ISTANBUL UNIVERSITY ENGINEERING FACULTY
JOURNAL OF ELECTRICAL & ELECTRONICS
YEAR : 2002 (461-466)
VOLUME : 2
NUMBER : 1

INTERFERENCE EXCISION IN SPREAD SPECTRUM COMMUNICATION SYSTEMS USING IF ESTIMATION

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ABSTRACT

In this paper, we consider the problem of jammer excision in Spread Spectrum (SS) communication systems. We apply a time--frequency mask obtained by the instantaneous frequency (IF) estimate of the interference signal. The IF of the received signal is estimated from an Evolutionary Spectrum. Performance of our algorithm is presented by means of examples.

Keywords: *Spread Spectrum, Time-Frequency Analysis, Jammer Excision, Instantaneous Frequency*

ÖZET

Bu çalýþmada Yaygýn Spektrum iletiþim sistemlerinde karþýlaþýlan duraðan olmayan bozucu giriþlerin Anlýk Frekans kestirimine dayalý bir zaman-freakans maskeleme yöntemi ile giderilmesi konusu incelenmektedir. Alýnan bozulmuþ iþarete ait anlýk frekans kestirimi evrimsel spektrumdan elde edilebilmektedir. Önerilen algoritmanýn baþarýmý örnekler üzerinde gösterilmiþtir.

Anahtar Kelimeler: *Yayýlý Spektrum, Zaman-Frekans Analizi, Anlýk Frekans*

1. INTRODUCTION

In this paper, we consider broadband jammer excision in Spread Spectrum (SS) communication systems. SS communication systems are widely used in transmission environments where there are high power jamming interferences or multipath problems. The main characteristic of SS systems is that the transmitted signal occupies a bandwidth much wider than the bandwidth necessary to send the information. Spreading of the information signal spectrum is accomplished by modulating it with a spreading or code signal before transmission [1]. This spreading of the transmitted signal energy over a wide frequency band allows the SS communication system to become robust to outside interferences or jammers during transmission.

The most widely used spreading signal is the direct sequence (DS) or so called pseudorandom noise (PN) sequence. The information sequence is modulated by this higher rate PN sequence at the transmitter end, spreading the spectrum of the signal. At the receiver end, the received ross the bandwidth of the PN sequence. Therefore, direct sequence spread spectrum (DSSS) systems are inherently immune to narrow-band interferences [2],[3].

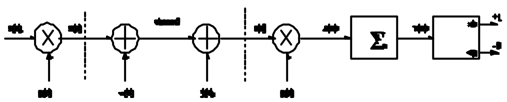


Fig. 1. A DSSS system with jammer exciser

The performance of DSSS communication systems can be further improved in terms of immunity to interference or jammers by estimating the interference and subtracting it from the received signal prior to despreading and demodulation [2],[3]. Jammer excision in DSSS communication systems is an important issue in both civilian and military applications. To solve this problem, different methods including adaptive notch filtering, decision feedback [4], FFT-based transfer domain methods [5], short-time Fourier transform based methods [6],[7] and time-frequency (TF) based new approaches [8],[9] have been recently applied. Figure 1, shows the block diagram of a DSSS system with such a jammer removing operation. Here *s(n)* is the information sequence and *p(n)* is the PN sequence with M chips per data bit. The transmitter output *x(n)* is assumed to be corrupted by additive white noise, *w(n)*, and a jamming interference, *j(n)*, during transmission over the channel. Time or frequency windowing methods are not appropriate for broad-band, non-stationary interference excision as removing the jammer in time or in fequency will destroy a large number of data bins.

In this work, we use an Evolutionary Spectrum (ES) estimate of the received signal and mask out the high power jammers using TF masking. The instantaneous frequency (IF) of the received signal is estimated from the ES to determine the TF masking function. Assuming there are strong interferers in the transmission environment results a high jammer-to-signal ratio (JSR) [8]. Hence the estimated IF of the received signal is dominated by the jammer's IF as the energy of information signal is spread over all frequency range. Then a TF mask is designed to eliminate the jamming components.

