Wireless Network Planning and Optimal Radio Placement Using Egly Empirical Model

Olatilewa R. Abolade, Ajibola Oyedeji, Martins Osifeko and Oluwatosi Adekoya

Department of Computer Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria

Abstract—Path loss and outages are crucial in networking and need to be put into consideration in wireless network planning. The recommendation of a network layout for a particular area should be given careful thought and analysis. Preparing the design of wireless communication networks require a detailed understanding of radio propagation over the specific environment. In general, there are two basic problems of multipath fading of the radio link and interference from other users in the cellular reuse environment. In this paper, Egly propagation model was used for network planning and management to achieve optimum resource usage and minimize outages by effectively reducing path loss through empirical transmitter and receiver placement.

Keywords: Empirical Model, Network Path Planning, Path Loss, Radio Placement

1 INTRODUCTION

Empirical Model (EM) is one of the fundamental tools for designing any fixed broadband wireless communication system. It is a propagation model that predicts what will happen to the transmitted signal while in transit to the receiver. EMs are based on observations or measurements. Measurements are typically done in the field to measure path loss, delay spread, or other channel characteristics. Parameters included in EMs are distance, frequency, base antenna height, customer premises equipment (CPE) height, and number of buildings (Ali-Ahmad, 2006). The terrain over which signals travel will have a significant effect on the signal. Obviously, hills which obstruct the path will considerably attenuate the signal, often making reception impossible. Additionally, at low frequencies the composition of the earth will have a marked effect. For example, on the Long Wave band, it is found that signals travel best over more conductive terrain, e.g. sea paths or over areas that are marshy or damp while dry sandy terrain gives higher levels of attenuation (Isabona et al, 2013).

EMs can be split into two subcategories namely, time dispersive and non-time dispersive. The former type is designed to provide information relating to the time dispersive characteristics of the channel i.e., the multipath delay spread of the channel. An example of this type is the Stanford University Interim (SUI) channel models developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group. Examples of non-time dispersive empirical models are ITU-R, Hata and the COST-231 Hata model (Abhayawardhana et al, 2005). This paper aims to carry out a wireless network planning for the Olabisi Onabanjo University, Ibugun campus using Egly Propagation Model.

The rest of this paper is organized as follows. Section 2 provides description of popular empirical models. In section we present a review of related works. In section 4 we present the method used in this research work. In section 5, we discuss the result of our findings. Finally, in section 6, we presented the conclusion of the work.

2 BACKGROUND

In this section, a brief overview of popular empirical models is given.

2.1 OKUMURA MODEL

Okumura’s model is widely used for signal prediction in urban areas. This model is applicable for frequencies range for 150MHz to 1920MHz and distances of 1km to 100km. This model can be expressed as:

\[ PL_{dB}(f, d) = LF + Amu(f, d) - G(h) - G(h) - G_{AREA} \]  

This model is good for urban and sub-urban areas but not good for rural areas (Rani et al, 2014).

2.2 HATA MODEL

Hata model is an empirical model based on Okumura model where some correction factors are included, and it is valid from 150 MHz to 1500 MHz. Hata represented the Urban area propagation loss as the standard formula along with additional correction factor for application in the other situations such as suburban, rural among others. The path loss in dB for the urban area is given by:

\[ PL_{dB}(f, d) = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h) - (44.9 - 6.55 \log_{10}(h)) \log_{10}(d) \]

For a small to medium sized city, the mobile antenna correction factor is;

\[ a(h) = (1.1 \log f - 0.7) h - (1.56 \log f - 0.8) \]

For a large city, it is given by

\[ a(h) = 8.29(\log h)^2 - 1.1 \text{ for } f < 300MHz \]

\[ a(h) = 3.2(\log 11.75)^2 - 4.97 \text{ for } f > 300MHz \]

To obtain the path loss in suburban area, the Hata standard formula is modified as

\[ PL_{dB} = PL_{Urban} - 2(\log f / 28)^2 - 5.4 \]

This model is well suited for large cell mobile system, but not personal communication (Sharma et al, 2010).

2.3 ECC 33 MODEL

The ECC-33 model was developed by Electronic communication committee (ECC). This is generally used for Fixed Wireless Access (FWA) system. The path loss is defined as;

\[ PL_{dB} = A_{f} + A_{bm} - G_{b} - G_{r} \]
Where, \( A_{fs} \), \( A_{bm} \), \( G_b \) and \( G_t \) are the free space attenuation, the basic median path loss, the Base Station height gain factor and the terminal height gain factor. They are then individually defined as,

\[
A_{fs} = 92.4 + 20 \log_{10}(D) + 20 \log_{10}(f) \\
A_{bm} = 20.41 + 9.83 \log_{10}(D) + 7.894 \log_{10}(f) + 9.56 [\log_{10}(f)]^2 \\
G_b = \log_{10}(h_b/200) [13.958 + 5.8 \log_{10}(D)]^2 \\
G_t = \{42.57 + 13.7 \log_{10}(f)\} \log_{10}(h_r) - 0.585
\]

The predictions using the ECC-33 model with the medium city option are compared with the measurements taken in suburban and urban environments (Prajesh & Singh (2012).

