

Narrow-band Interference Suppression in DSSS Systems Using Efficient Adaptive Filters

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Abstract

In this paper, we present a novel adaptive interference suppression method by combining with time-domain filters and frequency-domain filters. Demonstrated by simulation results, the method can significantly improve the performance of DSSS receiver serving at the narrow-band interference environment. The improvement of resulting SNR after NBI suppression will further enhance along with the increasing of interference intensities. Compared with the simple interference nulling and amplitude limiting processing, the proposed method has less complexity and better real-time performance without losing much signal performance.

1. Introduction

Direct sequence spread spectrum (DSSS) communication techniques offer a promising solution to an overcrowded frequency spectrum amid growing demand for mobile and personal communication services, because it possesses a number of attractive features, such as anti-disturbance, privacy, multipath fading resistance, increasing transmission capacity, etc. In the mobile and personal communication systems, DSSS systems share the same frequency band with the existing narrow-band frequency communication systems. Therefore the performance would inevitably be affected by narrow band interference (NBI).

Since NBI becomes a wideband signal after de-spreading, the system inherently can suppress NBI to a certain extent by using an appropriate bandpass filter[1]. However, the comparable performance is based on the assumption that direct spread (DS) signal power is great enough, or the spectrum of DS signal is much wider than the NBI. That is, the anti-interference

capability of a DSSS system is directly proportional to the spreading gain of itself. In case of the spreading gain decreases or interference signal is strong, this in turn may cause the performance to be somewhat unsatisfactory. However, practically and pre-conditionally, neither mobile nor personal communication systems will allow DS signal transmitting power of intruding the existing narrow-band communication systems. In addition, when such factors of communication rate and system engineering practicability are taken into consideration, the cycle of the PN sequence can not increase unboundedly, and the same, the de-spread module at the receiver can not unlimitedly expand NBI spectrum in DS communication system. All these factors confront the DSSS with inability of rejecting NBI. In order to improve the system anti-disturbance on condition that the system itself will not increase the spreading gain, an appropriate NBI suppression techniques need be employed prior to de-spreading,

2. NBI suppression technology

At present, based on digital signal processing technology, NBI suppression technology can be roughly sorted by time-domain filtering algorithm and transform domain filtering algorithm. These algorithms with fixed parameters exert good restraint on the NBI which is statistically stationary. However, due to the complex radio environment and the continuously changing of the interference signal, the statistical characteristics are always changing which leads to the fact that the algorithms of fixed parameters can not effectively suppress the time-varying NBI. Thus the parameters of the filter must be updated continuously. It is a complicated and time-consuming process to solve the parameter through the statistical characteristics. If the bit rate is too fast, the calculation may not meet the need of real-time processing. So

adaptive filter technologies turned out to be the mainstream of NBI suppression technologies in DSSS [2].

Among those adaptive algorithms, adaptive filter technologies that effectively restrain NBI can be categorized to the adaptive time-domain filtering algorithm based on the prediction / interpolation technology, the adaptive notch-filtering algorithms in transform domain and other auxiliary algorithms [3].

Adaptive time-domain filtering algorithm can fully inhibit the NBI in theory, but its stability is strictly required, still less its slower convergence and worse real-time ability. As to the adaptive transform-domain algorithm, data sequences of incoming signals of NBI suppression module are projected to the frequency domain via a certain time-frequency transform function, for instance, FFT. The algorithm makes nulling or similar treatment on the frequency bands, where the NBI resides, located through the comparison between sub-band signal energy and sub-band energy threshold, so as to achieve NBI suppression. Although the real-time quality relative to time-domain adaptive filtering methods has been significantly improved, the time windowing introduced before transformation makes the frequency domain produce much larger side lobes, which make it difficult to completely remove interference. Moreover, when the higher frequency resolution is required, a longer sub-FFT data are needed, and it will result in increasing complexity and time delay for partitioning calculation. Since the sub-band energy threshold of common adaptive frequency-domain filtering algorithm is usually designed to be unified values, the NBI suppression performance will decline drastically when the background color spectrum is dense.

An adaptive NBI suppression method with time-domain and frequency-domain combination is proposed to remedy the above-mentioned problems. The method presents good performance of NBI suppression with low time delay and low complexity.

3. NBI suppression receiver system model

Fig. 1 depicts a simplified block diagram of NBI suppression receiver, which combines processing of frequency-domain filtering and time-domain filtering. The spread spectrum signals received are divided into two ways passing through the A / D converter, and are input to the frequency-domain processing module and time-domain processing module respectively. The frequency-domain processing module consists of the FFT module, interference detection module, adaptive interference threshold generation module, and FIR

time-domain filter coefficient generation module. The time-domain processing module is a FIR filter module.

