

# Comparative Analysis of Channel Coding in Communication Technology

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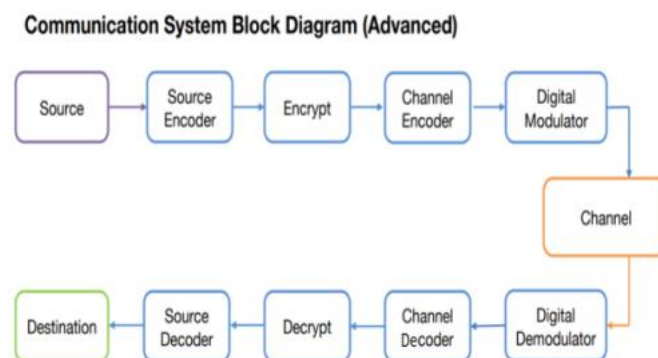
**Abstract.** The performance analysis of Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) employing error-correcting code is highlighted in this work. Several error-correcting code types were employed via an Additive White Gaussian Noise (AWGN) channel to determine the bit error rate. Two techniques were utilized as encoders and decoders: hamming code and cyclic code. Source coding used Huffman coding. Essentially, signal energy to noise power density ratio ( $E_b/N_0$ ) and the bit rate error (BER) were used to measure performance. Comparisons were also made between BPSK and QPSK in terms of symbol error capability. MATLAB R2022b was the program used for all the simulations. The conclusion is that different coding methods have a certain error correction range, and the signal-to-noise ratio (SNR) can only reduce the BER in the error correction range, and if it is not within the error correction range, it will increase the bit error rate.

**Keywords:** Error-correcting code, BER, AWGN, SNR.

## 1. Introduction

In the dynamic digital communication environment, the basic operation of the digital communication system is always the cornerstone of effective and secure data transmission, and plays a key role in ensuring efficient and secure information transmission. Today, with the unprecedented explosion of data volume and the continuous development of communication technology, people's demand for information has increased dramatically, and it is imperative to understand the complex operation of digital communication systems. In this case, digital communication systems must not only transmit large amounts of information efficiently, but also ensure the security and accuracy of the data, as well as the high performance and reliability of the transmission.

As shown in Fig. 1, these components together form the basic model of a digital communication system. After the information source has been encoded, encrypted, channel encoded and modulated, it is transmitted in the channel, then demodulated, decoded, and decrypted, and finally restored to the original information at the receiving end. The whole process ensures the reliability, security, and efficiency of the information for a variety of communication environments and requirements, some of which are discussed below.



**Fig. 1** Communication system block diagram.

### 1.1. Source Encoding and Decoding

During the next years, highly efficient and high reliable source en/decoding technologies will become key applications for the deep-space communication systems [1]. In communication systems, source coding and decoding are key steps performed to improve the efficiency and reliability of data transmission. This process encodes the information to make it more compact, reducing the bandwidth or storage space required for transmission and reducing the BER. The receiving end then reduces the information back to its original form by decoding. Among other things, source coding is the process of mapping a sequence of symbols generated by an information source into a shorter coded sequence. The aim is to reduce the number of bits required for transmission or storage and increase the efficiency of the system. And source decoding is the process of reducing the coded information sequence to the original information. The decoder decodes the code word according to the coding rules and regenerates the original symbol sequence. Among them, Huffman coding and Huffman decoding are well known. When selecting a source coding scheme, the choice should be based on the characteristics and requirements of the communication system to balance the coding complexity and reduce the BER.