### 2.4 Egly Propagation Model

Egly is a simplified model that assumes gently rolling terrain with average hill heights of approximately 50 feet. Because of this assumption, no terrain elevation data between the transmit and receive facilities is needed. Instead, the free space propagation loss is adjusted for the height of the transmitting and receiving antennas above ground. As with many other propagation models, Egly is based on measured propagation paths and then reduced to mathematical model. Egly, model consists of a single equation for the propagation loss.

\[
PL_{EG} = 117 + 40 \log_{10} d + 20 \log_{10} f - 20 \log_{10}(h_1 - h_2)
\]

Where \( PL_{EG} \) is attenuation in dB (between dipole), \( d \) is the path distance in miles, \( f \) is the frequency in megahertz (MHz), \( h_1 \) is the transmitter antenna height above ground level (in feet), \( h_2 \) is the receiver antenna height above ground level (in feet). The free space loss between half wave dipole antenna (in dB) is

\[
PL_{fs} = 32.27 + 20 \log_{10} d + 20 \log_{10} f
\]

To isolate the propagation of the loss

\[
PL = PL_{EG} - PL_{FS} = 84.73 + 20 \log_{10} d - 20 \log(h_1 * h_2)
\]

The Egly model should not be used in such type of areas like areas of rugged terrain, significant obstructions. Egly says it is limited to those areas which are similar to plain earth, such as relatively short over water and very flat barren land paths. (Archana et al, 2014).

### 2.5 Stanford University Interim (SUI) Model

IEEE 802.16 Broadband Wireless Access working group proposed the standards for the frequency band below 11 GHz containing the channel model developed by Stanford University, namely the SUI model. The basic path loss expression of the SUI model with correction factors is presented as:

\[
PL = A + 10 \log_{10}(d/d_0) + X_t + X_h + S \text{ for } d > d_o
\]

The parameter \( A \) is defined as;

\[
A = 20 \log_{10}(4 \pi d_0/\lambda)
\]

And the path loss exponent \( \gamma \) is given by

\[
\gamma = a - b h_b + c/h_b
\]

Where, the parameter \( h_b \) is the base station antenna height in meters. This is between 10 m and 80 m. The value of parameter \( \gamma = 2 \) for free space propagation in an urban area, \( 3 < \gamma < 5 \) for urban environment, and \( \gamma > 5 \) for indoor propagation. The constants used for \( a, b \) and \( c \) are given in Table 1.

The free space propagation loss is

\[
X_f = 6.0 \log_{10}\left(\frac{f}{2000}\right)
\]

For the frequency correction factor and the correction for receiver antenna height \( h \) for the model are expressed in

\[
X_h = -10.8 \log_{10}\left(\frac{h}{2000}\right), \text{ for terrain type A and B}
\]

\[
-20 \log_{10}\left(\frac{h}{2000}\right), \text{ for terrain type C}
\]

Where, \( f \) is the operating frequency in MHz, and \( h_r \) is the receiver antenna height in meter. With the correction factors given in equations 21 and 22, this model is extensively used for path loss prediction of all three types of terrain in rural, urban and suburban environments (Abhayawardhana et al 2005).

### 3 Review of Related Works

Nadir & Ahmad (2010) applied the Hata-Okumura model to investigate the GSM frequency band in Salalah city, Oman. They predicted the mean signal strength in different areas and observed that existing prediction models differ in their applicability over different terrain and environmental conditions. Further improvement of Okumura-Hata model was achieved by using mean square error (MSE) between measured and predicted path loss values in order to provide sufficient MSE for radio prediction. The placement of receiving and transmitting antenna has significant impact on path loss. (Alani et al 2002) showed impact of using different propagation models as well as antenna configuration settings in coverage prediction of the network planning process. They suggested that future work is to simulate different scenario with users on the network and show the performance of these propagation models in terms of the percentage outage caused by strong interference and shortage of power.

### 4 Method

#### 4.1 Site Description

Data on the type of terrain that exist, survey and the geographical area of Olabisi Onabanjo University (OOU), College of Engineering and Environmental Studies, Ibagun Campus were collected from the department of Urban and Regional Planning (URP). The campus has a gently rolling terrain which makes Egly propagation model suitable for it. The land area being used by the campus is in two parts tagged site A and site B. Site A is 52.725 hectares and site B is 1259.129 hectares and the map scale is 1:10000.

