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The Simulation of RS Codes and QC-LDPC Codes Concatenated in COFDM System

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Abstract

In OFDM system,error correction coding is essential to ensure the effective and reliable transmission in channels of various types of data. This paper mainly focus on cascading coding of RS codes, interweaving and QC-LDPC codes,using this encoding with OFDM system to construct new COFDM system. The paper also research about the structure of COFDM system and the performance of the concatenated code.Using Matlab to simulate the result from several aspects such as encoding, length of code, bit rate, decoding mode and different channels.The result has shown the promotion of the new concatenated coding in COFDM system compared with the traditional coding system.

Keywords*: COFDM; RS code; QC-LDPC code; Matlab simulation*

1. Introduction

Since COFDM (Coded Orthogonal Frequency Division Multiplexing) can be used in wireless channel in order to achieve high speed data transmission. The unique performance can be widely applied these days in many fields including ADSL, DAB, DVB, and WLAN and so on. Besides, COFDM also apply in the wireless local area network and wireless metropolitan area network which based on IEEE802.11 protocol and IEEE802.16 protocol [1].

For wireless communications, the transmission channel compared to other means of communication is more complicated. The signal may be interfered by various factors, such as reflection stack from tall buildings and trees, which will enlarge or weak the signal. It will lead the higher bit error rate (BER) and lower communication quality [2]. In the next generation of OFDM system research, to provide the high speed and high reliability of digital broadband multimedia services in the complicated wireless channel, forward error correction code technique is very important. It leads a compromising future of COFDM system. The combination of channel coding technique and multi-carrier technique make the system has multi-carrier modulation function and powerful error correcting ability as well. In this case, COFDM's several features, such as anti-multipath fading capability, anti-ISI capability and anti-doppler shift ability, have improved a lot.

Recently, with the development of information technique and social requirement, people always pursue more effective and correct encoding or decoding mode in order to approach the ideal boundary of Shannon theory. During this process, we have already achieved great progress from block code, algebraic code, RS code, convolutional code and today Turbo code, LDPC code. The distance from where we reach the performance to the ideal boundary of Shannon theory is shrinking.

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2. The Basic Principle of COFDM

2.1. System Architecture

COFDM is a special multi-carrier transmission scheme [3]. It can be seen as a kind of modulation technique or multiplexing technology. In the traditional parallel data transmission system, the whole signal frequencies is divided into N different frequency sub-channels. Each sub-channel transmit its own modulating signal, then use all sub-channels for frequent reuse. Though this method help avoid the interference between different channels, it cannot efficient use of the precious spectrum resource. In order to solve this inefficient use of spectrum resources problem, COFDM divided the given channels into some orthogonal sub-channels and the data into many data stream as well [4]. It can decompose the rate of data stream, then let data stream to modulate each sub-carrier. Because of these are parallel transmission, decreasing the dependence of single carrier. In order to further improve the system performance, the system always combines with coding techniques, which is the COFDM system.

The transmitter and receiver of COFDM system block diagram is shown in Figure 1 and Figure 2.

