PROPAGATION MODELS FOR WIRELESS COMMUNICATION SYSTEM

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Abstract – This paper gives an overview of the propagation models in wireless communication systems. Wireless communication system uses several physical media, ranging from sound to radio to light. These characteristics are affected by the physical environment between the transmitter and receiver. Wireless communication system suffers from various unwanted effects of fading which may be caused due to multipath propagation, path loss, shadowing, Doppler spread and co-channel interference. There are various signal propagation ranges in wireless communication channels.

Key Words: Characteristics of wireless communication system, path loss, fading, interference, types of propagation models-outdoor & indoor propagation model.

1. INTRODUCTION

The wireless communication system posses several challenges for the reliable and a high speed communication. It is not receptive of noise channel and other channel hindrance, but these obstacle changes with time in unforeseeable ways due to user movement. We will characterize in detail the variation in the received signal power over the distance due to path loss and shadowing. Path loss models describe the signal attenuation between a transmitter and receiver antenna as a function of propagation distance and other parameters which is caused by the dissipation of the power radiated by the transmitter as well as effects of the propagation channel. Shadowing is caused by obstruction between the transmitter and the receiver that attenuate the signal power through absorption, reflection, scattering, and diffraction. A very important practical issue is to test and validate the ability of the "smart" antenna array to meet performance requirements. For this purpose, a channel model is needed to take into account the temporal and spatial characteristics of radio propagation.

2. WIRELESS CHANNEL

The wireless signal proliferate in space, based on the rule of physics. An electromagnetic Radio Frequency (RF) signal which proceed in a medium suffers an attenuation (path loss) based on the nature of the medium. In addition, the signal experiences objects and gets reflected, refracted, diffracted, and scattered. The cumulative effect results in the signal getting absorbed, signal travel across multiple paths, signal's frequency being shifted due to relative motion between the source and objects (Doppler Effect), thus are getting modified in a sufficient way. It is clear that the radio frequency signal is a space-time-frequency signal.

3. CHARACTERISTICS OF WIRELESS CHANNEL

The main characteristics of wireless communication channel are as follows:
1. Path loss
2. Fading and shadowing
3. Interference
4. Doppler shift

3.1 Path loss

Path loss can be expressed as the ratio of power of transmitted signal to the power of the same signal received by the receiver on a given path. It is a function of the propagation distance.

- Estimation of path loss is very important for designing and deploying wireless communication networks.
- Path loss depends on the number of factors such as the radio frequency used and the nature of the terrain.
- The free space propagation model is the simplest path loss model in which there is a direct-path signal between the transmitter and the receiver with no atmosphere attenuation or multipath components.

In this model, the relationship between the transmitted power P_t and the received power P_r is given by

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\Pi d}\right)^2$$

Where,

- G_t is the transmitter antenna gain
- G_r is. the receiver antenna gain
- **d** is the distance between the transmitter and receiver
- **λ** is the wavelength of the signal

Two-way model also called as two path models is widely used path loss model. The free space model give a detail amount of above assumes that there is only one single path from the transmitter to the receiver.

It is actually experienced that the signal reaches the receiver through the multiple paths. The two path model struggles to capture this phenomenon. The model assumes that the signal reaches the receiver through two paths, one a line-of-sight and the other the path through which the reflected wave is received.

According to the two-path model, the power which is received is given by

$$P_r = P_t G_t G_r \left(\frac{h_t h_r}{d^2}\right)^2$$

Where,

- $\mathbf{P_t}$ is the transmitted power
- $\mathbf{G_t}$ represent the antenna gain at the transmitter
- $\mathbf{G_r}$ represent the antenna gain at the receiver
- **d** is the distance between the transmitter and receiver
- $\mathbf{h_t}$ is the height of the transmitter
- $\mathbf{h_r}$ are the height of the receiver

3.2 Fading

Fading mentions the fluctuations in strength of the signal when the signal is received at the receiver. Fading can be classified into two types –

- Fast fading/small scale fading and
- Slow fading/large scale fading

Fast fading refers to the swift fluctuations in the amplitude, phase or multipath delays of the received signal, due to the interference between the multiple versions of the same transmitted signal arriving at the receiver at slightly different time interval.

The time between the reception of the first version of the signal and the last echoed signal can be expressed as delay spread. The multipath propagation of the transmitted signal, which causes fast fading, is because of the three propagation mechanisms, namely –

- Reflection
- Diffraction
- Scattering

The multiple signal paths may sometimes add constructively or sometimes destructively at the receiver causing a variation in the received signal's power level. The received single envelope of a fast fading signal is said to follow a Rayleigh distribution to see if there is no line-of-sight path between the transmitter and the receiver.

