Digital interference signal filtering on laser interface for optical fiber communication

Shengnan Zhang[1] and Thippa Reddy Gadekallu[2,*]

[1] School of Transportation, Nanchang Jiao Tong Institute, Nanchang 330199, China
[2] School of Information Technology and Engineering, Vellore Institute of Technology, Vellore, India.

Abstract

INTRODUCTION: Fiber laser communication is a communication method that uses laser and fiber medium to realize data transmission and information output

OBJECTIVES: In order to reduce the signal interference of optical fiber communication laser interface and ensure the communication quality of optical fiber network. A filtering method of optical fiber communication laser interface interference signal based on digital filtering technology is designed.

METHODS: In this paper, the interface model of optical fiber communication network is firstly constructed, and the interface noise signal is input into the digital filter bank. The digital quadrature filtering method and the least square algorithm are used to separate the denoised signals to reduce the crosstalk between the signals in the channel. In this way, the crosstalk component in the signal can be filtered out, and a better filtering processing effect of the laser interface interference signal can be achieved.

RESULTS: The results of peak signal-to-noise ratio are above 25, which effectively filters the interference signal in the signal, and retains the effective signal completely. The intelligibility of optical fiber communication network in signal communication is above 0.94, and the highest value is 0.986. The distortion degree are all below 0.025, and the minimum value is 0.004. The communication bit error rate are all below 0.001, which ensures the communication quality of the network.

CONCLUSION: The experimental results show that the signal noise reduction effect of the proposed method is good, which provides a reliable basis for filtering and separating interference signals of optical fiber communication laser interface.

*Corresponding author. Email: thippareddy.g@vit.ac.in

1. Introduction

Fiber laser communication is a communication method that uses laser and fiber medium to realize data transmission and information output [1]. It has the advantages of low loss, wide transmission frequency band, large capacity, small volume, light weight, anti-electromagnetic interference, little cross talk, fast transmission speed, long transmission distance and so on. The most basic optical fiber communication system consists of data source, optical transmitter, optical channel and optical receiver. The data source includes all the signal sources, which are the signals obtained by the voice, image, data and other services through the source coding. The optical transmitter and modulator are responsible for transforming the signal into the optical

signal suitable for transmission on the optical fiber. The optical wave Windows used are 0.85μm, 1.31μm and 1.55μm successively.

Optical fiber communication network mainly transmits signals through the channel, which includes the most basic optical fiber, relay amplifier EDFA, photodetector, etc. [2]. The optical receiver receives the optical signal and collects energy from it [3], then converts it into electrical signal, and finally obtains the corresponding sound, image, data and other information. Optical fiber transmission system is an ideal channel for digital communication. Compared with analog communication, digital communication has the advantages of high sensitivity and good transmission quality, which further improves the performance of conventional CSK over three-color visible light communication channel [4]. Therefore, optical fiber communication systems with large capacity and long distance mostly adopt digital transmission mode. In optical fiber communication network, there are usually two kinds of interference signals, noise and interference, which will affect the utilization of effective signals and reduce the quality of signal transmission. By combining IP model and nonlinear Gaussian noise model, the influence of nonlinear interference noise can be effectively reduced, and the damage of additional link components can be reduced [5].

The transmission signal of the laser interface in the optical fiber communication is disturbed by the noise line spectrum disturbance, resulting in the output bit error and distortion. Therefore, it is more urgent to study the interference signal filtering method.

Reference [6] studies a machine learning-assisted denoising method for optical fiber communication. At the transmission layer, a principal component-based phase estimation algorithm is used for phase noise recovery of coherent optical systems. The K-means algorithm is used to reduce the influence of nonlinear noise in the probabilistic shaping system. At the network layer, long short-term memory algorithms and genetic algorithms are suitable for traffic forecasting and determining the reasonable placement of remote radio heads in a centralized radio access network. Reference [7] investigates an advanced modulation format method for probability-shaping bit loading for visible light communication based on 450-nm GaN laser diodes. The characteristics of the system are discussed, and the bit-loaded discrete multi-tone modulation helps to increase the spectral efficiency and improve the system performance. Higher entropy can be achieved with the same signal-to-noise ratio (SNR) and modulation bandwidth constraints. This method can realize the filtering of noise. Reference [8] proposed a mode-locked laser phase noise reduction method under the optical feedback of coherent DWDM communication. Optical feedback is a well-known method for reducing the linewidth of single-mode lasers and can be used to stabilize comb lasers. This paper reports the investigation of the phase noise characteristics delivered from a single-section QDash MLL under optical feedback. And it is shown that the ray width of each MLL longitudinal mode can be greatly narrowed. In the application process of the above method, the processing effect of the single interference signal is good, and the processing effect of the mixed interference signal still needs to be further verified.

However, the signal interference of optical fiber communication laser interface is always a difficult problem in optical fiber communication system. Digital filtering technology is used in the anti-interference auxiliary communication process in this field. Particular frequency in digital filtering technique is the operation of signal frequency filtering, and also is an important measure to restrain and prevent interference. In view of the optical fiber communication interface laser interference signal filtering problem, this paper designs a laser interference signal filtering method based on digital filtering technology of optical fiber communication interface. Before the noise reduction, this method processes the noise in the signal to improve the characteristics of the signal. On this basis, the signal of noise reduction is further separated by digital filter bank, and the interference signal in the signal is separated to realize the effective filtering of laser interface interference signal.

