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Performance Analysis of LMS Based MC-CDMA system

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ABSTRACT

Multiple Input and Multiple Output (MIMO) systems do affective utilization of available bandwidth. The Multicarrier systems like Multicarrier Code Division Multiple Access (MC-CDMA) are designed with the combination of different space time coding techniques like Alamouti's Space Time Block Codes (STBC) for fulfilling this demand. In this paper, we use different LMS based algorithms to measure the performance of this sub-optimum receiver. It is shown that proposed LMS based algorithm converges faster than conventional LMS.

Keywords: *MC-CDMA, LMS, Space- time block codes, MMSE*

1. INTRODUCTION

Support for very high data rate transmission is one of the key requirements for the next wireless communication standards such as IEEE 16m and 4G. In very high data rate transmission scenario, single carrier code-division multiple access (CDMA) systems have some critical problems such as the difficulty of synchronization and the severe inter-chip and inter-symbol interferences due to the multipath fading channels.

Recently, multicarrier transmission schemes such as orthogonal frequency-division multiplexing (OFDM), multicarrier CDMA (MC-CDMA) and multicarrier direct-sequence (MC-DS)-CDMA have been considered as a potential candidate for the next-generation high data rate wireless systems [1]. Each multicarrier transmission scheme has both advantages and disadvantages in comparison with the others. MC-CDMA system is a combination of frequency-domain spreading and OFDM. An available bandwidth is decomposed into a set of disjoint equal bandwidth of small size, each sub-band signal experiences only frequency-flat fading channel and therefore, MC-CDMA systems are more robust to the distortion induced by time-dispersive channels than single carrier CDMA systems.

The simple space-time block code (STBC) proposed by Alamouti in [2] offers maximum diversity gain. It has been adopted as one of the key technologies for obtaining the transmit diversity gain in the third generation communication standards [3], [4]. In case of employing Alamouti's STBC, two consecutive symbols are simultaneously transmitted using two transmit antennas at the first symbol time and their conjugated symbols with or without sign change are transmitted at the next symbol time. We have used two received antenna for fast convergence rate in space-time block codes. The multiuser receivers can be categorized into two types: optimal receivers and suboptimal receivers. Since the optimal receivers require too much complexity, they are not realistic. On the contrary, the suboptimal receivers have been attracted due to their low complexity. Among them, Minimum Mean-Squared Error (MMSE) receiver is one of the most popular ones, in which filter coefficients are designed to minimize the MSE. Batch-processed multiuser receivers for DS-CDMA or MC-CDMA systems employing STBC have been proposed in [5], [6], and [7]. In general, the batch-processed receivers require the estimation of the inverse autocorrelation matrix of the extended received signal.

In this paper, we propose a simple modified LMS adaptive sub-optimum receiver for uplink STBC MC-CDMA and analyze its convergence properties and minimum mean square error.

2. MMSE BASED SYSTEM MODEL

We consider an MC-CDMA system having Altamonte's simple space-time block code (STBC). For simplicity it is assumed that two transmit antennas are at the transmitter and two receive antenna are at the receiver in this model.

In the figure 1 MC-CDMA transmitter structure of M^{th} user considered in this paper is shown. We assume that we have two transmit antennas x and y respectively. On first symbol interval two consecutive symbols $t_m(2i-1)$ and $t_m(2i)$ are sent on antenna x and y and on next symbol interval two consecutive symbols and $-t_m^*(2i)$ are sent on antenna x and y respectively. We also used the spreading code pair $(c_{m,1}, c_{m,2})$ of size $M \times 1$ for frequency domain spreading from the antenna x and y respectively, where $\mathbf{c}_{m,u}$ is given by

$$\mathbf{c}_{m,u} = c_{m,u,1}, c_{m,u,2}, \dots\dots, c_{m,u,M}]^t \quad (1)$$

This spreading data is converted from serial to parallel and then, an N-point IFFT operation is performed on spreading data, where N is the number of subcarriers. It is assumed that the number of subcarriers is equal to the processing gain of the spreading code. The IFFT output signal is parallel-to-serial converted and also inserted by the cyclic prefix to reduce inter-symbol interference (ISI) and inter-carrier interference (ICI), and then transmitted through the channel. We used Additive white Gaussian noise (AWGN). We have

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used the Rayleigh fading channel with maximum tape delay is equal spreading gain.

