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4th year communications
Communication Systems
11/5/2022

Empirical path loss models

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Introduction

In Wireless Communications, there are several problems could face the system. Most of them are in the radio channel between transmitter & receiver.

Controlling the radio channel and handling its complexity improves the quality of transmission.

Classification of Channel Problems

1- Large scale effects: variation of received power within large distance (over a distance >> λ)

A- Path loss: Deterministic- Cause attenuation

B- Shadowing (Diffraction and scattering): Random - Cause attenuation

2- Small scale effects: (multi-Path fading): Random variation of received power within short distance (over a distance of order λ): May cause distortion

There are several models for the path loss calculation:

Models for free space attenuation:

Free-space path loss, Dipole field strength in free space, Friis equation

Models for outdoor attenuation:

Terrain models: ITU terrain, Egli , Two-ray ground-reflection

City models: Okumura , Hata , COST Hata

Models for indoor attenuation:

ITU , Log-distance path loss model

Okumura model

This model is used in cities with many urban structures but not many tall blocking structures.

It is one of the most widely used models for signal predictions in urban and sub-urban mobile communication areas

This model is applicable for frequencies ranging from 150 MHz to 1920 MHz

It can cover distances from 1 km to 100 km and it can be used for base station heights starting from 30m to 1000m

The model is based on empirical data collected in detailed propagation tests over various situations of an irregular terrain and environmental clutter

Okumura developed a set of curves giving the median attenuation relative to free space (Amu), in an urban area over a quasi-smooth terrain with a base station effective antenna height (hte) of 200 m and a mobile antenna height (hre) of 3 m. These curves were developed from extensive measurements using vertical omni-directional antennas at both the base and mobile, and are plotted as a function of frequency in the range 100–1920 MHz and as a function of distance from the base station in the range 1–100 km. 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 Amu(f, d) (as read from the curves) is added to it along with correction factors to account for the type of terrain. The model can be expressed as

$$L_{50}\left(dB\right) = L_F + A_{mu}\left(f,d\right) - G\left(h_{te}\right) - G\left(h_{re}\right) - G_{AREA}$$

L_{50} : the median value or 50th percentile value of the propagation path loss
L_F : the free space propagation path loss
A_{mu} : the median attenuation relative to free space
G_{AREA} : the gain due to the type of environment
$G_{(hte)}$: the base station antenna height gain factor
$G_{(hre)}$: the mobile antenna height gain factor

Hata model

Hata model was based on Okumura's field test results and predicted various equations for path loss with different types of clutter. The limitations on Hata Model due to range of test results from carrier frequency 150Mhz to 1500Mhz, the distance from the base station ranges from 1Km to 20Km, the height of base station antenna (hb) ranges from 30m to 200m and the height of mobile antenna (hm) ranges from 1m to 10m. Hata created several representative path loss mathematical models for each of the urban, suburban, and open country environments.

Hata model is not suitable for micro-cell planning where antenna is below roof height and its maximum carrier frequency is 1500MHz. It is not valid for 1800 MHz and 1900 MHz systems.

Path Loss for urban clutter:

$$L_p(urban) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) \\ - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d)$$

$$a(h_m) = (1.1\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8)$$

Path loss for suburban clutter:

$$L_p(suburban) = L_p(urban) - 2\{\log_{10}(f/28)\}^2 - 5.4$$

Path loss for the open country is :

$$L_p(open\ country) = L_p(urban) - 4.78\{\log_{10}(f)\}^2 + \\ 18.33\log_{10}(f) - 40.94$$

Cost 231 Hata Model

First generation GSM systems operate at 900 MHz band. As the demand on the service increased, allocation of new channels to the service has been provided by assigning 1800 MHz band to the system. Hence, first system can use Hata Model for prediction since Hata Model covers frequency range of 100 to 1500 MHz. However, second system cannot. Cost 231 have addressed this problem and a new model which covers frequency range of 1500 MHz to 2000 MHz has been brought forward by Cost 231.

