Chapter 4
Nonlinear Equalization with Symbol Error Aided in Beidou Satellite Navigation Communication System

Chengkai Tang, Baowang Lian and Yi Zhang

Abstract With consider of nonlinear interference in Beidou satellite channel and the higher transmission frequency is adopted in Beidou satellite system, the traditional equalization cannot satisfy the requirement. This paper proposed a novel nonlinear blind equalization algorithm. The algorithm utilizes the third-order Volterra model to obtain the revised nonlinear error by symbol error. Then the parameters of equalization are updated by the revised nonlinear error to track the model of satellite channel and remove the nonlinear interference. The simulation result shows that our proposed nonlinear equalization have lower symbol error ratio and quicker convergence speed than the neural network blind equalization algorithm and channel detection aided equalization algorithm and has a good application value in the field of engineering.

Keywords Beidou · Nonlinear interference · Symbol error aided · Blind equalization

4.1 Introduction

With development of Beidou satellite navigation communication system both in military and commercial field. The inter-symbol interference (ISI) and inter-channel interference (ICI) become larger due to the high order modulation techniques were utilized in Beidou satellite navigation communication system [1]. The distortion of

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amplitude and phase caused by ISI and ICI will degraded the communication performance of Beidou satellite navigation communication system [2]. Specially, the inter satellite channel have the nonlinear feature which produced nonlinear interference. The nonlinear ISI and ICI which combined the nonlinear interference and ISI or ICI is further increasing the difficulty of decoding. How to degrade the nonlinear ISI and nonlinear ICI is hot point in research of Beidou satellite navigation communication system [3].

The equalization is the most effective method to remove the nonlinear interference in current techniques. The traditional equalization utilizes the feature of satellite communication channel to compensate ISI and ICI. The equalization is divided into the self-adaptive trained equalization algorithm and self-adaptive blind equalization algorithm. The self-adaptive trained equalization algorithm require the transmitter send a series symbols which are known by receiver of satellite and train the equalization by them. This algorithm has higher accuracy because the training symbol is perfect correct. But the training time which is built the equalization will waste the satellite communication time and the equalization need be trained in every link establishment. The self-adaptive blind equalization algorithm utilized the seeker symbol to update the parameter of equalization in small range and adjust the parameter by data symbol.

Literature [4] proposed a self-adaptive blind equalization with minimum mean square error standard. Literature [5] proposed a self-adaptive blind equalization with recursive least squares standard. Both algorithms of [4, 5] are convenient to realize and the receiver of satellite didn't need the known signal to train the parameters of equalization. But both algorithms can't abate nonlinear ISI and ICI and are unsuitable for the satellite communication. Literature [6] proposed a neural network blind equalization algorithm which cans fully approximation for all of nonlinear satellite channel by the construction of multilayer neural network. But the neuron of neural network will produce small fluctuation error near zero due to the minimum interval of neuron's value. Literature [7] proposed a multimode blind equalization algorithm, the algorithm build an aim function which constructed by many kinds of values. The algorithm is convenient to implement and has better robustness. But the slower convergence is the main drawback of this algorithm. Literature [8] proposed a channel detection aided equalization algorithm. The algorithm utilizes maximum likelihood estimation, Bias estimation and the minimum error probability criterion estimation to detect satellite channel and decoding directly. But the error will enlarge by the decoding methods, so it is also unsuitable for satellite communication.

In view of the above equalization algorithms have higher calculation complexity, lower convergence speed and weak ability of nonlinear interference reducing [9]. But the satellite channel of Beidou satellite navigation communication system has obvious nonlinear characteristics and the distance of satellite channel is far away than the wireless communication channel [10]. It means every communication time of the satellite link is limited due to the satellite is moving, so keeping the convergence speed of equalization parameter quickly to save the time of equalization establishing [11]. In this paper, we proposed a symbol error revised nonlinear blind equalization algorithm. In Beidou satellite navigation communication system, the channel mainly has nonlinear feature and memory feature. Memory feature is close to multipath interference but is different from multipath interference. The multipath interference signal didn't overstep the main signal. Our proposed algorithm utilize the decision symbol to establish the nonlinear revised error based on the third-order Volterra model, then update the parameters of blind equalization by revised error. The construction of blind equalization just have feedback module due to the memory of satellite channel. Our proposed algorithm can degrade nonlinear ISI and ICI quickly and has the advantages of accurate, stable and efficient in Beidou satellite navigation communication system.

