Research Of The Blind Equalization Technology In The Non-Cooperative Communication Receiving System

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Abstract. Convergence rate and steady-state mean square error are the main parameters to evaluate the performance of blind equalization algorithm. In order to improve the blind equalization performance of non-cooperative communication reception under multipath fading channel, a modified super-exponential iterative blind equalization algorithm is adopted, which converges faster than the traditional constant modulus algorithm and achieves the same steady-state mean square error. Aiming at the MPSK non-cooperative signal with unknown modulation order, a two-mode blind equalization method based on fractional interval is proposed. The method makes full use of the robustness and fast convergence of the super-exponential iterative algorithm, and combines the low steady-state mean square error of the recursive least squares algorithm. The effectiveness of the method is proved by simulation and experiment.

1. Introduction

Under non-cooperative conditions, the receiver cannot know the modulation information such as the symbol rate, carrier frequency, roll-off coefficient and modulation mode of the received signal in advance. In order to complete the correct demodulation of the signal, blind signal processing technology is needed to estimate and extract the information parameters of the received signal. Blind equalization is an effective means for combating channel distortion and eliminating inter-symbol interference in digital communication in the case where the transmitted signal and channel characteristics are unknown. Therefore, blind equalization technology is one of the key technologies for blind demodulation of signals in non-cooperative communication receiving systems.[1]

Constant Modulus Algorithm (CMA) is usually used for blind equalization of MPSK modulated signals.[2-3]. The algorithm has a simple structure, and does not need to know the signal modulation order in advance, and can be used when the inter-symbol interference is serious, and the performance is stable. However, the convergence speed of the algorithm is slower and the error is larger after convergence. Aiming at the contradiction between equalizer convergence speed and stability, the literature [4-5] proposed a super-exponential iteration (SEI) blind equalization algorithm. Compared with the traditional steepest descent method, in any condition the super-exponential iterative algorithm can converge faster to the desired response solution. But the SEI algorithm is blind to the phase. When there is a carrier phase residual, the remaining phase fluctuations cause the equalizer output constellation to rotate, affecting subsequent blind demodulation. In [6-7], a modified Super-Exponential Iterative (MSEI) algorithm is proposed, which corrects the error control signal by correcting the real and imaginary parts of the equalizer output, thus correcting the carrier. The phase rotates, but the convergence residual error is still large. Based on Decision Directed (DD), the Recursive Least Square (RLS) blind equalization algorithm has a faster convergence speed and less...
convergence residual error, which is beneficial to subsequent demodulation processing. However, the premise of implementing the algorithm is that carrier synchronization and frame synchronization have been completed, and the modulation order of the MPSK signal is known. For non-cooperative signals, the traditional carrier-based and frame-synchronization methods that rely on the training sequence cannot be used. The characteristics of the power spectrum of the MPSK signal can be used to perform nonlinear transformation to estimate the carrier frequency offset and the frame start position. However, the premise of using this method is also to require a known modulation order M. When the inter-symbol interference is serious, it is very difficult to accurately identify the modulation order of the non-cooperative signal. Aiming at this problem, this paper proposes a two-mode blind equalization method based on Fractionally-Spaced Equalizer (FSE) MSEI-FSE-CMA and FSE-RLS, which can solve MPSK non-cooperative signals with unknown modulation order, effectively equalize and lay the foundation for blind demodulation.

2. System baseband equivalent model
The algorithm baseband equivalent model is shown in Figure 1. In the figure, \( s(k) \) is an independent and identically distributed transmit signal sequence belonging to the MPSK finite symbol set, \( n(k) \) is additive white Gaussian noise, \( h(k) \) is the impulse response of the baseband channel, \( w(k) \) represents the equalizer tap weight coefficient vector, \( e(k) \) is the decision leading error term, \( x(k) \) indicates the equalizer input vector, \( y(k) \) is the equalizer output, \( \hat{s}(k) \) represents the estimate of the source symbol after the quantization decision.