### 1.2. Channel Encoder and Decoder

In communication systems, channel coding and decoding are key techniques used to improve the reliability of communication. Channel coding is used to introduce redundancy in the transmission of information for error detection and correction, while channel decoding is used to restore the received information and eliminate as much as possible the errors introduced during transmission. The decoder is responsible for the decompression of code word, refinement, and reconstruction of channel state information [2]. Channel coding generally includes convolution codes, Hamming codes, etc. in forward error correction codes. The main function of channel coding is to perform error control. In this process, the signal is disturbed by noise during transmission and the noise cannot be eliminated in the communication, the rational channel is free of noise, but the noise cannot be eliminated in the transmission process. These noises cause errors in the transmitted signals, and to minimize the errors, "supervisory code words" are added to the code elements to be transmitted to monitor whether the transmitted code elements are incorrect or not. The receiver detects and corrects the error by adding the supervisory code element. The process of adding supervisory code elements is called channel coding and is implemented by a channel coder. In addition, certain coding schemes can increase the capacity of a channel to carry more information for a given bandwidth and signal-to-noise ratio.

### 1.3. Digital Modulator and Demodulator

Digital modulation and demodulation are core technologies in digital communication systems used to convert digital information into analog signals for transmission and then reduce it to digital form at the receiving end. This process allows information to be transferred between digital systems while making full use of the analog channel for transmission. There are five primary classes of modulation that abound in digital data transmission in terms of constellation and modulation schemes: cubic, orthogonal, circular, rectangular, and hexagonal [3]. Common modulation methods are BPSK, which uses two phases to represent the numbers 0 and 1. QPSK, which uses four phases to represent each symbol. hexadecimal phase shift amplitude modulation, which uses four phases and four different amplitudes in the phase and amplitude dimensions, respectively.

For modulation, the spectrum of the digital base band signal is ganged to the high frequencies to form a band pass signal suitable for transmission over the channel, and a digital demodulator is available at the receiving end to restore the digital base band signal using either coherent demodulation or incoherent demodulation. Digital modulation and demodulation are widely used in mobile communications and digital radio and television [4], for example, modulation methods such as QPSK and 16QAM used in wireless networks and QAM for the transmission of digital television signals. Due to the need to consider the BER performance, digital modulation and demodulation techniques can be used in different application scenarios to select the appropriate modulation method

as well as the corresponding demodulation method to guarantee reliable digital communication in noisy and distorted channels.

### 1.4. Channel

A channel is the medium or path through which information is transmitted from a transmitter to a receiver, allowing signals to travel along that path. A channel can be a physical medium (such as a wire, fiber, or wireless medium) or a logical medium (such as a logical communication path in a computer network). The primary function of a channel is to provide a path for the transmission of information, but it can also introduce noise, distortion, or other interference into the transmitted signal. Channel noise is one of the main sources of interference in a communications system. The presence of noise distorts the signal, allowing the receiver to misinterpret the transmitted information, thus increasing the bit error rate. A higher SNR usually corresponds to a lower BER, so when designing real signal systems, the BER is reduced to improve the reliability of the digital communication system.

## 2. Source Encoding and Channel Encoding

### 2.1. Huffman Source encoding

Huffman coding is a way of variable length coding (VLC), proposed by Huffman in 1952 [5]. This method provides the unique codes according to the probability of the original code occurrence and ensures that the average length is the shortest, so it is also called the optimal binary tree.

Firstly, the symbols need to be arranged by probabilities, then put them in sequence. Secondly, both the smallest probabilities need to be found in all values, and add them to construct a new probability. Next, compare the new values with other probabilities and repeat the previous step. Finally, stop circulations when the ultimate result equals one.

The key idea about the binary tree in Huffman Coding is the construction of the Huffman Tree in Fig. 2.