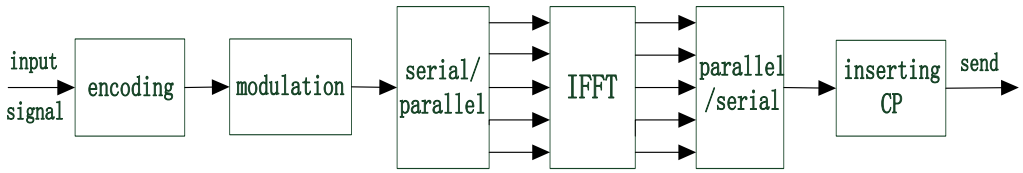

Figure 1. The Block Diagram of a COFDM Transmitter

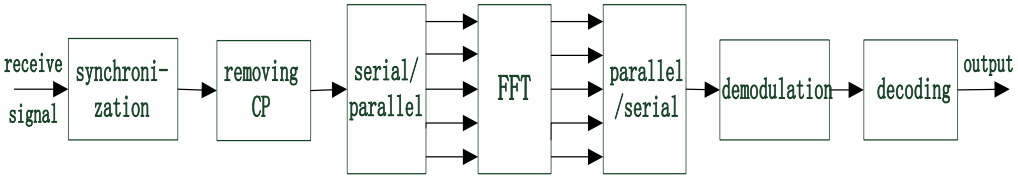

Figure 2. The Block Diagram of a COFDM Receiver

Set each carrier period is T, then the frequency of adjacent sub-carrier is 1/T. The receiving end use the orthogonality between sub-carriers to separate each signal, thus achieving demodulation. The COFDM system basic principle is that make the high-speed data stream through the serial-parallel conversion, assigned to some sub-channel to be transmitted which have relatively low transmission rate. Since each sub-channel period is increasing, the system can mitigate the effects of time diffuse generated by multipath delay spread in wireless channel. And insert the guard interval between COFDM symbols which can maximally eliminate the inter symbol interference (ISI) caused by multipath. Generally, using cyclic prefix (CP) as the guard interval is to avoid inter carrier interference (ICI) caused by multipath.

In the sender, system encode and modulate the original data, then make serial to parallel conversion. Dividing signal into several parallel N points and sending them to IFFT, in order to modulate the data in some orthogonal sub-carriers that they could be parallel to send. Next, the system take parts of the COFDM symbols which passed the IFFT conversion do cycle replication. In other words, it can copy the symbol latter parts to the front of the symbol, forming prefix. In this way, they will not generate any discontinuity in the intersection of signal and send them to the receiver.

The receiver perform the reverse process as the sender. First sending the received data

to timing and frequency offset estimation cells, according to the timing estimation find the starting of COFDM symbols. So the following system could remove the CP and send to FFT cells demodulate the sub-carrier signal. At last, it use demodulation and decoding to get the original data.

2.2. Mathematical Model

In the sender, the serial symbol sequence $C_0, C_1, C_2, \ldots, C_{N-1}$ firstly implement digital baseband modulation, then send to the serial parallel conversion [5]. Between the N sub-channel symbols, the k transmission symbol of sub-carrier is $X(k)$, the signal of COFDM can be expressed as:

$$x(t) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi f_k t) g_T(t) \quad (1)$$

Where $g_T(t) = \begin{cases} 1 & 0 \le t \le T \\ 0 & else \end{cases}$ is the symbol transmission waveform. f_k is frequency of the k sub-carrier. 1/T is the frequency difference between the adjacent sub-carrier. The total number of carriers is N. They are satisfied the following orthogonality relations in the symbol transmission time T:

$$\int_0^T \exp(j2\pi f_k t) \exp(-j2\pi f_l t) dt = 0, \quad k \ne l \quad (2)$$

If f_c is the lowest sub-carrier frequency, then the k sub-carrier can be expressed as:

$$f_k = f_c + k/T, \quad n = 0,1,2,\ldots,N-1 \quad (3)$$

So $x(t) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi k \cdot t/T) \exp(j2\pi f_c t)$

$$= y(t) \exp(j2\pi f_c t) \quad (4)$$

Where $y(t)$ is the low pass complex envelope of $x(t)$, the period of each envelope should be T, then

$$y(t) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi kt/N), \quad t \in [0,T]$$

If the sampling frequency of $y(t)$ is $f_s = 1/t$ in one OFDM symbol period T, it can obtain N sampling points, and the result is:

$$y(n) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi kn/N), \qquad 0 \le n \le N\text{-}1 \quad (5)$$

The equation of (5) is the N points IDFT of $\{X(k)\}$. It shows that the baseband modulation process of COFDM can be completed by the IDFT operation, and the demodulation process also can be achieved by using DFT. The modulation and demodulation could be equivalent to IDFT and DFT. Due to the N points IDFT operation need to implement the times of N^2 complex multiplication, IFFT can reduce the complexity of operation [6]. Thus, the actual COFDM system often use IFFT and FFT to achieve the modulation and demodulation process.

2. Channel Coding

3.1. RS Coding

RS code is a kind of non-binary BCH code which has the excellent ability of error correction [7]. Normally it is used as outer code in cascading coding, and become widely used in communication. The element symbols of RS is from the finite field GF(q), the root of its generating polynomial is also in GF(q), so the symbol field and root field of RS code are the same.

Each team consists of k bits of information, and the RS code which can correct t errors that has the following parameters:

Code length	n=q-1
The number of check bit	n-k=2t
The minimum distance	d=2t+1

RS code is taken from the finite field GF (2^m), which code length is n= 2^m -1. The procedure of encoding operation is as follows:

(1) To determine the generating polynomial g(x) of RS encoding, the general form of g(x) is as follows:

$$g(x) = (x+\alpha^1)(x+\alpha^2)(x+\alpha^3)\cdots(x+\alpha^{2t})$$

Among which, α is the primitive element of GF (2^m). The elements of GF (2^m) can be expressed by binary vector of length of m, so the code of length of n can be expressed by binary character.