2. EVOLUTIONARY SPECTRAL ANALYSIS

We show here that the instantaneous frequency of the jamming signal in SS communication systems can be estimated from a time--frequency representation (that is evolutionary spectrum) of the received, corrupted signal. Then the jammer can be excised in the TF plane by using a masking operation.

A finite-extent, discrete-time signal *x(n)* can be represented as a combination of sinusoids with time-varying amplitudes as

$$x(n) = \sum_{k=0}^{K-1} A_x(n,k) e^{jw_k n} \qquad (1)$$

where $0 \le n \le N-1$, $w_k = {}^{2p}\!/_{K}\, .k$ and $A_x(n,k)$ is a time-varying kernel of *x(n)*. The evolutionary spectrum (ES) of *x(n)* is then calculated as [10]

$$S_x(n,k) = \left| A_x(n,k) \right|^2$$

It is shown in [10] that the evolutionary spectral computation may be implemented using a multi-window Gabor expansion which is given for a finite length signal by

$$x(n) = \frac{1}{I} \sum_{i=0}^{I-1} \sum_{m=0}^{M-1} \sum_{k=0}^{K-1} a_{i,m,k} h_{i,m,k}(n) \qquad (2)$$

where the basis function or logon $h_{i,m,k}(n)$ is obtained as

$$h_{i,m,k}(n) = h_i(n - mL) e^{jw_k n}. \qquad (3)$$

Here the scaled synthesis window is generated by contracting a mother window as $h_i(n) = 2^{i/2}.g(2^i n)$, $i = 0, 1, ...I-1$ and *g(n)* is a unit-energy Gaussian window. The multi-window Gabor coefficients are then evaluated as

$$a_{i,m,k} = \sum_{n=0}^{N-1} x(n) g^{*}_{i,m,k}(n) \qquad (4)$$

where

$$g_{i,m,k}(n) = g_i(n - mL)e^{jw_k n}$$

and $g_i(n)$ is solved from the biorthogonality condition between $h_i(n)$ and $g_i(n)$ [10]

Evolutionary spectrum of $x(n)$ can be obtained by comparing the two representations of the signal given in (1) and (2). It can then be shown that

$$A_x(n,k) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k} h_i(n - mL)$$

$$= \frac{1}{I}\sum_{i=0}^{I-1} A_i(n,k) \qquad (5)$$

Furthermore, by substituting for the Gabor coefficients in the above equation, we have that

$$A_x(n,k) = \sum_{l=0}^{N-1} x(l) w(n,l) e^{-jlw_k} \qquad (6)$$

with the window function defined as

$$w(n,l) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} g_i^{*}(l - mL) h_i(n, mL)$$

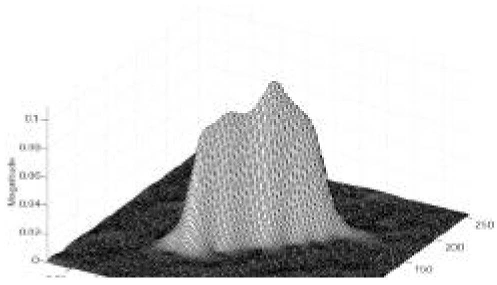
The ES calculation can then be done either by using (6) or by averaging $A_i(n,k)$ in (5), obtained from different scales, using different averaging techniques [10]

In the next section, the ES estimate obtained above will be used to estimate the IF of the jammer and define a TF mask.

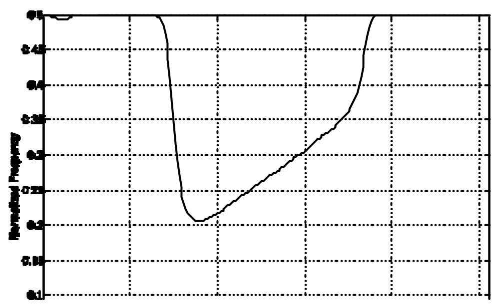
3. JAMMER EXCISION IN TIME-FREQUENCY

Here, we show that in a DSSS communication system, the IF of the corrupted signal, w^, can be estimated from the ES at the receiver end, and then jammers can be masked in the TF plane.

