A Survey on Various Propagation Model for Wireless Communication

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Abstract
Signal Propagation is used for wired or wireless communication. It is depend upon terrain, frequency of operation, height of mobile, base station and other dynamic factor. Propagation models predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance[5]. In this paper, Empirical propagation models such as Okumura, Hata, and Lee model has been surveyed exhaustively.

Keywords: Path Loss, Okumura model, Hata model and Lee model

Introduction
In Wireless communication signal is transmitted by transmitting antenna and received by receiving antenna, any distortion in signal strength at receiver is known as path loss. Propagation model are useful for predicting the signal attenuation or path loss between the transmitter and receiver. This path loss information may be used as a controlling factor for wireless communication system performance to achieve the perfect network planning [1].

The Propagation model is generally of two types: Empirical (statistical) models and Physical (Deterministic) models. In this paper empirical models are considered. Statistical methods (also called stochastic or empirical) are based on fitting curves with analytical expressions that recreate a set of measured data. Among the most commonly used such methods are Okumura Model, Hata Model, and Lee's Model [3]. The Empirical or statistical models are suitable for both macro cell and micro cell.

Path Loss Models
Okumura Model
The Okumura model [5] is empirical model to measure the radio signal strength in urban areas. The model was built by the collected data in Tokyo city. This model is applicable for frequencies in the range of 150 MHz to 1950 MHz and distance of 1 km to 100 km. it can be used for the base station antenna heights ranging from 30m to 1Km. To determine path loss using Okumura’s model, the free space path loss between the points of interest is first determined and then the value of $A_m(f, d)$ is added to it along with correction factors according to the type of terrain.

The expression of the model
$$\text{PL(dB)} = L_f + A_m(f, d) - G(h_t) - G(h_r) - G_{AREA} \quad (1)$$

Where
- $L_f$ is Free space path loss [dB]
- $A_m(f, d)$ is Median attenuation relative to free space [dB]
- $G(h_t)$ is Base station antenna height gain factor [dB]
- $G(h_r)$ is Mobile station antenna height gain factor [dB]
- $G_{AREA}$ is Gain due to the type of environment [dB]
- $h_t$: transmitter antenna height [m]
- $h_r$: Receiver antenna height [m], $d$ is Distance between transmitter and receiver antenna [km]

$$G(h_t) = 10 \log_{10} (h_t/200) \quad h_t < 3 \text{m}$$
$$G(h_t) = 20 \log_{10} (h_t/200) \quad 10 \text{m} > h_t > 3 \text{m}$$
$$G(h_r) = 20 \log_{10} (h_r/3)$$

Okumura Model is considered to be among the simplest and best in terms of accuracy in predicting the path loss for early cellular system. The major disadvantages of this model are its slow response to rapid changes in terrain profile. Therefore the model is fairly good in urban and suburban areas, but not good for rural areas.

Hata Model
Hata model [13] is basically an empirical model based on Okumura model where some correction factor 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 computation time is short and only four parameter are required in Hata model. The path loss in dB for the urban areas is given by:

$$\text{PL(dB)} = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_t) + a(h_r) + (44.9 - 6.55 \log_{10}(h_t)) \log_{10}(d) \quad (2)$$

Where
- $f_c$ = Frequency from 150 MHz to 1500 MHz, $h_t$ = The effective base station antenna height (30m to 200m), $h_r$ = The effective mobile antenna height (1m to 10m), $D$ = The transmitter-receiver (T-R) distance in km, $a(h_r)$ = The correction factor for effective mobile antenna height. For a small to medium sized city, the mobile antenna correction factor is given by
  $$a(h_r) = (1.1 \log_{10}(h_r) - 0.7)h_r - (1.56 \log_{10}(h_r) - 0.8)$$

For a large city, it is given by
  $$a(h_r) = 8.29 \log_{10}(5h_r)^2 - 1.1 \text{ for } f_c < 300 \text{MHz}$$

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

$$\text{PL (dB)} = \text{PL (Urban)} - 2[\log(f_c/28)]^2 - 5.4$$  \hspace{1cm} (3)

Although Hata’s model does not have any of the path specific correction which are available in Okumura model. This model is well suited for large cell mobile system, but not personal communication [3][12].