2. Interference signal filtering of optical fiber communication laser interface

2.1. Optical fiber communication network interface modeling

The interface environment of optical fiber networks is a very complex and unpredictable system [9]. In order to achieve good noise reduction effect, the interface characteristics need to be carefully studied. According to the communication transmission principle of optical fiber network [10], aassuming that I_{gs}, I_{dg} and I_{ds} represent nonlinear laser interfaces of different network communication, the calculation formula is as follows:

$$I_{gs} = I_{g0}\left(a_f V_g - 1\right) \tag{1}$$

$$I_{dg} = I_{d0}\left(a_r V_{dg} - 1\right) \tag{2}$$

$$I_{ds} = \frac{\beta\left(V_g - V_T\right)^2}{1 + b\left(V_g - V_T\right)}\left(1 + \lambda V_d\right)\tan\left(aV_d\right) \tag{3}$$

where: a_f, a_r and λ are attenuation parameters of different components, V_g, V_d, V_T and V_{dg} represent transmission frequencies of laser interface and communication system respectively; a and b represent random numbers in the range of [0,1] and Q, W and R are the original data of T, U and I.

In the transmission process of optical fiber communication network, interface modelling is a key step to optimize the communication network [11]. The forward and backward conversion of interface variables can be expressed as follows:

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) \frac{|f|}{\sqrt{2\pi}} \exp\left[\frac{-f^2(\tau - t)}{2}\right] \quad (4)$$

where: τ and h are harmonic pulses and amplitude-frequency responses of the interface, t represents communication time, and f represents interference frequency. Therefore, the interface model can be expressed by the following formula:

$$c(\tau, t) = \sum_{n=1}^{N''} a_n(t)^2 [1 - \tau_n] \quad (5)$$

where, n represents the number of interfaces.

2.2. Signal noise reduction for optical fiber communication ports

Based on the modeling of the fiber optic communication network interface, the nonlinear laser interface output can be calculated. In this way, the optical fiber communication network interface environment can be more clearly defined. Optical fiber network is easy to produce the above noise in any link of the communication process. Especially in the chaotic communication environment, the noise of multicarrier radar and communication system will cross [12] and attach to the real signal in the form of linear superposition. The noise signal can be described by the following formula:

$$x'(t') = s'(t') \cdot x'(k') \quad (6)$$

where $s'(t')$ belongs to pure signal, and $x'(k')$ describes noise.

Wavelet domain filtering is a new signal processing method. It decomposes various frequency components in the signal into non-overlapping frequency bands, which provides an effective way for signal filtering, signal-to-noise separation and feature extraction. The spectrum of some noise is distributed over the entire frequency domain. The development and maturity of wavelet theory provides a favorable tool for the analysis of non-stationary signals. In this paper, the wavelet domain filtering algorithm [13] is used to remove the interface noise signal. Assuming that the noise signal is represented as $x'(k')$, which is the discrete value of the noise signal x' at the point k', $C_{0,k'} = x'(k')$ is set and combined with the wavelet decomposition principle, the decomposition expression of wavelet transform is as follows:

$$C_{j,k'} = \sum_{n' \in N} f C_{j-1,n'} h'_{n'-2k'} \quad (7)$$

$$d'_{j,k'} = \sum_{n' \in N} f d'_{j-1,n'} \cdot g'_{n'-2k'} \quad (8)$$

where, $k' = 0, 1, 2, \cdots, N'$, N' is the length of discrete data, $C_{j,k'}$ and $d'_{j,k'}$ represent scale and wavelet coefficient respectively, h' and g' belong to A group of orthogonal filters, and j is the decomposition scale.

In order to realize the simultaneous removal of various noises in the channel, the above-mentioned wavelet domain filtering model is used for denoising. The specific process is shown in Figure 1.

Step 1: A reasonable number of layers is set to do wavelet decomposition of the noise signal;

Step 2: Since noise is mostly concentrated in detail coefficients, filter coefficients at any level [14], except scale coefficients;

Step 3: The appropriate threshold is determined and threshold denoising for the detail coefficient;

Step 4: Wavelet reconstruction is processed on the details and scale coefficients after noise reduction to get the noise reduction signal.
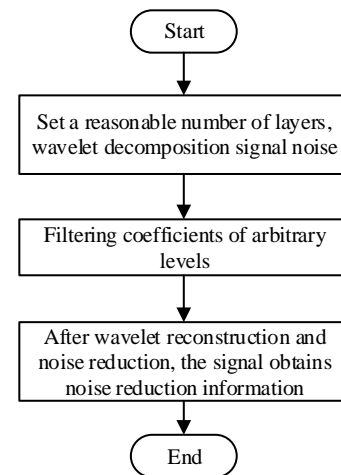

Figure 1. Denoising process using wavelet domain filtering model

It can be seen from the above process that the determination of decomposition layers and the calculation of threshold are the key to the wavelet domain filtering algorithm. Therefore, this paper focuses on the analysis of these two processes, which are to determine the reasonable selection of decomposition layers and threshold respectively. The details of the two processes are as follows.

(1) Determine the number of decomposition layers:

In the process of optical fiber communication, both signal and noise have modulus maxima, and their morphology in the wavelet domain is different. The amplitude and density of noise decrease with the increase of the number of layers. The trend of signal modulus maxima is opposite. Therefore, combining with this feature, it can be inferred that whether each layer after wavelet decomposition is dominated by noise, so as to get a reasonable number of decomposition layers.

