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Acceleration to LMS based STBC MC-CDMA Receiver

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Abstract— High data rate is one of the key demands of future networks like 4th generation (4G) networks. One of the key solutions is the systems like Multi-Carrier Code Division Multiple Access (MC-CDMA) or Orthogonal Frequency Division Multiplexing (OFDM). We have used Alamouti's space time coding with MC-CDMA system in this paper. We proposed different types of Least Mean Square (LMS) algorithm to measure the performance of sub-optimum MC-CDMA receiver with exceptional relationship. We find out that sign-sign LMS with proposed relation has the fastest convergence rate than the other types of LMS receiver.

Index Terms— Sub optimal systems, STBC, MC-CDMA, LMS Algorithm, Convergence rate.

1 Introduction

Data transmission is increasing hugely now a days in networks like IEEE 16m and 4th generation (4G) technologies. This demand cannot be fulfilled by single carrier systems like code-division multiple access (CDMA) systems. They have some critical problems such as the difficulty of synchronization, severe inter-chip and inter-symbol interferences due to the multipath fading channels.

Some of the solutions to fulfill high data demand are orthogonal frequency-division multiplexing (OFDM), multicarrier CDMA (MC-CDMA) and multicarrier direct-sequence (MC-DS)-CDMA. They are considered as a potential candidate for the next-generation high data rate wireless systems [1].

In this paper, we adopted MC-CDMA system. The MC-CDMA system is a blend 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 practiced only frequency-flat fading channel. So MC-CDMA systems are tougher to the distortion induced by time-dispersive channels than single carrier CDMA systems

In [2] , it is shown that maximum diversity gain is achieved through Alaumouti space time block codes (STBC). They are being used for attaining transmit diversity gain in the third generation communication standards [3], [4]. The two consecutive symbols are simultaneously transmitted using two transmit antennas at the first symbol interval in Alamouti's STBC. Their conjugated symbols with or without sign change are transmitted at the next symbol interval. We have used two received antenna for fast convergence rate in space-time block codes.

The multiuser receivers are categorized as: optimal receivers and suboptimal receivers. The optimal receivers are not realistic due to too much complexity. However, the suboptimal receivers have been attracted due to low complexity. One of them is minimum mean-squared error (MMSE) receiver 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 proposed different variations of LMS algorithm to STBC based MC-CDMA receiver by imposing a relationship on it.

The paper is organized as follows. Section 2 describes proposed system model and the proposed modified LMS adaptive sub-optimum receiver is given in Section 3. MMSE based accelerated receiver cost function is given in section 4. Proposed LMS sub-optimum adaptive receiver is in section 5. Simulation results are given in Section 6 Finally, Section 7 concludes the paper.

2 Proposed System Model

We used Alamouti's STBC code in MC-CDMA system. We considered two antennas on each of transmitter and receiver side.

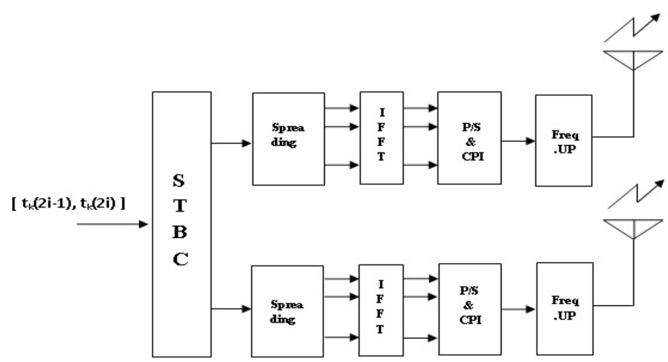

Fig.1.Transmitter structure for MC-CDMA system employing STBC

The fig 1 shows the MC-CDMA transmitter structure. We assume that we have two transmit antennas x and y respectively. The symbols $t_m(2\mathrm{i}-1)$ and $t_m(2\mathrm{i})$ are sent through antenna x and y on the first symbol interval. The two consecutive symbols $-t_m^*(2i)$and t_m^*(2i-1) are sent through antenna x and y respectively on the next symbol interval. We used the spreading code pair $(c_{m,1}, c_{m,2})$ of size M ×1 for frequency domain spreading from the antenna x and y respectively, where $c_{m,u}$ is given by

$$\mathbf{c}_{\mathrm{m,u}} = \left[\mathrm{c}_{\mathrm{m,u,1}}, \mathrm{c}_{\mathrm{m,u,2}}, \ldots \ldots, \mathrm{c}_{\mathrm{m,u,M}}\right]^{\mathrm{t}} \quad (1)$$

