# A study of BER Performance of OFDM Modulation in Multi-fading Channel

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***Abstract*—**The diversity and complexity of Multipath fading can influence performance of the Orthogonal Frequency Division Multiplexing (OFDM) modulation. The system performance analysis is based on correct design of a channel model. According to system characters of OFDM, a frequency selective slow fading channel model is built up, by combining the Trapped delay line model and the slow fading characters, such as the Rayleigh, Rician or Nakagami distribution. The theoretical Bit Error Rate (BER) of OFDM system under this channel model is deduced based on the BER or Symbol Error Rate of MQAM under Additive White Gauss Noise (AWGN) channel and the Probability Density (PDF) Function of different slow fading channel. The applicability of this channel model and the System BER performance under different slow fading channel is verified by simulation. The results indicate that the simulation result is consistent with the theoretical analysis under MQAM modulation method, which illustrates that the frequency selective slow fading channel model is suitable for the performance analyzing of OFDM system.

***Keywords***- *Orthogonal Frequency Division Multiplexing (OFDM); Multipath fading; frequency selective fading; Trapped delay line (TDL) model; Bit Error Rate (BER)*

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## INTRODUCTION

The current wireless communication technology is developing in the direction of high quality, high speed, high spectrum utilization and high reliability [1]. However, in the wireless communication environment, the channel environment is more diverse and complex [2],as the signal in the process of propagation is occluded, absorbed, reflected, refracted or diffracted caused by the various objects, the receiver can receive a number of path signals components, whose superimposition may produce severe multipath fading [1]. Orthogonal frequency division multiplexing (OFDM), as a multi-carrier modulation technique [3] [4], can solve the problem of frequency selective fading under multipath fading, improve the quality of information transmission and bandwidth. It is important to study the error rate performance of OFDM modulation technology under different multipath fading channel characteristics for analysis of the overall performance of OFDM system.

On a worldwide scale, BER performance of the flat fading OFDM system has been studied relatively in-depth. For example, the BER performance of the MFSK in the Lace fading channel and the Rayleigh fading channel is studied in [5]; [6] proposes a Nakagami fading simulation model based on channel decomposition and harmonic superposition. In [7 ~ 10], the BER performance of a variety of digital modulation in the Nakagami fading channel is studied. In [11], the performance of QPSK-based OFDM systems under Rayleigh multipath fading channel is studied. In [12], the BER performance of DPSK and PSK-based OFDM systems over flat fading channels is studied. The BER performance of the OFDM system using BPSK and QPSK in the Nakagami fading channel is studied in [13] .In summary, previous studies have analyzed the performance of OFDM modulation over narrowband or flat fading channels, On this basis, in this paper, the error bit rate performance of OFDM modulation technology under broadband channel or frequency selective channel is analyzed, and the performance of OFDM modulation technology under frequency selective channel model is analyzed and studied by simulating.

The structure of the article is as follows: Section 2 discusses the classification of multipath channel and establishes the channel model suitable for the technology according to the characteristics of OFDM modulation. Section 3 gives the theoretical derivation of BER performance of OFDM modulation technology under different slow fading characteristics. Section 4 has carried on the simulation research, and has carried on the analysis to the result, finally draws the conclusion.

## ESTABLISHMENT OF MULTI - PATH FADING CHANNEL AND OFDM SYSTEM CHANNEL MODEL

In this section, by discussing the classification of wireless fading channels, the applicable channel model is selected according to the characteristics of OFDM modulation technology, and the theoretical error bit rate expression of OFDM modulation technology under different fading channels is analyzed.

### *Fading channel classification*

According to the characteristics of channel fading, wireless communication fading channel classification shown in Figure 1 [14].

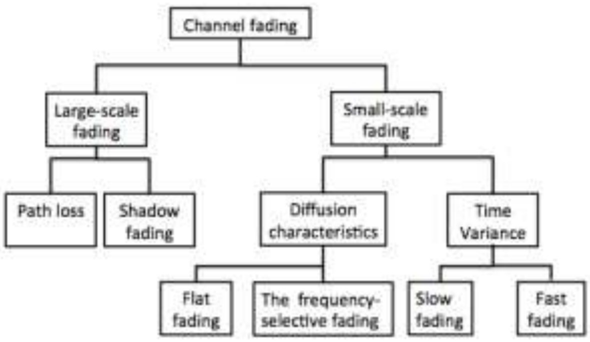


Figure 1. Classification of wireless communication fading channel types

The signal attenuation at the receiving end caused by the blocking of the mountains, buildings and other surfaces of the transmitted signal, is called large-scale fading. The signal level fluctuation caused by the wireless signal after multiple refraction, reflection, scattering superposition, or transmission medium change, receiving antenna movement, is called small-scale fading [2][15] [16]. Since the large-scale fading rate of these two factors is slow to change, it can be regarded as no change in a frame signal [14] [16], and thus this paper focus on small scale fading channels.