If signal $f^{'}$ is decomposed, the number of decomposition layers is set as m, whose value is usually [3,5], and the sequence of modulus maxima of all layers is labelled as $wpeak\left(j^{'}\right), j^{'}=1,\cdots,m$. If it meets the requirements of Formula (9), it indicates that signal $f^{'}$ is a useful signal; otherwise, it indicates that signal $f^{'}$ is dominated by noise.

$$wpeak(1)_2 \leq 2wpeak(2)_2 \leq ... \leq wpeak\left(j^{'}\right)_2 \quad (9)$$

To determine the number of decomposition layers, the adaptive process is as follows:

Step 1: The asynchronous data transmission noise signal is decomposed, the SNR, interference power and detection threshold of any number of interference sources are determined, and the noise interference signal is analyzed [15].

Step 2: The obtained scale coefficient $C_{1,k^{'}}$ is used to reconstruct the wavelet coefficient $d^{'}_{1,k^{'}}$ and a new signal $sig-new$ is obtained. If the signal conforms to the conditions constrained by formula (9), skip to step 4, otherwise proceed to the next step.

Step 3: The previous step is repeated. Every time the detail coefficient decomposition is completed, a new signal will be obtained to verify whether the maximum value of the signal can meet the conditions constrained by Formula (9). If not, further decomposition will be carried out until the requirements are met.

Step 4: The results obtained last time are discard and the number of layers of the final decomposition is set to $j^{'}$, then the final number of obtained layers is a reasonable choice of the threshold of $j^{'}-1$.

(2) Selection of reasonable threshold:

In this paper, the penalty algorithm is used to select a reasonable threshold. The expression of the penalty standard $crit\left(t^{*}\right)$ is as follows:

$$crit\left(t^{*}\right) = -sum\left[\left(d^{'}_{k}\right)^{2}\right] + 2\sigma t^{*}\left[\alpha + \lg\left(n^{*}/t^{*}\right)\right] \quad (10)$$

where: $d^{'}_{k}$ is the wavelet coefficient, which is arranged and saved according to the descending order of absolute value; n^{*} is the number of coefficients; α is a regulation parameter, a real number larger than 1, and usually takes the value of 2. σ is the standard noise value, whose calculation formula is as follows:

$$\sigma = \sum_{n^{*}=1}^{\alpha} d^{'}_{k} n^{*} \quad (11)$$

It can be seen from Formula (11) that formula (10) is a function t^{*}. Suppose that $crit\left(t^{*}\right)$ has a minimum value when t^{*} is $t^{*}_{\min}$, and the expression of threshold λ^{*} is as follows:

$$\lambda^{*} = d^{'}\left(t^{*}_{\min}\right) \quad (12)$$

There are two threshold processing algorithms: hard threshold and soft threshold. Because the hard threshold algorithm can generate discontinuity points, the latter is adopted in this paper. The formula of soft threshold function is as follows:

$$y^{*} = \begin{cases} \text{sgn}\left(d^{'}\right)\left(d^{'}-\lambda^{*}\right), d^{'} \geq \lambda^{'} \\ 0 \qquad d < \lambda^{'} \end{cases} \quad (13)$$

where, y^{*} represents the network laser interface signal after noise reduction. After the above process is completed, the noise in the channel can be effectively removed, and the signal characteristics are more obvious, which is helpful for the filtering and separation processing of interference signals.

2.3. Digital filtering of interference signals of optical fiber communication laser interface

2.3.1 Logical structure design of digital filter bank

After the signal denoising processing of optical fiber communication network laser interface is completed, in order to effectively filter the interference signal in the signal, this paper designs a digital filter bank [16] to separate the interference signal of the denoised signal and

realize the laser interference signal filtering. A digital filter bank is a set of filters with a common input or output, as shown in Figure 2.
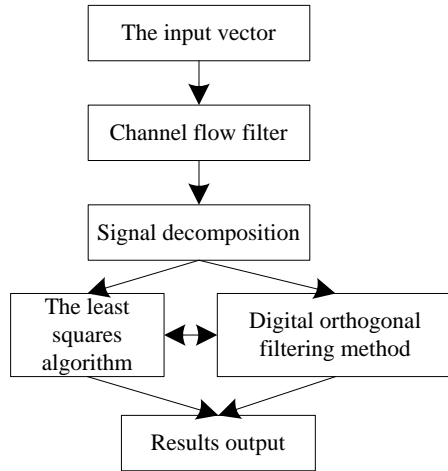

Figure 2. Structure of digital filter bank

Digital filter banks can decompose the signal spectrum into several adjacent band signals or combine several signals into a new signal using low-pass, band-pass and high-pass filters. The decomposition process is completed in the analysis part of the filter bank, and the cache is used to assist the communication process [17], while the synthesis process is completed in the synthesis part of the filter bank. The uniform M-channel filter bank is composed of low-pass, band-pass and high-pass filters. The bandwidth of each filter is equal, and the center frequency points are evenly distributed.

If the r-th band filter is calculated from a single prototype filter $h(n)$, then H is called DiscreteFourierTransform (DFT) filter bank. If the multi-phase decomposition of filter $h^r(n)$ and input signal y^* is adopted, an effective realization of the filter bank of R channels can be obtained. Since each band-pass filter is precisely sampled, the decomposition of R multi-phase signals is adopted. The relevant calculation formula is as follows:

$$h(n) = \sum_{k=0}^{R-1} h_k(n) \leftrightarrow h_k(m) = h(mR-k) \tag{14}$$

$$y^* = \sum_{k=0}^{R-1} y_k^*(n) \leftrightarrow y_k^*(m) = y_k^*(mR-k) \tag{15}$$

Equation (15) is substituted into Equation (14), it can be found that all band-pass filters $h^r(n)$ share the same phase filter $h_k(n)$, and the "rotation factor" of each filter is different, so as to ensure better denoising effect of

interference signal filtering [18]. Moreover, in the digital filtering technology, the digital orthogonal filtering method is introduced to separate the signal after noise reduction and filter the interference signal in the signal.

