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The research of score interval adaptive algorithms based on orthogonal wavelet transform in wireless communication

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ABSTRACT

On the basis of analysis of the orthogonal wavelet transform theory and scores interval often mathematical model algorithm (FSE-CMA), proposed a score interval norm adaptive algorithm (WT-FSE-CMA) based on orthogonal wavelet transform. The algorithm will be introduced to the theory of orthogonal wavelet transform T/2 scores between norm adaptive algorithm, make full use of the wavelet transform to the correlation of the signal, as well as the fractional spaced equalizer for signal sampling properties. With potter, T/2 scores intervals norm adaptive algorithm, the algorithm convergence speed, small steady-state error, equalization effect is better. Finally, use the wireless channel adaptive algorithm simulation results, verify the performance of the algorithm.

KEYWORDS

Score interval;
Orthogonal wavelet transform;
The adaptive;
The wireless channel.

INTRODUCTION

In the wireless communication system, the limited bandwidth and multipath propagation can lead to severe inter-symbol interference (Intel-Symbol Interference, ISI), need to use balancing techniques to eliminate at the receiving end. Compared with the traditional adaptive equalization, adaptive does not require periodic training series, the channel utilization ratio is high, thus is applicable to wireless channel equalization. In the adaptive algorithm, often mathematical model algorithm (Constant Modulus Algorithm, CMA) was widely used because of its simple operation, but the traditional norms of adaptive algorithm based on porter interval (Baud Spaced Equalizer, BSE-CMA) slow convergence speed and steady-state error is big. Adaptive algorithm based on fractional interval norm (Fractional Spaced Equalizer, FSE-CMA), at the receiving end to send yards yuan T (T for potter interval) the rate of the receiving signal sampling, to improve the performance of the algorithm[1], but it did not reduce the equalizer input signal of the correlation, this is one of the most important factors to influence the algorithm convergence speed. The research[2-4] shows: in the adaptive equalization algorithm, through the equalizer's input signal for wavelet transform, and the signal energy normalization processing, can reduce the signal of the correlation, and accelerate the convergence speed of equalization algorithm effectively.

In this paper, using the theory of orthogonal wavelet transform, the score interval often mathematical model adaptive of each sub-channel equalizer input signal for orthogonal wavelet transform, get a score interval norm adaptive algorithm (Wavelet Transform Fractional Spaced Equalizer, WT-FSE-CMA) based on orthogonal wavelet transform. The algorithm of equalizer structure different from the score interval equalizer, in terms of convergence speed and steady-state error of performance, superior to BSE-CMA and FSE-CMA algorithm.

SCORE INTERVAL EQUALIZER

The main idea of scores interval is received signal sampling, thus can get more information more detailed channel. Number of sampling rate model can be equivalent to a single input multiple output's (SIMO) multi channel model[5]. Scores interval (P as an integer) FSE much channel model, as shown in Figure 1.

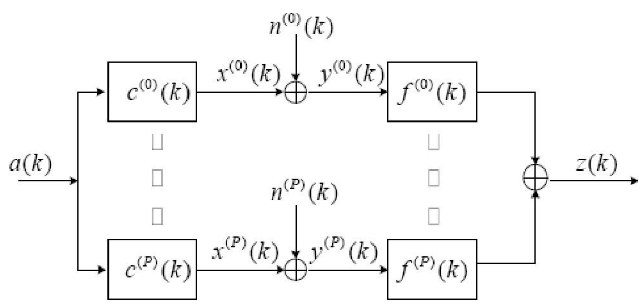


Figure 1 : Single input multiple output channel equilibrium model in discrete time

Set $a(k)$ is symbol length T cycle emission signal sequence, the NO. p sub-channels's $(p=0,1,\cdots,P-1)$ impulse response as:

$$c^{(p)}(k)=c[(k+1)P-p-1] \quad (1)$$

The output of the sub-channels for:

$$y^{(p)}(k)=\sum_{i=0}^{N_c-1} a(i)c^{(p)}(k-i)+n^{(p)}(k) \quad (2)$$

On the formula, N_c shows potter interval sampling of channel impulse response.