Then, an M-point IFFT operation is performed on spreading data, where M is the number of subcarriers. It is assumed that the number of subcarriers and processing gain of the spreading code are equal. The IFFT output signal is parallel-to-serial converted. The cyclic prefix are inserted to reduce inter-symbol interference (ISI) and inter-carrier interference (ICI) then transmitted through the channel. We used Additive white Gaussian noise (AWGN) and the rayliegh fading channel with maximum tape delay equal to spreading gain.

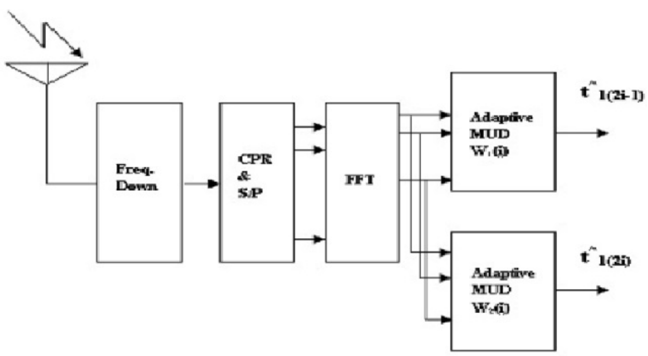

Fig.2. Receiver structure for MC-CDMA system employing STBC

The fig 2 shows the receiver structure of MC-CDMA system. The cyclic prefix from the received signal is removed initially. The resulting signal is serial-to-parallel converted which observes M-point FFT operation. The frequency domain received signal with assumption that the maximum delay spread is less than the cyclic prefix length for all users is given by

$$\mathbf{r}(2i-1) = \sum_{m=1}^{\mathrm{M}}\left\{\mathbf{S}_{m,1}\mathbf{c}_{m,1}\mathbf{t}_m(2i-1) + \mathbf{S}_{m,2}\mathbf{c}_{m,2}\mathbf{t}_m(2i)\right\} + \mathbf{u}(2i-1) \quad (3)$$

$$\mathbf{r}(2i) = \sum_{m=1}^{\mathrm{M}}\left\{-\mathbf{S}_{m,1}\mathbf{c}_{m,1}\mathbf{t}_m^*(2i) + \mathbf{S}_{m,2}\mathbf{c}_{m,2}\mathbf{t}_m^*(2i-1)\right\} + \mathbf{u}(2i) \quad (2)$$

Where $\mathbf{S}_{m,u}$ is the frequency-domain channel response of user m from the transmit antenna u given by

$$\mathrm{S}_{\mathrm{m,u}} = \mathrm{diag}\left(S_{m,u,0}, S_{m,u,1}, S_{m,u,2}, \ldots\ldots\ldots, S_{m,u,M-1}\right) \quad (4)$$

and $\mathbf{u}(i)$ is the complex additive white Gaussian noise (AWGN) with covariance matrix $\sigma_s^2\mathbf{I}_{2M}$ i.e; $\mathbf{I}$ is an identity matrix of size $2M \times 2M$, and zero mean. The m^{th} user u^{th} information data is $t_m(u)$ is an identically distributed random variable with unit variance and zero mean.