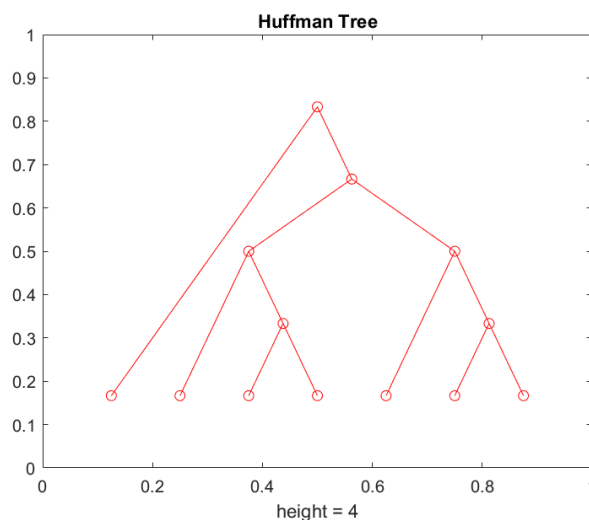


Fig. 2 Huffman tree.

### 2.2. Hamming Channel Code

Hamming codes are capable of correcting one-bit errors. The addition of  $k$  redundant bits to a data of length  $m$  constitutes a code word of  $n=m+k$  bits, and then  $k$  correction factors generated by  $k$  supervisory relations are used to detect and correct the error. In order to be able to correct an error of one bit, the length of the data and the number of redundant bits must satisfy (1), and the coding efficiency of the Hamming code is effectively (2).

$$2^k \geq m + k + 1 \tag{1}$$

$$R = \frac{m}{m+k} \tag{2}$$

In (1),  $m$  is the length of the data, and  $k$  is the number of Hamming code check bits.

### 2.3. Cyclic Channel Code

The cyclic code is a kind of linear block code which satisfy the cyclic property. For a  $(n,k,d)$  linear block code, if any code  $M=(m_n, m_{n-1}, \dots, m_0)$  shifts circularly and then obtain the new code  $M^{(i)}=(m_{n+1}, m_n, \dots, m_1)$  which also belongs to the original linear block code, this  $(n,k,d)$  code is called cyclic code. This kind of codes have a regular algebraic structure and they are subclosed, usually the code polynomial is used to present them [6, 7].

According to (3), the polynomial of degree  $n-1$  can present the cyclic code with length  $n$ , and the another polynomial (4) shows the new relation after left-shifting  $i$  bits. Then the ultimate relationship about the polynomials is showed in (5).

$$M(x) = m_{n-1}x^{n-1} + m_nx^n + \dots m_1x^1 + m_0 \tag{3}$$

$$M^{(i)}(x) = m_{i+1}x^{n-1} + m_{i+2}x^{n-2} + \dots m_nx^{n-i} + m_0x^{n-i-1} + \dots + m_{i-1}x + m_i \tag{4}$$

$$M^{(i)}(x) \equiv x^iM(x) \text{mod}(x^n - 1) \tag{5}$$

## 3. BPSK, QPSK and 16QAM Modulation

In wireless communication, when we want to transmit digital signals, the frequency band position of the digital signal should be high enough, and the frequency band width of the signal should not exceed the passband. Therefore, we need to modulate, the digital baseband signal must modulate a high frequency carrier, so that the baseband signal can be moved to a high enough frequency to form a frequency band communication signal suitable for transmission in the channel. In the actual wireless communication system, the choice of modulation mode is very important. BPSK, QPSK and 16QAM have their own advantages and disadvantages, so the choice must be weighed according to the specific application scenario and system requirements.

### 3.1. BPSK Modulations

BPSK is a modulation scheme that is widely utilized in different communication protocols. Because of its increased tolerance to non-linear degradation and capacity to give an optimum receiver sensitivity augmentation with balanced detection, it ensures quality of service (QoS) over weak wireless channels. The BPSK signal and its modulation types have been widely utilized in phonology and communications [8] because of their ease of implementation and mature technology. The detection of BPSK signals has been a research popularity in the academic circle. BPSK uses binary signals to represent data, with the carrier phase changing 180 degrees depending on the value of the bit within each bit interval.