According to the dispersion characteristic of the channel, if the coherent bandwidth of the channel is much larger than the signal bandwidth, it is flat fading, or frequency nonselective fading, otherwise frequency selective fading [14] [16].Because the channel has time-varying characteristics, if the coherence time of the channel is much longer than the duration of a signal symbol, the channel fading type is slow fading, otherwise fast fading. Channel fast fading will lead to serious distortion of the baseband signal, resulting in higher Error bit rate problem [14] [16].

*The channel model establishment according to the OFDM feature*

According to the [1] and [14], in the general OFDM system, the channel coherence time is much longer than the OFDM symbol duration, the channel fading can be assumed to be stable and slowly change, which channel presents quasi-static. Therefore the channel can be classified as a slow fading channel.On the other hand, the channel coherence bandwidth of the OFDM system is much smaller than the total transmission bandwidth, which is superimposed by multiple subcarriers, and it can be considered that the channel belongs to the frequency selective fading channel. Therefore, it is assumed that the OFDM system signal is transmitted in a frequency selective slow fading channel.

However, for OFDM modulation techniques, the channel-related bandwidth is often greater than the bandwidth of an OFDM subcarrier. Therefore, when OFDM modulation techniques are applied, the frequency selective slow fading channel can be transformed into a combination of several flat slow fading channels, and then analyze frequency selective channel characteristics in-depth [14 ~ 17]. The flat slow fading channel model is the easiest to analyze, and it is also the basis for establishing a frequency selective channel [14]. Therefore, we need to discuss flat slow fading channel modeling, and then analyze the frequency selective slow fading channel modeling.

Flat slow fading channel model

The low-pass equivalent signal passed over flat slow fading channel SL (T) can be described as [14][16]:

$$r_l(t)=c(t)s_l(t)+z(t) \tag{1}$$

In this case, $c(t)=a(t)e^{jf(t)}$ is a complex stochastic process with channel characteristics (or equivalent complex low-pass impulse response), $\alpha(t)$ is the amplitude characteristic of the channel fading, $f(t)$ indicates the phase characteristic of the channel fading, $z(t)$ is the additive complex Gaussian white noise.

The signal flow described in equation (1) is shown in Fig. 2 [14].

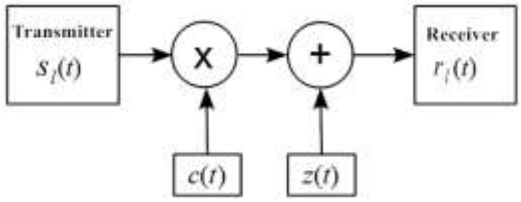


Figure 2. Flat slow fading channel model

According to the [15], the probabilistic statistical properties of multipath fading channels are usually modeled by Rayleigh fading, Rician fading, Nakagami fading (or Nakagami-m fading). When the number of scattering paths received by the receiver is large, the Gaussian process model [15], i.e. c (t), can be obtained by applying the central limit theorem. If the Gaussian process is zero mean, it is Rayleigh fading channel, which is more suitable for modeling with urban wireless multipath channel. If there is a more obvious direct path (LOS, Line of Sight), then the stochasticprocess is non-zero, for the fading channel, more suitable for rural wireless multipath channel modeling. The Nakagami channel model is more flexible and accurate to match the statistical data of the observed signals, which is best for suburban wireless multipath channel modeling [15].

In the Rayleigh channel,$c(t)$ is a zero mean complex Gaussian stochastic process, $\phi(t)$obeys a uniform distribution over (-π, π),$\alpha(t)$for the determined time t obey the Rayleigh distribution. The probability density function is:

$$p_\alpha(\alpha)=\frac{2\alpha}{\Omega}e^{-\frac{\alpha^2}{\Omega}}, \quad \alpha\ge 0 \tag{2}$$

Among them, $\Omega=E(\alpha^2)$.

In the Rician, channel, φ (t) obeys the even distribution over (-π, π), α (t) for the determined time t value is obeyed by the Rician distribution, and its probability density function is:

$$p_\alpha(\alpha)=\frac{\alpha}{\sigma^2}e^{-\frac{\alpha^2+A^2}{2\sigma^2}}I_0(\frac{\alpha A}{\sigma^2}), \quad \alpha\ge 0 \tag{3}$$

Among them, $I_0(z)$is the first class Bessel function, $A\ge 0$ is the distance from the reference point to the center point of binary distribution, $\sigma\ge 0$ is the scale factor. The ratio of the sum of the direct path power and the sum of the other non-direct path powers is $K_r=A^2/(2\sigma^2)$ [17]. The variance of the random variable α of Rician distributionis

