Combined ML-MMSE Receiver of an STBC-CDMA System for PSK/QAM Modulation

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Summary:
This paper presents a Space Time Block Code structure using spread spectrum in multi user context employing code division multiple access (CDMA). This communication system can guarantee full rate full diversity because its based on the famous Alamouti code using two transmit antennas and two receive antennas. The originality of this paper consists on extending the use of ST block codes to a multi user environment. This transmission scheme combines the benefits of both STBC, by taking advantages from spatial and temporal diversity to attend a high data rate, and spread spectrum to avoid Multiple Access Interference in a rayleigh fading channel**.**
Simulation results show that this simple multi user transmit diversity scheme provides considerable performance gains in term of bit error rate.

Key words:
STBC, PSK, QAM, spread spectrum, MAI, ML decoder, Rayleigh fading channel, multi user detection, MMSE.

1. Introduction

Internet traffic such as multimedia streaming applications is driving the demand for high speed data packet wireless services. The use of multiple transmit and receive antennas has been proposed for the fourth generation code-division multiple access (CDMA) wireless cellular networks in order to meet these demands. Multi-user CDMA multiple-input multiple-output (MIMO) systems have just recently been studied.

Spread spectrum is a signal processing technique that distinguishes CDMA, where a data symbol is modulated with a noise-like wideband signal called a pseudo-noise (PN) sequence. This process is also known as spreading, and is intended to suppress multiple access interference (MAI) due to interference from other users in the same cell (intracell-interference), Multi-user detection, or MUD, seeks to overcome the inherent shortcomings of conventional CDMA receivers by providing near-far resistance for the receiver in the process of eliminating the MAI. An optimum maximum likelihood (ML)

MUD receiver was proposed by Verdú [2]. The ML multi-user receiver encompasses a bank of matched filters that produces a set of sufficient statistics, followed by a Viterbi decoder. The complexity of the ML receiver is exponential in the number of users, rendering it impractical. Suboptimum linear receivers such as the decorrelating and the minimum mean-squared error (MMSE) receivers have been proposed to trade off complexity and performance among the conventional and optimal receivers [4].

Multi user detectors are robust in an AWGN channel; they provide considerable gain performance in term of bit error rate as a function of signal to noise ratio but they do not resist to attenuation of multipath channel.

Given the above facts, this paper proposes a new multi-user transmit diversity scheme based on space time block coding to mitigate both channel effects and MAI problem caused by other users communicating simultaneously in the same cell.

The remainder of this paper is organized as follows. In section 2, we present a description of the system model and mathematic modelisation, multi-user detection is treated in section 3; we discuss different cases such as minimum mean square error MMSE receiver. In section 4 we present numerical results obtained by matlab simulation showing performance gain of the different multi-user receivers studied above. The last section deal with performance evaluation of this new transmission scheme compared to single user communication system for PSK and QAM modulation and conclusion.

2. System Description

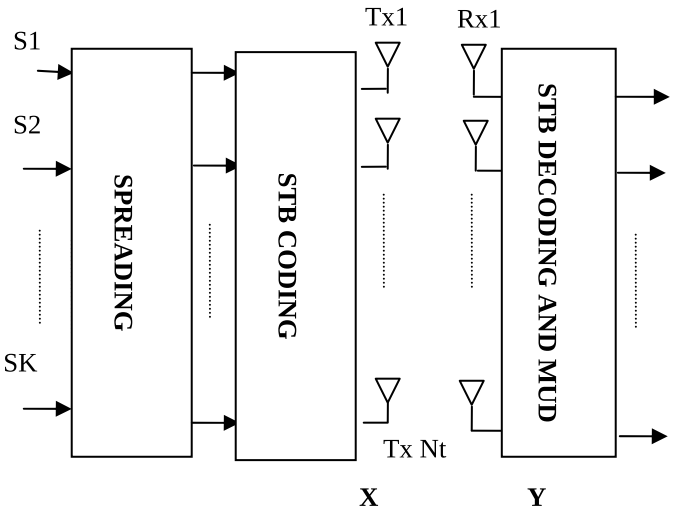

Fig 1. Block diagram of the multi-user transmit diversity scheme.

In this communication system, we suppose K users communicating simultaneously, where each of them transmit two data streams. We consider Nt transmit antennas and Nr receive antennas where are assumed to be far enough apart such that the complex fading coefficients among the antennas are uncorrelated.

