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A Performance Evaluation of CDMA/MIMO Communication System Using Permutation Spreading

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Abstract: In this study, we propose Code Division Multiple Access (CDMA) systems employing this technique, the calculated parity bits are used to select a spreading sequence from a set of mutually orthogonal spreading sequences. This technique was extended to CDMA systems using Multiple Input Multiple Output (MIMO) techniques. We compare the performance of the two techniques for MIMO-CDMA systems operating on frequency-flat slowly Rayleigh fading channels. The new designs improve the Bit Error Rate (BER) compared to MIMO-CDMA systems that use spreading permutations based on T-designs. This BER improvement comes without any increase in system complexity.

Key words: CDMA, MIMO, fading, Bit Error Rate (BER), compared, Rayleigh

INTRODUCTION

Severe attenuation in a multipath wireless environment makes it extremely difficult for the receiver to determine the transmitted signal unless the receiver is provided with some form of diversity, i.e., some less-attenuated replica of the transmitted signal is provided to the receiver. In some applications, the only practical means of achieving diversity is deployment of antenna arrays at the transmitter and/or the receiver. However, considering the fact that receivers are typically required to be small, it may not be practical to deploy multiple receive antennas at the remote station. This motivates us to consider transmit diversity (Krishna *et al*., 2012).

In this study, we combine the two techniques. Rather than appending the parity bits at the end of the information sequence, we use the (n-k) parity bits to select one of 2n-k orthogonal spreading sequences (D'Amours, 2005; Squires *et al*., 2003; Affes *et al*., 2003). This spreading sequence is then used to spread the k information bits. At the receiver, the received signal is correlated to the 2n-k different spreading sequences. By observing the matched filter outputs over the k signaling intervals, the probability that the receiver incorrectly identifies the correct spreading sequence is highly unlikely (Proakis, 2001). We will demonstrate the performance of this technique by employing linear and block codes, designed specifically for this system.

MATERIALS AND METHODS

Proposed transmitter: The block diagram of the transmitter is shown in Fig. 1. The information stream is segmented into blocks of k bits. Each information block is input to the parity bit calculator. The parity bits of parity vector p are found by multiplying the information vector and the parity matrix.

Consider a MIMO system that has Nt transmit antennas and Nr receive antennas. The serial data whose bit rate is Rb is converted into Nt parallel data streams, each with bit rate Rb/Nt. The ith data stream of user m is spread by spreading waveform wmi(t) which is an

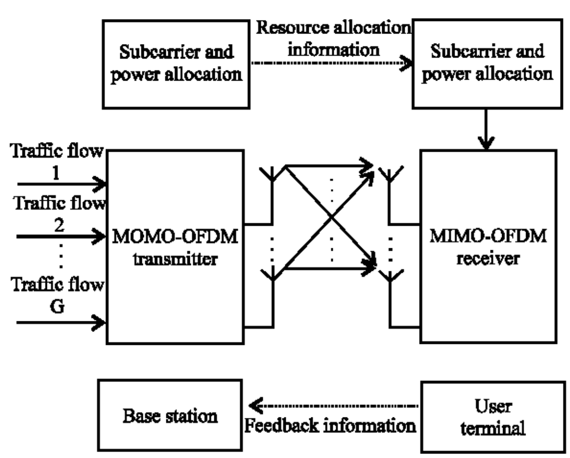

Fig. 1: CDMA/MIMO transmitter

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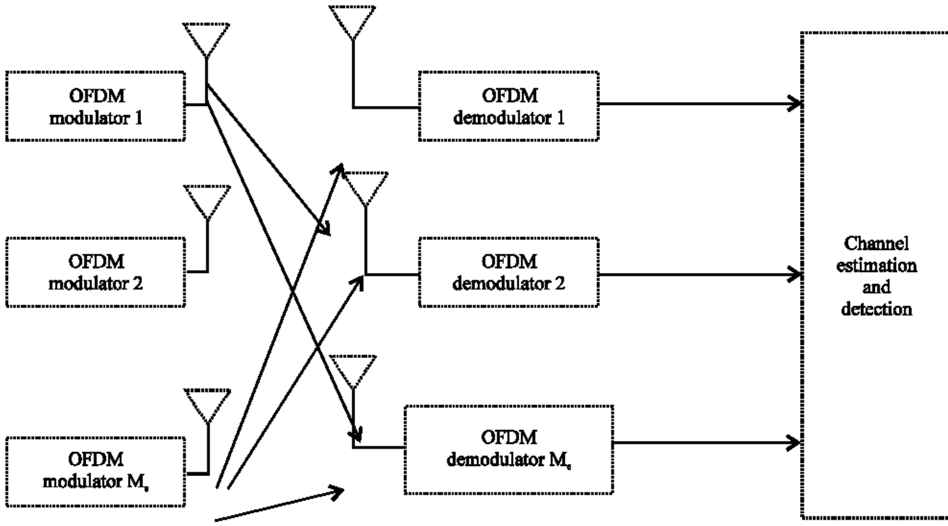

