Performance Analysis of Indoor Visible Light ACO-OFDM Coding

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Abstract: With the research and development of visible light communication technology, more and more researchers have begun to pay attention to more effective and reliable modulation technology and channel coding technology. In order to reduce the bit error rate of the shortwave wireless visible light communication system and increase the signal rate in the transmission process, the high efficiency and reliability of the modulation and demodulation technology must be realized. Therefore, the asymmetric limit orthogonal frequency division multiplexing technology (ACO-OFDM) is due to it's excellent anti-interference ability and power efficiency are widely used in visible light communication systems. This article will introduce in detail the basic principles of ACO-OFDM technology, Hermitian mapping, and use BPSK, 4-PPM,16QAM for bit error rate simulation analysis, and select a modulation method rate with a lower bit error rate; analyze the linear block code, BCH The basic principles of coding and convolutional codes, and ACO-OFDM systems based on these three coding methods are simulated by Simulink, and their bit error rates are compared. Finally, ACO-OFDM based on convolutional codes was selected. This system is more suitable for visible light communication.

Keywords: Visible Light Communication, ACO-OFDM, Channel Coding

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1 Introduction

Visible light communication technology uses fluorescent lights or light-emitting diodes to send out high-speed flickering signals that are invisible to the naked eye to transmit information. It has the advantages of rich spectrum resources, low consumption, low cost, and good confidentiality. With the popularity and rapid development of light-emitting diodes (LED), LED-based lighting and display systems have become more and more integrated into people's lives, and visible light communication technology has become one of the fastest-growing high-tech fields in today's society. In order to realize the effectiveness and reliability of data transmission in the visible light communication system, this article introduces an asymmetric limiting optical orthogonal frequency division multiplexing (ACO-OFDM) technology, and adds channel coding to the visible light communication system to improve. The system's error detection and correction capabilities. First, this article explains the general system framework of the visible light communication system; second, this article explains the working principle of the ACO-OFDM technology and Hermitian mapping; and simulates the ACO-OFDM system under the visible light channel, and compares the ACO-OFDM and 4-PPM , BPSK, QPSK, 16QAM bit error rate simulation comparison; then, this article briefly introduces the linear block code, BCH coding and convolutional code three channel coding techniques, and the three coding techniques for bit error rate comparison simulation. Finally, a modulation and channel coding technology more suitable for visible light communication is selected.

2. Principle of Visible Light Communication

The visible light communication system structure is shown in Figure 2.1. It can be seen that, similar to the traditional radio frequency communication system, the visible light communication system is also divided into three parts: visible light communication transmitter, visible light communication wireless channel, and visible light communication receiver.

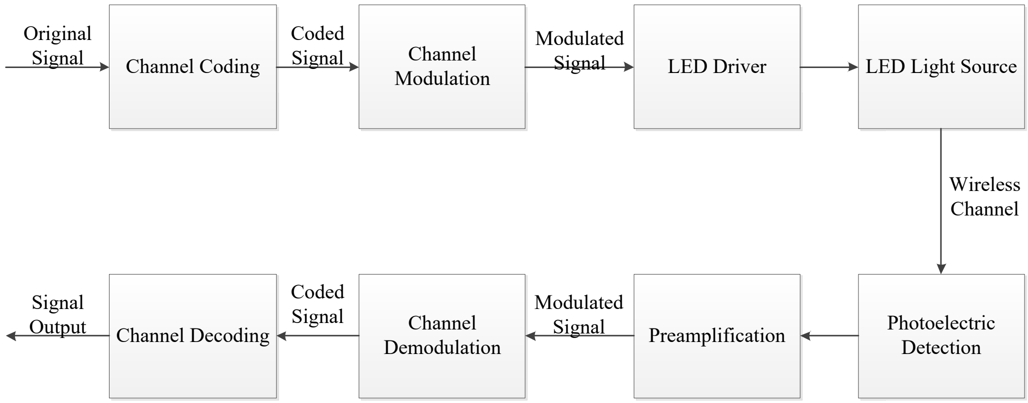

Figure 2.1 Visible light communication system block diagram

The specific functions of each part are as follows:

(1) Visible light communication transmitter

The original signal is a binary bit stream. First, pre-processing coding and modulation is performed, that is, an error correction code is added to the original signal to be transmitted and an appropriate modulation method is selected to improve the error correction capability and reliability of the transmission signal. After the LED is driven, the electrical signal is converted into an optical signal, and after passing through the LED semiconductor device, the electrical energy is converted into light energy and emitted. Among them, the light source used in the optical communication system can be a white LED.

