MULTI USER DETECTION FOR CDMA-OFDM/OQAM SYSTEM COMBINED WITH SPACE TIME CODING

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ABSTRACT

In this paper, we propose the combination of Multi Carrier (MC) OFDM/OQAM modulation and CDMA-called MC-CDMA-OQAM system with Space Time (ST) coding in a multi user context. This combination takes advantages from multicarrier modulation, spread spectrum and spatial time diversity. Indeed, the use of OFDM has proved its ability to fight against frequency selective channels but the insertion of guard interval yields spectral efficiency loss and sensitivity to frequency dispersion due to the use of rectangular pulse shape. Thus, cyclic prefix OFDM is replaced by an advanced filterbank-based multicarrier system OFDM/OQAM that operates without guard interval. However, OFDM/OQAM provides orthogonality only on the real domain, so transmitted symbols must be real valued. In the other hand, the CDMA component has two advantages: multiple access interference cancellation and providing orthogonality in the complex domain. From the orthogonality property provided, the Alamouti ST code can be combined with MC-CDMA-OQAM system.

The resulting MIMO-MC-CDMA-OQAM system improves the spectral efficiency of wireless system, combat channel fading and reduce narrowband interference. Numerical results show the utility of this new wireless communication system; a significant BER versus Signal to Noise Ratio (SNR) was achieved thus Multiple access interference (MAI) is suppressed and so supporting a large number of users.

KEYWORDS

CDMA, OFDM/OQAM, ST coding, MIMO, Multi User Detection

1. INTRODUCTION

Increasing the transmission rate and providing robustness to channel conditions are nowadays two of the main research topics for wireless communications. Therefore, a significant interest of late has been to develop systems that offer both high capacity and high data speed, along with MAI resistance. Indeed, much effort is done in the area of Multiple Input Multiple Output (MIMO) systems by using several antennas either at the transmitting side or at the receiving side. We can exploit space and time diversity by using Space time codes such as the famous Alamouti code [1]. In multi antennas communication systems, investigations of N_t transmit and N_r receive antennas showed that the capacity of such systems increases linearly with the minimum of N_t and N_r [1], [6]. High data rates are obtained by simultaneously sending signals from several transmit antennas. To protect the integrity of the transmitted information, transmit diversity is obtained by introducing redundancy among the transmitted signals over

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N_t transmit antennas (space) and T time periods (time). Under quasi-static fading channel, the maximum combined transmit–receive diversity order equals to $N_t N_r$ [1].

A variety of Space-Time codes exists in the literature. In [6], Alamouti proposed a new modulation scheme over $N_t = 2$ transmit and N_r receive antennas where a rate of one symbol per channel use (PCU) with $2 N_t$ diversity was achieved [8]. The ML detection of the Alamouti scheme can be implemented by a linear complexity decorrelator. On the other hand, multicarrier modulation (MCM) is becoming the appropriate modulation for transmission over frequency selective channels. The most popular MCM is the Cyclic Prefix Orthogonal frequency Division Multiplexing (CP-OFDM) that exploits frequency diversity by dividing the total bandwidth into M subcarriers and transmitting OFDM symbols over these subcarriers. However, the insertion of the CP yields spectral efficiency loss. In addition, the conventional OFDM modulation is based on a rectangular windowing in the time domain which leads to a poor (sinc(x)) behavior in the frequency domain. Thus CP-OFDM gives rise to two drawbacks: loss of spectral efficiency and sensitivity to frequency dispersion. In order to overcome these two problems, a variant of OFDM that is called OFDM-OQAM has been proposed [3].

OFDM/OQAM overcomes the two drawbacks of OFDM but it does not provide orthogonality on the complex domain, thus the idea is to use CDMA component for two reasons; firstly to avoid multiple access interference and secondly to provide orthogonality in the complex domain if the spreading codes are well chosen [4]. The originality of this paper consists on studying mutli user detection for MIMO-MC-CDMA-OQAM communication system.

This paper is organized as fallows; in section 2 we present the system model of MC-CDMA-OQAM system in order to describe this Multi carrier modulation. In section 3 we will present our new communication scheme combining ST coding with spread spectrum technique and OFDM/OQAM. Section 4 is reserved to ST decoding and multi user detection. In section 5 we present numerical results obtained by matlab simulation showing performance of different multi user receivers of the proposed system. The last section deal with synthesis and comparison between MC-CDMA and MC-CDMA/OQAM in two cases; with and without space time coding and we finish by a conclusion.