(2) Generating the redundancy check information p(x) of code through the modulus operator, where $x^{2t}m(x)$ is the dividend, the generating polynomial g (x) is divisor:

$$p(x) = (x^{2t}m(x)) \bmod (g(x))$$

(3) Using the following equation, finally it can generate RS code through the addition operation c(x).

$$c(x) = x^{2t}m(x) + p(x)$$

The RS decoding algorithm usually has three steps [8]. Firstly, computing the syndrome by the received code block; the second, based on the syndrome getting error pattern; finally, calculating the maximum possible sending code based on the error pattern and received code block, and completing the decoding.

3.2. Interweaving

The basic idea of interweaving coding is that reordering the data through the data interleaving in order to make the burst errors partly become random errors, and let the original burst errors distribution among some of the data but not in few data [9]. In fact, interweaving is also a method to modify the channel which make the burst channel transform random channel, then the errors can be discretization. The number of each group's error data will be greatly reduce.

3.3. QC-LDPC Coding

QC-LDPC that is the structured LDPC code [10], also called quasi-cyclic LDPC code. Its generator matrix and check matrix both have cyclic shift characteristics, so it can use shifting register to achieve uniform encoding. Compared with LDPC code, the advantage of QC-LDPC code is its quasi-cyclic structure which leads the lower complexity of encoding, fewer storage space and more convenient on the hardware.

The LDPC code can be completely determined by the check matrix which is showed

by $H_{(n-k)\times n}$, where n is code length, and k is the number of information bits, usually it use m to express n-k which is named check bit number; all code c satisfy the equation $cH^T = 0$ [11]; except a few elements are 1 in matrix, most of the elements are 0, so it called sparse parity check matrix. Normally the LDPC code is divided into regular LDPC code and irregular LDPC code; if the number of 1 is i in check matrix each row (row weight), and the number of 1 is j in each column (column weight), which can be called regular LDPC code [12]; Gallager proved when $j \geq 3$, this type of LDPC code has great characteristic of Hamming distance; if the number of 1 in the matrix each row or each column is different, we call it irregular LDPC code, which can get better performance than regular LDPC code through optimizing the distribution of 1 in check matrix [13]. We generally calculate rate using rate= (n-m) n, if the check matrix is not full rank and the rank is r, then the actual rate is rate= (n-r) n.

QC-LDPC code that is quasi-cyclic LDPC code, whose check matrix has the feature of block cycle. Every cyclic sub matrix row weight or column weight could be more than 1, or be equal to 1. A QC-LDPC check matrix can be expressed:

$$H_{\mathrm{qc}} = \begin{bmatrix} A_{1,1} & A_{2,1} & \cdots & A_{1,t} \\ A_{2,1} & A_{2,2} & \cdots & A_{2,t} \\ \vdots & \vdots & \ddots & \vdots \\ A_{c,1} & A_{c,2} & \cdots & A_{c,t} \end{bmatrix}$$

Every $A_{i,j}$ is cyclic sub matrix that the unit matrix I do dextroposition, and their orders all are b; due to QC-LDPC code has the characteristic of block cycle, it only needs to store the location of every non-zero cyclic sub matrix and the digit of cyclic shift in check matrix, so it can significantly reduce the storage space [14].

The method of QC-LDPC decoding mainly include BP (Belief Propagation) algorithm which also be called sum product algorithm or information transfer decoding algorithm, and the log-domain decoding algorithm and min-sum decoding algorithm [15,16]. Their central idea all are using soft information interaction between bit notes and check notes, through iterating many times to achieve a more accurate decoding [17].

4. The Concatenated Code of COFDM System

COFDM system which is the OFDM system adding channel coding. The encoding cells can improve the performance of OFDM system. Based on the introduce listed above about RS codes, interweaving and QC-LDPC codes, we can know that as a new kind of linear block code, QC-LDPC has outstand performance. It can theoretically achieves Shannon limit and has lower complexity of decoding. Yet RS code which has pretty good performance of error correction, especially be suitable as the outer code for concatenated code with the other code. So the paper selects these two codes and interweaving to do cascade as the channel coding of COFDM system. The purpose is to make COFDM system obtain better communication effects and meet requirements of getting very low BER in the wireless communication. The construction of system model is shown in Figure 3.

