www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 6 Issue 12 December 2017, Page No. 22264-22275
Index Copernicus value (2015): 58.10, 76.25 (2016) DOI: 10.18535/ijecs/v6i12.05

Optimum Step for multistep prediction blind equalizer

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Abstract
Blind equalizers may be implemented with linear prediction error filters (LPEF) but the delay (*D*) cannot be controlled with one-step predictors to minimize the mean square error (MSE). Consequently, multi-step prediction error filters (MSPEF) has been suggested as a solution to the problem. In this paper, a blind equalizer composed of the Godard algorithm (CMA) cascaded with MSPEF is proposed (CMA_MSPEF), and we extract the optimum value of step for multi-step prediction blind equalizer. Simulation results show comparable improvements of the proposed equalizer relative to the LPEF or the MSPEF equalizers with optimum step.

Keywords: blind equalizers, CMA equalizers and Multistep equalizers.

1. Introduction

A communication channel may introduce inter-symbol interference (**ISI**) in the received sequence. Blind equalization attempts to remove the **ISI** without a training sequence. If multiple samples per symbol are available at the receiver, blind equalizers can be derived from the second order statistics (**SOS**) of the received signal [4][6][8][9]. **MMSE** equalizers can be implemented with linear multi-channel prediction-error filters [1, 2] .For many practical channels, a small equalization error may be achieved by controlling the delay. Multi-step prediction has been suggested as a solution to the arbitrary-delay equalization problem [2][7]. The organization of the paper is as follows: the system model and the proposed algorithm are presented in Section 2. Simulation results are summarized in Section 3. Concluding remarks in Section 4, are summarized.

2. The CMA – MSPEF Proposed Model Algorithm

The proposed algorithm consists of a linear equalizer constant modulus algorithm (**CMA**) and multi-step forward prediction error filter (**MSPEF**) in cascade. The continuous time received signal is:-

$$a(t)=\sum_{k=-\infty}^{\infty} s(k)\, h(t-k) + v(t) \qquad (1)$$

where $s(k)$ is the sequence of complex information symbols , $h(t)$ is the complex baseband channel impulse response, and $v(t)$ is an additive white Gaussian noise (**AWGN**) . The fractionally spaced discrete-time model can be obtained by oversampling. A single-input single-output (**SISO**) system model results when the sampling rate at the receiver equals the symbol transmission rate. When several samples per symbol interval are taken, the system becomes single-input multiple-output **(SIMO)** as in fig.1

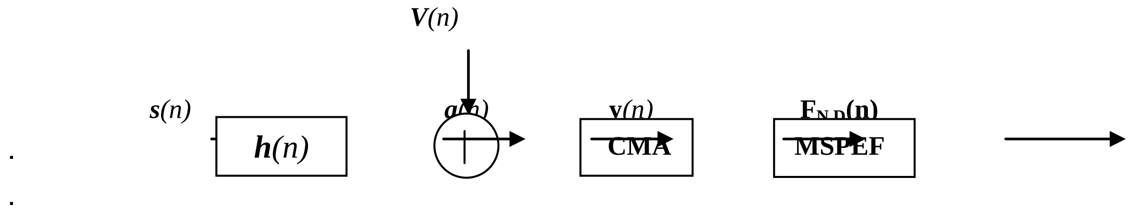

fig . 1. The CMA – MSPEF Proposed System

The corresponding **SIMO** model consists of P sub- channels (P ≥ 2). The ith subchannel response is defined as $h_i(n) = h(t_o + i / P + n)$ where n=0,1,2,…., L-1 , and L is the subchannel length . Its output $a_i(n) = a(t_o + i / P + n)$ is given by :

$$a_i(n) = \sum_{k=0}^{L-1} s(k)\, h_i(n-k) + v_i(n) \qquad (2)$$

where $0 \le i \le P-1$, and $v_i(n)$ are samples of $v_i(t)$ corresponding to $a_i(n)$. In each symbol interval , $\boldsymbol{a}(n)$ of length P is received in vector form as :

$$\boldsymbol{a}(n) = [a_0(n)\,, a_1(n)\,, a_2(n)\,, \ldots\ldots, a_{p-1}(n)\,]^T \qquad (3)$$

The channel impulse response can also be represented in vector form as :

$$\boldsymbol{h}(n) = [h_0(n)\,, h_1(n)\,, h_2(n)\,, \ldots\ldots, h_{p-1}(n)\,]^T \qquad (4)$$

and the noise as :

$$\boldsymbol{v}(n) = [v_0(n)\,, v_1(n)\,, v_2(n)\,, \ldots\ldots, v_{p-1}(n)\,]^T \qquad (5)$$

where $[\ ]^T$ denoting transposition .

For the system under consideration, we have assumed the following:

- *The input sequence s(t) is zero-mean with unit variance.*
- *The additive white Gaussian noise v(t) is zero-mean with variance* σ^2.
- *The sequences s(t) and v(t)* are uncorrelated .

2. a. Adaptation for the CMA equalizer

The adaptation algorithm for the weight of **CMA** equalizers is as follows [7] :

$$w_i(n+1) = w_i(n) + \mu_f\,(C - |\, y_i(n)\,|^2)\, y_i(n)\, A_i^*(n) \qquad , 0 \le i \le P-1 \qquad (6)$$

where $\boldsymbol{y}_i(n)$ and the $\boldsymbol{w}_i(n)$ are the outputs and weights of the i^th^ equalizer of length (M_1+M_2+1) . The outputs and weights in vectors the following is obtained:

$$\boldsymbol{y}(n) = [y_0(n)\,, y_1(n)\,, y_2(n)\,, \ldots\ldots, y_{p-1}(n)\,]^T \qquad (7)$$

$$\boldsymbol{w}(n) = [w_0(n)\,, w_1(n)\,, w_2(n)\,, \ldots\ldots, w_{p-1}(n)\,]^T \qquad (8)$$

Finally, C is the modulus given by [7] :

$$C = E\{|\, s(n)\,|^4\} / E\{|\, s(n)\,|^2\} \qquad (9)$$

and μ_f is the step size given by :

$$\mu_f = .001 / E[\,|\, s(n)\,|^4\,] \qquad (10)$$

$A_i^*(n)$ is the corresponding input vectors with length equal to (M_1+M_2+1) .