In fig.2 we have the receiver structure. At receiver side, we remove cyclic prefix from the received signal and the resulting signal is then converted into serial-to-parallel form, after that we performed by the N-point FFT operation. Assuming that the maximum delay spread is less than the cyclic prefix length for all users, the frequency-domain received signal vector after FFT operation is written as

$$\mathbf{r_1}(2i-1) = \sum_{m=1}^{M}\{\mathbf{s}_{m,1}\mathbf{c}_{m,1}t_m(2i-1) + \mathbf{s}_{m,2}\mathbf{c}_{m,2}t_m(2i)\} + \mathbf{u}(2i-1) \quad (2)$$

$$\mathbf{r_1}(2i) = \sum_{m=1}^{M}\{-\mathbf{s}_{m,1}\mathbf{c}_{m,1}t^*{}_m(2i) + \mathbf{s}_{m,2}\mathbf{c}_{m,2}t^*{}_m(2i-1)\} + \mathbf{u}(2i) \quad (3)$$

where $\mathbf{s}_{m,n}$ is the frequency-domain channel response from the transmit antenna m of user k given by

$$\mathbf{s}_{m,n} = \mathrm{diag}(s_{m,n,0}, s_{m,n,1}, s_{m,n,2}, \dots\dots\dots, s_{m,n,N-1}) \quad (4)$$

and $\mathbf{u}(l)$ is the complex additive white Gaussian noise(AWGN) with mean 0 and covariance matrix $\alpha^2_s\, I_{2M}$ where I_{2M} is an identity matrix of size 2Mx 2M.The l^{th} information

data of user m, $c_m(l)$ is an independent and identically distributed (i.i.d) random variable with zero mean and unit variance. If we define the effective spreading code at the transmit antenna m of user m by $c_{m,m}$, the received signal vector can be rewritten as

$$\mathbf{r_1}(2i-1) = \sum_{m=1}^{M}\{\mathbf{c}_{m,1}t_m(2i-1) + \mathbf{c}_{m,2}t_m(2i)\} + \mathbf{u}(-1) \quad (5)$$

$$\mathbf{r_1}(2i) = \sum_{m=1}^{M}\{-\mathbf{s}_{m,1}t^*{}_m(2i) + \mathbf{c}_{m,2}t^*{}_m(2i-1)\} + \mathbf{u}(2i) \quad (6)$$

$+\mathbf{u}(2i)$ (6)

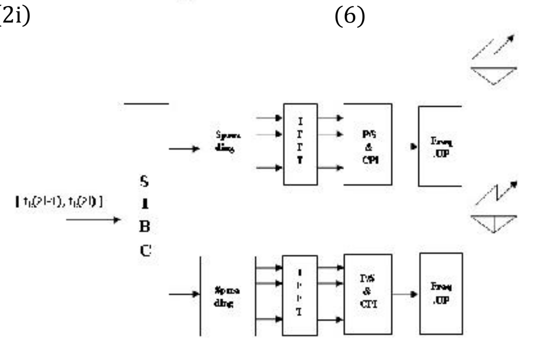

Fig.1. MC-CDMA Transmitter Structure

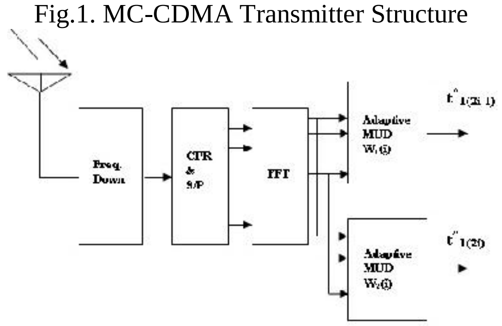

Fig.2. MC-CDMA Receiver Structure

3. MMSE BASED BATCH-PROCESSED RECEIVER

Defining the extended received signal vector for the two consecutive symbols by $\mathbf{y}(i)$yields

