PERFORMANCE ANALYSIS OF AN STFT-BASED BROADBAND INTERFERENCE EXCISION ALGORITHM IN DS-SS SYSTEMS

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ABSTRACT

A novel short-time Fourier transform (STFT)-based interference excision algorithm in direct-sequence spread spectrum (DS-SS) communication systems is introduced. The proposed excision algorithm is developed for chirp-type signals that have broadband frequency characteristics. It is based on the time-frequency analysis of received signals. To analyze the interference, STFT of the received signal is computed and thresholded. The interference detection is followed by an inverse-STFT computation to estimate the high-power jamming signal. The estimated jammer is then subtracted in time domain before demodulation. Simulations present adequate interference estimation results with mean estimation errors less than 0.01%. Various scenarios with different jammer-to-signal ratios (JSRs) and signal-to-noise ratios (SNRs) vs. bit error rates (BERs) are presented for single and multi-component chirp signals. Interference excision algorithms improve the system performance more than an order of magnitude.

I. INTRODUCTION

Today many communication systems make use of the advantages of spread spectrum techniques realized by either frequency-hopping or direct-sequence methods. In direct-sequence spread spectrum (DS-SS) systems, transmitted signal is spread over a bandwidth that is much wider than the minimum bandwidth necessary to transmit the information [1].

Although DS-SS systems have an intrinsic anti-jamming capability to some extend, both unintentional and intentional interference mitigation is still an important problem in communications, including military applications. There are various techniques of interference excision in the literature [2-4]. Many of them employ time-frequency distributions in the analysis of interference, including wavelet transform, Wigner distribution (WD), short-time Fourier transform (STFT) and their variants. Since time-frequency distributions are designed to characterize the frequency content of signals as a function of time and are usually applied to analyze process and synthesize signals with time-varying spectral content.

The standard usage of DS-SS techniques is usually as follows. To convert the data signal to a spread-spectrum signal, modulated data is multiplied by a pseudo-noise (PN) code with a chip rate much higher than the data bit rate. The ratio of the bit duration of data and chip duration of the PN code indicates the processing gain (PG) of the system. DS-SS systems have built-in interference suppression ability against jamming. However, if jammer power exceeds the PG, then DS-SS systems need additional preprocessing to increase the system performance.

Time-frequency distributions have been used as powerful analysis tools for depicting the jammer power on time-frequency plane [2- 3]. In [2], WD is used in the excision of interference signals. WD generates sharp and well-localized time-frequency representations of single-component signals; however it becomes ineffective for multi-component signals introducing cross-terms on the time-frequency plane [5].

To avoid the effects of cross-terms in WD, STFT may be employed as an attractive alternative in interference excision. STFT is defined as,

$$STFT_x(t,f) = \int x(t')h(t'-t)\,e^{-j2\pi f t}\,dt \qquad (1)$$

where h(t) is a low-pass, unit-energy window function centered at the origin and the spectrum of the windowed signal is computed for all time. STFT is a linear time-frequency distribution, it provides uniform resolution for all frequency bands on the time-frequency plane [6].

In the literature, interference excision algorithms on the time-frequency plane are usually followed by band-pass filters, notch filters or filter banks. In [3], after jammer analysis by STFT, zero-phase excision filters are used and in [5], FIR filters are applied to the received signal to excise jammer signals.

One of the distinguishing characteristic of this paper compared to [3-4] is the simulation of a whole DS-SS communication system with an interference excision algorithm. Moreover, the system performance is investigated by varying power of jammers that are mixed to the system. In this paper a novel STFT-based interference excision system is proposed. As the power of interfering signals is usually much higher than the desired signal in DS-SS communication systems, they can easily be identified on the time-frequency distribution of the received signal. Then, excision is achieved by signal extraction in time-domain.

The remainder of this paper is organized as follows. In Section II, a DS-SS communication system is described. In Section III, time-frequency distribution-based excision model is introduced. In the excision algorithm, an estimation of the interferer is synthesized using thresholded STFTs. The simulation results are discussed by presenting both SNR and JSR vs. BER values in Section IV. Finally, conclusions are drawn in Section VI.

