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A promising set of spreading sequences to mitigate MAI effects in MIMO STS systems

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Abstract

Multiple input, Multiple output space time spreading (MIMO STS) system is a scheme which can provide full diversity gain without extra resource requirements. However, its performance degrades significantly when multiple access interference (MAI) occurs. In order to mitigate MAI effects, we propose a criterion to build a promising set of combination of spreading sequences for users. Simulation results show that the average BER performance of users using this promising set is about thirty percent lower than that of users using another set in case of 64 chip length Walsh-Hadamard code.

Keywords

set, spreading, sequences, promising, mitigate, systems, mai, effects, mimo, sts

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***Abstract*—Multiple input, Multiple output space time spreading (MIMO STS) system is a scheme which can provide full diversity gain without extra resource requirements. However, its performance degrades significantly when multiple access interference (MAI) occurs. In order to mitigate MAI effects, we propose a criterion to build a promising set of combination of spreading sequences for users. Simulation results show that the average BER performance of users using this promising set is about thirty percent lower than that of users using another set in case of 64 chip length Walsh-Hadamard code.**

***Index Terms*—**MIMO, STS, MAI-mitigation, spreading

1. INTRODUCTION

MIMO STS technique is an open-loop transmit diversity scheme used in CDMA2000 standard [1]. As proposed in [2], a data stream of any single user is firstly separated into two or more sub-streams, and they are then spread by spreading sequences before transmitting. Fig. 1 together with (1), (2) illustrate a 2x1 MIMO STS system and the conversion process for incoming data.

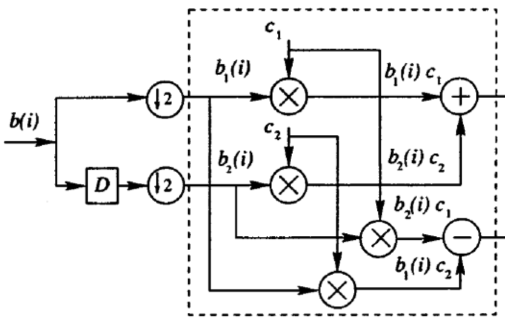

Figure.1: A 2x1 MIMO STS system [2].

$$t_1 = \left(\frac{1}{\sqrt{2}}\right)\left(b_1c_1 + b_2c_2\right) \quad (1)$$

$$t_2 = \left(\frac{1}{\sqrt{2}}\right)\left(b_2c_1 - b_1c_2\right) \quad (2)$$

where c_1, c_2 are the two orthogonal spreading sequences for the user, b_1, b_2 are the sub-streams of data and t_1, t_2 are transmit signals for the two antennas. At the receiver, the received signal r is represented by:

$$r = h_1t_1 + h_2t_2 + n \quad (3)$$

where h_i represents the wireless channel coefficients from the i^{th} transmit antenna to the receive antenna; i = 1, 2. This signal is de-spread with the relevant spreading codes into two de-spread signals d_1, d_2 :

$$\begin{aligned} d_1 &= \left(\frac{1}{\sqrt{2}}\right)\left(h_1b_1 + h_2b_2\right) + c_1^{'}n \\ d_2 &= \left(\frac{1}{\sqrt{2}}\right)\left(-h_2b_1 + h_1b_2\right) + c_2^{'}n \end{aligned} \quad (4)$$

The transmitted data is then recovered by:

$$\tilde{b}_i = \mathrm{Re}\{h_q'd\}$$

where h_q is the q^{th} column of the channel coefficient matrix H, and d is the column matrix of de-spread signal.

$$H = \begin{vmatrix} h_1 & h_2 \\ -h_2 & h_1 \end{vmatrix}; d = \begin{vmatrix} d_1 \\ d_2 \end{vmatrix} \quad (4a)$$

It was indicated in [3] that this diversity scheme performs better than traditional Alamouti scheme because the former can reconstruct transmitted data faster and it can overcome the problem of deep fade happening in a path from one of the two transmitting antennas to the receiver. However, the performance of MIMO STS system decreases sharply when multiple access interference (MAI) effects happen. In [4], the authors described a scenario in which MAI occurs, and this scenario is shown in Fig. 2.