$$\mathbf{y}(i) = \left[\mathbf{r}^T_1(2i-1) + \mathbf{r}^H_1(2i)\right] \quad (7)$$
$$= \sum_{m=1}^{M}\{f_{m,1}t_m(2i-1) + \mathbf{f}_{m,2}t_m(2i) + \mathbf{u}(2i-1)\} + \mathbf{v}(i)$$

Where $f_{m,n}$ and v(i) are given by

$$\mathbf{f}_{m,1} = \begin{bmatrix} c_{m,1} \\ \\ c^*{}_{m,2} \end{bmatrix}, \mathbf{f}_{m,2} = \begin{bmatrix} c_{m,2} \\ \\ -c^*{}_{m,1} \end{bmatrix}, \mathbf{v}(i) = \begin{bmatrix} u(2i-1) \\ u(2i) \end{bmatrix}$$

Assuming that the desired user is user 1 and Defining $\mathbf{P}_1 = \mathbf{f_{1,1}} \;\; \mathbf{f_{1,2}}]$ and $\mathbf{T_1} = [t_1(2i-1) \;\; t_1(2i)]^T$ the extended received signal vector $\mathbf{y}(i)$ is rewritten as

$$\mathbf{y}(i) = \mathbf{P}_1\,\mathbf{T_1}(i) + \mathbf{z}(i) \quad (8)$$

Where $\mathbf{z}(i)$ given by

$$\mathbf{z}(i) = \sum_{m=2}^{M}\{\mathbf{f}_{m,1}t_m(2i-1) + \mathbf{f}_{m,2}t_m(2i) + u(2i-1)\} + v(i) \quad (9)$$

If we define the filter weight vectors W_1 and W_2 of size $2N\,x\,1$ for detecting $t_m(2i-1)$ and $t_m(2i)$ respectively, the Minimum Mean-Squared Error (MMSE) at the filter output is given by

$$\mathbf{D}(\mathbf{w_1},\mathbf{w_2}) = E[|\mathbf{W}^H\mathbf{y}(i) - \mathbf{T}_1(i)|^2]$$
$$= E[|\mathbf{w_1}^H\mathbf{y}(i) - t_1(2i-1)|^2] + E[|\mathbf{w_2}^H\mathbf{y}(i) - t_1(2i)|^2]$$

$$\mathbf{D}(\mathbf{w_1},\mathbf{w_2}) = \mathbf{D_1}(\mathbf{w_1}) + \mathbf{D_2}(\mathbf{w_2}) \quad (10)$$

where $\mathbf{W} = [\mathbf{w_1} \quad \mathbf{w_2}]$ and

$$\mathbf{D_1}(\mathbf{w_1}) = E[|\mathbf{w}_1{}^H\mathbf{y}(i) - t_1(2i-1)|^2]$$
$$\mathbf{D_2}(\mathbf{w_2}) = E[|\mathbf{w_2}{}^H\mathbf{y}(i) - t_1(2i)|^2] \quad (11)$$

Where, the MMSE receiver for STBC MC-CDMA is obtained by solving the following optimization problem in [6].

$$\mathbf{w}_{1,opt} \;,\; \mathbf{w}_{2,opt}] = \mathrm{argmin}_{w_1,w_2}\mathbf{D}(\mathbf{w_1},\mathbf{w_2}) = \arg\{\min\mathbf{D_1}(\mathbf{w_1}) + \min\mathbf{D_2}(\mathbf{w_2})\}$$