Define three vector expressed in baud rate. $\boldsymbol{c}(k)=[c^{(0)}(k)\cdots c^{(P-1)}(k)]^T$, $\boldsymbol{y}(k)=[y^{(0)}(k)\cdots y^{(P-1)}(k)]^T$, $\boldsymbol{n}(k)=[n^{(0)}(k)\cdots n^{(P-1)}(k)]^T$.

In formula, $(\cdot)^T$ shows transpose. At this time, the equalizer's input signal vector isÿ

$$\boldsymbol{y}(k)=\boldsymbol{Ca}(k)+\boldsymbol{n}(k) \quad (3)$$

In the formula(3), $\boldsymbol{C}$ is the channel matrix,and

$$\boldsymbol{C}=\begin{bmatrix} c(0) & c(1) & \cdots & c(N_c-1) & & & \\ & c(0) & c(1) & \cdots & c(N_c-1) & & \\ & & \ddots & \ddots & & \ddots & \\ & & & c(0) & c(1) & \cdots & c(N_c-1) \end{bmatrix}$$

Set the NO. p sub-channels $c^{(p)}$ corresponds to the equalizer and the relationship between the sampling is $f^{(p)}(k)=f(kP-p)$, then the output of the equalizer for:

$$z(k)=\sum_{i=0}^{N_f-1} f^T(i)y(k-i)=\boldsymbol{f}^T\boldsymbol{y}(k) \quad (4)$$

Among them, $\boldsymbol{f}(k)=[f^{(0)}(k)\cdots f^{(P-1)}(k)]^T$. Take formula (3) into formula (4) available:

$$z(k)=\boldsymbol{f}^T[\boldsymbol{Ca}(k)+\boldsymbol{n}(k)]=\boldsymbol{f}^T\boldsymbol{Ca}(k)+\boldsymbol{f}^T\boldsymbol{n}(k)=\boldsymbol{h}^T(k)\boldsymbol{a}(k)+\boldsymbol{v}(k) \quad (5)$$

In formula, $\boldsymbol{h}^T(k)=\boldsymbol{f}^T\boldsymbol{C}$ shows system channel and equalizer of synthetic impulse response, $\boldsymbol{v}(k)=\boldsymbol{f}^T\boldsymbol{n}(k)$ shows the system of output noise.

Set the length of the equalizer for $N_f=2M_f$,the $T/2(P=2)$ score interval equalizer's the output of the signal as:

$$z_f(k)=\sum_{i=0}^{2M_f-1} f(i)y(k-i) \quad (6)$$

If the part of the output of the equalizer sampling to remove,only the odd index sampling $2k+1$, there are:

$$z(k)\triangleq z_f(2k+1)=\sum_{i=0}^{2M_f-1} f(i)y(2k+1-i)$$

$$=\sum_{i=0}^{M_f-1} f^{(0)}(i)y^{(1)}(k-i)+\sum_{i=0}^{M_f-1} f^{(1)}(i)y^{(0)}(k-i) \quad (7)$$

In formula, $f^{(0)}(i)=f(2i)$, $f^{(1)}(i)=f(2i+1)$, $y^{(0)}(i)=y(2i)$, $y^{(1)}(i)=f(2i+1)$. With often mathematical model al-