2. MC-CDMA-OQAM SYSTEM MODEL

The block diagram in Figure 1 illustrates the MC-CDMA-OQAM transmission scheme relative to the kth user. It consists on the combination of spread spectrum with multicarrier modulation OQAM [4]. The basic principle of OFDM/OQAM is to divide the transmission bandwidth into a number of subbands. Like for OFDM, the transmitter and receiver can be implemented by using Fast Fourier transform (FFT) algorithms. However instead of a single FFT or IFFT, a uniform filter bank based on a prototype filter is used. At the receiver side the dual operations are carried out.

Different kinds of prototype functions can be implemented such as Isotropic Orthogonal Transform Algorithm or other prototypes optimized in discrete-time using the Time-Frequency Localization criterion.

Let us introduce the CDMA technique used in our system. We denote by Q the spreading factor and K the number of users, each user k is distinguished by its spreading code

$$c_k = \left[c_{0,k}, c_{1,k}, \ldots, c_{Q-1,k} \right]^t$$

Walsh Hadamard codes are chosen because they are characterized by their perfect orthogonality.
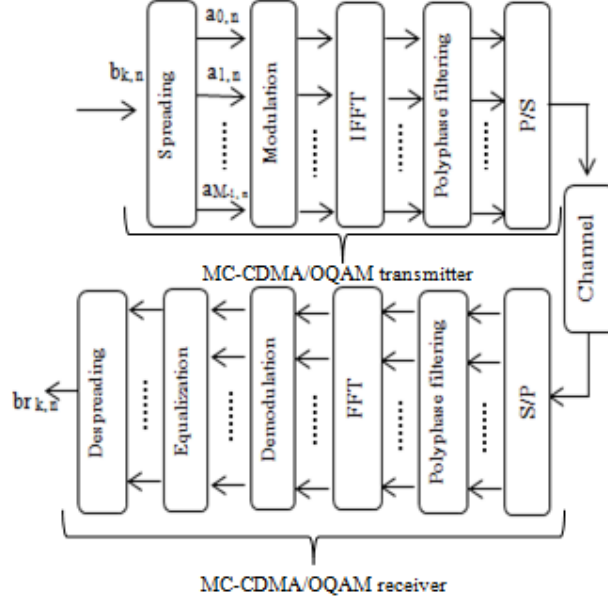

Figure 1 : MC-CDMA-OQAM system model

We consider the transmission of complex data in a free distorsion channel. The spreaded resultant signal of K users can be written as

$$x_{m,n} = \sum_{k=0}^{K} c_k b_{k,m,n} \tag{1}$$

With $b_{k,m,n}$ is the data of the kth user transmitted at time n over the mth subcarrier.

For each user, $b_{k,m,n} = a_{m,n}$

The baseband equivalent of a continous time Multicarrier MC-CDMA-OQAM signal is expressed as follows.

$$s(t) = \sum_{m=0}^{M-1} \sum_{n \in} x_{m,n} g(t - n\tau_0) \upsilon_{m,n} e^{j2\pi mF_0 t} \tag{2}$$

With : M the number of subcarrier, $g(t)$ The pulse shape, $F_0 = 1/T_0 = 1/2\tau_0$ the subcarrier spacing and $\upsilon_{m,n}$ an additional phase term.

The length of the prototype filter is a multiple of the number of subcarriers.
We denote by y the received signal, the output of the polyphase filters is obtained as follows.

$$y_{m0,n0} = \langle y, g_{m0,n0} \rangle \tag{3}$$

Then, we apply the despreading block to obtain signal relative to each user k. we get

$$yd_{n0,k} = \sum_{m0=0}^{M-1} c_k y_{m0,n0} \tag{4}$$

The despreaded signal is written as

$$yd_{n0,k0} = b_{n0,k0} + j\left(\sum_{k=0}^{K} \sum_{n=-2b+1}^{2b-1} b_{n+n0,k} \left(\sum_{p=0}^{M-1} \sum_{m=0}^{M-1} c_k c_{k0} \gamma_{m,n+n0}^{(p,n0)} \right) \right) \tag{5}$$