Fig. 2: CDMA/MIMO receiver

antipodal signal with chip Rate Rc and is selected from a set of mutually orthogonal spreading waveforms {cm1(t), cm2(t), …, cmN(t)}∈Cm. Therefore:

$$\frac{1}{T}\int_0^T C_{mi}(t)C_{mj}(t)dt = \begin{cases} 1 \text{ for } i = j \\ 0 \text{ for } i \neq j \end{cases} \quad (1)$$

Different users are assigned unique sets of spreading waveforms. Thus, Cm∩Cl = ø for l≠m. At the receiver, the output of each receiver antenna is correlated with each spreading waveform and the contributions from the different antennas are combined according to the technique under consideration. A generic CDMA/MIMO transmitter is shown in Fig. 1. The link gains are also shown, α_{ij} is the complex channel gain on the link between transmit antenna i and receive antenna j. Depending on the spreading method used, wi (n)(t) is the spreading waveform used to spread the data transmitted by antenna i on time interval n.

The CDMA/MIMO receiver is shown in Fig. 2. The kth matched filter output on receive antenna j is ujk. The value of these decision variables and how they are combined depends on the method used by the transmitter. For illustration purposes, we will examine the performance of a CDMA/MIMO system with 4 transmit antennas.

Parity bit selected spreading is discussed by Krishna *et al*. (2012). A block of data is input to the parity bit calculator of a systematic block code. Rather than append the parity bits to the end of the message block, the parity bits are used to select one of a set of 2(n-k) spreading sequences where, n-k is the number of parity bits of the code. The result is that the system divides the possible messages into groups that are carried by the same spreading waveform.

Let, M be the set off all possible message vectors. Let, M_1 be a subset of M that is closed under modulo-2 addition. Let, M_2, M_3, …, M_K be the co sets of M_1 where, $K = 2^{Nt}/L$, where, L is the number of vectors in M_1.

Each transmit antenna uses the same spreading waveform but the spreading waveform used is related to the message that is being transmitted much like parity bits are related to the messages in block coding. In the system that is demonstrated in this study, M1 = {0000, 1111}. This subset of M has 7 cosets, M2 = {0001, 1110}, M3 = {0010, 1101}, etc.

Permutation spreading in MIMO: This system is similar to CDMA/MIMO with parity bit spreading in that the possible message vectors are divided into cosets and that each coset has a unique spreading signature. In parity bit selected spreading, the data on different antennas are spread by a single spreading waveform that is selected based on the parity bits that are generated when a message is encoded. When permutation spreading is used, depending on which coset the message comes from a unique permutation of spreading waveforms are used. Each permutation employs Nt of the N spreading waveforms and we attempt to minimize the number of spreading waveforms that each permutation have in common. Furthermore, if a spreading waveform is used by antenna i in one permutation, it cannot be used by antenna i in any other permutation. The design of the different spreading permutations is based on t-designs which are used in permutation modulation schemes.

For the system discussed in this study, the spreading permutations are listed in Table 1. Thesystem employs 8 spreading waveforms per user. Each permutation of 4 spreading waveforms has 2 spreading waveforms in

Table 1: Spreading permutations for CDMA/MIMO system with 4 transmit antennas

Coset	Message vectors	$W_{m1}^{n}(t)$	$W_{m2}^{n}(t)$	$W_{m3}^{n}(t)$	$W_{m3}^{n}(t)$
M_1	0000 1111	C_1(t-nT)	C_3(t-nT)	C_5(t-nT)	C_7(t-nT)
M_2	0001 1110	C_8(t-nT)	C_1(t-nT)	C_4(t-nT)	C_5(t-nT)
M_3	0010 1101	C_2(t-nT)	C_4(t-nT)	C_3(t-nT)	C_8(t-nT)
M_4	0011 1100	C_5(t-nT)	C_2(t-nT)	C_6(t-nT)	C_3(t-nT)
M_5	0100 1011	C_6(t-nT)	C_7(t-nT)	C_1(t-nT)	C_4(t-nT)
M_6	0101 1010	C_3(t-nT)	C_6(t-nT)	C_8(t-nT)	C_1(t-nT)
M_7	0110 1001	C_7(t-nT)	C_8(t-nT)	C_2(t-nT)	C_6(t-nT)
M_8	0111 1000	C_4(t-nT)	C_5(t-nT)	C_7(t-nT)	C_2(t-nT)

common with 5 other permutations and 1 spreading waveform in common with the 2 other permutations. Each spreading waveform appears in 4 permutations and is used by a given antenna only once.