2.1 Slow Fading

The name Slow Fading itself indicates that the signal fades away slowly. The features of slow fading are as given below.

- Slow fading occurs when objects that partially absorb the transmission lie between the transmitter and the receiver.
- Slow fading is so called because the duration of the fade may last for multiple seconds or minutes.
- When the receiver is inside a building and the radio wave passes through the walls of a building slow fading occurs. The blocking object causes an irregular variation in the power of received signal.
- Slow fading may causes the received signal power to vary, though the distance between the transmitter and receiver remains the same.
- Slow fading can also be expressed as the shadow fading since the objects that cause the fade, which may be large buildings or other structures, block the direct transmission path from the transmitter to the receiver.

3.3 Interference

Interference is the sum of all signal contributions that are neither noise not the wanted signal. Lets understand how its effect, its type and what possible source for it.

3.3.1 Effects of Interference

- Interference is an important limiting factor in the performance of cellular systems.
- Interference degrades the quality of the signal.
- It initiates bit errors in the received signal.
- Bit errors are partly recoverable by means of the channel coding and the error correction mechanisms.
- The situation of the interference is not reciprocal to the uplink and downlink direction.
- Mobile stations and base stations are introduced to different interference situation.

3.3.2 Sources of Interference

- When another mobile is present in the same cell.
- When a call is in progress in the neighboring cell.
- When other base stations are operating on the same frequency.
- When any non-cellular system leaks energy into the cellular frequency band.

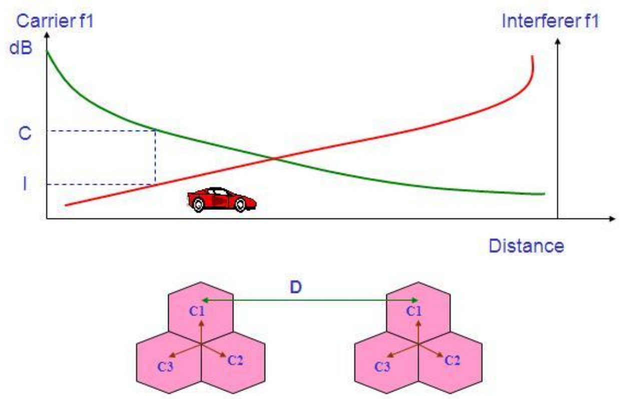

Fig-1: Interference

3.3.3 Types of Interference

There are two types of system generated interference

1. Co-channel interference
2. Adjacent channel interference

1. Co-Channel Interference

- Co-channel interference occurs the because of frequency reuse, i.e. several cells use the same set of frequency.
- These cells are called co-channel cells.
- Co-channel interference cannot be combated by increasing the power of the transmitter. This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells.
- To reduce the co-channel interference, the cells must be separated by a minimum distance to provide sufficient isolation due to propagation or reduce the footprint of the cell.
- Some factors other than reuse distance that influence co-channel interference are antenna type, directionality, height, site position etc.

2. Adjacent channel interference

- Interference concluding from the signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the pass band.
- Adjacent channel interference can be minimized through channel assignments and careful filtering.
- By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent interference may be reduced considerably.

4. DOPPLER SHIFT

The Doppler Effect is named after Austrian physicist Christian Doppler who proposed it in 1842. Doppler shift is referred as the change in frequency of a wave for an observer moving relative to the source of the wave. It is heard when a vehicle sounding a siren or horn approaches, passes, and recedes from an observer. The frequency is higher at the instant when it is emitted. The frequency is identical at the instant of passing by, and it is lower during the recession. For the waves that propagate in a medium like sound waves, where the velocity of the source and of the observer is corresponding to that of the medium in which the waves are transmitted. The total Doppler Effect may result from the motion of the observer, motion of the source, or motion of the medium. Each of these effects is examined separately. For the waves which do not require any medium, such as gravity or light in general relativity, only the relative difference in velocity between the source and the observer needs to be considered.

