An Improved Interference Suppression Algorithm Based on Regular WPT in the DSSS Satellite Communication System

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Abstract. Direct Sequence Spread Spectrum (DSSS), which is a typical spread spectrum technology with the characteristic of anti-jam, is widely used in satellite communication systems. Nevertheless, its processing gain is always limited because there are some restrictions on bandwidth and techniques in a practical system. When the interference is over threshold, it will lead to performance degradation. Transform domain processing technology does improve the system's anti-interference ability. Fourier transform possesses a certain analyzing ability in the time and frequency domain, and wavelet packet transform has a better one. Both of their results of signal processing are not satisfied due to the limited capability of the interference detection and suppression. Through comparing and summarizing the traditional algorithm, a novel interference suppression algorithm which combines wavelet packet transform with Fourier transform is put forward in this paper. Simulation results reveal that the proposed interference suppression algorithm significantly improves the anti-jamming capability the DSSS satellite communication system.

Introduction

Spread spectrum communication is an emerging high communication technology. It is widely applied to military communication systems because of its strong anti-jamming ability and multiple accessing performance. However, the anti-interference capabilities of DSSS system is limited to the processing gain. The performance of the system largely degrades when the interference power is higher than the jamming margin. It is of great significance to employ signal processing techniques to improve the anti-jamming performance of DSSS system.

Currently, two classes of interference suppression schemes have been extensively used: time domain processing techniques [1,2] and transform domain processing structures [3,4]. Time domain processing techniques can eliminate the narrowband interference completely because it estimates the interference exactly and is minused from the received signal and the interference free DSSS signal is left. But it needs a convergence time to reach the optimal solution, which is appropriate for slow-altered interference. On the other hand, the transform domain suppression can quickly track the changing interference, such as Fourier transform and Wavelet packet transform, by making use of the different characters which is displayed in frequency domain and the suitable algorithm to detect and suppress interference.

As a significant algorithm in transform domain, Fourier transform plays an important role in transforming time-domain signal of spread spectrum to frequency-domain signal, which provides us an easier way to detect and suppress the interference [5]. Compared with the Fourier transform, wavelet packet transform has a more superior performance--it can track the spectrum varieties of input signal, and then the interference is localized in a definite frequency domain. So the application of wavelet packet transform to interference-excision has aroused intensive interest.

Through comparing and summarizing the traditional algorithm, a novel interference suppression algorithm which combines wavelet packet transform with Fourier transform is put forward in this paper. Firstly, we use Fourier transform to detect and suppress interference primarily before signal reconstruction. Then, we make further judgments and suppression on the reconstructed signal by using wavelet pocket transform in order to eliminate residual interference better.
I. System model

The interference suppression and noise suppression model, which is built based on Fourier transform and wavelet packet transform, is shown in Fig. 1. The signal from the ground receiver usually includes spread spectrum signal component, narrowband interference and noise components. The received signal \( r(k) \) can be expressed as:

\[
r(k) = s(k) + J(k) + n(k)
\]

(1)

where the \( s(k) \) denotes spread spectrum communication signal using the BPSK modulation, \( J(k) \) presents the narrow-band interference signals, \( n(k) \) denotes the additive white Gaussian noise signal with a mean zero and the variance \( \sigma^2 \). Thus, the signal \( s(k) \) based on direct sequence spread spectrum system can be expressed as:

\[
s(k) = \sqrt{P} s_0(k) PN(k) \cos[\omega_0 k + \phi]
\]

where \( P \) represents power level of the spread spectrum signal, \( s_0(k) \) is the binary information bits, \( PN(k) \) is the spreading sequence, \( \omega_0 \) is carrier frequency, \( \phi \) is the phase.

II Theoretical analysis

(1) Fourier transform analysis basic

The narrowband interference is detected and suppressed by FFT based on the power distribution difference between itself and the DSSS signal in frequency domain. Discrete Fourier Transform (DFT) and its inverse transform (IDFT) are defined using the following sequence of functions with recursion:

\[
X(k) = \sum_{n=0}^{N-1} x(n) e^{-j \frac{2\pi n k}{N}} = \sum_{n=0}^{N-1} x(n) W_N^{-nk}, k = 0,1,\ldots,N-1
\]

(3)

\[
x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi n k}{N}} = \frac{1}{N} \sum_{k=0}^{N-1} X(k) W_N^{-nk}, n = 0,1,\ldots,N-1
\]

(4)

where it requires \( N \) multiplications and \( N-1 \) complex multiplications to calculate a \( X(k) \). The amount of calculation is so huge that Fast Fourier transform is introduced.

