Research on anti-jamming and anti-interception performance of MC-CDMA system based on Code-Hopping

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Abstract: In the wireless channel environment, there are all kinds of jamming. With the wide application of OFDM Technology in wireless communication system, the technology of signal analysis is becoming more and more mature. Pure OFDM signal exposed in the wireless channel is no longer safer, facing the risk of jamming and interception, especially in the military field. Multi-carrier Code Division Multiple Access (MC-CDMA) technology is what combines the characteristics of OFDM and CDMA. It has the advantages of OFDM system and CDMA system at the same time. It reduces the transmission rate and improves the reliability. Compared with OFDM system, MC-CDMA has better BER performance in the same SNR environment. Based on the single user MC-CDMA system, the system model and simulation analysis are carried out, and the performance comparison with OFDM system is carried out. Based on the above work, the theory of code hopping spread spectrum is introduced to design a new code hopping spread spectrum system based on MC-CDMA, and the anti-jamming and anti interception performance of the system is analyzed.

1. Introduction

In recent years, Orthogonal Frequency Division Multiplexing (OFDM) has been widely studied and applied in both civil and military fields due to its good anti-multipath performance and anti-inter-symbol interference performance. In the civil field, OFDM has become the European Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) system standard, as well as IEEE802.11 wireless local area network (WLAN), IEEE 802.16 wireless metropolitan area network (MAN) standard and 4G-LTE The basis of mobile communication standards[1][2][3]. In the military field, OFDM is used as the main modulation technology in the Joint Tactical Radio System (JTRS) and Wideband Network Waveform (WNW) [4].

At the same time, after decades of development, spread spectrum technology has become more and more mature. It has strong anti-jamming ability and can be submerged in noise for concealed transmission. The principle of CDMA technology is based on spread spectrum technology, which was first born in military technology. During the Second World War, CDMA technology was researched and developed due to the needs of the war. The original intention was to prevent the enemy’s jamming with its own communications and was widely used during the war. In the field of military anti-jamming communications, it was later updated by Qualcomm to become a commercial cellular telecommunications technology and became a mobile communications standard in the 3G era.
So far, the research on the two technologies has reached a mature stage. In order to obtain higher frequency band utilization and anti-jamming performance, researchers have proposed a method that combines orthogonal frequency division multiplexing technology with spread spectrum technology. The combined technology, namely multi-carrier code division multiple access technology, enables the new technology to have the advantages of both, and at the same time has a certain performance improvement compared to the original technology. At present, the research of this technology mainly focuses on the research of Multi-Carrier Code Division Multiple Access (MC-CDMA) system. Based on the MC-CDMA system, the author of literature [5] analyzed the effects of different modulation methods, the number of users in the system, and the presence or absence of coding on the performance of the system. The author of literature [6] analyzed the performance improvement of the system against frequency selective fading and fast fading brought about by the use of rotational modulation on this system. The authors of literature [7] built MC-CDMA and DS-CDMA system models respectively, and compared the simulation performance. The author of literature [8] made a simulation comparison between OFDM and MC-CDMA systems, and studied the performance of additive white Gaussian noise, multipath fading and forward error correction coding in the system. In [9], the author used orthogonal Walsh codewords for spread spectrum in MC-CDMA, and analyzed the system performance in multi-user scenarios. Literature [10] analyzed system performance and bit error rate performance based on Code-Hopping Multiple Access (CHMA) system. Therefore, the performance of the system can be evaluated by the bit error rate of the system. At the same time, the author’s work considers various parameters, such as modulation method, coding method, channel model, and spreading code type. However, in the military confrontation environment, it is still face other threats, that is, human jamming and the risk of interception. This article will take the above two threats as references, analyze the performance of the MC-CDMA system in the military field, and design a code hopping system based on MC-CDMA based on the frequency hopping system, taking the slow frequency hopping and fast frequency hopping as examples. Based on the theoretical basis, a model of slow code hopping and fast code hopping is proposed to deal with various threats in military confrontation.

2. System Model

This section first presents the transmitter and receiver models of the MC-CDMA system. Compared with the traditional OFDM system, the MC-CDMA system adds two modules of spreading and despreading. The positions of the two modules are added after modulation and before demodulation. The method of spreading is to combine the data symbols of the original subcarrier. Stretching to multiple sub-carriers for parallel transmission of 1vw, combining multiple sub-carriers at the receiving end and making a decision. In this process, different users are assigned to use different spreading codes, so each user can only be despread Get your own data. Figure 1 shows a block diagram of the MC-CDMA system flow.

