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Building and evaluating the performance of a digital data transmission system over a noisy Rician fading channel using a 16-QAM modulator, Hamming source encoding, and BCH channel encoding

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Abstract

In today's digital age, digital data transmission methods are becoming popular. In a wireless communication environment, interference can cause data loss and distortion. In this paper, the author builds and evaluates the performance of a data transmission system using a noisy Rician fading channel. This system combines the use of 16-QAM modulators, Hamming source coding, and BCH channel coding to improve the reliability of data transmission. The performance evaluation of the system is conducted under different interference conditions. The results show that the proposed system is capable of detecting and correcting errors in transmitted data and has good anti-interference ability.

Keywords: Digital data transmission; Rician fading; 16-QAM modulator; Hamming source coding; BCH channel coding; System performance.

1. Introduction

Wireless communication systems encounter various challenges, such as environmental interference, signal attenuation, and obstacle-induced distortion. Particularly, Rician fading stands out as one of the most intricate and unpredictable noise types, notably in urban or indoor settings. The transmission of data through a noisy Rician fading channel often severely compromises communication system performance. Signal fluctuations over time result in data loss and diminished communication quality. Consequently, the research and development of methodologies and techniques to enhance communication performance within such environments are imperative.

Numerous studies have contributed to the understanding and improvement of communication systems facing challenges like Rician fading. In [1], Proakis and Salehi provide insights into various digital communication techniques and challenges. In [2], Haykin and Moher offer contemporary perspectives on wireless communication technologies and their challenges.

Furthermore, empirical studies have been conducted to compare the performance of different error-correcting codes under specific channel conditions. In [3], Faisal et al. compare Reed-Solomon and BCH codes over Rayleigh fading channels, shedding light on their efficacy in error correction. In [4], Anish et al. provide valuable insights into their performance under different conditions.

Moreover, advancements in error correction techniques have been explored in the context of cooperative wireless networks. In [5], Adeleke and Akande employ game theory to analyze cooperative wireless networks utilizing error

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control coding. In [6], Saurabh and Singh evaluate the "Reed Solomon Code Performance for M-ary Modulation over the AWGN Channel," offering a nuanced understanding of its effectiveness. In [7], Himanshu et al. conducted a "Performance Evaluation and Comparative Analysis of Various Concatenated Error Correcting Codes Using BPSK Modulation for the AWGN Channel," providing a comparative assessment of different error correcting codes.

In addition, studies have focused on the comparative analysis of error-correcting codes in the presence of specific channel conditions. In [8], Arjun and Sudesh compare Reed Solomon and BCH codes in the presence of AWGN channels, elucidating their performance disparities. In [9], Sanjeev and Ragini undertake a "Performance Comparison of Different Forward Error Correction Coding Techniques for Wireless Communication Systems," offering insights into the suitability of various error correction techniques.

Overall, these studies collectively contribute to the development of methodologies and techniques aimed at enhancing communication performance in noisy Rician fading channels, thus facilitating more reliable wireless communication systems. In this paper, the authors build a data transmission system based on a Rician fading noise channel, combining the use of a 16-QAM modulator, Hamming source encoding, and BCH channel encoding. From there, evaluate the reliability and performance of the data transmission system.

2. Build a digital data transmission system

2.1. General block diagram of the system

The data transmission system uses a noisy Rician-fading channel. This system combines the use of 16-QAM modulators, Hamming source coding, and BCH channel coding. Therefore, the general block diagram of the system includes the following components:

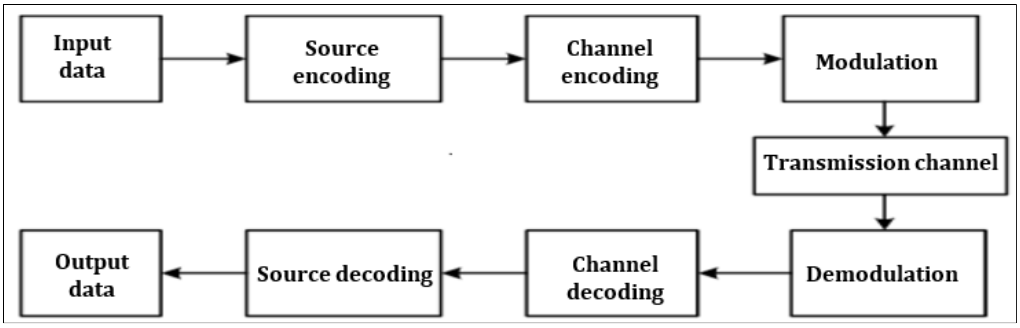

Figure 1 General block diagram of the digital data transmission system

- Input data block: Used to create input data.
- The transmitter side includes:
  Source encoding block: Encode the input data source using hamming code (7, 4).
  Channel encoding block: Encode the data channel coming from the source encoding block using the BCH code (15, 7).
  Modulation block: Modulates the input data coming from the channel coding block using a 16-QAM modulator.
- Transmission channel: Use the Rician-fading transmission channel.
- The receiver side includes 16-QAM demodulation, BCH channel decoding, and Hamming source decoding.
- Output data block: Data is restored.

2.2. Source encoding and decoding blocks

The proposed system uses the Hamming encoding and decoding method (7, 4). Hamming code is a linear error-correcting code used to detect and even correct errors in transmitted data. Hamming codes can detect single- and double-bit errors and are also capable of correcting single-bit errors. Typical parameters for Hamming codes include:

- Hamming distance: This is the number of bits that differ between two encoded words in the Hamming code. It is used to calculate the number of errors that can be detected or corrected. The hamming distance can also be called the signal distance.

- Hamming weight: The Hamming weight of a codeword is the number of 1's in that codeword. For example, the codeword 00111010 has a hamming weight of 4. The Hamming weight provides information about the error level of the codeword and plays an important role in the error detection and repair process.

2.3. Channel encoding and decoding blocks

The proposed system uses the BCH channel encoding and decoding method (15, 7). BCH (Bose-Chaudhuri-Hocquenghem) codes are a class of cyclic error-correcting codes built on a finite field. The BCH token has several important features:

- Adjust the number of correctable errors: When designed, the BCH code allows for precise adjustment of the number of errors it can correct. Specifically, the BCH code can be designed to correct multiple-bit errors in the binary code.
- Easy decoding: The BCH code can be easily decoded using an algebraic method called syndrome decoding. This simplifies decoder design for BCH codes while also saving energy in electronic hardware applications.
- Generating polynomial: Used to generate codewords from the input message during encryption and check the correctness of data during decoding. Generating polynomials are often represented as a series of coefficients. The codewords of the BCH code are generated by multiplying the message by the generating polynomial.
- BCH codes are used in many applications, such as satellite communications, CD and DVD players, disk drives, SSDs, and two-dimensional barcodes.

2.4. Modulation and demodulation blocks

The proposed system uses 16-QAM modulation and demodulation methods. 16-QAM modulation is a modulation method that combines amplitude modulation and phase modulation. The name orthogonal amplitude modulation comes from the fact that a 16-QAM signal is created by adding together 16-level amplitude modulation signals whose carriers are orthogonal. The 16-QAM modulation process is performed as follows: The encoded input bit stream carrying m bits is divided into two signal streams, I and Q. Each encoded signal carries m/2 bits, corresponding to two m/2 states. The state levels of the I and Q signals are represented in the constellation diagram. After converting from a digital signal to an analog signal, the two signals are passed through the I and Q modulators, which are 90^0 out of phase. The result of this modulation process will form a cluster of points called a constellation. Constellation diagrams are graphically depicted to visually observe the quality and distortion of a digital signal. The constellation diagram represents the amplitude and phase of the carrier wave mapped in the complex plane. In the constellation diagram of Figure 2, noise appears as the direction of the cursor as a circle for each signal state. In short, 16-QAM modulation is a two-way signal modulation method in which an information carrier signal is used to vary the amplitude of two orthogonal carriers.