Signal received by antenna p is given by:

$$r_p(t) = \sum_{n=1}^{Nt} h_{n,p} * S_n(t) + n_p(t) \qquad (2.1)$$

$$S_i(t) = \sum_{k=1}^{K} \sum_{j=0}^{Q-1} \sqrt{P_k} * b_{k,i} * c_{j,k} * P_{Tc}(t - jTc) \qquad (2.2)$$

Where :

Q : Spreading factor

$\sqrt{P_k}$ is the amplitude of k th user

$b_{k,i}$ is the modulated data symbol of the kth user transmitted over antenna i; where $i = 1..Nt$

c_k is the normalized pseudo noise PN sequence of the k th user.

P_{Tc} is the signature waveform of user k.

$h_{n,p}$ is the complex channel coefficient between the nth transmit antenna and the pth receive antenna. The channel amplitudes are independent, zero-mean complex Gaussian variables with unit variance.

$$E\left(h_{i1,j1}^{*} * h_{i2,j2}\right) = I_{NtNr} \qquad (2.3)$$

Where I_N denotes an identity matrix of size N.

From equation 2.1the data received matrix is given by :

$$Y = HX + n \qquad (2.4)$$

Where X is codeword matrix

H is channel matrix

n is AWGN

From equation 2.1:

$$x_i = C * A * b_i \qquad (2.5)$$

Where:

$C = [c_1, c_2, \ldots, c_K]$

$A = diag\left(\sqrt{P_1}, \sqrt{P_2}, \ldots, \sqrt{P_K}\right),$

$b_i = [b_{i,1}, b_{i,2}, \ldots, b_{i,K}]$ is the data information transmitted by the K users.

The channel between transmit antenna i and receive antenna j at time t may be modeled by a complex multiplicative distortion $h_{i,j}(t)$. Assuming that fading is constant across two consecutive symbols we can write:

$$h_{i,j}(t) = h_{i,j} = \alpha_{i,j} e^{j\theta_{i,j}} \qquad (2.6)$$

From equations 2.4 and 2.6 and discussing the special case of two transmit and two receive antennas; we can write:

$$\begin{pmatrix} y_1 & y_3 \\ y_2 & y_4 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h2,2 \end{pmatrix} \begin{pmatrix} x_1 & -x_2^{*} \\ x_2 & x_1^{*} \end{pmatrix} + \begin{pmatrix} n_1 & n_3 \\ n_2 & n_4 \end{pmatrix} \qquad (2.7)$$

n_1, n_2, n_3 and n_4 are complex random variables representing receiver thermal noise and interference.

3. STB decoding and MUD

We use system with channel State Information at the receiver. After channel estimation;

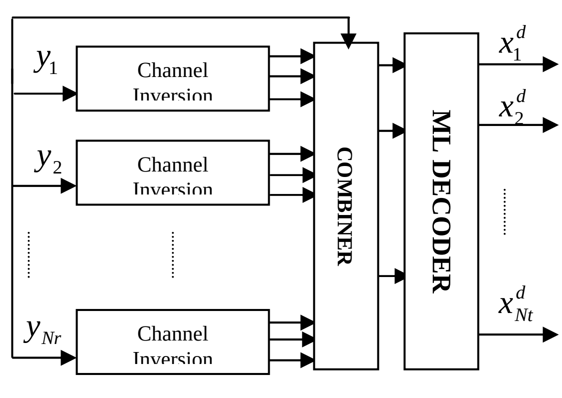

Fig 2: Block diagram of Space Time Block decoding

Combined signals are given by:

$$\tilde{x}_1 = \left(\alpha_{1,1}{}^2 + \alpha_{1,2}{}^2 + \alpha_{2,1}{}^2 + \alpha_{2,2}{}^2\right)x_1 + h_{1,1}^* n_1 + h_{1,2} n_2^* + h_{2,1}^* n_3 + h_{2,2} n_4^*$$

$$\tilde{x}_2 = \left(\alpha_{1,1}{}^2 + \alpha_{1,2}{}^2 + \alpha_{2,1}{}^2 + \alpha_{2,2}{}^2\right)x_2 - h_{1,1} n_2^* + h_{1,2} n_1 - h_{2,1} n_4^* + h_{2,2}^* n_3$$

These combined signals are then sent to the maximum likelihood detector. The ML decision rule at the receiver of combined signals is to choose signal x_j if and only if :

$$\sum_{i=1}^{K*Nr}\sum_{n=1}^{Nt} d^2\left(y_i, h_{i,n} x_j\right) \le \sum_{i=1}^{K*Nt}\sum_{n=1}^{Nt} d^2\left(y_i, h_{i,n} x_k\right) \forall j \ne k \quad (3.1)$$