2.b. Adaptation for the MSPEF equalizer

Stacking previously N output vectors of the **CMA** equalizers each of length into an *(NP X 1)* vector, then the **MSPEF** input can be represented as:

$$\boldsymbol{y}_N(n) = [\boldsymbol{y}^T(n)\,, \boldsymbol{y}^T(n-1)\,, \boldsymbol{y}^T(n-2)\,, \ldots\ldots, \boldsymbol{y}^T(n-N+1)\,]^T \qquad (11)$$

A ***D***-step forward predictor of order N produces an estimate $\hat{s}(n)$ of the received symbol s(n) based on the N previous symbols $\boldsymbol{y}_N(n-D)$. The **MSPEF** coefficients $U_{N,D}$ are obtained from Yule Walker Equations [3] as :

$$U_{N,D} = E\{\, \boldsymbol{y}_{N-D+1}(n-D)\, \boldsymbol{y}^+(n)\}\, (R^{-1}_{N-D+1}) \qquad (12)$$

where R_{N-D+1} is the covariance of $\boldsymbol{y}_{N-D+1}(n)$,

$(\ )^+$ and E( ) denoting transpose conjugation and statistical expectation respectively . A corresponding *D*-step forward prediction error filter (PEF) of order N produces the error $f_{N,D}(n) = s(n) - \hat{s}(n)$ as it output . The *D* -step prediction error is then :

$$f_{N,D}(n) = U^{*}_{N,D}\, \boldsymbol{y}_{N+D}(n) \qquad (13)$$

The blind equalization method considered here is based on the output of *D* and (*D+1)*-step prediction error filter's [7] ,so the output of **CMA_MSPEF** is given by:

$$F_{N,D}(n) = f_{N,D+1}(n) - f_{N,D}(n) \qquad (14)$$

where $f_{N,D+1}(n)$ is the output of *D+1-step* predictor and $f_{N,D}(n)$ is the output of *D-step* predictor .

3. Simulation Results

The proposed system was applied to 16-QAM and 4-QAM modulation techniques with additive white Gaussian noise. The performance of the CMA_MSPEF system is obtained via simulation to extract the optimum step D, for the following three channels given below and which were considered in [1], [3] and [7].

Channel one: (0.1632+j0.2056),(-0.9491+j0.1524),(1+j0),
(0.2393-j0.0077),(0.0041-j 0.5634),
(0.0041-j 0.5634),(-0.2452+j0.7152),
(0.8+j0),(-0.2393+j0.1775).

Channel two: (-0.05+j0.27),(-.37-j0.01),(0.02-j0.07),
(-0.21-j0.03),(0.5-j0.6),(0.25+j0.27),
(-0.1+j0.38),(0.22-j0.05),(0.26+j0.14),
(0.17-j0.72).

Channel three :(-0.005-j0.0004),(0.009+j0.0300),
(-0.024-j0.1040),(0.854+j0.5200),
(-0.218+j0.2730),(0.049-j0.0740),
(-0.016+j0.0200), (0.010+j0.0002),
(-0.018-j0.0150),(0.048+j0.0520),
(1+j0),(0.436+j0.1360),(-0.098+j0.0370),
(0.032-j0.0100).

The parameters used in the simulation are: $M_1=M_2=N=15$. Depicted results shown in figures (2-10), give the MMSE versus iterations for different channels, different SNR and the employed modulation techniques.

