Improving Coal Mine MIMO Performance Based on Space-time Coding

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Abstract: Transmission environment of mine laneway is non-free, wireless communication reliability is reduced by multipath fading. MIMO can efficiently overcome multipath fading, but MIMO channels in mine laneways have strong correlation. In this paper, the performances of space-time code in mine laneway are investigated, and the pair wise error probability (PEP) about mine laneway is analyzed. Following that, this paper proposes a novel space-time code construction which could compensate the impact of strong correlation MIMO channels in mine laneway—quasi-orthogonal space-time code. The simulation results show that the orthogonal qualification what every element must be pluralism in transfer matrix is reduced and the qualification of unattached coding is relaxed else .The less SNR is need merely under the satisfying high target bit error rate.

Keywords: mine communication; MIMO; multipath fading; correlation channels; quasi-orthogonal space-time code

1 Introduction

Mine laneway is non-free transmission space of space restricted, the transmitting properties of the electromagnetic waves is very complex, the actual multipath fading is the main characteristics of channel[1]. Mine communication channel does not have the ideal scattering environment, meanwhile , there will have a strong correlation among the MIMO channels in mine laneway[2] , which impacted by the antenna's distribution and distance, direction of arrival and angle spread, he results show that the System allows transmission error , the bigger correlation coefficient is, the larger signal-to-noise ratio is, when correlation coefficient close to 1, the gain of coded diversity will disappear completely, The system performance worsens seriously. Underground Coal Mine, the special production environment and the safety production request wireless communication devices of mine working accurately and reliably, if the relevance between the space channel is greater, not only reduces the MIM0 system channel capacity, but also has a negative impact in the performance of space-time code[3].

2 Mine Wireless MIMO System Model

Mine wireless communication environment is completely difference from land mobile communications environment[4], MIMO system can take full advantage of multi-antenna space-position system under terrestrial environment, thus avoid decline in communication capacity which the strong correlation between the MIMO channel creates, and the mine laneway is can not be achieved.

According to the mine channel's actual situation, It can be assumed that the duration of signal is much longer than delay spread and channel is a Rayleigh flat fading MIMO channel. Sending data streams into code matrix: $C=[c_0\ c_1 \cdots c_{k-1}]$, c is the M×1 vector, K is the code length. element number $h_{i,j}$ of H matrix express complex transmission from transmitting antenna i to , at t time ,transmitting antenna i transmit plural symbol c_k , received signals r_k of receiving antenna j at t time pass by noise interference and fading of propagation path is:

$$r_k=\sqrt{E_s}h_{i,j}c_k+z_k \tag{1}$$

In the formula(1), z_k is additive noise of receiving antenna j and white Gaussian noise which mean is zero and variance is σ^2,and all receiving antenna is independent identically distributed , E_s is the average symbol energy.

3 Performa nce of System-error in Channel Correlation

According to literature[5] calculate the way of error probability in correlated fading channels' space-time coding and analysis the error probability in mine strong correlation of MIMO channel . Supposing C_i and C_j express two

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different M×K encoding matrix, the channel matrix is H, matrix C_i which is transmitted by inchoation is judged erroneously as error probability of C_j:

$$P(C_i \to C_j / H) \le e^{-(E_s/4\delta^2) d^2(C_i, C_j/H)} \quad (2)$$

Where $d^2(C_i, C_j / H) = \sum_{k=0}^{K-1} \left\| H(c_k \sim e_k) \right\|^2$, in order to c-onvenience computation, define:

$$y_k = H(c_k \sim e_k),$$

$k = 0,1,\cdots,K-1$, so $Y = \left[y_0^T \; y_1^T \; \cdots \; y_{k-1}^T \right]^T$,

$d^2(C_i, C_j / H) = \left\| Y \right\|^2$, formula (2) can be written as:

$$P(C_i \to C_j / H) \le e^{-(E_s/4\delta^2)\|Y\|^2} \quad (3)$$

$C_Y = \Xi\left\{ YY^H \right\}$, $\lambda_i(C_Y)(i = 0,1,\cdots,r(C_Y)-1)$ is eigenvalue of C_Y, take the statistical average on both sides of formula (3):

$$\Xi\left\{ P(C_i \to C_j / H) \right\} \le \prod_{i=0}^{r(C_Y)-1} (1 + \lambda_i(C_Y) \frac{E_s}{4\delta^2})^{-1} \quad (4)$$