II. DS-SS SYSTEM MODELING

In the designed DS-SS communication system, data signal *d(t)* is defined as,

$$d(t) = \sum_{-\infty}^{\infty} d_k \, g(t - T_b) \qquad (2)$$

where d_k is $d_k \in \{-1, +1\}$, *g(t)* is a unit-amplitude rectangular pulse and T_b is defined as $T_b = 1/B$, *B* is the bandwidth of the data. Data signal *d(t)* is modulated by BPSK modulation generating *m(t)*,

$$m(t) = A_c d(t)\cos(2\pi f_c t) \qquad (3)$$

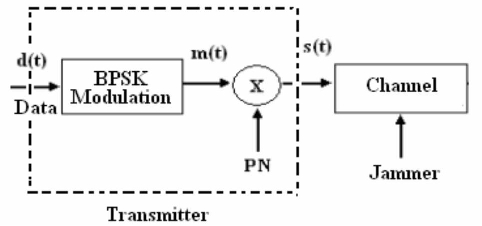
In (3), A_c and f_c are defined as the carrier amplitude of BPSK modulation and its frequency, respectively. Modulated data is transformed to the SS signal *s(t)*, by a PN code multiplication,

$$\begin{aligned} s(t) &= m(t)PN(t) \\ &= A_c d(t)\cos(2\pi f_c t)\left[\sum_{n=-\infty}^{\infty} PN[n]\,h(t - nT_c)\right] \end{aligned} \qquad (4)$$

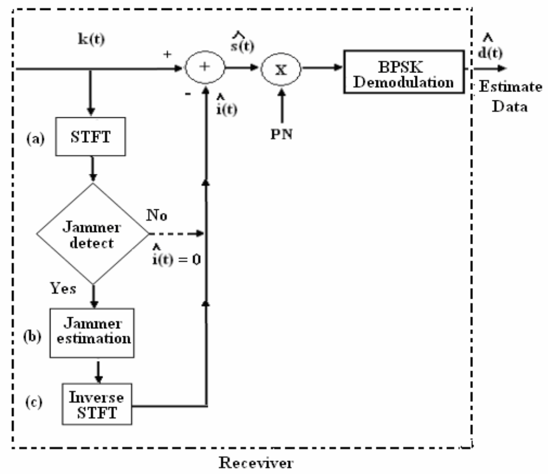
where PN(t) is the PN code, and *h(t)* is a unit-amplitude rectangular pulse and is the bit duration of *h(t)*. The transmitter and receiver parts of DS-SS system which are designed for excision algorithm are given Fig. 1 (a) and (b), respectively.

In the simulations, the channel effect is represented by AWGN and zero-mean white Gaussian noise is mixed to the modulated data.

The interference excision algorithm is proposed at the receiver as in Fig. 1. At first, STFT of a block of received signal *k(t)* is computed. Then, the STFT is used in the estimation of the mixed interference. To estimate the localization of interfering or jamming signal on the time-frequency plane, the support is constituted by thresholding the STFT image. The pixel values of the support image are assigned as either ‘0’ or ‘1’. Then, original values of STFT, corresponding to the coordinates determined by the support are taken into account.



(a)



(b)

Thus, an estimation of the STFT of the interference or jamming signal is obtained. By computing the inverse-STFT, estimated interference or jammer is computed in time-domain. Finally, the estimated jammer is subtracted from the received signal in time domain. The processing is finalized by correlation by PN code and BPSK demodulation. In Section 3, interference excision procedure based on the STFT and inverse-STFT computations is explained in detail.

III. TIME-FREQUENCY DISTRIBUTION BASED EXCISION MODEL

The main idea of STFT is to Fourier analyze time-varying signals during appropriate short time intervals and obtain the entire time-frequency behaviour of the signal by concatenating consecutive analyses [7]. At the receiver, STFT of the received signal is evaluated as in Fig. 2 (a) and Fig. 2 (b), for no-jammer and chirp-type jammer-mixed signal, respectively. The analytical form of chirp-type jammer is given in (5),

$$i(t) = \sum_{k} e^{j\pi(a_k(t-t_k)^2+2b_k(t-t_k))} \tag{5}$$

where the chirp rate $a_k = \arctan(\phi_k)$, a_k is the number of chirp components. In these simulations, chirp parameters are taken as $\phi=\pi/6$ and $\phi=\pi/3$, $b_1=-3$, $b_2=2$ and $t_1=3$, $t_2=1$.

