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Building and Evaluating the Performance of a Digital Data Transmission System Over a Noisy Rician Fading Channel Using a 32-QAM Modulator, Convolutional Source Encoding, and LDPC Channel Encoding

Do Manh Dung

Master, Lecturer, Faculty of Fundamental Technical, AD-AF Academy of Vietnam
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A B S T R A C T

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 32-QAM modulators, convolutional source coding, and LDPC 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's BER bit error rate is relatively high.

Keywords: Digital data transmission, Rician fading, 32-QAM modulator, convolutional source coding, LDPC channel coding.

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 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 32-QAM modulator, convolutional source encoding, and LDPC 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:

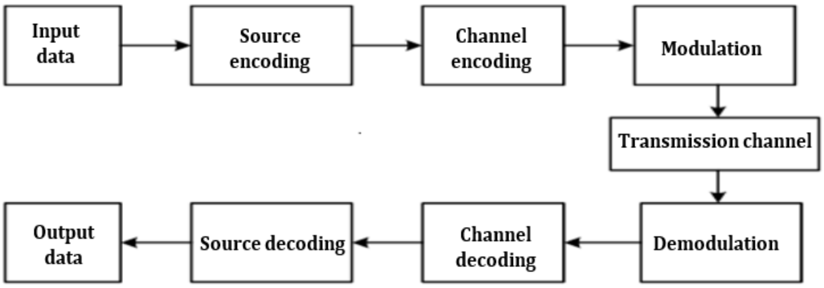

Fig.1. Block diagram of the digital data transmission system

- Input data block: Used to create input data.

- The transmitter side includes:

Source encoding block: Encode the input data source using convolution code.

Channel encoding block: Encode the data channel coming from the source encoding block using the LDPC code.

Modulation block: Modulates the input data coming from the channel coding block using a 32-QAM modulator.

- Transmission channel: Use the Rician-fading transmission channel.

- The receiver side includes 32-QAM demodulation, LDPC channel decoding, and Viterbi source decoding.

- Output data block: Data is restored.

2.2. Source encoding and decoding blocks

In addition to the components outlined in the digital data transmission system, the proposed system also incorporates source encoding and decoding blocks. Specifically, it employs the convolutional encoding and Viterbi decoding methods.