The gradient for $\mathbf{w_m}^*$ is given by

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$$\frac{\partial}{\partial \mathbf{w}_m^*}\mathbf{D}(\mathbf{w_1},\mathbf{w_2}) = \frac{\partial}{\partial \mathbf{w}_m^*}\mathbf{D_m}(\mathbf{w_m}) = \mathrm{E}[e^*{}_m(i)\mathbf{y}(i)]$$

$$= \mathbf{R_y w_m} - \mathbf{f_{1,m}}, m = 1,2$$

Where $\mathbf{R}_y$ is autocorrelation matrix given as

$$\mathbf{R_y} = \sum_{m=1}^{M}\{\mathbf{f}_{m,1}\mathbf{f}^{H}{}_{m,1} + \mathbf{f}_{m,2}\mathbf{f}^{H}{}_{m,2}\} + \boldsymbol{\alpha}^2{}_s\mathbf{I}_{2M}$$

and the filter output errors are given by

$$e_m(i) = \begin{cases} \mathrm{w_1}^H\mathbf{y}(i) - t_1(2i-1), & \text{if } m = 1 \\ \mathrm{w_2}^H\mathbf{y}(i) - t_1(2i), & \text{if } m = 2 \end{cases}$$

By setting the gradient to zero, the MMSE filter weight vectors for STBC MC-CDMA systems are given by

$$\mathbf{w_{1,opt}} = \mathbf{R}^{-1}{}_y\mathbf{f_{1,1}}, \quad \mathbf{w_{2,opt}} = \mathbf{R}^{-1}{}_y\mathbf{f_{1,2}}$$

The minimum MSE is given by

$$\mathbf{D}_{\min} = \mathbf{D}(\mathbf{w_{1,opt}},\mathbf{w_{2,opt}}) = \mathbf{D_{1,min}} + \mathbf{D_{2,min}}$$

where $\mathbf{D_{1,min}}$ and $\mathbf{D_{2,min}}$ are given by

$$\mathbf{D_{1,min}} = 1 - \mathbf{f}^{H}{}_{1,1}\mathbf{R}^{-1}{}_y\mathbf{f_{1,1}} \qquad (10)$$

$$\mathbf{D_{2,min}} = 1 - \mathbf{f}^{H}{}_{1,2}\mathbf{R}^{-1}{}_y\mathbf{f_{1,2}} \qquad (11)$$

4. PROPOSED LMS SUB-OPTIMUM ADAPTIVE RECEIVER

We proposed modified variations of LMS algorithm in order to implement adaptive ability of the receiver. These algorithms gives the MC-CDMA receiver better convergence rate, reduce computational complexity and decrease the steady state- error mean-square error. These LMS variations are signed, signed-regressor and signed-signed.

4.1. Proposed signed LMS algorithm for sub-optimum adaptive receiver

We have proposed modified LMS algorithm in this paper. The signed LMS algorithm is defined by following relationship:

$$\mathrm{w}(n+1) = \mathrm{w}(n) + 2\mu\, \mathrm{sign}(e(n))\mathrm{t}(n) \qquad (12)$$

where

$$sign(n) = \begin{cases} 1 & n > 0 \\ 0 & n = 0 \\ -1 & n < 0 \end{cases}$$

is the signum function. By introducing the signum function and setting μ to a value of power of two.

4.2. Proposed signed regressor LMS algorithm for sub-optimum adaptive receiver

The signed regressor or data sign algorithm is given as follows

$$\mathrm{w}(n+1) = \mathrm{w}(n) + 2\mu\, e(n)\mathrm{sign}(\mathrm{t}(n)) \qquad (13)$$

where the sign function is applied to t(n) on element by element basis.

4.3. Proposed signed-signed LMS algorithm for sub-optimum adaptive receiver

The Sign-Sign algorithm is given by

$$\mathrm{w}(n+1) = \mathrm{w}(n) + 2\mu\, \mathrm{sign}(e(n))\mathrm{sign}(\mathrm{t}(n)) \qquad (14)$$

where the sign function is applied to e(n) and t(n) on element by element basis.