![Figure 1 Baseband equivalent model block diagram](image)

3. Research on Dual Mode Blind Equalization Method
3.1 Traditional constant mode blind equalization algorithm
When the known signal modulation mode is MPSK, the traditional constant modulus algorithm can be used for blind equalization.

The transversal filter output is:

\[
y(k) = x^T(k)w(k-1)
\]

The error function \( e(k) \) can be expressed as:

\[
e(k) = y(k)\left(R_2 - |y(k)|^2\right)
\]

\( R_2 \) is the high-order statistical property modulus of the transmitted signal, defined as:

\[
R_2 = \frac{E[|s(k)|^4]}{E[|s(k)|^2]}\]
For MPSK signals, $R_2 = 1$, so
\[
e(k) = y(k)(1 - |y(k)|^2)
\] (4)

The iterative equation of the tap weight vector is:
\[
w(k) = w(k-1) + \mu x^*(k)e(k)
\] (5)

In the above formula, $\mu$ is the iteration step size.

3.2 Constant Modulus Blind Equalization Algorithm Based on Modified SEI

In [4], the super-exponential iteration (SEI) algorithm is derived from the super-exponential algorithm. The SEI algorithm is a constant-mode algorithm based on high-order statistics. Similar to the classical constant-mode algorithm, it uses the square of the modulus of the equalizer output and the minimum mean square error of the fourth-order statistic as the design criterion to obtain optimum coefficients of equalizer. However, in the iterative process of the equalizer tap coefficients, the SEI algorithm introduces the inverse matrix $Q$ of the input signal autocorrelation matrix, which can optimize the iterative step size and whiten the equalizer input signal, which makes the algorithm have faster convergence speed than the traditional constant modulus algorithm. The iterative expression of the equalizer tap coefficients is as follows:
\[
w(k) = w(k-1) + \mu Q(k-1)x^*(k)e_M(k)
\] (6)

The iterative formula for the inverse matrix $Q$ is as follows:
\[
Q(k) = \frac{1}{1 - \mu} \left[ Q(k-1) - \frac{\mu Q(k-1)x^*(k)x(k)Q(k-1)}{1 - \mu + \mu x^T(k)Q(k-1)x(k)} \right]
\] (7)

A modified super-exponential iteration (MSEI) algorithm can be obtained by nonlinearly transforming the real and imaginary parts of the equalizer output respectively. The form of the error is as follows:
\[
e_M(k) = \text{Re}[y(k)](R_{2R} - \text{Re}^2[y(k)]) + j \text{Im}[y(k)](R_{2I} - \text{Im}^2[y(k)])
\] (8)

In the formula:
\[
R_{2R} = \frac{E[\text{Re}[s(k)]^4]}{E[\text{Re}[s(k)]^2]}, \quad R_{2I} = \frac{E[\text{Im}[s(k)]^4]}{E[\text{Im}[s(k)]^2]}
\] (9)

Representing the modulus values obtained for the real and imaginary parts, respectively. Since the control error signal contains not only amplitude information but also phase information, the MSEI algorithm is no longer blind to the phase and can correct the carrier phase rotation introduced by the channel.

3.3 Recursive least squares blind equalization algorithm

When the modulation order of the MPSK signal is known, carrier synchronization and frame synchronization are completed, the recursive least squares algorithm is used for blind equalization. The calculation steps are as follows:

Calculate the output:
\[
y(k) = x^T(k)w(k-1)
\] (10)

Then estimate the error:
\[
e(k) = \hat{s}(k) - y(k)
\] (11)

Calculate the Kalman gain vector:
\[
G(k) = \frac{D(k-1)x^T(k)}{\lambda + x^T(k)D(k-1)x^T(k)}
\]

Update the inverse of the correlation matrix:
\[
D(k) = \frac{1}{\lambda} \left[ D(k-1) - G(k)x^T(k)D(k-1) \right]
\]

Adjust the filter tap weight vector:
\[
w(k) = w(k-1) + G(k)e(k)
\]

In the above formula, \( \lambda \) is a forgetting factor, and the value ranges from 0.8 to 1.