We define the effective spreading code at the transmit antenna u of user m by $\boldsymbol{d}_{m,u}$, than obtained signal vector can be written as

$$\mathbf{r}(2i-1) = \sum_{\mathrm{m=1}}^{\mathrm{M}}\left\{\mathbf{d}_{m,1}\mathbf{t}_m(2i-1) + \mathbf{d}_{m,2}\mathbf{t}_m(2i)\right\} + \mathbf{u}(2i-1)$$

$$\mathbf{r}(2i) = \sum_{\mathrm{m=1}}^{\mathrm{M}}\left\{-\mathbf{d}_{m,1}\mathbf{t}_m^*(2i) + \mathbf{d}_{m,2}\mathbf{t}_m^*(2i-1)\right\} + \mathbf{u}(2i) \quad (5)$$

3 MMSE Based Batch Processed Receiver

Defining the extended received signal vector for the two consecutive symbols by y(i) yields [8]

$$\boldsymbol{y}(i) = [\mathbf{r}^T(2i-1) \quad \mathbf{r}^H(2i)]^T = \sum_{m=1}^{M}\left\{\mathbf{f}_{m,1}\mathbf{t}_m(2i-1) + \mathbf{f}_{m,2}\mathbf{t}_m(2i)\right\} + \mathbf{v}(i) \quad (6)$$

Where $\mathbf{f}_{m,n}$ and $\mathbf{v}(i)$ are given by

$$\mathbf{f}_{m,1} = \begin{bmatrix}\mathbf{d}_{m,1}\\ \\ \mathbf{d}_{m,1}^*\end{bmatrix}, \quad \mathbf{f}_{m,2} = \begin{bmatrix}\mathbf{d}_{m,2}\\ \\ -\mathbf{d}_{m,1}\end{bmatrix}, \quad \mathbf{v}(i) = \begin{bmatrix}\mathbf{u}(2i-1)\\ \\ \mathbf{u}(2i)\end{bmatrix} \quad (7)$$

We assume that our desired user is 1. Defining $\mathbf{P}_1 = \left[\mathbf{f_{1,1}} \quad \mathbf{f_{1,2}}\right]$ and$\mathbf{t}_1 = [\mathrm{t}_1(2i-1) \ \ \mathbf{t}_1(2i)]^T$. The extended received signal vector **y(i)** in (6) can be rewritten as

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

Where $\mathbf{z}(i)$ is additive white Gaussian noise given by

$$\mathbf{z}(\mathrm{i}) = \sum_{m=2}^{M}\left\{\mathbf{f}_{m,1}\mathbf{t}_m(2i-1) + \mathbf{f}_{m,2}\mathbf{t}_m(2i)\right\} + \mathbf{v}(\mathrm{i}) \quad (9)$$

If we define the filter weight vectors $\mathbf{w}_1$ and $\mathbf{w}_2$with size $2M \times 1$ for distinguishing $t_m(2\mathrm{i}-1)$ and $t_m(2\mathrm{i})$ respectively, then minimum mean-squared error (MMSE) at the filter output is given by

$$\begin{aligned}\mathbf{D}(\mathbf{w_1}, \mathbf{w_2}) &= \mathrm{E}[|\mathbf{W}^H\mathbf{y}(i) - \mathbf{t}_1(i)|^2]\\ &= \mathrm{E}[|\mathbf{w}_1^H\mathbf{y}(i) - \mathbf{t}_1(2i-1)|^2] + [|\mathbf{w}_2^H\mathbf{y}(i) - \mathbf{t}_1(2i)|^2]\\ &= \mathbf{D}_1(\mathbf{w}_1) + \mathbf{D_2}(\mathbf{w_2})\end{aligned} \quad (10)$$

The minimization problem in [4] is required in order to attain the Minimum Mean Square Error (MMSE) receiver for the above mentioned STBC based MC-CDMA system:

$$\begin{aligned}\left[\mathbf{w}_{o,1}, \mathbf{w}_{o,2}\right] &= arg\underbrace{\min}_{\mathbf{w}_1,\mathbf{w}_2}\mathbf{D}(\mathbf{w}_1, \mathbf{w}_2)\\ &= \{\underbrace{\min}_{\mathbf{w}_1}\mathbf{D}_1(\mathbf{w}_1) + \underbrace{\min}_{\mathbf{w}_2}\mathbf{D_2}(\mathbf{w_2})\end{aligned} \quad (11)$$

The MMSE receiver works by setting the derivatives of these filter weight $\mathbf{w}_1$and $\mathbf{w_2}$ to zero which is

$$\mathbf{w}_{o,1} = \mathbf{R}_y^{-1}\mathbf{d}_{1,1}, \qquad \mathbf{w}_{o,2} = \mathbf{R}_y^{-1}\mathbf{d}_{1,2} \quad (12)$$