In the formula (4) $\Xi\left\{ P(C_i \to C_j / H) \right\}$ is the average error probability. Make the channel transfer matrix Substitute in C_Y, so:

$$C_Y = \left[(C_i \to C_j)^T R_{TX}^T (C_i \to C_j)^* \right] \otimes R_{RX} \quad (5)$$

Where, $\otimes$ is Kronecker product of matrix, comparing with formula (2), (4) and (5) can be seen, correlation matrix's characteristic influence system's PEP, the smaller the matrix rank, the stronger the correlation, the worse the system performance. in strong correlated MIMO channels environments of mine roadway, each coding scheme needs to consider fully the influence which the system performance drops caused by channel correlation.

4 The Coding Scheme that the Compensation Relevant Affects Error Probability

As can be seen from the above analysis, the influence of system performance caused by spatial correlation of channel is very large, mine laneway is a strong correlation channel, coding scheme of STBC not only need consider fully the influence which the system performance drops caused by the relevance of the compensation channel ,but also consider low complexity of encoding and decoding. Therefore, using space-time coding scheme in the transmitting terminal could obtain full diversity gain and maximum coding gain[6].

4.1 Quasi Orthogonal Space-time Coding Scheme

This paper proposes a space-time coding scheme that not only reduces requirements of orthogonal and relaxes the condition of independent decoding, but also compensates the influence of strong correlation——optimal rotation quasi orthogonal space-time block coding (QOSTBC).

Supposing MIMO system is 4 round of antenna systems ,choosing constellation mark are s_1, s_2, s_3, s_4, making the encoding matrix $x_k = s_k$, k =1, 2, 3, 4, this article according to literature [7] coding scheme of 4 antenna QOSTBC are as follows:

$$G = \begin{pmatrix} G(x_1, x_2) & G(x_3, x_4) \\ -G^*(x_3, x_4) & G^*(x_1, x_2) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{pmatrix} \quad (6)$$

In the formula (6) G^* is encoding matrix G's complex conjugate. Very easy to see, the quasi-orthogonal matrix G 's subspace is orthogonal, the wrong matrix's $D(C^i, C^j)$ smallest rank is 2, the receiving code word matrix is $C = G(s_1, s_2, s_3, s_4)$, showing formula（6） is a full speed code. Therefore, when the number of receiving antennas is N, the full speed obtains the largest diversity order is 2N, however, if each transmission mark choose the same constellation, it cannot achieve full diversity 4N.In order to achieve 4N, whirling the symbols become s_3 and s_4 before sending, meanwhile , in order to compensate the dropped performance caused by channel correlation, according to literature [8] analysis, the most superior angle of rotation of the star map Using QPSK modulation is $\phi = \pi / 4$,through divides 4 round of antennas into a group of two of the two groups, each group uses the Alamouti code, then may obtains the encoding matrix G is :

$$G = \begin{pmatrix} x_1 & x_2 & 0 & 0 \\ -x_2^* & x_1^* & 0 & 0 \\ 0 & 0 & x_3 & x_4 \\ 0 & 0 & -x_4^* & x_3^* \end{pmatrix} \quad (7)$$

s_k replace with x_k of G by using replacement method, that is $x_1 = s_1 + s_2$; $x_2 = s_3 + s_4$; $x_3 = s_1 - s_2$; $x_4 = s_3 - s_4$, so receiving code word matrix is:

$$C^H \cdot C = \begin{pmatrix} a+b & 0 & 0 & 0 \\ 0 & a+b & 0 & 0 \\ 0 & 0 & a-b & 0 \\ 0 & 0 & 0 & a-b \end{pmatrix} \quad (8)$$

In the formula（8）:

$$a = \sum_{k=1}^{4} \left| s_k \right|^2, \; b = 2\,\mathrm{Re}(s_1^* s_2 + s_3^* s_4)$$