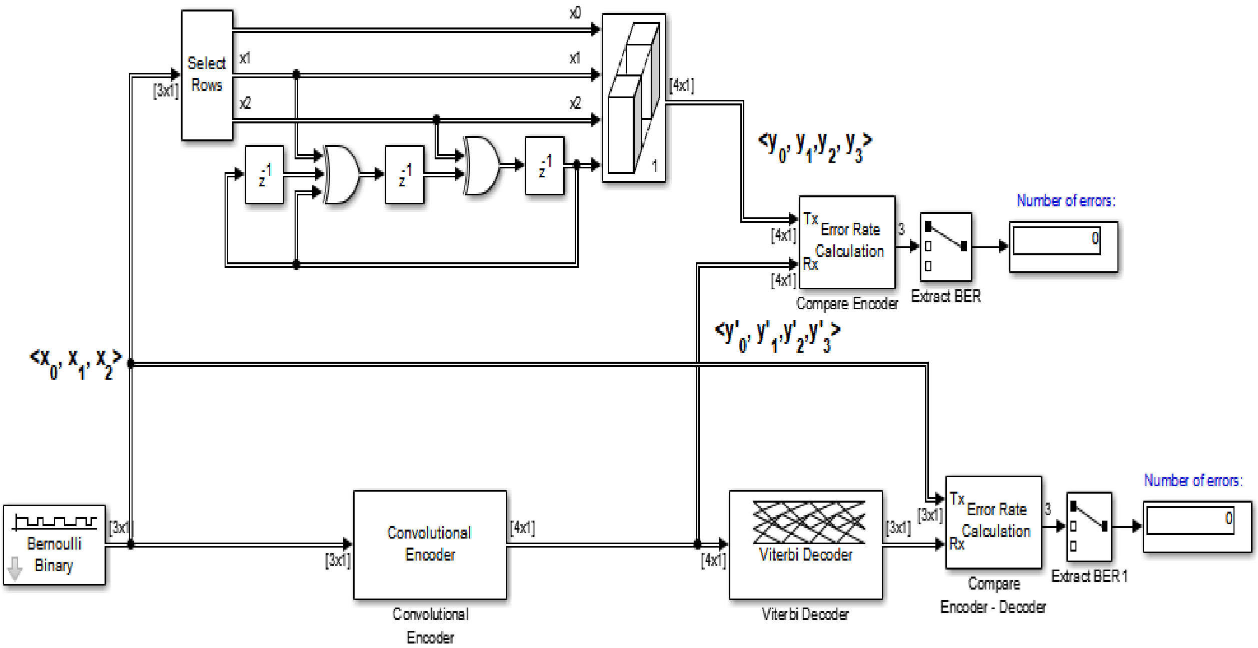

Fig.2. Convolution encoder and Viterbi decoder

Convolutional Encoding: Convolutional encoding is a method used to add redundancy to the transmitted data stream, thereby enhancing error detection and correction capabilities. This process involves applying a convolutional encoder to the input data stream, resulting in a coded sequence with a higher redundancy. The convolutional encoder operates by convolving the input data with a set of predefined code sequences, known as convolutional codes or generator polynomials. This process effectively introduces controlled redundancy into the data stream, which aids in error detection and correction at the receiver end.

Viterbi Decoding: Viterbi decoding is a maximum likelihood decoding algorithm commonly used with convolutional codes. It is based on the principle of dynamic programming and aims to find the most likely sequence of transmitted symbols given the received noisy sequence. The Viterbi decoder employs a trellis diagram representation of the convolutional code and performs a traceback process to determine the most likely transmitted sequence. By comparing the received sequence with all possible transmitted sequences, the Viterbi decoder selects the sequence with the highest likelihood, thereby minimizing decoding errors.

The incorporation of convolutional encoding and Viterbi decoding in the source encoding and decoding blocks enhances the robustness of the data transmission system, particularly in environments characterized by noise and interference. These techniques not only improve error detection and correction capabilities but also contribute to achieving reliable communication performance in noisy Rician fading channels.

2.3. Channel encoding and decoding blocks

- Encoding uses the generation matrix G

We have: $H = [A, I_{n-k}]$

In which:

A is the binary matrix (n-k)×k

I_{n-k} is the unit matrix

The generation matrix is defined: $G = [I_k, A^T]$

The encoding process here is simply to perform multiplication between the single row matrix representing the input message sequence with the found generation matrix:

$$c = uG = \begin{bmatrix} u_1 & \dots & u_k \end{bmatrix} \begin{bmatrix} PT \backslash Ik \end{bmatrix}$$
$$c = \begin{bmatrix} c_1 & \dots & c_n \end{bmatrix}$$

If, after performing the steps of the Gauss-Jordan test, we are given a row-elevated matrix with one row containing all 0s, then we are allowed to omit that row. The difficulty with this method is that the matrix G is not guaranteed to be as sparse as the matrix H. The encryption equation c = uG is performed in an encoder whose complexity is almost exactly equal to n^2 calculations. For codes with large codeword lengths, the encoder becomes extremely complex.

- Encoding uses parity matrix H

In this method, people directly use the matrix H. The idea of this method is to directly use permutation of rows and columns to still retain the characteristics of the matrix H. Where k is the message size, n is the code block length, m is the number of check bits m=n-k, g is called the encoding complexity.

First, just transpose the rows and columns to the approximate triangle shape below

$$H = \begin{bmatrix} A & B & T \\ C & D & E \end{bmatrix}$$

In which:

T is the lower triangular matrix, size (m-g)×(m-g)

B is the matrix size (m-g) × g

A is the size matrix (m-g) × k

C has dimensions g × k

D has dimensions g ×g

E has dimensions g × (m-g).

- LDPC decoding

Uses the iterative method to calculate variables on graphs and has many names such as:

Sum - Product Algorithm – SPA.

Belief Propagation Algorithm – BPA.

Message Passing Algorithm -MPA.

Some symbols in the decoding algorithm include:

c_n is the symbol for the nth bit node and z_m is the mth check node of the tanner graph.

M_n is the set of indices of the test nodes connected to bit node c_n on the Tanner graph or the set of indexes m with H(m, n) = 1 in the matrix H.

N_m is the set of indices of the bit nodes connected to the check nodes z_m on the Tanner graph or the set of indices n with H(m,n) = 1 in the matrix H.

