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Propagation Path-Loss Prediction Model for 4G Mobile Communication Systems

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***Abstract*- A Statistical-Sakagami model is proposed by using multiple regression formula for path loss prediction in urban and sub urban area. It is assumed that the three main parameters: h_B, W and α are not deterministic variables like those in theory propagation models, but statistical variables, and all the three parameters are varying at the same time in the simulation. The performance of the formula is studied by simulating the probability density functions, cumulative distribution functions, level cross rate and average fade duration. It proposed formula can predict the path loss in urban and suburban areas, and the frequency band is from 0.8GHz to 8GHz, more suitable for the Fourth Generation (4G) Mobile Communication Systems. However, it is not appropriate to apply the multiple regression formula in every urban and suburban area, because the average rooftop level 'h_B', the road width W and the road angle 'α' may be different. The statistical approach can solve above problem, let the formula be used in different areas, but only one parameter is variable in each simulation.**

Keywords*- *Nakagami distribution, Statistical-Sakagami model, Average fade duration, fading statistics, level crossing rate.

1. INTRODUCTION

For several years, the mobile communications sector has definitely been the fastest growing market segment in telecommunications. Due to the complexity of radio transmission in wireless communications, such as irregular terrain, different kinds of buildings, the mobile velocity, climate variety and even the leaves are the factors to cause interference and attenuation in the propagation. So, the most important thing of designing and developing a mobile communication system is to get the knowledge about the characteristics of wireless communication, establish suitable propagation models and modeling the channels.

There are some well-known conventional prediction models such as the Okumura-Hata model [1], COST231-Hata model [2], ITU Terrain Model [3], Egli model [3], and Sakagami model [4]. But there have some deficiencies in these models. For example, The Okumura-Hata model is the most popular and classical model to predict the signal of the urban areas, and the most precise method to predict the path loss of the GSM, CDMA systems, but the response of this model is much slowly to the fast change signal of the suburb area, the error is10 ~14dB, and being a set of curve, it is inconvenience to use. ITU Terrain Model is considered valid for losses over 15 dB and is not applicable to terrains where irregularities are high. Egli Model predicts the path loss as a whole and does not subdivide the loss into free space loss and other losses. COST231 model requires the base station antenna higher than all adjacent rooftops, etc.

Furthermore, ITU-R at the World Radio Communication Conference (WRC'07) has agreed on the spectrum for 4G.450-470 MHz band, 698−862 MHz band, 790−862 MHz band, 2.3−2.4 GHz band, 3.4−3.6 GHz band, and over 100 countries has agreed on 3.4−3.6GHz. But the frequency of conventional models is no more than 3GHz. Koshiro Kitao and Shinichi Ichitsubo proposed a multiple regression formula [5] which is based on the expanded Sakagami model.

This formula can predict the path loss in urban and suburban areas, and the frequency band is from 0.8GHz to 8GHz, more suitable for the Fourth – Generation (4G) Mobile Communication Systems. However, it is not appropriate to apply the multiple regression formula in every urban and suburban area, because the average rooftop level $\boldsymbol{h_B}$, the road width $\boldsymbol{W}$ and the road angle $\boldsymbol{\alpha}$ may be different. The statistical approach [6] can solve above problem, let the formula be used in different areas, but only one parameter is variable in each simulation. The conjunction of the three parameters ($\boldsymbol{h_B}$, $\boldsymbol{W}$, $\boldsymbol{\alpha}$) are estimated at the same time. It will be more close to the real circumstance.

II. FORMULA DESCRIPTION AND ESTIMATION

A. *Multiple Regression Formula*

The multiple regression formula [5] is based on the Expanded Sakagami formula [4].The Expanded Sakagami formula shown in (1).

$$\begin{aligned} Loss &= 100 - 7.1\log W + 0.023\alpha + 7.5\log h_B \\ &-\left\{24.37-3.7\left(h_B/h_b\right)^2\right\}\log\left(h_b\right) \\ &+\left\{43.42-3.1\log\left(h_b\right)\right\}\log d + 20\log\left(f\right) \end{aligned} \quad (1)$$

Where L is the propagation loss [dB], d is the Transmitter-to-receiver distance[m], ***W*** is the road width[m], ***α*** is the road angle [deg], $\boldsymbol{h_B}$ is the average building height[m], $\boldsymbol{h_b}$ is the height of transmitter antenna[m], and ***f*** is the frequency [MHz]. The height of receiver antenna is 1.5m.The multiple regression formula is derived for the prediction formula for urban areas and the formula is verified through a comparison with the Simplified Expanded Sakagami formula.