4.2 Maximum Likelihood Detecting and Decoding

Detection and decoding of receiving end must determine according to coding method of transmitting end and use space-time block coding, the maximum likelihood detection is the best decoding algorithm. As mentioned above, s_1 and s_2 which the coding length are K are two continual space-time block coding data block, receiving antenna j receive in any two consecutive received frame as follows:

$$r_{1,j} = \Phi_{1,j} s_1 + \Phi_{2,j} s_2 + z_1 \quad (9)$$

$$r_{2,j} = -\Phi_{1,j} s_2^* + \Phi_{2,j} s_1^* + z_2 \quad (10)$$

In the formula, z_1 and z_2 are Additive white Gaussian noise which mean is zero and variance is σ^2 in receiving antenna j .Selecting the smallest Decision Metric value from all possible values of s_1 and s_2 is the subs of maximum likelihood detection and decoding, namely:

$$\sum_{i=1}^{4}\sum_{j=1}^{N}\left| r_{i,j} - \sum_{k=1}^{2} \Phi_{k,j} s_k \right|^2 = \sum_{j=1}^{N}\left(\left| r_{1,j} - \Phi_{1,j} s_1 - \Phi_{2,j} s_2 \right|^2 + \left| r_{2,j} + \Phi_{1,j} s_2^* - \Phi_{2,j} s_1^* \right|^2 \right) \quad (11)$$

Neglect the irrelevant items of the transmitting signal in the above formula, minimization problem equivalent to two minimization metric value as follows:

When examines s_1, the minimization decision value is:

$$\left| [\sum_{j=1}^{N} (r_{1,j}\Phi_{1,j}^* + r_{2,j}^*\Phi_{2,j})] - s_1 \right|^2 + \left[\sum_{i=1}^{4}\sum_{n=j}^{N} \left|\Phi_{i,j}\right|^2 - 1 \right] \left| s_1 \right|^2 \quad (12)$$

When examines s_2, the minimization decision value is:

$$\left| [\sum_{j=1}^{N} (r_{1,j}\Phi_{2,j}^* - r_{2,j}^*\Phi_{1,j})] - s_2 \right|^2 + \left[\sum_{i=1}^{4}\sum_{j=1}^{N} \left|\Phi_{i,j}\right|^2 - 1 \right] \left| s_2 \right|^2 \quad (13)$$

At this point, the decoder will transmit 1 yards vector C_i judged C_j by mistake, the error probability can be approximately expressed as:

$$P(C_i \to C_j) \le \exp(-d_{\min}^2 / 2) \quad (14)$$

Where $d_{\min}^2 = (1/\sigma^2)\min\left\| HVE \right\|$, $E = C_i - C_j$,based on orthogonal space-time coding can obtain:

$$(C_i - C_j)(C_i - C_j)^H = \sum_{k=1}^{K} \left| s_{ki} - s_{kj} \right|^2 I = KE_S I \quad (15)$$

$$P(C_i \to C_j) \le \left\{ \det\left[I + \frac{N_0 E_S}{\sigma^2} \begin{pmatrix} \lambda_1 & 0 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 \\ 0 & 0 & \lambda_3 & 0 \\ 0 & 0 & 0 & \lambda_4 \end{pmatrix} \right] \right\}^{-N} \quad (16)$$

When the channel has a strong correlation, equation (15) can be approximated as:

$$P(C_i \to C_j) \le \left(\frac{N_0 E_S}{\sigma^2} \right)^{-4N} \left(\prod_{p=1}^{4} \lambda_p \right)^{-4} \quad (17)$$

Which shows that the diversity gain of system approximate equal to 4N and the system was equivalent to a 4 inputs and N outputs weak correlation MIMO system, This is the case which the paper would like to, it also achieves the conclusions of full diversity given by literature [7].

5 Simulation results

In this paper, coding efficiency proposed under Matlab environment, simulation conditions have been assumed that the receiver know the channel state information, adopting 4×1 MIMO system, correlation coefficient of transmit channel is 0.55, Signal modulation QPSK uses a square constellation diagram, QOSTBC uses $\phi = \pi / 4$ rotating Alamouti coding.

Figure 1 shows the BER curves of QOSTBC when M= 1、2、3、4, N=1, indicates the sending end using transmit diversity, system performance improves with the number of transmit diversity increases and the reliability of communications improves greatly. At the same time, the transmit power of the sending end also decreased, which is suited to requirements while limitation of transmit total power of mine particularly. Figure 2 shows the simulation results that the encoding scheme proposed in this paper has more than 2dB on performance improvement compared with QOSTBC of 4inputs and 1output in the same target BER = 10-4. Fig.3 shows the simulation results that the transmit end channel correlation coefficient is 0.55 when BER=10^{-2}, code performance of QOSTBC is close between correlated channel and independent channel, which compared with the traditional STBC code performance of correlated channel has about the 2dB gain. Figure 4 shows that when the correlation coefficient increases to 0.8, SNR must increase above 1dB under the same target BER (is equal 1dB in loses).

