Research on Equalization Technology of Broadband Satellite Communication Channel

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Abstract. Satellite channel is the representative non-linear channel with limited frequency band. The random change of the channel causes the communication stability to be affected. With the development of satellite communication technology, the bandwidth of satellite communication has increased and the data rate has also increased significantly, resulting in more serious code interference, which has become a key factor affecting communication quality. Finding an efficient equalization technology to eliminate channel inter-code interference is the key to ensuring satellite broadband communications. This article first briefly discusses the principle of eliminating inter-symbol interference and common equalizer algorithms, and summarizes the main factors that affect the performance of channel equalization algorithms. On this basis, an improved LSTM blind equalization algorithm is proposed.

1. Introduction

With the development of aerospace and communication technology, the development and utilization of foreign space in the world has been increasing. These include free communication satellites, earth observation satellites, data relay satellites, multimedia satellites and military satellites on low earth orbit. The satellite communication band includes multiple wavelengths, with a maximum capacity of 200Gbps\textsuperscript{[1]}. Current satellite communications require real-time processing and transmission of massive data, and the data rate of the star is even higher, and the data transmission rate is getting higher and higher. The broadband satellite communication system has many types of broadband filters to limit signal bandwidth and suppress noise. The liter cosine filter is the most representative, and the resulting cosine filter pulse response will keep the length of the length of the drag tail to obtain a better filter effect. If there is a sequence mismatch, it increases the interference between the rear and rear, thus forming the inter symbol interference. In addition, the nonlinear phase of the band-pass filter is also the main factor in the interference of the resulting code. The interference of the elimination code is the key to the high speed data transmission in the satellite channel. The equilibrium technique can greatly reduce the interference of the code, improve the channel distortion caused by the spectrum extension and nonlinear distortion, and improve the transmission rate. Therefore, the increase of the equalizer can balance the digital pulse of the distortion and effectively reduce the interference of the code. Therefore, the research on equilibrium technology is of positive significance.

2. Principle of inter symbol interference elimination

In baseband transmission, there is always interference between codes because of the non-ideal
characteristics of the channel. Therefore, it is necessary to insert some type of tunable filter in the baseband system to resist interference, i.e., equalizer. In other words, an equalizer is added between the receiving filter and the decider[2], as shown in Figure 1.

\[ a_0 \]
\[ G(t) \]
\[ C(t) \]
\[ R(t) \]
\[ x(t) \]
\[ y(t) \]
\[ H_{eq}(t) \]
\[ \text{decision} \]
\[ \{a_0^*\} \]

Fig.1 Baseband system with equalizer

If \( d(t) \) is the original signal and \( x(t) \) is the complex baseband impulse response, that is, \( x(t) \) fully reflects the overall transmission characteristics of the receiving/sending filter and channel, and the equalizer is actually the inverse filter of the transmission channel. If the transmission channel is frequency selective, the equalizer improves the frequency attenuation of the spectrum so that the attenuation region of each part of the received spectrum is flat and the phase tends to be linear. For time-varying channels, the adaptive equalizer can track the time-varying characteristics of the channel in real time.

3. Common equalizer technologies

Equalization techniques are usually divided into two categories: linear equalization and nonlinear equalization. The difference between the two types is how the output of an adaptive equalizer is used to control a partial equalizer sequence. Typically, analog signal \( y(t) \) performs amplitude limiting or threshold operations through the adjudicator in the receiver to determine the digital logic value \( y(t) \) of the signal. If \( y(t) \) is not applied to the feedback logic of the equalizer, the equalizer is linear. Conversely, if \( y(t) \) is applied to feedback logic and helps change the equalizer's subsequent output, the equalizer is non-linear. There are many types of filter structures to achieve equalization, and many algorithms for each structure. Common equalizer technologies can be classified according to the type, structure and algorithm of equalizer, as shown in Figure 2.

![Classification of equalizer and its corresponding algorithm](image-url)
3.1. Linear equalizer
Linear equalizers can be implemented with FIR filters, which are the simplest type. The current and past values of the received signal are linearly superimposed according to the filter coefficients, and the summation after superposition is used as the output. If the delay element and stage gain are analog signals, the continuous signal waveform output by the equalizer will be sampled at symbol rate and sent to the decision device. However, equalizers are usually implemented in the digital domain, and their sampled signals are stored in shift registers. Linear equalizers can also be implemented using raster filters. The advantages of grating equalizer are: good numerical stability and faster convergence rate. Because of the special structure of the grating equalizer, the most effective length can be dynamically adjusted. Therefore, if the time expansion feature of the channel is not obvious, it only takes a few steps to achieve, and if the time expansion feature of the channel is improved, the number of steps of the equalizer can be automatically increased by this algorithm, and the equalizer process does not need to be interrupted. However, the structure of grating equalizer is more complex than linear FIR filter.