M_n /m is the set M_n minus the values equal to m.

N_m /n is the set N_m minus the values equal to n.

The SPA decoding algorithm is an iterative decoding algorithm. Consists of three steps: initialization step, horizontal step, vertical step.

Step 1: The probabilities $q_{mn}(x)$ are initialized by the probability $f_n^{(x)}$ that is the APP prior probability of the n_{th} bit node. Where y_n is the nth symbol received after transmission through the channel.

Step 2: Step horizontally

The horizontal step of the algorithm will determine the value of the probabilities $r_{mn}(x)$

$$r_{mn}(x) = \sum_{c:c_n} P(z_m = 0 \backslash c) P(c \backslash c_n = x)$$

In there:

Vector c includes all the nodes connected to z_m except the nth bit node which is c_n.

The length of the vector is equal to w_r-1, there is $2^{w_r - 1}$ a possible vector combination c. But there are only a few satisfying combinations:

The probabilities $r_{mn}(x)$ are placed in the R matrix:

$$R = \begin{bmatrix} r_{11}(0) & r_{12}(0) & \dots & r_{1(n-1)}(0) & r_{1n}(0) \\ r_{11}(1) & r_{12}(1) & \dots & r_{1(n-1)}(1) & r_{1n}(1) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ r_{m1}(0) & r_{m2}(0) & \dots & r_{m(n-1)}(0) & r_{mn}(0) \\ r_{m1}(1) & r_{m2}(1) & \dots & r_{m(n-1)}(1) & r_{mn}(1) \end{bmatrix}$$

Step 3: Vertical step

Vertical step of the algorithm to determine the probabilities $q_{mn}(x)$

Apply Bayes formula:

$$q_{mn}(x) = P(c_n = x \backslash \{z_{m'} = 0, m' \in M_n / m\}) = \frac{P(c_n = x) P(\{z_{m'} = 0, m' \in M_n / m\} \backslash c_n = x)}{P(\{z_{m'} = 0, m' \in M_n / m\}}$$

$$q_{mn}(x) = \beta_{mn} f_n^{(x)} \prod_{m' \in M_n / m} r_{m'n}(x)$$

In which:

β_{mn} is calculated based on $q_{mn}(0) + q_{mn}(1) = 1$

Inferred:

$$\beta_{mn} = \frac{1}{\sum_x f_n^{(x)} \prod_{m' \in M_n / m} r_{m'n}(x)}$$

The probabilities $q_{mn}(x)$ are placed in the Q matrix:

$$R = \begin{bmatrix} q_{11}(0) & q_{12}(0) & \dots & q_{1(n-1)}(0) & q_{1n}(0) \\ q_{11}(1) & q_{12}(1) & \dots & q_{1(n-1)}(1) & q_{1n}(1) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ q_{m1}(0) & q_{m2}(0) & \dots & q_{m(n-1)}(0) & q_{mn}(0) \\ q_{m1}(1) & q_{m2}(1) & \dots & q_{m(n-1)}(1) & q_{mn}(1) \end{bmatrix}$$

Determine the posterior pseudo probability:

$$q_n\left(x\right) = \beta_n f_n^{(x)} \prod_{m \in M_n} r_{mn}(x)$$

In which: β_n is determined based on $q_n\left(0\right) + q_n\left(1\right) = 1$

The pseudo posterior probabilities are placed in the matrix Q':

$$Q' = \begin{bmatrix} q_1(0) & q_2(0) & \dots & q_{(n-1)}(0) & q_n(0) \\ q_1(1) & q_2(1) & \dots & q_{(n-1)}(1) & q_n(1) \end{bmatrix}$$

We can determine the codeword value as: $c_n = \arg max q_n(x)$

Finally, check the condition $H\hat{c}^T = 0$ and number of loops. If $H\hat{c}^T = 0$ then $\hat{c}$ the codeword is valid and the algorithm ends.

2.4. Modulation and demodulation blocks

The proposed system uses 32-QAM modulation and demodulation methods. 32-QAM modulation is a modulation method that combines amplitude modulation and phase modulation. The name orthogonal amplitude modulation comes from the fact that a 32-QAM signal is created by adding together 32-level amplitude modulation signals whose carriers are orthogonal. The 32-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, 32-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 32-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 32-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.

