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The Research of STBC in MIMO System

Xuexiang Piao, Yuqin Ao

School of Information and Electrical Engineering, Hebei University of Engineering, Handan, Hebei, China

Abstract: *MIMO technology refers to the use of multiple transmitting antennas and multiple receiving antennas to improve the quality of information transmission. MIMO technology includes space-time coding, channel modeling, channel estimation, and other technologies. This paper mainly studies the space-time coding technology and precoding technology in the MIMO system through Matlab. First, the Alamouti coding is extended to the MIMO system with more transmitting and receiving antennas. This way can get a space-time block code. Finally, this paper will introduce the precoding technology and compare it with simulation analysis by simulating and analyzing its bit error performance.*

Keywords: *MIMO, STBC, Alamouti, Precoding*

1. Introduction:

Wireless communication technology is still a hot topic in contemporary times. As users' requirements for communication performance are getting higher and higher, the requirements for system capacity and coverage of mobile communication systems are getting higher and higher. However, in the transmission process, the performance of the wireless system is limited due to the lack of transmission power spectrum resources, the fading effect of the wireless channel, and the occurrence of co-channel interference. The emergence of MIMO systems makes up for spectrum resources and improves spectrum utilization. Compared to existing traditional cellular wireless communication technology, the spectral efficiency is increased from 1~5bit/s/Hz to 20~40bit/s/Hz, providing a higher voice system.

At the beginning of the 20th century, research on MIMO technology began to rise. For example, Telator in 1955 and the Foschini in 1998 introduced multiple-input multiple-output (MIMO) technology with multiple antennas at the transmitter and receiver. And under the additive white noise channel, they concluded that MIMO technology improves the transmission rate. In addition, Foschini proposed MIMO system research with eight transmitting antennas and 12 receiving antennas in 1996, and the spectral efficiency reached 40bit/s/Hz. Under the leadership of these experiments, MMO system technology has become a research boom in the future, attracting the attention of all countries.

MIMO system is one of the hot topics and technologies in fifth-generation systems (5G). This system uses time, frequency, modulation, and antenna parameters to classify and reuse channels. Space-time coding, one of MIMO technologies, can maintain the reliability of channel transmission and reduce the influence of time-varying multipath fading in wireless systems. Its representative ones are Space-Time Trellis Codes (STTC) and space-time Block Codes (STBC). Another kind of technology is precoding technology which restrains channel interference. The representative technologies are Beamforming and finite feedback technology. This paper will mainly focus on Alamouti coding technology and precoding technology to analyze the channel reliability of the MIMO system in the closed-loop and open-loop states. And the results are verified by Matlab simulation experiments.

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2. MIMO system

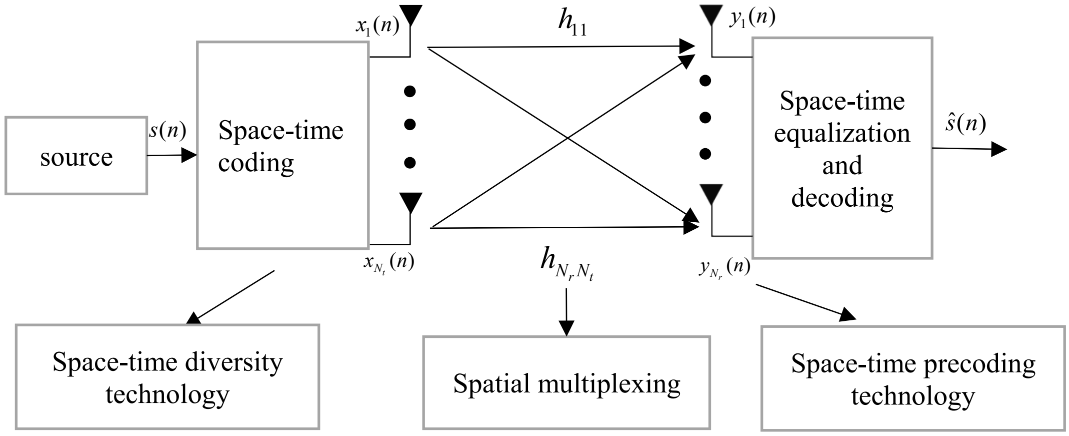

Figure 1: MIMO system

As shown in Figure 1, a MIMO system corresponds to r transmit antennas and t receive antennas. It indicates that the channel contains rt single-input single-output (SISO) sub-channels. This parameter represents the fading coefficient during signal transmission. Under the premise of considering Gaussian additive white noise, the information received by the r receiving antenna can be summarized as follows [1]:

$$y_{N_r}(n) = \sum_{N_{r \setminus t}=1}^{t} h_{N_r N_t} x_{N_t}(n) + n_{N_t}, N_t = 1,2,...,t \tag{1}$$

In flat fading signals, the equation can be simplified into a matrix composed of vectors:

$$Y = HX + n \tag{2}$$

$X = \left[x_1, x_2 ... x_{N_t}\right]^{\mathrm{T}}$ is the signal transmitted from the transmitter at time t.

$Y = \left[y_1, y_2 ... y_{N_r}\right]^{\mathrm{T}}$ is the signal received from the receiver at time t.

$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_t} \\ h_{21} & h_{22} & \cdots & h_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r 1} & h_{N_t 2} & \cdots & h_{N_r N_t} \end{bmatrix}$ is the channel fading coefficient of the channel matrix from the transmitting antenna to the receiving channel.

$n = [n_1, n_2 \ldots n_{N_r}]^{\mathrm{T}}$ is independent zero-mean additive white noise.

2.1. Diversity gain and multiplexing gain

Using multiple antennas at high SNR can improve diversity. Since the diversity gain is usually related to the transmit and receive antennas. The maximum diversity gain that a MIMO system with t transmit and r receive can give is tr [4].

The common diversity methods include time diversity, frequency diversity, and spatial diversity. Time diversity means that multiple signals are sent in a certain time slot, and multiple independent signals can be received at the receiving end. Frequency diversity is beneficial to resist selective fading by sending signals at different frequencies. Spatial diversity means that multiple antennas are used to transmit and receive signals, and the received signals are combined to ensure the irrelevance of the signals.

Multiplexing gain refers to the gain obtained by multi-antenna signal processing, which can be transmitted from several sub-channels through space channels. In MIMO systems with t transmitting and r receiving, the maximum multiplexing gain can be expressed by $\min(t, r)$.

If you want to obtain both diversity gain and multiplexing gain, you need to compromise between the two ways. If the multiplexing gain is 0, the corresponding diversity gain will reach the maximum diversity effect that can be realized. Taking Alamouti coding as an example, considering the diversity gain and multiplexing gain of the MIMO system, it is found that the optimal compromise is the two-transmitter and one-receiver system. Although the maximum diversity gain is 4 for a two-for-two system, the maximum multiplexing gain is only 1.

3. Space-Time Block Code

Space-Time Block Code (STBC) is a technology used in wireless communication MIMO systems for multiple copies of multiple sender data streams to improve the reliability of signal transmission. Since the receiver receives multiple copies from multiple transmitters, these redundancies reduce the bit error rate and improve the probability of correct decoding. In summary, Space-Time Block Code extracts information from multiple copies. In Space-Time Block Code, the representative encoding method is Alamouti encoding, which can achieve complete diversity gain in the two-transmitter and two-receiver MIMO system.

4. Alamouti Coding Scheme

Alamouti encoder is a hierarchical scheme for transmitting through two transmitting antennas. There is a specific process is shown in Figure 1.