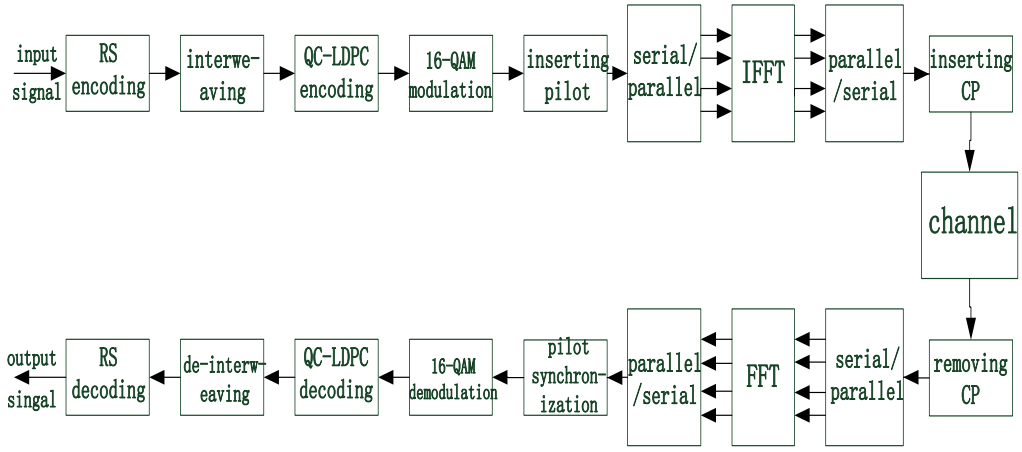

Figure 3. RS Code and QC-LDPC Code Cascade of COFDM System Block Diagram

In the sending end, after the input data stream passing through the cascade encoder, doing the baseband modulation (BPSK, M-PSK, 16QAM modulation), and inserting the pilot frequency, the data will be through serial-parallel conversion and IFFT conversion in turn. Then through the parallel-serial conversion to turn parallel data streams into the serial data streams, forming COFDM code with adding the guard interval (also called CP).

At the receiving end, which perform the reverse process as the sender, firstly it remove the CP. For the multipath selective fading channel, the system should add synchronization sequence and channel estimation sequence to make the receiver do channel estimation based on pilot frequency. Then the data pass through baseband demodulator and cascaded decoder output the bitstream.

5. The Comparison of System Performance Simulation

Encoding technique can modify the performance of OFDM system. In order to show that the concatenated code which is proposed in this paper make COFDM system BER improvement. The paper will be through the simulation to analyze the performance of system.

In this section, the paper use Matlab to establish the COFDM system simulation platform in order to simulate and analyze the error correction performance of cascade code in system. The simulation platform used by this paper reference the parameters and conditions of IEEE802.11g protocol.

In order to verify the COFDM system effectiveness of cascade code, the paper uses (Additive White Gaussian Noise) AWGN channel as a result of it is the basic model of noise and interruption. So the paper analyzes the influence of COFDM system from the features of concatenated code doing baseband simulation in AWGN. In AWGN channel, the paper compares and analyzes the different way of encoding; the different length of code; the different rate and the different ways of decoding. They generate the different influence in COFDM system, then the paper will choose the appropriate code parameter to make the system has the best performance.

For the error correction code, not only the code itself parameter may affect the performance, but also the channel is important. In the simulation platform of Matlab, the paper also use AWGN channel and multipath Rayleigh fading channel to do comparison to analyze the COFDM system performance comprehensive.

The table 1 gives all kinds of different simulation parameters in COFDM system, the paper will use the following data to do simulation.

Table 1. The Different Simulation Parameters of COFDM System

Encoded mode	RS and QC-LDPC concatenated code/convolutional code and interweaving concatenated code/LDPC code
Modulation mode	16QAM
Code rate	1/2 1/3 1/4
Code length	128 256 512
Decoded mode	BP decoding algorithm/Min-Sum decoding algorithm
FFT operation	512 points
Bandwidth	40MHz
Number of CP	16
Channel model	AWGN channel/Rayleigh fading channel

5.1. Cofdm System of Different Encoding Ways Performance Simulation

In this part, the paper compares system performance among the concatenated code proposed in the paper, the traditional encoding that is convolutional code and interweaving concatenated, LDPC code. These three COFDM systems are all same except the ways of encoding in order to make the simulation in the same condition. The parameter of concatenated code is RS (16, 12) and QC-LDPC(256,128).

