Nakagami-K Composite Channel Model in Urban-Rural Conjunction Areas

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***Abstract*—With the speeding construction process of urbanization in china, the areas with the characteristic of typical urban-rural conjunction gradually increase. Since residential areas, factory areas, farmlands are scattered randomly, varied and complex wireless communication environment is formed. Considering the power wireless communication network planning demands and radio propagation predictions in urban-rural conjunction areas, this paper established a Nakagami-K composite channel model based on combination of the Nakagami distribution and K-distribution. In this paper, we analyzed envelope distribution characteristics of the model, described the flowchart of the parameter estimation algorithm, and derived expressions of level crossing rate and average fading durations. We verified the validity and accuracy of the improved model according to the measured data and applied the improved model to Chongqing power wireless communication network planning and design.**

Keywords-component; nakagami-k distribution; composite channel model; nakagami distribution; k-distribution; urban-rural conjunction areas

I. INTRODUCTION

Radio waves will be affected by various obstacles occlusion, absorption, reflection, diffraction and scattering during the propagation process. Therefore, it is very necessary to study wireless channel transmission characteristics to analyze the various factors that affect the radio waves propagation for constructing an accurate and reasonable channel model to provide guidance to improve the performance of wireless communication systems.

With the speeding construction process of urbanization in china, the areas with the characteristic of typical urban-rural conjunction gradually increase. Since residential areas, factory areas, farmlands are scattered randomly, varied and complex wireless communication environment is formed. Urban-rural conjunction areas are characterized by multi-scenes, wide distribution, strong dispersion and so on [1].In the urban-rural conjunction areas, the received signal envelope is complex, which is composed of the fast variable components caused by the multipath effect, and the slow variation component caused by the shadow effect. Single channel model cannot accurately describe the channel propagation characteristics in the areas. Existing complex channel models based on Rayleigh-Lognormal and Nakagami-Lognormal distributions are also difficult to adapt to the complexity of urban-rural conjunction areas.

In this paper, we established a Nakagami-K composite channel model by combining the Nakagami distribution and the K-distribution, considering the power wireless communication network planning demands and radio propagation predictions in urban-rural conjunction areas. At the same time, we analyzed the envelope distribution characteristics of the model, and explained the flowchart of parameter estimation algorithm, and derived the level crossing rate and the average fading duration. We verified the validity and accuracy of the improved model according to the measured data and applied the improved model to Chongqing power wireless communication network planning and design.

II. NAKAGAMI DISTRIBUTION AND K-DISTRIBUTION

A. Nakagami Distribution

In the channel model based on Nakagami distribution, by adjusting the fading factor *m*, it can describe the characteristics of severe, moderate, mild and flat fading channel, and has higher flexibility and wider adaptability [2]. The channel model based on the Nakagami distribution obtains its approximate distribution by the measured data and the probability density function based on the variable parameter Gamma distribution to fit the channel [3]:

$$p(r)=\frac{2}{\Gamma(m)}(\frac{m}{\Omega})^m r^{2m-1}e^{-\frac{m}{\Omega}r^2},r\geq 0 \tag{1}$$

where $\Gamma(m)=\int_0^\infty x^{m-1}e^{-x}dx$ denotes complete Gamma function, second-order central moment $\Omega=E[r^2]$ denotes average power of scattered field, fading factor $m=\Omega^2/E[(r^2-\Omega)^2]\geq 0$ denotes the degree of signal envelope fading caused by the distribution of the scattering body and the multipath effect. The lower the m value is, the more serious the channel fading is.

B. K-Distribution

K-distribution is proposed by Jakeman and Pusey [4] and widely used in the fields of radar, communication, optical communication, remote sensing and remote sensing [5]. Probability density function of the received signal envelope r with K-distribution is given by

$$p(r) = b^{v+1} r^{v} K_{v-1}(br) / (2^{v-1}\Gamma(v)), 0 \le r < \infty \tag{2}$$

where $K_{v-1}(\cdot)$ denotes Bessel functions of the second kind, v denotes form factor, b denotes scale factor, and $P = 4v / b^2$ denotes average power.