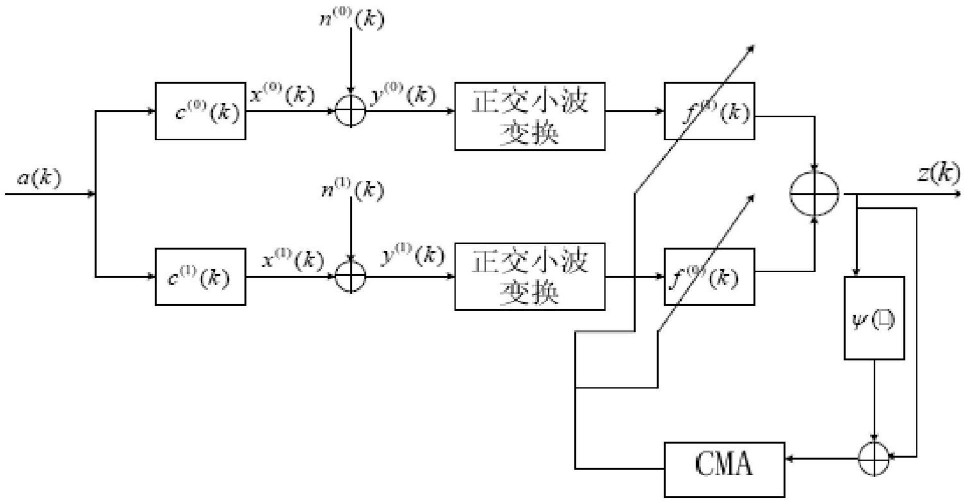


Figure 2 : The algorithm of $T/2$ scores interval adaptive based on orthogonal wavelet transform

gorithm to update $f^{(p)}(k)$, get updated formula as:

$$\boldsymbol{f}^{(p)}(k+1) = \boldsymbol{f}^{(p)}(k) + \mu_p \boldsymbol{y}^*(k)e(k)z(k) \quad \textbf{(8)}$$

In formula,

$$e(k) = R_{CM} - |z(k)|^2 \quad \textbf{(9)}$$

$$z(k) = z^{(0)}(k) + z^{(1)}(k) \quad \textbf{(10)}$$

In formula (7)~(10),constituted often model adaptive algorithm based on $T/2$ scores interval (T/2-FSE-CMA).

SCORE INTERVAL ADAPTIVE ALGORITHM BASED ON ORTHOGONAL WAVELET TRANSFORM

The theory of wavelet analysis shows that when the equalizer finite impulse response for $f(k)$, $f(k)$ can be used to represent a set of orthogonal wavelet basis function. In the fractional spaced equalizer, assuming that each sub-channels equalizer tap number $M_f = 2^J$, under the limited length, the equalizer $f(k)$ can be expressed as:

$$f(k) = \sum_{j=1}^{J}\sum_{m=0}^{k_j} d_{jm}\cdot\phi_{jm}(k) + \sum_{m=0}^{k_j} v_{jm}\cdot\varphi_{jm}(k) \quad \textbf{(11)}$$

In formula, $k = 0,1,\cdots,M_f$, $\phi_{jk}(k)$ and show the wavelet function and scaling function respectively, $k_j = M_f/2^j - 1$. $(j = 1,2,\cdots,J)$, J shows the biggest scale for the wavelet decomposition, d_{jm} and v_{jm} show the equalizer weights. According to the theory of signal transmission, sub-channels equalizer $z(n)$'s output:

$$z(k) = \sum_{i=0}^{M_f-1} f_i(k)\cdot y(k-i) = \sum_{i=0}^{M_f-1} y(k-i)[\sum_{j=1}^{J}\sum_{m=0}^{k_j} d_{jm}\cdot\phi_{jm}(k) + \sum_{m=0}^{k_j} v_{jm}\cdot\varphi_{jm}(k)]$$

$$= \sum_{j=1}^{J}\sum_{m=0}^{k_j} d_{jm}(k)[\sum_{i=0}^{M_f-1} y(k-i)\cdot\phi_{jm}(k)] + \sum_{m=0}^{k_j} v_{jm}(n)[\sum_{i=0}^{M_f-1} y(k-i)\cdot\varphi_{jm}(k)]$$

$$= \sum_{j=1}^{J}\sum_{m=0}^{k_j} d_{jm}(k)\cdot r_{jm}(k) + \sum_{m=0}^{k_j} v_{jm}(k)\cdot s_{jm}(k) \quad \textbf{(12)}$$

The formula shows that introducing the wavelet transform is the essence of the fractional spaced equalizer, the input signal of each sub-channel equalizer orthogonal wavelet transform, changing the structure of the equalizer[6], in the transform domain, after wavelet transform of signal to adjust the equalizer weights. At this point, the algorithm of scores interval principle of $T/2$ adaptive based on orthogonal wavelet transform, as shown in Figure 2.