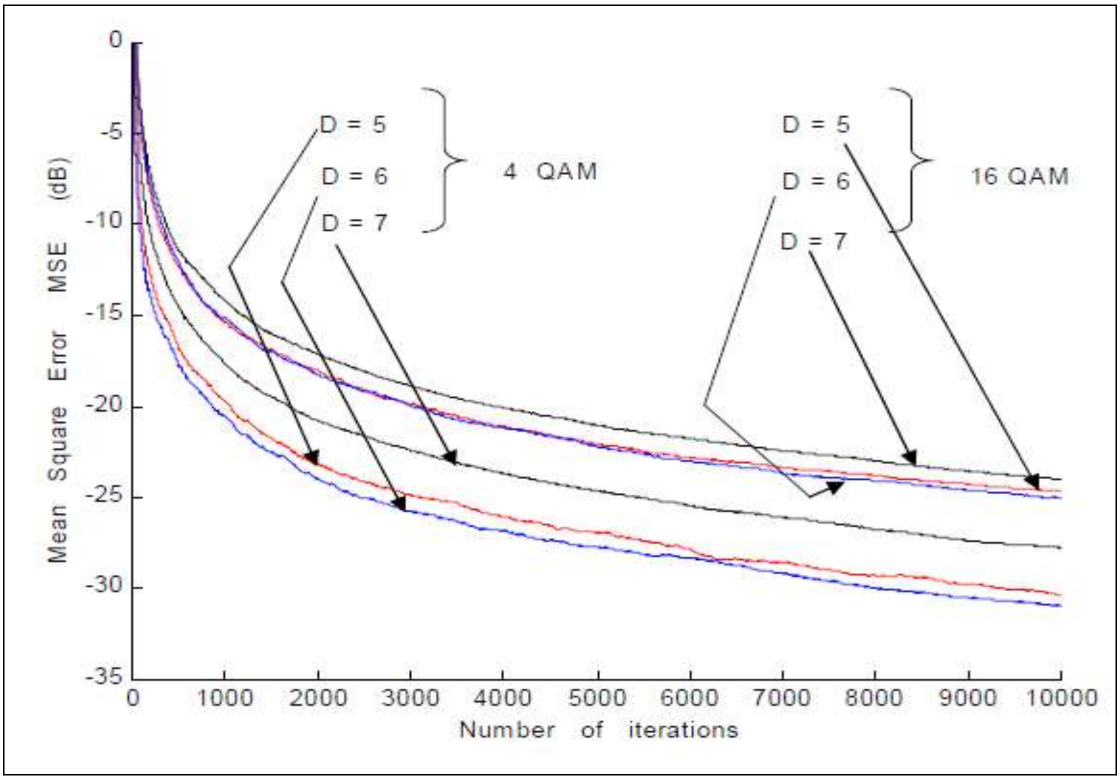

Fig.2. Optimum Step D for Channel one and SNR=0 dB

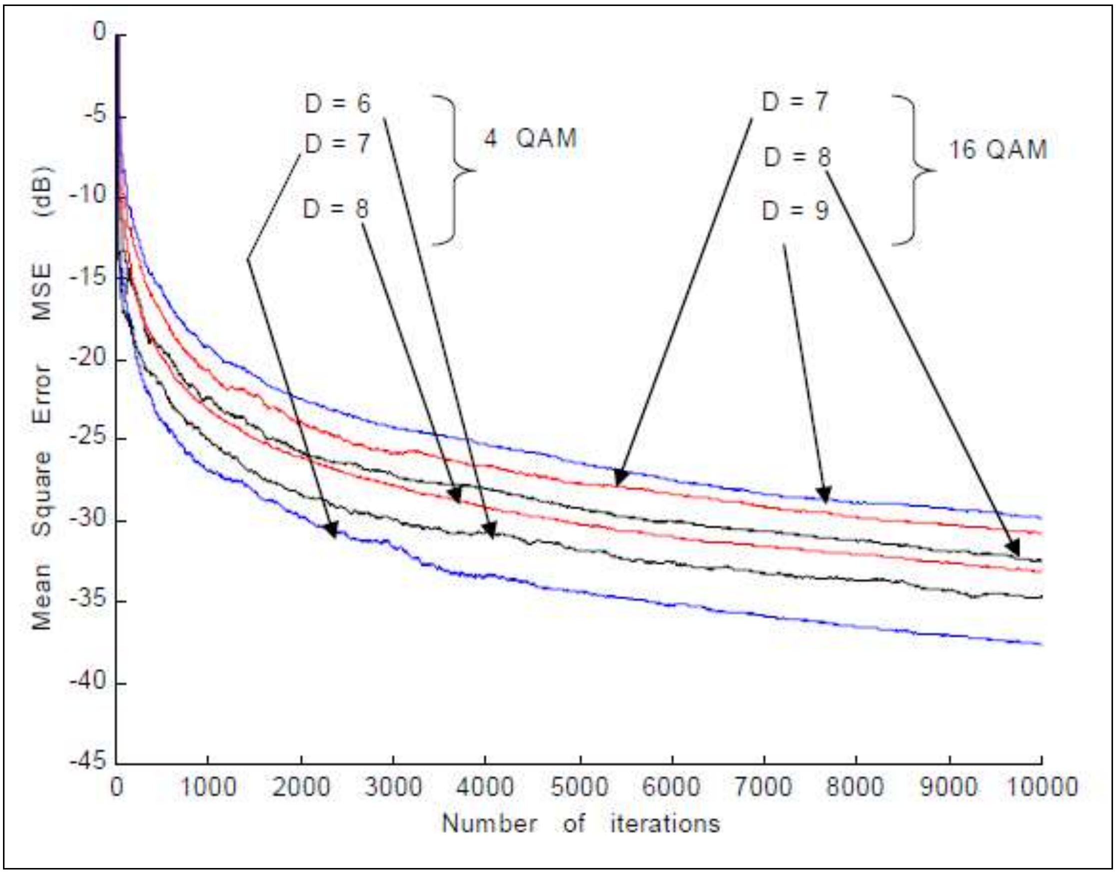

Fig.3. Optimum Step D for Channel one and SNR=5 dB

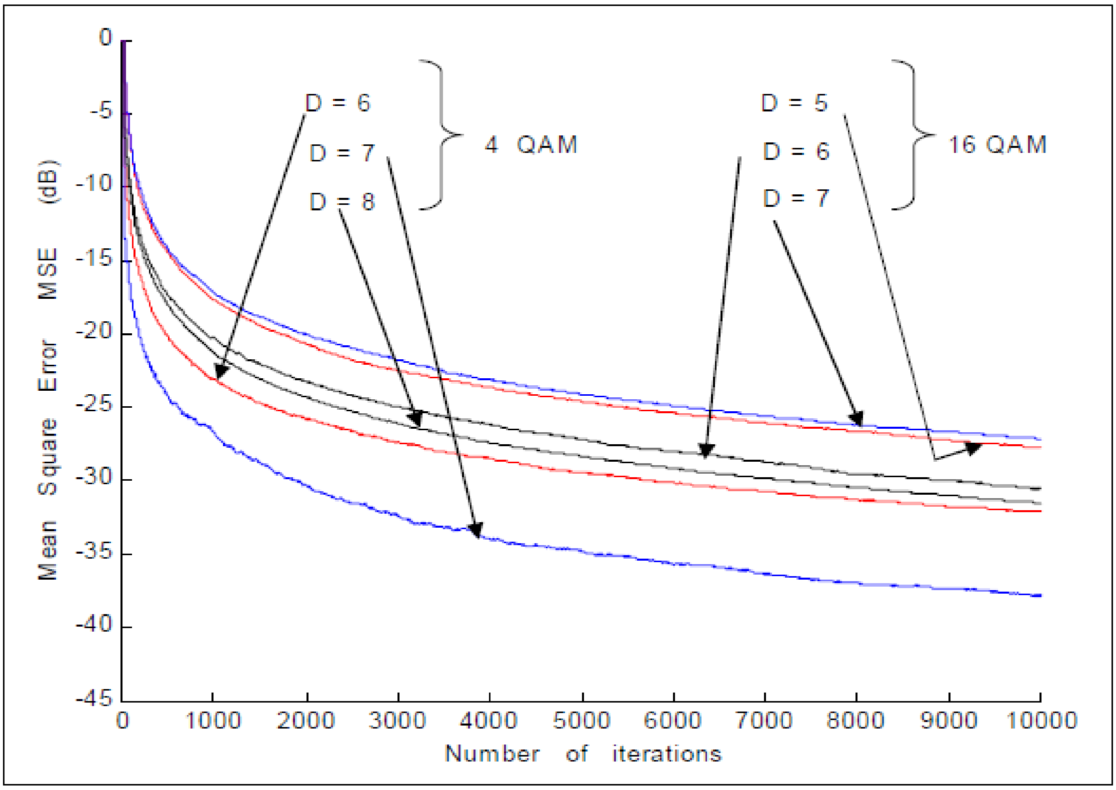

Fig.4. Optimum Step D for Channel one and SNR=10 dB

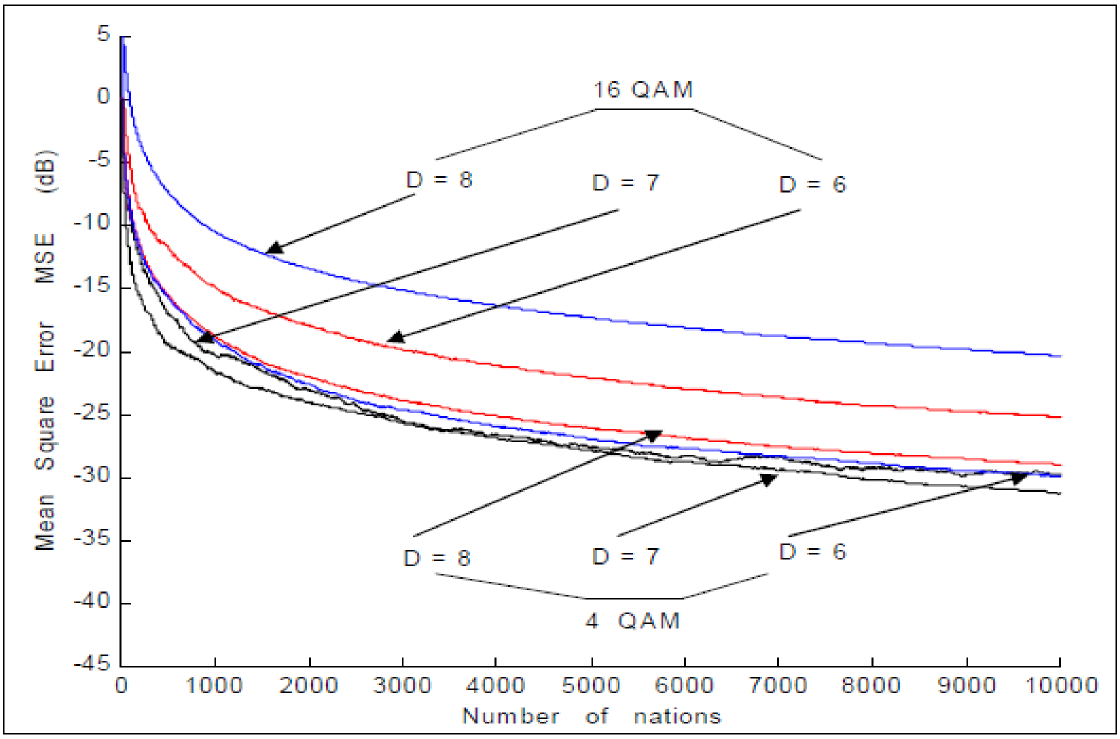

Fig.5. Optimum Step D for Channel Two and SNR=0 dB

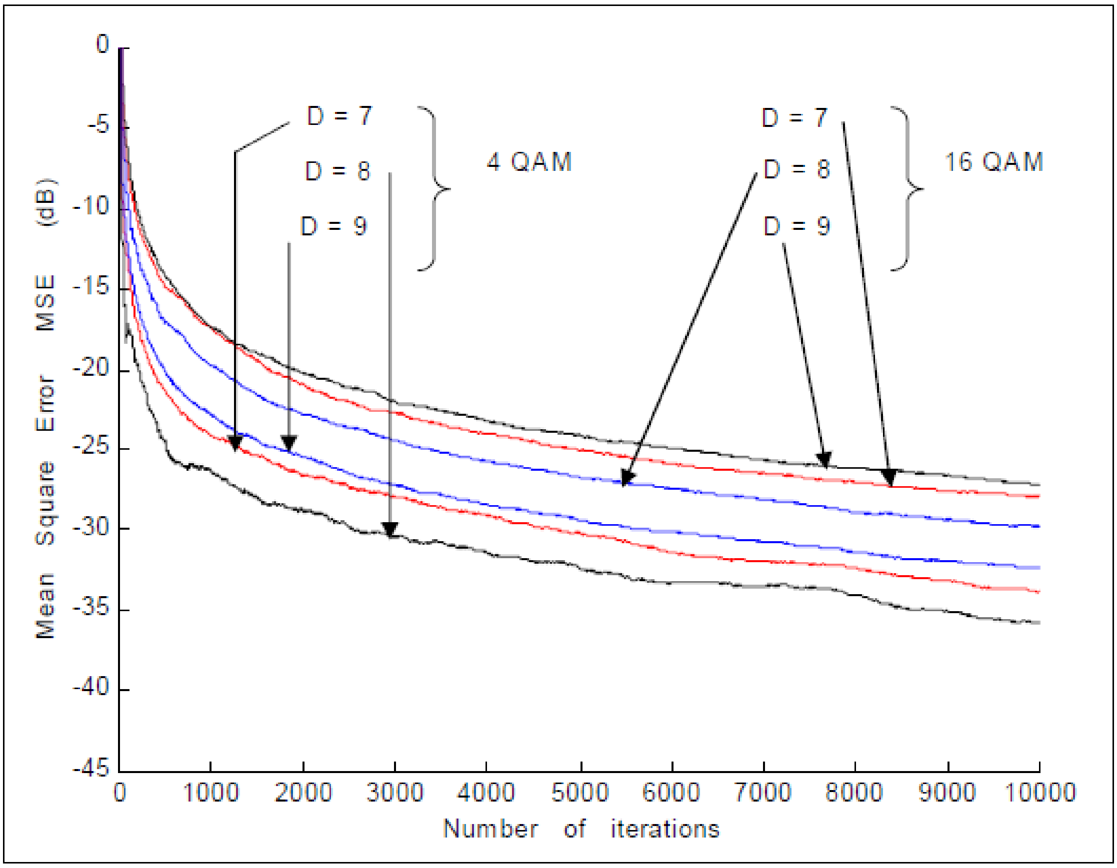

Fig.6. Optimum Step D for Channel Two and SNR=5 dB

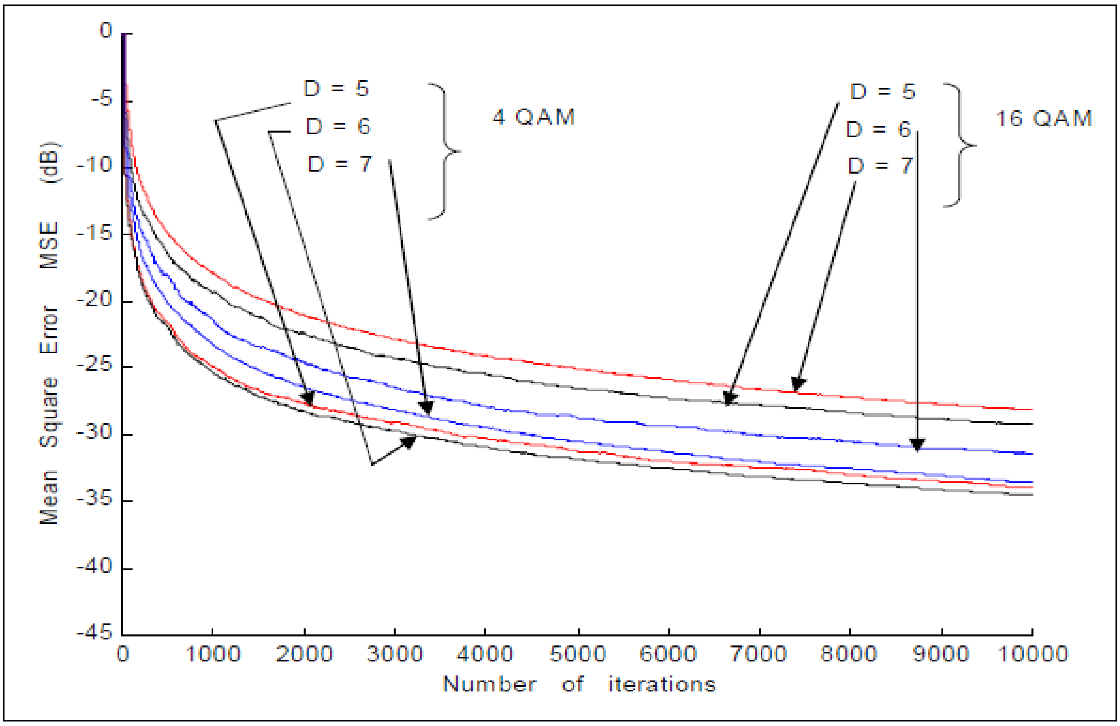

Fig.7. Optimum Step D for Channel Two and SNR=10 dB

