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Propagation Characteristics and Modeling Simulation of Signals in Wireless Channels

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Abstract: *This thesis studies the related performance of the hot-research wireless communication systems based on the fading phenomenon of signals in wireless channels, mainly introduces several typical cases of signal fading in the channel, studies the problem of signal attenuation loss, and carries out the Free space propagation Model, the modeling and simulation of the logarithmic path propagation loss model and its modified logarithmic normal shadow path loss model, and analyze the results of these models. In order to realize the construction of a better wireless communication system, according to the analysis of the results of the fading model of the signal in the channel, this thesis also simulates the Okumura model to predict the field strength of different terrains, and combines the correction of the model by Hata to analyze the propagation of radio waves in the wireless channel.*

Keywords: *Path loss, shadow fading, Gaussian random variable, median prediction*

1. Introduction

When the radio wave propagates in the wireless channel, it needs to be transmitted through air or other media whether it is propagating through direct radiation, reflection, refraction or diffraction. And factor such as changes in the field environment, the fading phenomenon of its signal cannot be avoided. It means that the amplitude of the signal has certain fluctuations in time and frequency on the propagation path. This fading phenomenon is mainly caused by factors such as path loss, multipath propagation and the influence of obstacles. Aiming at this phenomenon, this thesis mainly studies the influence of fading on wireless communication, and establishes a relevant simulation model to understand the problem of signal fluctuation during the propagation of radio waves.

According to the range of signal field strength variation between transmitter and receiver, the fading phenomenon of wireless channel can be divided into large-scale fading and small-scale fading. Large-scale fading refers to the change of field strength over a long distance or a long-time range between a transmitter and a receiver. Its propagation model is mainly used to predict the coverage of radio waves, which can be used for the design of wireless communication systems and wireless communication networks, and build a theoretical basis. Small-scale fading refers to the rapid change of the signal field strength in a short distance or a short period of time between the transmitter and the receiver, and it also refers to when the mobile station moves a small distance, the received signal fluctuates rapidly in a short period of time. Among it, large-scale fading includes propagation path loss and shadow fading, and small-scale fading usually refers to multipath effect and Doppler effect. This thesis mainly studies and analyzes large-scale fading, and simulates and builds its related propagation model.

This thesis studies the fading phenomenon of radio waves in wireless channels, establishes propagation models in various typical spaces, and analyzes the propagation loss of signals in the channel. Prediction of the propagation of radio waves in the channel is the basis of wireless communication network planning, so we need to establish an accurate prediction model, it is crucial to the design of wireless communication systems. For example, the Okumura model is one of the most widely used empirical prediction models in urban areas. Combined with Hata 's modification and improvement of this model, the propagation loss in large urban areas with quasi-flat terrain is used as the benchmark, and correction factors are used to improve other areas. The Okumura - Hata model is used to predict the field strength of different terrains, so as to analyze the propagation of radio waves in the actual environment.

2. Free space propagation loss

Radio waves send out signals at the transmitting end. Due to various physical phenomena such as direct radiation, reflection, refraction and diffraction[1] , the signal received at the receiving end is compared with the signal sent by the transmitting end, and the signal presents random changes. The propagation of direct radiation is usually considered in terms of propagation in free space, it means that it propagates in an infinite, isotropic homogeneous medium. Under such ideal conditions, the propagation of radio waves will not be affected by other environmental factors, but the spread of radiation energy is still unavoidable, and the phenomenon of signal amplitude attenuation still exists.

The free-space propagation model is the simplest and most ideal radio wave propagation model， but in the actual situation, the ideal wireless propagation situation does not exist. Usually, the propagation in an isotropic homogeneous medium, and the propagation path is neither affected by obstacles nor reflection and scattering, is regarded as propagation in free space. According to the Frisian transmission formula[2](1), a free-space propagation loss model is established.

$$P_R(d) = P_T G_T G_R (\frac{\lambda}{4\pi d})^2 \tag{1}$$

Among this formula, P_T is the transmit power of the isotropic antenna (unit: w), G_T is the gain of the transmitting antenna, is the gain G_R of the receiving antenna, λ is the wavelength of the transmitted wave (unit: m), and $\frac{\lambda^2}{4\pi}$ is the effective area of the isotropic antenna.