The prediction formula range is from 0.8 to 8GHz, the distance range is 0.1 to 3 km, and the range in the base station height is from 10 to 100m. In multiple regression formula, h_m is the receiver antenna.

The multiple regression equation is shown in (2).

$$\begin{aligned} Loss &= 42\log(d) - 30\log(h_B) + 21\log(f) + 0.3\alpha \\ &-0.003\alpha^2 - 9\log(W) - 5\log\left(h_m/1.5\right) + 54 \end{aligned} \quad (2)$$

Owing to the tiptop prediction frequency can reach to the 8GHz, this formula is more suitable for the 4G Mobile Communication Systems. The path los of the regression formula is shown in Fig 1.

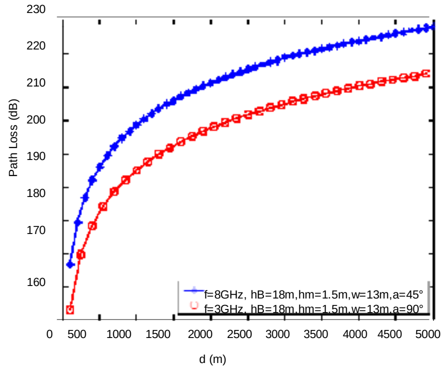

Figure 1.The variation of path loss as a function of ***d***

B. *The Estimation of some parameters in Regression Formula*

The regression formula can predict the path loss for urban areas on 4G frequency. In addition, when pulsed the additional parameter: occupation of buildings, it can be used for suburban areas. However, the circumstances of the regression formula are the buildings height and the street width is fairly uniform and is built in rows with small separation between neighboring buildings. This hypothesis is not corresponding with the real environment. In this study, the variation boundaries of three parameters: $\boldsymbol{h_B}$, ***W*** and ***α*** which vary depending on the areas are evaluated at the same time.

We assume that the parameters of $\boldsymbol{h_B}$, ***W*** and ***α***, in (2), are statistic other than deterministic. Regarding $\boldsymbol{h_B}$ and ***b*** as random variables and using a known statistic distribution to describe them.

The Nakagami distribution function is selected because it can be reduced to Gaussian distribution, Rayleigh distribution, and Rice distribution. The physical characteristics of the buildings and the streets width have these distributions [8].

$$f_X(x) = 2\mu^{\mu}\, x^{2\mu-1}/\Gamma(\mu)\,\omega^{\mu}\, e^{-\mu x^2/\omega} \quad (3)$$

With shape parameter μ and scale parameter $\omega > 1$, for $x > 1$.If x has a Nakagami distribution with parameters μ and Ȧ, then x^2 has a gamma distribution with shape parameter m and scale parameter ω/μ.

If $\mu = 1$, the Nakagami distribution is reduced to Rayleigh distribution, if $\mu = (1+k)^2/2k+1$, the Nakagami distribution is reduced to Rice distribution, and if $\mu \to +\infty$, the Nakagami distribution is reduced to Gaussian distribution.