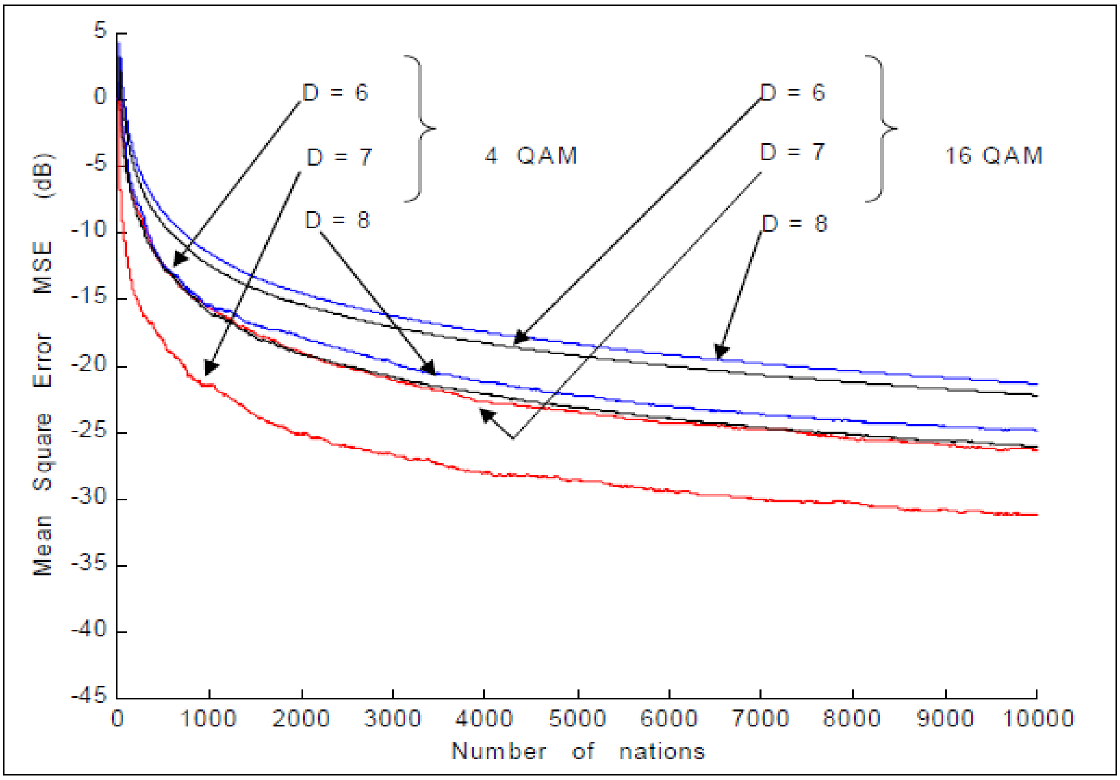

Fig.8. Optimum Step D for Channel Three and SNR=0 dB

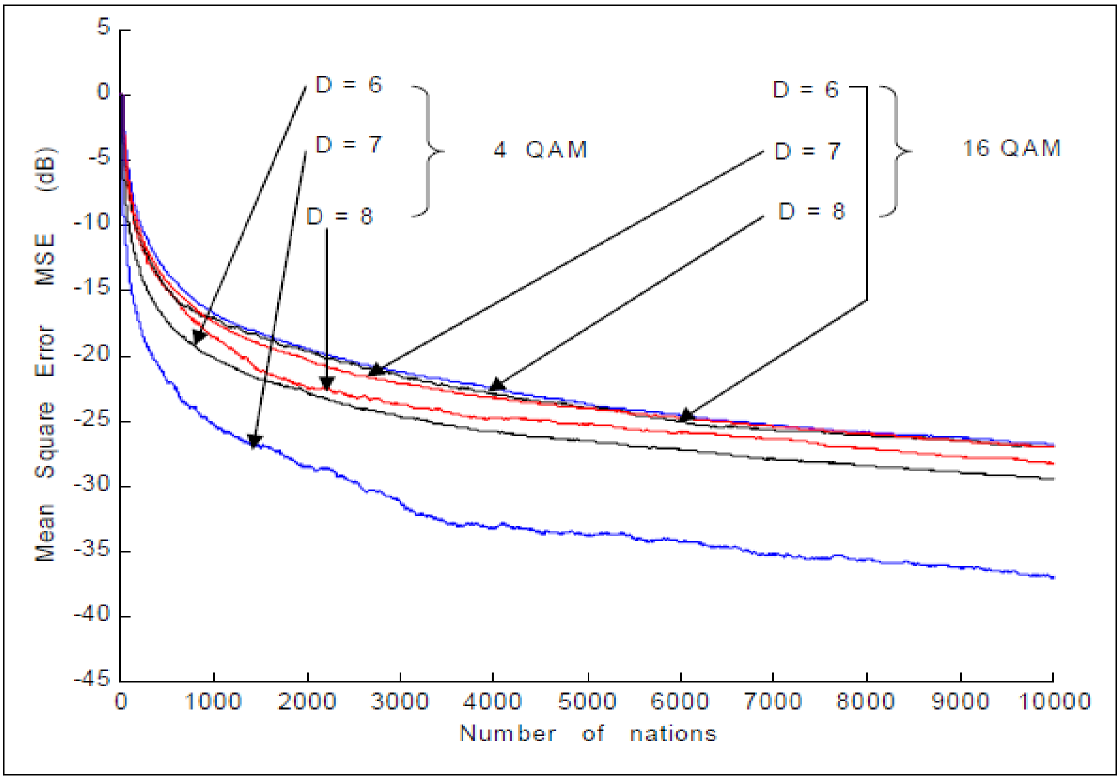

Fig.9. Optimum Step D for Channel Three and SNR=5 dB

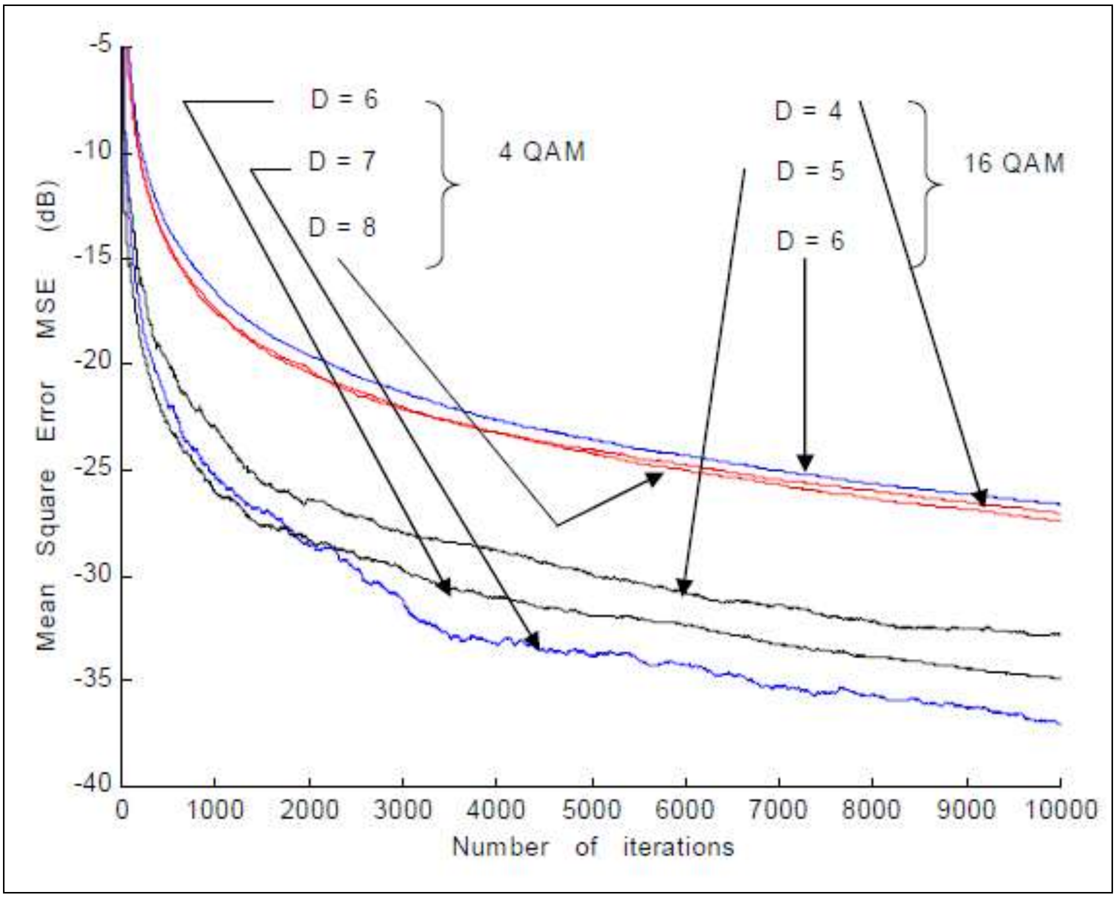

Fig.10. Optimum Step D for Channel Three and SNR=10 dB

Figures (2-10), show the optimum value of D for the three channels as follow:

(a) For SNR = 0 dB,

The optimum value of D is equal (7) for 4 QAM and 16 QAM.

(b) For SNR = 5 dB,

The optimum value of D is (8) for 4 QAM and it is equal (7) for 16 QAM

(c) For SNR = 10 dB,