The advantage to using permutation spreading is that the different spreading patterns create dependence between the parallel data streams yet still maintains orthogonality between the streams. In other words, the decision variables at the output of each antenna will contain either noise or a signal contribution from one transmit antenna but not all transmit antennas. The decision variables can be expressed as:

$$u_{jk} = \begin{cases} ATb_i^{(n)} a_{ij}^{(n)} + n_{jk}^{(n)} & \text{if } c_{mk}(t\text{-}nt) \text{ is used by transmit antenna i} \\ n_{jk}^{(n)} & \text{if } c_{mk}(t\text{-}nt) \text{ is not at all used} \end{cases} \quad (2)$$

On each receive antenna, 4 decision variables will contain a signal component plus a noise component (Song, 2005) while the other 4 will contain only a noise component. Maximum likelihood detection is used for this scheme. In this case, the detection rule is:

$$\tilde{b}^{(n)} = \min_{b \in \beta} \left\{ \sum_{i=1}^{N_i} \| u_i - b_i^{(n)} h_i^{(n)} \|^2 + \| \bar{u} \|^2 \right\} \quad (3)$$

Where:

- u_i = $[u_1 k_i, u_2 k_i, ..., uN_r k_i]$
- k_i = Corresponds to the subscript of the spreading waveform used by transmit antenna
- i = The nth signaling interval
- u = The vector containing all of the decision variables not in u1, u2, …, uNr
- hi(n) = The ith row vector of $H^{(n)}$ (Downes *et al.*, 2005)

RESULTS AND DISCUSSION

Simulations to determine the Bit Error Rate (BER) performance of the three systems discussed in this study are presented in this study. We consider systems with 4 transmit antennas and receivers with 1 or 4 receive antennas. The following assumptions were made in the simulation models: the fading is frequency nonselective. In other words, the multipath spread is 0 and there is no channel induced Inter Symbol Interference (ISI).

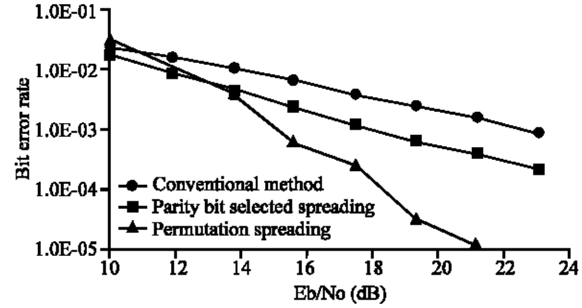

Fig. 3: BER for the different CDMA/MIMO systems with Nt = 4 and Nr = 4

The channel gains are slowly varying circularly symmetric complex Gaussian random variables with 0 mean and variance 1. The channel gains of different transmit antenna-receive antenna links are uncorrelated (therefore, they are independent). The receiver estimates the channel gains perfectly without a power penalty. In other words when detecting a symbol or message, the receiver uses the exact channel matrix.

Figure 3 shows the bit error rate of the three different CDMA/MIMO methods for the case when there are 4 transmitting antennas and 1 receiving antenna. Figure 4 shows the simulated BER of the three types of CDMA/MIMO systems when there are 4 transmitting and 4 receiving antennas.

It is also interesting to note that permutation spreading provides significant BER performance gains compared to parity bit selected spreading. This is due to the nature of the decision variables in each scheme. In parity bit selected spreading, one decision variable per antenna contains a signal component which is a sum of all of the transmitted signals. All other decision variables are noise. Although, this should make it easy to detect which spreading sequence was used in some cases even when all channel gains are strong, it is possible for the linear combination of these channel gains to yield a results that is close to 0. Thus, there is some self interference similar to SM systems. In permutation spreading, all decision variables are made up of one signal plus noise or noise only. There is no real self interference when the channel gains are independent.

In the previous study, we examined the performance of single user CDMA/MIMO systems. However, the advantage of CDMA systems is that multiple users can

Table 2: T-design permutation spreading for Nt = 4

Coset	Message vectors	$W_1(t)$	$W_2(t)$	$W_3(t)$	$W_4(t)$
M_1	0000 1111	$C_1(t)$	$C_3(t)$	$C_5(t)$	$C_7(t)$
M_2	0001 1110	$C_8(t)$	$C_1(t)$	$C_4(t)$	$C_5(t)$
M_3	0010 1101	$C_2(t)$	$C_4(t)$	$C_3(t)$	$C_8(t)$
M_4	0011 1100	$C_5(t)$	$C_2(t)$	$C_6(t)$	$C_3(t)$
M_5	0100 1011	$C_6(t)$	$C_7(t)$	$C_1(t)$	$C_4(t)$
M_6	0101 1010	$C_3(t)$	$C_6(t)$	$C_8(t)$	$C_1(t)$
M_7	0110 1001	$C_7(t)$	$C_8(t)$	$C_2(t)$	$C_6(t)$
M_8	0111 1000	$C_4(t)$	$C_5(t)$	$C_7(t)$	$C_2(t)$