Although Modified Hata could be used in the same ranges above, use of this model is more popular as representative of Okumura's curves in given ranges since model is very simple with respect to Modified Hata Model. A comparison of two models is given in figure 1 taken by using Wireless Simulator Program. In the figure, it is shown that Cost 231 Hata Model shows similar manner with Modified Hata Model in Urban area. They have 3 dB differences and one reason for this difference could be building percentage correction in Modified Hata Model. If used terrain had different building percentage, the difference would be increasing or decreasing depending on the terrain. However, when study is done for open area and Suburban area, Modified Hata model deviates much more from Cost 231 Hata Model. All these results mean that Cost 231 Hata Model agree well with Okumura Curves in Urban Area.

$$L_b = 46.3 + 33.9\log_{10}\frac{f}{\mathrm{MHz}} - 13.82\log_{10}\frac{h_B}{\mathrm{m}} - a(h_R, f) + \left(44.9 - 6.55\log_{10}\frac{h_B}{\mathrm{m}}\right)\log_{10}\frac{d}{\mathrm{km}} + C_m$$

where,

L_b Median path loss. Unit: decibel (dB)

f Frequency of Transmission. Unit: megahertz (MHz)

h_B Base station antenna effective height. Unit: meter (m)

d Link distance. Unit: Kilometer (km)

h_R Mobile station antenna effective height. Unit: meter (m)

$a(h_R, f)$ Mobile station antenna height correction factor as described in the Hata model for urban areas

Egli loss model

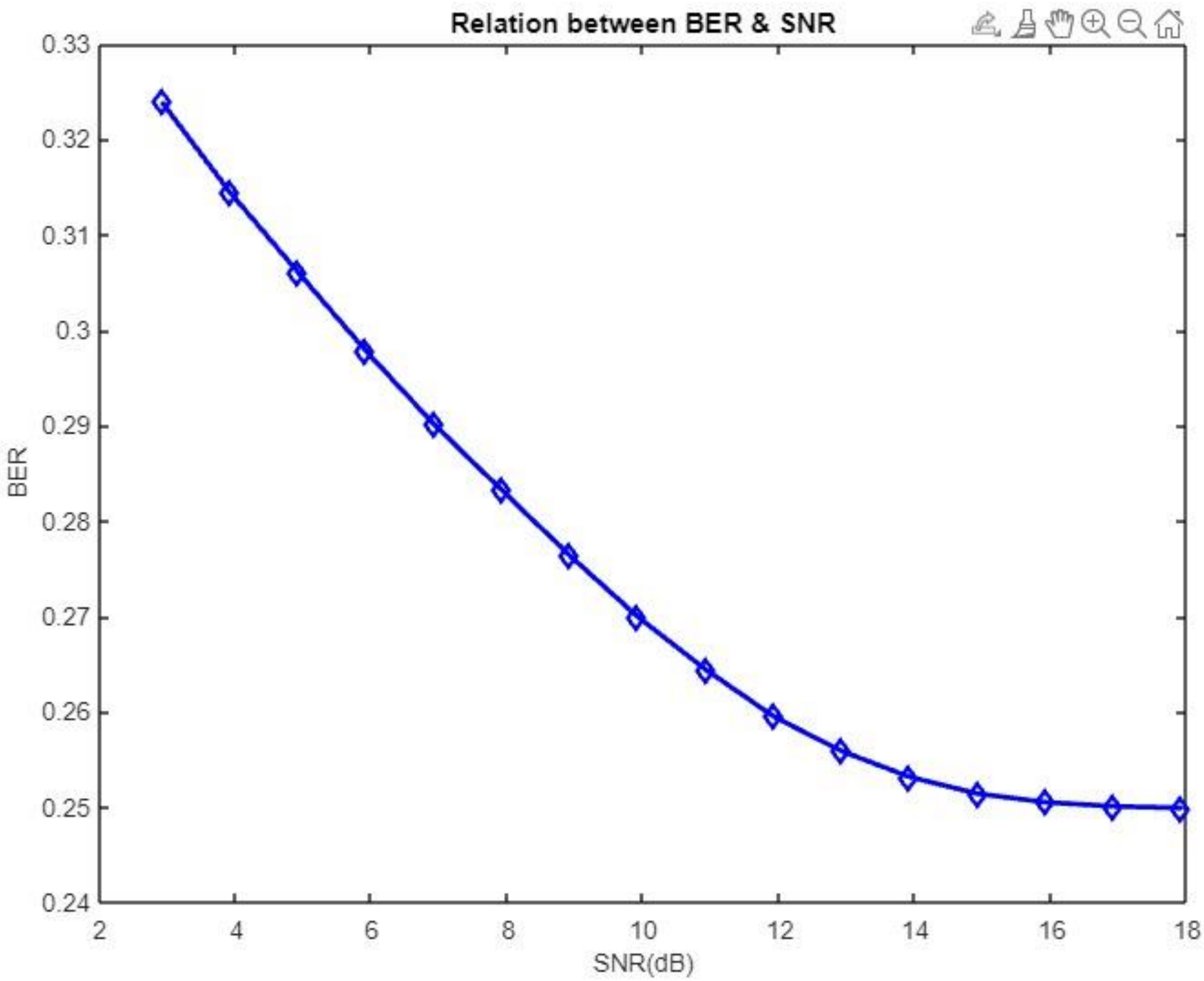
To understand the characteristics of electromagnetic propagation over irregular terrain, Egli developed graphs and correcting curves based on a statistical analysis of wide-range measurements made between 40 and 1000 MHz in a different region of the USA. This model fundamentally is the theoretical plane earth propagation model with added terrain factor (dependent on frequency) and an evaluation of position . Some of the literature works provide a distinctive mathematical expression of Egli's graphs, which approximately gives the same result when compared. Egli model is expressed in the form:

$$L_p(\mathrm{dB}) = 20\log_{10}(f_c) + 40\log_{10}(R) - 20\log_{10}(h_b) + \begin{cases} (76.3 - 10\log_{10}(h_m) & h_m < 10 \\ (85.9 - 20\log_{10}(h_m) & h_m \geq 10 \end{cases}$$

fc : the frequency (MHz),
hb : the base antenna (Tx) height in meter (m),
hm : mobile antenna (Mx) height (m),
R : Tx and Mx separation in kilometers (km)

Mini-Simulation

```
% System parameters
M = 16;             % Number of Symbols
k = log2(M);        % Number of bits per Symbol
N_bits = 1000000*k;    % total number of bits


Hte= 50;  %Base Station Height                        between 30 m and 1000 m
Hre= 5;   %Mobile Station Antenna Height              between 1 m and 10 m
d = 50;   %distance from base station                 between 1Km and 100Km
f= 1400;   %Frequency                                  between 150Mhz and
1920Mhz

P_sig = 250; %dB

% Generating Transmitted signal
Xn= randi([0 1 ],N_bits,1);          %Generate a sequence of bits equal to
the total number of bits
txSig = qammod(Xn,M,'InputType','bit','UnitAveragePower',true);  % Generate a
Modulated sequence

% Hata Model for small city
CH = 0.8 +((1.1*log( f))-0.7)*Hre - 1.56*log(f);
L=69.55+26.16*log (f)-13.82*log(Hte) -CH+(44.9-6.55*log(Hte))*log(d);

% Reciving
SNR_vec = [0:15] + P_sig - L ;
BER_vec = zeros(1,15); % Use this vector to store the resultant BER

for i = 1:length(SNR_vec)

    rxSig = awgn(txSig,SNR_vec(i));    % Generate a recieved seq.
    Dn = qamdemod(rxSig,M, 'bin','OutputType','bit'); % Generate a
DeModulated sequence
    [N_error_bits,BER_vec(i)] = biterr(Xn,Dn); %Calculate the bit error rate

end
figure;
% Plotting results
plot(SNR_vec,BER_vec,'d-b','linewidth',2); hold on;
xlabel('SNR(dB)','fontsize',10)
ylabel('BER','fontsize',10)
title('Relation between BER & SNR')
```


Relation between BER & SNR
0.33
0.32
0.31
0.3
0.29
0.28
0.27
0.26
0.25
0.24
BER
2
4
6
8
10
12
14
16
18
SNR(dB)