(2) Visible light communication receiver

The main device at the receiving end is a photoelectric detector, which can perform photoelectric conversion of the signal. After the optical signal is converted into an electrical signal, it is demodulated and decoded corresponding to the transmitting end to restore the original signal.

3. ACO-OFDM Technology

3.1 The Technical Principle of OFDM

OFDM technology is one of Multi-Carrier Modulation (MCM) technologies. The so-called OFDM technology is to divide the data stream to be transmitted into several sub-data streams, each sub-data stream has a much lower transmission bit rate, and the sub-data streams are used to modulate several mutually orthogonal carriers in parallel.

Each OFDM symbol is the addition of multiple modulated sub-carrier signals, and the modulation mode of each sub-carrier can be phase shift keying (PSK) or quadrature amplitude modulation (QAM). If N represents the number of sub-channels and T represents the width of the symbol, $d_i (i = 0,1,\cdots, N-1)$ is the data symbol assigned to each sub-channel， f_c is the carrier frequency，The OFDM symbol starting from can be expressed as $t = t_s$ can be expressed as：

$$s(t) = \mathrm{Re}\left\{\sum_{i=N/2}^{N/2-1} d_{i+N/2} \exp\left[j2\pi\left(f_c - \frac{i+0.5}{T}\right)(t-t_s)\right]\right\}, t_s \le t \le t_s + T \quad (1)$$

It is also possible to use the equivalent baseband signal as shown below to indicate the OFDM symbol beginning with $t = t_s$:

$$s(t) = \sum_{i=-N/2}^{N/2-1} d_{i+N/2} \exp\left[j2\pi \frac{i}{T}(t-t_s)\right], t_s \le t \le t_s + T \quad (2)$$

Among them, the real part and imaginary part in formula (2) respectively correspond to the in-phase component and the orthogonal component of the OFDM symbol. In practice, they can be multiplied by the cos component and sin component of the subcarrier to form the final OFDM signal.

3.2 The Technical Principle of ACO-OFDM

The OFDM signal is a bipolar signal, but for the traditional intensity modulation/direct detection optical communication system, the bipolar signal cannot be directly used because the light intensity cannot appear negative. Therefore, for optical OFDM, the usual solution is to add a DC bias DC bias to the OFDM signal during electrical-optical signal conversion, so that the bipolar signal becomes a unipolar signal, which can be transmitted on light.

However, the use of DC-biased OFDM will increase the average optical power of the transmitted optical signal while reducing the modulation depth, resulting in low power efficiency of the system. Now a new ACO-OFDM method can be used to solve the problem of bipolar OFDM signals. ACO-OFDM is considered to cut off the part of the original OFDM signal that is less than 0, leaving only positive values.

Figure 3.1 shows that the specific process of the ACO-OFDM system is: at the transmitting end, the original signal is first subjected to channel coding and PSK or QAM modulation, and the mapped signal is serial-parallel converted into a parallel data stream, and the pilot signal is inserted, Hermitian mapping, IFFT, adding a cyclic prefix, zeroing the negative part of the signal, and then converting it into a serial data stream, forming an ACO-OFDM symbol and transmitting it into the wireless channel.