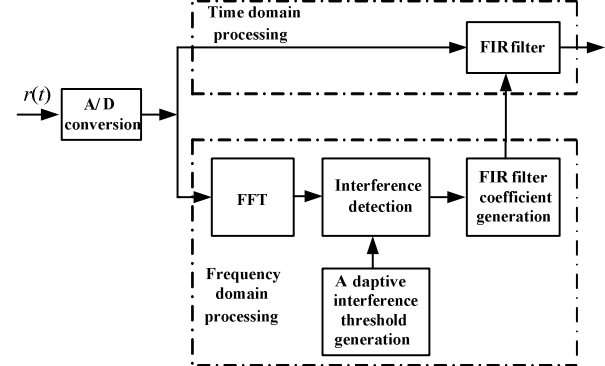


Figure 1. A simplified block diagram of NBI suppression receiver

The received can be expressed as

$$r(t) = s(t) + n(t) + i(t) \quad (1)$$

where $s(t)$ is the DS-SS signal and can be expressed as

$$s(t) = \sum_{n=1}^N a_n g(t - nT) c(t) \cos(2\pi f_c t) \quad (2)$$

where a_n is the message sequence, and $\{a_n = \pm 1, 1 \leq n \leq N\}$, $g(t)$ is the square pulse signal with unit energy during T interval, T is the duration of the information bit. $\cos(2\pi f_c t)$ is the modulation carrier, $c(t)$ is the spreading code signal and it can be expressed as

$$c(t) = \sum_{i=1}^{L_c} c_i p(t - iT_c) \quad (3)$$

where c_i is the PN sequence, $c_i \in \{\pm 1\}$, L_c is spreading multiple, $p(t)$ is a square pulse signal with unit energy during T_c interval, T_c is spreading code duration.

$n(t)$ is the Gaussian white noise which unilateral power spectral density is $N_0/2$, $i(t)$ is NBI which can be approximated by a deterministic finite sum of sinusoids, and is expressed as below

$$i(t) = \sum_{j=1}^K A_j \cos(2\pi f_j t + \phi_j) \quad (4)$$

where K is the number of single-frequency interferences, A_j is the amplitude of single-frequency interference, f_j is the frequency of single-frequency interference, ϕ_j is the original phase of single-frequency interference.

The received DS signal which contains narrow-band interference and the Gaussian white noise is sampled by the A / D firstly, and then exported to FFT module with windowed FFT. The interference detection module will compare each sample point from received signal spectrum with the threshold generated by the adaptive interference threshold generation module. The spectrum points with higher amplitude. Then the center frequency and bandwidth of the interference signal are sent to FIR time-domain filter coefficient generation module. Based on the interferences information, the module designs the FIR filter coefficient and sends the coefficient to the FIR filter module for the time-domain processing part. The FIR filter will proceed the time-domain filtering treatment with FIR filter coefficients.

In the above processing procedure, the time-domain processing is only deal with FIR filtering, and more complicated processings, such as interference signals estimation and filter coefficient design of batch treatment are completed in a frequency-domain processing part, which can sufficiently enhance the real-time ability of the system. Although the current FIR filter coefficients used in time-domain filtering are estimated based on the data blocks coming from the previous time unit, however, in an actual electromagnetic environment, interference signals varies much less in the lag time with respect to pre-estimated values, as not to impact on interference suppression. Compared with the simple frequency-domain interference suppression based on FFT, the complexity of this method is only half of it, while the real-time performance is significantly improved.

4. Adaptive interference threshold generation

If adaptive frequency-domain filter algorithm based on one-way input architecture[4] is convergent, the filter power output will be expressed as

$$P_{\text{out}} = [1 - w(\infty)]^2 \cdot \sigma^2 \quad (5)$$

where $w(\infty)$ is adaptive frequency-domain filter weight coefficient, can be expressed as

$$w(\infty) = \frac{\sigma^2}{\sigma^2 + B} \quad (6)$$

where σ^2 is the input signal power; B is energy threshold.

In (5) and (6), $\sigma^2 \ll B$, $w(\infty) \approx 0$, $P_{\text{out}} \approx \sigma^2$; $\sigma^2 \gg B$, $w(\infty) \approx 1$, $P_{\text{out}} \approx 0$. When the signal power is much smaller than the energy

threshold, $w(\infty)$ is approaching zero, the signal energy will be retained; when the signal power is far greater than the energy threshold, $w(\infty)$ is approaching to 1, the signal energy will be analoging nulling, that is, the signal energy is suppressed.