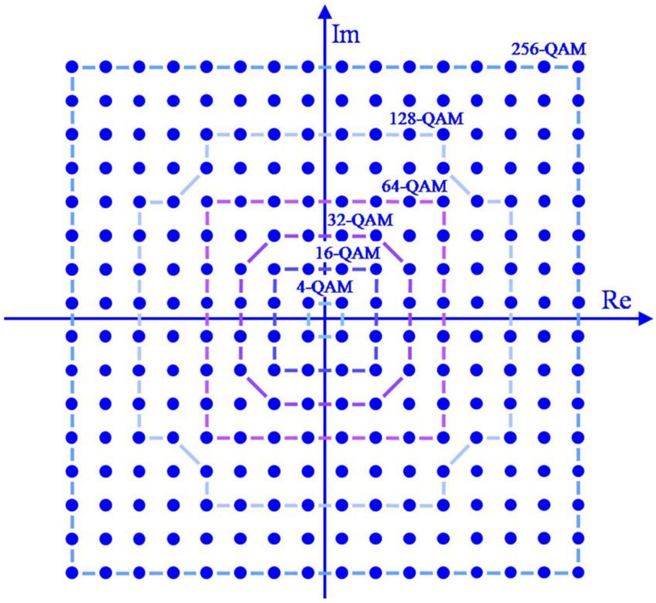

Fig.2. Constellation of a M-QAM signal

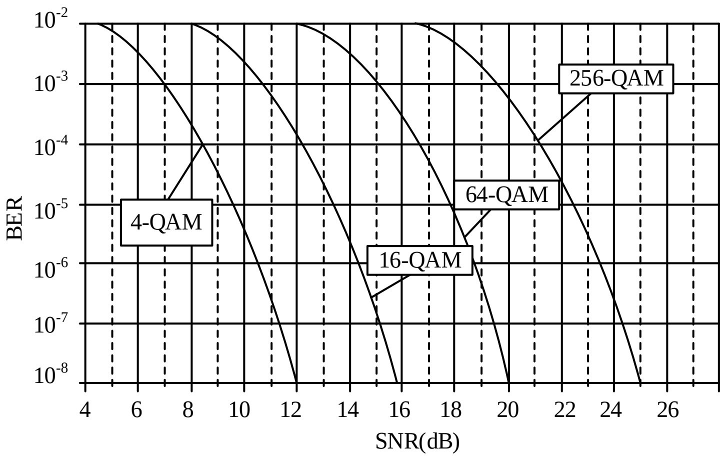

Fig.3. Bit error probability for M-QAM modulation

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:

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

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:

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

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:

$$p_z(z) = \frac{2z(K+1)}{P_r}\exp\left[-K - \frac{(K+1)z^2}{P_r}\right] I_0\left(2z\sqrt{\frac{K(K+1)}{P_r}}\right), z \ge 0 \qquad (3)$$

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:

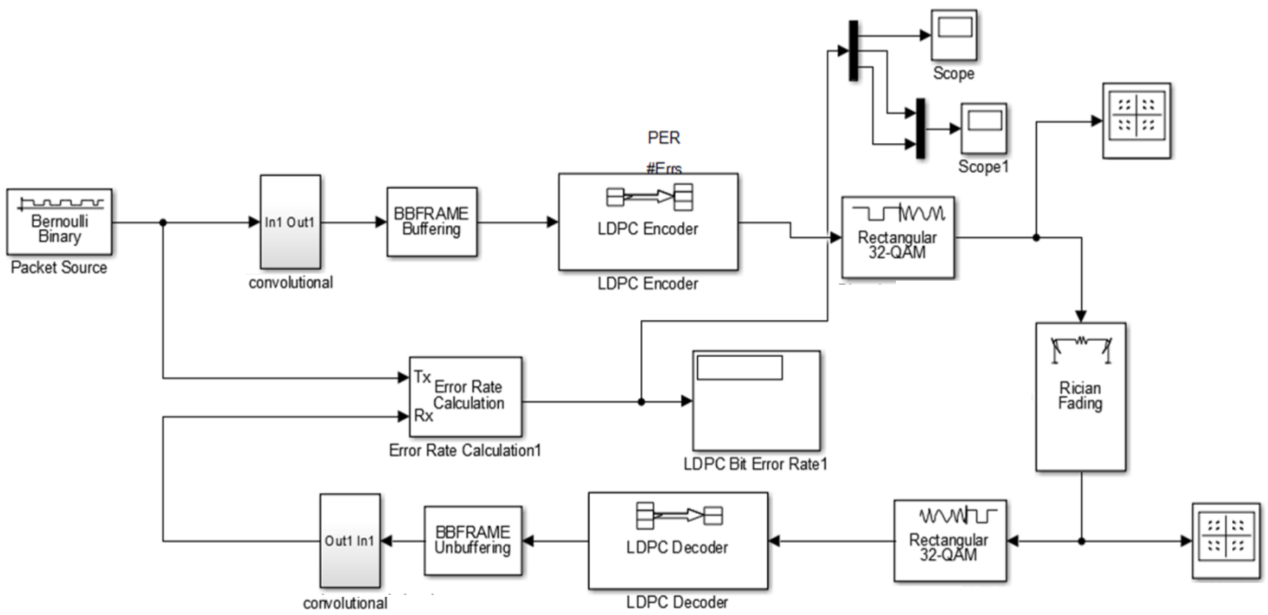

Fig.4. Simulation diagram of digital communication system

Bernoulli binary block: used to create input data;

Convolutional Encoder Block: Used to encode the Convolutional source;

LDPC encoder block: used to encode the LDPC channel;

Recrangular QAM Modulator block: used to modulate 32-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 32-QAM signal;

Convolutional Decoder Block: Used to decode Convolutional source;

LDPC Decoder Block: Used to decode the LDPC channel;

- Simulation results:

Constellation distribution

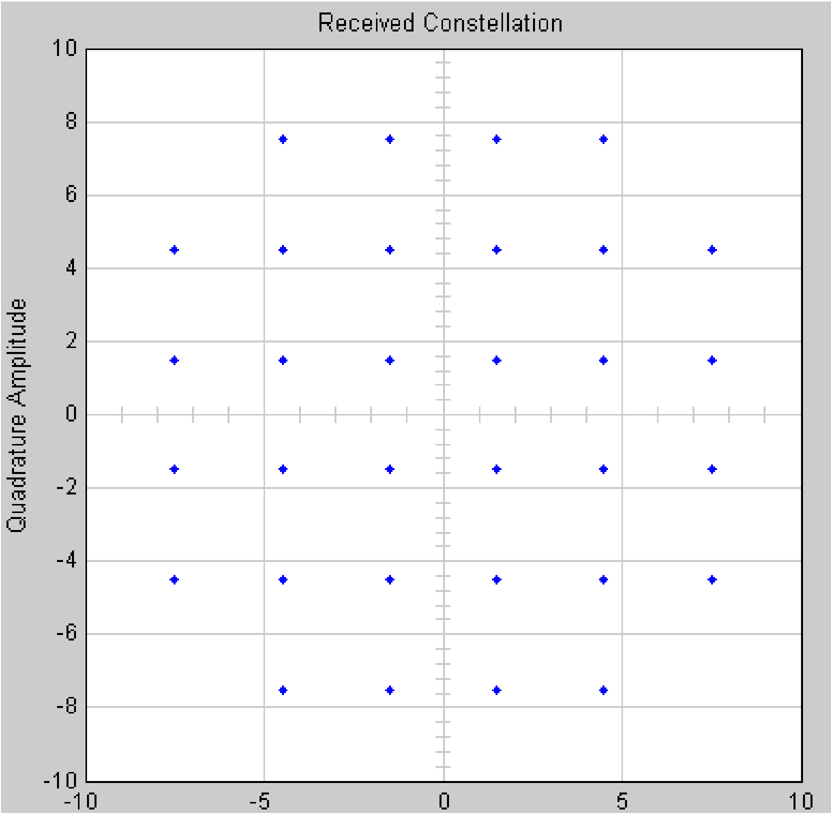

Fig.5. 32-QAM constellation distribution

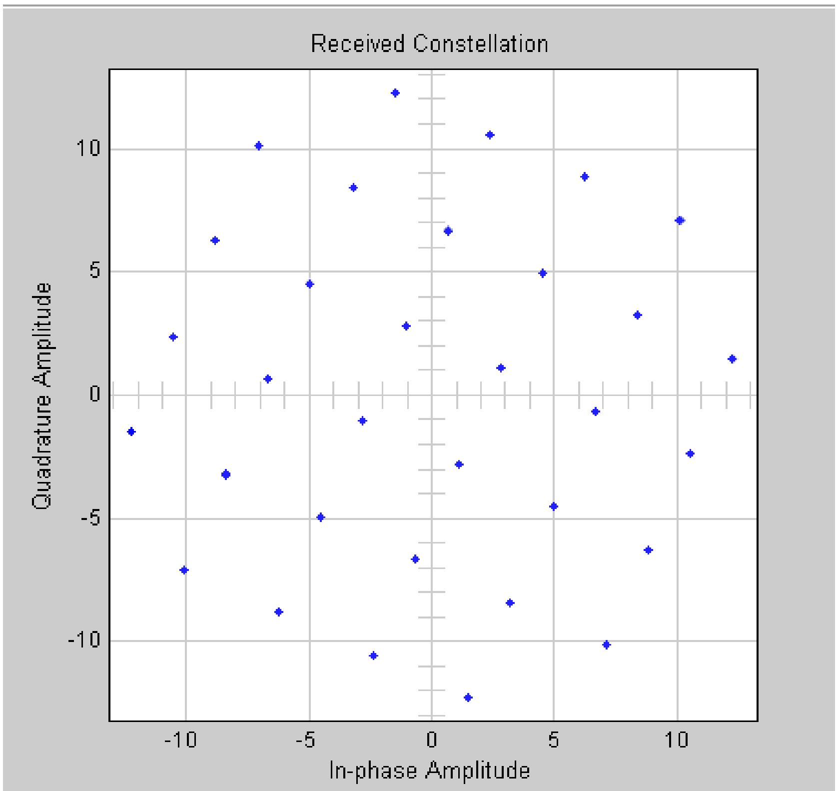

Fig.6. Constellation distribution when affected by noise on the Rician channel

The bit error rate when transmitting information is shown in Figure 7.