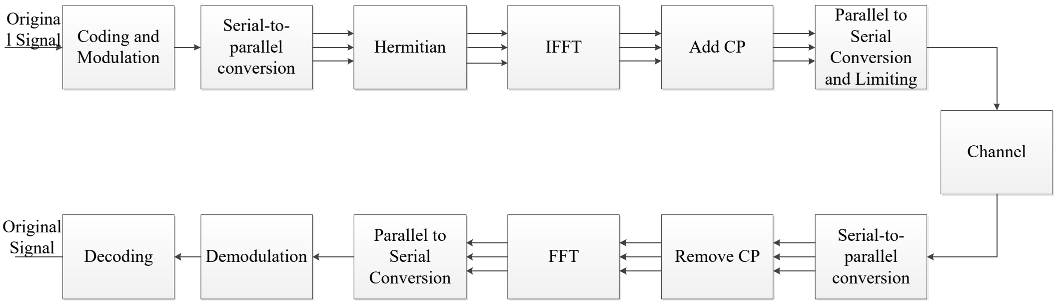

Figure 3.1 Block diagram of visible light communication system based on ACO-OFDM

When a signal is detected at the receiving end, the signal is first converted into a parallel data stream, the cyclic prefix is removed, and the parallel data stream is converted into a serial data stream after FFT. At this time, the PSK or QAM modulated data is obtained. The original data can be obtained by corresponding demodulation.

Hermitian Mapping

Suppose the time domain sampling of an OFDM symbol in the baseband without cyclic prefix is：

$$x(k) = \frac{1}{N}\sum_{m=0}^{N-1} X_m \exp\left(\frac{j2\pi km}{N}\right),\quad 0 \le k \le N-1 \quad (3)$$

Where： $x(k)$ represents the sampled value sequence in the time domain； k represents the serial index of time sampling；N represents the number of subcarriers； X_m represent the frequency domain data symbol modulated onto the m-th subcarrier after mapping.

When X has a Hermitian symmetric structure：

$$\begin{aligned} X &= (X_0, X_1, X_2, \cdots, X_m, \cdots, X_{N-1}) \\ &= (X_0, X_1, X_2, \cdots, X_{N/2-2}, X_{N/2-1}, X^*_{N/2-1}, \cdots, X^*_1) \end{aligned} \tag{4}$$

Where： X^* represent the conjugate of X ,The OFDM signals obtained after IFFT are all real-valued signals. X in this case, if only odd-numbered subcarriers are selected to transmit modulated data, and at the same time, even-numbered carrier modulated data is set to zero, which is expressed as:

$$X = (0, X_1, 0, \cdots, X_1, 0, X^*_{N/2-1}, \cdots, 0, X^*_1) \tag{5}$$

Then when X satisfies the above structure, the OFDM signal obtained after IFFT is a real value, and the part less than zero is set to zero before transmission, the amplitude of the odd-numbered information transmitted after the debit becomes the original general, and the other The information is not affected. This method of making the signal meet real-valued unipolarity is called asymmetric clipping (ACO).

Suppose the time domain expression of the OFDM signal after IFFT transformation is $x(t)$, $x_{ACO}(t)$ represents the unipolar ACO-OFDM signal after $x(t)$ is limited：

$$x_{ACO}(t) = \begin{cases} x(t), x(t) > 0 \\ 0, x(t) \le 0 \end{cases} \tag{6}$$

The ACO-OFDM system uses the odd-numbered sub-carrier to transmit data in the sub-carrier allocation, and the even-numbered sub-carrier does not transmit information. This method brings two advantages: First. The single-polarization operation of the signal can be realized directly by the method of zeroing the complex signal, which is relatively simple; second, the noise generated during the asymmetric limiting operation only falls on the even carrier that does not transmit information.

Guard Interval and Cyclic Prefix

In the OFDM system, inserting a guard interval between OFDM signals can eliminate inter-symbol interference to the greatest extent. The length of this guard interval is generally greater than the maximum delay extension of the wireless channel, so that the component of a symbol generated by multipath propagation is not will interfere with the next symbol.

In the guard interval, it is not necessary to add a signal, that is, the guard interval is a blank transmission time. However, in the OFDM system, due to multipath propagation, the blank guard interval will cause inter-channel interference (ICI), which will cause the gap between the sub-carriers. The destruction of orthogonality causes interference between different sub-carriers.