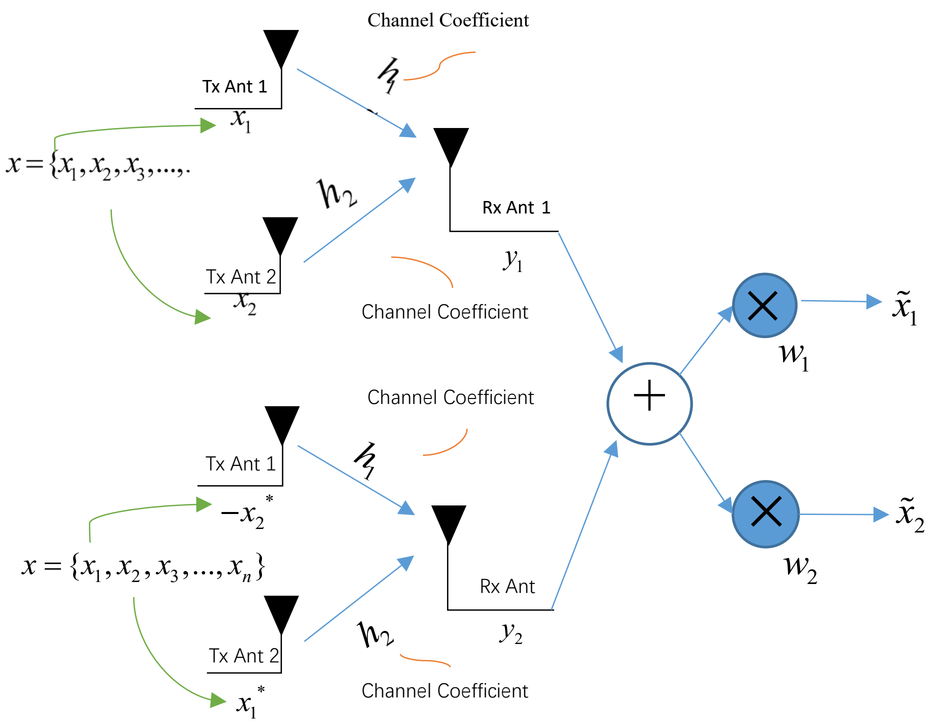

Figure 2: Alamouti scheme

The encoder and decoding process of the Alamouti scheme is shown in Figure X. The transmission signal passes through a space-time encoder composed of two Tx antennas, and transmits information from two transmission channels respectively. Each transmits and receive antenna corresponds to a channel, and each channel corresponds to a channel coefficient. In wireless systems, channel coefficients have become one of the main research areas of MIMO technology, and the complexity of the system will vary with the number of antennas[1]。

The Alamouti space-time encoder receives two modulation symbols, in which case it is called x_1

and x_2,and creates a coding matrix X, where symbols and the two transmitting antennas are mapped into two transmitting gaps. The coding matrix is shown in the following:

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{3}$$

In the previous period of the signal, the x1 and x2 information symbols are output from antenna1 and antenna2, and in the later transmitting period x_1^* and $-x_2^*$ information symbols are also output from both antennas simultaneously.By the type of matrix, it can be seen that the Alamouti codeword X is a complex orthogonal matrix using orthogonal knowledge.

$$XX^{\mathrm{H}} = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2) I_2 \tag{4}$$

In the above formula 4, I_2 is an identity matrix with dimension 2×2.

In the Alamouti receiver, it is assumed that the channel gain has perfect state information during the signal period, and the Alamouti code is analyzed through ML signal detection. The signals received by the Jth receiving antenna in the period are represented by y_1 and y_2 [2].

$$y_1^j = h_{j,1} x_1 + h_{j,2} x_2 + n_1^j \tag{5}$$

$$y_2^j = -h_{j,1} x_2^* + h_{j,2} x_1^* + n_2^j \tag{6}$$

In the above formulas, y_1^j and y_2^j represent the reception vector of the antenna in two- time. $h_{j,1}$ and $h_{j,2}$ represent the channel coefficient, n_1^j and n_2^j represent the noise vector during time slot 1 and time slot 2.

Now, in the case that all signals in the modulation constellation are equally likely, the maximum likelihood decoder selects the smallest distance in the modulation constellation.

$$\begin{aligned} & d^2(y_1^j, h_{j,1}\widehat{s}_1 + h_{j,2}\widehat{s}_2) + d^2(y_2^j, -h_{j,1}\widehat{s}_2^{\,*} + h_{j,2}\widehat{s}_1^{\,*}) \\ & = \left| y_1^j - h_{j,1}\widehat{s}_1 - h_{j,2}\widehat{s}_2) \right|^2 + \left| y_2^j + h_{j,1}\widehat{s}_2^{\,*} - h_{j,2}\widehat{s}_1^{\,*}) \right|^2 \end{aligned} \tag{7}$$