The \( x(n) \) sequence is divided into an even sequence \( x_e(n) \) and an odd sequence \( x_o(n) \), and the length of them is \( n/2 \) :

\[
x(n) = x_e(n) + x_o(n)
\]

(5)

then
\[ X(k) = \sum_{n=0}^{N-1} x_1(n)W_N^{2nk} + \sum_{n=0}^{N} x_2(n)W_N^{(2n+1)k}, k = 0,1,\ldots,N-1 \] (6)

Due to \( W_N^{2nk} = W_{N/2}^{nk} \),

\[ X(k) = \sum_{n=0}^{N-1} x_1(n)W_{N/2}^{nk} + \sum_{n=0}^{N} x_2(n)W_{N/2}^{nk} = X_1(k) + W_n^k X_2(k), k = 0,1,\ldots,N-1 \] (7)

where \( X_1(k) \) and \( X_2(k) \) are DFT of \( n/2 \) corresponding to \( x_1(n) \) and \( x_3(n) \). Both of \( X_1(k) \) and \( X_2(k) \) are the cycle of \( n/2 \), and \( W_N^k + N/2 \) is equal to \( -W_N^k \). \( X(k) \) can be given as:

\[ X(k) = X_1(k) + W_n^k X_2(k), k = 0,1,\ldots,N/2-1 \] (8)

\[ X(k + N/2) = X_1(k) - W_n^k X_2(k), k = 0,1,\ldots,N/2-1 \] (9)

(2) Wavelet packet analysis basis of DSSS signal

1) Theoretical calculation

Wavelet packet transform has an excellent localization features in time-frequency and multi-resolution analysis ability. When the interference changes in real-time, the interference will be located quickly and efficiently in a limited sub-band and then will be eliminated through the relevant suppression algorithm.

The transform process of Wavelet packet is defined using the following sequence of functions with recursion:

\[ U_{2n}(t) = \sqrt{2} \sum_{k \in Z} h(k) U_n(2t-k) \quad U_{2n+1}(t) = \sqrt{2} \sum_{k \in Z} g(k) U_n(2t-k) \] (10)

where \( U_0(t) \) is the scaling function of \( \phi(t) \), \( U_1(t) \) is the mother wavelet of \( \psi(t) \), \( \{U_n(t), n \in Z\} \) is known as Wavelet Packet Group of \( U_0(t) \), \( \{h(k), k \in Z\} \) and \( \{g(k) = (-1)^k h(L-k-1), k \in Z\} \) respectively represents a low-pass filter coefficient group and high-pass filter set of coefficients of quadrature mirror filters QMF with supporting length L, and satisfy the following condition:

\[
\begin{align*}
\sum_{k \in Z} h(k-2a)h(k-2b) &= \delta_{a,b} \\
\sum_{k \in Z} h(k) &= \sqrt{2}
\end{align*}
\] (11)

Wavelet packet is in discrete form in practical applications. A following recursive discrete wavelet packet transform was given by C.K.Chui[6]:

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The corresponding inverse discrete wavelet packet transform is given as follows:

\[
S^2_{i+1}(i) = \sum_{k \in \mathbb{Z}} h(i-2k) \times S^n_{i+1}(k) \\
S^2_{i+1}(i) = \sum_{k \in \mathbb{Z}} g(i-2k) \times S^n_{i}(k)
\]

(12)

The corresponding inverse wavelet packet transform is given as follows:

\[
S^2_{i}(i) = \sum_{k \in \mathbb{Z}} h(i-2k) S^2_{i+1}(k) + \sum_{k \in \mathbb{Z}} g(i-2k) S^2_{i+1}(k)
\]

(13)

where \( l \) represents the corresponding layers of wavelet packet decomposition, \( n \) indicates the lateral nodes position of the corresponding level; \( S^n_i \) represents the decomposition sequence of node \( n \) at the layer of \( l \). The received signal can be separated to a uniform or non-uniform spectral sub-band by exploiting wavelet packet transform.