2.3.2 Laser interface interference signal filtering processing

The digital orthogonal filtering method can reduce the crosstalk between signals in the channel, deal with the crosstalk components in the signal, and ensure better filtering processing of laser interface interference signals.

I channel represent co-trust channel in optical fiber communication network, and Q channel represent orthogonal channel. $i(t)$ and $q(t)$ are the two signals I and Q generated by the transmitter; $g(t)$ and $f(t)$ are square root rising cosine (SRRC) low-pass forming filter functions; ω_c represents the minimum carrier frequency that shifts the negative frequency domain of base-band signal to the positive frequency domain. $h(t)$ represents the channel impact response; $p_I(t)$ and $p_Q(t)$ represent the impulse responses of in-phase and orthogonal filters at the transmitter, respectively. $p_I(t)$ and $p_Q(t)$ form Hilbert transform pairs [19], and the calculation formulas of impulse responses $r_I(t)$ and $r_Q(t)$ of corresponding Hilbert transform pairs matching $h_k(n)$ at the receiver are as follows:

$$\begin{cases} r_I(t) = p_I(-t) \\ r_Q(t) = p_Q(-t)^\circ \end{cases} \tag{16}$$

In the digital filter, the algorithm based on Hilbert transform is introduced to achieve the orthogonality calculation formula between two channels:

$$r_A(t) \otimes p_B(t) = \begin{cases} \delta(t-T_0), A = B \\ 0, \quad A \neq B \end{cases} \tag{17}$$

where, A and B correspond to I and Q respectively; T_0 is the time delay caused by digital filtering; $\delta(t-T_0)$ is the impulse function; $\otimes$ stands for convolution. Ideally, there is no loss and delay in the channel between the output of the filter at the transmitter and the input of the matched filter. The combination of

prime interleaving is adopted to improve the anti-interference effect under the same SNR level [19].

Therefore, $h_k(n)$ output with the same matching path can be calculated as:

$$i'(t) = t\left\{ \left[i \otimes p_I \otimes r_I \right] + \left[q \otimes p_Q \otimes r_I \right] \right\} \quad (18)$$

where, the second term $q(t) \otimes p_Q(t) \otimes r_I(t)$ is the interference of channel Q to channel I. By substituting equation (16), it can be seen that the result of the second term $\left[q \otimes p_Q \otimes r_I \right]$ is 0, that is, the crosstalk between channels can be eliminated by using digital orthogonal filtering.

Digital orthogonal filtering is generally used for multiplexing two signals to one channel, and it is used in the mode division multiplexing transmission of two degenerate modes to reduce the influence of signal crosstalk between channels from the perspective of intelligent frequency hopping, so as to obtain the intelligent fiber mode channel hopping sequence of jammer and target transmitter. In the mode division multiplexing transmission system, the fiber mode channel is not ideal, and the transmission of signals $i(t)$ and $q(t)$ will be affected by the channel response $h(t)$. Therefore, the signal output of the channel matched filter at the receiver can be expressed as:

$$i'(t) = t\left[i \otimes p_I \otimes h \otimes r_I \right] + t\left(c_{QI} + f_I \right) \quad (19)$$

$$c_{QI}(t) = t\left(q \otimes p_Q \otimes h \otimes r_I \right) \quad (20)$$

According to Equation (4), in addition to useful signals, the output of I path matched filter also includes the crosstalk component $c_{QI}(t)$ of Q-path to it and the interference component $f_I(t)$ of I-path. Similarly, the output function of Q-path matched filter can be calculated as follows:

$$q'(t) = t\left[q \otimes p_Q \otimes h \otimes r_Q \right] + \\ t\left[i \otimes p_I \otimes h \otimes r_Q \right] + f_I(t) + f_Q(t) \quad (21)$$

where, the interference signal component of Q-path is represented by $f_Q(t)$.

The crosstalk component between channels will seriously degrade the channel transmission performance, so crosstalk cancellation is needed. To reconstruct $c_{QI}(t)$, the sender $q(t)$ must be known, while $q(t)$ is obviously unknown. The actual received signal $q'(t)$ of Q, path is used as the estimate value to replace $q(t)$, then the crosstalk signal estimation can be expressed as follows.

$$e_{QI}(t) = t\left(q' \otimes p_Q \otimes h \otimes r_I \right) \quad (22)$$

Similarly, the estimate $c_{QI}(t)$ of crosstalk component $e_{QI}(t)$ can be obtained. The crosstalk components $c_{QI}(t)$ and $e_{QI}(t)$ between channels after using digital orthogonal filtering are smaller than those without using digital orthogonal filtering, so crosstalk can be reduced and interference signal filtering effect can be achieved [20].