The optimum value of D is (6) for 4 QAM and it is equal (7) for 16 QAM

From the previous values, it is clear that D is dependent on the SNR and the modulation technique even for the same channel. So optimum **D=7** for **channel one**, optimum **D=8** for **channel two**, and optimum **D=6** for **channel three**. Furthermore, it varies from a channel to the other.

The MSE simulation comparative results for channel two versus the number of iterations (10000) for the CMA , LPEF, MSPEF and CMA_MSPEF are depicted in fig.11 .

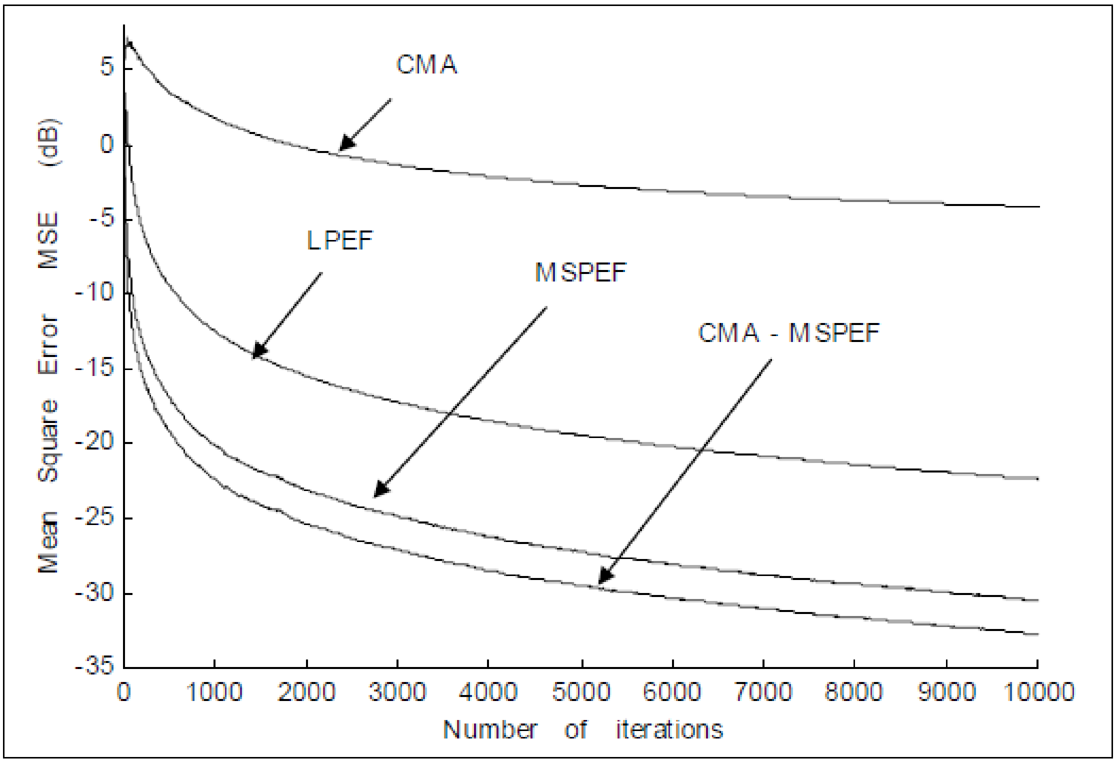

Fig.11. Comparison between CMA, LPEF, MSPEF, and CMA_MSPEF

Figure (11) shows that the proposed algorithm CMA_MSPEF dominates the three algorithms CMA, LPEF, and MSPEF, for channel two, D = 8, 16 QAM, and SNR=10 dB. From this figure, it is clear that MSPEF dominates LPEF and CMA by 14.34 dB and 32.5 dB respectively. Secondly, it indicated that the CMA_MSPEF system overcomes the MSPEF by 2.25 dB.
Figures (12-17) indicate that the CMA_MSPEF system dominates the MSPEF by 5 dB , 5 dB and 2.25 dB for SNR = 0 , 5 and 10 dB respectively for 16-QAM , and by 8 dB , 5 dB and 4 dB for 4-QAM under the same SNR's respectively .