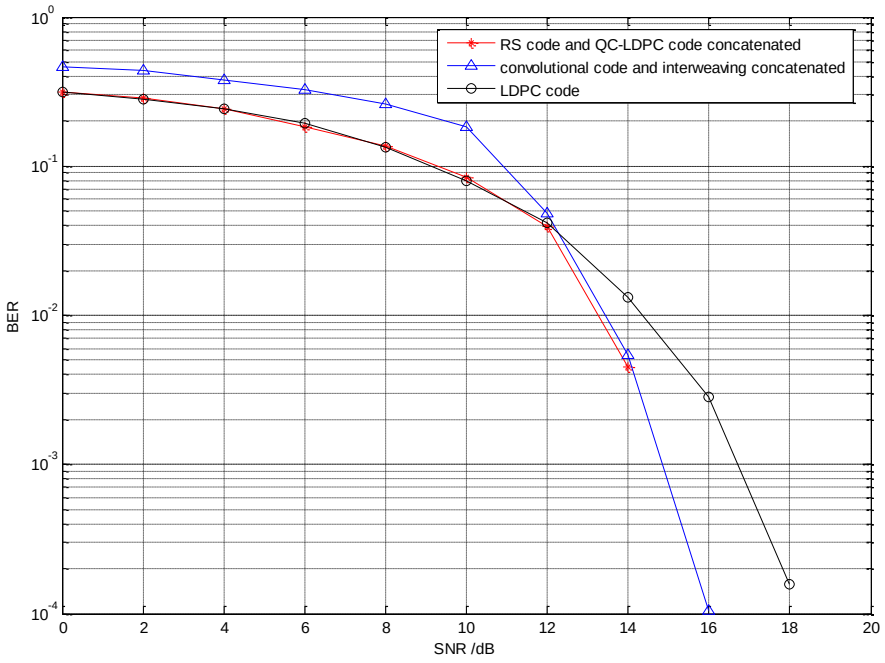

Figure 4.The COFDM System BER Curve of Proposed Concatenated Code, Classic Concatenated Code and LDPC Code

From the figure 4, COFDM system of the concatenated code proposed in the paper which has RS code, interweaving, QC-LDPC code and the system of LDPC code both have similar performance before the SNR is 12dB. But the two code performance both be better than the traditional concatenated code which is convolutional code and interweaving. As SNR is larger than 12dB, more and more clearly reflect that the system performance of paper proposed concatenated code is lower than the system of single LDPC code. All told, the paper propose the channel encoding performance in COFDM system that is better than the other ways. The result also show the advantage of RS code and QC-LDPC code.

5.2. COFDM System of Different Code Length Performance Simulation

As the linear block code, the code length of QC-LDPC is also be an important influence to the performance of COFDM system. Under confirming the length of RS code, the code rate which is 3/4, QC-LDPC code rate that is 1/2 and the decoding algorithm is BP, the paper simulates the COFDM system for the different code length of QC-LDPC in concatenated code: (128, 64), (256, 128), (512, 256). To analyze the performance influence from code length.

