHz 
\end{cases} \tag{12}
\]

\[
B = \begin{cases} 
26.16, & 150 < f < 1500 MHz \\
33.9, & 1500 < f < 2000 MHz 
\end{cases} \tag{13}
\]

For sub urban area

\[
L = L_{urban} - 2[\log_{10}(f/28)]^2 - 5.4 \tag{12}
\]

For rural areas

\[
L = L_{urban} - 4.78[\log_{10}(f/28)]^2 + 18.33 \log_{10}(f) - 40.94 \tag{13}
\]

Hata model is not suitable for micro-cell planning where antenna is below roof height.

3 LINEAR REGRESSION

Regression analysis is a statistical technique for investigating and modeling the relationship between variables from previous statistics data. Applications of regression are numerous and occur in almost every field, including engineering, the physical and chemical sciences, economics, managements, biological sciences and the social sciences. In fact regression analysis may be the most widely used statistical technique[8].

There are three types of regression; linear regression, multi linear regression and nonlinear regression. The linear regression type has been used in this work because it is the most suitable type for such work, and will be discussed briefly below[9].

In a linear regression model, the variable of interest (the so-called “dependent” variable) is predicted from another variable (the so-called “independent” variables). A line representing the best fitting to the relation between the dependent and the independent variable, which are the scattered points in the x-y plan, is obtained. This line is called best fitting line,
and can be represented mathematically from equation 14.

\[ y_i = \beta_0 + \beta_1 x_i + \epsilon_i, \quad i=1,2,\ldots,n \quad (14) \]

Where:
- \( y \) denotes the dependent variable,
- \( x_1, \ldots, x_n \) are the independent variables,
- \( \beta_0 \) called the intercept, is the predicted value of \( y \) when \( x_i = 0 \),
- \( \beta_1 \) called the slope, may be interpreted as a change in \( y \) for unit change in \( x \).
- \( \epsilon_i \) is representing the error, which is the difference between the actual data values and the best fit line calculated values.

The Root Mean Square Errors (RMSE) method is used to obtain the values of the parameters \( \beta_0 \) and \( \beta_1 \) as follows[9].

Equation (14) can be rewritten as

\[ \epsilon_i = y_i - \beta_0 - \beta_1 x_i, \quad i=1,2,\ldots,n \quad (15) \]

The summation of squared error will be

\[ S(\beta_0, \beta_1) = \Sigma_{i=1}^{n} \epsilon_i^2 = \Sigma_{i=1}^{n} (y_i - \beta_0 - \beta_1 x_i)^2 \quad (16) \]

The value of \( \hat{\beta}_0 \) and \( \hat{\beta}_1 \) that minimize \( S(\beta_0, \beta_1) \) are given by

\[ \hat{\beta}_1 = \Sigma (y_i - \bar{y})(x_i - \bar{x}) / \Sigma (x_i - \bar{x})^2 \] \quad (17)

and

\[ \hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x} \] \quad (18)

where:
- \( \bar{y} \) is the average of the dependent variable \( y_i \).
- \( \bar{x} \) is the average of the independent variable \( x_i \).

The values of \( \hat{\beta}_0 \) and \( \hat{\beta}_1 \) are called the least squares estimates of \( \beta_0 \) and \( \beta_1 \) and will be used in the final form of the equation. The intercept and the slope of the line that has the smallest possible sum of squares of the vertical distances from each point to the line. For this reason, the line is also called the least squares regression line, and the fitted value \( \hat{Y}_i \) will be given by;

\[ \hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i \] \quad (19)

4 MEASUREMENTS METHODOLOGY

The areas of Tripoli has been divided into small parts based on their morphology, which is depends on the population density, the height of buildings and how far they are separated from each others. Each part of Tripoli was classified as one of five area types; Dense Urban - Urban- Dense Suburban - Suburban- Rural. In this work the classification of Tripoli parts was based on previous work done by Ericsson company[12].

The measurement environments were chosen to have high accuracy results.

**Transmitter parameter**
1- Transmitter power is 20dBm.
2- The feeder loss is 38dBm.
3- Antenna gain is 2 dBi.
4- Frequency is 900MHz.
5- Transmitter height is 28m in Dense urban area and 20m for the others.

**Receiver parameter**
1- Antenna gain 2 dBi.
2- Receiver height is 1.5m.

Ten locations were chosen to conduct the measurement in order to get ten different paths, two paths for each area type. The RSS measurement was taken in each path starting from the base station to about 1 km apart from the base station. The measurement rate was 15 sample for 40 \( \lambda \), where \( \lambda \) is the wavelength of the measured signal. Each 15 samples were averaged and subtracted from the transmitted power to get the path loss corresponding to the average distance of these 15 samples. The values of these pathloss and the corresponding distances were put in a table.

The above process was repeated for each path of the selected 10 paths and ten tables we obtained. Two tables for each area type.

The linear regression method was applied to the values of the first table of each area type to obtain the best fitting line. Which is representing the correction factor in the
modified Hata model that matches the Tripoli environment.