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$\Omega=\mathrm{E}\left(\alpha^2\right)=2\sigma^2+A^2$ . Substituting $\Omega$ and $K_r$into Eq. (3) yields:

$$p_\alpha(\alpha)=\frac{2(K_r+1)\alpha}{\Omega}e^{[-K_r-(K_r+1)\frac{\alpha^2}{\Omega}]}I_0(2\sqrt{\frac{K_r(K_r+1)}{\Omega}}\alpha) \tag{4}$$

If the channel is Nakagami channel, φ (t) obeys the uniform distribution over (-π, π), α (t) is the Nakagami distribution for the determined time t value, and its probability density function is [16]:

$$p_\alpha(\alpha)=\frac{2m^m\alpha^{2m-1}}{\Gamma(m)\Omega^m}e^{-m\alpha^2/\Omega},\ \alpha\geq 0 \tag{5}$$

Where $\Gamma$ is a Gamma function, m is the fading parameter, and $m \geq 1/2$ indicates the depth of fading. When m = 1, the Nakagami channel is equivalent to the Rayleigh channel. When $1/2<m\leq 1$,the fading of the Nakagami channel is severer than the Rayleigh channel. When m> 1, the Nakagami channel is similar or equivalent to the Lace channel [14][

Frequency selective slow fading channel model

The most commonly used technique for converting a frequency-selective slow fading channel into asynthesis of several flat slow fading channels is the trapped delay line (TDL) model. Using the TDL model and the flat slow fading channel model, we can get the frequency selective slow fading channel model [2] [14] [16]. The TDL model can describe synthesis of several flat fadingchannelswhich have a relative delay, independent of each other and each have a fixed average power.The TDL model equates a large number of multipath components with several multipath components with relative time delays. Each multipath component is modeled by a flat slow fading channel model. The power ratio of each multipath component is determined by the power delay profile (PDP) [14] [16] [17].

The most commonly used broadband TDL model is the L-tap Rayleigh-fading model [17]. L is the number of Rayleigh flat fading paths. The simulation is based on this model, and on this basis LOS is added, which makes the model suitable for Rician and Nakagami frequency selective slow fading channels. The impulse response of the TDL model system is:

$$h(t)=a_0\delta(t-t_0)+\sum_{k=1}^{L}c_k(t)\delta(t-t_k) \tag{6}$$

The gain $a_0$ of the LOS portion of the relative delay $t_0$ is a fixed value and gain of the other path of the relative delay $t_k$ is a zero mean complex Gaussian stochastic process [17]. In most cases, $\tau_0=\tau_1$ [17].When $\alpha_0=0$,this model is applicable to Rayleigh multipath fading channels. When $\alpha_0\neq 0$ , this model was applied to Rician or Nakagami multipath fading channels.In order to reduce the complexity of the model,and simulate easily, the delay of the PDP is set as an integer multiple of *1/W*. *W* is the bandwidth of the low pass equivalent transmit signal $s_l(t)$, which is the bandwidth of an OFDM signal in the OFDM system. Thus, $\tau_k=k/W$ $k$ = 1, 2 ... *L*. The model structure is shown in Fig.3

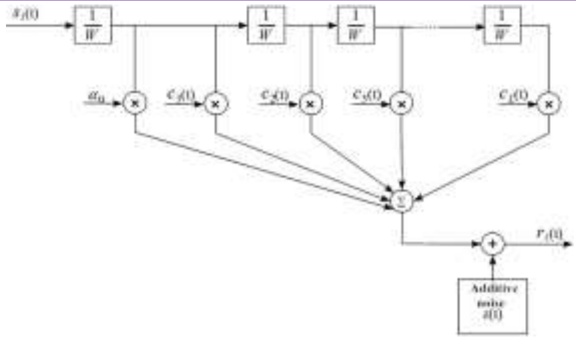



Figure 3. Model of frequency selective channel

According to Figure 3, the equivalent received signal can be described as:

$$r_l(t)=\alpha_0 s_l\left(t-\frac{1}{W}\right)+\sum_{k=1}^{L}c_k(t)s_l\left(t-\frac{k}{W}\right)+z(t) \tag{7}$$

Where $c_k(t)=\alpha_k(t)e^{j\phi(t)}$, $k$=1, 2, …$L$， $\alpha_k(t)$ is the Rayleigh distribution of random processes, *z(t)* is complex Gaussian white noise.