The least squares algorithm is used to estimate the channel matrix h. The training sequences are sent by I and Q channels be $x_1(t)$ and $x_2(t)$, respectively. The channel matrix formula is:

$$h = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad (23)$$

Then the signal of the receiving end is:

$$\begin{cases} y_1(t) = h_{11} \times x_1(t) + h_{12} \times x_2(t) \\ y_2(t) = h_{21} \times x_1(t) + h_{22} \times x_2(t) \end{cases} \quad (24)$$

It is known that the sending and receiving vectors of the training sequence of route I and route Q are x_t and F y_t respectively, then:

$$y_t = hx_t + f \quad (25)$$

The estimated value $\hat{h}$ of the channel response h is:

$$\hat{h} = \arg \min_h \| y_t - x_t h \|^2 \quad (26)$$

where: $(\cdot)^H$ is conjugate transpose. Therefore, the values of $e_{QI}(t)$ and $e_{IO}(t)$ can be calculated, and then the estimated value of the corresponding crosstalk component can be subtracted from the received signal of each channel to cancel the crosstalk [21], and the new estimated value of the received signal can be obtained as follows:

$$\begin{cases} i''(t) = i'(t - T_E) - e_{QI}(t) \\ q''(t) = q'(t - T_E) - e_{IQ}(t) \end{cases} \quad (27)$$

where, T_E is the delay of crosstalk estimation signal. $i''(t)$ and $q''(t)$ can replace $i(t)$ and $q(t)$ for the next step of signal demodulation, or can be substituted into equation (27) for the second iteration to further reduce the remaining crosstalk components and interference signals.

3. Experimental Test

In order to verify the filtering effect of the proposed method on laser interface interference signals in optical fiber communication networks, Matlab Simulink tool is used for simulation test, where the signal waveform is completed by an arbitrary waveform generator (AWG2005), the number of sampling points of interference noise is N=125, and the signal noise ratio of signal interference is set as -12.7dB. The initial sampling frequency of laser interface signal is 100kHz, the termination sampling frequency is 500kHz, the frequency range of broadband signal detection is 14-26khz, and the pulse width of laser interface signal sampling is 20ms.

3.1. Signal noise reduction effect test of laser interface

In order to verify the denoising effect of the proposed method on optical fiber communication laser interface signals, the proposed method is used to conduct denoising processing on the sampled laser interface signals containing interference signals. The results of laser interface signals before and after denoising are shown in Figure 3.
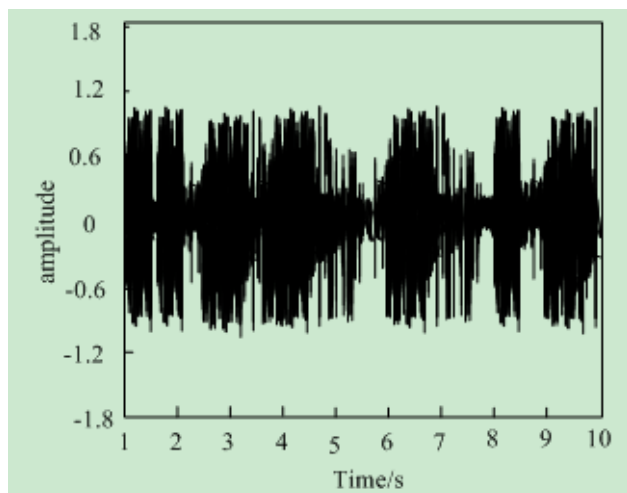
(a)Signal results before noise reduction
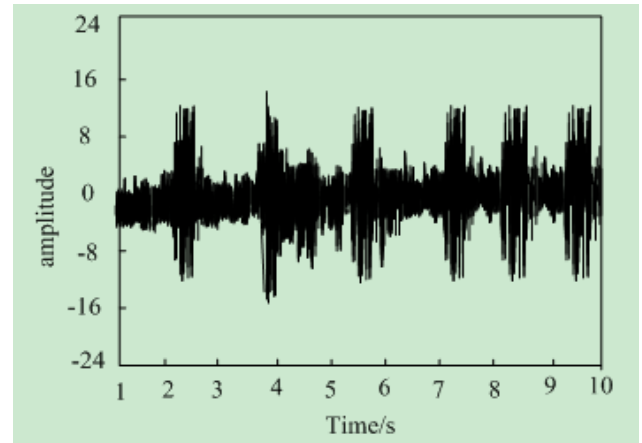
(b)Signal result after noise reduction

Figure 3. Test results of signal noise reduction effect of laser interface

After analyzing the test results in Figure 3, it can be concluded that the sampled laser interface signal of optical fiber communication is disturbed by noise, which leads to poor signal resolution, and the effective signal is covered by a large area, and the effective signal cannot be accurately identified. The noise in the signal can be effectively removed and the effective signal can be recovered by using the proposed method. The signal waveform of noise reduction is more regular. Therefore, the signal noise reduction effect of the proposed method is good, and it can provide a reliable basis for filtering and separating interference signals of optical fiber communication laser interface.

3.2. Peak signal-to-noise ratio test

To further measure the noise reduction effect of the proposed method, the peak signal-to-noise ratio (PSNR) is adopted as the metric. We chose Gaussian noise, salt and pepper noise, and mixed noise as interference signals. Gaussian noise refers to a class of noise whose probability density function follows a Gaussian distribution (ie, a normal distribution). Salt and pepper noise refers to two kinds of noise: salt noise and pepper noise. Salt noise is generally white noise, pepper noise is generally black noise, the former is high grayscale noise, and the latter is low grayscale noise. Generally, two kinds of noise appear at the same time, and they appear as black and white noise on the image. Mixed noise is caused by the accumulation of a large number of fluctuation disturbances randomly generated in time. Noise whose value cannot be predicted at a given instant. In this way, the denoising results of the method in this paper under different types of interference signals are obtained. As the noise density gradually increases, the desired criterion for the peak signal-to-noise ratio is above 25.