4.2 System Model

In Beidou satellite navigation communication system, the modulation of transmitter signal and coding rule are certain [12], but the satellite channel will change due to the environment alter. So we focus on the blind equalization of receiver to degrade nonlinear ISI and ICI form the satellite channel. In this paper, the blind equalization system model is shown on Fig. 4.1.

In Fig. 4.1, $y(n)$ represents receiver's signal which pass by the match filter and downsample to remove out of band interference. $s(n)$ represents the interference signal which produced by blind equalization. $r(n)$ represents the interference cancelation signal which is processed by blind equalization. $w_1, w_2, \ldots, w_{N_b-1}, w_{N_b}$ represent the parameters of blind equalization, N_b represents the length of feedback module, $\hat{X}(n)$ represents the decision symbol, n is sample time.

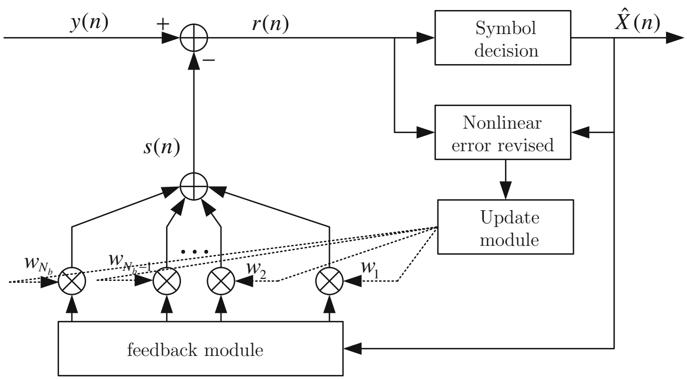


Fig. 4.1 The blind equalization system model

4.3 Blind Equalization Algorithm

We utilized the feedback module to obtain the current decision symbol and delay decision symbol, then multiply the parameters of blind equalization respectively and accumulate all of results to get the interference signal $s(n)$ as follow:

$$s(n) = \sum_{j=1}^{N_b} w_j \hat{X}(n-j) \tag{4.1}$$

The interference cancelation signal $r(n)$ can be obtained by signal $y(n)$ subtract the interference signal $s(n)$.

$$r(n) = y(n) - s(n) \tag{4.2}$$

Then the interference cancelation signal $r(n)$ though the symbol decision module to obtain the decision symbol $\hat{X}(n)$. The decision rule adopts the minimum distance criterion.

$$\begin{aligned} \hat{X}(n) &= \arg\min_{X(n)}(|r(n) - X(n)|) \\ X(n) &\in C \end{aligned} \tag{4.3}$$

C represents the data symbol set. The current error is obtained from the interference signal $r(n)$ and decision symbol $\hat{X}(n)$ as follow:

$$e(n) = r(n) - \hat{X}(n) \tag{4.4}$$

4.4 Nonlinear Error Revised Model

Multiple amplitude and multiple phase modulation will be widely applied in Beidou satellite navigation communication system and other satellite communication system. In order to simplify the calculation, the error is complex number. Due to the satellite channel have nonlinear feature, so we should establish the nonlinear error model. The mainly nonlinear model includes the memory polynomial model and Volterra model. Volterra model is greater adaptation and higher accuracy. With large enough order of Volterra model, it can eliminate all kinds of nonlinear interference, and it is superior in the precision than memory polynomial model. Truncate of the Volterra filter model at a certain length derived by the required accuracy will ensure the fast signal pre-distortion. Volterra series are memory expansion of Tyler series, and it can be written as

$$z(t) = \sum_{k=0}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} g_k(\tau_1, \tau_2, \ldots, \tau_k) \prod_{i=1}^{k} [v(t-\tau_i)d\tau_i] \tag{4.5}$$

where $g_k(\tau_1, \tau_2, \ldots, \tau_k)$ is the kth order continual Volterra kernel. $v(t)$ represents the input signal of Volterra model, $z(t)$ represents the output signal of Volterra model. And τ_{k} is the corresponding delay at the kth time slot. Equation (4.4) represents the continual time domain and it's hard to achieve in practice, so we rewritten the Eq. (4.4) in discrete domain as follow:

$$z(n) = \sum_{k=0}^{(P-1)/2} \sum \cdots \sum g_k(m)|v(n)|^{2k} v(n-m) \tag{4.6}$$

where $z(n)$ and $v(n)$ represent the discrete input and output of Volterra model respectively, and $g_k(m)$ is the discrete Volterra Kernel, P denotes the nonlinear order. Beidou satellite navigation communication system will focus on wide-band and high-frequency data transmission, so the equalization requires higher coefficients updating speed. The truncated Volterra model also can track the nonlinear feature of satellite channel, so we utilize the error and third-order Volterra model to establish the symbol error revised model as follow:

$$\begin{aligned} z(n) = & \sum_{m=-M}^{M} g_1(m)v(n-m) \\ & + \sum_{m=-M}^{M} \sum_{i=-M}^{M} \sum_{j=-M}^{M} g_3(m,i,j)v(n-m)v^*(n-i)v(n-j) \end{aligned} \tag{4.7}$$

where $2M+1$ denotes the memory length. $g_1(m)$ represents the first-order Volterra kernel and $g_3(m,i,j)$ represents the third-order Volterra kernel. m is the corresponding delay. M represents the length of delay. The first-order part describes the linear interference and the third-order part describes the nonlinear interference. The value of kernels adopts the decrease model based on literature [2] which describe the memory effect of different kernel.

$$g_1(m) = 1/2^{|m|} \tag{4.8}$$

$$g_3(m,i,j) = 1/2^{|m|+|i|+|j|} \tag{4.9}$$

Then we obtained the nonlinear error revised model as follow:

$$\begin{aligned} \hat{e}(n) = & \sum_{m=-M}^{M} g_1(m)e(n-m) \\ & + \sum_{m=-M}^{M} \sum_{i=-M}^{M} \sum_{j=-M}^{M} g_3(m,i,j)e(n-m)e^*(n-i)e(n-j) \end{aligned} \tag{4.10}$$

$\hat{e}(n)$ represents the revised nonlinear error.

In Beidou satellite navigation communication system, communication transmission speed mainly depends on the equalization parameter updating speed. So we adopt the current sampling time of received signal instead of the vector of received signal to save the computation. The minimum mean square error (MMSE) is adopted to build the different value function $\Delta(n)$ as follow:

$$\Delta(n) = \frac{\partial[\hat{e}^2(n)]}{\partial w(n)} = -\hat{e}(n)\hat{X}^*(n) \tag{4.11}$$

where, the $\hat{X}^*(n)$ represents the Conjugate signal of decision symbol $\hat{X}(n)$. The parameter updating function of equalization is obtained as follow:

$$w_i(n) = w_i(n-1) + \mu\hat{e}(n)\hat{X}^*(n) \tag{4.12}$$

where, μ represents the convergence factor and the range of it is from 0 to 1. The larger value of μ will accelerate convergence speed of equalization but the fluctuation of error is larger. The smaller value of μ will produce the little fluctuation of error but the convergence speed is slower. So we set the value is 10^{-2} in this paper.

4.5 Simulation and Analysis

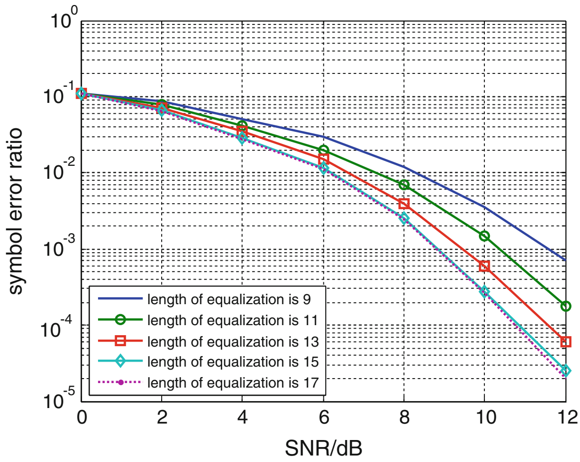
In Beidou satellite navigation communication system, the signal modulations include BPSK, QPSK, BOC, AltBOC and so on. The QPSK have good transmission feature and be utilized in this paper. The pulse shaping filter and match filter both adopt 64 samples (or 8 symbols). The roll off factor of filter is 0.25. The training symbol length is 10^5 and the transmitted symbol length is 10^7.

4.5.1 Symbol Error Ratio

We first treat the case of symbol error ratio. The length of equalization has larger effect on the symbol error ratio (SER). So the different lengths of equalization were adopted to test the performance and result is shown on Fig. 4.2.

Form Fig. 4.2 we can see, the length of equalization become longer, the performance of SER is better. The reason is that longer equalization will cover the more nonlinear ISI and ICI. But the SER curve of length of equalization is 15 and the SER curve of length of equalization is 17 are close to each other. The result indicates the length is 15 can cover most of nonlinear ISI and ICI, so we adopt the length of equalization is 15 in the later simulation.