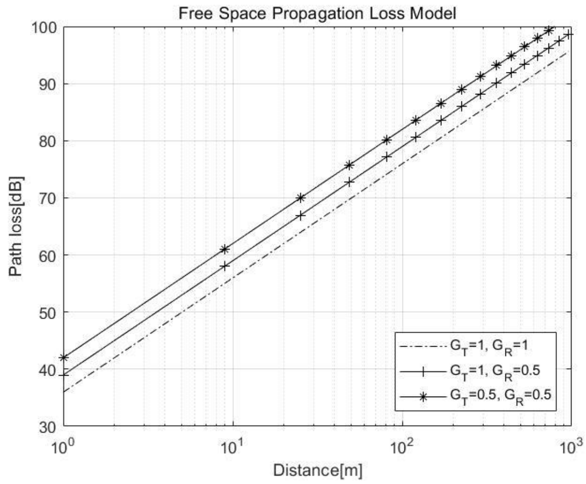

Figure 1: Simulation diagram of free space propagation loss model

The gain of the transmit antenna and the receive antenna are both 0dB, it means that there is no antenna gain ($G_T = 1$, $G_R = 1$), the free-space propagation loss can be simplified as:

$$PL_{fs}[dB] = 10\lg\frac{P_T}{P_R} = 10\lg(\frac{4\pi d}{\lambda})^2 = 20\lg\frac{4\pi d}{\lambda} = 20\lg\frac{4\pi fd}{c} \tag{2}$$

Among this formula, d is the propagation distance (unit: km), f is the operating frequency (unit: MHz).

According to the formula (2), when the propagation environment belongs to the ideal free space state, with the increase of the propagation distance, the propagation loss of the free space increases, and the two are proportional.

According to the simulation diagram of the established free-space propagation loss model, it can be seen that under the condition of constant propagation distance, as the antenna gain increases, the propagation loss also decreases, it means that if increasing the antenna gain, within a certain range of the antenna the signal strength of the antenna increases or the coverage of the signal in a certain direction of the antenna increases. By using smart antenna technology and Massive MIMO technology to improve the coverage and transmission efficiency of wireless communication systems.

3. Logarithmic Path Propagation Loss

In practical situations, an ideal free-space propagation loss model does not exist. When radio waves propagate in the actual space, obstacles in the propagation path will inevitably hinder the propagation of radio waves. There are phenomena such as absorption, reflection, refraction and diffraction of radio waves by obstacles, which will reduce radio waves. The power of a signal, its energy is attenuated, the phenomenon known as shadow fading. The logarithmic path propagation loss obeys the logarithmic normal distribution, and the degree of influence of obstacles on the radio wave is not fixed. To describe the degree of occlusion of obstacles, parameters need to be introduced to describe the changes in this propagation environment, so that the idealized model can be corrected, the introduced parameter is the path loss factor n [3] , and the new logarithmic path propagation loss formula is:

$$PL_{LD}[dB] = PL_{fs} + 10n\lg(\frac{d}{d_0}) \tag{3}$$

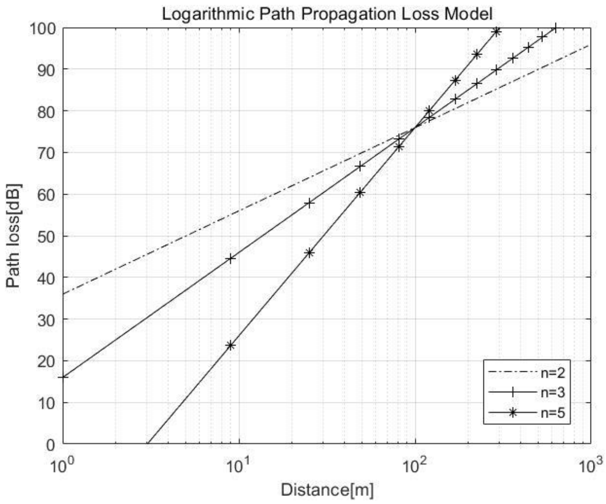

Figure 2: Simulation diagram of logarithmic path propagation loss model

When $n = 2$, the radio waves described above could be considered as propagating in free space. It can be seen from figure 2 that when the path loss factor n remains unchanged, as the propagation distance increases, the propagation loss of radio waves in this environment also increases, and in the process of short propagation distance (within 100m), the smaller the path loss factor, the greater the propagation loss; when the radio wave propagates over a distance of 100 meters, the larger the path loss factor, the greater the propagation loss. Therefore, 100m can be selected as the reference distance. Under this condition, the logarithmic path propagation loss model is consistent with the actual measurement situation.