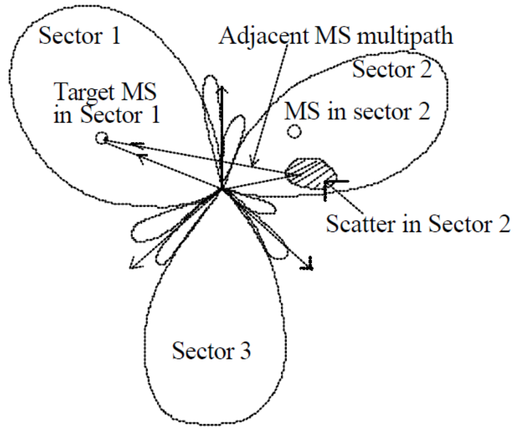

Figure. 2: System with scatter in Sector 2 producing MAI in Sector 1 [4].

In order to illustrate the effect of MAI, the BER of a 2x1 STS system is calculated with different numbers of MAI users versus signal to interference ratio (SIR). Here SIR is the ratio between the power of target signal and that of interference signals while SNR is fixed at 6 dB. This is shown in Fig. 3.

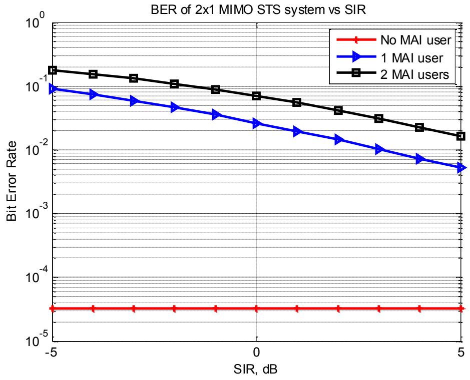

Figure. 3: BER of MIMO STS system with different number of MAI users.

One approach to mitigate MAI effect was proposed in [5] by selecting a good combination of spreading sequences. So as to prove the usefulness of the proposed approach, the authors in [5] use eight single sequences to generate different pairs of sequences and one of them is used for MAI user. Correlation functions of these pairs of sequences are then calculated with the sequence pair of MAI user, and the results are compared to each other. The promising pair of sequence for the target user is the one which has lowest correlation functions with the sequence pair of MAI user. It can be seen from this approach that the promising pairs may not always improve the BER in the target user. This is because the peak correlation functions will change when other pairs of sequences are used by MAI user. Unfortunately, this is often the case in reality because the choice of sequence pair by the MAI user is beyond the control of the desired user.

Instead of basing on MAI user's sequence pairs to find the promising pair, in this paper, we use mean square correlation functions to indicate a promising set of sequence pairs. Mean square correlation functions introduced in [6] are widely used in literature to compare the performance of two sets of spreading sequences. Mean square auto-correlation (RAC) and mean square cross-correlation (RCC) functions are defined in [6] as:

$$RAC = \frac{1}{S}\frac{1}{N^2}\sum_{x=1}^{S}\sum_{l=1-N}^{N-1}\left|C_X(l)\right|^2$$
$$RCC = \frac{1}{S(S-1)}\frac{1}{N^2}\sum_{x=1}^{S}\sum_{y=1,y\neq x}^{S}\sum_{l=1-N}^{N-1}\left|C_{XY}(l)\right|^2 \quad (5)$$

Where S is number of sequences in the set, N is the length of a spreading sequence and $C_{XY}(l)$ is the cross-correlation function between sequence X and Y.

$$C_{XY}(l) = \begin{cases} \sum_{k=0}^{N-1-l} u_X(k)u^*_Y(k+l) & 0 \le l \le N-1 \\ \sum_{k=0}^{N-1+l} u_X(k-l)u^*_Y(k) & 1-N \le l \le 0 \\ and \quad 0 \quad elsewhere & \end{cases} \quad (6)$$

It was proved in [6, 7] that the set with lower RCC and RAC is better. Therefore, in this paper, we propose a criterion to select combinations of spreading sequences into a promising set which has lower RCC and RAC than another set including remaining combinations of spreading sequences. Simulations in MATLAB will show that the average BER performance of users using sequences in the promising set will be lower than that of users using sequences in another set.

