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Application and Performance of Space Time Coding in MIMO System—Analysis of Alamouti Space Time Coding Scheme

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Abstract: This research first intuitively shows the implementation diagram of a MIMO system, and then introduces transmission diversity and space-time coding technology, with space-time coding technology belonging to the category of spatial diversity technology. The earliest and most classical Alamouti space-time coding scheme is then applied to MIMO wireless communication systems. The principle of the Alamouti space-time coding scheme is demonstrated, and a theoretical demonstration is carried out in a MIMO diversity system with two transmitters and one receiver. Finally, the Alamouti space-time coding scheme is simulated using MATLAB, and it is verified that the diversity gain and coding gain are obtained by using the Alamouti space-time coding scheme in the MIMO system.

1. Introduction

The integration of technologies such as 5G, big data, cloud computing, artificial intelligence, and blockchain has formed a new generation of information and communication technology, which has become a reorganized global element resource [1]. Large scale 5G-oriented MIMO systems have dozens or even thousands of antenna arrays, and operate in the millimeter wave spectrum range. They can obtain large design redundancies in terms of antenna size and power, which allows them to support spatial multiplexing, spatial diversity (such as space-time coding technology/diversity reception), and beamforming, or their joint design. This greatly improves the overall system design [2]. In general, MIMO systems are implemented based on three technologies: spatial multiplexing, spatial diversity, and beamforming. When these technologies are applied to MIMO systems, they bring different gains and improve system performance. According to the ITU (International Telecommunication Union), 5G has three cognitive application scenarios, one of which is ultra-reliable communication, mainly for sensitive application scenarios [3]. To enhance the transmission quality in MIMO systems, this paper will focus on space-time coding technology in MIMO wireless communication systems to overcome multipath effects and fading.

Space-time coding technology is an effective method for enhancing the transmission quality in

MIMO systems. It can effectively overcome multipath effects and fading, which are major challenges in wireless communication systems. By transmitting multiple copies of the same data over different antennas and at different times, space-time coding technology provides a higher level of diversity, which improves the robustness of the transmission. This is particularly useful in 5G scenarios where ultra-reliable communication is required. Additionally, space-time coding technology can be combined with other technologies such as beam forming to further improve system performance.

In conclusion, 5G integration of big data, cloud computing, artificial intelligence, block chain and others has formed a new generation of information and communication technology that reorganized the global resource. Large scale 5G-oriented MIMO systems have large design redundancy in antenna size and power which can support spatial multiplexing, spatial diversity and beam forming, or their joint design. ITU (International Telecommunication Union) points out that 5G has three scenarios for cognitive applications, one of which is ultra-reliable communication. By focusing on space-time coding technology in MIMO wireless communication systems, this paper aims to overcome multipath effects and fading, and enhance the transmission quality in MIMO systems.

2. Literature Review

Implementation of MIMO System

The MIMO technology can be realized through three main methods: spatial multiplexing, spatial diversity (such as space-time coding and diversity reception), and beam forming (space-time precoding). These methods are not often used independently in large-scale MIMO systems, instead, they are often jointly designed based on the characteristics of the communication system [4-6]. By using these methods separately or in combination, the MIMO system can achieve a range of performance improvements such as multiplexing gain, diversity gain, coding gain, antenna gain, and interference suppression. These improvements can increase data rate, improve spectral efficiency, reduce error rate, improve reliability, and ultimately improve system performance. Figure 1 illustrates the implementation of the MIMO system.