The simulation was done using MATLAB R2013b framework. In the calculation, we set three different antenna heights (i.e. 3m, 6m and 10m) for receiver; the
distances used in simulation vary from 0.1km to 1.7km and antenna height is 30m. Using different parameters, we simulated the network using one base station at a distance of 1610m between transmitting and receiving antenna. Number of base stations was then increased to two with each base station connected to three antennas (two receivers and one transmitter). Two receiving antennas were connected with the base station so that the base station can compare signals and select the best antenna for each user within the cell. Table 2 shows the path loss parameters used in simulation.

| Parameters                  | Values                |
|-----------------------------|-----------------------|
| Operating frequency (F)     | 900MHz and 1500MHz    |
| Transmitter antenna height (Tx) | 30m                  |
| Receiver antenna height (Rx) | 3m, 6m and 10m        |
| Distance between Tx - Rx    | 1.61km and 0.805km    |

5 RESULTS AND DISCUSSION

Graphs for the different models shown in Figures 1 to 6 were obtained through simulations. Table 3 shows the parameters used for further simulations carried out when one base station was used at a distance of 1610m between transmitting and receiving antenna.

| Frequency(MHz) | Tx-Rx | Transmitter | Receiver |
|----------------|-------|-------------|----------|
| 900 and 1500   | 1610  | 30          | 3        |
| 900 and 1500   | 1610  | 30          | 6        |
| 900 and 1500   | 1610  | 30          | 10       |

Figures 1 to 3 show that an increase in the frequency will increase the path loss. Since high frequency signals propagate less through obstacles because of increased path loss, there is need to use low frequency signals in order to reduce the path loss.

Table 4 shows parameters used for further simulations carried out when two base stations were used at a distance of 805m between transmitting and receiving antenna.

| Frequency (MHz) | Tx-Rx | Transmitter Height(m) | Receiver Height(m) |
|-----------------|-------|-----------------------|--------------------|
| 900             | 805   | 30                    | 3                  |
| 900             | 805   | 30                    | 6                  |
| 900             | 805   | 30                    | 10                 |

Two base stations were used with each base station connected to three antennas (two receivers and one transmitter). The base station compares signals and selects the best antenna for each user.

When two base stations and six antennas were used, the maximum distance coverage was 0.805km (805m). Theoretically, path loss is higher at higher frequencies, radio waves with a higher frequency generally experience a higher attenuation, and thus propagate a shorter distance before the carried signal strength falls below a threshold (Chu et al., 2013). 900MHz frequency was used so as to reduce path loss in the remaining part of the work, in order to obtain better connectivity at lower power consumption rate.
Figures 4 to 6 show result of simulations for path loss at 900MHZ frequency for varied receiver antenna heights.

Fig. 4: Path loss at 3m receiver antenna height (D = 805m) at 900MHz

![Fig. 4](image1)

Fig. 5: Path loss at 6m receiver antenna height (D = 805m) at 900MHz

![Fig. 5](image2)

Fig. 6: Path loss at 10m receiver antenna height (D = 805m) at 900MHz

![Fig. 6](image3)

The result of simulations using two base stations are presented from Figures 4 to 6. Figure 4 presents the highest path loss (105.2722 dB) due to the receiver antenna height when compared with Figure 2 that has 121.7504dB and Figure 2 that has117.3134 dB as path losses, it therefore shows that Figure 4 has higher propagation signal strength compared to Figure 1 and this due to the reduction in the distance. The figure with the lowest path loss is Figure 6 (94.8146 dB). The reduction in path loss was achieved because the number of base station has been increased by one so as to reduce the outages and increase the lifespan of the wireless devices used.

The first base station was placed at the point marked 1 at (51oNE) on the map to be able to cover 805m in both directions because the antennas used are omnidirectional antennas and are capable of transmitting in all directions within the first 1610m land distance with a maximum path loss of 105.2722 which was the minimum path loss achievable from the simulation. The second base station was placed at the point marked 2 at, (54o NE) which is 805m from the end-point of the area marked A at (54o NE) on the map, a distance which can be effectively covered based on finding from simulation, the antenna is therefore capable of covering the remaining 1610m distance.

These placements would yield minimum path loss and minimum energy consumption during transmission.

6 CONCLUSION
The path loss of the gently rolling terrain was determined using Egly model, optimization of network performance was achieved by the optimum configuration achieved through simulation of the terrain type, resulting in better connectivity and lower power consumption thereby improving the life span of the devices. The two base stations operated at a frequency of 900MHz and a maximum path loss of 105.2722 dB, the choice of the base station locations together with variation in antenna height of a few meters played a major role in path loss reduction as seen in Figs 4 to 6.

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