Analyzing Study of Path loss Propagation Models in Wireless Communications at 0.8 GHz

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\textbf{Abstract.} The paths loss propagation model is an important tool in wireless network planning, allowing network planner to optimize the cell towers distribution and meet expected service level requirements. However, each type of path loss propagation model is designed to predict path loss in a particular environment that may be inaccurate in other different environment. In this research different propagation models (Hata Model, ICC-33 Model, Ericson Model and Coast-231 Model) have been analyzed and compared based on the measured data. The measured data represent signal strength of two cell towers placed in two different environments which obtained by a drive test of them. First one in AL-Habebea represents an urban environment (high-density region) and the second in AL-Hindea district represents a rural environment (low-density region) with operating frequency 0.8 GHz. The results of performing the analysis and comparison conclude that Hata model and Ericsson model shows small deviation from real measurements in urban environment and Hata model generally gives better prediction in the rural environment.

\textbf{Keywords:} Hata model, Path loss, Signal strength, Ericsson model, 0.8 GHz.

1. Introduction

In recent years, mobile wireless communications have developed rapidly, leading to make the mobile phones become an integral part of people's lives. Hence the demand on services from mobile wireless communications companies has increased [1][2]. Wireless network planners are looking to improve connectivity between different points. Path loss propagation models is an experimental mathematical formula for characterizing the propagation of radio waves as a distance function between the antennas of transmitter and receiver. These models are designed based on a large dataset collected from specific environments. Propagation model determine is very important parameter in network planning and studies of interference with starting deployment [3].

The remainder of the research is arranged as follows: Section 2 explores the related work. Section 3 describes the path loss propagation models. Radio link budget calculation is explained in section 4. Section 5 details the performance evaluation. In section 6, results and
discussion is presented. The conclusions are discusses in section 7. The last section list the research references.

2. Related Work

Several studies have been completed in the fields of path loss propagation model where good results are obtained. All these studies are very important and play a vital role in wireless network planning. Authors in [4] estimate five path loss propagation models Stanford University Interim (SUI), COST-231, Hata-Okumura Extended Model (called also ECC-33 Model), Ericsson and the Hata-Okumura model. The results of these models compared with actual measured data. The results of comparison show that the ECC-33 model suitable for a suburban environment. In [3] authors gave a brief introduction to loss models, concluding that each model is suitable for a specific environment. While [5] has analyzed and compared the path loss values of the selected models in different environments with frequency 1700 MHz. They concluded that SUI model calculations consistent with measurements data and it is suitable for urban areas, unlike the cost 231 W-I model whose calculations do not correspond to the measure data.

In this research, present four path loss propagation models (Hata Model, ICC-33 Model, Ericson Model and Coast-231 Model) and then calculate the signal strength of theirs. The signal strength of these models are analyzed and comparison with real measured data to see whether these models are accurately used for prediction to the path loss.

3. Path Loss Propagation Models

Generally, some of propagation factors for instance reflection, scattering, diffraction, absorption, and atmospheric particles affect the signal of wireless communication when transmitted through a path [2, 6]. The main benefit for the use of the standard path loss models are time-saving and cost, despite the limited accuracy. Through the results of many measurement efforts, the existing equations are used in empirical models. The following are examples of the path loss propagation models[4, 7]:

a. Free Space Path Loss Model
b. Okumura Model
c. HATA Path Loss Model
d. LHata Model (LHata)
e. COST 231 Extended Hata Model
f. ECC-33 or Hata – Okumura Extended Model
g. Walfisch-Ikegami Model
h. Stanford University Interim (SUI) model
i. Ericson Model

Field data for various environments have been used in the design of all the models mentioned above. In this research, four path loss propagation models were used (HATA, COST 231, ECC-33 and Ericson Models) because they are suitable to be implemented in the study area environment at frequency 0.8 GHz.

3.1 HATA Path Loss Model

This model introduces by Okumura model and it is useful for frequency range 150MHz to 1500MHz. This model is the most widely used in urban area, the path loss equation of this model is [1] [8]:

\[
PL(\text{dB}) = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_b) - (ahm) + (44.9 - 6.55 \log_{10}(h_b)) \log_{10}(d) - C
\]  

(1)
\[\begin{align*}
\text{ahlm} & = \begin{cases} 
2.1(\log(11.75h_m))^2 - 4.97 & \text{in urban, } f > 400\text{MHz} \\
(1.1\log_{10}(f - 0.7)h_m - (1.56\log_{10}(f - 0.8)) & \text{in open area}
\end{cases} \\
C & = \begin{cases} 
0 & \text{in urban} \\
(40.49 + 4.78(\log_{10}(f))^2 - 18.33\log_{10}(f) & \text{in open area}
\end{cases}
\end{align*}\]

