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Comparison of Propagations Models in Mobile Telecommunication Systems

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ABSTRACT

Wireless channels are subject to random fluctuations in received signal power arising from multipath propagation and shadowing arising from the multiple scattering conditions. Considerable efforts have been devoted to the statistical modeling and characterization of these different effects, resulting in a range of models for wireless channels which depend on the particular propagation environment and underlying communication scenario. The comparative analysis of different theoretical and empirical propagation models, such as Okumura, Hata, COST-231 Hata, and Longley-Rice, is given in this paper. After a brief introduction and description of these models, we present some numerical results using MATLAB and RadioWORKS.

INTRODUCTION

Radiowave propagation through wireless channels is a complicated phenomenon characterized by different effects such as reflection, diffraction and scattering phenomenon. An exact mathematical description of this effects is either too complex for tractable communication system analysis, although considerable efforts have been devoted to the statistical modeling and characterization of wireless channels.

In this paper we will characterize the variation in received signal power over distance due to path loss and shadowing. Path loss is caused by dissipation of the power radiated by the transmitter as well as effects of the propagation channel. Path loss models generally assume that path loss is the same at the given transmit-receive distance, which means that path loss model does not include shadowing effects. Shadowing is caused by obstacles between the transmitter and receiver that absorb power. When the obstacle absorbs all the power, the sognal is blocked. Variation due to path loss occurs over very large distances (100-1000 meters) and variation due to shadowing occurs over distances proportional to the length of the obstruction object (10-100 meters in outdoor environments and less in indoor environments). Variations due to path loss and shadowing are usually refered to as large-scale propagation effects or local-mean attenuation, because they occure over relatively large distances. Variation due to multipath propagation occurs over very short distances, on the order of the signal wavelenght, and are usually refered to as smale-scale propagation effects or multipath fading.

The primary purpose of this paper is to briefly review the principal characteristics of large-scale propagation models *such as Okumura, Hata, COST-231 Hata, model.*

BASIC MECHANISMS OF PROPAGATION

Signal path on its way from transmitter to receiver may vary from the clear line of sight (LOS path), the path is inhibited by obstacles (NLOS path) such as buildings, mountains, hilly areas and even obstacles such as leaves, street lighting, traffic signs, etc.

Most cellular radio systems are located in an urban area where there is no direct line of sight between the transmitter and receiver, but is hidden by tall buildings, that are the cause of various losses. The height of base station is on the order of 30 meters and they are normally placed on the protruding areas where nearby obstructions. However, cellular receivers are much lower than natural and artificial objects in the environment. The typical height at which the mobile receiver is located 1, 5 to 3 meters. That basically means that something is often found on the road between the base station and mobile receivers.

The typical way of propagation of signals in mobile telecommunications is the multiple propagation paths or multipath propagation. The reason for this is that the received signal is the sum of signals coming from different directions with different phases and amplitudes, and thus the sum of such signals is vary considerably. Path of the reflected waves are usually longer than the path of direct waves, which causes the reflected wave reaches the receiver later. This phenomenon is called delayed propagation (delay spread).Typical valley of this phenomenon in the cities is 3 μs, while GSM can tolerate this effect to 16 μs, corresponding to the difference of time of about 3 km.

In digital systems, especially those who work with high bit rates, causes a delayed propagation in which every bit of information overlaps with the previous or next bit. More precisely, in real situations where we have hundreds of different ways, at the reception we have a much weaker pulse. Since each path has a different attenuation, these impulses come from a variety of forces. Some of them will even be so weak that it will be detected as noise. If each pulse represents a symbol, it means that energy is intended in part to cross a symbol and other symbols. This effect is known as Intersymbol interference (ISI). When the signal is spread over 20% of the symbol duration, ISI can be a problem. What is more rapid transfer to the effect is more pronounced and it limits the bandwidth of radio channel with multipath propagation. As a solution equalizer is used for adapt.

While the ISI and the spread of the signal but also occur in case of the fixed radio links , the situation is even worse in case the receiver, transmitter or both are moving. Then the characteristics of radio signals change over time. Received signal power can vary considerably over time. Such changes of the signal in time is characterized by temporal fading statistics.

Effect that is caused by displacement transmitter or receiver is called the Doppler effect. Specifically Doppler effect is a phenomenon that is caused by movement between the receiver and transmitter is made between the frequency of the received signal.