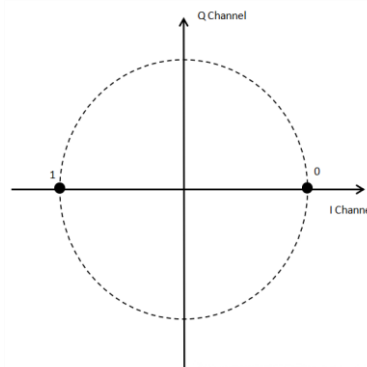


Fig. 3 BPSK constellation diagram.

In Fig. 3 constellation diagram, the BPSK signal switches between two points, which represent the phase of 0 and  $\pi$  respectively. Specifically, when the data is 0, the phase of the carrier is 0; when the data is 1, the phase of the carrier is  $\pi$  [8].

At the receiving end, the synchronization signal is used for demodulation, and the original data is recovered by detecting the phase. The advantages of BPSK are simple, easy to implement, and stable performance in noisy environments. However, since it can only switch between two points, the frequency band utilization is low.

### 3.2. QPSK Modulations

One commonly used multi-level format with differential detection receivers is QPSK. This format is more spectrally efficient than BPSK because the bit rate per symbol is doubled, while the spectral footprint is almost the same as BPSK [9]. QPSK uses four different phases to represent two bits of information.

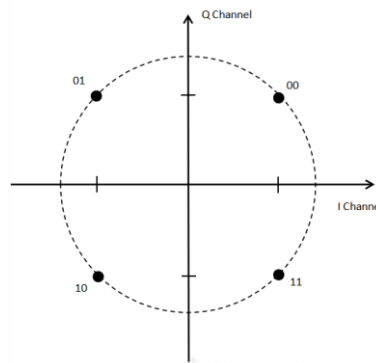


Fig. 4 QPSK constellation diagram.

In the constellation diagram in Fig. 4, the QPSK signal switches between four points representing the phases of 00, 01, 10 and 11. Specifically, when the data is 00, the phase of the carrier is 0; when the data is 01, the phase of the carrier is  $\pi/2$ ; when the data is 10, the phase of the carrier is  $\pi$ ; when the data is 11, the phase of the carrier is  $3\pi/2$ .

At the receiving end, the synchronization signal is used for demodulation, and the original data is recovered by detecting the phase and time. QPSK is superior to BPSK in bandwidth utilization and anti-noise performance because it can represent more information per symbol. However, QPSK is more complex to implement than BPSK and requires more precise timing and frequency synchronization.

## 4. AWGN Channel and BER

The AWGN channel adds noise to the modulated signal, which is additive in nature, time independent, and has a Gaussian distribution structure. The Gaussian distribution is made up of the probability density function (pdf) with a mean of zero ( $=0$ ) and a noise variance of two, as shown in (6).

$$\text{Pdf}_{\text{AWGN}}(x) = \frac{1}{\sqrt{2 * \pi * \sigma^2}} * e^{-\frac{(x-\mu)^2}{2 * \sigma^2}} \quad (6)$$

Equation (7) shows the mathematical calculation of the BER for the AWGN channel.

$$\text{BER}_{\text{AWGN}} = Q(1/\sigma) = 0.5 * \text{erfc}(\sqrt{\text{SNR}}) = 0.5 * \text{erfc}(\sqrt{2 * R * (\text{Eb}/\text{No})}) \quad (7)$$

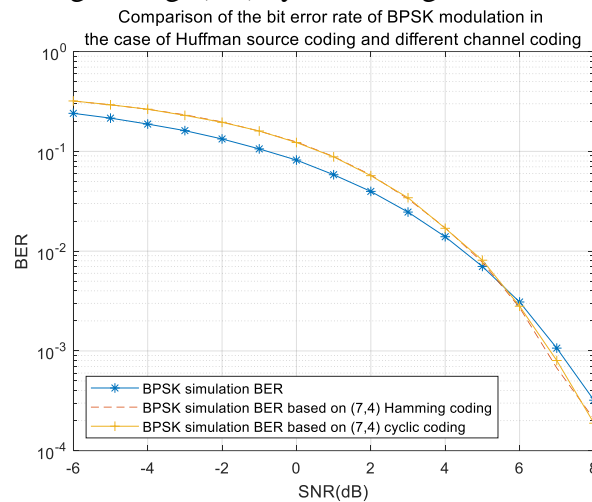
The capacity of the AWGN channel can be expressed as the highest rate at which data can be transmitted without loss, calculated by (8) [10].