Table 1. Variation results of PSNR

| The noise density	Gaussian noise	Salt and pepper noise	Mixed noise
0.1	26.6	27.3	27.7
0.2	26.5	26.9	29.4
0.3	29.7	27.2	29.7
0.4	26.7	28.4	28.2
0.5	27.1	28.2	17.6
0.6	28.4	26.6	26.6
0.7	27.6	27.7	28.3
0.8	27.4	29.4	29.1
0.9	28.8	28.1	28.8
1	29.1	26.5	27.5

After analyzing the test results in Table 1, it can be concluded that: With the gradual increase of noise density, the results of peak signal-to-noise ratio (PSNR) also changed differently under the interference signals of Gaussian, salt and pepper, and mixed noise. However, the results of PSNR are all above 25 under the noise signals of the three types, where the minimum value is 26.2 and the maximum value is 29.7, which meets the application effect. Therefore, the noise reduction effect of the proposed method is good and can reliably remove the noise in the laser interface signal. Because the channel model of the optical fiber communication network is first constructed in this paper, the wavelet domain filtering algorithm is used to reduce the noise in the channel and highlight the signal characteristics. Thereby, the effect of signal removal is optimized.

3.3. Effect test of interference signal separation

In order to measure the separation effect of the proposed method on interference signals, a sampled laser interface signal is randomly selected, and the proposed method is used to perform interference signal separation processing on the signal after noise reduction to obtain the effect before and after interference information separation, as shown in Figure. 4.
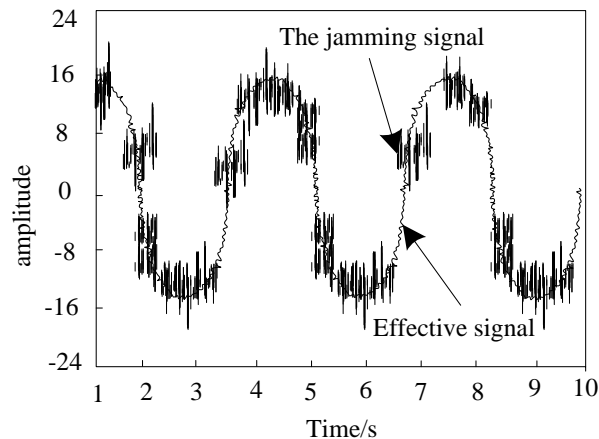
(a) Signal effect before interference signal separation
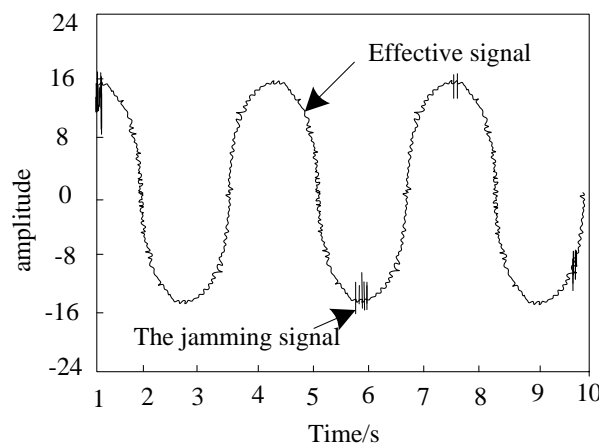
(b) Signal effect before interference signal separation

Figure 4. Test results of interference signal separation effect

After analyzing the test results in Figure 4, it can be concluded that there are still obvious interference signals in the communication signals after noise reduction processing, which will affect the effectiveness of the signals. The interference signal in the signal is effectively filtered, and the effective separated signal is retained without damaging the effective signal. Therefore, the proposed method has a good effect on interference signal separation and can retain intact effective signals to a large extent.

3.4. Signal filtering effect test

In order to further verify the filtering effect of the proposed method on optical fiber network laser interface signals, the effective resolution φ and mean square deviation ε are adopted as the measurement standards. The application standard of φ is above 20.5 digits, and

the application standard of ε is below 0.02. The calculation formulas of the two indexes are as follows:

$$\varphi = \log_2\left(\frac{2^M}{\varepsilon}\right) \qquad (28)$$

$$\varepsilon = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left|x_i - \overline{x}\right|^2} \qquad (29)$$

where: x_i represents the i -TH data; $\overline{x}$ is the average value of data. M represents the number of signal quasi-transposition. N represents the number of laser interface signals.

According to the above formula, the test results of the two indexes of the proposed method under the interference components of different size pairs are calculated, as shown in Figure 5.
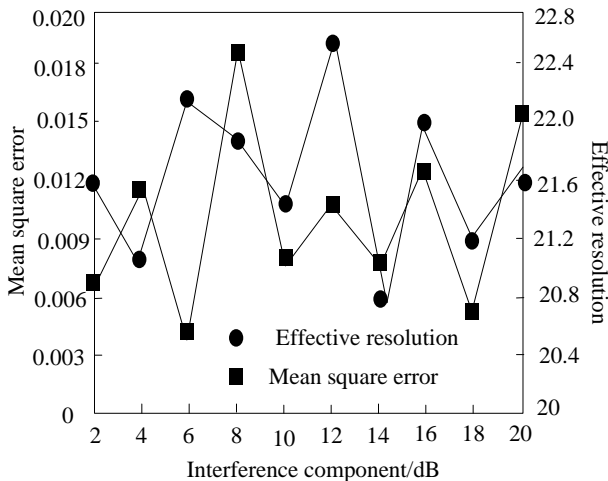

Figure 5. Test results of effective resolution and mean square deviation index

After the analysis of the test results of figure 5, the effective resolution results of this method are more than 20.5, with the maximum value of 22.6, and the minimum value is 20.8. The maximum value of ε is 0.018. the minimum is 0.002. The results show that the proposed method has good noise reduction performance, because the digital filter bank is used to separate the interference signals of the optical fiber communication laser interface, which can decompose the signal spectrum into several adjacent frequency band signals or combine several signals into a new signal by using low-pass, band-pass and high-pass filters. The decomposition process is completed in the analysis division of the filter group, and the synthesis process is completed in the comprehensive part of the filter group. The uniform m channel filter group is composed of low pass band and high pass filter, the bandwidth of each filter is equal, the center frequency point is evenly distributed, so it is reliable to complete the

interference signal separation, so as to ensure the good interference signal filtration effect.