**ECC-33 Model**
The ECC-33 model is developed by Electronic communication committee (ECC). This is generally used for FWA (Fixed Wireless Access) system. The path loss is defined as [10].

$$\text{PL (dB)} = \text{Afs} + \text{Abm} - \text{Gb} - \text{Gr}$$  \hspace{1cm} (4)

Where $A_{fs}$, $A_{bm}$, $G_b$ and $G_r$ are the free space attenuation, the basic median path loss, the BS height gain factor and the terminal height gain factor. They are the individually defined as

$$A_{fs} = 92.4 + 20 \log_{10}(D) + 20 \log_{10}(f)$$

$$A_{bm} = 20.41 + 9.83 \log_{10}(D) + 7.894 \log_{10}(f) + 9.56[\log_{10}(f)]^2$$  \hspace{1cm} (5)

$$G_b = \log_{10}(h_b/200)[13.958 + 5.8[\log_{10}(D)]^2$$  \hspace{1cm} (6)

And for medium city environments,

$$G_r = [42.57 + 13.7 \log_{10}(f)]\log_{10}(h_r) - 0.585$$  \hspace{1cm} (7)

Where $f$ is the frequency in GHz, $D$ is the distance between Transmitter and Receiver in km, $h_b$ is the BS antenna height in meters and $h_r$ is the CPE antenna height in meters. The predictions using the ECC-33 model with the medium city option are compared with the measurements taken in suburban and urban environments [3][6].

**COST-231 Model**
The COST-231 model was devised as an extension to the Hata-Okumura model. The COST-231 model is designed to be used in the freq range 1500MHz to 2GHz. This model contains corrections factor for urban, suburban and rural (flat) environments. The basic equation for path loss in dB is, 

$$\text{PL (dB)} = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b)$$

$$- 8.65 \log_{10}(h_t) \log_{10}(D) + c$$  \hspace{1cm} (8)

Where $f$ is the frequency in MHz, $D$ is the distance between AP and CPE antennas in km, and $h_b$ is the AP antenna height above ground level in meters. The parameter $c$ is defined as 0 dB for Medium sized city and suburban environments and 3dB for urban environment. All the parameters are

$$f = 1500\text{MHz to } 2\text{GHz}, h_b = 30\text{m to } 200\text{m}$$

$$h_t = 1\text{m to } 10\text{m}, d = 1\text{km to } 20\text{ km} [3],$$

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are defined for the Multipoint Microwave Distribution System (MMDS) frequency band in the USA, which is from 2.5 GHz to 2.7 GHz. Their applicability to the 3.5 GHz frequency band that is in use in the UK has so far not been clearly established[6]. The SUI models are considered into three types of terrains, namely A, B and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities. The basic path loss equation with correction factors is presented by [7], [8], where

\[ PL = A + 10 \gamma \log_{10}(d/d_0) + \gamma \log_{10}s \]  (12)

where
d is the distance between the AP and the CPE antennas in meters, \( d_0 = 100 \) m and \( s \) is a log normally distributed factor that is used to account for the shadow fading owing to trees and other clutter and has a value between 8.2 dB and 10.6 dB [7]. The other parameters are defined as,

\[ A = 20 \log_{10}(4\pi f/\lambda) \]
\[ \gamma = a - b h_s + c/h_0 \]

Where,

The parameter \( h_s \) is the base station height above ground in meters and should be between 10 m and 80 m. The constants used for \( a, b \) and \( c \) are given in Table I. The parameter \( \gamma \) is given above which is equal to the path loss exponent. For a given terrain type the path loss exponent is determined by \( h_s \).