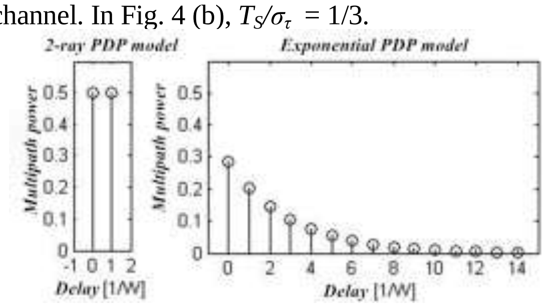
In addition, the average power of the individual paths of the frequency selective fading channel model can be assigned according to the PDP, i.e. the parameters of each non-direct path are determined by the PDP:

$$\Omega_k=\mathrm{E}\left(\alpha_k^2\right)=P_k\ \sum_{1}^{L}P_k=1 \tag{8}$$

The indoor channel delay power distribution model can usually be established as a 2-ray model and an exponential model [14]. The PDP of the two models are shown in Figure 4, for the 2-ray model, $P_1=P_2=0.5$ , for the exponential model:

$$P_k=P_k e^{-(k-1)T_s/\sigma_\tau},k=2,3...L \qquad \sum_{1}^{L}P_k=1 \tag{9}$$

Where TS is the sampling period, $\sigma_\tau$is the standard deviation of the delay $\sigma_\tau \approx B_C$,$B_C$ is the coherence bandwidth of the channel. In Fig. 4 (b), $T_S/\sigma_\tau$ = 1/3.




(a) (b)

Figure 4. 2-ray PDP model (a)Exponential PDP model (b)

## THEORETICAL BER PERFORMANCE ANALYSIS OF OFDM MODULATION IN MULTIPATH FADING CHANNEL

In order to compare the performance of OFDM systems over various channels, such as frequency selective channels or

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flat fading channels, and to prove the correctness of the simulation results, it is necessary to obtain the theoretical symbol error rate (SER) or BER performance under various channels.

M-ary Quadrature Amplitude Modulation(MQAM) has been increasingly concerned recent years,due to its superior anti-jamming capability and efficient spectrum utilization, which is also suitable for OFDM systems [7] [9].

If the BER theoretical value $P_{AWGN}$ of the MQAM modulation in the AWGN channel is known, the average BER [2] in the fading channel can be obtained according to Eq. (10) by combining the aforementioned probability density function $p_\alpha(\alpha)$ of $\alpha$in *II-B*[8] [15] [18].

$$P_b = \int_0^\infty P_{AWGN}(\gamma_b)\, p_{\gamma_b}(\gamma_b)\, d\gamma_b \quad (10)$$

Where $\gamma_b$ is the SNR, which is defined as:

$$g_b = a^2 E_b / N_0 \quad (11)$$

$\alpha$, i.e.$\alpha$（$t$）, is the random variable of the fading channel amplitude, which is the probability density function of$\gamma_b$. It can be obtained from the probability density function $p_\alpha(\alpha)$:

$$p_{\gamma_b}(\gamma_b) = \frac{p_\alpha\left(\sqrt{\frac{\Omega\gamma_b}{\overline{\gamma_b}}}\right)}{2\sqrt{\frac{\gamma_b\overline{\gamma_b}}{\Omega}}}$$

Where $\Omega$=$E(\alpha^2)$, $\overline{\gamma_b} = \Omega^2 E_b / N_0$ .

If the probability density function$p_\alpha(\alpha)$ of$\alpha$ and SER under the AWGN channel is known, the average SER under the fading channel can be obtained according to Eq. (10).Further more,in the case of channel coding is unused,the BER in the fading channel can be obtained according to the relational expressionsbetween the SNR per symbol andSNR per bit $E_s/N_0 = (E_b/N_0)\log_2 M$ (or $\gamma_s = \gamma_b \log_2 M$ ) and the relational expressions between BER and SER in the MQAM modulation [18] .

$$P_s = \int_0^\infty P_{AWGN}(\gamma_s)\, p_{\gamma_s}(\gamma_s)\, d\gamma_s \quad (12)$$

Where the SNR per symbol is $\gamma_s = \alpha^2 E_s / N_0$ , Then, $p_{\gamma_s}(\gamma_s)$ is obtained from the probability density function $p_\alpha(\alpha)$ .

According to the above method, BER theoretical expression under a variety of channel model can be obtained:

Theoretical BER expression of MQAM modulation under AWGN channel[14]is shown in Equation (13).

$$P_b = \frac{2(\sqrt{M}-1)}{\sqrt{M}\log_2\sqrt{M}} Q\left(\sqrt{6\gamma_b \cdot \frac{\log_2\sqrt{M}}{M-1}}\right) \quad (13)$$

The theoretical BER expression in Rayleigh channel with MQAM modulation [18] is

$$P_b = \frac{(\sqrt{M}-1)}{\sqrt{M}\log_2\sqrt{M}} \cdot \left(1 - \sqrt{\frac{3\gamma_b \log_2\sqrt{M}/(M-1)}{3\gamma_b\log_2\sqrt{M}/(M-1)+1}}\right) \quad (14)$$

The theoretical BER expression of MQAM modulation in Rician channel is [17]

$$P_b = \frac{1+K_r}{\overline{\gamma}_b}\exp\left(-\frac{\gamma_b(1+K_r)+K_r\overline{\gamma}_b}{\overline{\gamma}_b}\right) I_0\left(\sqrt{\frac{4(K_r+1)K_r\gamma_b}{\overline{\gamma}_b}}\right) \quad (15)$$

In (15), Kr refers to the ratio of the direct path power and the sum of the other non-direct path powers.