3.5. Communication quality test

In this paper, the communication effect of the optical fiber network in the communication process is measured, and the range of the three indexes is [-0.5, 4.5]、[0, 1]、[0, 1] respectively. The larger the first two indicators indicates that the better the signal communication, the better the communication effect is, the better the quality of the signal communication is, while the smaller the last indicator indicates that the better the quality of the signal is, the better the quality of the communication is. The results of the three indicators are shown in Table 2, in the case of different noise resolution.

Table 2. Test results of speech quality, intelligibility and distortion of output signal

Noise signal-to-disturbance ratio /dB	Voice quality	intelligibility	The distortion degree of
25	4.22	0.955	0.015
20	4.34	0.962	0.017
15	4.47	0.965	0.009
10	4.24	0.967	0.011
5	4.16	0.977	0.014
0	4.33	0.984	0.008
-5	4.48	0.957	0.013
-10	4.5	0.974	0.019
-15	4.29	0.986	0.022
-20	4.38	0.973	0.004
-25	4.46	0.969	0.008

After the analysis of the test results in Table 2, it can be concluded that the speech quality, intelligibility and distortion of the signal have different changes after the application of the proposed method under different SNR. Among them, the speech quality index results are all above 4.0 and close to the maximum limit of the value to a large extent. The intelligibility values are all above 0.94, and the highest value is 0.986. The results of distortion degree are all below 0.025, and the minimum value is 0.004. The results show that the proposed method has good applicability, effectively reduces the signal noise interference of optical fiber network laser interface, and ensures the communication quality of the network. Because the digital quadrature filtering method and the least square algorithm can effectively separate and process the denoised signal. Thus, the communication quality is effectively improved.

3.6. Bit error rate test

In order to verify the filtering effect of the proposed method on laser interface interference signals, the bit-error rate is used as a measurement standard to test the bit-error rate results of the proposed method in the transmission process under different signal lengths, and the application standard is lower than 0.001. The test results are shown in Table 3.

Table 3. Test results of bit error rate

The length of the signal/bit	Signal to noise ratio /dB		
	10	20	30
100	0.0072	0.0047	0.0087
200	0.0055	0.0022	0.0095
300	0.0061	0.0008	0.0055
400	0.0059	0.0011	0.0047
500	0.0011	0.0019	0.0033
600	0.0023	0.0034	0.0016
700	0.0006	0.0022	0.0009
800	0.0019	0.0008	0.0011
900	0.0017	0.0011	0.0006
100	0.0024	0.0033	0.0037
1100	0.0025	0.0024	0.0051

After the analysis of the test results in Table 3, it can be concluded that under different communication signal lengths, with the gradual increase of optical signal-to-noise ratio, the communication bit error rate results of the signal are all below 0.001. When the communication signal length is 1100, the maximum bit error rate results are 0.0095, and the minimum bit error rate results are 0.0006. Therefore, the proposed method can reliably complete the laser interface interference signal filtering of optical fiber communication network, and reduce the noise in the signal, and effectively separate the interference signal to ensure the communication effect of the network.

3.7. Pseudo-bit rate test

In order to further measure the application effect of the proposed method, the pseudo-code rate is adopted as the measurement standard (the application requirement is less than 0.003) to test the change result of the pseudo-code rate of the proposed method with the gradual increase of the communication length under different communication distances, as shown in Table 4.

After analyzing the test results in Table 4, it can be concluded that: Under different communication signal lengths, with the gradual increase of communication distance, it can still maintain good communication effect. The pseudo-rate results in the signal are all lower than the application standard of 0.003. When the communication distance is 100km, the highest value of pseudo-rate results is 0.0027, and the minimum value is 0.0011. When the communication distance is 10km, the highest pseudo-code rate result is 0.0014, and the minimum result is 0.0004. The longer the communication distance, the communication quality of the network communication process will be slightly affected after interference, but the proposed method can still ensure the communication effect at a long distance, and the application effect is good.

Table 4. Pseudo-code rate test results of optical fiber network communication

The communication distance /km	The length of the signal /bit		
	5	15	25
10	0.0004	0.0009	0.0014
20	0.0005	0.0011	0.0016
30	0.0006	0.0012	0.0015
40	0.0005	0.0014	0.0017
50	0.0007	0.0011	0.0016
60	0.0008	0.0012	0.0015
70	0.0007	0.0015	0.0019
80	0.001	0.0017	0.0022
90	0.0009	0.0016	0.0021
100	0.0011	0.0019	0.0027

4. Conclusion

Fiber laser communication is widely used in secure communication and military satellite communication because of its large bandwidth and low transmission bit error rate. However, the laser interface in optical fiber communication is easily affected by electromagnetic radiation and medium disturbance in data output transmission control, resulting in signal interference and distortion.