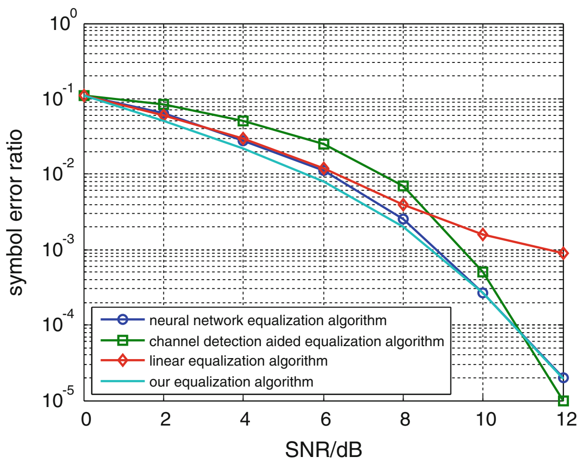
Fig. 4.2 SER curve with different length of equalization



The performance of our blind nonlinear equalization algorithm compare with the neural network blind equalization algorithm was proposed by literature [6], channel detection aided equalization algorithm was proposed by literature [8] and linear equalization algorithm. The results of the comparison can be seen as Fig. 4.3.

Form the Fig. 4.3 we can see, the linear equalization algorithm have a higher error floor due to the nonlinear ISI and ICI are remained in satellite channel. The channel detection aided equalization algorithm is mainly effected by channel parameter accuracy of satellite channel estimation. So when the SNR is lower, the performance of channel detection aided equalization is bad, for example, the SNR is 8 dB, the SER is about 7×10^{-3} and is higher than the other nonlinear equalization.

Fig. 4.3 SER curve with different equalization algorithm



When the SNR is higher, the performance of channel detection aided equalization is better than other nonlinear equalization, for example, the SER is close to 10^{-5} with the SNR is 12 dB. Our equalization algorithm is better than network blind equalization algorithm. When the SER is 10^{-3}, the SNR of both algorithms are 8.5 dB. It means our proposed algorithm can remove nonlinear ISI and ICI perfectly.

4.5.2 Convergence Speed

In Beidou satellite navigation communication system, the convergence speed will affect the communication link building time. The convergence speed mainly focus on the iteration times and fluctuation of mean square error (MSE). We also compare our algorithm with the neural network blind equalization algorithm was proposed by literature [6] and channel detection aided equalization algorithm was proposed by literature [8]. The results of the comparison can be seen as Fig. 4.4.

Form Fig. 4.4 we can see, the convergence speed of channel detection aided equalization algorithm is slower than other algorithms due to the channel detection need more iteration times to have accuracy and the MSE is also higher than other algorithms. Neural network blind equalization algorithm have higher convergence speed due to the neuron have good nonlinear feature but it bring the fluctuation caused by itself factor. Our proposed equalization algorithm has quickly convergence speed and lower MSE due to the nonlinear error model can track all kinds of nonlinear ISI and ICI.

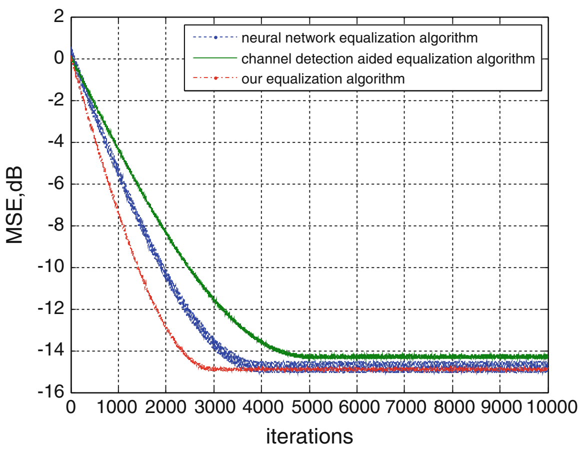


Fig. 4.4 Convergence speed with different equalization algorithms

4.6 Conclusions

Aim to satellite channel of Beidou satellite navigation communication system has strong nonlinear ISI and ICI, so the traditional wireless channel equalization algorithm isn't satisfied in satellite channel. Beidou satellite communication's frequency and capacity are larger than the wireless communication; it means the equalization algorithm should have higher updating speed to track the frequency and code. This paper proposed a nonlinear blind equalization algorithm. The algorithm utilized the symbol error to construct the third-order nonlinear revised error, and then we update the parameter of equalization by the revised error under MMSE standard. From the simulation results we can see, our proposed equalization algorithm has good value in application field.

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