3.2. Decision feedback equalizer
The basic principle of decision feedback equalization is that once an information symbol is recognized and determined, it can predict and eliminate the inter-symbol interference caused by the information symbol before recognizing the subsequent symbols. Decision feedback equalization can be realized directly by transverse filter or grid filter. The transverse filter consists of feed-forward filter and feedback filter. The feedback filter is driven by the output of the detector, and its coefficients can be adjusted to eliminate the interference between the previous symbol and the current symbol. Like traditional decision feedback equalization, predictive decision feedback equalization also has a feed-forward filter. However, the feedback filter is driven by the difference between the output of the detector and the output of the feed-forward filter. Because it predicts residual interference between noise and symbols contained in the feed-forward filter and subtracts the detector's output after the feedback delay, the feedback filter is referred to here as a noise predictor. The performance of predictive decision feedback equalization is similar to that of conventional decision feedback equalization due to the finite number of taps in feed-forward filter and the infinite size of feedback filter. The feedback filter in predictive feedback equalizer can also be realized by grating structure. At this point, RLS grid algorithm can be used to quickly form convergence.

3.3. Adaptive equalizer
During satellite communication, due to noise factors, communication bandwidth is limited and communication capacity is reduced. Because of the group delay characteristics, inter-symbol interference is more serious than ground communication, which greatly reduces communication throughput and data quality. Researchers propose equalization techniques to reduce noise and inter symbol interference in data transmission quality. The traditional method is to use the training sequence to transmit in the channel based on the channel parameters, and compare the training sequence with the received sequence deviation, so as to update the tap coefficient to reduce the deviation. This iterative calculation makes the receiving sequence in the middle of the equalizer the best estimate of the transmitting sequence, and the final tap coefficient is stored for actual communication. The adaptive equalizer that changes the weight belongs to the adaptive equalizer. Adaptive equalizer to produce good input signal, the output signal of the error is minimized, and tap coefficient can adaptive setting, variable in the channel performance is better, but the adaptive equalizer has a disadvantage, in order to send actual information it must be in the actual signal before sending training sequences, and through learning weights training sequences, which reduces the frequency utilization[3].

3.4. Blind equalizer
Adaptive equalizers must repeatedly send training sequences to recover and equalize data with time-varying channel characteristics. Blind equalization technology to realize the data need for
training, effectively made up for the shortcomings of adaptive equalization technology, blind equalization algorithm is the first to use the input signal of prior information to design the function value, and then through learning algorithm to minimize cost function to obtain the best solution, so as to realize the function of convergence, its purpose is to make the output sequence is close to the best estimate of transport order column.

4. Blind equilibrium algorithm with RL feedback

4.1. Blind balanced system framework

In the broadband satellite communication system, the ground modulation signal is transmitted through the satellite channel to the satellite to reduce the signal-to-noise ratio, and the blind equilibrium technique is used to realize the channel blind equilibrium without training and to recover the initial signal as much as possible. In order to balance the transmission characteristics of the normal channel, improve the balance ability, make the modulation recognition signal more reliable, and improve the detection rate of the modulation detection network. The text proposes a blind equilibrium system with integrated transport load (RL) feedback. In the process of transmission of the link to the ground station, the signal is transmitted through the blind balanced network to improve the signal-to-noise comparison, then send it to the Saprk distributed parallel processing platform, the corresponding signal is processed, and the signal pattern identification network is trained, and the final training network is sent to the satellite through the upward link, and the subsequent modulation signal pattern recognition is carried out. The interference of the signal in the signal of the satellite channel reduces the detection effect of the modulation signal. In order to reset the modulation signal with code interference as the original modulation signal, the blind equilibrium algorithm with RL feedback is used, and before the modulation signal goes into the deep convolution neural network (DCNN), the detection accuracy of the modulation signal is improved by reducing the interference of the original signal by means of equilibrium technology[4].