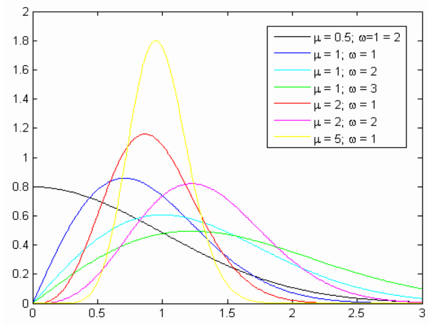

Figure 2. Probability density function for Nakagami distribution

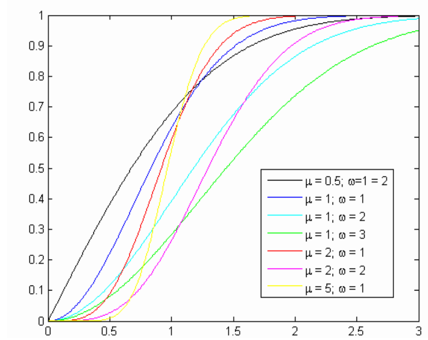

Figure 3. Cumulative distribution function for Nakagami distribution

III. THE SIMULAITON RESULTS

The path loss of the regression formula is simulated at the frequency of 6 GHz. In the simulation, the average rooftop level $\boldsymbol{h_B}$, the road width $\boldsymbol{W}$ and the road angle $\boldsymbol{\alpha}$ are modeled as random variables because these parameters are not constancy at different areas.

Two set of parameters are used in the simulation.

- Fig.4 and Fig.5 depict the PDF and the CDF for the path loss, respectively, when $\boldsymbol{h_B}$ conforms to Nakagami distribution function with the shape parameter $\mu \to +\infty$ and scale parameter $\omega = 1$, $\boldsymbol{W}$ conforms to Nakagami distribution function with $\mu = 1$, $\omega = 1$, and the parameter $\boldsymbol{\alpha}$ is modeled with the uniform distribution function, with the range from 0 to 2π.
- Fig.6 and Fig.7 depict the PDF and the CDF for the path loss, respectively, when $\boldsymbol{h_B}$ conforms to Nakagami distribution function with the shape parameter $\mu = 100$ and scale parameter $\omega = 3$, $\boldsymbol{W}$ conforms to Nakagami distribution function with $\mu \to +\infty$, $\omega = 1$, and the parameter road angle follows the uniform distribution with the range from 0 to 2π.

The parameters h_B, W, and α can choose other values according to the different circumstances.

