International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Literature Survey on Various Outdoor Propagation Model for Fixed Wireless Network

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Abstract: ***The main focus of this review paper is to encompass the earlier and recent advances in popular propagation model for wireless communication channel. The paper covers the wide area of radio communication in a subtle and elastic manner. The advantages and disadvantages of the existing propagation models have also been discussed.***

Keywords: Path-loss, Path-Loss Models, Attenuation

1. Introduction

For the proper designing of a cellular network, it is very important to determine the parameters such as coverage area, frequency assignment, SNR and C/I ratio. These parameters are determined by conducting a series of propagation measurements, which are expensive and time consuming. It is therefore important to develop an effective radio propagation model for cellular network. [1] Radio propagation models can be classified into Indoor propagation model and Outdoor Propagation model

2. Review of Propagation Model

Different outdoor models deployed in radio propagation [2] are
Empirical Model
Deterministic Model
Stochastic Model

2.1 Empirical Models

An empirical model is simply based on observed and measured data alone. It can be further classified in to two sub heads, time-dispersive and non-time-dispersive. The SUI (Stanford University Interim) model is one of the perfect examples of time-dispersive models. The models like COST-231 Hata model, Hata and ITU-R model are examples of non-time dispersive models.

2.2 Deterministic Models

These kinds of models deploy laws of electromagnetic wave propagation for determination of received signal strength in a definite region of concern. And as the modern times are the times of site-specific propagation studies, these can be deployed both for outdoor & indoor scenarios in deterministic form. Here actual 3-D designs of buildings or concerned environment like foliage equivalent to some dielectric slab etc. are made based on some database. There after ray tracing techniques are used to associate representation with the software being used, representing fundamental phenomenon of reflection, diffraction and scattering. It is more of computerized form of comparative analysis and is becoming increasingly important with advent of high-speed computational technologies coming in.

2.3 Stochastic Models

Stochastic models are used in terms of random variables being deployed for representation of some or the other factors influencing the behavioural nature of radio waves in action. These models have a concern of correctness and accuracy. These are mostly used for prediction at and above 1.8 GHz.

3. Models for Path Loss

3.1 Free Space Path Model

In this model, the received power is a function of transmitted power, antenna gain and distance between the transmitter and the receiver. The basic idea is that the received power decreases as the square of the distance between the transmitter and the receiver subjected to the assumption that there is one single path between the transmitter and the receiver. The received signal power in a free space at a distance‘d’ from the transmitter is [2], [8]

$P_R=P_TG_TG_R(\lambda / 4\pi d)^2$ (1)

where,
P_T -Transmitted signal power
P_R-Recieved signal power
G_T-Transmitter antenna Gain
G_R-Reciever Antenna Gain
λ-is the wavelength

It is common to select $G_T=G_R=1$

$$\frac{P_T}{P_R} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \quad (2)$$

Expressed in dB as

$$L(dB) = 10\log\left(\frac{P_T}{P_R}\right)$$
$$=10\log\left(\frac{4\pi df}{c}\right)^2$$
$$=20\log\left(\frac{4\pi df}{c}\right)$$
$$=32.44+20\log d+20\log f \quad (3)$$

From the above equation, we can clearly see that as the frequency or the distance is doubled, the path loss increases by 6dB

Table 1: Path loss comparison for 900MHz and 1800 MHz

Freq=900 MHz		Freq=1800 MHz	
Dis(km)	Path loss(dB)	Dis(km)	Path loss(dB)
0.1	71.52	0.1	77.55
0.2	77.55	0.2	83.57
0.3	81.07	0.3	87.09
0.4	83.07	0.4	89.59
0.5	85.5	0.5	91.52
1	91.52	1	97.55
2	97.5	2	103.57