When the modulation signal pattern identifies the blind equilibrium, the modulation signal is disturbed by the satellite channel generation code. The blind equilibrium algorithm with RL feedback is used to eliminate the interference between codes. The signal is compressed and stored in the storage, and the distributed spark computer platform is used for parallel computing and training deep convolution neural network DCNN. Until the condition is fulfilled, the best training model is saved, and then the modulation mode of the signal modulation and the accuracy of the evaluation model is submitted. In order to improve the quality of the signal, it is necessary to restore the original signal as much as possible so that the signal can be obtained through the RL feedback algorithm. The blind equalizer that has RL feedback is a equalizer based on the network of long and short memory networks (LSTM) network. LSTM network not only can learn the characteristics of current information and input information, but also adjust the characteristics relationship between current information and previous information, and better restore the original signal to achieve a better equilibrium effect. By entering the data at the time of learning, the enhanced learning can be applied to the blind equilibrium technology, and the purpose of the training sequence is not required. After retrieving the input data, the current model is updated and the performance of the current network is evaluated using the model and the next update direction is determined, and the iteration is updated until the model converges. Enhanced learning algorithms require explicit goals. For example, the goal used in the equalizer is to restore the equilibrium data to obtain the best estimate of the transmission sequence, and then run the network update based on this target. Therefore, enhance learning to treat the network and the uncertain environment as a whole[5].

4.2. The blind equilibrium algorithm with RL feedback is designed

Based on the known channel parameters, the training sequence and the received sequence deviation are compared, so that the stroke coefficient is updated to reduce the deviation, the optimal estimate of the sending sequence is obtained, and the final extraction coefficient is stored for actual
communication, which must be sent in advance to send the training sequence, waste a lot of bandwidth, and reduce the efficiency of the transmission of information. In addition, the algorithm requires frequent transmission of training sequences for communication systems that are used in real-time adjustment of channel conditions. Therefore, the blind balanced technology that does not require training sequences is widely concerned. The blind equilibrium technique containing RL feedback can effectively improve the equalization, make the modulation signal in the modulation detection network more reliable, and the detection accuracy of the high profile detection network.

After the transmission of the satellite channel, the signal can be run by the blind equilibrium algorithm with RL feedback, and the difference between the modulation signal output and the original signal value of the current network recovery is evaluated, and the difference is constantly reduced to improve the balance effect. In the case of the equalizer, the signal is compressed and stored in the storage, and the DCNN network is calculated and evaluated on the spark platform, until the completion condition is reached, the accuracy of the current model is predicted and the forecast modulation mode is output. The modulation signal of the satellite channel is used to obtain the recovery modulation signal, compressed the modulation signal and put it in the storage, and then USES the flow calculation module to handle the flow, and sends the modulation signal to the DCNN network to carry out the iterative training, until the termination condition is reached, the best model is saved and the new modulation signal is predicted[6]. The pseudo-code for blind equilibrium algorithm containing RL feedback is shown in figure 3.

```
img=open('/path/Pictures');
forecastImg =open('/path/ forecastPictures');
newImg=img.shuffle();
epoch=50000;
NL=4; lr=0.1;
for i in range(0,epoch) do
    c(0)=newImg;
    for j in range(0,NC) do
        c(j)=LSTM(c(i-1));
    end for
    \bar{x}_m = c(NL)
    J(m)=\sum_n(\bar{x}_m - x_a)^2/2n
    min(f(i))=\min(\sum_n w_k/m \cdot J(m))
    model=save(a, \beta);
end for
img=mod(model(forecastImg))
return img
```

Fig.3 Blind equilibrium algorithm containing RL feedback

As input of broadband satellite modulation signal, it is divided into test set, training set, initialization filter, learning rate and other parameters. The signal first passes the 4 layer LSTM network, and then evaluates the current number of iterations based on the loss function. Also calculate the value function of the current result and save the current model. Update the weights and iterate the offset to minimize the value of the loss function and set the maximum iteration times. When the maximum iteration number is reached, the test set is used to predict the value function of the current model, the difference between the signal and the recovery signal and the difference between the final output signal of the modulation. According to the simulation analysis of error curve, the signal is the independent and distributed sequence of {±1}(BPSK), the total of N=3000 data points, the finite length coefficient is the first of the \( Lf = 41 \), \( R2 = 1 \), \( Lh = 5 \), and the adaptive learning rate is \( \mu = 0.001 \). The error curve is shown in figure 4.
Results:

The noiseless channel estimation: \( h = \begin{pmatrix} -0.07809 \\ 0.11818 \\ -0.21688 \\ 1.2021 \\ 0.43782 \\ -0.16754 \end{pmatrix} \), error rate = 0.

The noise channel estimation: \( h = \begin{pmatrix} -0.07778 \\ 0.11942 \\ -0.21419 \\ 1.2053 \\ 0.43829 \\ -0.16937 \end{pmatrix} \), error rate = 0.

5. Conclusion
In conclusion, the poor and changeable satellite communication channel conditions affect the effect of the channel equilibrium and reduce the accuracy of the modulation signal pattern recognition. In this paper, several major equalizer is analyzed, and then the blind equilibrium algorithm with RL feedback is proposed to reduce the bandwidth of the information transmission by using the normal equilibrium in advance.

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