The BER derivation of the MQAM modulation in the Nakagami channel is as follows: The theoretical SER expression of MQAM modulation in the Nakagami channel is shown in Equation (16): [9]

$$P_s = \frac{2q\Gamma\left(m+\frac{1}{2}\right)}{\sqrt{\pi}\Gamma(m+1)}\phi_\gamma(g_{MQAM})\cdot {}_2F_1\left(m,\frac{1}{2};m+1;\frac{1}{1+\frac{g_{MQAM}\overline{\gamma}_s}{m}}\right) - \frac{2q^2}{\pi(2m+1)}\phi_\gamma(2g_{MQAM})\cdot F_1\left(1,m,1;m+\frac{3}{2};\frac{1+\frac{g_{MQAM}\overline{\gamma}_s}{m}}{1+\frac{2g_{MQAM}\overline{\gamma}_s}{m}},\frac{1}{2}\right) \quad (16)$$

With

$$\phi_\gamma(s) = \int_0^\infty e^{-s\gamma} p_\gamma(\gamma)\, d\gamma = \left(1+\frac{s\overline{\gamma}}{m}\right)^{-m}, \quad m \ge \frac{1}{2}$$

$$g_{MQAM} = \frac{3}{2(M-1)}$$

$F_1(a,b;c;z)$ refers to Gauss Hypergeometric functions,

$F_1(a,b,b';c;x,y)$ refers to Appell Hypergeometric functions **Error! Reference source not found.**

Then basing on $\gamma_s = \gamma_b \log_2 M$ and $P_b = P_s / \log_2 M$ , the theoretical BER expression of MQAM modulation in Nakagami channel is deduced as shown in equation (17)

$$P_b = \frac{2q\Gamma\left(m+\frac{1}{2}\right)}{\sqrt{\pi}\Gamma(m+1)}\phi_\gamma(g_{MQAM})\cdot {}_2F_1\left(m,\frac{1}{2};m+1;\frac{1}{1+\frac{g_{MQAM}\overline{\gamma}_b}{m}}\right) - \frac{2q^2}{\pi(2m+1)}\phi_\gamma(2g_{MQAM})\cdot F_1\left(1,m,1;m+\frac{3}{2};\frac{1+\frac{g_{MQAM}\overline{\gamma}_b}{m}}{1+\frac{2g_{MQAM}\overline{\gamma}_b}{m}},\frac{1}{2}\right) \quad (17)$$

## SIMULATION AND ANALYSIS

### *OFDM system model and channel simulation model*

In this paper, OFDM system simulation diagram is shown in Figure 5. In order to facilitate the comparison of effects of different channels on BER of OFDM modulation technology,the system is simplified. Assuming that the cyclic prefix length of the system is greater than the maximum delay of the multipath channel, the receiver obtains the accurate channel parameters through channel estimation and so on, with the cyclic prefix is precisely removed. Channel coding, channel decoding, interleaving, deinterleaving, insertion of the pilot module, channel estimation, time synchronization module, etc. are omitted, but it does not affect the performance comparison. Since the channel estimation is omitted, the channel parameters are obtained directly from the channel impulse response h (t) setting in the simulation process. And H (k) is obtained

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through the Fourier transform, which is used as the channel response frequency response parameter. That is,channel equalization can be achieved by divided FFT data by H (k).

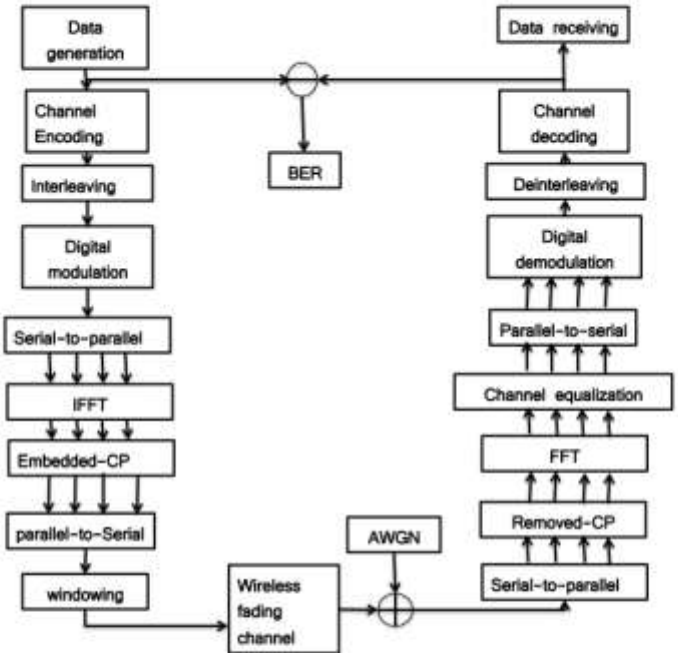


Figure 5. Structure diagram of simulation of OFDM system

Characteristics and classification of wireless channel have been discussed in detail in Section II-B, and mathematical models of flat channel and multipath channels are established. Following the conclusions from Section II-B, here we establish simulation model.