$$C_{\text{AWGN}} = 0.5 * \log_2(1 + \text{SNR}) = 0.5 * \log_2(1 + 2 * R * (\text{Eb}/\text{No})) \quad (8)$$

## 5. Simulation Results

### 5.1. Comparison of Hamming Code and Cyclic Code in the Case of BPSK Modulation

Simulation results of comparison of the BER of BPSK modulation in the case of Huffman source coding and different channel coding in Gaussian channel have been presented in this section. Channel coding includes (7,4) Hamming coding, (7,4) cyclic coding, and non-channel coding.

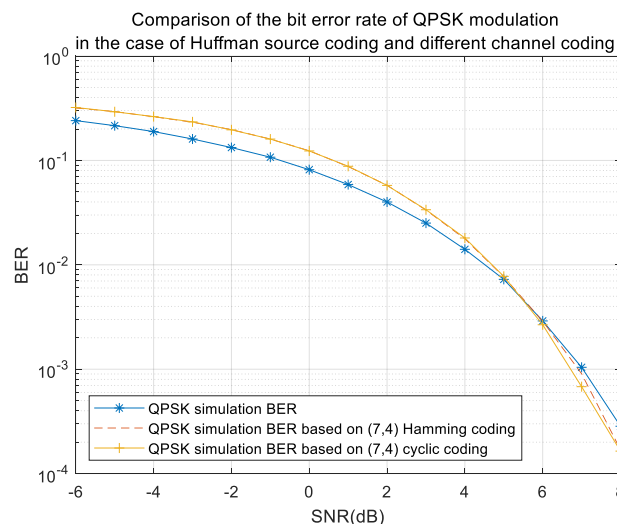


**Fig. 5** Comparison of the BER of BPSK modulation in the case of Huffman source coding and different channel coding in AWGN channel.

In Fig. 5, before the SNR is equal to 5 dB, BER of BPSK modulation based on (7,4) Hamming coding is similar with that based on (7,4) cyclic coding and is higher than that based on non-channel coding. But after the SNR is equal to 5 dB, BER of BPSK modulation based on (7,4) Hamming coding and that based on (7,4) cyclic coding is smaller than that based on non-channel coding.

### 5.2. Comparison of Hamming Code and Cyclic Code in the Case of QPSK Modulation

The digital communication system is similar to the previous section, except that BPSK becomes QPSK in this section.



**Fig. 6** Comparison of the BER of QPSK modulation in the case of Huffman source coding and different channel coding in AWGN channel.

In Fig. 6, the results are similar to those of QPSK. Before the SNR is equal to 5 dB, the BER of QPSK modulation based on (7,4) Hamming coding is similar to that based on (7,4) cyclic coding and higher than that based on non-channel coding. However, after the SNR is equal to 5 dB, the BER of

QPSK modulation based on (7,4) Hamming coding and that based on (7,4) cyclic coding is lower than that based on non-channel coding.

## 6. Conclusion

In this study, one hundred thousand information sources consisting of one to six and their probability distributions are [0.5 0.125 0.125 0.125 0.125 0.0625 0.0625], respectively, will be put through Huffman source coding. This source of information is discriminated by channel less coding, cyclic code and Hamming code and modulated by BPSK and QPSK respectively, after additive Gaussian white noise. The modulated code word is obtained. The symbols obtained after decoding are compared with the information source for BER at different signal to noise ratios. The conclusion is that different coding methods have a certain error correction range, and the signal-to-noise ratio can only reduce the bit error rate in the error correction range, and if it is not within the error correction range, it will increase the bit error rate.

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