![Figure 1 MC-CDMA System model](image)

The transmitter first encodes the data received from each user, and the encoding adopts RS-CC concatenation or LDPC. Then input the encoded data to the modulation module, which uses QPSK and 16QAM modulation modes, and then sends the modulated data to the spread spectrum module. At this time, the spread spectrum code generation module generates the spread spectrum assigned by the user. Frequency code, and multiply the spreading code with the modulated data. The specific algorithm of the
spread spectrum module is shown in Figure 2. Each piece of modulated data is multiplied by a spreading code and distributed to different consecutive subcarriers. The spreading factor is SF, that is, the length of the spreading code is SF. In this operation, each piece of data is copied into SF. The different user data completed by spreading is superimposed and inserted into the pilot and long and short preambles, and the IFFT operation is performed to transform the symbols into the time domain, and the cyclic prefix is added to the signal, and finally transmitted to the channel after oversampling and filtering.

At the receiving end, the receiver performs inverse processing on the signal, and sequentially completes acquisition, synchronization, frequency offset estimation and correction, channel estimation, equalization, phase tracking, despreading, demodulation and decoding. The receiver can obtain the information needed by the user by despreading the spreading code corresponding to the user, and complete a data reception. Finally, by comparing the obtained data with the data at the transmitting end, the bit error rate can be obtained, and the noise power or jamming signal power can be adjusted to obtain the final calculation result.

![Figure 2 Spread spectrum module of MC-CDMA system](image)

2.1. Spreading code

MC-CDMA, compared to the system using OFDM technology, in principle has increased the spreading and despreading modules, so the choice of spreading code is also an important part of it. Generally speaking, spreading codes should have good cross-correlation and auto-correlation performance. Good cross-correlation can provide lower Multiple Access Interference (MAI) when multiple users exist. Auto-correlation characteristics reflect this code. The correlation between a word and a code word after a period of time delay, and the theoretical formulation of auto-correlation and cross-correlation is as follows:

\[
R_{\text{cc}}(\tau) = \int_{-\infty}^{\infty} x(t)x(t-\tau)dt
\]

\[
R_{\text{xc}}(\tau) = \int_{-\infty}^{\infty} x_1(t)x_2(t-\tau)dt
\]

In this model, a codeword with good orthogonality to each other is usually selected as the spreading code, such as the orthogonal Walsh codeword commonly used in CDMA systems. Orthogonal Walsh codewords can be generated by Hadamard matrix, which has the characteristics of easy generation and strong practicability. The Hadamard matrix is a square matrix, and any two rows (or two columns) of it are orthogonal. The elements in the matrix are composed of +1 and -1, so each row in the matrix can represent a unique Walsh code. The Hadamard matrix can be generated by the following iterative generation method:

\[
H_{2n} = \begin{bmatrix} H_n & H_n \\ H_n & -H_n \end{bmatrix}, n \geq 1
\]

When n=1, then any 2n-order Hadamard matrix can be generated by iteration.
It can be seen that when the order of the matrix \( n \geq 2 \), \( n \) must be a power of 2. According to the requirements of use, the elements in the Hadamard matrix of different orders can be selected as the spreading code, and the order \( n \) is equal to the spreading factor \( SF \). That is, the code length of the spreading code. The CDMA system defined by IS-95a uses the 64-order Walsh codeword.

2.2. Channel model

The channel model in the system adopts Additive White Gaussian Noise (AWGN) channel. As the name suggests, AWGN is a kind of noise that follows Gaussian distribution. In the system model, it is added to the signal and the average power of the noise is adjusted to generate different signal-to-noise ratios.

2.3. Jamming model

According to the actual channel, the jamming signal model can be divided into single-tone jamming, multi-tone jamming, narrow-band jamming and broadband jamming.

Single-tone jamming can also be called single-frequency jamming. This type of jamming is a continuous jamming in the time domain and presents the characteristics of a single frequency in the frequency domain, which can be a sine wave. In communication systems, complex data streams are usually transmitted, so the time-domain expression of single-tone jamming can be expressed as:

\[
J_{\text{Single Tone}}(t) = A \exp(j2\pi f_0 t + \theta)
\] (4)

After Fourier transformation, converted to frequency domain, we get:

\[
J_{\text{Single Tone}}(\omega) = 2\pi \delta(\omega - \omega_0), \omega_0 = 2\pi f_0
\] (5)

Adding single-tone jamming to the signal is equivalent to interfering with a single frequency point of the communication signal.