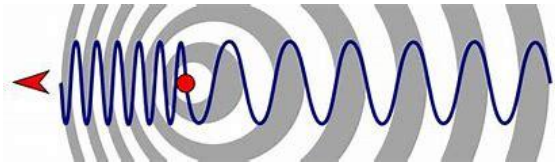

Fig-2: Doppler Shift

4. Radio propagation model

The radio propagation model is an experimental mathematical formulation for the characterization of radio wave propagation as a function of distance frequency and other conditions. A single model is usually developed to anticipate the behavior of propagation for all identical links under identical constraints. Create with the goal of formalizing the way radio waves are propagated from one place to another, such models typically predict the path loss along a link or the effective coverage area of a transmitter.

The propagation models are classified mainly into two types:

1. Outdoor propagation model.
2. Indoor propagation model.

4.1 Outdoor propagation models

In the mobile communication system radio transmission often takes place over discontinuous terrain. The terrain profile may vary from a simple curved earth profile to a highly mountainous profile. The presence of trees, buildings, and other obstacles also must be taken into account. A number of propagation models are available to predict path loss over irregular terrain. Some commonly used outdoor propagation models are now discussed.

4.1.1 Longley-Rice Model

The Longley-Rice model is application to point-to-point communication systems in the frequency range from 40 MHz to 100 GHz, over different kinds of terrain. The main transmission loss is predicted using the path geometry of the terrain profile and the refractive of the troposphere. Geometric optics techniques are used to predict signal strengths within the radio horizon. The Longley-Rice model is also available as a computer program to calculate large – scale median transmission loss relative to free space loss over irregular terrain for frequencies between 20 MHz and 10 GHz.

The Longley-Rice method operates in two modes. For the availability of complete path terrain, the path-specific parameters can be easily determined and the prediction is called a point-to-point mode prediction. On the other hand , if the terrain path profile is not available, the Longley-Rice method provides techniques to estimate the path-specific parameters, and such a prediction is called an area mode prediction.

There have been many predictions and corrections to the Longley-Rice model since its original publication. One important modification deals with radio propagation in urban areas and this particularly relevant to mobile radio. This modification introduces an excess term as an allowance for the additional attenuation due to urban clutter near the receiving antenna. This extra term called, urban factor, has been derived by comparing the prediction by the original Longley-Rice model with those obtained by Okumura.

4.1.2 Okumura model

Okumura model is one of the most widely used models for signal prediction in urban areas. This model is applicable for frequencies in the range 150 MHz to 1920 MHz and distances of 1km to 100 km. It can be used for base station antenna ranging from 30 m to 1000 m.

Okumura developed a set of curve giving the median attenuation relative to free space (A_{mu}) in an urban area over a quasi-smooth terrain with a base station effect antenna height (h_{te}) of 200 m and the height of mobile antenna (h_{re}) of 3m. 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_{mu} (f,d) is added to it along with correlation factors to account for the type of terrain. The model can be expressed as

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

Where, L_{50}=50th percentile value of propagation path loss.
L_F=free space propagation loss.
A_{mu}=median attenuation relative to free space.
G (h_{re}) = mobile antenna height gain factor.
G_{AREA}=gain due to the type of environment.

4.1.3 Hata Model:

It is an empirical formulation of graphical path loss data provided by Okumura and is valid from 150MHz-1500MHz. Hata established empirical mathematical relationships to describe the graphical information given by Okumura. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain. The mathematical expression and their ranges of applicability are as follows:

L (db) = 69.55 + 26.16fc - 13.82loghte - a (hre) + (44.96.55loghte) log10d
Carrier frequency: 150MHz≤ fc ≤1500MHz
Base station antenna height (hte): 30m ≤ hb ≤ 200m
Mobile unit antenna height (hre): 1m ≤ hm ≤ 10m
Transmission distance (d):1km≤ d ≤ 20 km
The following expressions have considerably enhanced the practical value of the Okumura method, although Hata's formulations do not include any of the path specific corrections available in the original model.

4.1.4 Durkin's Model

It provides a perspective in to the nature of propagation over irregular terrain and the losses occur due to obstacles in a radio path. The demerit of this model is it cannot predict propagation effects due to foliage, buildings, and other human structures and doesn't support multi path communication.

This model provides anticipations which satisfy well with measurements when the base station antenna is above rooftop height, giving mean output errors of about 3db with standard deviations in the range 4-8 db. However the performance degrades as hb reaches hr and is quite poor when hb<<hr. The model produces much bigger errors in the microcellular situation.

4.2 Indoor Propagation Models

It provides a alternative in to the nature of propagation over irregular terrain and the losses occurred due to obstacles in a radio path. The disadvantage of this model is it cannot assumes propagation effects due to foliage, buildings, and other manmade structures and does not supports multi path communication.