Table 1 Some typical types of M-QAM modulation

No	Modulation Type	Number of bits I (Q)	Number of bits/symbols	Status number
1	4-QAM	1(1)	2	4
2	16-QAM	2(2)	4	16
3	64-QAM	3(3)	6	64
4	256-QAM	4(4)	8	256

We see that the points of the constellation are distributed according to Gray code (neighboring star points have only one bit different). This Gray code distribution is very significant because most common types of errors occur because the decoded symbol is similar to a nearby symbol. In this case, using Gray code will only result in one bit error while binary code can cause many error bits. The sensitivity of the constellation to disturbances is represented by the distance between the star points. In Figure 1 is the 16-QAM constellation distribution model. We see that if the farthest points in the constellations all have the same amplitude, the distance between neighboring constellation points decreases as the number of points in the constellation increases. This meaning is true for all types of two-way signal modulation. This makes large constellations like 256-QAM much more vulnerable to interference than small constellations like 16-QAM. Figure 3 shows the theoretical BER results for M-QAM modulation. The plot shows the relative BER for each QAM constellation as a function of the SNR per bit and the SNR divided by the number of bits in each symbol. This result proves the above observations to be correct and clearly shows that the SNR ratio changes when the constellation changes.

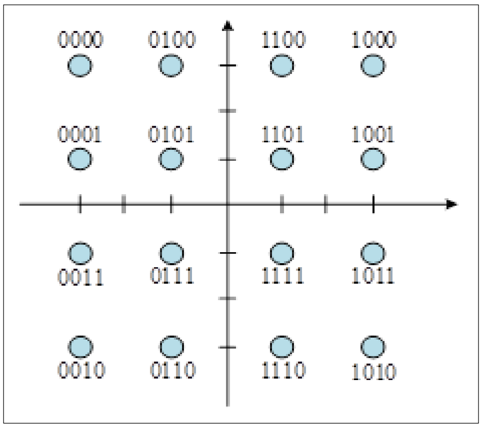

Figure 2 Constellation of a 16-QAM signal

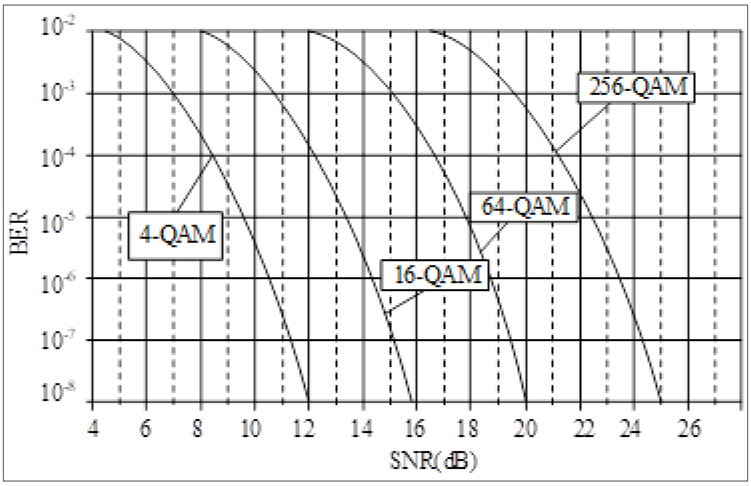

Figure 3 Bit error probability for M-QAM modulation

2.5. Transmission channel

The proposed system uses a Rician fading channel. This is a type of wireless transmission channel in which the transmitted signal is affected by many different transmission paths between the sending and receiving stations. This results in the received signal being reflected from many different sources, causing fading or fluctuations in signal power over time.