Multi-tone jamming, also called multi-frequency jamming, can be understood as the superimposed jamming of multiple single-tone jamming. The law of the jamming is that there are multiple discrete jamming frequency points in the frequency domain, which can be viewed in the time domain. For the superposition of multiple sine waves of different frequencies, the mathematical model of its complex number can be expressed as:

\[
J_{\text{Multi Tone}}(t) = \sum_{i=1}^{m} A_i \exp\left[j(2\pi f_i t + \theta_i)\right] \quad (i = 1, 2, \ldots, m)
\] (6)

Among them, \( A_i \) represents the amplitude of each single-tone jamming, \( f_i \) represents the frequency of the single-tone jamming, and \( \theta_i \) represents the phase of each single-tone jamming, which are uniformly distributed on \([0, 2\pi]\) and independent of each other.

Broadband jamming is a kind of jamming signal with a certain bandwidth, and the bandwidth of the jamming signal shows broadband characteristics, and the jamming bandwidth extends to the full frequency band of the communication signal, forming complete jamming of the signal. In theory, broadband jamming is the most effective jamming method among all jamming methods. However, in actual situations, broadband jamming requires high jammers under the same power. It is difficult to maintain high jamming power and achieve full-band jamming in communication. And the efficiency is low, but it is the most effective jamming method when the interfering party is not clear about the communication frequency band or signal structure and cannot be targeted for jamming. The wideband jamming signal can be expressed by the following expression:

\[
j(t) = d(t)e^{j(2\pi f_i t + \theta)}
\] (7)

Where \( d(t) \) is a baseband signal, expressed as:

\[
d(t) = A \text{sinc}(2\pi f_i t)
\] (8)

Then introduce the control parameters into the formulation to get:
Where $f_c$ is the center frequency of broadband jamming, $f_s$ is the sampling frequency, and $B$ is the bandwidth of broadband jamming.

### 3. Code-Hopping of MC-CDMA

On the basis of MC-CDMA, since the number of data subcarriers in each OFDM symbol is fixed, that is, the spreading factor $SF$ is equal to the factor of the number of data subcarriers, and orthogonal Walsh codewords are used, so after the spreading factor is determined the user's codeword set has also been determined. It is relatively easy for non-cooperative parties to intercept and analyze our data. Therefore, from the perspective of countering non-cooperative parties' interception, the original system does not meet the security requirements. Combined with the model of the frequency hopping communication system, Figure 3 shows the code hopping MC-CDMA model with code word hopping as the core.

![Figure 3 MC-CDMA model based on code hopping](image)

It can be seen that compared with the MC-CDMA system, a code hopping pattern control module is added to the model, and the code word used by each user is no longer fixed, but is controlled by the code hopping pattern. On this basis, the code hopping method is subdivided, and two basic code hopping methods can be obtained, namely, inter-symbol hopping code and intra-symbol hopping code, which can be called slow hopping code and fast hopping code respectively.

As shown in Figure 4, a communication model of two users is assumed in the model. The model assumes that there are 6 available codewords. In the same OFDM symbol, the same spreading code is used for the same user, and hopping occurs between different OFDM symbols; as shown in Figure 5, it is related to inter-symbol hopping. The code difference is that the abscissa becomes a sub-carrier block, which is a collection of adjacent sub-carriers. There are multiple sub-carrier blocks in an OFDM symbol, and the spreading codes used in these sub-carrier blocks are Hopping, that is, the divided sub-carrier blocks within an OFDM symbol use different spreading codes for spreading.

![Figure 4 Slow-Code-Hopping MC-CDMA model](image)
3.1. Anti-interception analysis

In military confrontation, due to the existence of non-cooperative parties, the communication signal of the cooperative party faces the risk of being intercepted by the non-cooperative party. Anti-interception performance is also a key indicator of concern to military communication researchers. This article measures the anti-interception performance of the system from the perspective of the correlation between the signal constructed by the interception of the non-cooperative receiver and the conventional signal.

Using the correlation to calculate the correlation of the signal, you can use the formulation (2), the obtained cross-correlation value is used to estimate the spreading sequence used in our signal, and the estimated result is finally obtained. The estimated accuracy is the anti-intercept ability. Important indicators.

