ADAPTIVE AND BLOCK EXCISIONS IN SPREAD SPECTRUM COMMUNICATION SYSTEMS USING THE WAVELET TRANSFORM

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Abstract

Adaptive wavelet domain filtering techniques are applied for interference excision in spread spectrum communication systems to immunize the receiver to a large class of jammers, specifically those with burst energy characteristics. Fast wavelet transform along with the sparse structure of the transform-domain correlation matrix can be used to speed up convergence. In this paper, we present the adaptive wavelet transform baseband receiver and delineate its properties and performance.

I. Introduction

The most commonly used type of spread spectrum (SS) is the direct sequence (DS) in which modulation is achieved by superimposing a pseudorandom (PN) sequence upon the data bits. The modulation is then accomplished in complex form, creating in phase and quadrature components of a transmitted carrier signal. In the receiver, the complex cross correlation processor functions with the replica of the PN sequence and transfers the information signal back to its original bandwidth, while reducing the level of a narrow-band interference by spreading it across the bandwidth occupied by the PN sequence.

The performance of a PN SS system can be further improved, with respect to its immunity to narrow-band interference, by applying an excision filter prior to despreading. This filter suppresses the interference with minimum distortion of the desired signal, and thus increases the signal to noise ratio at the output of the correlator. Interference excision can be performed using different techniques applied in the time domain or the transform domain. In any given domain, the excision can be carried out adaptively, every data sample or every data block, or nonadaptively, where the excision algorithm has no learning characteristics and does not converge to an optimum solution. Most commonly adaptive and nonadaptive excision techniques have been applied in time or the frequency domain[1,2,3]. Recently, time-frequency signal representation tools have been employed to allow a large class of interference signals to be efficiently eliminated from the data. This includes
the time-frequency distributions using Cohen's class[4] and the wavelet transform[5]. While the former is a bilinear transformation and its excision power lies in its ability to estimate the instantaneous frequency of the undesired mono- and multi-component signals, the wavelet transform is linear, computationally simple and can be effectively used against interfering signals with abrupt changes or burst energy characteristics. Below, we summarize existing methods for interference excision in SS communication systems:

1)*Frequency Domain*: The FFT of the data over one information bit is weighted by appropriate values (excision coefficients) and then transformed back to the time domain[1,2]. This is an effective method for stationary narrow-band interference. Sidelobes may present a problem in removing the interference without loosing some of the signal energy.

2)*Time domain*: This includes adaptive linear predictors and smoothers(LMS, RLS) [1,3]. Tracking is highly dependent on the SNR and often fails under rapidly time-varying interference.

3) *Time and frequency domains*: A time-domain transversal filter is designed from the spectral information of the data[1]. Spectral estimation methods combined with open loop adaptive filtering have been shown to suffer from the same drawbacks as frequency-domain techniques.

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4) *Wavelet domain:* The discrete wavelet transform (DWT) is applied to the data and the coefficients of high energy are removed prior to the inverse transform[4]. The DWT is appropriate for cases of pulse jamming or interference with burst characteristics. Sparse autocorrelation matrix structure can be used to achieve fast convergence when the excision coefficients are adaptive[5,6,7,8].

5) *Time-frequency domain*: Time-frequency (t-f) distributions are employed for performing time-varying spectral analysis on the received signal. On the basis of the instantaneous frequency estimate, a linear phase open loop adaptive filter is applied to annihilate the time-varying interference with minimum loss of signal energy (see Fig.1)[9]. This excision technique is computational intensive, but as explained below, it succeeds in making use of the interference time-varying characteristics, when other methods fail. Fig.2 illustrates the main ideas behind frequency, wavelet, and time-frequency domain based excision techniques. It shows that the frequency and wavelet domain excisions, in essence, respectively remove all desired signal information over the frequency band ΔF and time duration ΔT. As such, although effective and powerful, we maintain that in the case of a chirp as well as other similar time-varying interfering signals, frequency-domain methods ignore the fact that only few frequency bins are contaminated by the jammer at a given time. On the other hand, wavelet-domain excision techniques do account to a greater degree for the interference characteristics where only few time samples may be contaminated by the jammer for a given frequency. Applying either method will eliminate the interference, but may unnecessarily reduce the desired signal energy dependent on the frequency time structure of the interference.

II. Excision Issues in the Wavelet Domain

The wavelet transform decomposes temporal (spatial) waveforms into frequency and time (distance). Contrary to short time Fourier transform, where time resolution is independent of frequency, the wavelet transform offers multi resolution signal analysis, where broad and fine time resolutions are provided for low and high frequencies, respectively. Since signals occupying short time duration have wider bandwidths, wavelet domain analysis can better fit signals with varying time bandwidth products.