Obviously, setting of energy threshold B is such a major factor in the adaptive frequency-domain filtering algorithm for the NBI suppression.

The adaptive interference threshold generation module in this paper is used to complete the interference threshold. It is designed as follows:

Choose N_{FFT} points out of the received DS signal, and it is expressed as

$$s_w(n) = s(n)w(n) \quad (7)$$

where $s(n)$ is the spread spectrum signals after A / D conversion, $n = 1, 2, \dots, N_{\text{FFT}}$, N_{FFT} is the FFT points. $w(n)$ is the window function, $s_w(n)$ is the signal after windowed FFT. A N_{FFT} -point FFT is computed for $s_w(n)$ and is expressed by

$$u(m) = \sum_{n=1}^{N_{\text{FFT}}} s_w(n) e^{-j2\pi nm / N_{\text{FFT}}} \quad (8)$$

where $u(m)$ is the FFT of $s_w(n)$, $m = 1, 2, \dots, N_{\text{FFT}}$. The signal energy of each frequency point is expressed as

$$\xi_m = [\text{abs}|u(m)|]^\lambda = [\sqrt{\text{Re}^2(u(m)) + \text{Im}^2(u(m))}]^\lambda \quad (9)$$

where λ is the weighted factor, $\lambda \geq 1$. Adaptive threshold is determined by the energy of frequency point of M number of the nearest FFT blocks and can be expressed as

$$B = B_{\text{min}} + \eta \frac{1}{MN_{\text{FFT}}} \sum_{i=1}^M \sum_{m=1}^{N_{\text{FFT}}} \xi_{i,m} \quad (10)$$

where B is the adaptive threshold, B_{min} is the minimum threshold denoting spread spectrum signals have no interference, M to the number of FFT blocks determining the adaptive threshold, η is a coefficient relative to the received signal which adjustable per the distance between transmitter and receiver.

5. Adaptive NBI suppression simulation

The adaptive NBI suppression method is simulated in this section to verify the analyses and the

simulations about interference nulling and amplitude limiting filtering are also shown for comparison at the same time. Simulation parameters are set as follows: data rate is 1Kbps, the length of PN sequence 1023, spread spectrum code rate 1023Kbps, Gold code used, the production polynomial about optimization pair of m sequence $x^{10} + x^3 + 1$ and $x^{10} + x^9 + x^8 + x^6 + x^3 + x^2 + 1$, carrier frequency 1023MHz, sampling frequency 4092MHz, simulation codewords 100,000, the point frequency interference used, the length of FFT / IFFT in frequency-domain transform 4,096, and the other settings to adaptive interference threshold module $\lambda = 1$, $M = 1$, $\eta = 4$.

Fig.2 depicts the received signal spectrum containing point frequency interference with interference frequency of $f_j = f_c - R_s / 2$ and SIR is -35 dB, denoting a distinct interference popup. Fig.3 depicts the filtered signal spectrum after the FIR filter via NBI suppression. In Fig.3, there is a noticeable spectrum declination near the interference point indicating successful suppression to be the interference signal by the combining method introduced in the paper. As a result, a certain amount of received signal energy is lost, however, the minority loss of energy will barely effect on result after the spectrum is spreaded. It can be further demonstrated by the latter simulation.

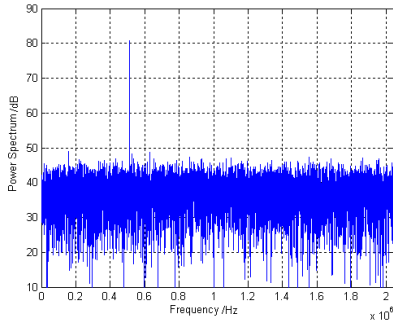


Figure 2. Spectrum before NBI suppression

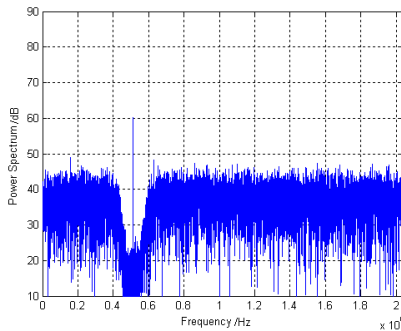


Figure 3. Spectrum after NBI suppression

Fig.4 depicts the BER curves pre-and-post NBI suppression when interference frequency is $f_j = f_c - R_s / 2$ and SIR is -25dB. In Fig.4, the system has significantly improvement via NBI suppression. When $BER = 10^{-4}$, the performance is comparatively improved by 4dB, it differs with that of theoretical curve of non-interference only by 0.5dB and competes with that of interference nulling and amplitude limiting processing of frequency-domain transformation by 0.5dB.