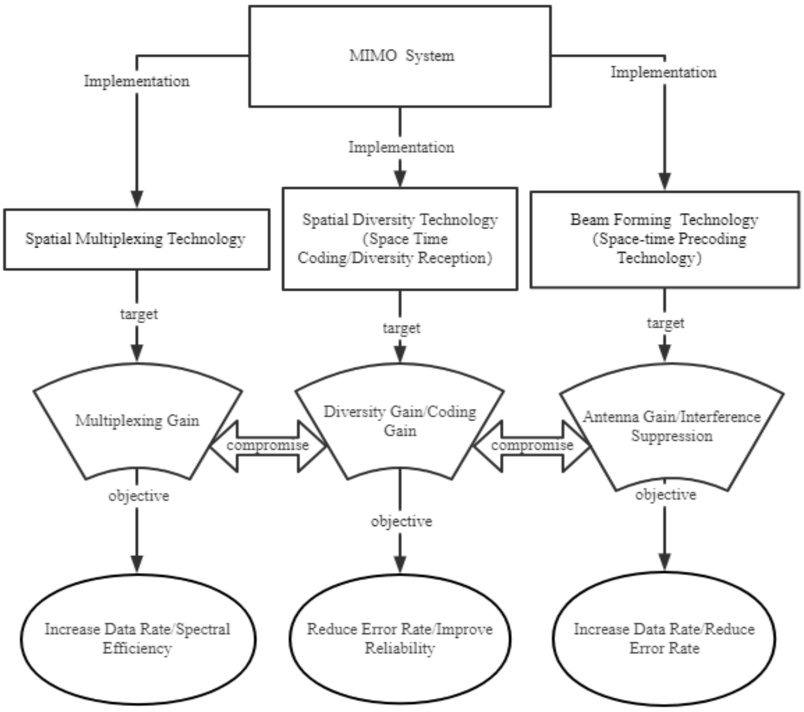

Figure 1: Implementation of MIMO system

Transmit Diversity and STC

Diversity technology includes two meanings: one is decentralized transmission, that is, the transmitter sends multiple independent information samples of the same signal at the same time; The second is centralized processing, where the receiving end combines multiple independent information samples received. In this way, the multipath characteristics of the original signal causing interference are fully utilized to reduce the impact of fading and improve the correct decision rate of the received signal. With diversity technology, there is no need to increase the transmission power of the transmitter to compensate for anti-fading, so the transmission power of the transmitter is saved.

MIMO system constitutes a multi antenna system. For a MIMO system with M transmitting antennas and N receiving antennas, with M * N channels, space-time coding technology, a coding technology for multiple transmitting antennas, can be used to integrate the coding technology into spatial and temporal decentralization. After space-time coding, spatial and temporal correlation can be generated between multiple transmission antennas and transmission signals of various time periods. This space-time correlation can achieve transmission diversity and gain some coding gain without sacrificing bandwidth.

It is the unremitting pursuit of researchers to constantly design new efficient space-time coding methods to improve MIMO performance to meet the ever-changing needs of wireless communication systems, while minimizing system complexity.

Diversity technology has two main components: decentralized transmission, where multiple independent information samples of the same signal are sent at the same time by the transmitter, and centralized processing, where the receiving end combines multiple independent information samples that it receives[7]. In this way, the multipath characteristics of the original signal that cause interference are fully utilized to reduce the impact of fading and improve the correct decision rate of the received signal. With diversity technology, there is no need to increase the transmission power of the transmitter to compensate for fading, resulting in saved transmission power.

A MIMO system comprises a multi-antenna system. For a MIMO system with M transmitting antennas and N receiving antennas, and M * N channels, space-time coding technology can be employed as a coding technology for multiple transmitting antennas, to integrate the coding technology into spatial and temporal decentralization. By using space-time coding, spatial and temporal correlation can be generated between multiple transmission antennas and transmission signals of various time periods, which can achieve transmission diversity and gain some coding gain without sacrificing bandwidth.

It is the ongoing pursuit of researchers to continually design new, efficient space-time coding methods to improve MIMO performance and meet the evolving needs of wireless communication systems while minimizing system complexity."

a. Alamouti Space-Time Coding Scheme

The Alamouti space-time coding scheme is a method of transmit diversity that can be used in wireless communication systems that employ multiple-input multiple-output (MIMO) technology. The scheme was first proposed by Alamouti in 1998, and it is a simple and effective way to achieve full-diversity and full-rate space-time coding.

The basic idea behind the Alamouti scheme is to transmit the same information over multiple antennas, but with different spatial and/or temporal coding. This allows the receiver to exploit the multiple paths created by the multiple antennas to achieve diversity and improve performance. The scheme uses two transmit antennas, and the two signals are transmitted at the same time but with a specific coding scheme, in a way that the received signal can be reconstructed with high accuracy.

The Alamouti scheme is particularly useful in wireless communication systems that operate in a frequency-selective fading environment, such as in mobile communication systems. It is considered as a powerful technique for combating fading and interference, and is particularly useful for improving the performance of wireless systems in challenging environments, such as in the presence of multi-path fading and interference.

Overall, the Alamouti space-time coding scheme is a widely used and efficient method for achieving transmit diversity in wireless communication systems that employ MIMO technology.

Alamouti proposed a transmission method using two transmit antennas and one receive antenna. It takes two moments to complete the transmission of an Alamouti space-time codeword, which is sent by two antennas at the same time by line, that is, the first line is sent at the first moment, and the second line is sent at the second moment. Therefore, each column of symbols in the matrix is actually transmitted by the same transmission antenna at different times. Because the columns of its coding matrix are orthogonal to each other (the constellation point symbols sent on the same sub-antenna are orthogonal to the symbols sent on any other antenna), such codes are called orthogonal space-time block codes (STBC). This algorithm encodes the transmitted symbols in the space (antenna domain) and time domain, and does not require CSI at the transmitter. The performance is the same as that of MRC (maximum ratio combining) (diversity receiving technology of one transmitting antenna and two receiving antennas) [8].