In the K-distribution, the received signal envelope is the product of two factors: speckle component (fast variable component) and basic amplitude modulation component (slow variable component). The speckle component is subject to Rayleigh distribution, which is composed of a large number of scattered reflections. The basic amplitude modulation component obeys Γ distribution, which reflects the average level of the scattered beam.

III. NAKAGAMI-K COMPOSITE CHANNEL MODEL

A. Envelope Distribution Characteristic

The Nakagami-K composite channel model is constructed based on the Nakagami distribution and K- distribution, and the received signal envelope can be expressed by the product of the Nakagami distribution signal envelope $X(t)$ and the K-distribution signal envelope $Y(t)$:

$$R(t) = X(t) \cdot Y(t) \tag{3}$$

Assuming that the stochastic processes $X(t)$ and $Y(t)$ are independent of each other, then the probability density function can be expressed as

$$p_{N-K}(r) = p_N(x) \cdot p_N(y) = \int_0^{\infty} \frac{1}{y} p_N(\frac{r}{y}) \cdot p_K(y) dy \tag{4}$$

where Nakagami distribution probability density function $P_N(x)$ denotes fast variable component caused by multipath effect in the received signal envelope, K-distribution probability density function $P_K(y)$ denotes slow variable component caused by shadow effect in the received signal envelope. Combined with the probability density function of two kinds of distribution, the formula (4) is rewritten as

$$p_{N-K}(r) = \frac{b^3 r^2}{\Gamma(v) \cdot \Gamma(m)} \left(\frac{m}{\Omega}\right)^m \int_0^{\infty} K_{v-1}(\frac{br}{y}) \cdot \exp(\frac{-my^2}{\Omega}) \cdot y^{2m-1} dy \tag{5}$$

B. Parameter Estimation

The usual method for parameter estimation of the channel model is the maximum likelihood method [6]. However, due to the high complexity of solving the transcendental equation based on the parameters to be estimated, this paper uses the method of moments [7] to estimate the parameters m, v, b of the Nakagami-K composite channel model. First, the fading factor m is estimated, and the k-order moment of the Nakagami-K composite channel model is

$$\mu_k = \mathrm{E}[R^k] = \frac{\Gamma(m + k/2)}{\Gamma(m)} \left(\frac{\Omega}{m}\right)^{k/2} \tag{6}$$

Using Iterative characteristic of Gamma function, the ratio of μ_4 to μ_2 can be obtained as below

$$\frac{\mu_4}{\mu_2} = (m+1)\left(\frac{\Omega}{m}\right) \tag{7}$$

Using the INV method [8], the estimation of fading factor m can be derived as

$$\hat{m} = \hat{\mu}_2^2 / (\hat{\mu}_4 - \hat{\mu}_2^2) \tag{8}$$

where $\hat{\mu}_k$ denotes k-order moment of the received signal envelope. In this paper, the form factor v and scale factor b are still estimated by the method of moments. Form factor is estimated by the following equation

$$C_1 F^2(\frac{3}{2};1;\hat{v}) F(3;1;\hat{v}) = C_2 F^3(2;1;\hat{v}) \tag{9}$$

where $C_1 = \Gamma^2(3/2)\hat{\mu}_2 / 2\hat{\mu}_1^2$, $C_2 = \hat{\mu}_4 / 4\hat{\mu}_2^2$, $F(\cdot)$ denotes confluent hyper-geometric function. Estimating $\hat{v}$ by numerical search, define the following functions

$$f(\hat{v}) = C_1 F^2(\frac{3}{2};1;\hat{v}) F(3;1;\hat{v}) \tag{10}$$

$$g(\hat{v}) = C_2 F^3(2;1;\hat{v}) \tag{11}$$

Selecting the real number $L < H$, so that it meets the following inequality

$$(f(L) - g(L))(f(H) - g(H)) < 0 \tag{12}$$

Figure I shows the flowchart of iterative search algorithm for form factor estimation. The estimation of scale factor b is similar to that. If $|f(L) - g(L)| \le \varepsilon$ (ε is small enough positive real number) or if $|f(M) - g(M)| \le \varepsilon$, then correspondingly $\hat{v} = L$ or $\hat{v} = H$ .Otherwise, generating a new real number $M = (L+H)/2$. If $|f(M) - g(M)| \le \varepsilon$, then $\hat{v}=M$. Otherwise, judging whether to meet $(f(L)-g(L))(f(M)-g(M))>0$. If satisfied, let $L=M$ and repeat search process. Otherwise, let $H=M$ and repeat search process until suitable $\hat{v}$ is generated.