Length of M_f sub-channel equalizer of the input signal $\boldsymbol{y}(k) = [y_{01}\ \ y_{02}\ \ \cdots\ \ y_{0M_f-1}]^T$. According to the Mallat fast algorithm, if make $\boldsymbol{Q}$ matrix for the orthogonal wavelet transform:

The $\boldsymbol{Q} = [\boldsymbol{G}_0; \boldsymbol{G}_1\boldsymbol{H}_0; \boldsymbol{G}_2\boldsymbol{H}_1\boldsymbol{H}_0; \cdots; \boldsymbol{G}_{J-1}\boldsymbol{H}_{J-2}\cdots\boldsymbol{H}_1\boldsymbol{H}_0; \boldsymbol{H}_{J-1}\boldsymbol{H}_{J-2}\cdots\boldsymbol{H}_1\boldsymbol{H}_0]$

In formula, $\boldsymbol{H}_j$ and $\boldsymbol{G}_j$ is consisting of matrix by the wavelet filter coefficient $h(n)$ and scale filter coefficient $g(n)$ respectively,among of $\boldsymbol{H}_j$ and $\boldsymbol{G}_j$,each of the elements respectively: $H_j(l,k) = h(k-2l)$, $G_j(l,k) = g(k-2l)$, ($l = 1 \sim M_f / 2^{j+1}$, $k = 1 \sim M_f / 2^j$).

Set

$$\boldsymbol{R}(k) = [r_{1,0}(k),\ r_{1,1}(k) \cdots r_{J,k_J}(k),\ s_{J,0}(k),\ \cdots s_{J,k_J}(k)]^T$$

$$,\boldsymbol{W}(k) = [d_{1,0}(k),\ d_{1,1}(k)$$

$$\cdots d_{J,k_J}(k), v_{J,0}(k), \cdots v_{J,k_J}(k)]^T$$

the $\boldsymbol{R}(k) = \boldsymbol{y}(k)\boldsymbol{Q}$ **(13)**

$$z(k) = \boldsymbol{W}^H(k)\boldsymbol{R}(k) \quad \textbf{(14)}$$

At this point, formula (8) into

$$\boldsymbol{W}(k+1) = \boldsymbol{W}(k) + \mu\hat{\boldsymbol{R}}^{-1}(k)e(k)\boldsymbol{R}(k)z(k) \quad \textbf{(15)}$$

In formula, $\hat{\boldsymbol{R}}^{-1}(k) = diag[\sigma_{1,0}^2(k), \sigma_{1,1}^2(k), \cdots, \sigma_{J,k_J-1}^2(k), \sigma_{J+1,0}^2(k), \cdots, \sigma_{J+1,k_J-1}^2(k)]$, the

$$\sigma_{J,n}^2(k+1) = \beta\sigma_{J,n}^2(k) + (1-\beta)\,|\,r_{j,n}(k)\,|^2 \quad \textbf{(16)}$$

$$\sigma_{J+1,n}^2(k+1) = \beta\sigma_{J,n}^2(k) + (1-\beta)\,|\,s_{j,n}(k)\,|^2 \quad \textbf{(17)}$$

In formula, β is forgetting factor. Equalizer of the input signal after the orthogonal wavelet transform, and on the energy normalization process. In order to keep the consistency of each sub-channel equalizer structure, input signal of each sub-channel equalizer using the same wavelet decomposition, and decomposition series is the same. Formula(9), (10), (13)-(17) constitutes the $T/2$ score interval often mathematical model adaptive algorithm based on orthogonal wavelet transform.

PERFORMANCE ANALYSIS

A) Convergence analysis

Score interval equalizer for input and output signals are sampled at a rate of about T/P ($P > 1$), avoids the frequency aliasing caused by undersampling, can effectively compensate the distortion of channel characteristics[5]. After introducing orthogonal wavelet transform, the input signal of each sub-channel equalizer for orthogonal wavelet transform, signal autocorrelation matrix into zonal distribution[6,7], its energy is concentrated near the diagonal, decline since the correlation of the signal, speed up the convergence speed.