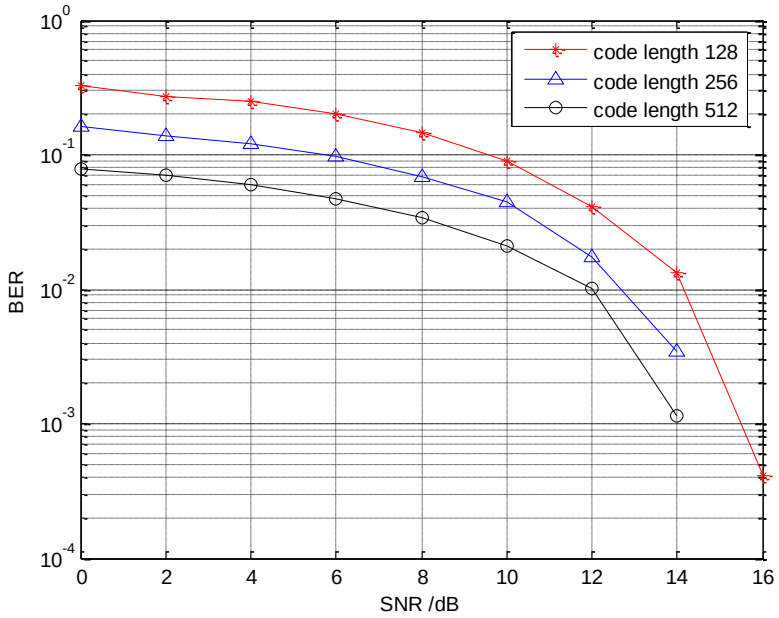

Figure 5. The COFDM System BER Curve Of Different Code Length

From the figure 5, we can see under the same rate of coding, system performance is as the length of code larger as better. However it does not mean we could use the length of code as long as possible, it will also increase the complexity of coding.

5.3. COFDM System of Different Code Rate Performance Simulation

For QC-LDPC code, code rate equals to the ratio of information bits and code length. The lower rate it is, the less useful information bits code contains and more check bits it uses.

As concatenated code, if we want to do comparison in different rate, we should guarantee not only in the same code length and also the rate of RS code are all 3/4. The paper ensure the length of QC-LDPC code are all 384 and the rate respectively are 1/2, 1/3, 1/4 to do concatenated code. The decoding methods all are BP algorithm and the same parameters of system to compare the performance of COFDM system.

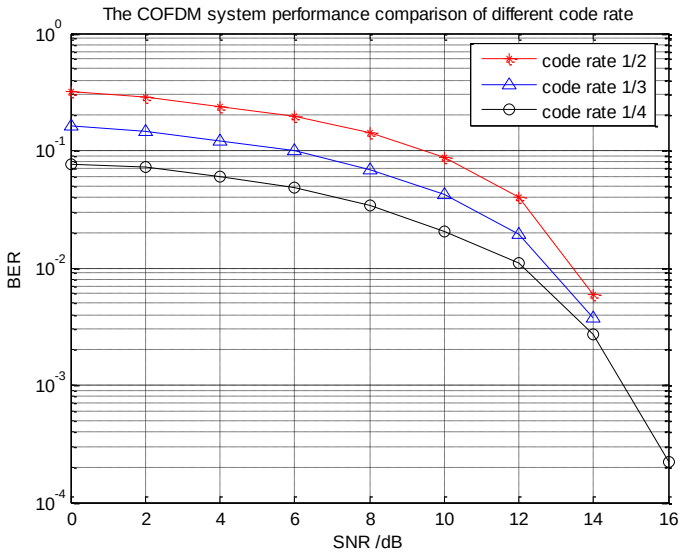

Figure 6.The COFDM System BER Curve of Different Code Rate

From the figure 6, as the code rate is lower, BER get lower that it means the performance of concatenated code is better. The simulation that fit the theory nicely. When the SNR is low, the BER of rate 1/4 is clearly smaller than the rate 1/3 and 1/2. With the increasing of SNR, the curve of rate 1/3 and 1/4 is very close. When BER is 1×10^{-2}, the system performance of using 1/4 code rate to encoding keep ahead of the 1/2 rate encoding system 1.9dB.

5.4. COFDM System of Different Decoding Ways Performance Simulation

When the channel output symbol set of information transfer algorithm and the send information symbol set in the decoding process, and they both are real number set. That is when using the continuity of data, selecting the information mapping function properly which is Belief Propagation algorithm. The core concept of BP algorithm is using the received soft information between variable nodes and check nodes to do iteration operation, getting the maximum coding gain. Thus, it has good performance and can be used in the situation which has a higher requirement on performance. At the same time, BP algorithm is a parallel algorithm that the parallel implementation can greatly improve decoding speed in the hardware.

Min-Sum decoding algorithm is raised a simplified algorithm based on BP decoding algorithm of log-domain. It use minimum operation to simplify the functional operation and greatly decreases the complexity of computation. The decoding method does not need the estimation for channel noise, but the performance reduce in a certain degree.