Where $\mathbf{R}_y = E[\mathbf{r}(k)\mathbf{r}^H(k)]$ which is the autocorrelation matrix of $\mathbf{r}(k)$. The MMSE with respect to (12) is

$$\begin{aligned}D_{min} &= \mathbf{D}\left(\mathbf{w}_{o,1}, \mathbf{w}_{o,2}\right)\\ &= \left(1 - \mathbf{d}_{1,1}^H\mathbf{R}_y^{-1}\mathbf{d}_{1,1}\right) + \left(1 - \mathbf{d}_{1,2}^H\mathbf{R}_y^{-1}\mathbf{d}_{1,2}\right)\end{aligned} \quad (13)$$

4 MMSE Based Accelerated Receiver Cost

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FUNCTION

The unique association between the optimum weights $\mathbf{w}_{o,1}$ and $\mathbf{w}_{o,2}$ is described in this part as in (17). Suppose $\mathbf{R}_y$ by its sub matrices of dimensions $M \times M$.

$$\mathbf{R}_y = \begin{bmatrix} \mathbf{R}_1 & \mathbf{R}_2 \\ \mathbf{R}_3 & \mathbf{R}_4 \end{bmatrix} \quad (16)$$

It was noted that $\mathbf{R}_y$ has a certain relationship in its diagonals. The relationship is $\mathbf{R}_4 = \mathbf{R}^*{}_1$ and $\mathbf{R}_3 = -\mathbf{R}^*{}_2$. This association between MMSE filter weight vectors is used in (13) to derive a special relationship. The optimal weight vectors $\mathbf{w}_{o,1}$ and $\mathbf{w}_{o,2}$ of dimension $M \times 1$are presented as

$$\mathbf{w}_{o,1} = \begin{bmatrix} \mathbf{w}_{1,1} \\ \mathbf{w}_{1,2} \end{bmatrix}, \quad \mathbf{w}_{o,2} = \begin{bmatrix} \mathbf{w}_{2,3} \\ \mathbf{w}_{1,4} \end{bmatrix} \quad (17)$$

and the following relation is satisfied by these vectors as in [9]:

$$\mathbf{w}_{1,2} = \mathbf{w}^*{}_{2,3}, \quad \mathbf{w}_{1,4} = -\mathbf{w}^*{}_{1,1} \quad (18)$$

The MMSE filter weight vectors are given in (17) satisfies the relation given in (18). So it's a very good sign in order to increase the convergence rate by only updating the weight vectors satisfying the relationship in (18). The cost function of MMSE in (10) can be reformed as only function of $\mathbf{w}_d$ and $\mathbf{w}_e$:

$$\mathrm{D}_N = \mathrm{D}_{N1}(\mathbf{w}_d, \mathbf{w}_e) + \mathrm{D}_{N2}(\mathbf{w}_d, \mathbf{w}_e) \quad (19)$$

where

$$\mathrm{D}_{N1}(\mathbf{w}_d, \mathbf{w}_e) = E[\mathbf{w}_d^H r(2i-1) + \mathbf{w}_e^T r^*(2i) - d_1(2i-1)|^2]$$

and

$$\mathrm{D}_{N2}(\mathbf{w}_d, \mathbf{w}_e) = E[|\mathbf{w}_e^H r(2i-1) + \mathbf{w}_d^T r^*(2i) - d_1(2i)|^2]$$

5 PROPOSED LMS SUB-OPTIMUM ADAPTIVE RECEIVER

We have proposed modified LMS algorithm in this paper. These algorithms were designed to be adaptive in order to improve the performance of sub-optimum receiver in terms of better convergence rate, reduce computational complexity and decrease the steady state- error mean-square error. These algorithms are signed, signed -regressor and signed-signed.

5.1 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:

$$\mathrm{w(n+1) = w(n)} + 2\mu\, \mathrm{sign}\big(e(\mathrm{n})\big)\mathrm{t(n)} \quad (20)$$

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.