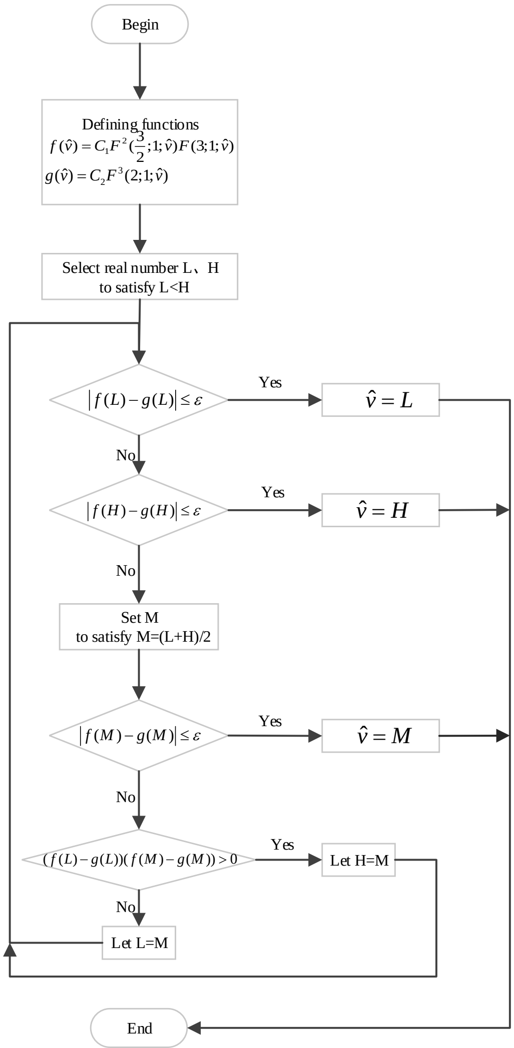

FIGURE I. FLOW CHART OF PARAMETER ESTIMATION ITERATION ALGORITHM

C. Level Crossing Rate and Average Fading During

Crossing during rate (LCR) and average fading during (AFD) are the most important second-order statistics describing channel fading characteristics. In order to derive the LCR and AFD of the Nakagami-K composite channel model, we should calculate the joint probability density function $p_{N-K}(r,\dot{r})$ of signal envelope $R(t)$ and the derivative $\dot{R}(t)$ of signal envelope.

$$\begin{aligned}
p_{N-K}(r,\dot{r}) = {} & \int_0^\infty\int_{-\infty}^\infty \frac{2}{\Gamma(m)}(\frac{m}{\Omega})^{\frac{2m-1}{2}}\frac{r^{2m-1}}{y^3}\frac{2}{\Gamma(m)}(\frac{m}{\Omega})^{\frac{2m-1}{2}}\frac{r^{2m-1}}{y^3}\cdot \\
& \exp(-\frac{mr^2}{y\Omega}-\frac{2m\cdot(y\dot{r}-\dot{y}r^2)}{y^2\Omega\phi''(0)})\frac{1}{\sqrt{2\pi\cdot\phi''(0)}}\cdot \\
& \frac{2v^{v+\frac{1}{2}}y}{\pi\kappa(\sqrt{P/k})^{v+\frac{1}{2}}\sqrt{\beta\psi''(0)}}\cdot\int_0^\infty\frac{\sqrt{\pi}\xi^{2v-4}}{\sqrt{\frac{y^2}{2\beta\xi^4}+\frac{2v}{\sqrt{P/k}\psi''(0)}}}\cdot \\
& \left[-\frac{1}{2\xi^2}\left(\frac{y^2}{\kappa}+\frac{\dot{y}^2}{\beta}\right)-v\frac{\xi^2}{\sqrt{P/k}}+\frac{y^2\cdot\dot{y}^2}{2y^2\beta\xi^2+\frac{8v\beta^2\xi^6}{\sqrt{P/k}\psi''(0)}}\right]d\xi d\dot{y}dy
\end{aligned} \tag{13}$$

