Performance Analysis of OFDM System under Rice Channel

Bo Qian¹, Siyao Xie¹, Jinhan Huang¹, Yongxin Feng²*

¹School of Information Science and Engineering, Shenyang Ligong University, 110159 Shenyang, China
²School of Graduate Studies, Shenyang Ligong University, 110159 Shenyang, China
fengyongxin@263.net

Abstract. For improving the capacity of the communication, the OFDM technology is used widely. The anti-jamming performances of OFDM system are analysed with the full-band interference, partial-band interference and comb spectrum interference under the rice channel. With the same parameters that the sampling frequency, the number of IFFT points, the cyclic prefix, and so on, when the numbers of subcarriers are 128, 256, and 512, respectively, the anti-jamming performances of OFDM system are simulated. The result of simulation shows that the anti-interference performance is obviously superior when the number of subcarriers is 128.

1. Introduction
With the rapid development of mobile communication technologies, various communication networks have emerged in an endless stream. Because the limited wireless resources are more crowded and interfering with each other more serious, there are restricting the reliability of mobile communications. Orthogonal Frequency Division Multiplexing (OFDM) is suitable for high-speed data transmission, high spectrum utilization, multipath fading channels and good resistance to frequency selective fading and narrowband interference. In this paper, under the rice channel, the anti-jamming performance of OFDM system is analyzed with full-band interference, partial-band interference, and comb-like interference.

2. The system model
2.1. OFDM system model
In the OFDM communication system, the literature [2, 3] mainly discusses that the basic principle of OFDM is to modulate serial data in parallel on multiple orthogonal subcarriers, which can reduce the symbol rate of each subcarrier and increase the symbol period of the symbol. It can improve the ability of system to resist fading and interference. At the same time, due to the orthogonality of each subcarrier, the spectrum utilization is improved greatly, so it is very suitable for high-speed transmission in fading mobile occasions. \([D_1, D_2, \ldots, D_N]\) is the symbol sequence. After IDFT transformation, the OFDM symbol \([d_1, d_2, \ldots, d_N]\) can be obtained.

Among them:

\[
d_x = \sum_{s=0}^{N-1} D_s e^{j2\pi s x / N}
\]  

(2-1)

After D/A conversion and low-pass filtering, the baseband transmission signal can be obtained as follows
\[ x(t) = \sum_{n=0}^{N-1} D_n e^{j2\pi n t / T} \] \hspace{1cm} (2-2)

where \(-\frac{k}{f_s} < t < \frac{N+k}{f_s}\), \(k_1, k_2\) are the length of the cyclic prefix and suffix, respectively.

On the assumption that the OFDM symbol period of the system is \(T\), then the width of one OFDM symbol is \(T_s = NT\), and the frequency of the \(n\)-th subcarrier is \(f_n = f_o + n / T_s\), where \(f_o\) is the lowest available frequency.

The OFDM signal is expressed as:
\[ r(t) = \int_{0}^{\infty} x(t - \tau) h(t, \tau) d\tau + n(t) \] \hspace{1cm} (2-3)

After A/D transformation, the digital signal can be obtained as follows:
\[ r(n) = \sum_{k=0}^{N-1} H_c D_n e^{j2\pi n k / T} + n(k) \] \hspace{1cm} (2-4)

The block diagram of OFDM communication system is shown in Figure 1.

2.2. The Rice channel model

In mobile communication, the signal propagation can be summarized as three basic modes of reflection, diffraction, and scattering. Due to the complexity of the wireless channel, the signal will transmitted in different fading channel. In the actual communication environment, there are several fading forms such as Rayleigh fading, Rice fading, Nakagami fading, etc. The Rice distribution is one of the most common models used to describe the time-varying characteristics of the received signal envelope statistics. Rice factor is an important parameter reflecting channel quality, which plays an important role in the calculation of channel quality and link budget, mobile speed and direction finding performance analysis. Because of the Multipath and Doppler, the received signal includes not only the direct component but also the multipath component. The envelope of the signal obeys the Rice distribution and the probability density function of the Rice distribution.

\[ p_s(x) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2 + S^2}{2\sigma^2}\right) I_0\left(\frac{xS}{\sigma^2}\right) \] \hspace{1cm} (2-5)

Where \(S\) is the power of the direct component, \(\sigma^2\) is the average power of the multipath component, and \(I_0(\cdot)\) is the first type of zero order modified Bessel function. The Rice factor \(K\) is defined as the ratio of the direct component power to the average power of the multipath component, and the parameter \(K\) is the Rice factor and the Rice distribution is completely determined. The value of \(K\) reflects the
influence of multipath scattering on the signal distribution. The larger the K value, the lower the multipath power relative to the direct wave power. When \( K=0 \) and \( S=0 \), there is almost no direct path signal, and the signal envelope distribution obeys the Rayleigh distribution.