4. Simulation results

First of all, this article will provide simulation parameters for MC-CDMA and OFDM systems, as shown in Table 1. After the previous model analysis, it can be known that the MC-CDMA and OFDM systems have great similarity. The difference lies in whether the system has spread spectrum and despread modules. In this model simulation, the number of subcarriers of an OFDM symbol is 256, of which data subcarriers are 192, pilot subcarriers are 8, and the remaining 56 are zero subcarriers, so the number of points for FFT transformation is 256. Two modulation methods, QPSK and 16QAM are used in the simulation, RS-CC concatenated code is used for encoding, 8-bit Walsh orthogonal code is used, the number of users is 1, the channel is AWGN channel, and the receiver uses zero-forcing equalization.

| Parameters                        | Value/Characteristics |
|-----------------------------------|-----------------------|
| Number of subcarriers(Data+Pilot+Null) | 256(192+8+56)         |
| Number of FFT                     | 256                   |
| Modulation                        | QPSK or 16QAM         |
| Coding                            | RS-CC                 |
| Equalization scheme               | Zero Forcing(ZF)      |
| Spreading Code                    | Walsh                 |
| Spreading Factor                  | 8                     |
| User number                       | 1                     |
| Channel                           | AWGN                  |

4.1. AWGN channel

First of all, the performance evaluation of the different modulation methods used in the system using the signal-to-noise ratio-bit error rate curve. The simulation curves of OFDM and MC-CDMA and MC-
CDMA systems based on code hopping under the AWGN channel will be given below as important indicators for evaluating system performance.

Figure 6 shows the performance comparison of each system in QPSK and 16QAM modulation modes in the case of a single user. The systems used in the simulation mainly include OFDM system, MC-CDMA system, slow hopping code MC-CDMA system, and fast hopping code MC-CDMA system. It can be seen from the figure that in QPSK and 16QAM modulation modes, the three MC-CDMA systems have a performance improvement of about 3dB in the bit error rate performance compared with the OFDM system, and have better transmission reliability. Among the three types of MC-CDMA, the performance of the original MC-CDMA is slightly better, the fast code hopping MC-CDMA is medium, and the slow code hopping MC-CDMA is slightly worse, but the difference between the three is less than 0.5dB, and the bit error rate performance is basically maintained Consistently, the new code hopping system does not deteriorate the reliability of transmission. In any system, the error rate performance of QPSK modulation is always higher than that of 16QAM, and the error rate performance is about 9dB. For the purpose of anti-jamming, QPSK modulation will continue to be used in subsequent simulations.

4.2. AWGN channel and jamming

In order to analyze the reliability of the system in the presence of jamming, its anti-jamming performance will be demonstrated in the next work. In the simulation, single-tone jamming, multi-tone jamming and broadband jamming are mainly used as common jamming and added to the channel.

First, as shown in Figure 7, it is a curve of the bit error rate changing with the signal-to-noise ratio in the presence of single-tone jamming for each simulation system. The signal center frequency fc of the system used in the simulation is 500MHz, the jamming center frequency f0 of single-tone jamming is also 500MHz, and the jamming-signal ratio (JSR, Jamming-Signal Ratio) is -10dB. It can be seen from the figure that the jamming effect of single-tone jamming is poor. In the OFDM system, a certain jamming effect is produced after the signal-to-noise ratio is 6dB, and there is an impact of 0.5dB, which has an impact on MC-CDMA and FCH-MC-CDMA (fast Code hopping (MC-CDMA) does not have a good jamming effect. After the signal-to-noise ratio is 3dB, it also has a certain jamming effect on SCH-MC-CDMA (slow code hopping MC-CDMA), with an impact of 0.5dB. It can be seen that MC-CDMA and FCH-MC-CDMA have better anti-single-tone jamming capabilities.
Secondly, as shown in Figure 8, the figure shows the bit error rate curve of the simulation system in the presence of multi-tone jamming. The same as the previous simulation, the signal center frequency is 500MHz, and the number of jamming frequencies for multitone jamming is 3. The three jamming frequencies are $f_1=490MHz$, $f_2=500MHz$, $f_3=510MHz$, and JSR is also -10dB. It can be seen from the figure that the addition of multi-tone jamming makes the performance of the OFDM system sharply deteriorated. In MC-CDMA and FCH-MC-CDMA, the multi-tone jamming also has a certain impact, and the performance loss is 3dB and 6dB respectively. But compared to the OFDM system, it already has a better ability to resist multi-tone jamming; although the performance of SCH-MC-CDMA has also been deteriorated, the overall performance is better than that of the OFDM system. In summary, the designed MC-CDMA system and code hopping system have the ability to resist multi-tone jamming.