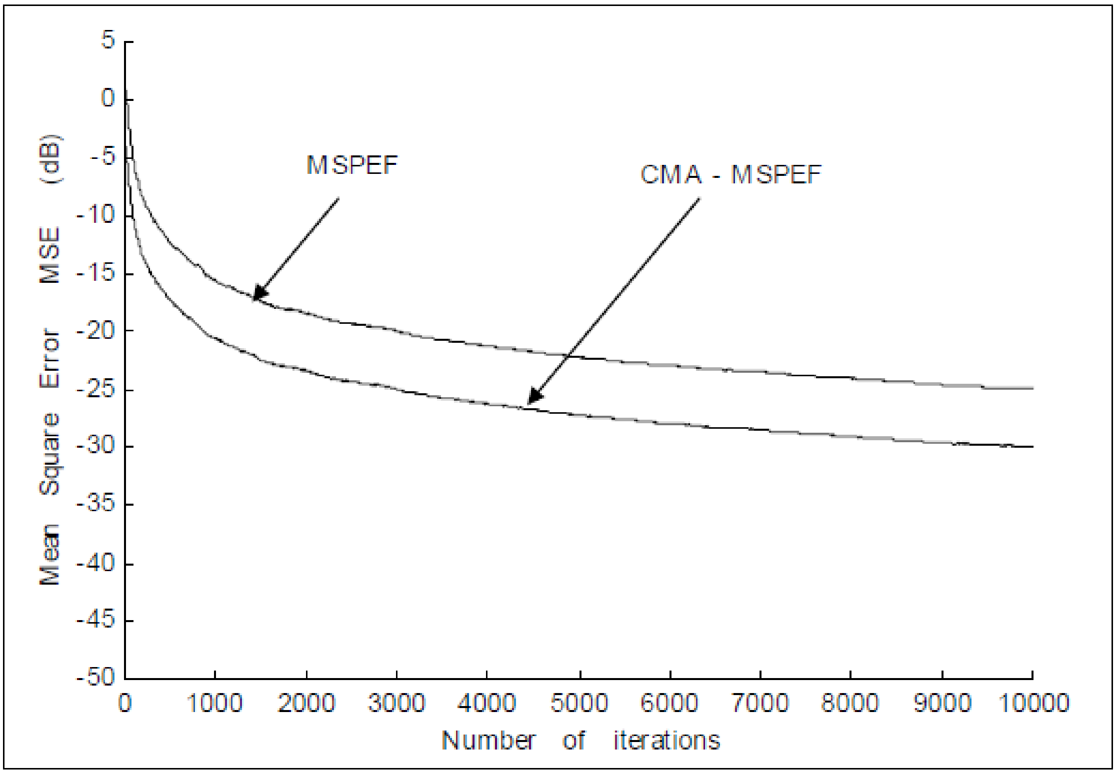

Fig.12. Covergence Curve for MSPEF, and CMA_MSPEF for 16 QAM, and Channel Two , with SNR=0 dB, and D=8.

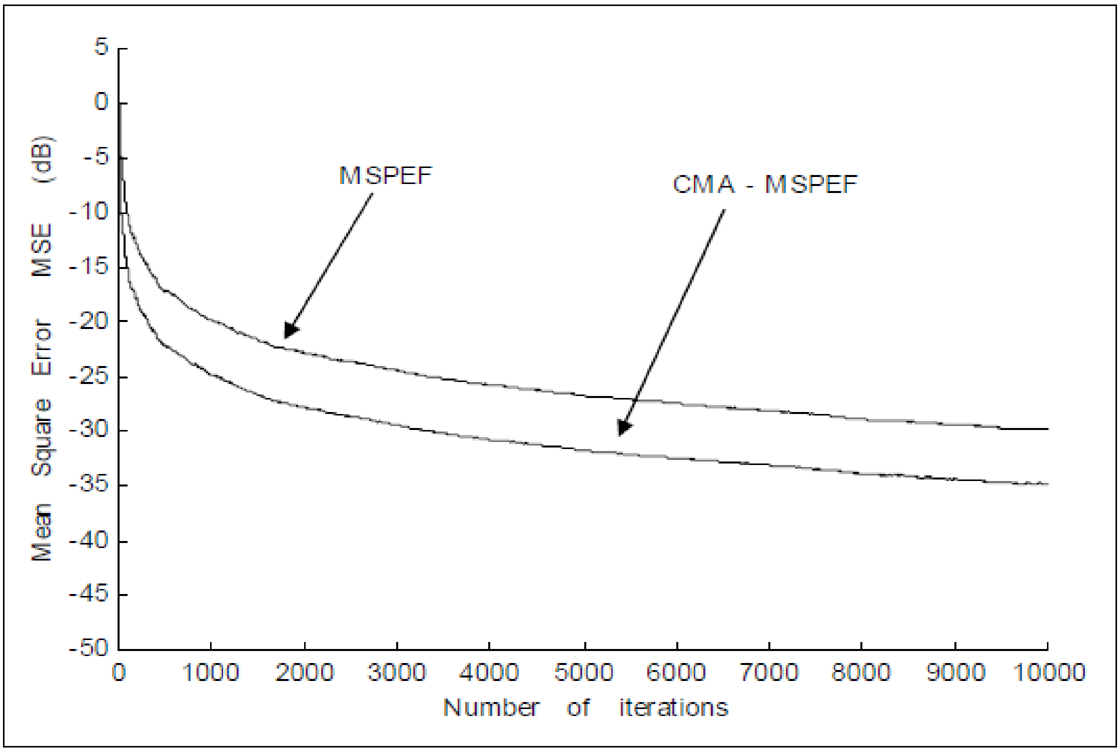

Fig.13. Covergence Curve for MSPEF, and CMA_MSPEF for 16 QAM, and Channel Two , with SNR=5 dB, and D=8.

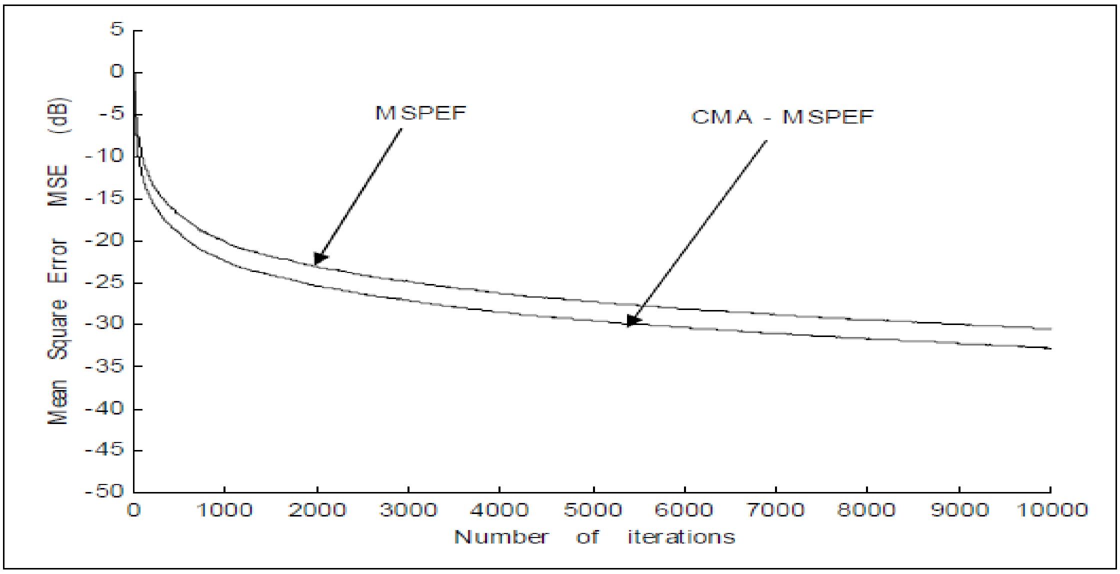

Fig.14. Covergence Curve for MSPEF, and CMA_MSPEF for 16 QAM, and Channel Two , with SNR=10 dB, and D=8.

Also for the same channel, D = 8, 16 QAM, and SNR=0, 5, 10 dB, we notice the figures (12-14) which show that also the proposed algorithm CMA_MSPEF dominates the algorithm MSPEF.