The MIMO wireless communication system corresponding to Alamouti space-time coding scheme uses two transmit antennas, and the principle block diagram of its space-time encoder is shown in Figure 2.

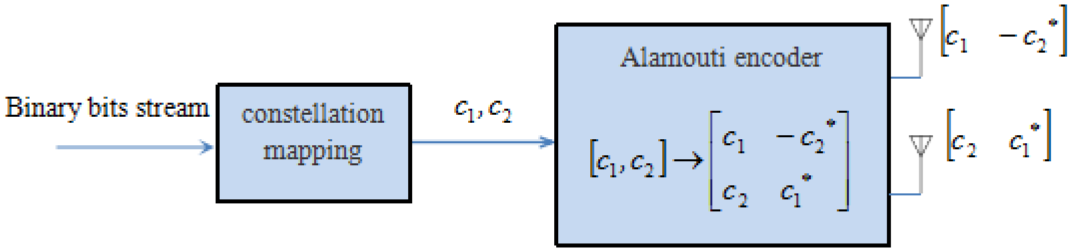

Figure 2: Schematic diagram of Alamouti space-time encoder

First, the source binary information bit stream $\{c_t\}$ is mapped into two pairs of packets by constellation mapping. If the currently received packet is $[c_1, c_2]$, the space-time coding matrix $\begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix}$ is generated by Alamouti encoder, where is the representation symbol * of complex conjugate. In the current time slot and the next time slot immediately following, the transmitting antenna 1 sends c_1 and $-c_2^*$ in turn, and the transmitting antenna 2 sends c_2 and c_1^* in turn. The columns of the space-time coding matrix $\begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix}$ correspond to the antenna order, and the rows correspond to the slot order.

$$\text{because} \begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix} \cdot \begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix}^T = \begin{bmatrix} |c_1|^2 + |c_2|^2 & 0 \\ 0 & |c_1|^2 + |c_2|^2 \end{bmatrix} = \left(|c_1|^2 + |c_2|^2\right) I_{2\times 2} \tag{1}$$

Therefore, Alamouti space-time coding matrix $\begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix}$ is a complex orthogonal matrix, which is equivalent to forming two orthogonal channels. This transmission coding scheme completes the transmission of two symbols in two time slots, so the rate of Alamouti code is $R = \frac{N}{T} = \frac{2}{2} = 1$. Because the symbol rate of the output is not changed, the Full Rate is satisfied.

$$\text{Error matrix } B(c,c') = \begin{bmatrix} c_1 - c_1' & c_2'^* - c_2^* \\ c_2 - c_2' & c_1^* - c_1'^* \end{bmatrix} \tag{2}$$

Its determinant is:

$$\det B(c,c') = \begin{bmatrix} c_1 - c_1' & c_2'^* - c_2^* \\ c_2 - c_2' & c_1^* - c_1'^* \end{bmatrix} = \begin{bmatrix} c_1 - c_1' & (c_2' - c_2)^* \\ c_2 - c_2' & (c_1 - c_1')^* \end{bmatrix} = |c_1 - c_1'|^2 + |c_2 - c_2'|^2 \tag{3}$$

If $c \neq c'$, $\det B(c,c') \neq 0$, then $c \neq c'$, there is always a full rank matrix $B(c,c')$, and all eigenvalues of the codeword distance matrix $A(c,c')$ are also greater than 0, so Alamouti codes obtain Full Diversity, and their diversity gain is $N_T \times N_R = 2 \times 1 = 2$. In this way, Alamouti space-time coding matrix satisfies determinant criterion and rank criterion.

b. Theoretical Demonstration of Alamouti Scheme Diversity System

The MIMO wireless communication system corresponding to the Alamouti scheme uses two transmitting antennas and one receiving antenna. The two transmitting and one receiving diversity system is shown in Figure 3.

