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Tone interference suppression in DS-SS systems with modified DFT

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ABSTRACT

The performance of traditional interference excision methods based on the discrete Fourier transform (DFT) in direct sequence spread spectrum (DS-SS) systems varies significantly with the frequency of the interference because the DFT of the interference becomes more dispersive with the increase of grid biases in the DFT operation. This paper presents a new excision method using modified DFT (MDFT) with an estimated grid bias. Minimum dispersion of the interference is achieved in the MDFT domain. Both theoretical analysis and experimental simulation are presented to show that the interference can be excised with a minimum distortion of the desired signal in a large range of interference-to-signal ratio.

1. Introduction

Narrow band interference excision in DS-SS communication systems has been extensively studied in recent years [1–8]. Among the numerous reported excision methods, the transform domain-based excision technique is the most popular framework for the interference excision because it has a simple concept and can be easily implemented. It usually transforms the received signal into another domain where the interference can be distinguished from the desired signal and, therefore, can be easily suppressed. For the tone interference, the Fourier transform (FT)-based frequency excision method was studied extensively [1] because of its simple implementation and the easiness of tracking rapidly changing interference. The FT implemented by surface acoustic wave devices was originally applied to excise the tone interference [1,2]. The discrete FT (DFT)-based excision technique was developed to provide a larger dynamic range [9]. In practice, excision has to be implemented within a finite observation interval. Some window function has to be used to segment the interfered signal for the DFT computation. This windowing operation undesirably causes spectral leakage into the side lobes. It is extremely difficult to remove the interference components, without distortion of the desired signal, from the DFT side lobes of the interfered signals because of the difficulties in distinguishing the interference components from the desired signal. Previously, the spectral leakage problems were alleviated by time-weighting DFT-based methods [4–8]. In this method, various time weighting techniques were applied by using non-rectangular windows to minimize the magnitudes of the side lobes. Meanwhile, several frequency mapping algorithms, including fraction zeroizing, threshold zeroizing and fraction clipping [6,7], were also developed as the complement of the time-weighting DFT-based methods for interference excision.

Since the DFT is evaluated with the grid of discrete frequencies, the DFT of the windowed interference is shifted by a distance decided by the frequency of the interference. If the product of the interference frequency and the processing block length is an integer, the peak of the spectrum is sampled and the DFT of the interference becomes most concentrated. If the bias, which is the distance of the above product to the nearest integer,

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increases, the DFT of the interference becomes more dispersive. This phenomenon severely influences the complexity and performance of the time weighting DFT-based excision method. In general, additional procedures have to be used to decide the optimal number of bins to be excised when the DFT of the interference becomes more dispersive. The performance metrics [6,7] corresponding to different combinations of windows and frequency mapping algorithms are developed according to the dispersion severity of the interference in the DFT domain. The other issue, which is more important, is that the so-called optimal performance is merely a compromise between the residual energy of the interference and the distortion of the desired signal because the energy of the remaining interference after excision and that of the desired signal decrease when the number of the DFT bins being excised is increased.

In this paper, a modified DFT (MDFT) is proposed with an additional estimated bias to achieve the minimized frequency dispersion of the interference. Since MDFT is the traditional DFT shifted by a distance of the bias, the concentration of DFT does not vary with the frequency of the interference. The closed forms of the bit error rate (BER) for the traditional DFT-based method and the proposed method are derived with respect to the estimation performance of the bias and the number of the excised bins in the DFT domain. For the traditional DFT-based methods, the performance is sensitive to the frequency of the interference because the dispersion of the interference in DFT domain is decided by the frequency of the interference. If the interference is dispersive in the DFT-domain, increasing the number of the excised bins may improve the performance. Nevertheless, the performance is still much worse than that when the DFT of the interference is concentrated. With the newly estimated bias, it is shown that the proposed method achieves significant performance enhancement regardless of the frequency of the interference. This is because the grid bias is estimated and used to shift the DFT to achieve the minimum dispersion of the interference in the MDFT domain. A condition for achieving the optimal performance with minimum distortion of the desired signal is also derived in terms of the estimation accuracy of the bias. For a specific estimation method, it is found that the condition is always satisfied except when interference-to-signal ratio (ISR) is extremely large.