The statistical results of the two decisions generated by the received signals after merging and information transmission channels are expressed as follows:

$$\tilde{s}_1 = \sum_{i=1}^{2} \sum_{j=1}^{M} \left| h_{j,1} \right|^2 s_1 + \sum_{j=1}^{M} h_{j,1}^* n_1^j + h_{j,2} (n_2^j)^* \tag{8}$$

$$\tilde{s}_2 = \sum_{i=1}^{2} \sum_{j=1}^{M} \left| h_{j,1} \right|^2 s_2 + \sum_{j=1}^{M} h_{j,2}^* n_1^j + h_{j,1} (n_2^j)^* \tag{9}$$

Now, the decoding result after ZL detection can be divided into two independent signals $\widehat{s}_1$ and $\widehat{s}_2$.

$$\widehat{s}_1 = \arg\min_{\widehat{s}_1 \in S} \left[\left(\sum_{j=1}^{M} \left(\left| h_{j,1} \right|^2 + \left| h_{j,2} \right|^2 \right) - 1 \right) \left| \widehat{s}_1 \right|^2 + d^2(\tilde{s}_1, \widehat{s}_1) \right] \tag{10}$$

$$\widehat{s}_2 = \arg\min_{\widehat{s}_2 \in S} \left[\left(\sum_{j=1}^{M} \left(\left| h_{j,1} \right|^2 + \left| h_{j,2} \right|^2 \right) - 1 \right) \left| \widehat{s}_1 \right|^2 + d^2(\tilde{s}_2, \widehat{s}_2) \right] \tag{11}$$

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5. Space-time precoding technology

Space-time precoding technology refers to the closed-loop MIMO system, through the channel estimation of the signal by the receiver, the result is fed back to the sender in whole or in part. The sender can determine the channel information through the feedback information, precoding the sent signal in advance, ensuring the reliability of the signal, and improving the system capacity. In LTE, for example, WiMAX uses precoding technology to suppress signal interference and increase system capacity[6]. For linear precoding, the channel response matrix can be represented by W, and the system using precoding can be represented as:

$$y = HWx + n \tag{12}$$

X is the information character vector, and n is the additive noise of the channel. For the space-time coding system, the system model using precoding can be expressed as:

$$Y = HWX + N \tag{13}$$

In formula 13, X is the space-time encoded transmitted signal, Y is the corresponding received signal, and N is the additive noise matrix.

Space-time precoding can be based on the reciprocity of the channel or the CSI feedback from the sender to the receiver, and the transmitter knows the CSI.

The reciprocity of the channel refers to the channel gain correlation between sender and receiver, that is, they are mutually beneficial. If the time difference between uplink and downlink is less than the coherent time in a TDD transmission system, the channel has reciprocity. However, in the FDD transmission system, the reciprocity of the channel does not exist due to different transmission frequencies.

CSI feedback is different from the reciprocity of the channel. The receiver directly feeds back to the transmitter to obtain channel information for pre-coding. However, this method has certain disadvantages, that is, additional resources are needed to feedback the transmission information, and the feedback information increases with the number of antennas. Therefore, in a multi-antenna MIMO system, the CSI feedback can be compressed at the receiving end to reduce occupied resources[6]. Among them, the commonly used method is to quantize the channel gain. By quantizing the channel gain H, the mean square error of the channel reaches the minimum value $E\{\|H - Q(H)\|\}$, and $Q(H)$ represents the quantization result of the channel gain H . Another method is to share a codebook between the transmitter and the receiver, and the codebook represents the quantized set. In this method, the receiver will perform channel estimation on the signal to obtain the corresponding channel gain, and then select a suitable codeword number from the codebook for estimation, and feedback its corresponding code like the transmitter. Because it is CSI feedback after compression, each number is represented by F_B bits, that is, the size of each codebook is $L = 2^{F_B}$ codewords. W_i is used to represent the ith codeword, and the corresponding codebook is $F = \{W_1, W_2, \ldots, W_L\}$.