The IF of a signal is defined as the derivative of the phase of its corresponding analytical signal [11]. Moreover, the IF of a signal can also be obtained from its time-frequency distribution function as the average of frequencies at a given time [11]. IF estimation from the ES is shown to be effective and reliable in [12]. Fig. 2-a shows the ES estimate of a typical DSSS signal corrupted by a high-power, linear-chirp jammer. The IF estimate obtained from this ES estimate is given in Fig. 2-b. As shown, the IF estimate of the corrupted signal is dominated by the jammer's IF, since the energy of the information signal is spread over all frequency range.



(a)



(b)

After estimating the IF, $\hat{w}$, of the received signal, we design a TF mask around it and excise the jammer by a masking operation. Evolutionary spectral masking is achieved by modifying the kernel $A_x(n,k)$ with a binary masking matrix **M** as

$$A_y(n,k) = A_x(n,k) M(n,k) \qquad (7)$$

where $A_y(n,k)$ corresponds to the kernel of the masked signal and $M(n,k)$ are the entries of the matrix **M**:

$$M(n,k) = \begin{cases} 1 & (n,k) \in R \\ 0 & otherwise \end{cases} \qquad (8)$$

and R is the TF region around the jammer which is obtained by converting the IF estimate to a 2-dimensional TF matrix.

The output can then be synthesized through

$$y(n)=\sum_{k=0}^{K-1} A_y(n,k)e^{jw_k n} \qquad (9)$$

and demodulated to obtain the information sequence. In the next section, we show that this method can be effectively used in removing broad-band jammers with high JSR and low SNR conditions by means of examples.

4. SIMULATION RESULTS

Example 1. In this example, we consider a 32 bit data (binary coded, 8-digit social security number) that is multiplied by 1:8 PN sequence to spread its spectrum. Fig. 3 shows the ES of information signal. As corrupting interferences, white noise with SNR=2 dB, and a sinusoidal FM jammer with JSR=15 dB are added to data. Fig. 4 shows the ES of the corrupted signal with gray levels in dB scale. If no jammer excision is used at the receiver, the data is recovered with 8 bits error (25 % bit error rate). After using the proposed TF masking algorithm, data is recovered with no bit error. The recovered signal after TF masking is given (dashed line) together with the corrupted signal (solid line) in Fig. 5. As we see from the figures, the jamming component is successfully removed by TF masking.

Example 2 We consider the same DSSS signal used in Example 1, with sweeping chirp jammers with JSR=18 dB. ES of the corrupted signal is given in Fig. \ref{fig6} and the IF estimate of the signal obtained from this ES is given in Fig. 7. After masking the jammer, the signal is synthesized and demodulated to get the information sequence. The corrupted signal (solid line) and the masked signal (dashed line) are given in Fig. 8. Using the proposed algorithm, the information sequence is recovered with zero bit error, while there is five bits error if no excision is used.