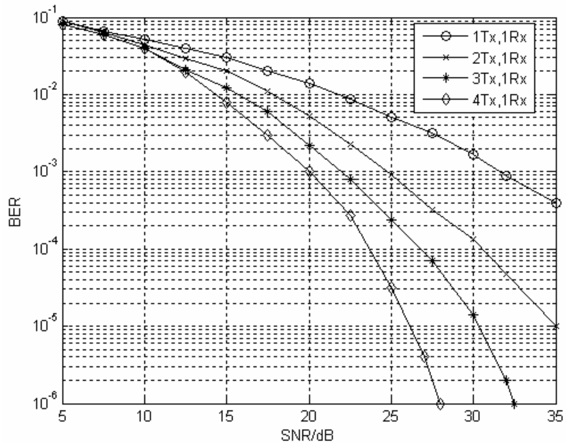

Figure 1. BER curve for Tx=1、2、3、4 and Rx=1

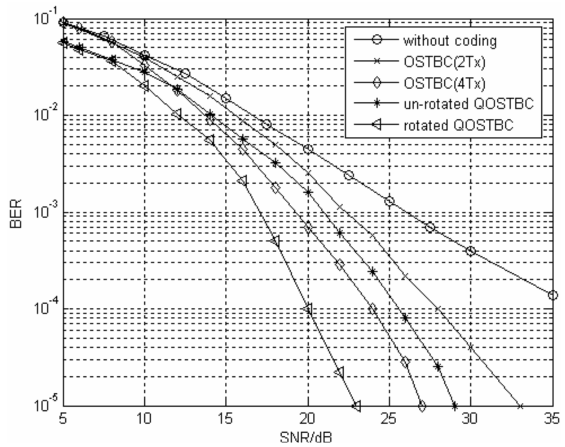

Figure 2. BER performance compare data different coding scheme

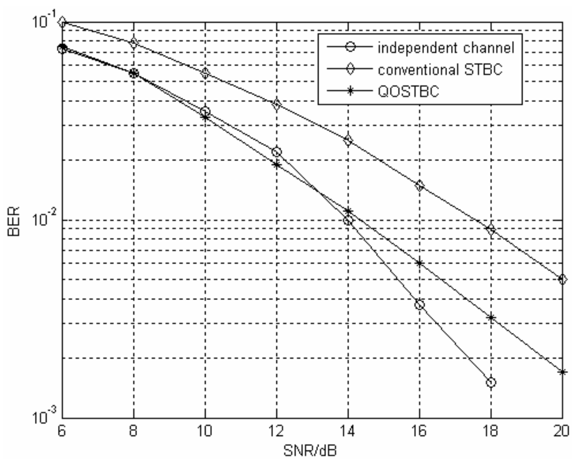

Figure 3. BER performance for correlation factor=0.55

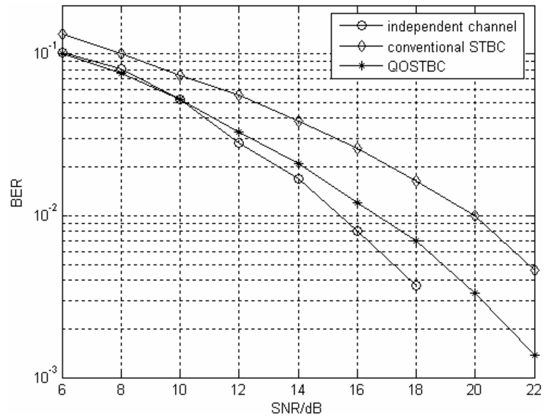

Figure 4. BER performance for correlation factor=0.8

6 Conclusion

The spatial strong relevance of mine MIMO causes space and time code performances to decrease seriously, and non-free space in mine laneway to establish the multi-antennas can't avoid correspondence quality dropping caused by strong correlation between MIMO channels. This article proposes QOSTBC ,which although increase the decoding complexity slightly, but can compensate System reliability caused by Strong channel-related, error performance of the system has improved when satisfies high goal BER ,and can reduce the total transmit power of the communication system ,and it has a certain practical value for the design of mine MIMO system.

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