JAMMER EXCISION IN SPREAD SPECTRUM COMMUNICATIONS VIA WIENER MASKING AND FREQUENCY-FREQUENCY EVOLUTIONARY TRANSFORM

L. F. Chaparro and A. Alshehri

Department of Electrical Engineering
University of Pittsburgh
Pittsburgh, PA 15261, USA

ABSTRACT

In this paper, we propose jammer excision techniques for direct sequence spread spectrum communications when the jammers cannot be parametrically characterized. The representation of the non-stationary signals is done using the time-frequency and the frequency-frequency evolutionary transformations. One of the methods, based on the frequency-frequency representation of the received signal, uses a deterministic masking approach while the other, based in non-stationary Wiener filtering, reduces interference in a mean-square fashion. Both of these approaches use the fact that the spreading sequence is known at the transmitter and the receiver, and that as such its evolutionary representation can be used to estimate the sent bit. The difference in performance between these two approaches depends on the support rather than on the type of jammer being excised. The frequency-frequency masking approach works well when the jammer is narrowly concentrated in parts of the frequency-frequency plane, while the Wiener masking approach works well in situations when the jammer is spread over all frequencies. Simulations illustrating the performance of the two methods, in different situations, are shown.

1. INTRODUCTION

Direct sequence spread spectrum (DSSS) communications offer advantages such a code division multiple access (CDMA), low probability of intercept, communication over channels affected by multi-path propagation, and robustness to intentional jamming or interference from other users [1]. This is achieved by spreading the message so that it ocuppies a bandwidth in excess of the minimum needed for transmission. Despreading at the receiver with a synchronized replica of the spreading function permits not only recovery of the message but reduction of interferences added in the transmission. The performance of DSSS communication systems degrades, however, when the power of the interferences increases, especially in the case of non-stationary jammers. Due to the ease in tracking jammers in the time-frequency domain, different time-frequency methods have been recently proposed for jamming excision [2, 3, 4, 5, 6, 8, 7].

When transmitting the m^{th} data bit using DSSS, the received baseband signal is given by

$$r_m(n) = d_m p(n) + i_m(n) \qquad 0 \leq n \leq (L-1), \qquad (1)$$

where the data bit is $d_m = \pm 1$, $p(n)$ is a pseudo-noise signal of length L chips, and the interference signal is

$$i_m(n) = j_m(n) + \eta_m(n) \qquad 0 \leq n \leq (L-1), \qquad (2)$$

composed of the jamming signal, $j_m(n)$, and the channel white noise, $\eta_m(n)$, for that bit. The last two signals are added during transmission. Many of the available excision techniques assume the characteristics of the jammers (e.g., sinusoidal or chirp jammers) and then project the received signal either onto the signal-plus-noise space and use time-varying filtering to excise the jammer, or onto the jamming subspace to synthesize and subtract the jamming signals. In most situation the characterization of the jammer is not known, only its support may be available as obtained, for instance, from a frequency representation of the received signal. However, the spreading signal is always known both at the transmitter and at the receiver and the direct sequence signal $d_m p(n)$ has the same spectrum independent of the value of d_m. We can thus set-up the excision as a problem where the desired signal is $d_m p(n)$, so that knowing $p(n)$ we estimate d_m, and the jammer and the channel noise constitute the interference. The problem can be treated as a deterministic masking problem, or as a mean-square estimation problem. We will show it can be done using the frequency-frequency evolutionary transformation and that it would work well when the jammer is narrowly concentrated, while the Wiener masking method is capable of dealing when the jammer spreads over the whole or most of the frequency space. For both aproaches we use the discrete evolutionary transform (DET) [9] to represent the non-stationary signals.

0-7803-7663-3/03/$17.00 ©2003 IEEE

2. FREQUENCY-FREQUENCY MASKING JAMMER EXCISION

The discrete evolutionary transformation provides a representation for a non-stationary signal $x(n)$ in terms of a time-varying kernel $X(n,\omega)$. The discrete evolutionary transform (DET) and it inverse are given by

$$X(n,\omega_k) = \sum_{\ell} x(\ell) W_k(\ell,n) e^{-j\omega_k \ell},$$
$$x(n) = \sum_k X(n,\omega_k) e^{j\omega_k n}, \tag{3}$$

where $W_k(\ell,n)$ is a window obtained from the Gabor or the Malvar representation of $x(n)$ [9]. Using the discrete Fourier transform with respect to n, we obtain the frequency-frequency DET and its inverse as

$$X(\Omega_s,\omega_k) = \sum_{\ell} x(\ell) W_k(\ell,\Omega_s) e^{-j\omega_k \ell},$$
$$x(n) = \sum_k \sum_s X(\Omega_s,\omega_k) e^{j(\omega_k+\Omega_s)n}. \tag{4}$$