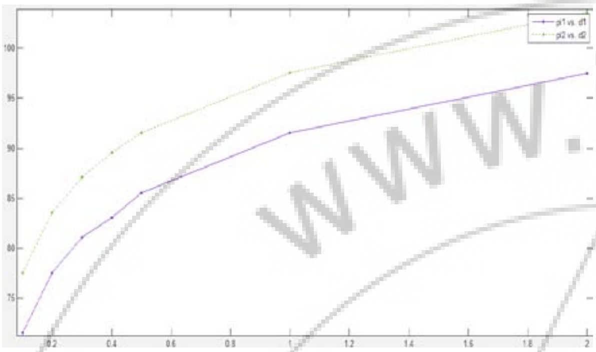

Figure 1: Path Loss Graph for table 1

3.2Two Ray Ground Model

The two ray ground reflection model is based on geometric optics and considers both direct path and the ground reflected propagation path between transmitter and the receiver. This model has been found to be reasonably accurate for predicting the large scale signal strength over the distance of several kilometres. The received power at a distance'd' from the transmitter for the two ray ground model has been expressed as [2]

$$P_R = P_T G_T G_R \frac{(h_T h_R)^2}{d^4} \quad (4)$$

when expressed in dB:

$$L\,(dB) = 40 \log d - (10 \log G_T + 10 \log G_R + 20 \log h_T + 20 \log h_R) \quad (5)$$

3.2 Okumura Model

The model developed by a Japanese radio scientist, Okumura, as a part of extensive measurement campaign conducted in 1968, is one of the most widely used models for propagation in urban areas [4]. This model is applicable for frequency range from 150 MHz to 1920 MHz, but can be extrapolated to 3GHz and up to a distance of 1Km to100 Km from the base station. To determine the path loss using Okumura model, the free space path loss between the points of interest is initially calculated and then the value A_{mu} (f,d) is added to it along with the correction factor (to account for the terrain type). The model can be expressed as [3]

$$L_{50}(dB) = L_f + A_{mu}(f,d) - G(h_t) - G(h_R) - G_{Area} \quad (6)$$

where,
L_f is the free space propagation loss
A_{mu} is the medium attenuation relative to the free space
$G(h_t)$ is the base station antenna height gain factor
$G(h_R)$ is the mobile station antenna height gain factor
G_{Area} is the gain due to the environment

The values of $G(h_t)$ and $G(h_R)$ can be determined as

$$G(h_t) = 20 \log \left(\frac{h_t}{200}\right) \quad 1000m > h_t > 30\,m \quad (7)$$

$$G(h_R) = 10 \log \left(\frac{h_r}{3}\right) \quad hr \leq 3m \quad (8)$$

$$G(h_R) = 20 \log \left(\frac{h_r}{3}\right) \quad 10m > h_r > 3m \quad (9)$$

The major disadvantages of this model are the slow response to the rapid changes in the terrain. Hence the model gives good result in urban and sub-urban region but is not good in rural areas. Common standard deviation between the predicted and the measured path loss values are around 10 dB to 40 dB.

3.3 Hata Model

The Hata Model is the empirical formulation of the graphical path loss data provided by the Okumura. This model is applicable from 150 MHz to 1500 MHz [5]
The median path loss in urban area is given by

$$L_{50}(urban) = 69.55 + 26.16 \log f_c - 13.82 \log h_t - a(h_r) + (44.9 - 6.55 h_t). \log d \quad (10)$$

where,
f_c is the frequency in MHz
h_t is the effective base station antenna height ranging from 30m to 200m
h_r is the effective mobile antenna height ranging from 1m to 10m
d is the separation between transmitter and the receiver in km
$a(h_r)$ is the correction factor for effective mobile antenna height

For small to medium size city $a(h_r)$ in dB is given by[3] [5]:

$$a(h_r) = (1.1 \log f_c - 0.7) h_r - (1.56 \log f_c - 0.8) \quad (11)$$

and for a large city $a(h_r)$ in dB given by:

$$a(h_r) = 8.29 (\log 1.54 h_r)^2 - 1.1; \; f_c \leq 300\text{ MHz} \quad (12)$$

$$a(h_r) = 3.2 (\log 11.75 h_r)^2 - 4.97 \; ; f_c \geq 300\text{ MHz} \quad (13)$$

In order to obtain the path loss in open rural areas, the modified formula is:

$$L_{50}(dB) = L_{50}(urban) - 4.78 (\log f_c)^2 + 18.33 \log f_c - 40.94 \quad (14)$$

The following table shows the path loss using Hata model using following set of parameters in urban areas
Base Station Antenna ht.30m
Mobile station Antenna ht.2m
Transmitting Frequency: 900 MHz

Table 2: Path Loss for small & medium and large cities

Distance	Path Loss(Small & Med Cities)	Path Loss (large Cities)
1	125.13	125.37
2	135.73	135.98
3	141.93	142.18
4	146.34	146.58
5	149.75	149.99