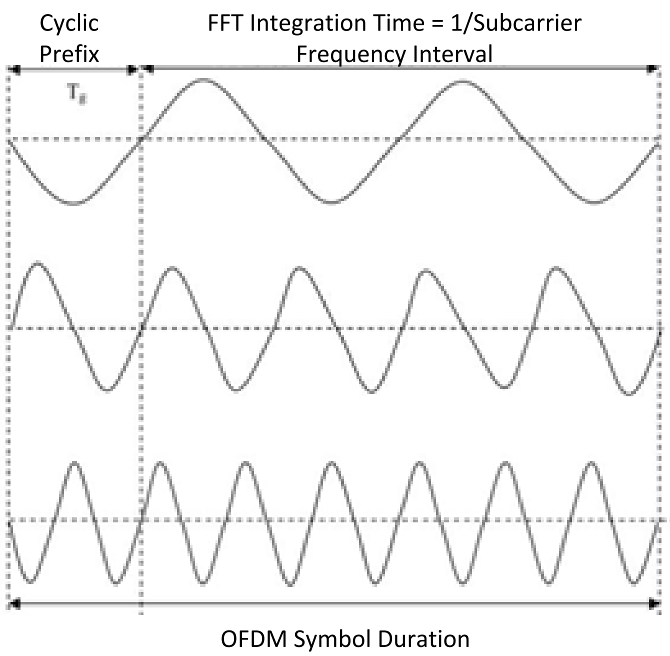

Figure 3.2 OFDM symbols with cyclic prefix

As a result, the original OFDM signal with a width of T can be periodically extended, using the extended signal as a guard interval, as shown in Figure 3.2. The signal in the guard interval is called the cyclic prefix (Cyclic prefix). The signal of the cyclic prefix is the same as the part of the tail time of the OFDM signal. The OFDM symbol transmitted in this way is at the receiving end, and the part with the initial time is first removed, and the remaining part with a width of T is Fourier transformed, and then demodulated. In the process of time domain convolution, the periodicity of OFDM symbols can be well protected by adding a cyclic prefix, and the ICI of other subcarriers is reduced or eliminated.

4.1 ACO-OFDM System Simulation

This article uses Simulink software to build an ACO-OFDM system. The model is shown in Figure 4.1. The source sampling time is 0.001, 128 sub-data carriers, 512-point FFT, cyclic prefix length 16,1024 OFDM symbols, and the bit error rate statistics module accepts Extension 131076.

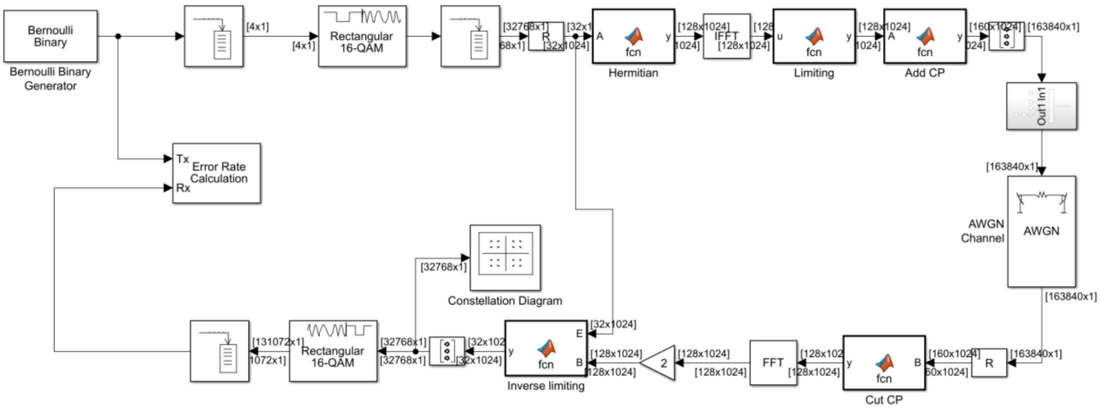

Figure 4.1 ACO-OFDM system model

Set the SNR of the Gaussian white noise module to 40, run the simulation, and get the ACO-OFDM symbol constellation diagram as shown in Figure 4.2.