In a wireless environment, there can be direct paths between the sending and receiving stations (line-of-sight, LOS), as well as reflected paths from surrounding objects (multipath). A fading Rician channel is a medium with a strong LOS path (direct path) and weaker reflected paths, each with a random phase and possibly different bias coefficients.

The Rician probability distribution function has the form:

$$p_z(z) = \frac{z}{\sigma^2}\exp\left(\frac{-\left(z^2+s^2\right)}{2\sigma^2}\right) I_0\left(\frac{zs}{\sigma^2}\right), z \geq 0 \qquad (1)$$

In there:

$2\sigma^2$ is the average power of the component that does not contain the LOS (Light Of Sight) direct path.

s^2 is the power of the direct line component.

I_0 is the zero degree Bessel function.

The average received power in a fading Rician channel is:

$$P_r = \int_0 z^2 p_z(z)dz = z^2 + 2\sigma^2 \qquad (2)$$

The Rician probability distribution function has the characteristic of depending on the ratio of the direct component energy to the scattered component energy *K.*

$$K = \frac{s^2}{2\sigma^2}$$

Substituting $s^2 = KP_r/(K+1)$ and $2\sigma^2 = P_r/(K+1)$ we can rewrite the rician distribution in terms of K as P_r follows:

$$p_z(z) \quad \frac{2z(K+1)}{P_r}\exp \quad K \quad \frac{(K+1)z^2}{P_r} I_0 \quad 2z\sqrt{\frac{K(K+1)}{P_r}}, z \quad 0 \qquad (3)$$

When $K = 0$, we have no direct path, and the Rician distribution becomes a Reyleigh distribution. With the value $K = \infty$, the Rician distribution becomes a Gaussian distribution. The LOS component of the Rician distribution provides a stationary signal component and helps reduce fading effects.

3. Simulate and evaluate system performance

3.1. System simulation

- The system simulation diagram is presented in Figure 4, including:

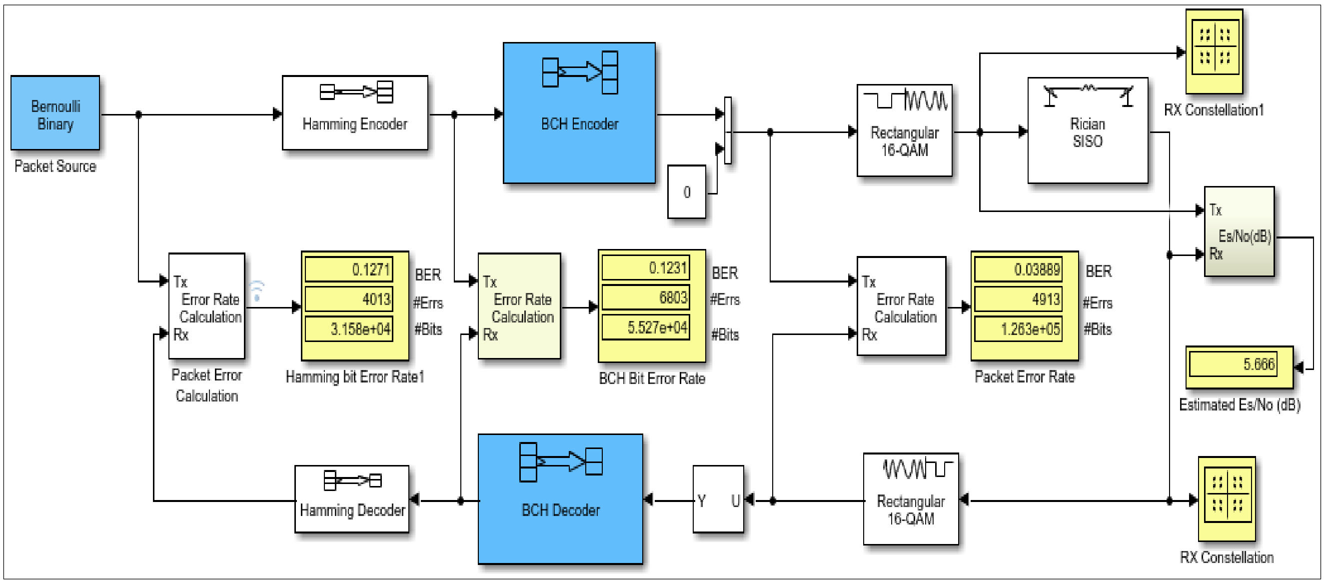

Figure 4 Simulation diagram using Simulink

Bernoulli binary block: used to create input data;