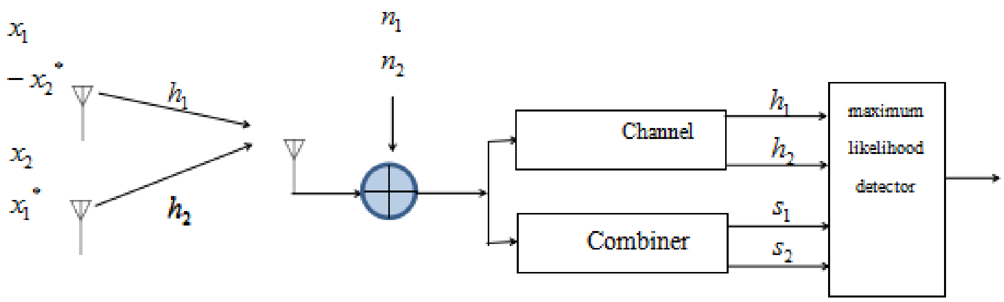

Figure 3: Principle diagram of Alamouti two transmitter one receiver diversity system

The path gains of transmitting antenna 1 and transmitting antenna 2 from the channel estimator in Figure 3 to the receiving antenna are h_1 and h_2 respectively, according to the formula:

$$r_t = H_t c_t + n_t = (r_t^1, r_t^2, \cdots, r_t^{N_R})^T \tag{4}$$

The signals received by the decoder in the current time slot and the next time slot are r_1 and r_2 respectively:

$$\begin{cases} r_1 = h_1 c_1 + h_2 c_2 + n_1 \\ r_2 = -h_1 c_2^* + h_2 c_1^* + n_2 \end{cases} \tag{5}$$

Where, n_1, c_2 and represent the independent complex Gaussian additive white noise of the current slot and the next slot respectively. Take r_2 complex conjugation and express formula (5) in matrix form as follows:

$$\begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \quad (6)$$

Both sides of equation (6) above are multiplied by the Emmett transpose matrix $\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$ of the channel matrix $\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}$ at the same time to obtain:

$$\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \quad (7)$$

Equation (7) is expressed as Equation (8):

$$\begin{bmatrix} r_1' \\ r_2' \end{bmatrix} = (|h_1|^2 + |h_2|^2) \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} n_1' \\ n_2' \end{bmatrix} \quad (8)$$

Among them, $\begin{bmatrix} r_1' \\ r_2' \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix}$, $\begin{bmatrix} n_1' \\ n_2' \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}$.

Now turn equation (8) back to equations:

$$\begin{cases} r_1' = (|h_1|^2 + |h_2|^2) c_1 + n_1' \\ r_2' = (|h_1|^2 + |h_2|^2) c_2 + n_2' \end{cases} \quad (9)$$

It can be seen that there is no c_2 in r_1' ,no c_1 in r_2', In this way, c_1 and c_2 are separated from the signal interleaving relationship between the two antennas. This effect can be achieved precisely because of the establishment of equation (1), which makes use of the property that Alamouti space-time coding matrix $\begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix}$ is a complex orthogonal matrix.

The receiver adopts the maximum likelihood decoding method, that is, to search all possible code-words (c_1', c_2') from the constellation to minimize the value of formula (10) below.

$$\begin{cases} |c_1' - r_1'|^2 \to \min \\ |c_2' - r_2'|^2 \to \min \end{cases} \quad (10)$$

A pair of code-words (c_1', c_2') found, that is, the decoded output.

MATLAB Simulation Analysis of Alamouti Space Time Coding Scheme

Use MATLAB software to simulate BER(the bit error rate) curve of (1×1) SISO(single in single out), (2×1) Alamouti space-time coding, (2×2) Alamouti space-time coding, (1×2) MRC and (1×4)MRC.

Simulation environment: The channels of these five schemes are slow Rayleigh fading, the link fading from each transmitting antenna to each receiving antenna is independent, and the receiver has known channel state information (CSI). (The use of large-scale antenna arrays makes large-scale MIMO systems have a new channel characteristic - nonstationarity. Therefore, the channel complexity we face in the actual scene is far from the situation in the experimental simulation [9, 10].)

The simulation results are shown in Figure 4:

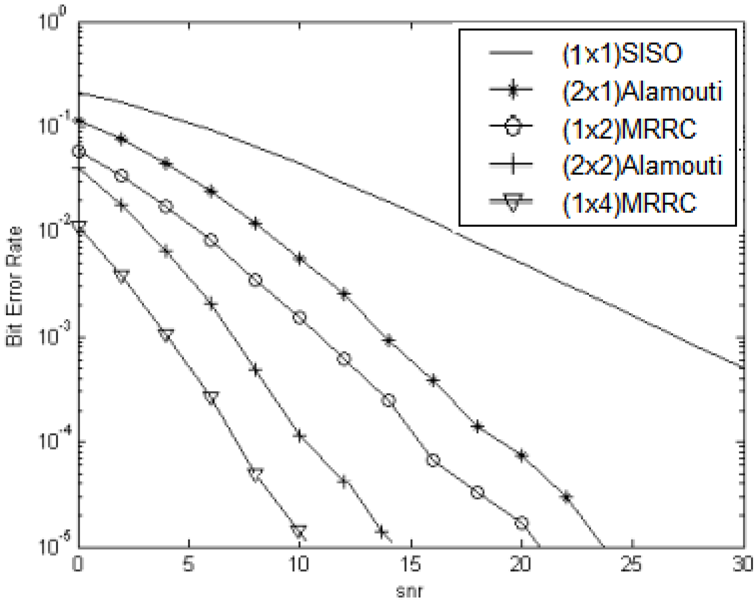

Figure 4: BER Performance Curves of Five Schemes

According to the BER performance curve shown in the simulation result diagram, it can be seen that:

a. (2×1) Alamouti scheme and (1×2) The MRC scheme has the same diversity order (the slope of the curve is the same).

b. (2×1) In Alamouti scheme, each transmitting antenna is equally divided (1×2) The MRC scheme transmits the radiation energy of the antenna, and the latter can obtain power combining gain at the receiver, so the BER performance of the latter is better than that of the former by 3dB (The curve of the latter is translated down by 3dB), and the simulation curves of the two schemes are similar.

c. (2×2) Alamouti scheme and (1×4) The MRC scheme has the same diversity order (the slope of the curve is the same).

d. The BER performance of Non diversity (1×1)SISO scheme is the worst. (The curve is the highest and the slope is the most gentle)

3. Conclusion

The following rules can be obtained from the simulation diagram:

◆ With the increase of snr (signal to noise ratio), the BER performance curves of the above five schemes are monotonically decreasing. That is to say, with the increase of snr, the BER of the received signals of the five schemes is reduced. It shows that the greater the gain (snr) of the receiving antenna, the better the quality of the received signal.

◆ Under the same antenna gain, the bit error rate of one receiving antenna is higher than that of two. Conversely, the number of antennas is proportional to the quality of the received signal.

◆ Under the same transmission diversity conditions, the number of receiving antennas is inversely proportional to the bit error rate of the received signal, that is, the number of receiving antennas is proportional to the quality of the received signal.

◆ The curves of (2×1) Alamouti scheme and (2×2) Alamouti scheme are both lower and steeper than the curve of uncoded (SISO), indicating that the system using this scheme has obtained a smaller BER.So Alamouti space-time coding scheme is adopted in MIMO system have obtained diversity gain and coding gain.

In conclusion, the results show that the BER performance of the five schemes decreases as the SNR increases. This suggests that as the gain (SNR) of the receiving antenna increases, the quality of the received signal improves. Additionally, it is observed that under the same antenna gain, the bit error rate of one receiving antenna is higher than that of two. This implies that the number of antennas is proportional to the quality of the received signal. Under the same transmission diversity conditions, it is found that the number of receiving antennas is inversely proportional to the bit error rate of the received signal, meaning that the number of receiving antennas is proportional to the quality of the received signal. It is also noted that the Alamouti space-time coding scheme is adopted in MIMO system to obtain diversity gain and coding gain.

The results of the study indicate that the BER performance of the five schemes improves with increasing SNR. It also suggests that increasing the number of receiving antennas can result in better received signal quality. Furthermore, the results suggest that the use of the Alamouti space-time coding scheme in a MIMO system can effectively achieve both diversity gain and coding gain, which ultimately results in improved system performance. Based on these findings, it can be inferred that the use of MIMO with sufficient number of antennas and appropriate space-time coding scheme is an effective way to enhance the performance of wireless communication systems in challenging environments.

A key design principle of space-time coding is to achieve spatial diversity, with the aim of improving performance incrementally through increased coding gain. However, it should be noted that the impact of coding gain on performance is limited, and diversity gain remains a crucial factor in the overall performance of space-time coding.

As the number of antennas increases, the technical and processing complexity of wireless communication systems also increases dramatically. Large-scale MIMO systems employ many antennas, which help to average out the effects of thermal noise and fast fading and often only require simple processing using coding and detection techniques [11]. However, it is not possible to obtain the CSI of an unlimited number of terminals, so there is a limit to the number of terminals that can be served simultaneously [12]. Additionally, experiments have shown that mutual coupling can increase system capacity to a certain extent [13].

In summary, the design principle of space-time coding is to achieve spatial diversity, which helps to improve performance by increasing coding gain. However, it is important to note that the impact of coding gain on performance is limited, and diversity gain is still the dominant factor in space-time coding performance. Additionally, as the number of antennas in a MIMO system increases, the technical and processing complexity also increases. Large-scale MIMO systems can average out the effects of thermal noise and fast fading and are typically simple to process but they have a limited number of terminals can be served at the same time. Experiments also showed that mutual coupling effect can increase the system capacity.

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