4.2.1 Free Space Path Loss

The free space path loss model is not directly related with the indoor propagation. As it is required to compute the path loss at a close-in reference distance as desired by the models. The free space model gives a measure of path loss as a function of T-R separation when the receiver and transmitter are under the LOS range in a free space environment. The model is defined by equation given below, which depicts the path loss as a positive quantity in dB:

$$PL(d) = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$$

Where, G_t and G_r are the individual ratio gains of the transmitting and receiving antennas respectively, l gives the wavelength in meters, and d is the T-R separation in meters. When antennas are removed, we assume that $G_t = G_r = 1$. The free space path loss equation gives desired results only if the receiving antenna is in the far-field or Fraunhofer region of the transmitting antenna. The far-field denoted as the distance d_f given by equation below.

$$d_f = \frac{2D^2}{\lambda}$$

Here, D = largest linear dimension of the antenna. Additionally, for a receiver to be assumed in the far-field of the transmitter, it must satisfy $d_f >> D$ and $d_f >> \lambda$.

4.2.2 Log-Distance Path Loss

The log-distance path loss model assumes the path loss variations takes place exponentially with distance. The path loss in dB is given by equation (7.3).

$$\overline{PL}(d)=\overline{PL}(d_0)+10n\log\left(\frac{d}{d_0}\right)$$

Where n gives the path loss exponent, d defines the T-R separation in meters, and d_o defines the close-in reference distance in meters. PL (d_o) is calculated using the free space path loss equation mentioned above. The value d0 should be considered such that it is in the far-field of the transmitting antenna; however some small relative to any practical distance used in the mobile communication system. The path loss exponent value n varies according to the environment. In free space environment, n is equal to 2. In practice, the value of n is calculated using empirical data.

4.2.3 Log-Normal Shadowing

One major drawback of the log-distance path loss model is that it does not counts for shadowing effects which can be caused by changing degrees of clutter between the transmitter and receiver. The log-normal shadowing model tries to overcomes this. The log-normal shadowing model assumes path loss as a function of T-R separation.

$$PL(d)=\overline{PL}(d_0)+10n\log\left(\frac{d}{d_0}\right)+X_\sigma$$

Where, Xs denotes the zero-mean Gaussian random variable with standard deviation s. Both Xs and s are defined in dBs. The random variable Xs tries to counteract for random shadowing effects that can result from clutter. The values n and s are considered from empirical data.

4.2.3.1 Addition of Attenuation Factors to Log-Distance Model

Many researchers have attempted to enhance the log-distance model by taking into account certain additional attenuation factors based upon measured data. One relevant example is the attenuation factor model proposed by Seidel and Rappaport. The attenuation factor model includes a special path loss exponent and a floor attenuation factor to give an estimation of indoor path loss. The model is described in equation mentioned below:

$$PL(dB)=PL(d_0)+10n_{sf}\log\left(\frac{d}{d_0}\right)+FAF$$

PL

where n_{sf} provides the exponential path loss for a same floor measurement and FAF defines a floor attenuation factor completely based on the counts of floors between transmitter and receiver. Both n_{sf} and FAF are approximated from empirical data. A quite familiar model was developed by Devasirvatham. Devasirvatham's model has an additional loss factor which improves exponentially with distance. The modified path loss equation is given below:

$$PL(d)=PL(d_0)+20\log\left(\frac{d}{d_0}\right)+\alpha d+FAF$$

Where, α denotes an attenuation factor in dB/m for a defined channel. A third model includes additional attenuation factors. This new model was developed by Motley and Keenan and is of the form shown below:

$$PL(d)=PL(d_0)+10n\log(d)+kF$$

Where, k gives the number of floors within the transmitter and receiver and F is the individual floor loss factor. The main point of difference between Motley and Keenan's model and the one developed by Seidel and Rappaport is that Motley and Keenan give an individual floor loss factor which is later multiplied by the number of floors separating transmitter and receiver. Seidel and Rappaport proposed a table comprising of floor attenuation factors which changes are based upon the number of floors separating the transmitter and receiver respectively.

4.2.3.2 An Additive Path Loss Model

An additional path loss model which has been found out by researchers is named as an additive path loss model. In this model, individual losses occured due to obstructions between transmitter and receiver are approximated and added together. Researchers have proposed tables of recorded average attenuation values for different obstructions including walls, floors, and doors. However, maximum of the recorded information is related to only a few carrier frequencies. Furthermore, the resulting attenuations are not equal among various researchers.

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