Hamming Encoder Block: Used to encode the Hamming source;

BCH encoder block: used to encode the BCH channel;

Recrangular QAM Modulator block: used to modulate 16-QAM;

Rician SISO block: used to set Rician fading channel parameters;

Error Rate Calculation Block: Used to calculate bit error rate;

Rectangular QAM Demodulator Block: Used to demodulate the received 16-QAM signal;

Hamming Decoder Block: Used to decode Hamming source;

BCH Decoder Block: Used to decode the BCH channel;

- *Simulation parameters*

Bernoulli Binary Block: Generates 4 bits of data;

Hamming Encoder block: Use Hamming Encoding (7,4);

BCH Encoder block: Use BCH (15,7) encoding, generate polynomial G = [1 1 1 0 1 0 0 0 1], primitive polynomial P = [1 1 0 0 1];

Recrangular QAM Modulator Block: Used to modulate 16-QAM, input data 16 bits, distance d = 1;

Rician SISO block: Create a Rician fading channel with K = 3;

- *Simulation results*

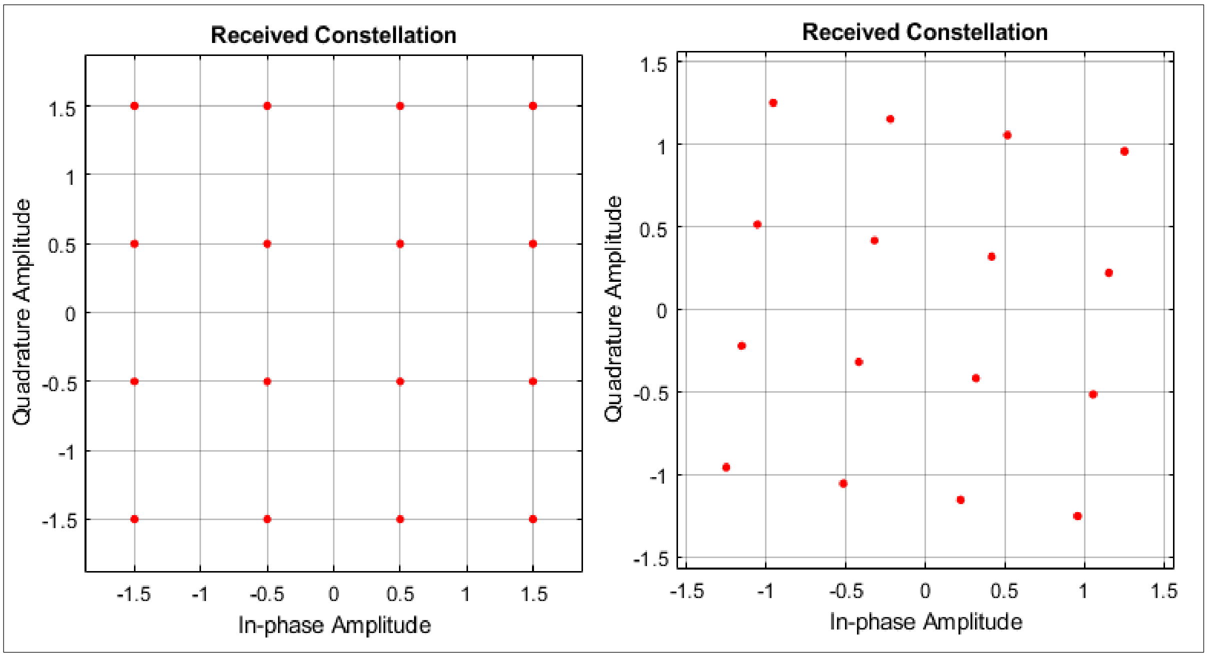

Figure 5 16-QAM constellation distribution

Figure 5 simulates the constellation distribution of 16-QAM modulation before and after transmission through a noisy Rician fading channel.