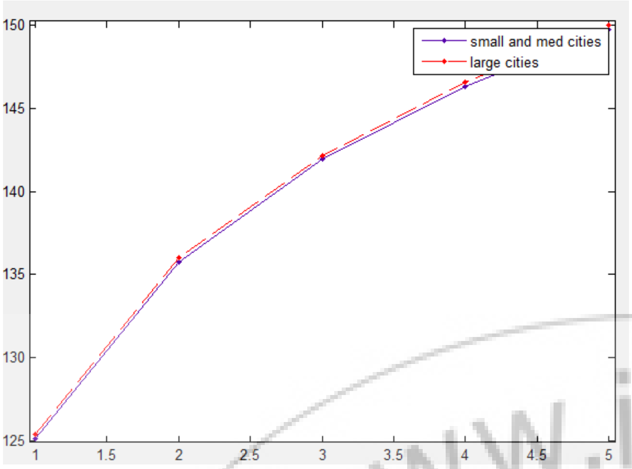

Figure 2: Path Loss graph for table 2

3.4 Cost 231 Hata Model/PCS extension to Hata Model

Hata model is applicable till the max. frequency range of 1500 MHz[1] and hence cannot be used for GSM 1800 or for systems operating at frequency range above 1500 MHz. The extension of the frequency range is achieved by the COST 231 Hata model. Cost 231 Hata model is usable in the frequency range of 1500 MHz to 2000 MHz.
The formula for the median path loss is given by:

$$L_{50}(urban)=46.3+33.9\log f_c-13.82\log h_t-a(h_r)+(44.9-6.55\log h_t)\log d+C_m \quad (15)$$

Where,
d is the distance between transmitter and the receiver in km
f is the frequency in MHz
h_t and h_r is the effective height of the transmitting and receiving antenna in m
Parameters C_m is defined as 0dB for sub-urban and rural environment and 3dB for urban environment.
For small and medium sized city,a(hr) in dB is given as

$$a(h_r)=(1.1\log f_c-0.7)h_r-(1.56\log f_c-0.8) \quad (16)$$
$$a(h_r)=8.29(\log 1.54h_r)^2-1.1;\ f_c\leq 300\text{ MHz} \quad (17)$$
$$a(h_r)=3.2(\log 11.75h_r)^2-4.97;\ f_c\geq 300\text{ MHz} \quad (18)$$

Cost-231 Hata Model is restricted to the following range of parameters
f: 500MHz to 2000 MHz
h_t: 30m to 200m
hr:1m to 10m
d=1Km to 20 Km

The following table shows the path loss using COST 231 Hata model using following set of parameters in urban areas:
Base Station Antenna ht.30m
Mobile station Antenna ht.2m
Transmitting Frequency: 1800 MHz

Table 3: Path Loss for sub-urban and metro cities

Distance	Path Loss (Sub-Urban)	Path Loss (Metro Cities)
1	134.79	137.79
2	145.39	148.39
3	151.59	154.59
4	155.99	158.99
5	159.41	162.41

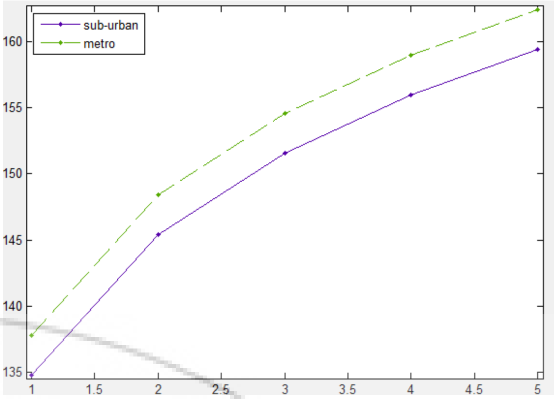

Figure 3: Path Loss graph for table3

3.5 Stanford University Interim(SUI) model

SUI model was proposed by IEEE 802.16 wireless group of frequency range below 11GHz. This is basically the extension of Hata Model with frequency band greater than 1900 MHz. The correction factor in SUI model is its terrain based classification along with the foliage distribution. The path loss expression for the SUI along with its correction factor is

$$L=A+10\gamma\log\left(\frac{d}{d_0}\right)+X_f+X_h+e \text{ for } d>d_0 \quad (19)$$

where,
d:distance between transmitter and receiver antenna
d_0=100
λis the wavelength
X_f is the correction factor for frequency>2GHz
X_h is the correction factor for receiving antenna height
e is the correction factor for shadowing effect
γ is the path loss component

The factor 'e' is log normally distributed and accounts for the shadowing due to foliage and other similar hindrances. The typical value of 'e' lies between 8.2 to 10.6 dB.