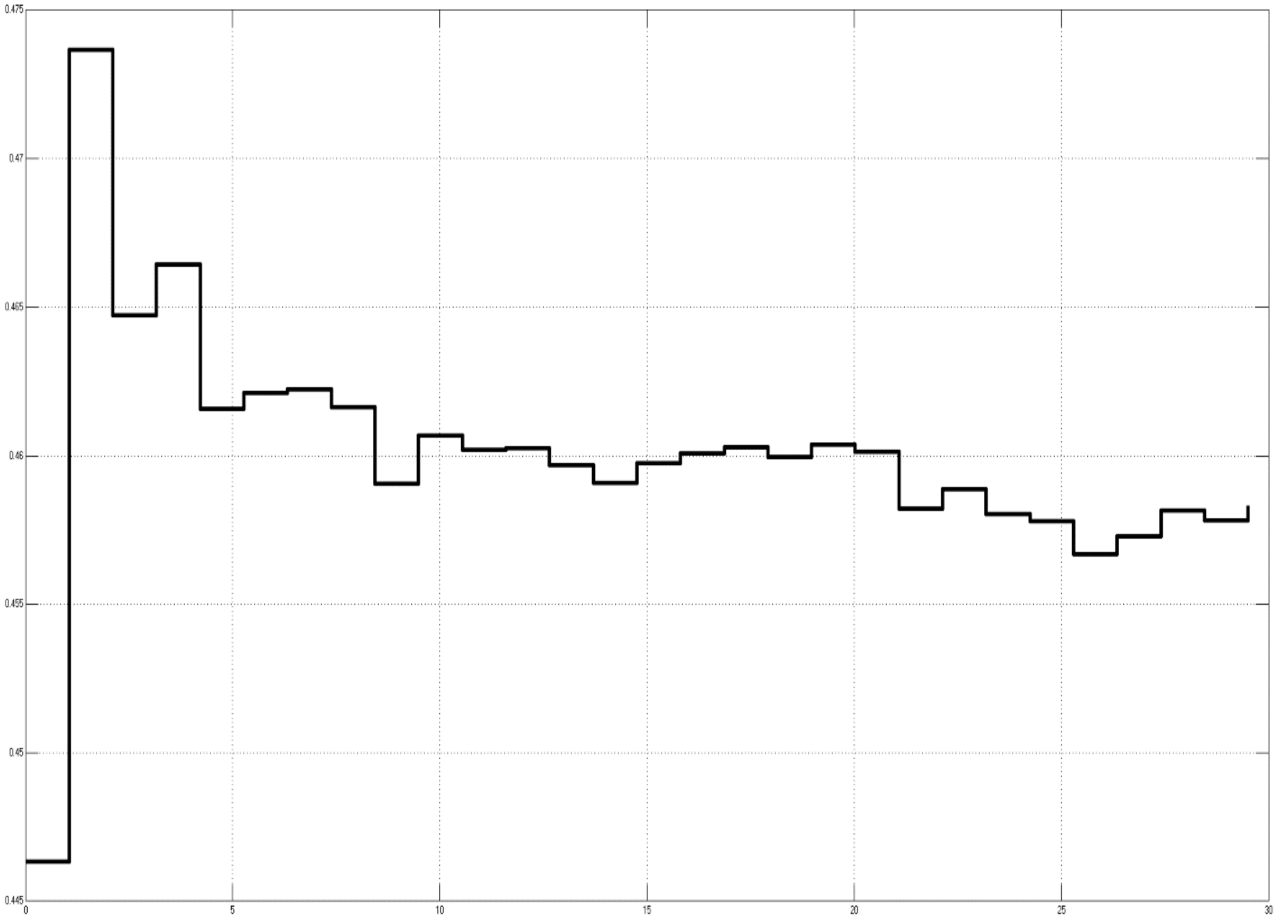

Fig.7. Ber diagram

3.2. Evaluate system performance

Following the simulation of the proposed system, a comprehensive evaluation of its performance was conducted. The results yielded valuable insights into the system's efficacy under real-world conditions, particularly in the context of noisy Rician fading channels.

The Bit Error Rate (BER) obtained from the simulations stands at 45.83%. This metric signifies the proportion of bits that are incorrectly received due to channel impairments, noise, and other factors. The relatively high BER underscores the challenges inherent in transmitting data through channels affected by Rician fading noise.

The utilization of convolutional source coding and LDPC (Low-Density Parity-Check) channel coding techniques in the information transmission channel offers a degree of robustness against channel impairments. However, despite the incorporation of these advanced coding techniques, the BER remains comparatively high.

The prevalence of Rician fading noise poses significant hurdles to effective communication. Rician fading, characterized by multipath propagation and a dominant line-of-sight component, introduces variability and unpredictability into the communication channel. This, in turn, complicates the task of error detection and correction, leading to a higher BER.

Furthermore, it's worth noting that encryption processes are particularly challenged when dealing with data affected by significant levels of noise. The complexity and computational demands associated with encryption increase substantially under such conditions. Consequently, achieving reliable communication performance in the presence of Rician fading noise necessitates not only sophisticated coding techniques but also efficient encryption methodologies that can mitigate the adverse effects of noise.

In summary, while the utilization of convolutional source coding and LDPC channel coding provides a foundation for robust communication in noisy environments, the challenges posed by Rician fading noise persist. Future research endeavors may focus on developing more advanced coding schemes and encryption techniques tailored to address the specific challenges posed by Rician fading channels, ultimately enhancing communication reliability and performance in such environments.

4. Conclusion

In this article, a comprehensive simulation of a communication system utilizing convolutional codes and LDPC codes has been presented. Convolutional codes offer several advantages, including computational efficiency, inherent feature learning ability, scalability, and flexibility, rendering them widely adopted in various data encryption applications. However, convolutional encoding also exhibits drawbacks, notably concerning data volume, computation, overfitting, and model complexity.

On the other hand, LDPC codes emerge as efficient encoding methods with easy deployment and robust fault tolerance, making them favored choices across digital communications and mobile networks. Nonetheless, they are not devoid of limitations, requiring substantial computational resources, complexity in design and tuning, and experiencing performance degradation when approaching the channel limit.

Looking ahead, future research endeavors may concentrate on optimizing and refining encoding and decoding methodologies to bolster the performance and reliability of communication systems. Moreover, conducting simulations and real-life tests will be pivotal in validating these results and applying the developed methods in practical applications, thereby advancing the field of communication technology.

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