Where $d^2(x, y)$ is the squared Euclidian distance between signals x and y calculated by the following expression:

$$d^2(x, y) = (x - y)\left(x^* - y^*\right) \quad (3.2)$$

ML detector uses the decision criteria for signal x_1

Choose x_i if and only if

$$\begin{aligned}&\left(\alpha_{1,1}^2 + \alpha_{1,2}^2 + \alpha_{2,1}^2 + \alpha_{2,2}^2 - 1\right)\left|x_i\right|^2 + d^2\left(\tilde{x}_1, x_i\right) \le \\ &\left(\alpha_{1,1}^2 + \alpha_{1,2}^2 + \alpha_{2,1}^2 + \alpha_{2,2}^2 - 1\right)\left|x_j\right|^2 + d^2\left(\tilde{x}_1, x_j\right) \forall i \ne j\end{aligned} \quad (3.3)$$

For PSK signals we have equal energy constellations:

$$\left|x_i\right|^2 = \left|x_j\right|^2 = E_x \forall i \ne j \quad (3.4)$$

The last in equation becomes:

Choose x_i if and only if:

$$d^2\left(\tilde{x}_1, x_i\right) \le d^2\left(\tilde{x}_1, x_j\right) \forall i \ne j \quad (3.5)$$

Similarly for signal x_2

Choose x_i if and only if ,

$$d^2\left(\tilde{x}_2, x_i\right) \le d^2\left(\tilde{x}_2, x_j\right) \forall i \ne j \quad (3.6)$$

Let x_1^d and x_2^d be the output signals of the ML detector.

The output of the ML detector will be the input of a multi user detector in order to find a desired user k

As mentioned above; the disparity in complexity and performance between the conventional detector and optimum multi-user detectors motivated researchers to seek suboptimum alternatives that exhibit better performance/complexity tradeoffs. There two kinds of multi user detectors that are linear and iterative multi user detectors.

3.1 Linear Mud

Collectively the matched filter output for all K users and L bytes can be expressed in a long vector as:

$$Y = \left[Y^T(1), \ldots, Y^T(L)\right]^T \quad (3.7)$$

Where :

$$Y(i) = \left[Y_1(i), \ldots, Y_K(i)\right]^T$$

$$Y(i) = C^T * C * A * b_i + n_i$$

$$Y = R * A * B + n \quad (3.8)$$

Let w be a linear transformation vector for the multi user detector. The decision vector is:

$$d = w^T * Y \quad (3.9)$$

The decorrelating detector in [3] has a linear transformation equivalent to the inverse of the correlation matrix $R = C * C^T$.

$$w = R^{-1} \quad (3.10)$$

The decision vector is then:

$$d = R^{-1}(R * A * B + n) = A * B + R^{-1} n \quad (3.11)$$

And since BPSK is used, the bit decision is determined by the sign of the decision vector:

$$\hat{b} = sign(d) \quad (3.12)$$

The decision vector has covariance matrix:

$$E\left[\left(R^{-1} n\right)\left(R^{-1} n\right)^H\right] = \sigma^2 R^{-1} \quad (3.13)$$

Which can results in noise power enhancement, creating a gap between the single-user error performance and the decorrelator error probability.

Another linear detector with the same structure as decorrelating detector based on the optimization of the minimum mean-squared error (MMSE) criteria:

$$w = \min E\left[\left(b-\hat{b}\right)^T \left(b-\hat{b}\right)\right] \qquad (3.14)$$

The solution of the equation above equation is:

$$w = \left(R + \sigma^2 \left(A^T A\right)^{-1}\right)^{-1} \qquad (3.15)$$

While the single-user matched filter combats white noise exclusively and the decorrelator eliminates MAI disregarding background noise, the MMSE linear detector forms a compromise between the two, taking the relevant importance of the background noise and interfering users into account.

4. Simulation results and discussion

Unless otherwise stated, we will assume that both the mobile and base station have two antennas, i.e. NT = NR = 2. We assume NT independent data streams of one user will be spread by the same Gold code of length 31, and transmitted through the NT transmit antennas. We suppose that each user transmit Nt symbols.

Fig 3 shows the plot of the BER as a function of SNR for the combined ML-MMSE receiver proposed in this paper.

Simulation results improve that this new STBC-CDMA structure improve performance gain in a reyleigh fading channel similar to a CDMA system in an AWGN channel.