Where:

\(\text{PL} = \) path loss
\(f(\text{MHz}) = \)Frequency
\(d (\text{Km}) = \) Distance between transmitter and receiver antennas
\(h_b (\text{m}) = \) Base station antenna height
\(h_m (\text{m}) = \)Mobile station antenna height
\(C = \) environment factor

3.2 COST 231 Extended Hata Model

Cost 231 model and also called Personal Communication System (PCS) Extension, it is the first model used up to date. This model is an extension of the Okumura-Hata model to cover a wide range of frequencies between (0.5-2 GHz), and is used for medium to small cities [3][4].

\[\begin{align*}
\text{PL} & = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ahlm(44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + C \\
ahlm & = \begin{cases} 
2.1(\log(11.75h_m))^2 - 4.97 & \text{in urban, } f > 400\text{MHz} \\
(1.1\log_{10}(f - 0.7)h_m - (1.56\log_{10}(f - 0.8)) & \text{in open area}
\end{cases} \\
C & = \begin{cases} 
0 & \text{in urban} \\
(40.49 + 4.78(\log_{10}(f))^2 - 18.33\log_{10}(f) & \text{in open area}
\end{cases}
\end{align*}\]

3.3 ECC-33 or Hata – Okumura Extended Model

It is appropriate model for the Ultra High Frequency (UHF) band, and according to recent recommendations of International Telecommunication Union-Radio communication (ITU-R), it uses up to 3.5GHz. This model proposed based on the Okumura model [4].

\[\begin{align*}
\text{PL} & = 92.4 + 20\log(d) + 20\log(f) + 20.41 + 9.83\log(d) + 7.89\log(f) + 9.56(\log(f))^2 + \log(h_b/200)(13.958 + 5.8\log(d)) + Gr \\
Gr & = \begin{cases} 
[42.57 + 13.7\log(f)][\log(h_m) - 0.585] & \text{in median city} \\
0.759(h_m) - 1.862 & \text{in large city}
\end{cases}
\end{align*}\]

3.4 Ericson Model

Ericsson model is software provided by Ericsson Company to use for wireless network planner. This model was developed based on the modified Okumura-Hata model for use in differing propagation environments according to the parameters shown in Table 1 [5][9].

\[\begin{align*}
\text{PL} & = k_0 + k_1 + \log_{10}(d) + k_2 \log_{10}(h_b) + k_3 \log_{10}(h_b) \log_{10}(d) - 3.2[\log_{10}(11.75h_r)^2] + 44.49\log_{10}(f) - 478[\log_{10}(f)]^2
\end{align*}\]

| ENVIRONMENT | TYPE  | \(K_0\) | \(K_1\) | \(K_2\) | \(K_3\) |
|-------------|-------|--------|--------|--------|--------|
| RURAL       | 45.95 | 100.6  | 12     | 0.1    |
| SUBURBAN    | 43.20 | 68.63  | 12     | 0.1    |
| URBAN       | 36.20 | 30.20  | 12     | 0.1    |
4. Radio Link Budget Calculation

The link budget calculation in the cell is calculates for the farthest point from the cell tower. In order to calculate the maximum coverage, consideration must be given to the minimum signal intensity received by the receiver. The most important parameters of the budget calculation is discussed in the following[6, 10].

**Transmitter Power:** the maximum transmission power from cell towers antenna typical value from 36-46 dBm.

**Antenna Gain:** Antenna gain depends mainly on carrier frequency, size of antenna and device type. The cell tower antenna gain is a typical 15-18 dBi.

**Losses:** Includes cable and body losses on both sides (cell tower antenna and phone). Cable losses depend on the length and type of cable and frequency; it varies from 1-6 dB for cell tower antenna, and phone losses, in practical planning it is considered to be 0 dB[11].