The values of the second table of each area type is used to verify the model results and to calculate its accuracy, by implementing the Root Mean Square Error method (RMSE). The RMSE was calculated between actual measured path loss value and the calculated values from the modified model using the following equation

$$RMSE = \sqrt{\frac{1}{N-1} \left( \sum (P_m - P_r)^2 \right)}$$  \hspace{1cm} (20)

Where;

- $P_m$: Measured path loss (dB)
- $P_r$: calculated path loss from the modified model (dB)
- $N$: Number of measured data points

The Standard Deviation (STD) is also calculated for measurements. The accuracy assessment using RMSE was done for both Hata model and the modified model. Both results were put in one table for the sake of comparison.

### 5 OBTAINED RESULTS

The results of this work has been presented as follows:

a) The equations of the modified model is given also for each type of area as follows;

- \[ L_{mod \ DU} = 7.32 + 0.649 \cdot L_{Hata \ U} \] \hspace{1cm} (21)

- \[ L_{mod \ U} = 17.5 + 0.655 \cdot L_{Hata \ U} \] \hspace{1cm} (22)

- \[ L_{mod \ DSU} = 47.89 + 0.63 \cdot (7.32 + 0.649 \cdot L_{Hata \ U}) \] \hspace{1cm} (23)

- \[ L_{mod \ SU} = 9.87 + 0.74 \cdot (17.5 + 0.655 \cdot L_{Hata \ U}) \] \hspace{1cm} (24)

- \[ L_{mod \ R} = 32.82 + 0.69 \cdot (17.5 + 0.655 \cdot L_{Hata \ U}) \] \hspace{1cm} (25)

Where;

- $L_{mod \ DU}$, $L_{mod \ U}$, $L_{mod \ DSU}$, $L_{mod \ SU}$, and $L_{mod \ R}$ are the modified path loss for Dense urban, Urban, Dense suburban, Suburban and Rural area types respectively.

$L_{Hata \ U}$ is the Hata path loss for Urban area.

b) For each area type, the values of the path losses obtained from the measurements were plotted as a function of distance along with the modified model in one graph. Also another line was drown in the same graph which is representing the Hata model values. The graphs for Dense urban, Urban, Dense suburban, Suburban and Rural area types are shown in figures 1, 2, 3, 4, and 5 respectively.
The RMSE and the STD for both Hata and the modified Hata models were calculated for the all area types are presented in table 2. The RMSE used the pathloss values of the first path which are used in developing the modified model.

<table>
<thead>
<tr>
<th></th>
<th>HATA model</th>
<th>Modified HATA model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE</td>
<td>STD</td>
</tr>
<tr>
<td>DU</td>
<td>35.5029</td>
<td>5.0616</td>
</tr>
<tr>
<td></td>
<td>5.2647</td>
<td>4.677</td>
</tr>
<tr>
<td>U</td>
<td>20.3028</td>
<td>6.9172</td>
</tr>
<tr>
<td></td>
<td>5.4649</td>
<td>5.2946</td>
</tr>
<tr>
<td>DSU</td>
<td>10.1761</td>
<td>5.5055</td>
</tr>
<tr>
<td></td>
<td>5.3426</td>
<td>4.4787</td>
</tr>
<tr>
<td>SU</td>
<td>27.7714</td>
<td>7.0201</td>
</tr>
<tr>
<td></td>
<td>4.6089</td>
<td>4.6506</td>
</tr>
<tr>
<td>R</td>
<td>11.6074</td>
<td>8.4583</td>
</tr>
<tr>
<td></td>
<td>6.879</td>
<td>4.9127</td>
</tr>
</tbody>
</table>

d) The modified model for each area type was validated by calculating the RMSE and STD from the measured values of the second path and the modified model obtained from the first path. These values are given table 3

6 RESULTS DISCUSSION COMMENTS

General comments on the obtained results are given below in the following points:-

1- The RSME between the Hata model and the measured data is varying from 10.1 to 35.5 dB, where the RSME was within 4.6 to 6.8 dB between the modified model and the measured data in first path and 5.4 to 11.9 dB for the measured data for second path. That is mean the modified model gives 4.7 to 23.6 dB improvement in the accuracy of predicting the path loss (46.5% to 66.4%)

2- This improvement is expected since the defined urban area in Tokyo is totally different from the urban area in Tripoli. The difference is from the height, buildings density, and width of roads point of views.

3- Another cause for improvements is the environmental and topological differences between Tokyo and Tripoli.

4- the values of RMSE and STD for different areas in Tripoli whereas the acceptable range is up to 6 dB [11].

7 CONCLUSION

The accuracy of predicting the RSS is key issue in mobile network design. Several works have been done to the propagation path loss mathematically. Hata model, which has been devolved based on measurements done in Tokyo, is the most used one in designing cellular network because of its simplicity. A lot of work has been carried out to modify the model to get accurate results with other places.

This paper illustrated the modification process of Hata model at frequency band [900]MHz to match the environments at the Tripoli area. The model is
depending on the area type, since there are 5 types of areas depending on their morphology.
The path loss was measured in ten different paths. Five of them were used to develop the modified model suitable for Tripoli averments using the linear regression method, which was used to adopt the Hata model to the measured values. Where the values of the other paths were used to verify the developed model using the root mean square error (RMSE) method, which is used to evaluate the new model accuracy.
The devolved model showed 4.7 to 23.6 dB improvement in the accuracy of predicting the path loss, i.e. (46.5% to 66.4%) on the original Hata model.

REFERENCES