6. Alamouti coding with space-time precoding

Suppose a MISO system with N transmitter antennas and 1 receiver antenna, When the space-time coded transmitted signal C passes through the precoding system, a suitable channel state is selected from the codebook $F = \{W_1, W_2, W_3, \ldots W_L\}$, and then multiplied by the space-time coded space-time codeword C . Assuming that in the MISO system, each channel remains unchanged within T time to ensure the reliability of the channel and improve the channel capacity or bit error rate of the system, the received signal can be expressed as follows[5]:

$$y = \sqrt{\frac{E_x}{N_{Tx}}} hwc + z \tag{14}$$

Since it still takes a lot of time to solve the encapsulation of feedback information in the precoding process, the DFT matrix design method happens to solve the above problems:

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In the formula, the (k, L) element in the DFT matrix is $\frac{e^{\frac{j2\pi(k-1)(l-1)}{N_{TX}}}}{\sqrt{N_{TX}}}$, and when θ is a diagonal matrix, $\{u_i\}_{i=1}^{N_{TX}}$ represents the variable to be determined. Since for a random channel, the optimal codebook is determined by the maximum and minimum chord distances, so the corresponding variables can be determined [5].

The OSTBC design parameters set for the codebook size in IEEE802.16e are as follows:

Table 1: The OSTCBC design parameters set for the codebook size in IEEE802.16e

N_{Tx}	M	L	c	U
2	1	8/(3)	[1]	[1,0]
3	1	32/(5)	[1]	[1,26,28]
4	2	32/(5)	[1,2]	[1,26,28]
4	1	64/(6)	[1]	[1,8,61,45]
4	2	64/(6)	[0,1]	[1,7,52,56]
4	3	64/(6)	[0,2,3]	[1,8,61,45]

According to Table 1, for example, Alamouti2x1 as an example, when comparing the table N=2, M=1, L=8, the corresponding.

7. Experimental Results

Alamouti coding can achieve complete transmit diversity of N=2, assuming that the channel is a Rayleigh flat fading environment. The modulation method used is QPSK. The simulation results show the BER and Eb/No performance of the Alamouti encoder [3].

As shown in Figure 3, Compared with the AWGN channel and SISO Rayleigh fading channel, Alamouti coding has higher performance advantages. Alamouti space-time coding has a higher signal-to-noise ratio than the AWGN channel. In addition, BER is smaller than the SISO system and has higher reliability.

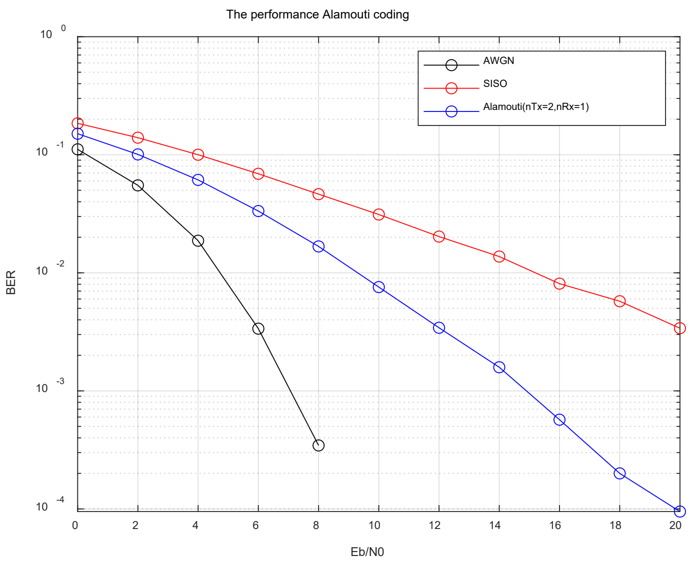

Figure 3: The performance of Alamouti coding

As can be seen from the simulation analysis diagram in Figure 4, the BER curve of space-time coding is determined BER by the number of transmitting antennas and receiving antennas[3]. The bit error rate curve becomes steeper as the diversity gain increases. From the figure, the different curves are offset vertically. Although the coding gain is one in the definition, the total power is normalized during the simulation. So the transmit power of each antenna is evenly distributed. Therefore, the transmitting power of the transmitter will vary with the transmitting antenna. The more transmitting antennas, the more vertical deviation of the curve, and the coding gain will decrease. The more transmitting antennas, the