According to the definition, the LCR and AFD of Nakagami-K composite channel model can be obtained as below

$$\begin{aligned}
N_R = {} & \int_0^\infty\int_{-\infty}^\infty\int_0^\infty\frac{2}{\Gamma(m)}(\frac{m}{\Omega})^{\frac{2m-1}{2}}\frac{r^{2m-1}}{y^3}\exp(-\frac{mr^2}{y\Omega}-\frac{2m\cdot(y\dot{r}-\dot{y}r^2)}{y^2\Omega\phi''(0)})\cdot \\
& \frac{1}{\sqrt{2\pi\cdot\phi''(0)}}\frac{2v^{v+\frac{1}{2}}y}{\pi\kappa(\sqrt{P/k})^{v+\frac{1}{2}}\sqrt{\beta\psi''(0)}}\int_0^\infty\frac{\sqrt{\pi}\xi^{2v-4}}{\sqrt{\frac{y^2}{2\beta\xi^4}+\frac{2v}{\sqrt{P/k}\psi''(0)}}}\cdot \\
& \left[-\frac{1}{2\xi^2}\left(\frac{y^2}{\kappa}+\frac{\dot{y}^2}{\beta}\right)-v\frac{\xi^2}{\sqrt{P/k}}+\frac{y^2\cdot\dot{y}^2}{2y^2\beta\xi^2+\frac{8v\beta^2\xi^6}{\sqrt{P/k}\psi''(0)}}\right]\cdot\dot{r}d\xi d\dot{y}dyd\dot{r}
\end{aligned} \tag{14}$$

$$T_R=\frac{\int_0^R\frac{b^3r^2}{2\Gamma(v)}\left(\frac{m}{\Omega}\right)^{\frac{1}{2}}\int_0^\infty K_{v-1}(\frac{br}{s})\cdot\exp(\frac{-my^2}{\Omega})\cdot y^{2m-1}dydr}{\begin{aligned}&\int_0^\infty\int_{-\infty}^\infty\int_0^\infty\frac{r^{2m-1}}{y^3}\exp(-\frac{mr^2}{y\Omega}-\frac{2m\cdot(y\dot{r}-\dot{y}r^2)}{y^2\Omega\phi''(0)})\cdot\\&\frac{1}{\sqrt{2\pi\cdot\phi''(0)}}\frac{2v^{v+\frac{1}{2}}y}{\pi\kappa(\sqrt{P/k})^{v+\frac{1}{2}}\sqrt{\beta\psi''(0)}}\int_0^\infty\frac{\sqrt{\pi}\xi^{2v-4}}{\sqrt{\frac{y^2}{2\beta\xi^4}+\frac{2v}{\sqrt{P/k}\psi''(0)}}}\cdot\\&\left[-\frac{1}{2\xi^2}\left(\frac{y^2}{\kappa}+\frac{\dot{y}^2}{\beta}\right)-v\frac{\xi^2}{\sqrt{P/k}}+\frac{y^2\cdot\dot{y}^2}{2y^2\beta\xi^2+\frac{8v\beta^2\xi^6}{\sqrt{P/k}\psi''(0)}}\right]\cdot\dot{r}d\xi d\dot{y}dyd\dot{r}\end{aligned}} \tag{15}$$

IV. SIMULATION RESULTS

The performance of Nakagami-K composite channel model is verified by comparing the cumulative distribution function (CDF) and, AFD, LCR of the model data and the measured data [9]-[11].