With $\gamma_{m,n}^{(p,n0)} = \Im\left\{ (-1)^{m(n+n0)} \, j^{m+n-p-n0} A_g \left(n-n0, m-p \right) \right\}$

A_g is the ambiguity function of the prototype function g defined as

$$A_g(n,m) = \int_{-\infty}^{\infty} g(u-n\tau_0) g(u) e^{j2\pi F_0 u} \, du$$

3- SPACE TIME CODING IN MC-CDMA-OQAM SYSTEM

OFDM/OQAM provides orthogonality in the real domain, a pseudo Alamouti code was proposed in [8]. This pseudo code is very complex so we think to take advantage from The CDMA-OFDM/OQAM combination that results the orthogonality in the complex domain so we can combine space time coding to this multi carrier communication system. We consider 2 transmit antennas and 2 receive antennas where are assumed to be far enough apart such the complex fading coefficients among the antennas are uncorrelated. We apply Alamouti ST coding scheme to each user k data.
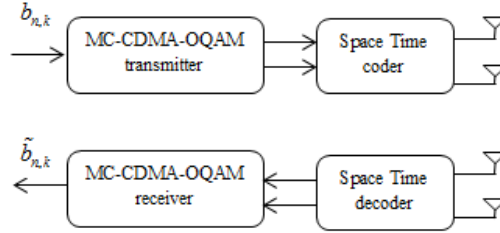

Figure 2 : MC-CDMA/OQAM system with space time coding

We dote by $h_{i,j}$ the complex channel coefficient between the ith transmit antenna and the jth receive antenna. The channel amplitudes are independents, zero mean complex Gaussian variables with unit variance.

The received code word is given by [6] :

$$Y = HX + n \tag{6}$$

With X the transmitted code word, H is channel matrix and n is an Additive White Gaussian Noise.

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

$$h_{i,j}(t) = h_{i,j} = \alpha_{i,j} e^{j\theta_{i,j}} \tag{7}$$

Form equations (6) and (7), we can write

$$\begin{pmatrix} y_1 & y_3 \\ y_2 & y_4 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} s_{n_0,k} & -s_{n_0+1,k}^{*} \\ s_{n_0+1,k} & s_{n_0,k}^{*} \end{pmatrix} + \begin{pmatrix} n_1 & n_3 \\ n_2 & n_4 \end{pmatrix} \tag{8}$$

With $s_{n_0,k}$ and $s_{n_0+1,k}$ data of kth user transmitted by the first antenna respectively at time n_0 and n_0+1 after spreading and passing through the polyphase filters.

$-s^*_{n_0+1,k}$ and $s^*_{n_0,k}$ data of kth user transmitted by the second antenna.

y_1 and y_3 signals received by the first antenna,

y_2 and y_4 signals received by the second antenna.

$$\begin{cases} y_1 = y_1(t) = h_{1,1}s_{n_0,k} + h_{1,2}s_{n_0+1,k} + n_1 \\ y_2 = y_2(t) = h_{2,1}s_{n_0,k} + h_{2,2}s_{n_0+1,k} + n_2 \\ y_3 = y_3(t+T) = -h_{1,1}s^*_{n_0+1,k} + h_{1,2}s^*_{n_0,k} + n_3 \\ y_4 = y_4(t+T) = -h_{2,1}s^*_{n_0+1,k} + h_{2,2}s^*_{n_0,k} + n_4 \end{cases} \tag{9}$$

n_1, n_2, n_3, n_4 are complex random variables representing noise.