Table 1: Path loss factor under typical environment [4]

Environment	Path loss factor (n)
free space	2
urban micro-cell	2.7~3.5
urban macro-cell	3.7~6.5
line-of-sight transmission in the building	1.6~1.8
obstruction in the building	4~6
factory	1.6~3.3

In the actual propagation process, because of the fact that the propagation environment passed by radio waves is not fixed, but changes dynamically, and when the environmental medium is not uniform, the position of the radio wave receiver will also affect the medium distribution of the surrounding environment. Therefore, even under the condition of the same propagation distance, different propagation paths will have different propagation losses. The transmission loss of radio waves can no longer be described by the logarithmic path propagation loss model, so the existing model can be modified by introducing a Gaussian random variable X_σ [5] with a mean of zero and a variance of σ^2.

$$PL_{LD}[dB] = \overline{PL} + X_\sigma = PL_{fs} + 10n\lg(\frac{d}{d_0}) + X_\sigma \tag{4}$$

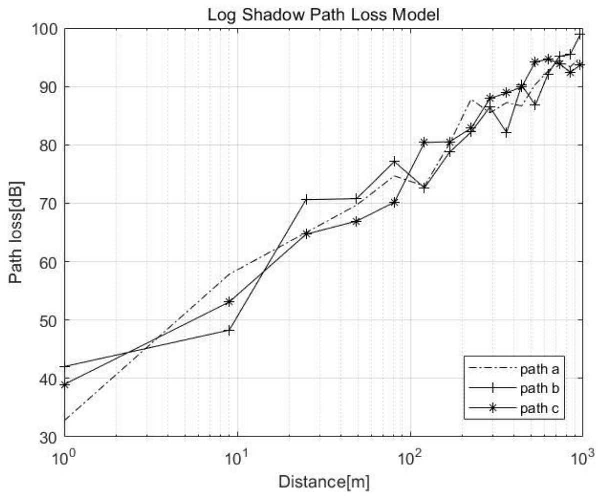

Figure 3: Simulation diagram of logarithmic shadow path loss model

It can be seen from Figure 3 that after superimposing a Gaussian random variable on the basis of the logarithmic path propagation loss model, even under the same propagation distance, it can meet the actual requirement that radio waves have different propagation losses in the propagation process of different paths. Therefore, the established logarithmic shadow path loss model is more applicable in a more realistic actual propagation environment.

Aiming at the phenomenon of shadow fading in the established logarithmic shadow path loss model, macro-diversity technology can be used, that is, multiple base stations are set up in different geographical locations to communicate with the same mobile station in the cell, and the one with the highest communication signal is selected. A good base station for communication can ensure that the signal is not interrupted during communication, but it is necessary to ensure that the number of signals of the base station is sufficient, so that all base stations will not be affected by the phenomenon of shadow fading at the same time. The use of macrodiversit technology can reduce the influence of shadow fading effectively.

4. Radio wave propagation prediction model

Predicting the propagation loss of radio waves can lay a foundation for the design of wireless communication systems and the deployment of wireless communication networks. Okumura et al. taking into account the terrain differences in various regions of Tokyo, conducted a large number of field tests by using different frequencies, antenna heights and test distances, and built the Okumura model based on the experience curve [6] . This model is also popularized in China to predict field strength in urban areas, and it is also widely used in the VHF and UHF frequency bands. The median path loss in the Okumura model is:

$$PL_{OK}(d)[dB] = PL_F + A_M(f,d) - G_{Rx} - G_{Tx} + G_{AREA} \tag{5}$$

Among this formula, $A_M(f,d)$ is the median loss relative to free space when the base station antenna height is 200 meters and the mobile station antenna height is 3 meters, G_{Rx} is the gain of the receiving antenna, G_{Tx} is the gain of the transmitting antenna, and G_{AREA} is the gain of environmental.

Hata model corrects the path loss in suburbs, open areas, large cities and medium and small cities, and builds the Okumura- Hata model [7] . Hata summarizes the formula for the median path loss based on the experience curve of the Okumura model:

$$L_M = 69.55 + 26.16\lg f - 13.82\lg h_b - a(h_m) + (44.9 - 6.55\lg h_b) \times \lg d \quad (6)$$

Among this formula, h_b is the base station antenna height, h_m is the mobile station antenna height, $a(h_m)$ is the mobile station antenna correction factor, and it is related to factors such as the height and distribution of obstacles in the propagation environment.