FREE SPACE PROPAGATION

Propagation models in free space are used to predict the received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. The received signal strength is given by Friis free space equation:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (1)$$

Where P_t is the transmitter power, $P_r(d)$ is the received power which is a function of distance, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, is the distance between transmitter and receiver, L is the system loss factor not related to propagation $(L \geq 1)$,and λ is wavelength.

First Friis's equation shows that power consumption decreases in proportion to the square of the distance between the transmitter and receiver. This leads to the conclusion that the receiving power decreases with increasing distance between the transmitter and receiver in steps of 20 dB / decade.

In case of an isotropic antenna that radiates energy is equally in all directions and is commonly used as a referential antennas in wireless systems, then the EIRP (effective isotropic Radiated Power) is defined as:

$$EIRP = P_t G_t \qquad (2)$$

And it is maximum power available from the transmitter in the direction of maximum antenna gain compared to the isotropic radiator. In practice, instead of the EIRP, it is commonly used ERP (Effective Radiated Power) which provides maximum power in comparison with the dipole antenna (instead of isotopic antenna). As dipole antenna has a gain of 1.64 (which is 2.15 dB higher than the isotope antenna), the ERP will be for 2.15 dB lower than the EIRP of the same transmission system. Practical antenna gain expressed in dBi (antenna gain in dB relative to the isotopic source) and dBi (antenna gain in dB relative to a dipole antenna).

Losses due to signal propagation in free space, are weakening the signal expressed in dB, which defines the difference between the effective transmit power and received power and can, and does not need to include the antenna gain. Losses in signal propagation in free space when the antenna gain is included:

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \qquad (3)$$

If isotropic radiator is used as a receiving antenna, then weakening of propagation in free space is defined as:

$$L_s = \frac{EIRP}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (4)$$

While, if we use non- isotropic radiator as receiving antenna, path loss in free space is given by equation:

$$L_s = \frac{P_t G_t G_r}{P_r} \qquad (5)$$

RADIO WORKS

Radio Works package is a set of tools that allows the calculation, numeric and graphic analysis of a series of variables related to radio waves and their propagation. With it we can get detailed information on the frequency, such as wavelength band propagation methods to be used, the configuration of the transmitter and the like. Calculates the length of the antenna and its frequency. Allows graphical representation of the signal coverage of 3D maps, with the required coordinates (latitude and longitude) and height of the transmitter. Gives the ability to view two-dimensional map of signal coverage between the two desired points, including compensation amount of the transmitting and receiving antenna, adjustment due to the curvature of the earth's surface as well as the percentage of freedom of the first Fresnel zone. Calculated losses due to signal propagation in free space by offering a choice of different propagation models such as Hata model for open, suburban and urban area, ITU Terrain, Weissberger, 231 COST Hata model and many other models.

PROPAGATION MODELS

Propagation models can be theoretical (deterministic), empirical (static) or a combination of both. Most radio propagation model is based on a combination of theoretical predictions and empirical data or measurements.

Theoretical models are based on the physics of the problem of propagation, solving Maxwell's equations and their approximation-equations of geometrical optics. Specifically, the empirical approach is the application of a family of curves and the analytical expressions, which are based on data obtained by measurements and observations.

Empirical models can be divided into two groups, time-dispersive and non time dispersive models. The first type of this model is designed in such a way to provide information on time and multiple scattering in the propagation delay through the channel. An example of this model is the channel model developed at Stanford University by the IEEE (Institute of Electrical and Electronics Engineers), and the Hata and COST-231 Hata model are non time dispersive models.

While the goal of all these models predicted signal strength in a particular destination point or specific area called sector, their approaches, the complexity of the calculations are very different.

PATH LOSS

Radio transmission in mobile communication systems are often carried out in irregular terrain. Profile of the terrain of the area must be taken into account when assessing the losses in free space propagation. It can range from mild to very problematic curved profile of the mountain. Also must be considered and the presence of buildings, trees and other existing obstacles. Today there is accessible to a large number of propagation model to predict losses due to propagation in free space in the irregular terrain.

Most of these models are based on the interpretation of measurement data.

And theoretical considerations and practical measurements indicate that the propagation losses are depending on the distance between the transmitter and receiver and can be represented as:

$$PL = 10\log\frac{P_t}{P_r} = PL\left(d_o\right) + 10n\log\left(\frac{d}{d_o}\right) \qquad (6)$$

Where, *n* is path loss exponent. Parameter value depends on the specific propagation environment. In free-space value of this parameter is 2, while in an environment with obstacles has a higher value.