In the AWGN channel, the simulation model is [20, 21]:

$$r_l(t) = s_l(t) + z(t) \tag{18}$$

In the Rayleigh channel, the simulation model is:

$$r_l(t) = \sum_{k=1}^{L} c_k(t) s_l\left(t - \frac{k}{W}\right) + z(t) \tag{19}$$

Where $c_k$ *(t)* is obtained by $c_k(t) = X_k + jY_k$, *Xk* and $Y_k$ are two independent complex Gaussian stochastic processes. Then, the amplitude of $c_k$ *(t)* follows the Rayleigh distribution and the phase is uniformly distributed.

In the Rician channel, the simulation model is :

$$r_l(t) = \alpha_0 s_l\left(t - \frac{1}{W}\right) + \sum_{k=1}^{L} c_k(t) s_l\left(t - \frac{k}{W}\right) + z(t) \tag{20}$$

Where the fixed value of α0 is determined according to the Rayleigh channel parameter Kr.

In the Nakagami channel, the simulation model is

$$r_l(t) = \sum_{k=1}^{L} c_k(t) s_l\left(t - \frac{k}{W}\right) + z(t) \tag{21}$$

Where the amplitude of$c_k$ *(t)*is subject to the Nakagami distribution and the phase is uniformly distributed over (-π, π). When the parameter of the Nakagami channel $m > 1$, the Nakagami channel can be simulated by using the Rician channel model [17].

*Simulation results analysis*

In this section, the channel simulation methods described in section IV-Aare used for the OFDM system, and the BER performance results are compared and analyzed. The OFDM simulation parameters are shown in Table 1.

OFDM SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| IFFT/FFT length | 128 |
| Data sub-carrier | 128 |
| Guard Interval | 26 |
| Digital modulation | MQAM |
| Roll-off factor of Window function | 0.05 |

BER simulation results of different MQAM modulation and OFDM modulation combined with AWGN channel is shown in Figure 6. It can be seen that the simulation values are in agreement with the theoretical values, indicating that in the AWGN channel OFDM simulation method combined with different MQAM modulation methods is correct and feasible.

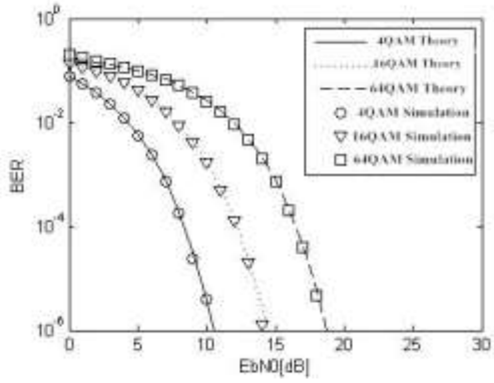


Figure 6. BER Simulation of MQAM + OFDM Modulation in AWGN Channel

Comparison between simulation and theory of fading channel simulation model

Before fading channel BER performance simulation, the fading channel simulation model is simulated first. In the Rayleigh channel model, by using the formula (19), selecting the parameter $L = 1$, Rayleigh parameter $\Omega$ can be obtained according to Figure 4 (b) and (10). The amplitude distribution of the channel impulse response h (t) of the Rayleigh channel is shown in Fig. 7, and the simulation curve is in accordance with the theoretical curve. Therefore, the simulation method of (19) is feasible.

In Rician channel,utilizing (20), the same parameter $L = 1$ is selected, the direct path power is, $K_r/(K_r+1)$ that is $\alpha_0 = \sqrt{K_r/(K_r+1)}$ , the non-direct path power is $1/(K_r+1)$ ,the amplitude of channel impulse response *h (t)* of the Rayleigh channel is shown in Fig. 8, simulation curve and the theoretical curve are in well agreement, so the simulation method of Eq. (20) is feasible. As described in [17], when $m > 1$, the Nakagami channel parameter m can be transformed into the Rician channel parameter$K_r$:

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$$K_r = \frac{\sqrt{m^2 - m}}{m - \sqrt{m^2 - m}} \quad (22)$$

The Nakagami channel simulation is achieved by using the Rician channel model. The simulation results are shown in Fig.9. The simulation curve agrees well with the theoretical value. It can be seen from the figure that the simulation value is slightly different from the theoretical value when the impulse response amplitude $r$ is small.However, the gap can be neglectedwhen $m$ is large.