Block Processing and Excision Coefficients

Two important properties exist for the desired and interference signals in SS systems which draw a distinction between the underlying problem and several other signal enhancement and noise canceling problems. The desired signal has a flat spectrum, especially for the example described herein, and the interference appears of much higher power than the modulated signal over a short time or/and frequency band. It is because of these properties that adaptive linear prediction techniques and nonadaptive frequency domain excision techniques have been very successful in eliminating narrowband interference. In frequency domain processing, the DFT is applied to disjoint data blocks. Often, the data blocks represent different information symbols. In the

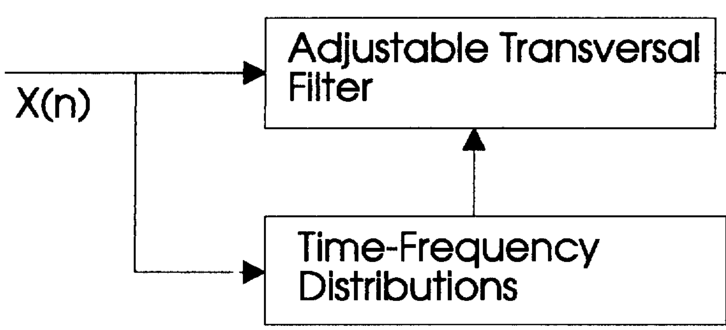

Fig. 1 Time-frequency distribution tool in interference excision

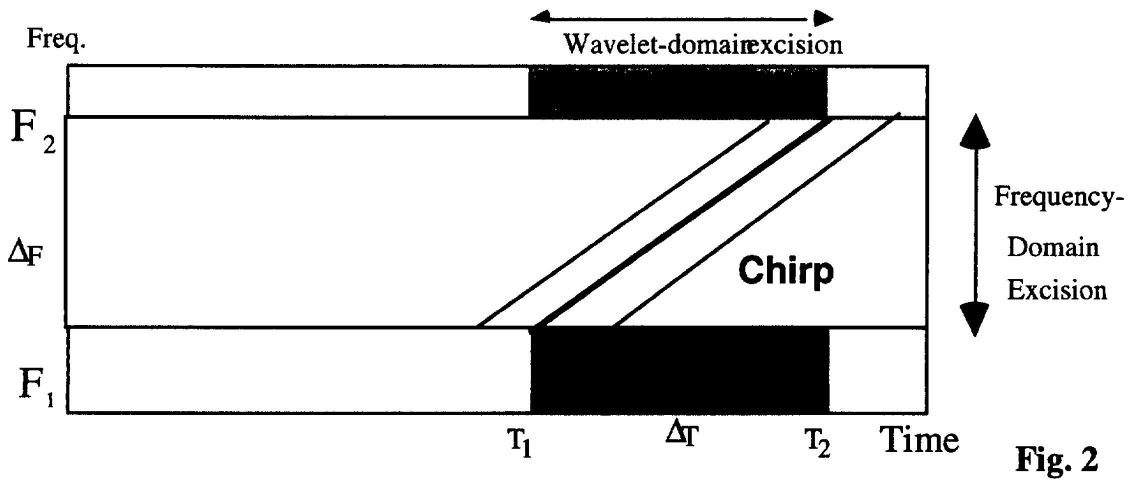

Fig. 2

case of narrowband interfering signals, only few bins will show high energy values in the frequency domain. For excision, these bins are either entirely eliminated or its power reduced by clipping through the application of threshold or multiplying by a weighting function proportional to its inverse spectral magnitude, and then taking the inverse FFT. This operation has the effect of flattening the spectrum , i.e., reducing the dynamic range defined as the ratio of the maximum/minimum spectral points.

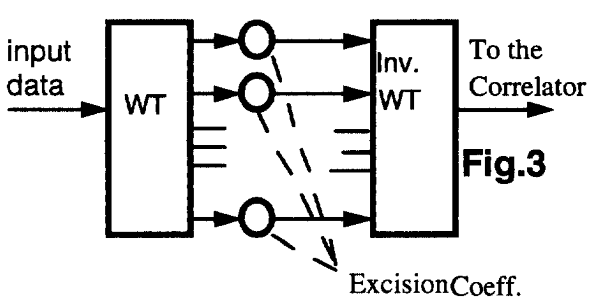

Fig.3

Due to the fact that wavelet spectrum of white noise is almost flat[4] and also peaks at abrupt changes, we maintain that the same excision procedure by removal, clipping, or weighing holds if the wavelet transform is applied to interference with high burst of energy(see Fig.3). It can be shown that the optimum excision coefficients required to obtain the maximum SNR at the receiver output are inversely proportional to the power carried in their corresponding wavelets(band) [10]. This is analogous to the results obtained for the frequency transform domain excision[11].