Correction factor for large city path loss:

$$\begin{aligned} a(h_m) &= 8.29[\lg(1.54h_m)]^2 - 1.1 \qquad 150MHz \le f \le 300MHz \\ a(h_m) &= 3.2[\lg(11.75h_m)]^2 - 4.97 \qquad 300MHz \le f \le 1500MHz \end{aligned} \quad (7)$$

Correction factor for path loss in small and medium cities:

$$a(h_m) = (1.11\lg f - 0.7)h_m - (1.56\lg f - 0.8) \quad (8)$$

Correction factor for suburban path loss:

$$K_s = 2[\lg(\frac{f}{28})]^2 + 5.4 \quad (9)$$

Correction factor for path loss in open areas:

$$K_o = 4.78(\lg f)^2 - 18.33\lg f + 40.94 \quad (10)$$

Within the range of distance d, the Okumura-Hata model has $1 \sim 20\text{km}$ basically the same prediction results as the Okumura model.

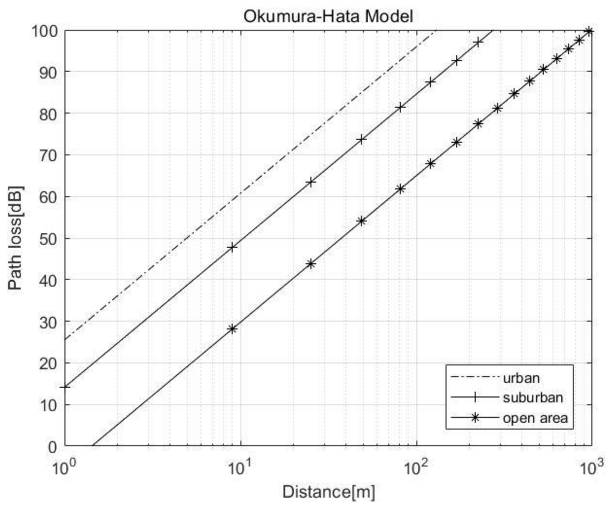

Figure 4: Okumura- Hata model simulation diagram

The European Society for Scientific and Technological Research has extended the Okumura-Hata model to extend the scope of the model to PCS systems, and the applicable frequency reaches 2 GHz.

$$L_M = 69.55 + 26.16\lg f - 13.82\lg h_b - a(h_m) + (44.9 - 6.55\lg h_b) \times \lg d + C_M \quad (11)$$

Among this formula, in mid-sized cities and suburbs, $C_M = 0dB$. In the center of a large city, $C_M = 3dB$.

After the establishment and simulation of the Okumura-Hata model, the simulation results in figure 4 show that under the condition of a certain frequency, with the increase of the distance, the radio wave propagation loss also increases. When the frequency and distance are the same, the propagation loss of radio waves is related to the terrain and the distribution of buildings. The theoretical basis of the Okumura model is consistent.

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5. Conclusion

Through the study of the large-scale fading phenomenon, it is known that the path loss in the large-scale fading is related to the propagation distance, and the shadow fading phenomenon is not only related to the propagation distance, but also related to the distribution of buildings in the propagation environment. According to the research on the free space propagation loss model, the logarithmic path propagation loss model and its modified models, the simulation and comparison of the models are carried out, and the relevant conclusions are drawn. When a radio wave propagates in ideal free space, the greater the propagation distance, the greater its propagation loss in the wireless channel. In shadow fading, the sparser the buildings in the propagation environment, the smaller the propagation loss of radio waves. On the contrary, the denser the buildings are, the greater the propagation loss is. In the process of propagation, even if the propagation distance is the same, However, under different propagation paths, since the distribution of the receiver and the transmitter itself will affect the propagation of radio waves, it is also necessary to consider the limitation of random variables on the propagation model.

Finally, the relevant prediction model of radio wave propagation loss is analyzed, and the modified Okumura-Hata empirical curve correction model is established to lay a foundation for field strength prediction of different terrains. The parameters of the model are easy to obtain, but it does not take into account the height and distribution density of buildings, there is still a partial error between the predicted value and the actual value, while the CCIR model takes into account the influence of the distribution of buildings on the propagation loss, and the COST 231-Walfisch-Ikegami model fully considers the building due to the influence of factors such as density and the height of the transmitting antenna, the accuracy of the prediction of the propagation loss of radio waves has been significantly improved. This thesis analyzes the related problems of propagation loss in wireless communication from the perspective of fading phenomenon, which helps to deeply understand the availability of wireless channels and the choice of transmission technology.

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