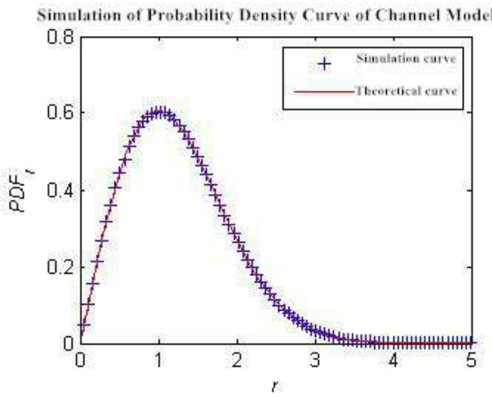


Figure 7. Rayleigh channel model ($L$ = 1)

In this figure, $r$ refers to the magnitude of $c(t)$, and $PDF_r$ is the probability density of $r$.

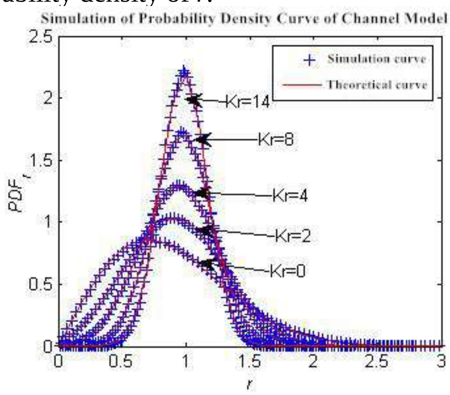


Figure 8. Rician channel model

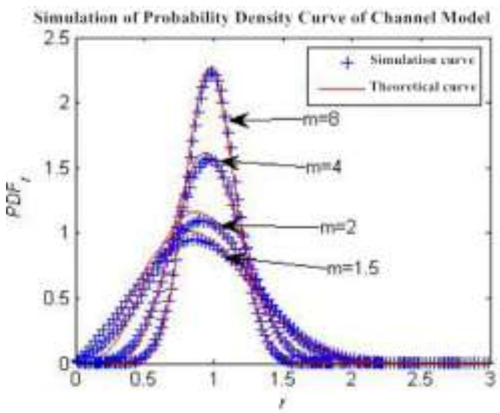


Figure 9. Nakagami channel model

Influence of Channel Equalization on BER Performance of Fading Channel

In this paper, the BER performance of the fading channel is compared with and without channel equalization.Using the TDL model and the exponential PDP model described in Section 2.2, the 16QAM simulation results in Rayleigh channel are shown in Fig. 10, where the Rayleigh parameter Ω can be obtained from Fig. 4 (b) and (10).It can be seen from the figure that the BER simulation curve after channel equalization is consistent with the theoretical value, while BER of the channel simulation curve is too large, that is the interference between OFDM symbols (ISI) is serious, without channel equalization. Therefore, channel equalization can effectively overcome the ISI within OFDM symbols. To achieve better performance, OFDM systems must perform channel equalization.

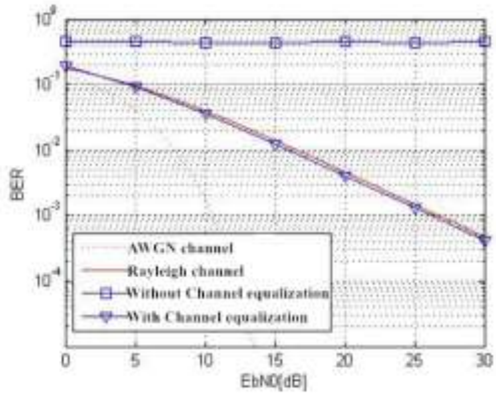


Figure 10. The influence of channel equalization on the performance of OFDM system under Rayleigh channel (PDP adopts exponential model)

BER performance under different MQAM modulation

Using the TDL model and the exponential PDP model described in *II-B*, the simulation results of Rayleigh channel simulation under 4QAM (QPSK), 16QAM and 64QAM modulation methods are shown in Fig. As can be seen from the figure, when the other things equal,the BER of MQAM modulation will be degraded with the addition of $M$.