2) Wavelet decomposition

As shown in Fig.2, the received spread spectrum signal is decomposed by wavelet packet of M-ary in order to get a rule wavelet packet decomposition tree. The number of nodes is \( M^{(L-1)} \) in every layer, where \( M \) is an ary number, \( L \) is the decomposition level.

![Diagram of rule wavelet packet decomposition tree (decomposition level 3) and the corresponding uniform bandwidth of decomposition.](image)

III. THE INTERFERENCE POSITIONING AND SUPPRESSION ALGORITHM ON THE BASIS OF WAVELET PACKET TRANSFORM

The steps of the proposed interference suppression method of combining Fourier transform with wavelet packet transform are as follows:

**STEP 1** DSSS signal is processed with FFT transform, and the value \( \theta_i \) of signal spectral components can be achieved and then set a detection threshold \( G \) whose value is the sum of the standard deviation and the median of \( \theta_i \). If \( \theta_i \) satisfies the condition \( \theta_i \geq G \), it indicates that the value of the spectral component is mainly composed of interference and it will be set as zero directly; The remaining components are without any processing. Finally, the DSSS signal will be reconstructed.

**STEP 2** As is shown in the Fig.2, the reconstructed DSSS signal is evenly decomposed to a rule wavelet packet using wavelet packet transform algorithm, and then read coefficient of each node, calculate the variance of coefficient and get the minimum variance \( \sigma^2_{\text{min}} \). Finally, reset the
coefficient of each node with scale factor $\sigma_{\text{min}}^2 / \sigma_i^2$, where $\sigma_i^2$ is the variance of each node. It can be inferred that the interference will be significantly suppressed, when the variance $\sigma_i^2$ is great, in other words, the scale factor $\sigma_{\text{min}}^2 / \sigma_i^2$ is small. On the other hand, when the variance $\sigma_i^2$ is close to $\sigma_{\text{min}}^2$, the coefficient of each node will not be attenuated.

IV. THE SIMULATION RESULTS AND ANALYSIS

In the simulation subsection, we spread the signal with a pseudo-random sequence of length of 32 and the modulation scheme is BPSK modulation, wavelet packet decomposition takes generation function of db16 (Daubechies wavelets), M of M-Ary takes two, the channel of AWGN is taken. Because the spreading code length is 32, the system has a certain anti-interference tolerance, in order to reflect the performance of the algorithm for interference suppression well, jamming-to-signal ratio (JSR) must be greater than $15.051\text{dB} \left(10 \times \log_{10} (32) = 15.051 \text{dB}\right)$, jamming-to-signal ratio is from 20 to 50dB in simulation process. The maximum decomposition level of wavelet packet tree is 5 to satisfy both the suppression performance and the complex of decomposition. The normalized digital frequencies of two-tone interference to spreading rate are 0.314 and 1.57, phase in $[0, 2\pi]$ is uniform.

From the Fig.3, it can be seen that interference deteriorate the performance of the DS system seriously. It is difficult to continue to communicate normally without suppression, while the transform domain processing structures can effectively improve the performance of the system. From the graph, we can know that the inhibitory effect of traditional FFT interference suppression is the worst, and the effect of the interference suppression algorithm based on wavelet packet transform is better than the former, while the effect of the novel interference suppression algorithm which combines wavelet packet transform with Fourier transform is the best.

From the Fig.4, The traditional FFT interference suppression has inhibition on interference in a certain degree. Comparatively, the interference suppression algorithm based on wavelet packet transform present a more excellent performance, the anti-interference effect of the novel interference suppression algorithm which combines wavelet packet transform with Fourier transform is the best.

Figure 3. The BER performance comparison versus jamming-to-signal ratio for different algorithms (SNR = 8dB).

Figure 4. The BER performance comparison versus signal-to-noise ratio for different algorithms (JSR = 8dB).
CONCLUSION

In this paper, a novel interference suppression algorithm which combines wavelet packet transform with Fourier transform is proposed. Simulation results reveals that the considered interference suppression algorithm achieves a more excellent performance, since it limits the interference to a few number of sub-bands to avoid damage to the useful signal and then eliminates the interference. Therefore, our proposed algorithm significantly enhances the anti-interference ability of DSSS satellite communication system.

REFERENCES