**EIRP:** Is a stand for Effective Isotropic Radiated Power, the term is used to express how much transmitted power is radiated in the desired direction. It takes into account all type of losses and the gain of the transmitter antenna as:

\[
\text{EIRP (dBm)} = \text{Pt (dBm)} + \text{Ga (dBi)} – \text{Cable losses} \tag{10}
\]

Where:
- Pt(dBm): Cell tower transmitting power
- Ga(dBi): Antenna gain in reference to isotropic antenna

**RX Level:** Is a stand for received signal level, which considered the signal strength obtained by the mobile phone from cell tower antenna. It is importing factor who determines that the reception was good or not[12]. The RX level ranges and rating shown in table (2) and mathematical formula to calculate the Rx level is [6][13]:

\[
\text{RxLev (dBm)} = \text{EIRP} - \text{Pl} - \text{ABl} - \text{IDM} - \text{LSM} - \text{LACC} - \text{GA} \tag{11}
\]

Where:
- EIRP (dBm)= Effective Isotropic Radiated Power
- Pl (dB) = path loss propagation model
- ABl (dB) = antenna / body loss.
- IDM (dB) = degradation margin of Interference.
- LSM (dB) = Log normal shadowing margin.
- LACC (dB) = cell tower antenna cable and connector (0 dB).
- GA (dB) = Cell tower antenna gain.

| VALUE          | RATING             |
|----------------|--------------------|
| -47 TO -10DBM  | Very good          |
| -60 TO -47DBM  | Good               |
| -75 TO -60DBM  | better range of coverage |
| -90 TO -75DBM  | average coverage   |
| -95 TO -90DBM  | poor coverage      |
| -110 TO -95DBM | very bad coverage  |

Table 2. RX level ranges and rating [14]
5. Performance Evaluation

Practically, measured the signal strength by a drive test for two cell towers. First one in AL-Habebea represents an urban environment (high-density region) and the second in AL-Hindea district represents a rural environment (low-density region), Figure (1) and figure (2) show the location maps of the computerized areas of the cell towers (rural and urban) under study in which the drive test was applied. The path loss propagation of four models (Hata Model, ICC-33 Model, Ericson Model and Coast-231 model) are calculated using the parameters shown in table (3) in MATLAB 2016. Then, the signal strength of these models are computed using equations (11), (12).

![Figure 1. Drive test Simulation Environments in Urban](image1)

![Figure 2. Drive test Simulation Environments in Rural](image2)
Table 3. Path loss parameters

| PARAMETERS                        | VALUE                  |
|----------------------------------|------------------------|
| FREQUENCY                        | 800 MHz                |
| TRANSMITTER POWER                | -46 dBm                |
| CELL TOWER ANTENNA HEIGHT        | 20 m urban, 30 m rural |
| PHONE ANTENNA HEIGHT             | 1.5 m                  |
| ANTENNA GAIN                     | 18 dB                  |
| ANTENNA CABLE LOSS               | 1.5 dB                 |
| ANTENNA BOUY LOSS                | 3 dB                   |
| IDM                              | 3 dB                   |
| LSM                              | 5 dB for 90% coverage  |

The root mean square error (RMSE) of signal strength for these four type models has been calculated and compared with measurement data to predicate an appropriate path loss model [4].

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{N} (RX_{mi} - RX_{i})^2}{N}}
\]

(12)

Where \(RX_{mi}\) is the measured signal strength in dBm, \(RX_{i}\) is the calculated signal strength in dBm, and \(N\) is the samples number of measured signal strength.

6. Results and Discussion

After calculating the path loss propagation values of the four models as shown in figure (3) and figure (4) and then calculating the RMSE as shown in the table (4)

![Figure 3. Comparison Signal Strength of Four Models with Measured Data from Urban Area](image-url)
7. Conclusions

The main objective of this research is to analyze and compare the appropriate path loss propagation model in wireless communication systems in different environments. The measured data and signal strength values of selected empirical path loss models in urban and rural environments are analyzed and compared at frequency 0.8 GHz. Path loss model is the most important parameter for network planners to achieve an acceptable quality of service for the users in wireless systems. This research study the path loss using four models: Hata Model, ICC-33 Model, Ericsson Model and Coast-231 Model based on using the same parameters. The results of comparison conclude that the Hatta Model and Ericsson model are better predictive

| PATH MODELS   | LOSS URBAN | LOSS RURAL |
|---------------|------------|------------|
| HATA MODEL    | 23.43      | 4.23       |
| COST 32 MODEL | 31.68      | 27.09      |
| ECC33 MODEL   | 170.09     | 207.44     |
| ERICSON MODEL | 23.88      | 7.75       |

Figure (3) shows the path loss in the urban environments (Al-Habebea) using Hata model and Ericsson model have small deviation compared to other models.

Figure (4) shows the path loss in the rural environments (AL-Hindea) using Hata model has small deviation compared to other models.

The difference in empirical values (the non-straight line graph) to Baghdad's urban environment has many obstacles in the way, such as many nearby high buildings.
of the urban environments. In addition to, Hata models generally gives better prediction in the rural environment.

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Acknowledgment:
The authors wish to acknowledge Watanea Wireless Communication for technical support.