B) Computational analysis

Compared with the T/2-FSE-CMA, WT-T/2-FSE-CMA in each weight coefficient iteration process, need to run the point N (N is the length of the equalizer) signal $y(k)$ of orthogonal wavelet transform, has a certain amount of calculation. The wavelet analysis theory shows that the orthogonal wavelet transform $\boldsymbol{Q}$ for $N \times N$ orthogonal matrix. In considering the actual signal length is very long, and the length of the filter is very short, namely $\boldsymbol{Q}$ for sparse matrix. Assume that $\boldsymbol{Q}$ number for each line of the non-zero elements in L ($L \ll N$), the formula (13) the required number of multiplication is LN . Compared with the T/2-FSE-CMA, WT-T/2-FSE-CMA to complete a weights updated, increases the total number of calculation for LN .

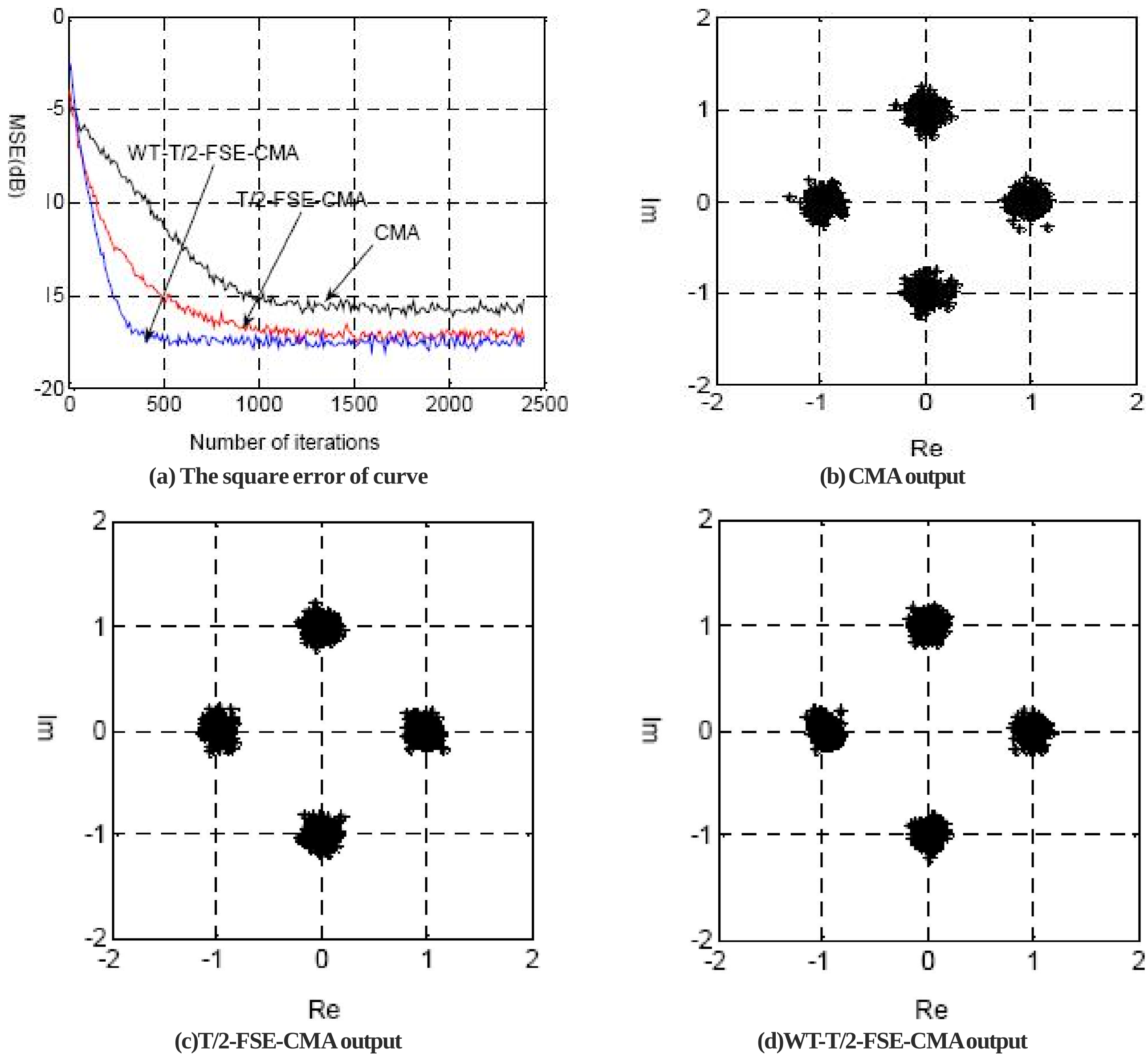
THE SIMULATION RESULTS

To test WT-T/2-FSE-CMA's effectiveness, use the wireless channel simulation experiment, and T/2-FSE-CMA and CMA are compared.

[Experiment 1] The mixed phase wireless channel

Mixed phase wireless channel for $c = [0.3132\ \ -0.1040\ \ 0.8908\ \ 0.3134]$[8]; emission signal for 4PSK ; signal to noise ratio for 20dB ; right of equalizer long is 32; step length $\mu_{\text{WT-T/2-FSE-CMA}} = 0.04$, $\mu_{\text{T/2-FSE-CMA}} = 0.01$, $\mu_{\text{CMA}} = 4.8 \times 10^{-3}$;use the center tap coefficient of initialization; for the input signal of each sub-channels using DB2 orthogonal wavelet decomposition, decomposition level is 3 layers,the power initial value is set to 4,forgetting factor $\beta = 0.999$;500 Monte Carnot simulation, the simulation results is shown in Figure 3.

Figure 3 (a) shows: on the convergence speed, WT-T/2-FSE-CMA algorithm than T/2-FSE- CMA algo-