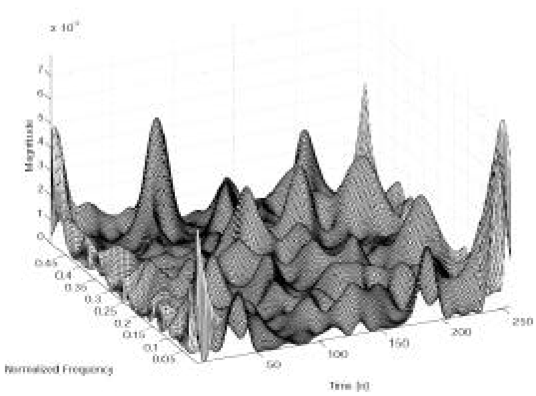


Fig. 3. ES of the SS signal in Example 1

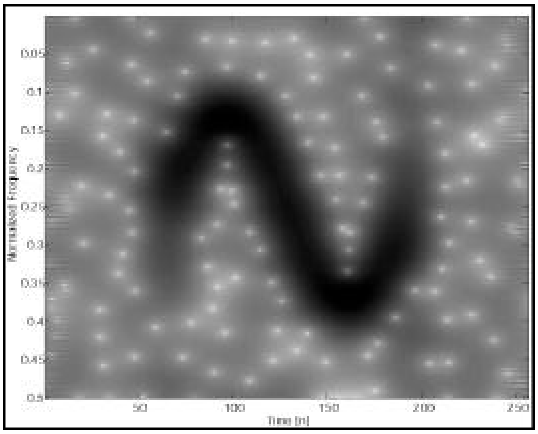


Fig. 4. ES of the distorted signal in gray levels

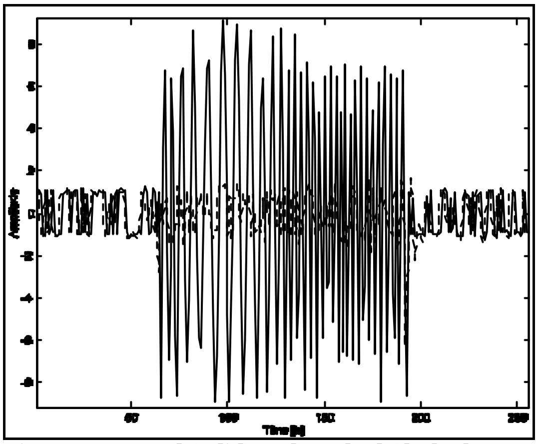


Fig. 5. Corrupted (solid) and masked (dashed) signals

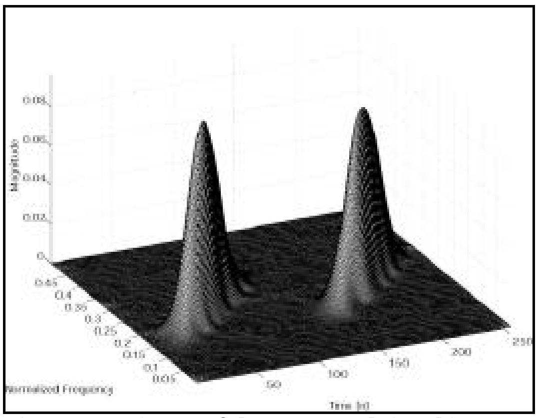


Fig. 6. ES estimate of the corrupted signal in Example 2

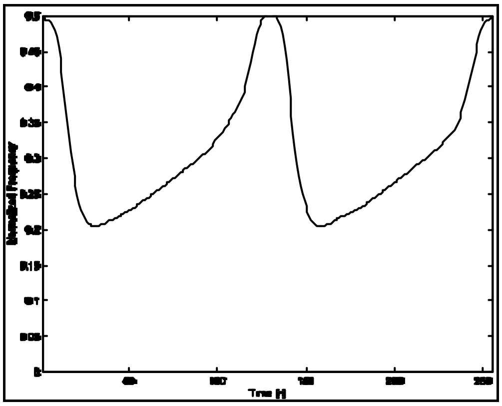


Fig. 7. IF estimate of the corrupted signal

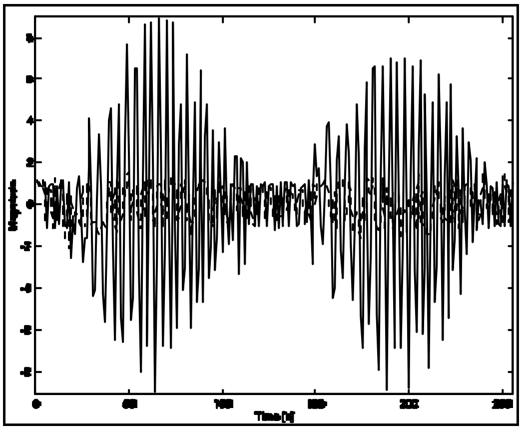


Fig. 8. Corrupted (solid) and masked (dashed) signals

5. CONCLUSION

In this work, we examined the problem of jammer excision in Spread Spectrum communication systems. We applied a TF based masking on the evolutionary spectrum of the received signal. Evolutionary spectral computation is achieved by means of a multi-window Gabor expansion. TF masking function is obtained from the IF estimate of the jammer. Simulation results show that the bit error performance is increased by using the proposed TF masking procedure.

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