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higher the curve deviation degree, indicating that the coding gain is smaller. Two a closed Alamouti coding compared with the SISO system, found that deviation exists in the vertical direction. From the curve slope analysis, it can be seen that Alamouti (nTx=1, nRx=2) and Alamouti (nTx=2, nRx=1) have the same slope. From the bit error rate analysis, since Alamouti (nTx=2, nRx=1) has the largest diversity gain, its performance is higher. In addition, comparing Alamouti (nTx=1, nRx=2) and Alamouti (nTx=2, nRx=1), it can be found that Alamouti (nTx=2, nRx=1) is more prominent in coding gain.

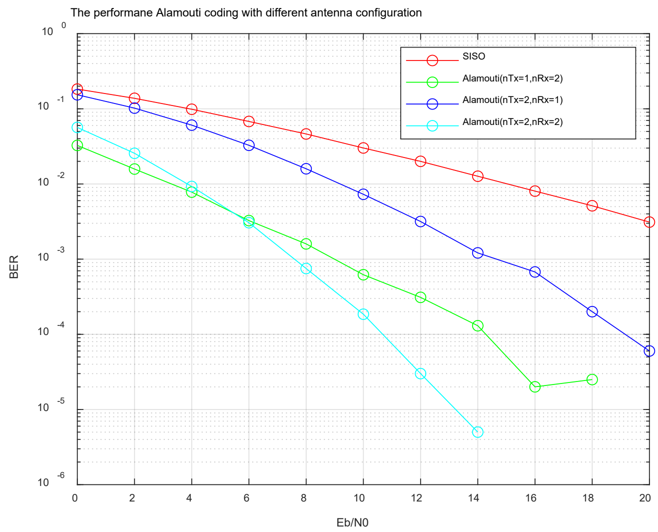

Figure 4: The performance of Alamouti coding with the different antenna configuration

When some or all of the CSI is known, the throughput of the MIMO transmission system will increase, and the bit error rate will increase. It can be seen from the analysis in Fig. 5 that under the same channel state information, the bit error rate of Alamouti coding after precoding is lower.

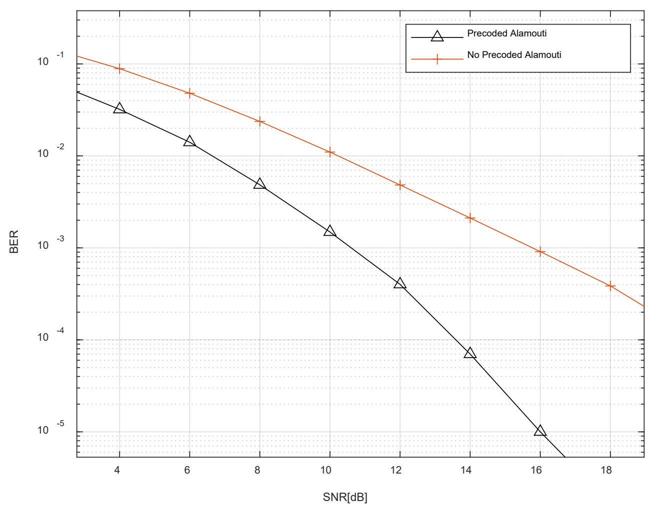

Figure 5: The performance of the precoded Alamouti (nTx=2, nRx=1)

8. Conclusion

This paper explains the space-time coding technology and precoding technology of MIMO technology. Based on a simple Alamouti. It describes the relevant formula analysis and uses BPSK modulation to simulate the Rayleigh channel distribution. It also compares and analyzes the BER of MIMO systems using multiple transmit multiple receive antennas.

Therefore, results in that space-time coding reduce BER through orthogonalization of time and space domains and achieve better transmission reliability and diversity gain. Finally, extending from Alamouti to precoding techniques, simulations are performed using BPSK modulation in Rayleigh

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channels and compared with no precoding. The result is that Alamouti precoding improves BER with a better linear curve. Therefore, space-time coding and precoding are indispensable core technologies in MIMO technology. It provides the basis for better transmission rate and transmission reliability.

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