The rest of this paper is outlined as follow. Section 2 describes about criterion to build the promising set. Section 3 is about simulation results. Summary and conclusion are provided in section 4.

2. PROPOSED CRITERION

Consider a 2x1 STS system; two single spreading sequences are adopted for one user. In order to represent these two sequences, we use sequence x which is defined as:

$$x = \frac{(C_1 + C_2)}{2} \quad (7)$$

And for general case, when n single sequences are used for one user, the sequence x will be:

$$x = \frac{\sum_{i}^{n} C_i}{n} \quad (8)$$

The auto-correlation function of pair sequence x can be calculated by:

$$C_{xx}(l) = \sum_{k=0}^{N-1-l} x(k)x^*(k+l) \quad (9)$$

Replace (5) into (7) we have:

$$P_{\text{auto-correlation}}(x) = P_{\text{auto-correlation}}(C_1) + P_{\text{auto-correlation}}(C_2) + 2P_{\text{cross}}(C_1, C_2) \quad (10)$$

It can be seen that the auto-correlation function of a sequence pair x combines the auto-correlation functions of single spreading sequences C_1, C_2 and the cross-correlation function between these two single sequences. Hence, auto-correlation function of a sequence pair can be used as a criterion to classify all possible sequence pairs. The number of possible combinations of m spreading sequences that can be selected from the set of N single sequences is given by (11).

$$\binom{N}{m} = \frac{N!}{m!(N-m)!} \tag{11}$$

The detail steps for the case of 2x1 STS system is described as follows. The auto-correlation functions of all these sequence pairs and the average of them are calculated. The sequence pairs which have smaller auto-correlation function than the average value are selected into a '*set to use*' S_u; the other sequence pairs are left in a *'not to use'* S_{nu} set. The process of constructing S_u and S_{nu} is summarised as follow:

Start: Single sequences C_i with i=1 to N
Find all possible of pair sequences: PairNo=N(N-1)/2
$x_j = (C_i + C_k)/2 \quad i, k=1,2\ldots N; j=1,2\ldots PairNo$
For j=1 to PairNo
$P_{auto}(x_j)=?$
End
$AvPauto = \sum P_{auto}(x_j)/PairNo$
If $P_{auto}(x_j) < AvPauto$ *then* $x_j \in S_u$
else $x_j \in S_{nu}$
Finish

After classifying all sequence pairs into two sets S_u and S_{nu}, the RCC and RAC of each set are calculated. Table 1 shows the RCC and RAC of two set S_u and S_{nu} in two cases which are 32-chip length Walsh-Hadamard codes and orthogonal Gold codes. In case of orthogonal Gold code, the number of sequences is 33 due to the method used to generate the Gold code. Although all these 33 sequences are not mutually orthogonal, in this paper, we still consider all since the probability that all of them are used concurrently is very low.

From Table 1, it is clear that the RAC and RCC of S_u of both two codes are smaller than those of S_{nu}. However, the difference is more significant in case of Walsh code. The same phenomenon also occurs to these two codes in case of 64-chip length as shown in Table 2.

Table 1: RAC and RCC of two sets for both spreading families with 32 chip length in a MIMO 2x1 STS systems

Walsh-Hadamard codes	Number of pairs	RAC	RCC
S_u	316	0.9047	0.26687
S_{nu}	180	1.4963	0.3016
Orthogonal Gold codes	Number of pairs	RAC	RCC
S_u	303	0.4306	0.2474
S_{nu}	225	0.5688	0.2556

Table 2: RAC and RCC of two sets for both spreading families with 64-chip length in a MIMO 2x1 STS system

Walsh-Hadamard code	Number of pairs	RAC	RCC
S_u	1210	1.2506	0.2744
S_{nu}	806	2.1545	0.3046
Orthogonal Gold code	Number of pairs	RAC	RCC
S_u	1169	0.4441	0.2494
S_{nu}	911	0.5510	0.2514

One possible explanation for this phenomenon is that Orthogonal Gold code has better performance than Walsh code as confirmed in [8]. From these results, we can expect that S_u may bring better BER performance than S_{nu} in case of Walsh code; meanwhile, these two sets may perform equally in case of orthogonal Gold code.