Adaptive Processing and Matched Filters

In frequency domain excision, if the DFT is taken every data sample, the structure is referred to as the frequency sampling filtering[12], which is a special case of filter banks[13]. The frequency sampling filters have equal frequency bandwidths and cover the entire Nyquist interval. In this case, the excision decision has to be made every data sample. It is therefore preferable to apply adaptive excision algorithms such as LMS. Fig.4 depicts adaptive linear predictor implemented using M-band adaptive wavelet filter banks.

Let x(n) represent the received data which consists of the desired signal s(t), the broadband noise, and the interference. using the M-band wavelet filter bank shown in Fig.4, the output y(n) is

$$y(n) = \sum_{m=1}^{M} w_m(n)(x(n-1) * h_m(n))$$

where w_m are the excision coefficients and are determined adaptively using the LMS algorithm. The predictor error filter output e(n) and impulse response are

$$e(n) = x(n) - y(n),$$

$$h(n) = 1 - \sum_{m=1}^{M} w_m(n)h_m(n-1)$$

At convergence, the error signal , which is fed to the receiver correlator for detection, should be jammer free. The structure in Fig.4 can be presented by its simplified equivalence in Fig.5(a). One can use this equivalent structure to obtain further improvement in the SNR at the correlator output. This is achieved by using a cascading filter with impulse response h(-n)(see Fig.5(b). The justification is similar to that given in [1] for time-domain adaptive excisions. It is based on the fact that the combined narrowband interference plus wideband noise represent a colored noise process added to the desired PN desired signal. The optimum linear detector leading to maximum signal to noise ratio is obtained by first decorrelating the noise by the whitening filter h(n) , then matching the signal spectrum at the filter output by applying a filter with frequency response H*(f)S*(f), where S(f) is the

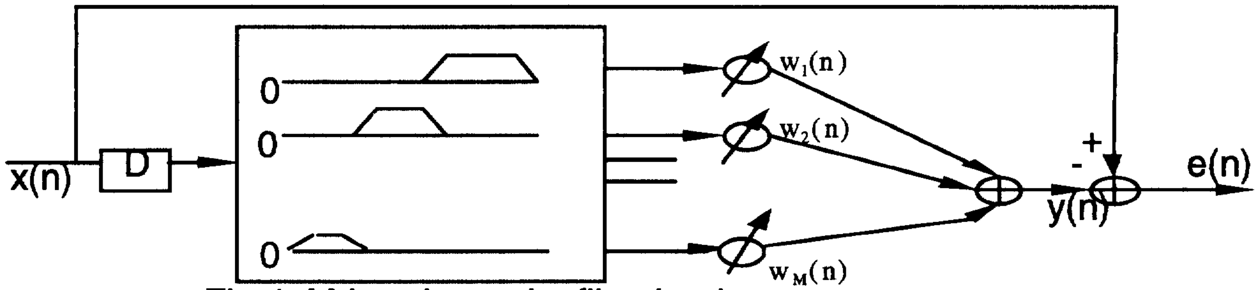

Fig.4 M-band wavelet filter banks

desired signal density function. The structure in Fig 5(c) is equivalent to that of Fig 5(b), except that the h(-n) has moved to process the receiver PN code.