In the STFT computations, a 129-point Hanning window is used. Following the STFT computation, a detection procedure compares the total energy of the STFT to a designated threshold value and decides, whether any interfering signal exists or not. If an interference signal is detected, the procedure continues, otherwise, the algorithm assumes the estimated interference $\hat{i}(t)$ as,

$$\hat{i}(t)=\begin{cases} i(t), & \max\limits_{i,j}(S)>\gamma \\ 0, & \max\limits_{i,j}(S)<\gamma \end{cases} \tag{6}$$

where $i(t)$ is the inverse STFT for the estimated jammer and is indicated threshold value. The threshold is chosen experimentally by comparing scenarios with AWGN channel characteristics for both jammer-free and low-power jammer situations.

In the algorithm, the support of the jammer on STFT is constituted by thresholding the STFT as in Fig. 2 (c).
As the jammer power in the simulations, is higher than the transmitted signal, jammers are well-localized on the STFT image. The support is composed of pixel values of '0' or '1'. Then, using the original values of STFT corresponding to the coordinates determined by the support, an inverse-STFT operation is performed. Inverse-STFT computation employs the overlap-add (OLA) method [8]. Detailed computational complexity of the overall system is given in Table 1.

In Table 1, N denotes for the STFT window length, *a* and *b* are row and column of STFT image, respectively. The number of flops required in this algorithm is less than many other proposed algorithms, including the one in [2], which employs WD and least squares methods to excise interference.

An immediate next step for this system design is to employ a classical rake receiver, decreasing the fading and shadowing effects. In this paper, the focus of the performance analysis is on the excision algorithm. In Section IV, several computer simulations that present the effect of both SNR and JSR versus BER are given.

Table 1. Computational complexity of jammer excision in the DS-SS system.

Operation	**Approx. no of flops**
STFT	$N^2 \log N$ multiplications
Inverse-STFT	$N^2 \log N$ multiplications
Thresholding	*2 x a x b* comparisons

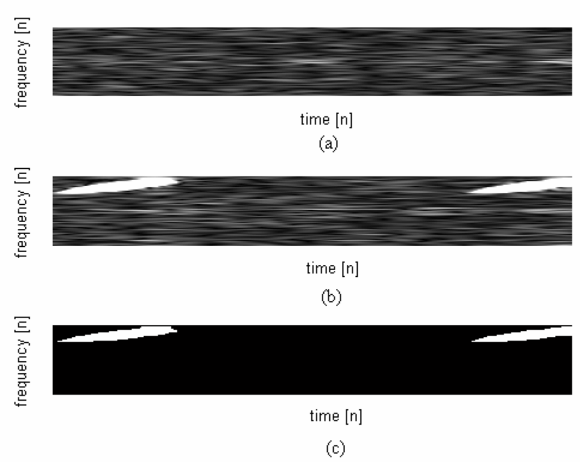


Figure 2. (a) STFT of received signal when no jammer is mixed, (b)STFT of chirp signals with duty cycle of 33% in the DS-SS system and (c) the support.

IV. SIMULATIONS

In the designed DS-SS communication system, Fig. 2 (a) shows the STFT of received signal when no jammer is mixed at the channel. Moreover, Fig. 2 (b) shows the STFT of a chirp-type jammer signal that has a duty cycle of 33%. Fig. 2 (c) presents the support which is obtained from the STFT shown in Fig. 2 (b).

After the jammer is synthesized, it is subtracted from the received signal in time domain. Estimation error of simulations is shown in Fig. 3(c). JSR is selected as 20 dB and BER is evaluated for SNR values from 1 dB to 7 dB. Mean estimation errors happen to be less than 0.01%.

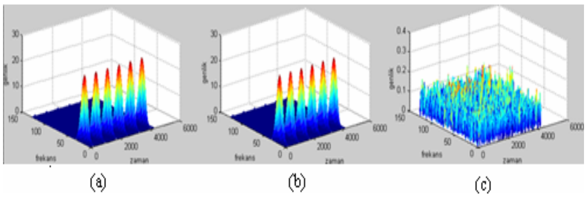


Figure 3 In the DS-SS system; (a) STFT of total received signal, (b) estimation of the jammer signal, (c) estimation error.

In the first part of the simulations, JSR is fixed to 20 dB and SNR is varied. SNR vs. BERs are computed for 10.000 trails. Fig. 4 represents the BER vs. SNR curve for the data together with the chirp jammer whose STFT is shown in Fig. 2 (b).

If jammer consists of two chirp components, BER vs. SNR performance gets worse as presented in Fig. 5. To compare the success of the interference excision part of the system, BER vs. JSR curves for the "pre-processing disabled" and "pre-processing enabled" cases for a single-component chirp jammer are simulated. In this situation, SNR is set to 7 dB and JSR is changed from 0 dB to 60 dB which means that no jammer signal is mixed into the data.