The frequency-frequency DET of the received signal (1) is thus

$$R_m(\Omega_s,\omega_k) = d_m P(\Omega_s,\omega_k) + I_m(\Omega_s,\omega_k), \tag{5}$$

where $P(\Omega_s,\omega_k)$ and $I_m(\Omega_s,\omega_k)$ are the frequency-frequency DETs of the pseudo noise and the interference signal. In the stationary case, getting rid of an interference is done by designing a filter with a bandwidth coinciding with that of the desired signal. In this non-stationary case, we define a mask

$$M_k(\Omega_s,\omega_k) = \frac{|P(\Omega_s,\omega_k)|}{|R_m(\Omega_s,\omega_k)|}. \tag{6}$$

to do the jammer excision. The advantage of the frequency DET representations is the compactness of the information, and that analogous to the stationary case the mask will be unity for some points in the frequency-frequency plane where the support of the interference kernel does not overlap with the support of the kernel of the pseudo noise signal.

Thus, in the case of jammers that have a frequency-frequency kernel with a support that does not cover the whole frequency-frequency plane, whenever the mask is close to unity (given that the white noise has as support the whole frequency-frequency plane) the kernel of the received signal, $R_m(\Omega_s,\omega_k)$, gives an estimate of the kernel $d_m P(\Omega_s,\omega_k)$. And since $P(\Omega_s,\omega_k)$ is known, we can determine whether the value of d_m is either 1 or -1, an estimate of the received bit. As expected, such a procedure works well whenever no channel noise is present, and the jammer kernel is not spread over the whole frequency-frequency plane. The actual type of jammer is not important. When the jammer has as support the whole frequency-frequency plane, or when the channel noise is very strong this method would not work well. For that case, we propose a Wiener mask excision method.

3. JAMMER EXCISION VIA WIENER MASKING

One piece of information that is critical for the direct sequence spread spectrum technique to work properly is that the pseudo noise sequence used as the spreading function in the transmiter be known in the receiver. Thus,for each bit, the information about the spreading sequence does not change and we can compute *a priori* its evolutionary spectrum, $|P(n,\omega_k)|^2$. This spectrum and the spectrum of the received baseband signal $y(n) = r_m(n)$ can be used to obtain a mean-square estimate of the DS signal, $x(n) = d_m p(n)$. This is a special case of the non-stationary Wiener filtering [10], where we want a linear time–varying estimator for $x(n)$ embedded in a non-stationary interference $\psi(n) = i_m(n)$. The data is given by equation (1), and an estimate can be found by minimizing the mean-square error

$$\varepsilon(n) = E|x(n) - \hat{x}(n)|^2, \tag{7}$$

where $\hat{x}(n)$ is the output of a linear time-varying mask. The estimator has the Wold-Cramer representation

$$\hat{x}(n) = \int_{-\pi}^{\pi} Y(n,\omega) B(n,\omega) e^{j\omega n} dZ_y(\omega), \tag{8}$$

where $Y(n,\omega)$ is the evolutionary kernel of $y(n)$, and $B(n,\omega)$ is the masking function. The minimization of $\varepsilon(n)$ requires, according to the orthogonality principle, that

$$E\left[x(n) - \hat{x}(n)\right] \hat{x}^*(n) = 0$$

which can be shown to be equivalent to

$$\int_{-\pi}^{\pi} \left[\frac{S_x(n,\omega)}{Y^*(n,\omega)} - G(n,\omega)\right] G^*(n,\omega) d\omega = 0,$$

where $G(n,\omega) = Y(n,\omega)B(n,\omega)$. To minimize the above equation we let

$$G(n,\omega) = Y(n,\omega)B(n,\omega) = \frac{S_x(n,\omega)}{Y^*(n,\omega)},$$

so that the mask is given by

$$B(n,\omega) = \frac{S_x(n,\omega)}{S_y(n,\omega)} \tag{9}$$

or the ratio of the evolutionary spectra of $x(n)$ and that of the data $y(n)$. This result is analogous to the non-causal stationary Wiener filter. The optimal estimator and the minimum mean square error are found to be

$$\begin{aligned} \hat{x}(n) &= \int_{-\pi}^{\pi} \frac{S_x(n,\omega)}{Y^*(n,\omega)} dZ_y(\omega), \\ \varepsilon_{\min}(n) &= \int_{-\pi}^{\pi} \frac{S_x(n,\omega) S_\psi(n,\omega)}{S_y(n,\omega)} d\omega. \end{aligned} \quad (10)$$

The Wiener masking, using a DET implementation, is given by the ratio of the spectrum of $d_m p(n)$ and that of $r_m(n)$. As before, the evolutionary spectrum of $d_m p(n)$ is the same independent of d_m, and the spectrum of the received signal is available for every bit transmitted. Finally, the estimated message signal is the inverse discrete evolutionary transform of the kernel $R_m(n,\omega)B(n,\omega)$. The above is only possible because of the connection between the evolutionary kernel and the signal. It is important to emphasize that the above derivation does not require any characterization of the jammer, and thus applies to a large class of jammers.