Therefore, this paper studies the digital filtering technology of optical fiber communication laser interface interference signal filtering method, laser interface interference signal in optical fiber communication is effectively filtered. This method through the wavelet transform method to implement signal noise reduction, highlight the signal characteristics. On this basis, a double filter design method is adopted to improve the output anti-interference ability of optical fiber communication, and the interference signal is separated, so as to complete the filtering of such signals, improve the fidelity of communication, and reduce the output bit error rate of optical fiber communication. The test results show that signal communication of optical fiber communication network, the intelligibility value is above 0.94. The highest value is 0.986. The distortion results are all below 0.025, with the minimum value of 0.004. The results of the communication bit error rate are all below 0.001, which ensures the communication quality of the network. And the interference signal separation effect is good, can

reliably separate the interference signal in the signal to ensure the communication quality of optical fiber communication network, the application effect is good.

The next work will be the recognition in laser communication network. The method in this paper separates and processes the denoised signals, which effectively reduces the crosstalk between the signals in the channel, thereby reducing the pseudo-code rate. In order to further improve the optimal design of the interference signal of optical fiber communication, it is also necessary to deeply study the reliability of the positioning result of the interference signal, so as to improve the quality of optical fiber communication.

Acknowledgements

References

[1] He, Y., Li, M., Shu, Y., Ning, Q., & Luo, A. (2021). Generation of h-shaped pulse rains induced by intracavity fabry–perót filtering in a fiber laser. Optical Fiber Technology, 61(14), 102453.

[2] Ghosh, S., Kumar, H., Mukhopadhyay, B., & Chang, G. E. (2021). Design and modeling of high-performance dbr-based resonant-cavity-enhanced gesn photodetector for fiber-optic telecommunication networks. IEEE Sensors Journal, 21(8), 9900-9908.

[3] Son, V. V., Duong, D. T., Hoang, T. M., Quan, D. T., & Hiep, P. T. (2020). Analysing outage probability of linear and non-linear rf energy harvesting of cooperative communication networks. IET Signal Processing, 14(8), 541-550.

[4] Gao, Q., Qaraqe, K., & Serpedin, E. (2020). Rotated color shift keying for visible light communications with signal-dependent noise. IEEE Communications Letters, 24(4), 844-848.

[5] Kaliteevskiy, N. A., Ivanov, V., Sterlingov, P., Downie, J., & Hurley, J. (2020). Transponder implementation penalty-accounted gaussian-noise-based performance modeling of fiber-optic transmission systems. Journal of Lightwave Technology, 38(8), 2253-2261.

[6] Pan, X., Wang, X., Tian, B., Wang, C., & Guizani, M. (2021). Machine-learning-aided optical fiber communication system. IEEE Network, 35(4), 136-142.

[7] Li, G., Hu, F., Zou, P., Wang, C, Lin, G. R., & Chi, N. (2020). Advanced modulation format of probabilistic shaping bit loading for 450-nm gan laser diode based visible light communication. Sensors, 20(21), 1-12.

[8] Verolet, T., Aubin, G., Lin, Y., Browning, C., & Ramdane, A. (2020). Mode locked laser phase noise reduction under optical feedback for coherent dwdm communication. Journal of Lightwave Technology, 38(20), 5708-5715.

[9] Zhang N., Yang Y., Chen T., et al. (2021). Research on Optimization Policy Routing Technology of Optical Fiber Communication Network[J]. Journal of Physics: Conference Series, 1746(1):012084 .

[10] Yu H., Li P., Zhang L., et al. (2020). Application of optical fiber nanotechnology in power communication transmission[J]. AEJ - Alexandria Engineering Journal, 59(6):5019-5030.

[11] Zoofaghari, M., Arjmandi, H., Etemadi, A., & Balasingham, I. (2021). A semi-analytical method for channel modeling in diffusion-based molecular communication networks. IEEE Transactions on Communications, 69(6), 3957-3970.

[12] Wang, F., & Li, H. (2021). Power allocation for coexisting multicarrier radar and communication systems in cluttered environments. IEEE Transactions on Signal Processing, 22(3), 1-10.

[13] You S., Wang H., He Y., et al. Frequency Domain Design Method of Wavelet Basis Based on Pulsar Signal[J]. Journal of Navigation, 2020, 73(6):1223-1236.

[14] Chen, G., Wang, J., Zuo, L., Zhao, D., & Wen, Y. (2020). Two-stage clutter and interference cancellation method in passive bistatic radar. IET Signal Processing, 14(6), 342-351.

[15] Dehkordi, J. S., & Tralli, V. (2020). Interference analysis for optical wireless communications in network-on-chip (noc) scenarios. IEEE Transactions on Communications, 68(3), 1662-1674.

[16] Wang Y., Jiang Z. (2020). Miniaturised multi-channel millimetre wave filter bank[J]. Electronics Letters, 56(24):1328-1330.

[17] Mohajer, S., Bergel, I., & Caire, G. (2020). Cooperative wireless mobile caching: a signal processing perspective. IEEE Signal Processing Magazine, 37(2), 18-38.

[18] Lin, X., M., Liu, S.,Shi, Z., L. (2022).Multi-Sensor Signal Denoising Based on Adaptive Kalman Filter. Computer Simulation,39(2):507-511.

[19] Yang J, Zhou C. A fault feature extraction method based on LMD and wavelet packet denoising[J]. Coatings, 2022, 12(2): 156.

[20] Liu, S., Chen, P., Woźniak, M. (2022) Image Enhancement-Based Detection with Small Infrared Targets. Remote Sensing, 14, 3232.

[21] Liu, S., Bai, W., Srivastava, G. et al. (2020) Property of Self-Similarity Between Baseband and Modulated Signals. Mobile Networks & Applications, 25(4): 1537-1547.