4. SPACE TIME DECODING AND MUD

4.1. Space time decoding

We consider system with (CSI) Channel State Information at the receiver. Combined signals are given by:

$$\tilde{s}_{n_0,k} = \left(\alpha^2_{1,1} + \alpha^2_{1,2} + \alpha^2_{2,1} + \alpha^2_{2,2}\right)s_{n_0,k} + h_{1,1}n_1 + h_{1,2}n_2 + h_{2,1}n_3 + h_{2,2}n_4 \tag{10}$$

$$\tilde{s}_{n_0+1,k} = \left(\alpha^2_{1,1} + \alpha^2_{1,2} + \alpha^2_{2,1} + \alpha^2_{2,2}\right)s_{n_0+1,k} - h_{1,1}n^*_2 + h_{1,2}n_1 - h_{2,1}n^*_4 + h^*_{2,2}n_3 \tag{11}$$

These combined signals are then sent to the Maximum likelihood (ML) detector. The ML decision rule, at the receiver, is to choose $s_{j,k}$ if and only if

$$\sum_{i=1}^{2K}\sum_{n=1}^{2} d^2\left(y_i, h_{i,n}s_{j,k}\right) \le \sum_{i=1}^{2K}\sum_{n=1}^{2} d^2\left(y_i, h_{i,n}s_{m,k}\right) \ \forall j \ne m$$

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

The output of the ST decoder will be sent to the MC-CDMA-OQAM receiver. At this stage, the first step is to apply polyphase filtering and the second step is to apply multi user detector. The polyphase filtering, at the receiver, consists on using M uniform filters like at the transmitter with a simple FFT.

4.2. Multi user Detection (MUD)

We consider K users communicating simultaneously, each of them transmit L data. Collectively the matched filter output for all K users can be expressed in a long vector as [5]:

$$Z = \left[Z(1)^t \dots Z(L)^t\right]^t \tag{12}$$

With $Z(i) = \left[Z_1(i) \dots Z_K(i)\right]^t$

We denote by $C = [c_1, c_2, \ldots, c_K]$ the vector containing spreading codes of K users, $A = I(K)$ the identity matrix of size K and B the vector containing the data of K users. From equation (12), we can write:

$$Z = CC^t AB + n \tag{13}$$

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

$$d = w^t Z \tag{14}$$

The Zero Forcing (ZF) detector in [2] has a linear transformation equivalent to the inverse of the correlation matrix $R = CC^t$

$$w = R^{-1} \tag{15}$$

The decision vector is then,

$$d = R^{-1} \left(RAB + n \right) \tag{16}$$

The decision vector has covariance matrix

$$E\left[\left(R^{-1}n \right)\left(R^{-1}n \right)^H \right] = \sigma^2 R^{-1} \tag{17}$$

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

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

$$w = \min\left(E\left[\left(b - \tilde{b} \right)^t \left(b - \tilde{b} \right) \right] \right) \tag{18}$$

The solution of the equation above is

$$w = \left(R + \sigma^2 \left(A^t A \right)^{-1} \right)^{-1} \tag{19}$$

While the single user matched filter combats white noise exclusively and the Zero Forcing eliminates Multiple Access Interference (MAI) disregarding background noise, the MMSE linear detector forms a compromise between the two, taking the relevant importance of noise and interfering users into account. Differently to linear MUD there is iterative MUD such Successive Interference Cancellation (SIC) receiver [7] which is less complex.

5. SIMULATION AND NUMERICAL RESULTS

In this section, we present numerical results of the MC-CDMA/OQAM communication system.
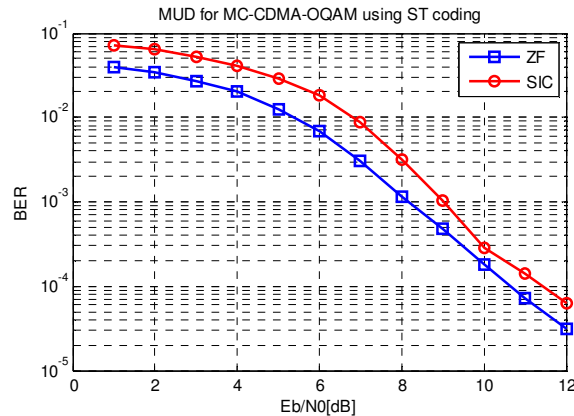
Figure 3: Mutli user detection for Space time coding MC-CDMA/OQAM communication system.

We assume that both the mobile and the base station have two transmit and two receive antennas, we consider K users communicating simultaneously, each user has his spreading code of length Q=16. We use Quadrature Amplitude Modulation QAM 4. The length of fast Fourier Transform is 64.