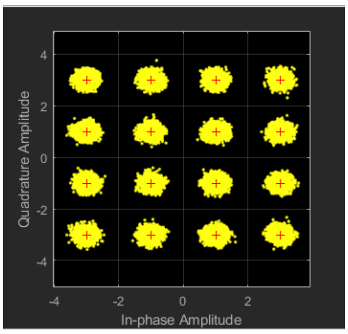

Fig. 4.2 star constellation

It can be observed from Figure 4.2 that the ACO-OFDM technology still decomposes the data stream into several independent sub-data streams, which greatly improves the spectrum utilization and maintains the orthogonality of each sub-data stream. As shown in Figure 4.2, the ACO-OFDM system mapping in this article uses 16QAM modulation. After the transmitter transmits the signal, the constellation diagram after removing the cyclic prefix, FFT, and inverse clipping after the channel (direct link and Gaussian white noise) is removed. The distortion is small.

4.2 Bit Error Rate Simulation

This article then carried out a comparison simulation of the bit error rate for BPSK, QPSK, 16QAM, ACO-OFDM, and PPM. The sampling time of the Bernoulli binary generator is 0.001, the constellation sequence is Gray, the simulation duration is 100s, and the bit error rate range: 0 —40, the simulation results are shown in Figure 4.3.

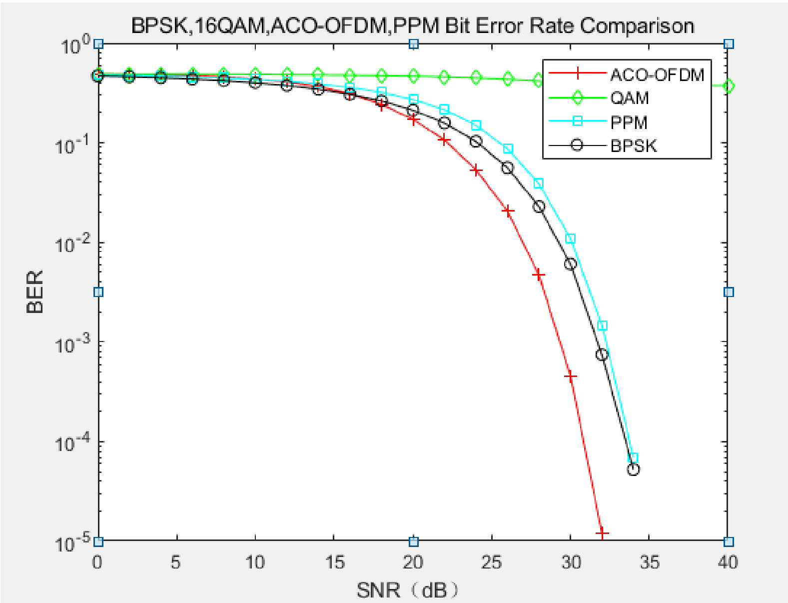

Figure 4.3 BPSK,QPSK,16QAM,ACO-OFDM,PPM bit error rate comparison

As shown in Figure 3.3, the original signal transmitted by the source is transmitted to the visible light communication channel (direct link, Gaussian white noise) after different modulation methods, and after demodulation, the ACO-OFDM system has the lowest bit error rate, and the PPM system The bit error rate of the BPSK system and the QPSK system is basically the same. The 16QAM system has the highest bit error rate and with the increase of the signal-to-noise ratio, the decrease is not large. So in terms of the bit error rate, the modulation method adopts ACO-OFDM technology. The visible light communication system has the best performance.

5. Channel Coding

Due to the interference and fading in the channel during the transmission of the digital signal, error codes are generated in the transmitted data stream, thereby causing signal distortion at the receiving end. Therefore, through the link of channel coding, the digital signal adopts error and error detection coding technology, and the data stream is processed accordingly, so that the system has a certain error correction ability and anti-interference ability, which can greatly avoid bit errors in the code stream transmission happened.

Channel coding technology has been widely used in mobile communications and wired communications. There are few researches on channel coding in visible light communication systems. Therefore, the research and implementation of channel coding in visible light communication systems are particularly important for improving the performance of visible light communication systems. Below we briefly introduce several main coding methods used in simulation research.