3.4 MSEI-FSE-CMA and FSE-RLS dual mode blind equalization method

The literature [8-9] pointed out that the fractional interval equalizer (FSE) has the characteristics of being insensitive to the timing phase error. With FSE, timing recovery and channel equalization can be realized at the same time, which greatly simplifies the processing of timing synchronization. The MSEI-FSE-CMA blind equalization algorithm has stable performance and fast convergence speed, but the convergence residual error is large. The FSE-RLS algorithm has faster convergence speed and less convergence residual error, but requires knowing the modulation order of the MPSK signal. Then completes carrier synchronization and frame synchronization.

In view of the above problems, this paper designs a dual mode blind equalization method, as shown in Figure 2. Firstly, the received signal is preprocessed to realize coarse carrier synchronization and oversampling. The preprocessed signal also has a certain frequency offset and phase offset. Then the coarse equalization is realized by the MSEI fractional interval equalizer with robust performance, and the characteristics of the power spectrum of the MPSK signal are used to estimate the carrier frequency offset by nonlinear transformation, and the carrier synchronization and frame synchronization are performed. Finally, the DD-based RLS fractional interval equalizer is used to achieve blind equalization.
Carrier coarse synchronization and Oversampling

MSEI-FSE-CMA blind equalization

Is the MPSK modulation order known?

Yes

MPSK modulation order identification

No

Carrier and frame synchronization

FSE-RLS blind equalization

Blind demodulation

Figure 2 Dual mode blind equalization method

4. Simulation and actual signal analysis

In order to simulate and verify the performance of three different blind equalization algorithms, CMA, MSEI-FSE-CMA and FSE-RLS, simulation verification comparison is carried out for 8PSK signals. Set the symbol length to 3000, the symbol rate to 2400 baud/s, and the sampling rate to 9600 sps. Use a radio complex channel with Doppler phase rotation \([-0.005-0.004j 0.009+0.030j -0.024-0.104j 0.854+0.520j -0.218+0.273j 0.049-0.074j -0.016+0.020j]\). The 8PSK signal-to-noise ratio is 13 dB, the equalizer length is 8, the CMA iteration step is 0.002, the RLS forgetting factor is 0.99, and the 1000 square Monte Carlo simulation plots the mean square error curve as shown in Figure 3.
The simulation results in Fig. 3 show that as the number of iterations increases, the mean square error of the signals obtained by different algorithms is gradually reduced. Among them, the convergence speed of MSEI-FSE-CMA and FSE-RLS algorithm is faster, MSEI-FSE-CMA is equivalent to the steady-state mean square error of conventional CMA algorithm, and the steady-state mean square error of FSE-RLS algorithm is significantly smaller than other two algorithms.

In order to further verify the effectiveness of the dual-mode blind equalization method for shortwave non-cooperative mining signals, a short-wave 8PSK signal collected from the field of Cang-long Island in Jiang-xia District of Wuhan City for blind equalization processing. The signal is a USB-modulated single-sideband digital signal with a symbol rate of 2400 baud/s, a sampling rate of 9600 sps, and a signal-to-noise ratio of approximately 14 dB. The signal is equalized by the dual mode blind equalization method, and the equalizer parameter setting is the same as the simulation. The constellation comparison before and after the equalization is shown in Figure 4.
It can be seen from Fig. 4 that the received signal constellation is mixed into a group, and there is serious inter-symbol interference. After adopting the dual-mode blind equalization method proposed in this paper, the signal convergence can be obtained to obtain a clear constellation.

5. Conclusion
Aiming at the blind equalization problem in non-cooperative communication receiving systems, this paper proposes a dual-mode blind equalization method based on fractional interval MSEI-FSE-CMA and FSE-RLS. The method is for MPSK non-cooperative signals with unknown modulation order. Firstly, the MSEI-FSE-CMA algorithm with robust performance is used to realize coarse equalization, and the modulation order and frequency offset are estimated. Then, the FSE-RLS algorithm with fast convergence rate and small steady-state mean square error is used to achieve the final blind equalization, and the convergence is clear. The constellation map lays the foundation for blind demodulation with low bit error rate. The effectiveness of the proposed method is verified by simulation and real-time signal processing.

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