### Table I

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Terrain A</th>
<th>Terrain B</th>
<th>Terrain C</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )</td>
<td>4.6</td>
<td>4.0</td>
<td>3.6</td>
</tr>
<tr>
<td>( b(\text{m}^{-1}) )</td>
<td>0.0075</td>
<td>0.0065</td>
<td>0.005</td>
</tr>
<tr>
<td>( c(\text{m}) )</td>
<td>12.6</td>
<td>17.1</td>
<td>20</td>
</tr>
</tbody>
</table>

**Numerical Values for the Sui Model**

The correction factors for the operating frequency and for the CPE antenna height for the model are [7]

\[ X_f = 6.0 \log_{10}(f/2000) \]

and

\[ X_h = -10.8 \log_{10}(h_s/2000) \] for terrain types A & B
\[ = -20.0 \log_{10}(h_s/2000) \] for Terrain type C

where

\( f \) is the frequency in MHz and \( h_s \) is the CPE antenna height above ground in meters. The SUI model is used to predict the path loss in all three environments namely rural, suburban and urban.

**Egli propagation model**

Egli is 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 transmit and receive antennas above ground. As with many other propagation models, Egli is based on measured propagation paths and then reduced to mathematical model. In case of Egli, the model consist of a single equation for the propagation loss[9].

\[ A = 117 + 40 \log_{10}(D_{\text{miles}}) + 20 \log_{10}F - 20 \log_{10}(H_T H_R) \]  (13)

Where

\( A \) is the attenuation in dB (between dipole), \( D \) is the path distance in miles, \( F \) is the frequency in Mega Hertz, \( H_T \) is the transmitter antenna height above ground level(AGL) in feet, \( H_R \) is the receiver antenna height above ground level in feet.

The typical equation used for Free Space loss between half wave dipole antenna (in dB) is

\[ A_{FS} = 32.27 + 20 \log_{10}(D_{\text{miles}}) + 20 \log_{10}F_{\text{MHz}} \]

To isolate the propagation of the loss attributable to Egli consideration, subtract the free-space portion from the computed Egli attenuation:

\[ A_{Eg} = A - A_{FS} = 84.73 + 20 \log_{10}(D_{\text{miles}}) + 20 \log_{10}(H_T H_R) \]  (14)

If the value of \( A_{Eg} \) is zero or less, then free space valued is used. The Egli model should not be used in such type of areas like areas of rugged terrain, significant obstructions etc. Egli 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.

**COST 231 Walfish-Ikegami (W-I) Model**

This model is a combination of J. Walfish and F. Ikegami model. The COST 231 project further developed this model. Now it is known as a COST 231 W-I model. It is used to compute the diffraction loss over multiple knife edges. It defines the new effective obstacle at the point where the line of sight from two antennas crosses. This model many practical applications in urban and rural areas [11].

For LOS condition

\[ (PL)_{\text{LOS}} = 42.6 + 26 \log_{10}(d) + 20 \log_{10}(f) \]  (15)

And for NLOS condition

\[ (PL)_{\text{NLOS}} = \{L_{\text{FSL}} + L_{\text{rts}} + L_{\text{msd}} \} \]  (16)
Epstein-Peterson model

This Epstein-Peterson model is similar in nature to the Bullington model but the exception is that it takes to draw line of sight between revelent obstacles, and to add the diffraction loss at each obstacles. However this model does not take urban losses into account and 10 dB or more must be added to the calculated loss in urban areas [11].

Conclusion

In this paper we surveyed different types of propagation model with their path loss equation. some of them model are used in urban, suburban area but some are in rural areas. For example Hata-Okumura are better in suburban areas and the Longley-rice model in rural areas.

References


Authors Biography

Mrs. Pooja Prajesh was born on 30th June 1978 in Roorkee, Uttarakhand (India). She received her M.Tech.degree in Digital Communication from Uttarakhand Technical University (U.K.), India. She is a Associate Member of the AMIETE. She has published several Research papers in national and international journals/conferences. She is presently research scholar in Uttarakhand Technical University, Dehradun (India). Her present research interest is in Wireless Communication.

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