Before transmitting through the noisy channel, the constellation distribution of 16-QAM is square-shaped with regularly arranged star dots. However, after transmitting through the Rician fading noise channel, the constellation distribution is changed; the constellation points are no longer regular and fluctuate. This demonstrates that noise in the transmission channel affects data transmission, causing variation in the constellation distribution and increasing the bit error rate (BER).

The bit error rate of the construction system is shown in Figure 6.

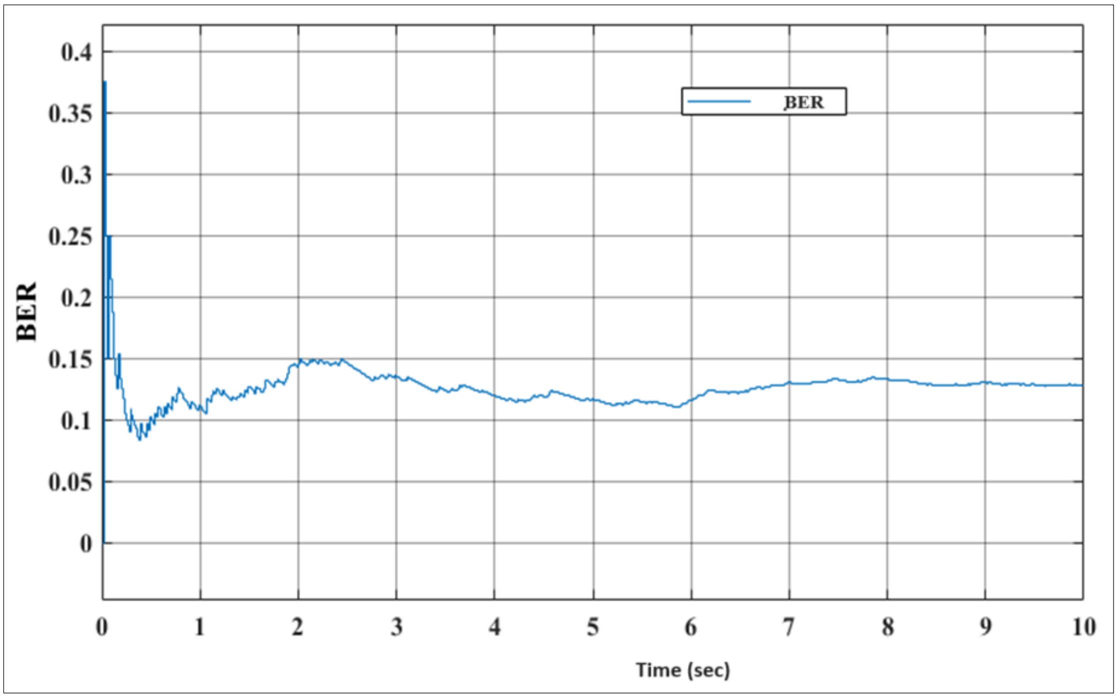

Figure 6 Bit error rate of the constructed channel system

The bit error rate of the constructed transmission channel is shown in Figure 6. We see that the bit error rate changes strongly in the first period of time and then gradually stabilizes over time.