The paper compares these two kinds of decoding algorithm used in the proposed concatenated code decoding, the simulation diagram as follows:

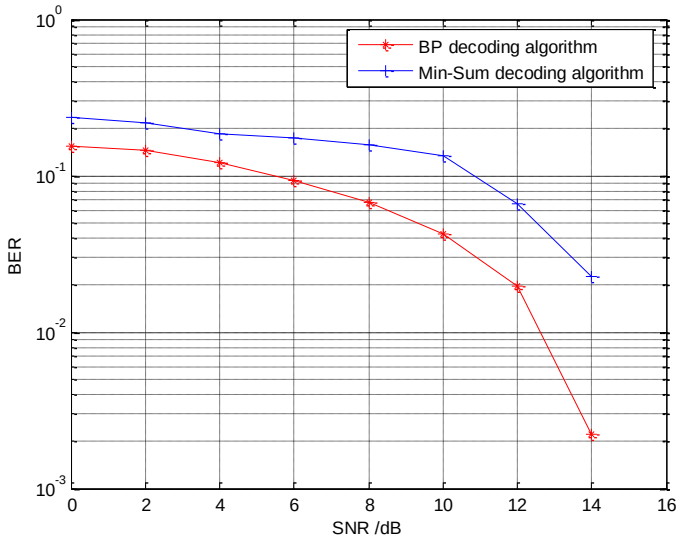

Figure 7. The COFDM System BER Curve of Different Decoding Algorithm

From the figure 7, the decoding performance of BP algorithm is better than the min-sum decoding in the COFDM system of concatenated code. The min-sum BER curve is very gentle and the BP BER curve relatively change fast. So the COFDM system will choose the BP decoding algorithm in order to make the whole system has better performance.

5.5. COFDM System of Rayleigh Channel Performance Simulation

In order to measure the effectiveness of COFDM system, we need to use Rayleigh fading channel to simulate the system because of the Rayleigh channel is more complex than AWGN channel. The channel of above simulation are all AWGN, the following figure is going to compare two concatenated codes in the Rayleigh channel.

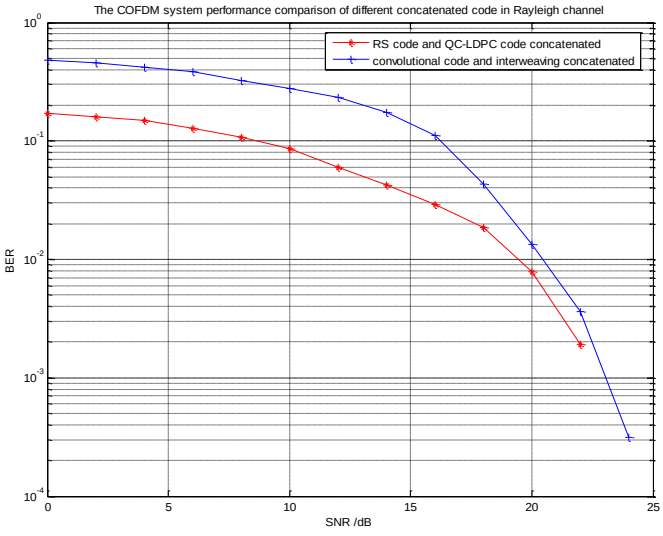

Figure 8. The COFDM System BER Curve of Different Concatenated Code in Rayleigh Channel

From the figure 8, when SNR is relatively low, both BER of code has gap until the intersection point of SNR is 20dB. It indicates that the concatenated code still make the

system have low BER in Rayleigh channel. Through the simulation in Rayleigh channel, we can conclude that not only in good channel the system is but only worsening wireless channel, the performance of concatenated code this paper proposed is better than the traditional encoding. However, wireless channel is always very complicated and exasperate, the Rayleigh channel is so close the real wireless transmission environment that RS and QC-LDPC concatenated code plays an important role in the COFDM system.

6. Conclusion

The paper applies the RS codes and QC-LDPC codes in COFDM system based on the protocol of IEEE802.11g and puts forward a COFDM system scheme of concatenated code. This paper mainly research the performance influence from this concatenated code in the COFDM system. First, the paper simulates the performance of COFDM system with the concatenated code in order to prove the effectiveness of concatenated code in the COFDM system. Then the paper simulates and analyzes for the new COFDM system under many factors that is different encoding ways, different code length, different rate and different decoding methods. Based on the simulation result shows that this new concatenated code improves system performance a lot and it is better than traditional convolutional code, interweaving and the single encoding.

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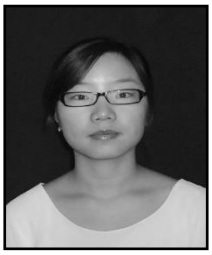

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