5.2 Proposed signed regressor LMS algorithm for sub-optimum adaptive receiver

The signed regressor or data sign algorithm is given as follows

$$\mathrm{w(n+1) = w(n)} + 2\mu\, e(\mathrm{n})\mathrm{sign}\big(\mathrm{t(n)}\big) \quad (21)$$

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

5.3 Proposed signed-signed LMS algorithm for sub-optimum adaptive receiver

The Sign-Sign algorithm is given by

$$\mathrm{w(n+1) = w(n)} + 2\mu\, \mathrm{sign}\big(e(\mathrm{n})\big)\mathrm{sign}\big(\mathrm{t(n)}\big) \quad (22)$$

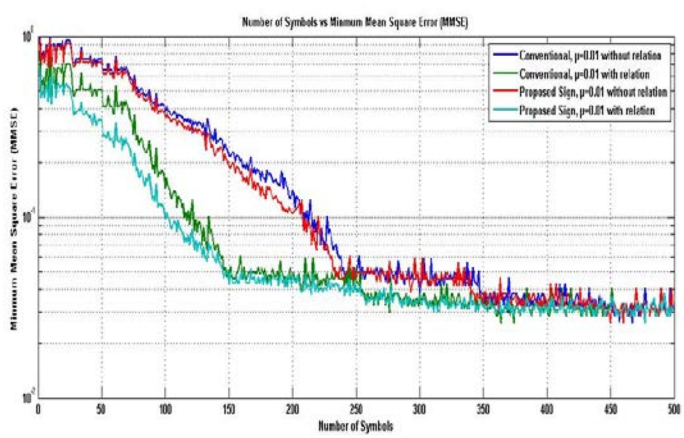
where the sign function is applied to e(n) and t(n) on element by element basis.

6 SIMULATIONS 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 without relation is 340 and number of symbols for conventional LMS algorithm without relation is 350. The number of symbols for proposed signed LMS algorithm with relationship is 250. The number symbols for conventional LMS algorithm with relationship is 260. This result shows that convergence rate of proposed signed LMS algorithm and conventional LMS algorithm with relation is faster than signed LMS and conventional LMS without relation.

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



conventional LMS algorithm with and without relation

The fig. 4 shows MMSE learning curves with numbers of users are M=20 and signal to noise ratio (SNR) is 25dB. The number of symbols for proposed signed regressor algorithm without relationship is 330. The number of symbols for conventional LMS algorithm without relationship is 350. The number of symbols for proposed signed regressor algorithm

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with relationship is 230. The number symbols for conventional LMS algorithm with relationship is 260. This result shows that convergence rate of proposed signed LMS algorithm and conventional LMS algorithm with relationship is faster than the schemes without relation.

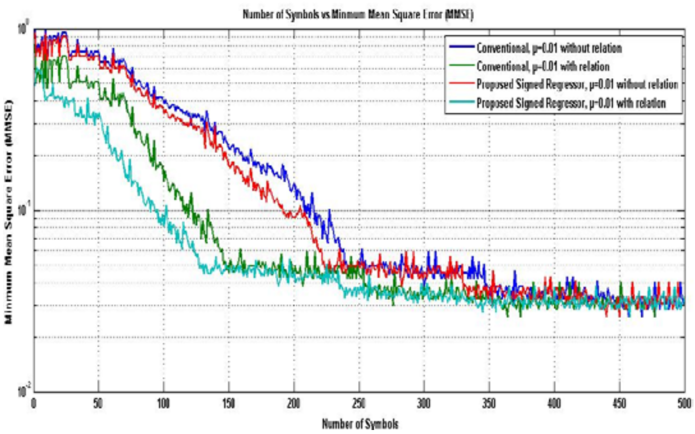


Fig.4. MMSE learning curves for proposed signed regressor algorithm and conventional LMS algorithm with relation and without relation