5. SIMULATIOS AND RESULTS

We supposed a STBC based MC-CDMA system. The number of sub carriers is N=32 equivalent to length of the spreading sequence. The complex random spreading sequence is used for each user. The values of its real and imaginary parts are independently and randomly taken as $1/\sqrt{2}$ and $-1/\sqrt{2}$ with equal probability. The Rayleigh multipath fading channels with three paths is used for each user. The fading gains are generated by using a complex Gaussian distribution, which are normalized such that the average energy of the channel is unity. The spreading sequences and channel coefficients are fixed over all simulation cycles.

The fig. 3 shows MMSE learning curves for proposed signed LMS and conventional LMS. The number of users is M=20 and signal to noise ratio (SNR) is 25dB. The number of symbols for proposed signed LMS algorithm is 340 and number of symbols for conventional LMS algorithm is 350. This shows that convergence rate of signed LMS algorithm is little better than conventional LMS algorithm.

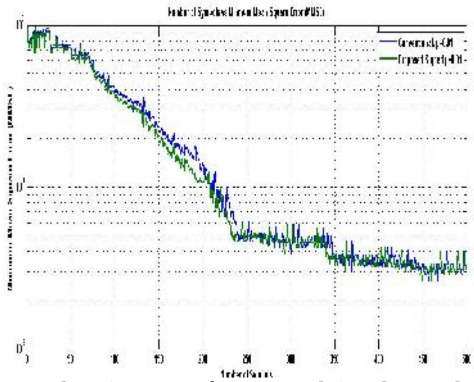

Fig.3. MMSE learning curves for proposed signed LMS algorithm and conventional LMS algorithm

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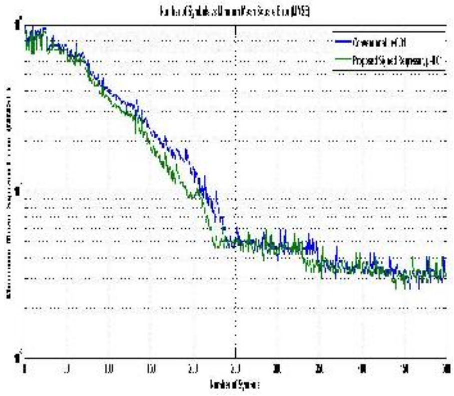

Fig.4. MMSE learning curves for proposed signed regressor LMS algorithm and conventional LMS algorithm

The Fig. 4 shows MMSE learning curves for signed regressor LMS and conventional LMS. The number of users is M=20 and SNR is 25 dB. The number of symbols for proposed signed regressor algorithm is 330 and for conventional LMS algorithm is 350. The results show that convergence rate of signed regressor algorithm is faster than the convergence rate of conventional LMS algorithm.

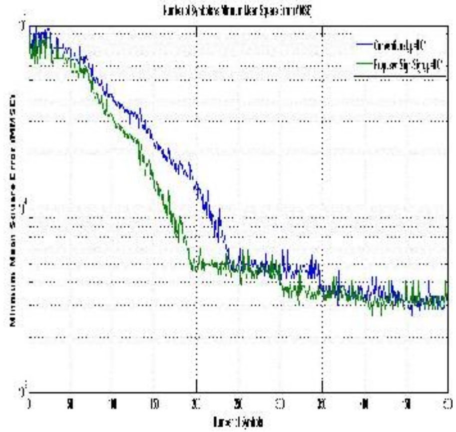

Fig.5. MMSE learning curves for proposed sign-sign LMS algorithm and conventional LMS algorithm

The Fig.5 shows MMSE learning curves for sign-sign LMS and conventional LMS. The number of users is M=20 and SNR is 25dB. The number of symbols for proposed sign-sign algorithm is 320 and number of symbols for conventional LMS algorithm is 350. This result shows that convergence rate of sign-sign algorithm is very much better than conventional LMS algorithm.

6. CONCULSION

In this paper, we use different LMS based algorithms to measure the performance of sub-optimum MC-CDMA receiver. The three different LMS flavors are signed, signed-regressor and sign-sign LMS. It is noted that convergence rate of all these three flavors is faster than conventional LMS. However, sign-sign LMS has low computation complexity and faster convergence rate with steady bit error rate (BER) than all other flavors of LMS.

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