Furthermore, as shown in Figure 9, the figure presents a bit error rate-signal-to-noise ratio curve under broadband jamming. The signal center frequency is 500MHz, and broadband jamming covers the entire frequency band, so there is no center frequency in the simulation, and the JSR is -10dB. It can be seen from the simulation diagram that broadband jamming has a certain impact on the reliability of all systems. The OFDM system loses 6dB performance, while MC-CDMA, SCH-MC-CDMA and FCH-MC-CDMA lose 3dB and 3dB and 2dB respectively, reducing the impact of broadband jamming on reliability. It can be obtained that the designed system meets the requirements of combating broadband jamming.
4.3. Anti-interception performance analysis

Anti-interception performance is also an aspect that has attracted much attention in military confrontation. This article uses correlation analysis to evaluate the anti-interception capability.

In the simulation, it is assumed that the non-cooperative party intercepting receiver exists in the channel, and the intercepting receiver can receive our signal, analyze the protocol and get the transmission data. It is assumed that the Sino-African partner already knows the processing flow of all our modules except for spread spectrum, and can parse the signal according to this flow, so the OFDM signal is completely exposed to a non-secure environment. Since the spreading sequence is used in the system to spread the signal, the non-cooperative party does not know the spreading sequence used, so the signal is concealed at this time, but the spreading sequence has strong autocorrelation and weak Cross-correlation, using the signal correlation angle to design the interceptor to estimate our spread spectrum sequence.

Figure 10 shows the estimation accuracy curve of the spread spectrum sequence used in our signal by the intercepted receiver in the simulation. In the simulation, it is assumed that the intercepted receiver knows the spreading factor of our spreading spectrum (SF=8), and can construct the waveform according to the sequence set that may be generated under this length, and perform correlation calculations with the received signal one by one, with the highest correlation As the final estimation result.

It can be found that in MC-CDMA, as the signal-to-noise ratio increases, the intercepted receiver's estimation accuracy of our spreading sequence is getting higher and higher, reaching the highest at SNR=12dB, and the estimation accuracy is close to 100%. The time signal is insecure, and the anti-interception performance is poor; in SCH-MC-CDMA, when the signal-to-noise ratio is between 0dB and 5dB, it almost coincides with FCH-MC-CDMA, and the estimated accuracy rate is 13%. After 8dB, the accuracy rate is similar to MC-CDMA, and the estimated accuracy rate is close to 100%. Although SCH-MC-CDMA also uses code hopping, it only needs enough computing performance to track codewords for interception, and anti-interception performance. Moderate; In FCH-MC-CDMA, the use of this estimation method can never achieve the ideal sequence estimation effect, and it is stronger than the previous two systems in anti-interception ability. This is because 24 continuously hopping signals are used in one signal frame. The spreading code forms an intra-frame code hopping pattern. If the interceptor uses correlation calculations to estimate the spreading code, it needs to pay 8 (24-1) times more computational cost than the original system.

From the above analysis, we can see that the designed SCH-MC-CDMA and FCH-MC-CDMA have stronger anti-interception capabilities.
Figure 10 The accuracy curve of the estimated spread spectrum sequence of the intercepted receiver

5. Conclusion
Based on the anti-jamming and anti-interception performance, this paper analyzes the performance of the orthogonal frequency division multiplexing system and the multi-carrier code division multiple access system by designing different types of common jamming signals, and designs the multi-carrier code division using the code hopping mechanism. Multiple access system. First of all, the simulation under the AWGN channel is carried out under the two modulation modes of QPSK and 16QAM, and the bit error rate curve is calculated, and it is obtained that QPSK shows better bit error rate performance, while multi-carrier code division multiple access can achieve better The anti-noise ability. Secondly, the designed jamming is added to the system. Compared with the orthogonal frequency division multiplexing system, the multi-carrier code division multiple access shows excellent anti-jamming ability, especially in the fight against multi-tone jamming. Finally, this paper uses the correlation to design the spread spectrum sequence estimation method of the interception receiver, analyzes the anti-interception ability of the three types of multi-carrier code division multiple access systems, and can obtain the multi-carrier code division multiple access with slow hopping code and fast hopping code. More excellent anti-interception ability, which can effectively hide data symbols in spreading code words. If the enemy does not have the same spreading code set and code hopping pattern as ours, it will be difficult to effectively intercept information.

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