2. MDFT-based method

It is assumed that binary phase-shift-keying (BPSK) signals are used in a DS-SS systems and normalized by the energy of the transmitted signal. The received BPSK signals are sampled at the chip rate and have the form

$$r(n) = p(n)s + A_0 g(n) + w(n), \quad 0 \leqslant n < N, \tag{1}$$

where $A_0 = \sqrt{\mathrm{ISR}}$ is the amplitude of the interference, $p(n)$ is the PN sequence of length L, s, the transmitted bit, is either 1 or -1, $g(n)$ is the tone interference with the form of $e^{j2\pi(k_0 n+\theta)}$, and $w(n)$ is the additive white Gaussian noise with zero mean and variance $\sigma_n^2 = 1/\mathrm{SNR}$. Also k_0 and θ represent the frequency and the phase of the interference, respectively, and SNR is the signal to white Gaussian noise energy ratio.

A proper type of the window is needed for the proposed interference excision method. Rectangular window is selected for two reasons. The first one is that adaptive demodulation techniques, instead of the conventional maximum likelihood receiver, are required if non-rectangular windows are used [5,8]. The use of adaptive demodulation complicates the receiver implementation, and therefore increases the total computational cost. The second reason, which is more important, is that the interference with rectangular window can be most concentrated compared with that using other windows. The DFT of the interference is a sampled version of SINC ($\sin(\pi x)/x$) function, as shown in Fig. 1, where the dash line represents the SINC function and the solid line represents the DFT of the interference. It can be seen from Fig. 1(a) that if the bias $\delta = 0$, the DFT of the interference has only one non-zero maximum value in the main lobe

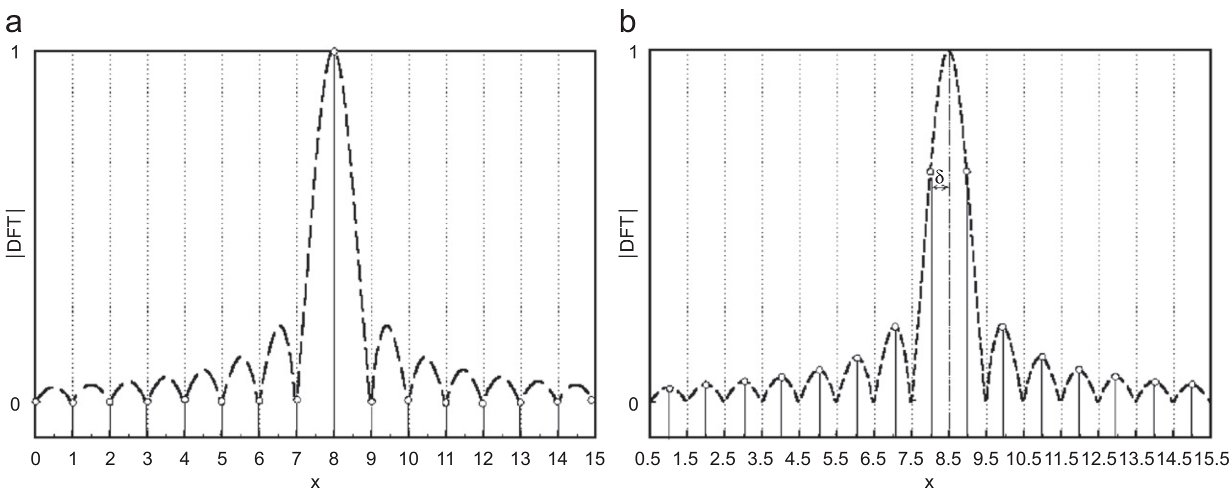

Fig. 1. The windowed interference in the frequency domain. (a) (k_0N) is an integer and (b) (k_0N) is not an integer.