5.1 Linear Block Code

Linear block codes are represented by (n, k, d), n is the code length, d is the mi nimum distance of the code, and k is the length of the information group. Linear bloc k code encoding requires two matrices, one is the generator matrix, represented by G, and the other is the check matrix, represented by H. Find a set of code words in cod e words $g_{k-1}, g_{k-2} g_{k-3}, \cdots, g_1, g_0$, So that all code words can be represented by this set of numbers $C = m_{k-1} g_{k-1} + m_{k-2} g_{k-2} + m_{k-3} g_{k-3} + \cdots + m_1 g_1 + m_0 g_0$. These codewords form t he generator matrix G of the linear block code;

The error correction capability of linear block codes is closely related to the minimum distance d. In the linear block code encoding process, the setting of the d value requires special attention:

（1）When the number of random errors detected is e， $d \geq e+1$;

（2）When the number of corrected random errors is t, $d \geq 2t+1$;

（3）When correcting the number of errors t and detecting the number of errors e at the same time（ $e \geq t$ ）, $d \geq t+e+1$;

（4）When correcting the error number t and deleting the error number e at the same time, $d \geq 2t+e+1$.

5.2 BCH Code

The BCH code is a linear block code in a finite field, which has the ability to correct multiple random errors. Given any finite field $GF(q)$ and its extended field $GF(q^m)$, Where q is a prime number or power of a prime number, m is a positive integer.

The most commonly used BCH code is the binary BCH code. All symbols of the binary BCH code are composed of 0 and 1, which is convenient for the realization of the hardware circuit. The binary primitive BCH code has the following important parameters:

1. Yard length: $n = 2^\wedge m - 1$;

2. Check bit length: $n - k \leq m * t$;

The generator polynomial of the BCH code is the product of the 2t smallest polynomial least common multiple of $GF(q^\wedge m)$. The generator polynomial of the BCH code with error correction capability t is $g(x) = LCM\{m_1(x), m_2(x), \cdots, m_{2t-1}(x), m_{2t}(x)\}$, Where LCM represents the least common multiple, m(x) is the smallest polynomial.

Known from the polynomial theory, if the element a^i in the finite field $GF(2^\wedge m)$ is m-th degree, which is approximately the root of the polynomial $m_i(x)$, $(a^i)^2, (a^i)^4, (a^i)^8, \cdots$ is also the root of $m_i(x)$, $(a^i)^2, (a^i)^4, (a^i)^8, \cdots$ is called the conjugate root system. If two roots are conjugate, they have the same minimum polynomial. Therefore the generator polynomial:

$$\begin{aligned} g(x) &= LCM\left\{m_1(x), m_2(x), \cdots, m_{2t-1}(x), m_{2t}(x)\right\} \\ &= m_1(x) * m_3(x) * \cdots * m_{2t-1}(x) \end{aligned} \quad (7)$$

Through the above steps, the generator polynomial of the BCH code can be obtained. The information can be encoded by obtaining the generator polynomial.

5.3 Convolutional Code

Convolutional code (n,k,N) is a non-blocking code. Although convolutional codes also encode k-bit information segments into n-bit code groups, the supervision symbols are not only related to the current k-bit information segments, but also the same as the previous $(N-1)$ information. Paragraph related. In other words, the supervision symbols in a code group supervise N information segments. Usually N is called the coding constraint degree, which means the number of code segments related to each other during coding. The code rate is defined as: $R_c = k / n$ 。

Figure 5.1 is the (2,1,2) convolutional code encoder used in this paper with output code length n=2, degree of constraint N=2, input bit k=1. The current input signal, the previous state signal and the previous two state signals are subjected to a modulo two addition operation as the first output, and the current input signal and the previous two state input signals are used as the second output.

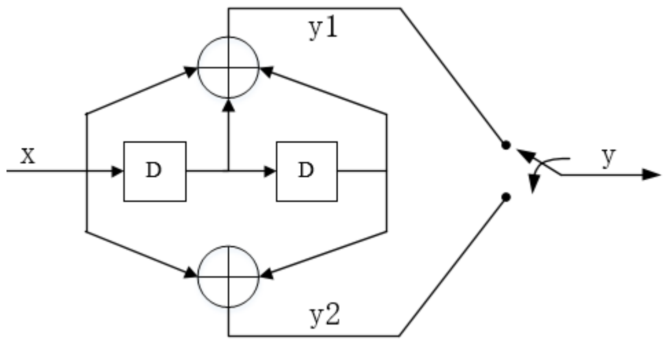

Figure 5.1 (2,1,2)Convolutional code encoder

This article adopts Viterbi algorithm as the decoding of convolutional codes. The basic principle of this algorithm is to compare the received signal sequence with all possible transmission signal sequences, and select the sequence with the smallest Hamming distance as the current transmission signal sequence.