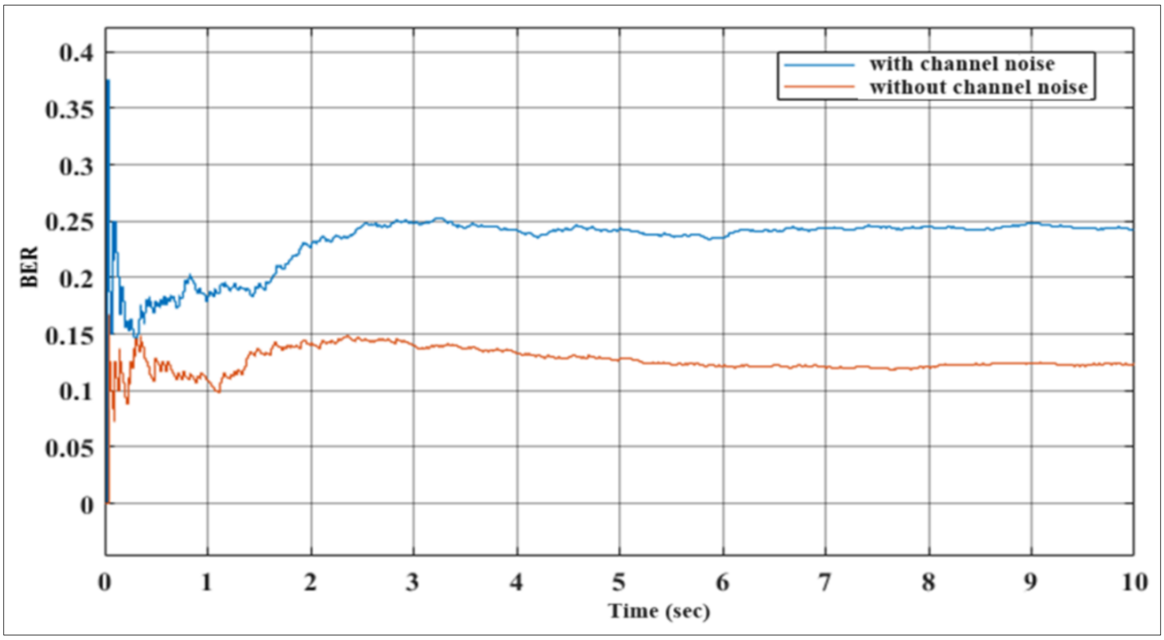

Figure 7 Bit error rate with and without channel noise Rician fading

Figure 7 compares the bit error rate (BER) over time between two different scenarios: one with a fading channel and one without a fading channel. This emphasizes the impact of channel fading on data transmission errors. Figure 7 clearly illustrates that channel fading can significantly increase the bit error rate (BER), an important aspect to consider in wireless communication systems to ensure data integrity.