4. SIMULATIONS

The performance of the proposed algorithms is illustrated by means of simulations. We consider 2 jammers: one with a concentrated support, and one with a broad support. The frequency-frequency kernels of the jammers, and of the pseudo noise are displayed in Fig. 1, 2 and 4.

The goodness of the algorithms to estimate the sent bit was measured by the bit error rate (BER) in simulations where 5000 trials at each SNR (corresponding to the DS signal and the channel noise) are performed, and each of the jammers has a jammer-to-signal ratio (JSR) of 25 dB. The SNRs in this case vary from 0 to 20 dBs. As expected, the performance of the frequency-frequency algorithm is the best when the support of the jammer is narrowly concentrated, in which case the results are better than those from the Wiener algorithm (see Fig. 5). In the case of the broad support jammer, Fig.3, the frequency-frequency algorithm does not work well, as there are no regions where the mask is close to unity and so the estimation of d_m is not accurate, while the Wiener masking method performs better. Applying the Wiener masking algorithm when we consider set of values of the SNR from -6 dB to 6 dB, to the case of the broad support jammer gives the results shown in Fig. 6.

5. CONCLUSIONS

In this paper, we propose two methods to excise jammers in DSSS, one that uses a frequency-frequency DET masking approach and the the other a Wiener or mean-squared based mask. In both it is assumed that the pseudo noise signal is available, and we wish to determine the value of the sent bit d_m. No special characterization for the jammer is made, only we need to know if it is narrowly or broadly supported. Given the compression of the data in the frequency-frequency kernels, it is shown that by locating the regions in the frequency-frequency plane where the jammer is not present an estimate of the bit value can be obtained. When the jammer is of broad support, the Wiener masking method performs better than the frequency-frequency method. The application of one algorithm instead of the other depends on *a-priori* information on the type of support of the jammer, rather than on its characterization. Also, the Wiener masking depends on the connection between the signal and the kernel, a unique property of the evolutionary methods.

6. REFERENCES

[1] Proakis, J.G, and Salehi, M., *Communication Systems Engineering.* Prentice Hall, Englewood Cliffs, NJ, 1994.

[2] Barbarossa, S., and Scaglione, A., “Adaptive time-varying cancellation of wideband interferences in spread spectrum communications based on time-frequency distributions,” *IEEE Trans. Sig. Process.*, pp.957-965, Apr. 1999.

[3] Amin, M.G., Wang, C., and Lindsey, A.R., “Optimum interference excision in spread spectrum communications using open-loop adaptive filters,” *IEEE Trans. on Signal Proc.*, pp. 1966-1976, Jul. 1999.

[4] Ramineni, R.S., Amin, M.G., and Lindsey, A.R., “Performance analysis of subspace projection techniques for interference excision in DSSS communications,” *Proc. ICASSP*, pp. 2825-2828, 2000.

[5] Tazebay, M.V., and Akansu, A.N., “Adaptive subband transforms in time-frequency excisers for DSSS communications systems,” *IEEE Trans. Sig. Process.*, pp. 2776-2782, 1995.

[6] Akay, O., and Boudreaux-Bartels, F.G., “Broadband interference excision in spread spectrum communication systems via fractional Fourier transform,” *Proc. Asilomar Conf.*, pp. 823-827, Nov. 1998.

[7] Chaparro, L.F., Suleesathira, R., Akan, A., and Unsal,B., “Instantaneous frequency estimation using discrete evolutionary transform for jammer excision,” *Proc. ICASSP*, Vol. 6, pp. 3525-28, 2001

[8] Suleesathira, R., and Chaparro, L.F., “Interference mitigation in spread spectrum using discrete evolutionary and Hough transforms,” *Proc. ICASSP*, pp. 2821-2824, 2000.

[9] Suleesathira, R., Chaparro, L.F., and Akan, A., “Discrete evolutionary transform for time-frequency signal analysis,” *J. of the Franklin Institute*, Vol. 337, pp. 347-64, 2000.

[10] Khan, H., and Chaparro, L. F., “Formulation and implementation of the non-stationary evolutionary Wiener filtering” *Signal Proc.*, pp. 253-267, 1999.