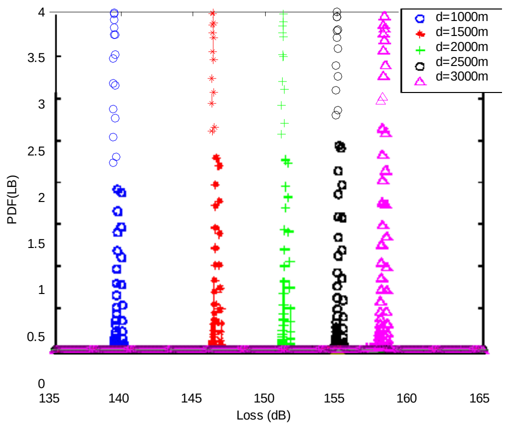

Figure 4. Probability density function for Path Loss

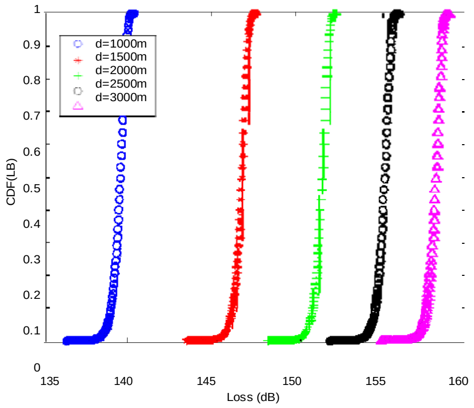

Figure 5. Cumulative distribution function for Path Loss

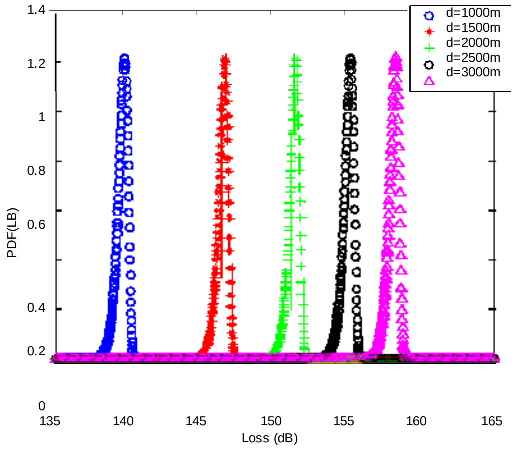

Figure 6. Probability density function for Path Loss

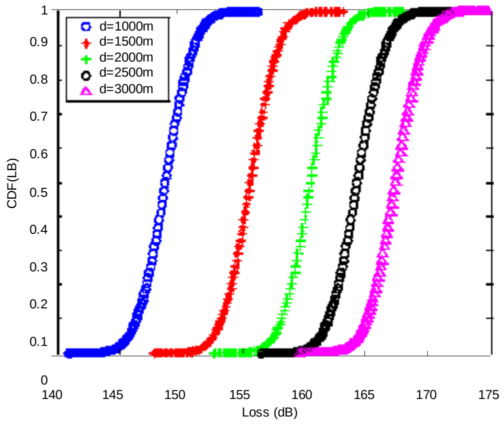

Figure 7. Cumulative distribution function for Path Loss

Apart from the probability density function and the cumulative distribution function, in order to optimize the digital communication systems, which are required for error correction, other characteristic quantities describing the statistics of mobile fading channels are of importance. These quantities are the level-crossing rate and the average duration of fades.

To search for the level-crossing rate and the average duration of fade, it is assumed that the vehicle circles the base station at the rate of 36 kilometers per hour. All three parameters $\boldsymbol{h_B}$, $\boldsymbol{W}$, $\boldsymbol{\alpha}$ are variable at the same time, where, $\boldsymbol{h_B}$ conforms to Nakagami distribution function with the shape parameter $\mu \to +\infty$ and scale parameter $\omega = 1$, $\boldsymbol{W}$ conforms to Nakagami distribution function with $\mu = 1$, $\omega = 1$, and the parameter $\boldsymbol{\alpha}$ is modeled with the uniform distribution function, with the rang from 0 to 2π. Fig. 8 and Fig. 9 Show the level crossing rate and the average duration of fade of the regression formula.

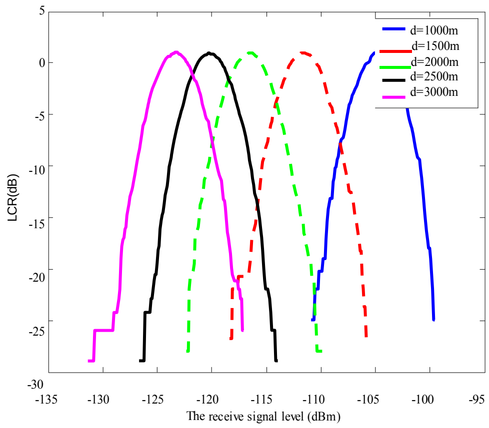

Figure 8. The Level Crossing Rate for the receiving signal

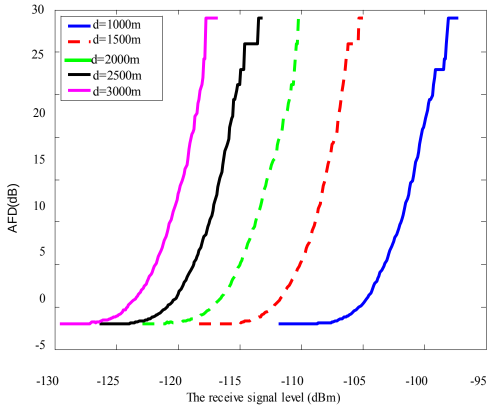

Figure 9. The Average Duration of Fade for the receiving signal

IV. CONCLUSION

This paper proposes statistical method on the multiple regression formula, which can be used to predict the path loss in urban areas and suburb areas. A multiple regression formula is derived for the prediction formula for urban areas and the formula is verified through a comparison with the Simplified Expanded Sakagami formula. As a result of the verification, the forms of the two formula are almost the same; therefore, we propose that the Simplified Expanded Sakagami formula be used as the prediction formula for urban areas. Moreover, the correction formula is examined for suburban areas.

The probability density function and cumulative distributive function, Level Cross Rate and the Average Duration of Fade are studied. Combining the statistical analysis with the regression formula, the developed model is more practicable due to the unnecessary for the precise build-up parameters such as the building heights, building width and the road angles. The statistical method can be applied to the different propagation environment for its statistical parameters. The model introduced in this paper is a useful tool for the design and analysis of data transmission schemes of the 4G mobile communication systems.

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