In Figure 3 multi user detection is presented. It represents Bit Error rate (BER) versus Signal to Noise Ratio (SNR). Simulation results improve that linear multi user detectors provide better performance gain in comparison with nonlinear detectors. However, nonlinear detectors can attend the compromise performance and simplicity.
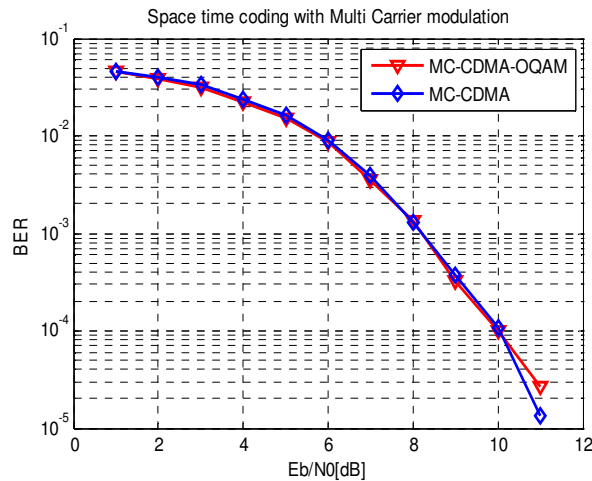

Figure 4: Space time coding with mutli carrier modulation: Comparison between MC-CDMA/OQAM and MC-CDMA.

Figure 4 shows a comparison between the classic MC-CDMA and MC-CDMA/OQAM. MC-CDMA is based on the combination of CDMA and OFDM with cyclic prefix but MC-CDMA/OQAM is based on the combination of CDMA and the advanced multi carrier modulation OFDM/OQAM. Simulation results improve that MC-CDMA/OQAM provide similar BER as MC-CDMA. Furthermore MC-CDMA/OQAM provides better data rate since that operates without guard interval.

In Figure 5 we compare the two multi carrier modulations MC-CDMA and MC-CDMA/OQAM in, both, Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) channels. Both SISO and MIMO channels attend good performance in term of BER versus

SNR. In addition, MIMO channel gives the possibility of exploiting the space and time diversity by transmitting different data symbols simultaneously the thing that increases the data rate in comparison with SISO channel.
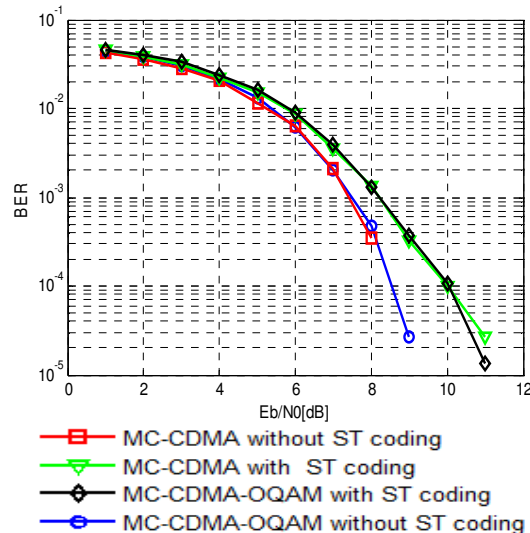

Figure 5: Comparison between MC-CDMA/OQAM and MC-CDMA with and without space time coding.

6. CONCLUSION

In this paper, we have studied and evaluated multi user detection in MC-CDMA-OQAM system in presence of MIMO channel. The idea is to use multicarrier modulation in order to combat channel effects. Two kinds of multi carrier modulations are compared; cyclic prefix OFDM and OFDM/OQAM. OFDM/OQAM operates without guard interval so it eliminates spectral efficiency loss present in OFDM. The idea of combining the CDMA component with multi carrier modulation has two advantages; the first one is to eliminate multiple access interference and the second one is to take advantage from the orthogonality in the complex domain provided by CDMA technique. The resulting is an MC-CDMA/OQAM communication system that provides orthogonality in the complex domain.   So we can use space time coding in order to exploit spatial and time diversity. The ST code used is the Alamouti code. Numerical results improve the performance gain of multicarrier modulation in two cases; with and without space time coding in multi user environment. Both linear and iterative multi user detectors applied to the proposed system attend a BER of 10^{-4} for a Signal to Noise Ratio (SNR) approximately equal to 10 dB. As perspective, we think to extend this work to a large number of transmit and receive antennas and to use other ST coders.

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