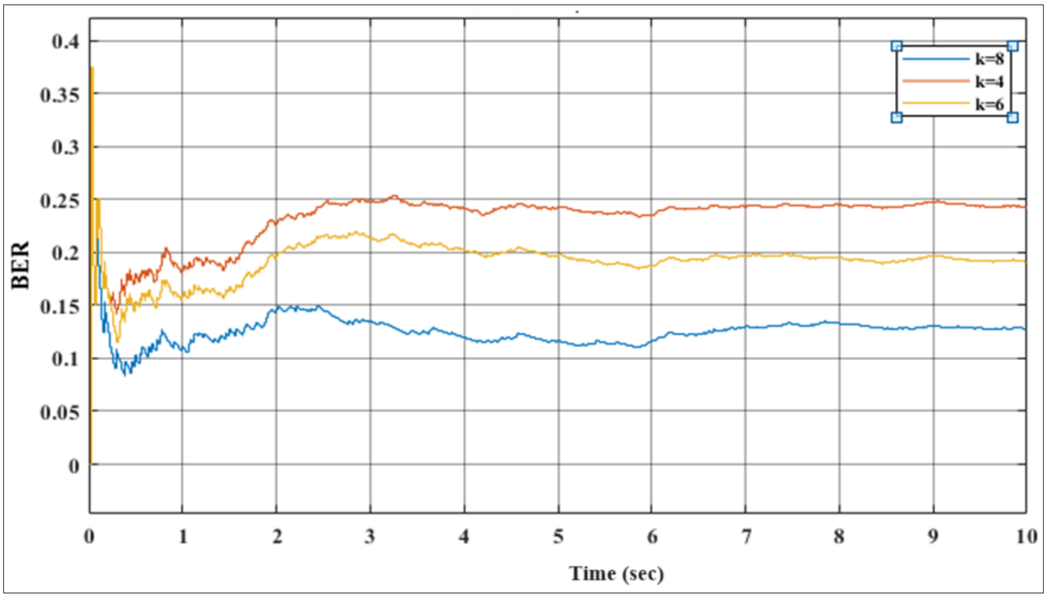

Figure 8 Bit error rate of the system when changing the coefficient k of the noisy channel Rician fading

Figure 8 depicts the bit error rate (BER) over time for different values of k in the presence of a Rician fading channel. Figure 8 provides information about the performance and reliability of the communication system under different channel interference conditions, characterized by the parameter k.

3.2. Evaluate system performance

Based on the simulation results, below is a detailed evaluation of the performance of a digital data transmission system over a noisy Rician fading channel using a 16-QAM modulator, Hamming source coding, and BCH channel coding:

- Before transmitting through the noisy channel, the constellation distribution of 16-QAM has a square shape with regularly arranged constellation points. After transmitting through the Rician fading noise channel, the constellation distribution is changed; the constellation points are no longer regular and fluctuate. This shows that noise in the transmission channel affects data transmission, causing variation in the constellation distribution and increasing the bit error rate (BER).
- The bit error rate of the system changes over time and fluctuates strongly in the first period of time, then gradually stabilizes over time. Comparing the bit error rate between two different scenarios (with fading channels and without fading channels) demonstrates the significant impact of fading channels on data transmission errors. Channel fading can significantly increase the bit error rate, an important aspect to consider in wireless communication systems to ensure data integrity.
- Bit error rate over time for different values of parameter k in the presence of a Rician fading channel. The communication system under different channel noise conditions is characterized by the parameter k. When we change the ratio between the energy of the reflected component and the energy of the direct component K, we see that as we increase K, the bit error rate decreases and the channel becomes better. The more K increases, the channel will gradually improve.

In summary, the simulation results provide important information on the performance of a digital data transmission system over a noisy Rician fading channel while also highlighting the impact of key components such as the modulator, source codec, and channel encoding with respect to bit error rate. This helps in evaluating and improving the performance of digital data transmission systems in practical applications.

4. Conclusion

In this paper, we have delved into building and evaluating the performance of a data transmission system using Rician fading channels and combining coding methods such as Hamming code and BCH code. The results of the simulation show that the proposed system is capable of detecting and correcting errors in transmitted data and resisting interference effectively.

Hamming codes have been shown to improve the system's anti-interference ability by detecting and correcting bit errors during information transmission. However, it has limitations in handling large-bit errors and does not perform well in error-rich environments.

The BCH code, a powerful error-correcting code, has been shown to detect and correct errors in transmitted data and is highly resistant to interference. This suggests that combining encryption methods can enhance the performance and reliability of communication systems.

In the future, research can continue to focus on optimizing and improving coding methods, as well as studying methods of combining code types to improve system performance and reliability. communication in noisy environments.

Compliance with ethical standards

Acknowledgments

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Disclosure of Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential sources of interest.

Author Contributions

The authors have made a substantial direct and intellectual contribution to the work and approved it for publication. Each author contributed equally to all sections of the paper.

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She was born in Hanoi, Vietnam, on March 9, 1977. She holds a Master's degree in Information Technology. Her primary research interests include voice and image processing, machine learning, smart control, smart grid demand response, building automation systems, renewable energy, and applications of the Internet of Things. Currently, she has authored or co-authored more than 10 international journal papers.

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