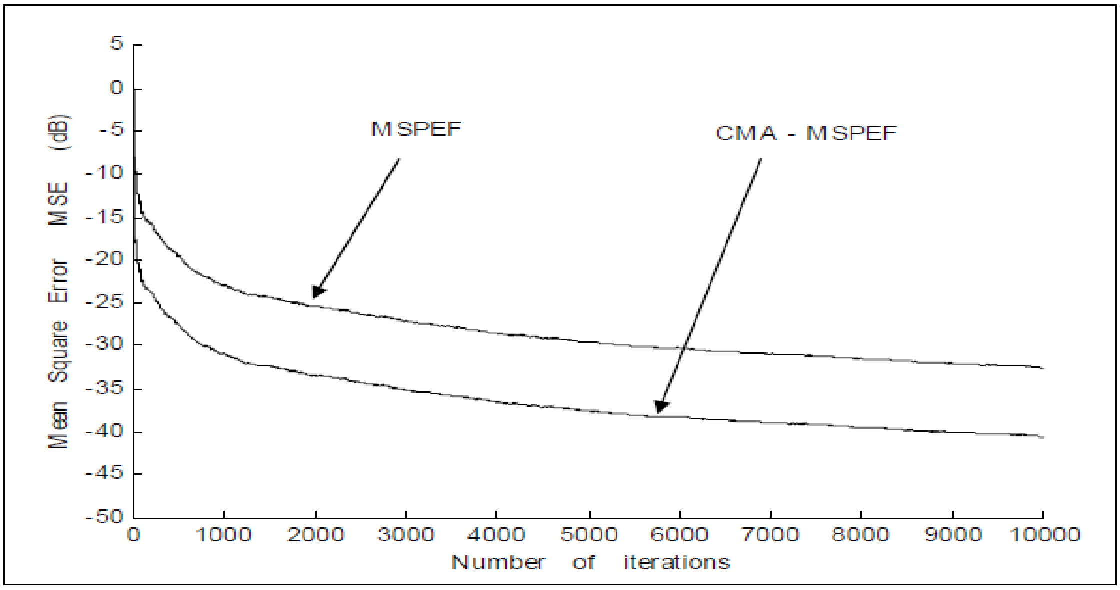

Fig.15. Covergence Curve for MSPEF, and CMA_MSPEF for 4 QAM, and Channel Two , with SNR=0 dB, and D=8.

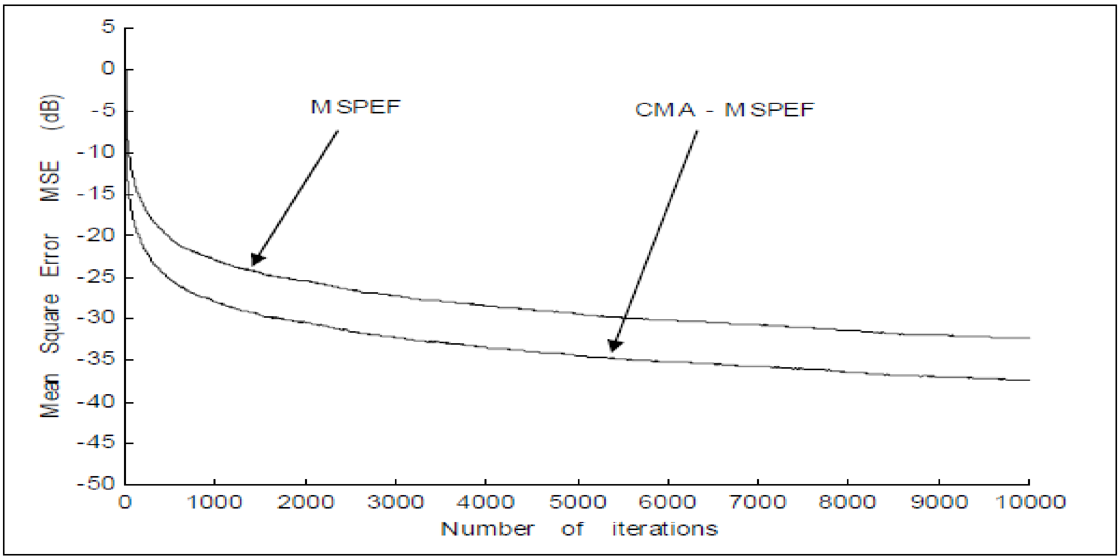

Fig.16. Covergence Curve for MSPEF, and CMA_MSPEF for 4 QAM, and Channel Two , with SNR=5 dB, and D=8.

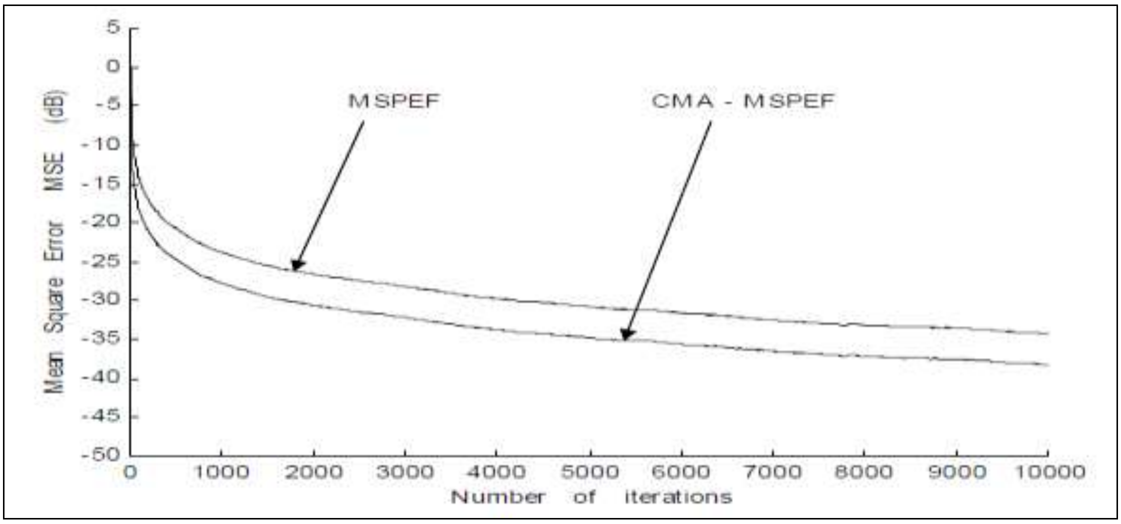

Fig.17. Covergence Curve for MSPEF, and CMA_MSPEF for 4 QAM, and Channel Two , with SNR=10 dB, and D=8.

Figures (15-17), show that the proposed algorithm CMA_MSPEF dominate the algorithm MSPEF for different SNR (0, 5, 10 dB), and D=8 for 4 QAM.

4. Convolution

In this paper, a new CMA_MSPEF blind equalizer which uses two techniques constant modulus algorithm cascaded with multi-step prediction error filter. This algorithm to overcome slow convergence of the conventional equalizers and to test the performance of this algorithm and to extract the optimum step value . It is clear that a cascade of CMA_MSPEF provides good performance. We can conclude that the CMA_MSPEF system is strongly recommended for its appreciable gain in performance when we use the optimum step calculated..

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