3.6 Walfisch and Bertoni Model

This semi-deterministic model was developed by Walfisch and Bertoni and considers the impact of roof-top and building heights by using diffraction to predict average signal strength at the street level[6][12]. This model considers the total path-loss to be the product of three factors i.e

$$S=L_0\times Q^2\times L_{rts} \quad (20)$$

where,
L_0 is the free space path loss between isotropic antennas
L_{rts} is based on the diffraction and determines the signal loss from the roof-top to the street
Q^2 reflects the reduction in the signal power due to hindrances from the building blocks

3.7 Walfisch and Ikegami Model

This model utilizes the Walfisch Bertoni model [12] and comprises of the three terms[9]

$$L_b=L_b+L_{rts}+L_{msd}\ ;\ \text{for } Lrts+Lmsd>0 \quad (21)$$

$L_b=L_0$; for Lrts+Lmsd>0 (22)
where,
L_0 is the free space path loss

L_{rts} is roof to street diffraction loss
L_{msd} is multi-screen diffraction loss
The roof to street diffraction and scatter loss is given as
L_{rts}= -16.9-10 log (W)+10 logf+20 log Δh_{mobile} +L_{ori} (23)
where,
Δh_{mobile}- (h_{roof}-h_{mobile}) is the difference between the height of the building on which the base station is located (h_{roof}) and the height of the mobile antenna (h_{mobile})

$$L_{ori}=\begin{cases} -10+0.354\Theta & 0 \le \Theta \le 35 \\ 2.5+0.075(\Theta-35) & 35 \le \Theta \le 55 \\ 4.0-0.114(\Theta-55) & 55 \le \Theta \le 90 \end{cases} \quad (24)$$

Θ is the angle of incidence relative to the direction of the street
L_{msd}=L_{bsh}+K_a+$K_d$log d+$K_f$log f-9 log b (25)
where,
b is the distance between the building along the signal path.
L_{bsh} and K_a represents the increase of the path loss due to reduction of the base station antenna height.
Δh_{base}=h_{base}-h_{roof}
Recently modification to Cost-231 Walfisch Ikegami model has been reported which takes into account multiple reflections due to building blocks [13]

3.8 Ericsson 9999 model

This model was developed by Ericsson engineers and permits modification of the parameters according to the propagation environment [10].
Path loss for this model is given by

$$L=a_0+a_1\log d+a_2 \log h_t+a_3 \log h_t \log d-3.2(\log(11.75h_r))^2+g(f) \quad (26)$$

$$\text{and } g(f)= 44.49 \log f-4.78(\log f)^2 \quad (27)$$

Parameters a_0, a_1, a_2 and a_3 are constants having the default values of a_0=36.2, a_1=30.2, a_2=-12 and a_3=0.1

3.9 Lee Model

W.C.Y. Lee proposed this model in 1982.This model consists of two parts. The first part is an area to area prediction which is used to predict path loss over a general flat terrain but does not account for a particular terrain. But this area to area to prediction is not adequate for hilly terrain. The second part of the Lee Model uses area to area prediction model as the base and then develops a point to point model. The point to point prediction considers whether LOS conditions exist or not. In case the LOS exists, the influence of the reflected radio waves is carefully examined. In the case LOS does not exist, the obstruction are modelled as knife edges and then the waves diffracted are computed [11]
The basic area to area model can be represented as

$$P_r=P_{r0}\left(\frac{r}{r_0}\right)^{-\gamma}\left(\frac{f}{f_0}\right)^{-n}\alpha_0 \quad (28)$$

Where,
P_r is the signal power (in watts) at a distance of r from the transmitter
P_{ro} is the signal power (at the point of interception) at a distance of r_0 from the transmitter
f is the signal frequency
f_0 is the reference signal frequency
α_0 is the adjustment factor for the antenna height transmitter power and antenna gains
γ is the path loss slope

4. Conclusion

The survey of the important model discussed gives a clear insight into the fact that for an analysis to be drawn out regarding the specific model with respect to any data set, the median values of the path-loss is calculated which is specific to the kind of environment, terrain and other such factors.

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