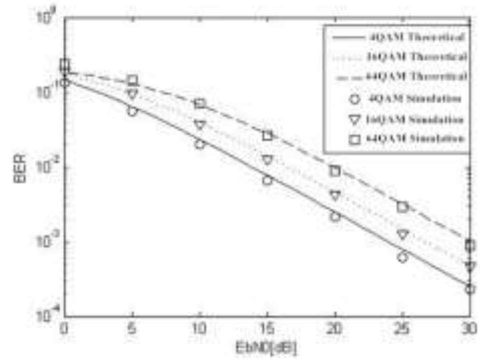


Figure 11. The influence of different MQAM modulation on BER performance under Rayleigh channel (PDP uses exponential model)

The Influence of the Number of Multipath Components on BER Performance

By changing the number of multipath channels $L$, we can analyze the effect of $L$ on the system BER. The BER performance results of the 16QAM modulation using the 2-ray model ($L$ = 2) and the exponential model ($L$ = 15) of the PDP in Fig. 4 are shown in Fig. 12. It can be seen from the figure that the BER performance of the 2-ray model is better than that of the exponential model. It shows that, the BER performance will be worse with the addition of the number of paths.

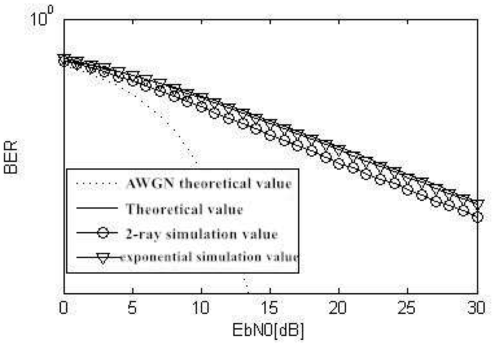


Figure 12. Effects of path number L of Rayleigh channel

BER Performance of OFDM System in Rician Channel

Using the TDL model and the exponential PDP model, we simulate the Rician channel under different direct and non-direct power ratios parameters Kr. The BER performance of the OFDM system with 16QAM modulation is shown in Fig 13. As can be seen from the figure, BER performance will be better with the addition of Kr, which squared with the theory.

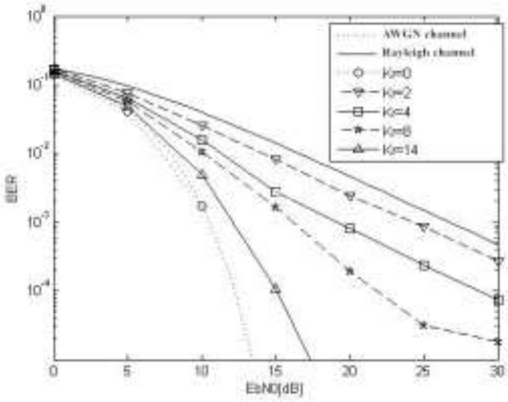


Figure 13. BER performance of OFDM system with 16QAM modulation in Rician channel (PDP uses exponential model)

BER Performance of OFDM System in *Nakagami* Channel

When the $m = 1$, the Nakagami channel is simulated by the Rayleigh channel model, while the Nakagami channel is simulated by the Rician channel model when $m > 1$. In Nakagami channel of different value of *m*, the BER performance of the 16QAM modulated OFDM system is shown in Fig. 14. As can be seen from the figure, BER performance will be better with the addition of *m*, which squared with the theory.

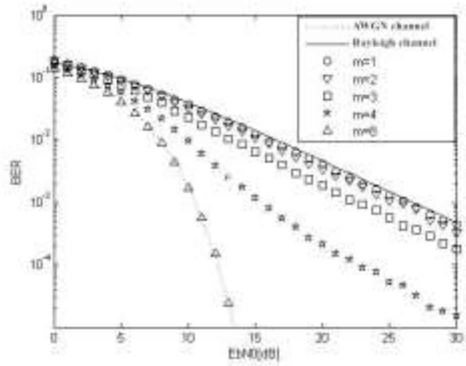


Figure 14. BER performance of OFDM system with 16QAM modulation in Rician channel (PDP uses exponential model)

CONCLUSION

In this paper, the influence of multipath fading channel on BER performance of OFDM system is analyzed from the theoretical and simulation aspects. The simulation method of Rayleigh channel, Rician channel and Nakagami channel model is validated. The feasibility of using TDL combined with flat fading feature to establish frequency selective slow fading channel is analyzed. The influence of channel equalization on the performance of OFDM system is analyzed. The influence of different multipath number L on the performance of BER is analyzed. The BER performance of the OFDM system under Rayleigh channel, Rician channel and Nakagami channel is analyzed.

According to the theory and simulation analysis, the following conclusions are obtained:

a) The frequency selective slow fading model established by TDL model superimposed Rayleigh, Rician or Nakagami channel is suitable for the performance analysis of OFDM system.
b) In the multipath channel, especially the frequency selective channel, the performance of the channel equalization technology will seriously affect the BER performance of the OFDM system;
c) The BER performance of OFDM system will be worse with the increase of the number L of multipath component;
d) BER performance will be better with the addition of Kr, which squared with the theory.BER performance will be better with the addition of *m*, which squared with the theory.

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