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2,7 to 3,5
Shadowed urban cellular radio	3 to5
In building line-of-sight	1,6 to 1,8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Tabele 1. Path Loss Exponent for Differente Environments

The disadvantage of this model is that it does not take into account the fact that the areas through which the signal spreads can be significantly different for two different locations at equal distance.

A common model for the variation of mean signal strength is log-normal model. Empirical evidence proves that for any value of the distance, the losses due to propagation of random with a normal logarithmic distribution given in dB:

$$PL = PL\left(d_o\right) + 10n\log\left(\frac{d}{d_o}\right) + X_{\pm} \qquad (7)$$

Where, $X_{\pm}$ is a random variable with Gaussian distribution and zero mean value with standard deviation is also given in dB.

The reference distance d_o must be chosen so that lies in the far field (in practical systems with low gain antenna which is the range of 1 to 2 GHz, typically 1 m in indoors space and 100m or 1km in open environment.)

OKUMURA'S MODEL

Original Okumura propagation model is an empirical propagation model, based on extensive measurements and collected data obtained by measuring in Tokyo, Japan. It is given in the form of graphics and conditional equations.

Okumura model is one of the most commonly used models for prediction signals prediction in urban areas. This model is applied to signals whose range of frequencies is from 150 MHz to 1920 MHz (though in some cases it could be used in practice even for signal frequencies up to 3000 MHz) and the distance of 1 km to 100 km. It is used for antenna positioned at a height of 30 m to 1000 m.

Okumura has defined a family of curves, which determines the high attenuation, relatively, compared to the model of free space in urban areas with an effective base station height of 200 m and height of mobile station of 3 m. These curves were obtained from measurements using the vertical omni-directional antennas as both as base and mobile station, at the distance between the transmitter and receiver in the range of 1 km to 100 km.

In order to determine the path loss using Okumura's model, we must first determine the losses in free space between the desired points, then the value of the middle pad that is relative to the free space that is read from the family of curves, which adds a correction factor to calculate terrain type. The model can be represented by the equation:

$$L_{50}(dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{\mathrm{AREA}} \quad (8)$$

Where, L_{50}, is 50% value of propagation path loss, L_F free space propagation loss, $A_{mu}(f,d)$ Is the median attenuation relative to free space, $G(h_{te})$ Is the base station antenna height gain factor, $G(h_{re})$ Is the mobile station antenna height gain factor and G_{AREA} is the gain due to the type of environment (model makes a difference between three types of environments urban, suburban and rural).

This method allows the prediction of the strength of the received signals without knowing the details of the real signal path between the base station and mobile station. As inputs the model used specific, easily measurable, the general characteristics of the terrain like effective fight of a base station, to wave field, angle of incidence, the parameters of isolated obstacles and water surfaces,

The main disadvantage of this model is the slow reaction to rapid changes in the observed field, because of this model is good in urban and suburban areas. Standard permissible error between predicted and by measured path loss is between 10dB and 14dB.

HATA MODEL

Masaharu Hata has developed a mathematical formula, based on measurements by Okumura, to make the calculation of the field easier. This model was published in the 1980th and has been the most popular model of propagation is derived from which many other models based on additional measurements and theoretical corrections. It works in the frequencies range from 150 MHz to 1500 MHz. Hata model is based on the Okumura's model where some correction factors are included. The standard formula for median path loss in urban areas is given by:

$$L_{50}(urban)(dB) = 69.55 + 26.16\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d \quad (9)$$

Where:

f_c ,is frequencies from 150 MHz to 1500,

h_{te} , effective base station antenna height (30m to 200m),

h_{re} , effective mobile antenna height (1m to 10m),

d , transmitter-receiver distance in km (it should be noted that the simplified Okumura model come to the conclusion that the impairment can be determined only in areas with a maximum distance of 20 km transmission),

$a(h_{re})$, correction factor for effective mobile antenna height which is in the function of the size of coverage area.