Interference excision algorithms improve the system performance more than an order of magnitude as shown in Fig. 6. As the power of the interference rises, the spreading gain loses its ability to compensate for the presence of the jammer and consequently, the BER increases.

In the simulations, for 7 dB SNR, when jammer excision algorithm is enabled BER is less than 10^{-2}. However, if this algorithm is not used, BER is obtained nearly 10^{-1}. Therefore, the overall system improves noticeably.

V. CONCLUSION

In this paper, excision of broadband interference in a DS-SS communication system is proposed and simulated by subtracting an estimate of the interference from the received signal in time domain. The estimation of the interference is obtained by employing STFT followed by thresholding [8].

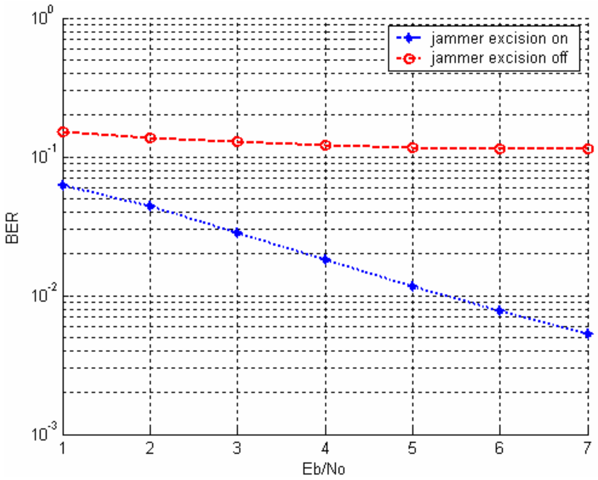


Figure 4 BER vs. SNR values of both cases, in which preprocessing is disabled and enabled for a single-component chirp jammer with 33% duty cycle (JSR = 20dB).

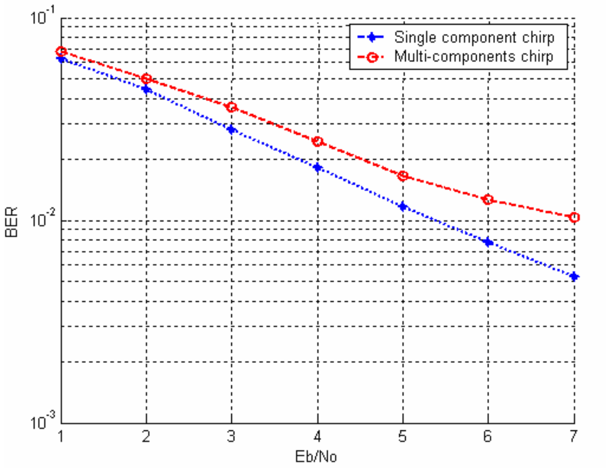


Figure 5 BER vs. SNR for a single and two-component chirp jammer with 33% duty cycle and JSR is set to 20 dB.

Since interfering signal power is usually greater than the desired signal, interference localization can be obtained easily by STFT on the time-frequency plane. Interference estimation errors are less than 0.01% for chirp-type jamming signals.

BERs with respect to various JSR and SNR values are investigated for single and multi-component chirp signals. The interference excision algorithm improves the system performance more than an order of magnitude.

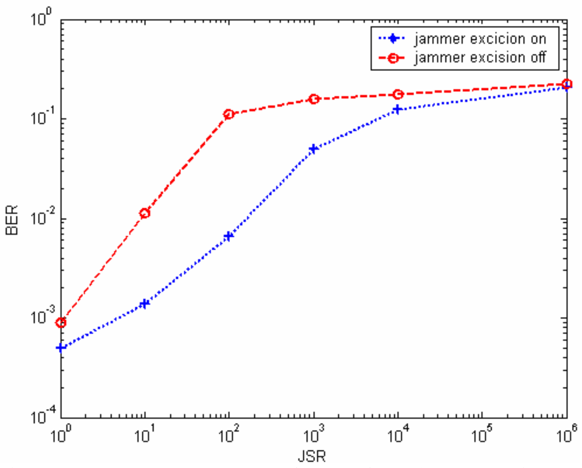


Figure 6 BER vs. JSR values of both cases, in which preprocessing is disabled and enabled for a single-component chirp jammer (SNR=7 dB).

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