Its probability density function is:

\[
P_a(x) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) \quad (2-6)
\]

If \( K=\infty \), the channel degenerates into a Gaussian white noise channel. The Rice distribution phase probability density function is identical to the Rayleigh distribution phase probability density function.

3. Anti-jamming performances analysis

3.1. Full-band interference

The full-band interference is actually a band-limited interference, and the effective bandwidth is exactly the entire frequency bandwidth. The full band interference power is \( J_a \) and the frequency hopping frequency is \( K \). Then, the interference signal acts on all frequency points \( K \) in the entire frequency bandwidth, and the mean value is 0. The interference power in one frequency band \( B \) is \( P_a \), and the variance is \( \sigma_a^2 \), and the probability density function is:

\[
f_{P_a}(x) = \frac{1}{\sqrt{2\pi\sigma_u}} \exp\left(-\frac{x^2}{2\sigma_u^2}\right) \quad (3-1)
\]

Where \( \delta_a = \frac{J}{K} \)

The full-band interference can be approximated as a Gaussian random process with a mean of zero, and its power spectral density is flat on a part of the total bandwidth, and the other parts are zero. Its equivalent unilateral spectral density is \( N_a \).

In Fig.2, the performance of the OFDM system is simulated, which under the conditions that the number of FFT points is 1024, and the subcarrier numbers are 128, 256 and 512.

![Fig.2 The performance of OFDM system under the full-band interference](image)

In Fig.2, it can be showed that as the signal-to-noise ratio increases, the bit error rate gradually decreases. The performance of OFDM system with the number of subcarriers 128 is significantly superior under the full-band interference. When the BER is \( 10^{-3} \), the performance of the OFDM system with the number of subcarriers 128 is better about 1 dB than the number of subcarriers 256, and about 3 dB than the number of subcarriers 512.
3.2. Partial band interference

Similar to full-band interference, the partial band interference is also a band-limited interference. The effective interference bandwidth used in this paper is half of the entire frequency bandwidth. The mean value of the interference signal is 0. The interference power in a frequency band $B$ is $p_a$, and the variance is $\sigma^2_a$. The probability density function is:

$$f_{a,x}(x) = \frac{1}{\sqrt{2\pi\sigma^2_a}} \exp\left(-\frac{x^2}{2\sigma^2_a}\right)$$  \hspace{1cm} (3-2)

Where $\delta_a^c = \frac{J}{K}$

In Fig.3, the performance of the OFDM system is simulated under the partial band interference. The simulation conditions are consistent with the full-band interference in Fig.2.

3.3. Comb spectrum interference

The comb spectrum interference is a particular interference. The effective interference bandwidth used in this paper is the entire frequency bandwidth.

$$D(t) = \sum_0^\infty b_i \cos(2\pi f_i)$$  \hspace{1cm} (3-3)

The value range of $f_i$ is included in the entire frequency bandwidth of OFDM signal. In this paper, the comb spectrum interference signal is composed of 5 cosine signals. The spectrum of each cosine signal is within the frequency band width. The simulation conditions are consistent with full-band interference and partial band interference. Figure 4 shows the result of simulation with 128, 256 and 512 subcarriers, respectively.

In Fig.4, it can be showed that as the SNR increases, the BER gradually decreases. The performance of OFDM system with the number of subcarriers 128 is significantly superior under the comb spectrum interference. When the BER is $10^{-3}$, the performance of the OFDM system with the number of subcarriers 128 is better about 1 dB than the number of subcarriers 256, and about 2 dB than the number of subcarriers 512.
3.4. Partial band interference simulation analysis under the same subcarriers

In order to analyse and compare the performance of OFDM system under the same subcarriers, the performance of OFDM system is simulated under the full-band interference, the partial-band interference and the comb spectrum interference. The results of simulation are shown in Fig.5 (a) ~ (c).

![Figure 5](image)

(a) the number is 128  
(b) the number is 256  
(c) the number is 512

In Fig.5 (a) ~ (c), it can be shown that the anti-full-band interference performance of OFDM system is superior to against partial-band interference and comb spectrum interference. With the constant interference power, the spectrum of the comb spectrum interference is the narrowest, so the amplitude of the power spectral density is higher than the full-band interference and partial-band interferences. Therefore, for OFDM systems, the interference effect of comb spectrum interference is relatively poor.

4. Conclusion

Under the Rice fading channel, the OFDM system with smaller number of subcarriers has better anti-interference performance. With the application of OFDM systems becoming more and more extensive, by deeply comparing the anti-jamming performance under different subcarriers numbers and interferences, it is significant to OFDM systems and other communication systems.

Acknowledgments

This work is supported by the National Defense Basic Scientific Research Planed Project (2018), Natural Science Fund of Liaoning Province NO.20170540775, Program for Liaoning Innovative Research Team in University, Science and Technology Foundation from Liaoning Education Department No.L2015462, Shenyang Ligong University Liaoning Province Information Network and Countermeasure Technology Key Laboratory Open Foundation (2015).
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