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

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8)\text{ dB} \qquad (10)$$

and for a large sity, it is given by

$$a(h_{re}) = 8.29(\log 1.54 h_{re})^2 - 1.1\text{ dB} \text{ for } f_c \le 300\text{MHz} \qquad (11)$$

$$a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.97\text{ dB} \text{ for } f_c \ge 300\text{MHz} \qquad (12)$$

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

$$L_{50}(dB) = L_{50}(urban) - 2\left[\log(f_c/28)\right]^2 - 5.4 \qquad (13)$$

And path loss in open rural areas the formula is modified as

$$L_{50}(dB) = L_{50}(urban) - 4.78(\log f_c)^2 - 18.33\log f_c - 40.98 \qquad (14)$$

While Hata model has no specific path correction available in Okumura's model equations are derived here are of great practical importance. If we compare Hata and Okumura model in terms of prediction values decline, we will see that we get approximately the same size, as long as the distance between the transmitter and receiver greater than 1 km. This model is suitable for use in large cellular mobile radio systems, but not with PCS in which cells are arranged in a radius of 1 km.

COST-231 HATA MODEL

This model is designed by EURO-COST (European Co-operative for Scientific and Technical Research) as an extended version of the basic Hata model. COST-231 Hata model is designed to be used for signals with a frequency range 1500 MHz to 2000 MHz. It also contains a correction factor for urban, suburban and rural environment. Although his band beyond measure, due to correction factors, this model is greatly simplified and can be used to predict the decline outside of this range.

The standard formula for median path loss areas is given by

$$L_{50}(urban) = 46.3 + 33.9\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d + C_M \qquad (15)$$

Where, C_M is a parameter whose value in the case of urban areas is 0dB, while the suburban and rural area is 3 dB, while the correction factor $a(h_{re})$ is given using the equation in original Hata model.

COMPARISON OF PROPAGATIONS MODELS

Using the software package Radio Works comparison of losses due to signal propagation, for different models. The input parameters required by the program as frequency, distance, height of antenna mobile station and antenna height base station. On the dependence graphs for data propagation losses while changing the values some of the input parameters.

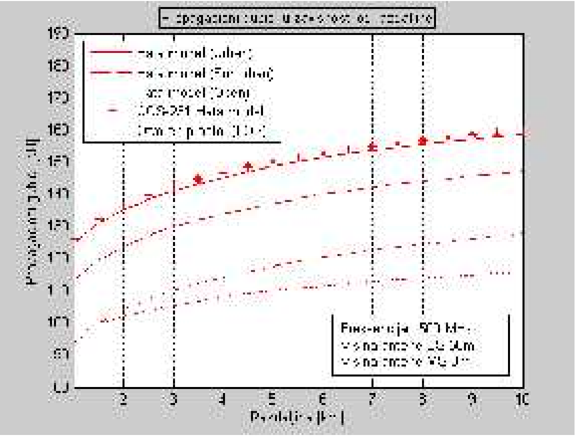

Figure 1. Path loss in function of distance

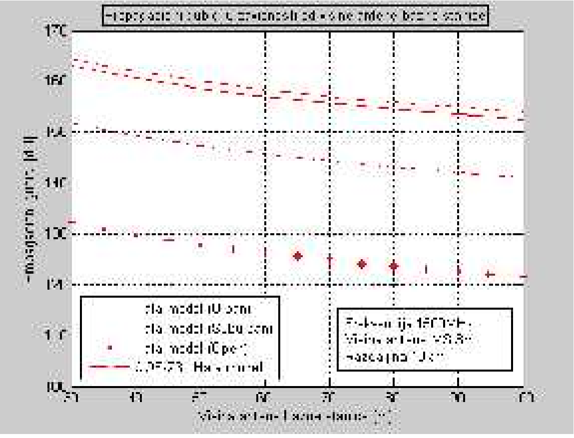

Figure 2.Path loss in function of effective base station antenna height

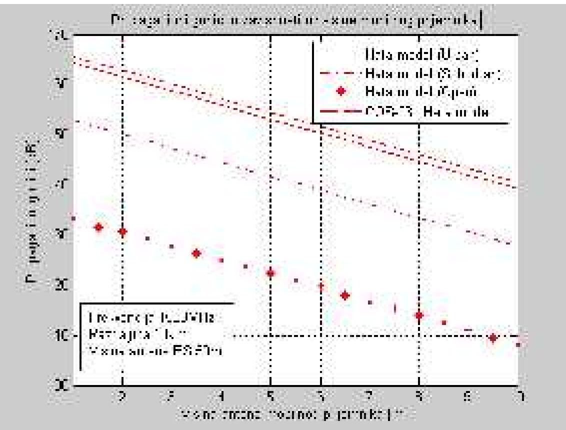

Figure 3. Path loss in function of effective mobile station antenna height

It should be noted that the measurements were made at a frequency of 1500 MHz, and that in case of Hata model propagation losses relating to the cities of medium and small size.