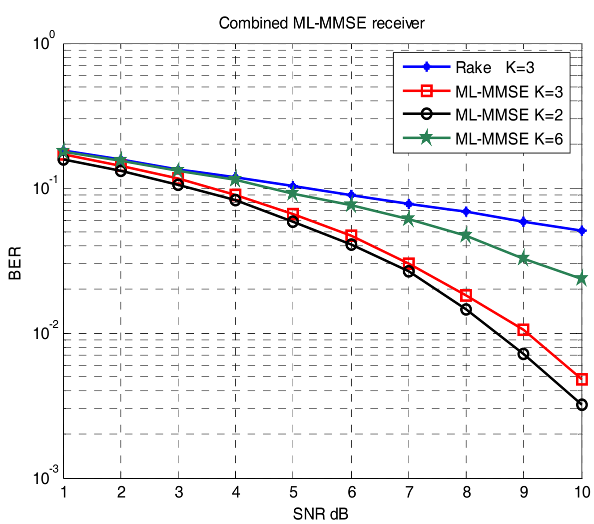

Fig 3: Combined ML-MMSE receiver for BPSK modulation

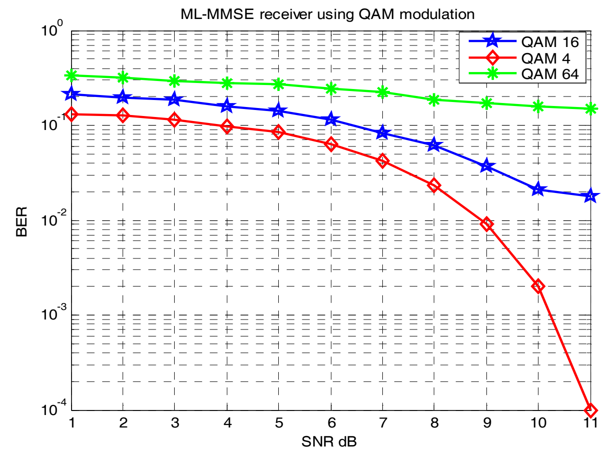

Fig 4: Combined ML-MMSE receiver for QAM-4 modulation scheme

Fig 5 and 6 shows the constellation representation for noisy received signal. Simulation results shows that an STBC CDMA system based on QAM 4 modulation scheme provide better performance gain than QAM 16 modulation.

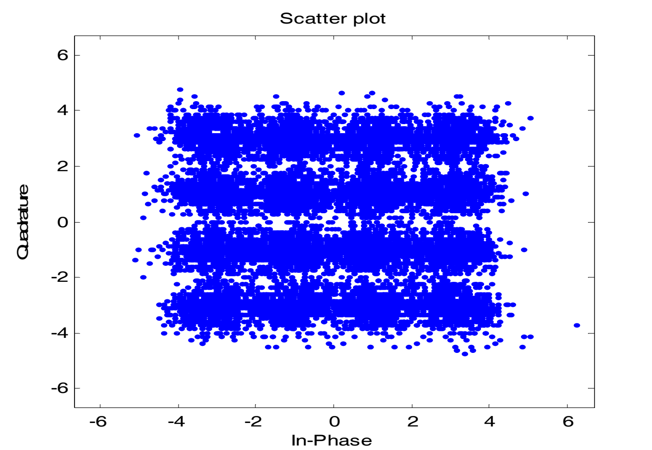

Fig 5 : constellation representation for QAM 16 SNR=10dB

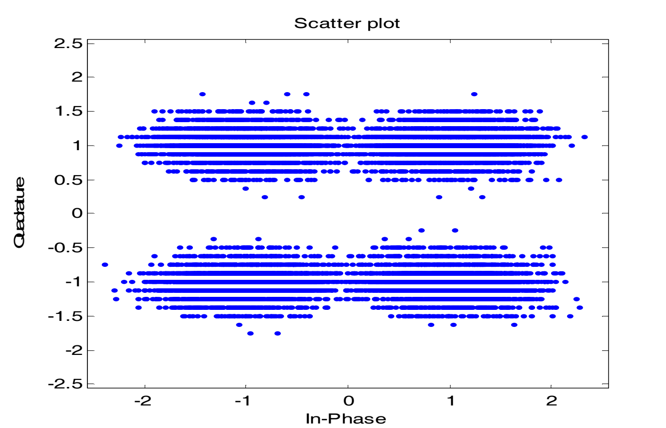

Fig 6 : constellation representation for QAM 4, SNR=10dB

5. Conclusion

The diversity gain is a function of many parameters, including the modulation scheme and FEC coding. In this paper we have study a wireless communication system based on Space Time Block Coding STBC for PSK and QAM modulation scheme to mitigate channel effect in a multi-user environment. A combined ML-MMSE receiver was proposed in order to detect a desired user. Simulation results shows that exploiting spatial-time diversity improve a performance gain in bit error rate specially for BPSK modulation scheme and so eliminate fading channel effect for a CDMA system.. One other interesting and important issue to investigate is the assignment of spreading codes for the transmit antennas among the multiple users in the CDMA MIMO system

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