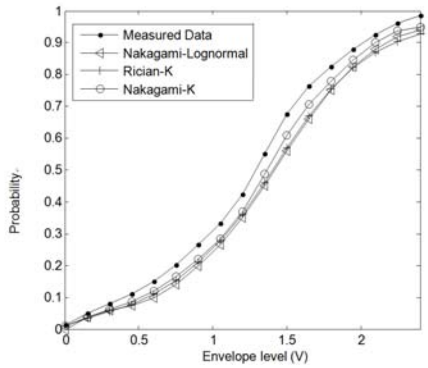

FIGURE II. CDF COMPARISONS BETWEEN SAMPLE DATA SET IN URBAN-RURAL CONJUNCTION AREAS

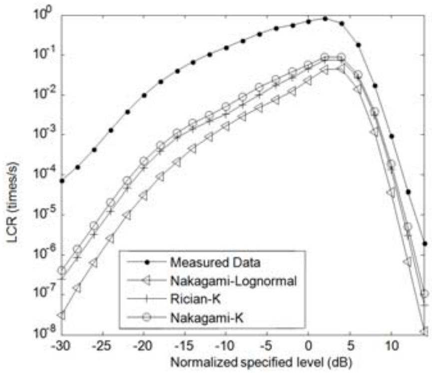

FIGURE III. LCR COMPARISONS BETWEEN SAMPLE DATA SET IN URBAN-RURAL CONJUNCTION AREAS

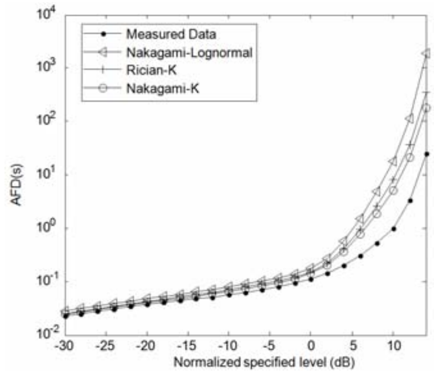

FIGURE IV. AFD COMPARISONS BETWEEN SAMPLE DATA SET IN URBAN-RURAL CONJUNCTION AREAS

The Nakagami-lognormal model, Rician-K model and Nakagami-K model are compared and verified. Figure Ⅱ respectively demonstrate the results of CDF fitting for sample data set. From the figure we can see that the Nakagami-K model has a better fitting result on the sample data set which contain the multipath fading and shadow fading, which verifies the validity of the Nakagami-K model. The fitting results of AFD and LCR are respectively shown in figure Ⅲ and figure Ⅳ. From the figure we can see that the fading characteristics of Nakagami-K model are more close to the measured data than other models. This is due to the sample data set contain multipath fading and shadow fading components, while the Nakagami distribution and K-distribution have a good fitting performance for multipath fading and shadow fading respectively.

TABLE I. AVERAGE AND STANDARD DEVIATION OF DIFFERENCE BETWEEN CHANNEL MODELS AND SAMPLE DATA SET

Channel model type	***CDF***		***LCR (times/s)***		***AFD (s)***	
	μ	σ	μ	σ	μ	σ
Nakagami-Lognormal	0.0573	0.0297	54.1	17.6	0.0040	0.0051
Rician-K	0.0543	0.0262	37.7	11.6	0.0026	0.0035
Nakagami-K	0.0367	0.0175	33.9	9.9	0.0020	0.0026

Table I show average and standard deviation of difference between theoretical value of three kinds of composite channel model and sample data set. As can be seen from the tables, the average and standard deviation of Nakagami-K are the smallest, which shows the best agreement with the measured data, so the performance is the best. Nakagami-Lognormal model is the worst. This is due to that the main features of urban-rural conjunction areas are moderate shadow fading and the scattered bodies have the low height, the random distribution and the asymmetrical shape. At this time, the K-distribution is more suitable than the log normal distribution.

V. CONCLUSION

In this paper, we constructed a Nakagami-K composite channel model based on combination of the Nakagami distribution and K-distribution, considering the power wireless communication network planning, base station location and frequency allocation demands in urban-rural conjunction areas. We analyzed the envelope distribution characteristics of the model, and explained the flowchart of parameter estimation algorithm, and derived expressions of the level crossing rate and average fading duration. We verified the validity and accuracy of the improved model according to the measured data and applied the improved model to Chongqing power wireless communication network planning and design.

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