6. ACO-OFDM System Coding Simulation

This article uses simulink to build an ACO-OFDM system using linear block codes, BCH codes and convolutional codes, and compares the bit error rates of different coding methods. Linear block code generation matrix: [[1 1 0; 0 1 1; 1 1 1; 1 0 1] eye(4)]; convolutional code: poly2trellis(7, [171 133]); BCH code word length 15, The message length is 5, and the code rate is 1/3. The simulation results are shown in Figure 6.1.

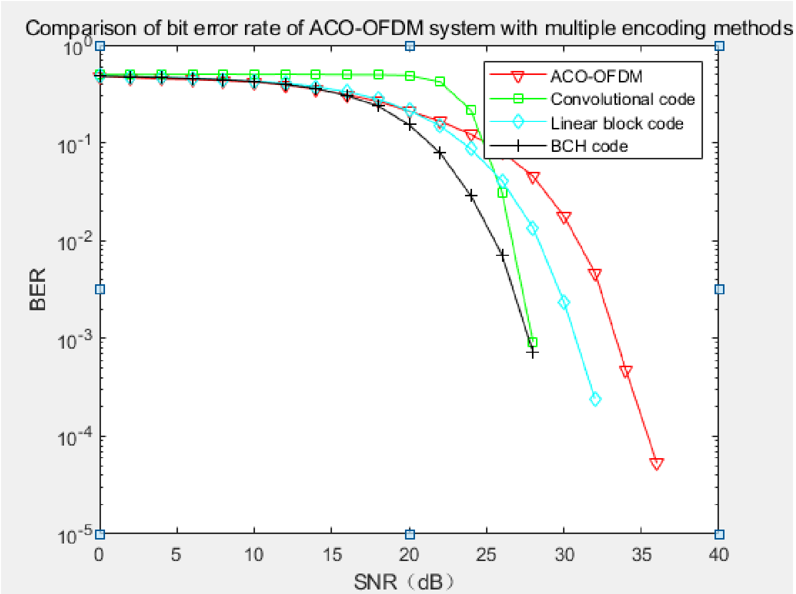

Figure 6.1 Comparison of bit error rate of multiple encoding methods

It can be seen from Figure 6.1 that after the signal generated by the source is subjected to different encoding methods, ACO-OFDM systems, and corresponding decoding, when the channel signal-to-noise ratio is greater than 28dB, the convolutional code has the fastest convergence speed and errors. The bit rate is the lowest; the second is the case of using BCH coding, and the linear block code has the worst improvement ability on the bit error rate.

7. Concluding Remarks

This article briefly introduces the general system framework and channel model of visible light communication, and explains the principles of ACO-OFDM system and PPM system, Hermitian mapping and cyclic prefix. Simulink is used to simulate the visible light communication system based on ACO-OFDM technology and PPM modulation technology, and compares and analyzes the bit error rate with BPSK, QPSK and 16QAM. The experimental results verify the feasibility of ACO-OFDM technology in visible light communication systems and the relatively low bit error rate performance. Combined with ACO-OFDM technology, compared with other modulation methods, it has strong anti-fading ability, high spectrum utilization, suitable for high-speed data transmission, simple modulation and demodulation, no complex equalization technology at the receiving end, and strong anti-inter-symbol interference (ISI) ability, etc. Advantages, choosing ACO-OFMD technology as the modulation method of the visible light communication system has more advantages. After that, this article introduces the principle and compares and simulates the three coding methods of linear block code, BCH code and convolutional code. It is concluded that the ACO-OFDM system based on convolutional code channel coding is more suitable for the choice of visible light communication system.

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