INDOOR PROPAGATION

The field of indoor radio propagation is a relatively new, first appeared in the early 1980s at AT & T Bell laboratory as well as in British Telecom when they first time carefully study losses due to propagation in and around the area with a large number of houses and office buildings .

By continuous development of Personal Communications Systems (PCS), there is a great deal of interest in the introduction of radio systems propagation inside. They are becoming increasingly important for extending voice and data communication services within the workplace. Indoor radio channels are different from standard mobile radio channel in two aspects:

- the area to be covered is much smaller,
- environment variables are much larger for smaller distances between the transmitter and receiver.

Indoor radio propagation is dominated by the same mechanisms as outdoor, such as reflection, diffraction and scattering. However, conditions are much more variable. In general, indoor channels may be classified as line-of-sight (LOS) or obstructed (OBS), with varying degrees of clutter.

PARTITION LOSSES

It was observed that propagation within buildings depends on the special features such as the layout inside the building, construction material and type of building. The buildings have a wide variety in terms of partitions and obstacles that create internal and external structure. Residential buildings, houses, commercial, sports arenas, factory plants are significantly different in its design and materials that are used.

Parts that are formed as part of the structure of the building and which are not insurmountable are called hard partition, while the parts that can move are called soft partition.

Buildings that have fewer metal and hard partitions typically have small delay spreads 30ns to 60ns, while for buildings with large amounts of metal and open space, this phenomenon is even up to 300ns.

PARTITION LOSSES BETWEEN FLOORS

Predicting radio coverage between floors of building has proven to be difficult, but measurements have shown that there are general rules that can by applied. To predict losses, we can use same equation for path loss in free space. Error that can accrue using this model is in the range of 13dB. To reduce the difference between measured values and predictions of losses to about 4 dB, applied to the model that is given by equation:

$$PL(d)[dB] = PL(d_0)[dB] + 10 n_{SF} \log\left(\frac{d}{d_0}\right) + FAF[dB] \quad (16)$$

Where n_{MF} represents the exponent value for the ‘some floor’ measurement. If we have a good approximation of the exponent of loss for a floor, then we can determine the value of the propagation losses on the second floor by adding an appropriate value loss factors between floors (FAF). Alternative version is that in the previous equation loss factor between floors replace the corresponding exponent losses related to a number of floors.

$$PL(d)[dB] = PL(d_0) + 10 n_{MF} \log\left(\frac{d}{d_0}\right) \qquad (17)$$

A large number of telecommunications companies, research laboratories and universities, made a series of practical measurement to collect as much data base related to this phenomenon.Test was performed in San Francisco in three different buildings that lead to the conclusion that the propagation losses between floors increase with number of stories, but also come to the conclusion that after the fifth or sixth floor propagation losses very slightly.Turkmani also observed this phenomenon, except that in his research, decreased at the rate of 2dB per floor from the ground level up to the ninth floor and then increased above ninth floor. Walken was performing measurements of radio signals within fourteen different buildings in Chicago. The measurement results show that losses are reduced penetration in steps of 1.9 dB per floor as seen from the ground floor to the fifteenth floor, and then begin to grow. Devasirvatham, came to the conclusion that losses due to propagation losses inside the building fit into the open air if they are adding additional losses exponentially with increasing distance. Measurements have shown that the percentage of windows was impacts on penetration loss, as does the presence of tinted metal in the windows. Metallic tints can provide from 3 dB to 30 dB attenuation in a single pane of glass.

CONCLUSION

Modeling of wireless channels is the biggest challenge in designing the mobile system. Today there is a great number propagation model to predict losses due to signal propagation in a free and indoor space. While the goal of all these models is predicted signal strength in a particular destination point or specific area called, sector, their approaches, the complexity of the calculations are very different. This paper presents the most important models used in practice.

Recent years, computer and visual capacity of computers is increasing rapidly. New methods for prediction coverage of radio signals are pulled along using standard graphics software package for designing wireless systems within an enclosed space. Or using a system of overhead images or photos of cities by satellite I can use to develop a useful base of 3D data in the event propagation model for prediction of signal strength in free space.

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