simultaneously transmit over the same range of frequencies by assigning each user a unique spreading waveform. In CDMA/MIMO, we need to assign each user a unique set of spreading waveforms. Consider an asynchronous CDMA system. Let us suppose that each user's signal is received with the same average Eb/No. In other words, power control is used to correct for the large scale fading. Let us further assume that the power control is not fast enough to correct for the small scale fading. It is shown that, if we assume random signature spreading waveforms and we have perfect power control, the energy per bit to effective noise spectral density is:

$$\frac{E_b}{N_0} = \frac{E_b/N_o}{1+(U-1)(2/3)(E_b/N_o)(R_b/R_c)} \tag{4}$$

Where:

U = The number of simultaneously transmitting users

R_c/R_b = The spreading factor

For CDMA/MIMO systems, the random signature spreading waveform assumption is not correct since an interfering user cannot use any spreading waveform since the desired user is assigned a handful of mutually orthogonal spreading waveforms. However, if the spreading factor is high, there are many spreading waveforms available and since, the system is asynchronous even orthogonal codes can yield poor cross-correlation properties, thus, the random signature assumption is still a good approximation.

From Table 2, the T-design method does not respect the code symmetry discussed in the previous study for co sets that have two spreading codes in common and therefore some degrees of freedom are lost in the squared Euclidean distance between different messages. The lack of code symmetry accounts for the slightly increased BER. Figure 4 shows, at the BER of 10-3, the STBC permutation systems have 0.7 and 0.2 dB gain over T-design permutation system in the case of 1 and 4 receive antennas, respectively.

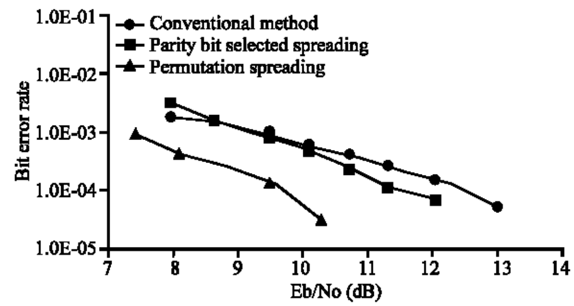

Fig. 4: Simulated BER for the different CDMA/MIMO systems with Nt = 4 and Nr = 4

CONCLUSION

In this study, we have only considered uncorrelated fading links. Adding correlation to the channel model would not affect the performance of the system which employs a conventional spreading approach as there is no dependency between the different data streams nor is there any self interference at the receiver due to the orthogonality of the spreading waveforms. However, correlation should degrade the performance of the two new strategies, so, it would be advantageous to determine the performance on these systems in correlated fading channels. In this study, we presented new techniques for spreading parallel data streams in CDMA/MIMO systems. The new techniques create dependency between the streams and provide performance improvement or improved spectral efficiency compared to a more conventional spreading approach.

The disadvantage of the new techniques is that each user must be assigned additional spreading waveforms and there is an overall increase in system complexity. However, in the case of permutation spreading, the gains are large and may warrant the additional complexity.

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REFERENCES

Affes, S., N. Kandil and P. Mermelstein, 2003. Efficient use of pilot signals in wideband CDMA array receivers. Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP 2003), April 6-10, 2003, IEEE, Hong Kong, China, ISBN:0-7803-7663-3, pp: 2526-2531.

Downes, G., T. Willink and C. D'Amours, 2005. Capacity limitations of real MIMO channels and their impact on system performance. Proceedings of the 17th IASTED International Conference on Wireless Communication, July 12-15, 2005, IASTED, Calgary, Canada, pp: 100-104.

D'Amours, C., 2005. Parity bit selected spreading sequences: A block coding approach to spread spectrum. IEEE. Commun. Lett., 9: 16-18.

Krishna, M.G., Y.P. Kumar, V.G.P. Kumar and U. Sankar, 2012. OFDM based MIMO testing for RF ICs. Intl. J. Electron. Commun. Instrum. Eng. Res. Dev., 2: 23-35.

Proakis, J.G., 2001. Digital Communications. 4th Edn., McGraw-Hill, New York, USA.

Song, Y., 2005. Parity bit selected spreading sequences for spread spectrum and code division multiple access systems. MA Thesis, University of Ottawa, Ottawa, Ontario.

Squires, C., T. Willink and B. Caron, 2003. A flexible platform for MIMO channel characterisation and system evaluation. Proceedings of the 15th International Conference on Wireless Communication, June 16-20, 2003, Springer, Calgary, Alberta, pp: 441-450.