In terms of 4x1 STS systems, four single sequences are used for one user. The RAC and RCC of two sets for both codes are illustrated in Table 3.

Table 3: RAC and RCC of two sets for both spreading families with 32 chip length in 4x1 MIMO STS systems

Walsh-Hadamard code	Number of pairs	RAC	RCC
Su	18350	0.1554	0.06398
Snu	17610	0.2106	0.06410
Orthogonal Gold code	Number of pairs	RAC	RCC
Su	22792	0.1071	0.0620
Snu	18128	0.1418	0.0652

Obviously, RCC of the two sets are now almost the same in both (two) types of code. The reason is that when the number of spreading sequences for one user is high, the difference of spreading codes between two users is lower. Consequently, the performance of the two sets S_u and S_{nu} may not significantly differ.

3. SIMULATION RESULTS

The simulation scenario is set as in Fig. 1 with all users in sector 1 use spreading sequences from S_u while those in sector 3 use spreading sequences from S_{nu}. There are three MAI users allocated in sector 2 which produce randomly delayed signals on two other sectors. The spreading sequences for MAI users are also randomly adopted with two MAI users using sequences in S_u and one MAI user using sequences in S_{nu}. Average BER performances of all users in sector 1 and sector 3 will be compared to each other. The simulations are conducted for three cases including 32-chip and 64-chip length of Walsh-Hadamard and orthogonal Gold codes in case of 2x1 STS system as well as 32-chip length of these two codes in case of 4x1 STS system. Simulation results of these cases are respectively listed in Tables 4, 5 and 6.

Table 4: Average BER of all users in two sectors of 2x1 MIMO STS systems with 32 chip length

	Walsh code	orthogonal Gold code
Average BER of users in Sector 1 (using S_u)	0.0164	0.0168
Average BER of users in Sector 3 (using S_{nu})	0.0200	0.0168

Clearly, in case of Walsh code, pair sequences in S_u mitigate MAI effects better than those in S_{nu} with average BER performance of users in sector 3 is about 1.2 times higher than that of users in sector 1. This result is more significant in case of 64-chip length simulations.

Table 5: Average BER of S_u and S_{nu} for both families with 64 chip length

	Walsh code	Orthogonal Gold code
Average BER of users in Sector 1 (using S_u)	0.0061	0.0059
Average BER of users in Sector 3 (using S_{nu})	0.0089	0.0058

As expected in section 2, the two sets perform equally in case of orthogonal Gold code since average BER performance of these two sets are almost the same. This phenomenon also happens to both two codes in case of 4x1 STS system.

Table 6: Average BER of all users in two sectors of 4x1 MIMO STS systems with 32-chip length

	Walsh code	orthogonal Gold code
Average BER of users in Sector 1 (using S_u)	0.0266	0.0259
Average BER of users in Sector 3 (using S_{nu})	0.0271	0.0262

From these results, it can be concluded that the approach we use about selecting a promising combination of spreading sequences to mitigate MAI effects works well with the case of Walsh-Hadamard code. However, it does not bring any benefit in the case of a good performance code family such as the orthogonal Gold codes.

4. CONCLUSION

In this paper, we proposed a criterion to classify all possible combinations of spreading sequences for users into two sets. The criterion based on auto-correlation function of the sequence pair which represents the combination of single sequences. Simulation results show that from all possible combinations of spreading sequences, we can construct a promising set which can mitigate MAI effects better than the remaining one in case of Walsh-Hadamard code. The benefit is more significant when longer chip length code words are used. This promising set should be allocated for higher priority customers.

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