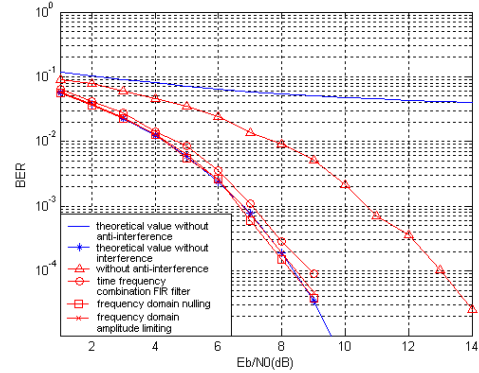


Figure 4. The system performance when $f_j = f_c - R_s / 2$ and SIR is -25 dB

Fig.5 depicts the BER curves pre-and-post NBI suppression when SIR is -35dB. In Fig.5, the system via NBI suppression is more largely improved than that before NBI suppression. The NBI suppression effects of interference nulling and amplitude limiting processing are slightly better than FIR filtering with respect to the receiver, as shown in Fig.5. However, both methods are based on the block transformation. The FFT / IFFT should be long enough to improve the frequency resolution. It will be a complicated and time-consuming process. The proposed method provides parallel processing of time-domain and frequency-domain, so as to reduce the complexity to a half, and to improve real-time performance prevailing over each of the two algorithms.

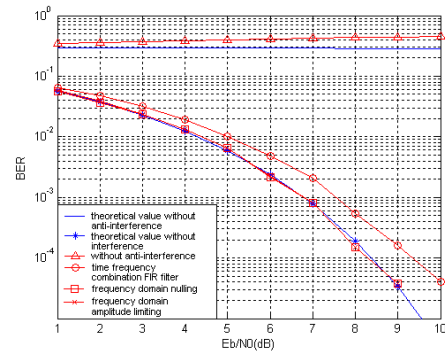


Figure 5. The system performance when $f_j = f_c - R_s / 2$ and SIR is -35 dB

Fig.6 and Fig.7 depict respectively system performance curves pre-and-post filtering when interference is approaching the carrier frequency, i.e. $f_j = f_c - 500$ Hz. The system performance has been improved significantly by the filtering as shown in Fig.6 and Fig.7.

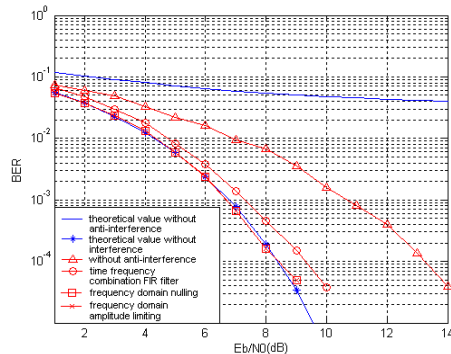


Figure 6. The system performance when $f_j = f_c - 500$ Hz and SIR is -25 dB

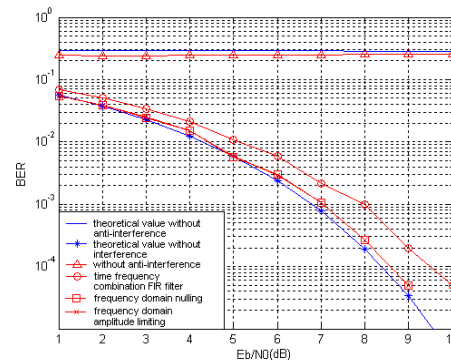


Figure 7. The system performance when $f_j = f_c - 500$ Hz and SIR is -35 dB

6. Conclusion

A novel adaptive interference suppression method with time-domain and frequency-domain combination was proposed. The method can significantly improve the performance of DSSS receiver serving at the narrow-band interference environment. Simulation results demonstrated that, when SIR is -25dB, the system performance only reduces by 0.5dB compared with that of the non-interference system, but will be improved by 4dB prevailing over that of the system without NBI suppression. A further improvement of resulting SNR via NBI suppression will be attained with the increasing of interference intensities. Compared with the simple interference nulling and

amplitude limiting processing, the proposed method has less complexity and better real-time performance with slight signal losing.

7. References

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