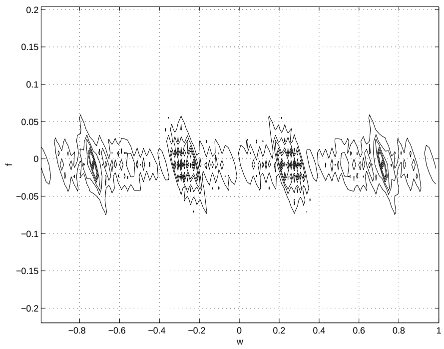

Fig. 1. Frequency-frequency DET of jammer with concentrated narrow support.

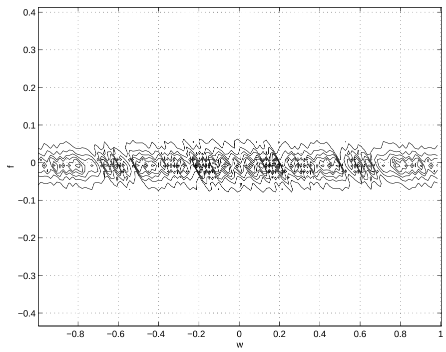

Fig. 2. Frequency-frequency DET of jammer of broad support.

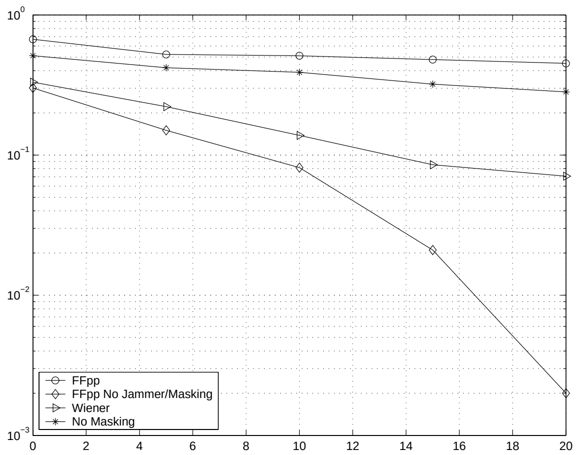

Fig. 3. Excision of jammer with broad support: (○) frequency-frequency and (▷) Wiener maskings; (∗) no masking and (◇) frequency-frequency masking and no jammer.

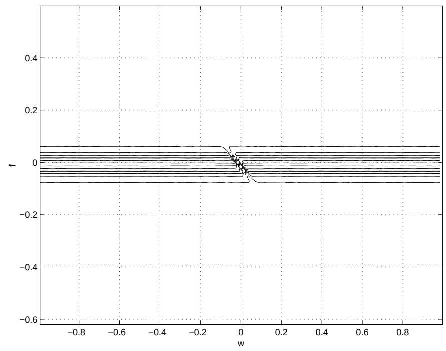

Fig. 4. Frequency-frequency DET of pseudo noise.

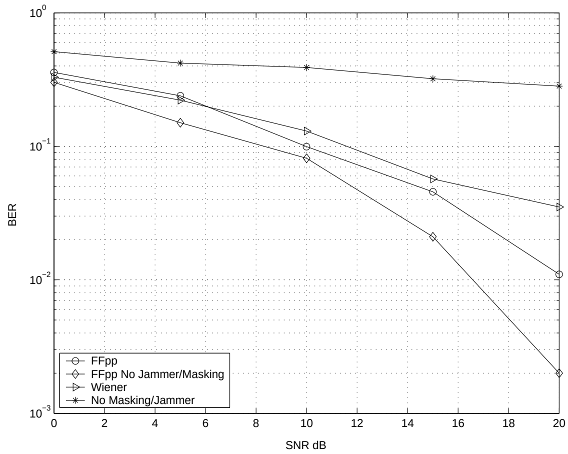

Fig. 5. Excision of jammer with concentrated narrow support: (○) frequency-frequency and (▷) Wiener masking;(∗) no masking and (◇) frequency-frequency masking when no jammer is present.

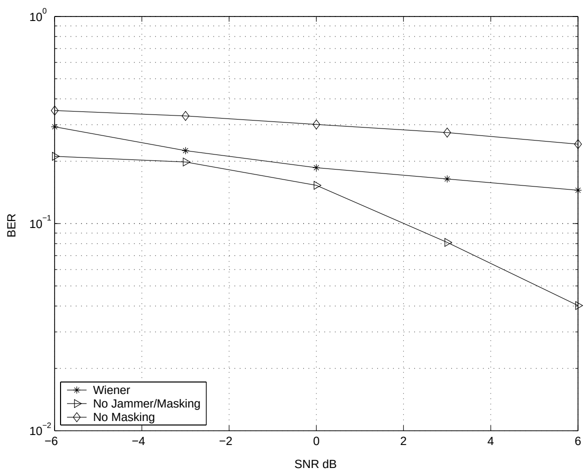

Fig. 6. Excision of jammer with wide support: Wiener masking (∗); no Wiener masking (◇) and masking (▷) when no jammer is present.