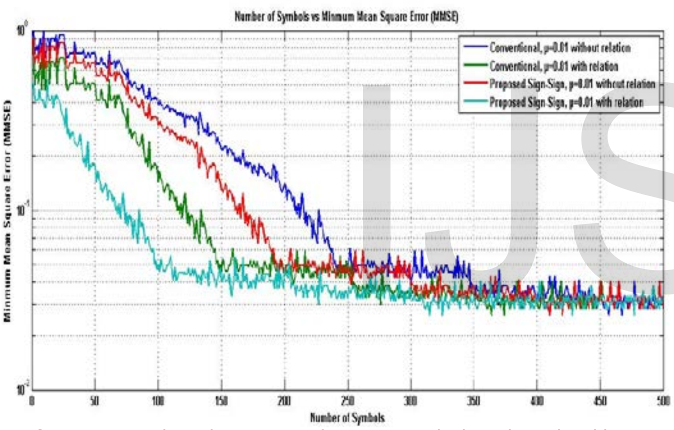


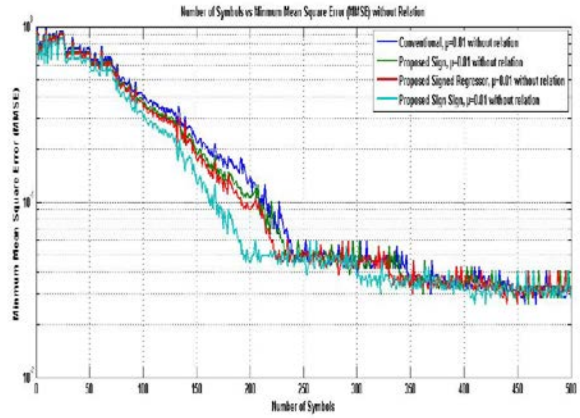
Fig.5. MMSE learning curves for proposed sign-sign algorithm and conventional LMS algorithm with and without relation

The fig. 5 shows MMSE learning curves with numbers of user are M=20 and signal to noise ratio (SNR) is 25dB. The Number of symbols for proposed sign-sign algorithm without relation to achieve the constant Bit Error Rate (BER) is 300. The number of symbols for conventional LMS algorithm without relation to achieve constant BER is 350. While, the number of symbols for proposed sign-sign algorithm with relation to achieve the constant BER is 200. The number symbols for conventional LMS algorithm with relationship to achieve the constant BER is 250. This result shows that convergence rate of proposed signed LMS algorithm and conventional LMS algorithm with relation is faster than without relation.

The fig. 6 shows MMSE learning curves for proposed LMS algorithms without relationship. The numbers of user are M=20 and signal to noise ratio (SNR) is 25dB. The Number of symbols to achieve constant bit error rate for conventional LMS, signed LMS, signed regressor LMS and sign-sign LMS algorithm without relationship are 350, 340, 330 and 300. This result shows that convergence rate of proposed sign-sign LMS algorithm is faster than the other LMS based schemes.

Fig.6. Comparison of MMSE learning curves for proposed LMS algorithm without relation

The fig. 7 shows MMSE learning curves for proposed LMS



algorithms with relation. The numbers of user are M=20 and signal to noise ratio (SNR) is 25dB. The Number of symbols to achieve constant bit error rate for conventional LMS, signed LMS, signed regressor LMS and sign-sign LMS algorithm without relationship are 260, 250, 230 and 200. This result shows that convergence rate of proposed sign-sign LMS algorithm with relation is faster than the other LMS based schemes.

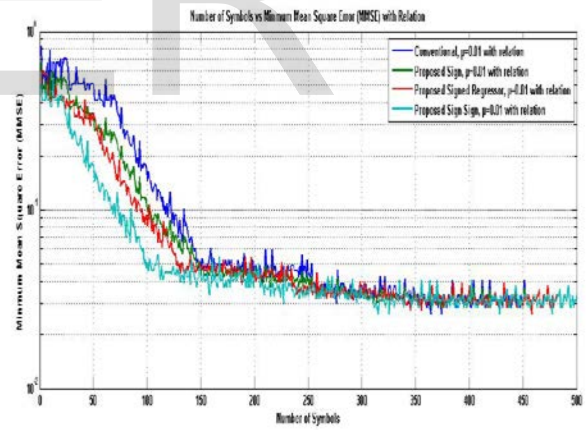


Fig.7. Comparison of MMSE learning curves for proposed LMS algorithm with relation

7 CONCLUSION

In this paper, we use different LMS based algorithms to measure the performance of sub-optimum MC-CDMA receiver by imposing a relationship on it. These 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. It is noted that sign-sign LMS with relation has low computation complexity and faster convergence rate than all other flavors of LMS.

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