(a) The square error of curve **(b) CMA output**

(c)T/2-FSE-CMA output **(d)WT-T/2-FSE-CMA output**

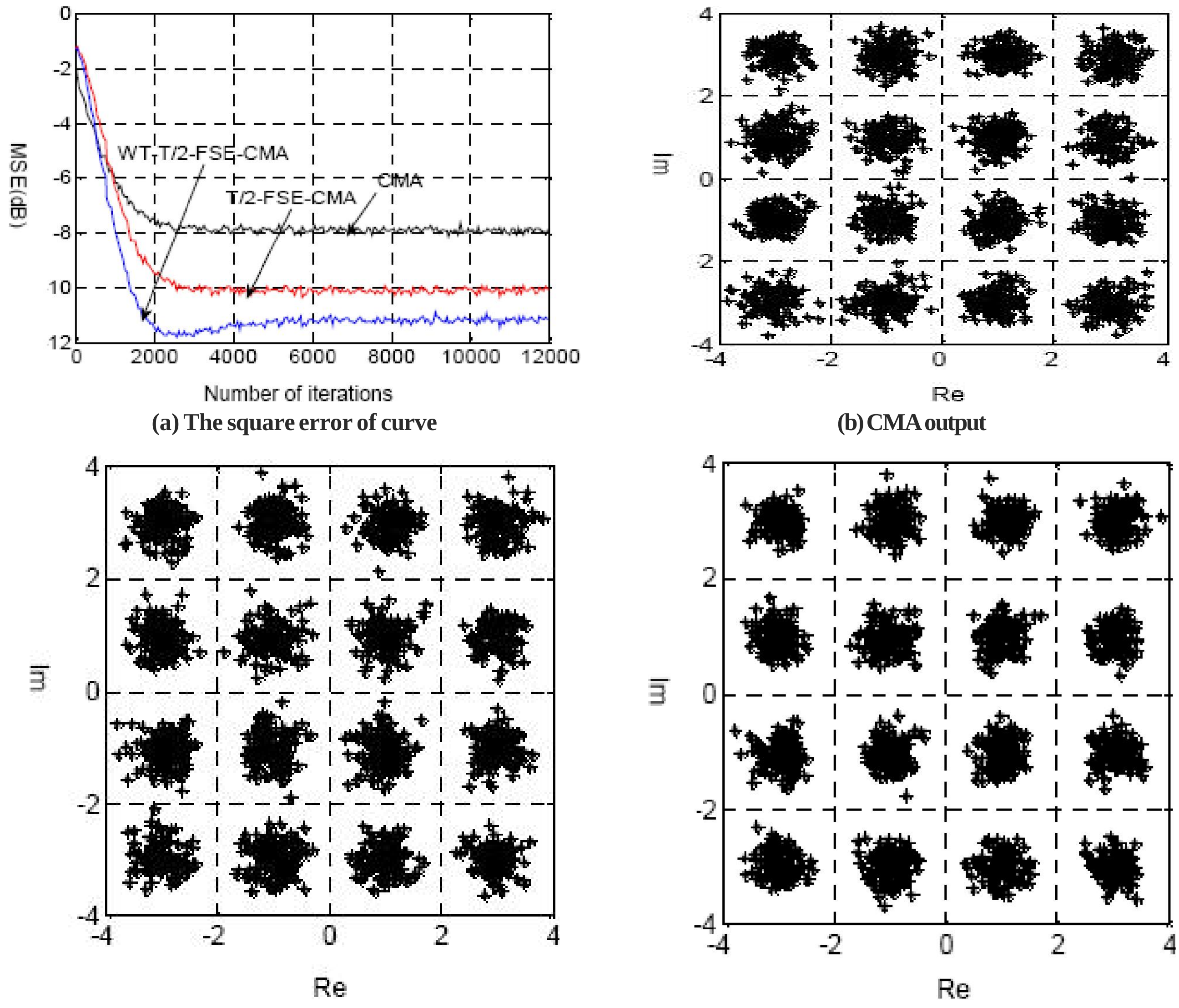
Figure 3 : The results of simulation

rithm and CMA algorithm nearly twice as fast. On the steady-state error, WT-T/2-FSE-CMA algorithm compared with T/2-FSE-CMA algorithm basic same, compared with the CMA algorithm, reduced nearly 2dB. Figure 3 shows: introducing orthogonal wavelet transform into the score interval equalizer, the output eye diagram of the equalizer is more clear and compact.

[Experiment 2] The minimum phase wireless channel

The minimum phase channel for $c = [0.9656\ \ -0.0906\ \ 0.0578\ \ 0.2368]$[8], emission signal for 16QAM signal; signal to noise ratio for 25dB;right of equalizer long is 32; step length $\mu_{\text{WT-T/2-FSE-CMA}} = 1.2\times10^{-3}$, $\mu_{\text{T/2-FSE-CMA}} = 0.7\times10^{-3}$, $\mu_{\text{CMA}} = 2.5\times10^{-5}$; use the center tap coefficient of initialization; for the input signal of each sub-channels using DB2 orthogonal wavelet decomposition, decomposition level is 2 layers,the power initial value is set to 4,forgetting factor $\beta = 0.9999$;2500 Monte Carnot simulation, the simulation results is shown in Figure 4.

Figure 4 (a) shows :on the convergence speed, WT-T/2-FSE-CMA algorithms and T/2-FSE-CMA algorithm and CMA algorithm is basically the same. On the steady-state error, WT-T/2-FSE- CMA algorithm re-



(a) The square error of curve

(b) CMA output

(c) T/2-FSE-CMA output

(d) WT-T/2-FSE-CMA output

Figure 4 : The results of simulation

duced nearly 2dB than CMA algorithm, compared with the T/2-FSE-CMA algorithm, reduced 1dB. Figure 4 showsÿintroducing orthogonal wavelet transform into the score interval equalizer, the output eye diagram of the equalizer is more clear and compact.

CONCLUSION

On the basis of analysis of the orthogonal wavelet transform theory and scores interval equalizer, proposed T/2 scores interval adaptive algorithm based on orthogonal wavelet transform. The algorithm makes full use of the wavelet transform to the correlation of the signal, and combined with the advantages of the score interval equalizer for signal before sampling. The wireless channel simulation results showÿcompared with T/2-FSE-CMA and CMA, the algorithm on the convergence speed and steady-state error has certain improvement, and increase the amount of calculation is not many. Therefore, the algorithm can effectively realize the separation of signal and noise and signal real-time recovery.

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