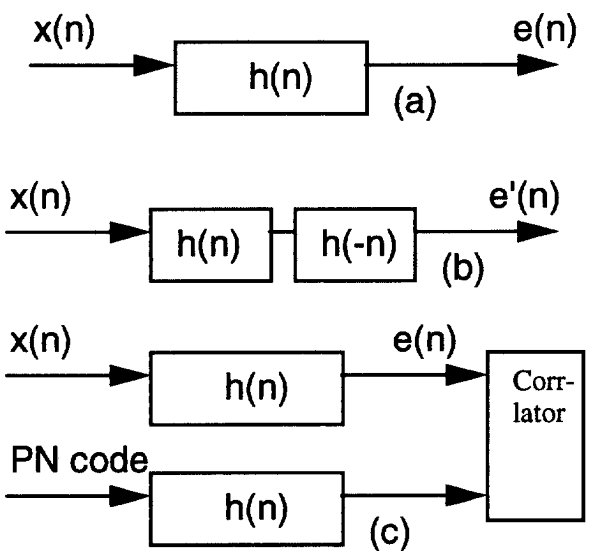

Fig.5 Match filter structures

In fact, if the coefficients in the filter structure shown in Fig. 4 are scalar quantities, we lose the time resolution possible with the wavelet transform. Thus, the weights should be in fact vectors, adjusting the amplitudes of all of the shifted wavelet coefficients. Unfortunately, the pulsed nature of some interfering signals renders the statistics of the interference highly unstationary, especially if the interference is deriving from hybrid frequency hopped pseudo noise spread spectrum systems, JTIDS being a primary example. Therefore, it may be very difficult for an LMS filter to follow the variations in signal level.

III. Wavelet Transform Filer Modeled

In this paper, the research reported on has progressed to the point of (1) Modeling (Using the C-Math ToolChest) a particular spread spectrum system invented at RL, having a very flat spectrum, and (2) combining this transmitter processor at baseband with a non-adaptive wavelet domain processor. The problem of non-stationary is seen clearly here, as even the low frequency wavelet filter outputs would differ significantly from one transform block to another. Given that the wavelet transform be derived from a continuous stream as outputs of a pyramidal down sampled FIR filter bank, the results may be more continuous and a form of LMS vector filtering can be applied. The third item investigated was a (3) wavelet type function matching the shaping filter for the pseudo noise transmission. These results are compared to those obtained for the very compact and famous Daubechies for a single burst of impulsive interference as suggested in [9].

A block diagram of the model is given in Fig. 6. Shown here is a complex quadrature signal generator, which excites the shaping filter. The shaping filter consists of a raised cosine windowed Shannon Wavelet with expansion factor chosen to generate the desired signal of uniform bandwidth. All wavelets used to generate the transmitted signal are then shifted versions as generated by the shaping filter. Real and Imaginary interference was added

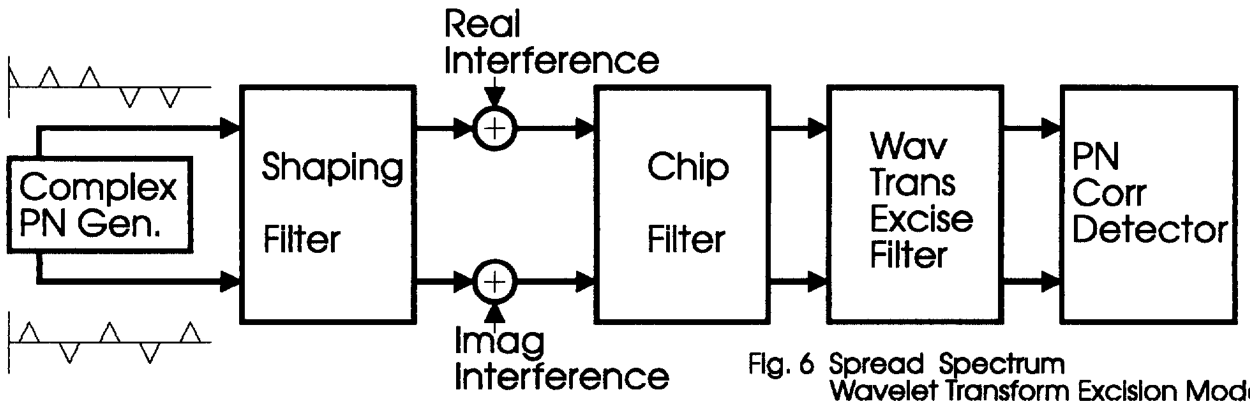

Fig. 6 Spread Spectrum Wavelet Transform Excision Model

consisting of a combination of white noise and a pulse type of interference. In this form of the experiment the wavelet transform filter preceded the correlation demodulator which itself contained a chip matched filter. This was done as the wavelet filter itself limits the white noise bandwidth into the demodulator. Experiments were run on Fig. 6 with two forms of wavelets used, one being the DAUB4 wavelet, and the second being the windowed Shannon wavelet. Very promising results were obtained. For this pulse the DAUB4 wavelet performed better overall than the weighted Shannon Wavelet.

IV. Summary and Conclusions

Research performed here gave very impressive results. Research will continue along the lines of construction of an adaptive vector wavelet filter using a select pseudo noise reference signal extracted from the transmitted signal. Experiments will be run with both stationary and non stationary types of interference to evaluate the block transform Vs the continuous adaptive transform. The use of the different types of wavelet filters will be examined in detail. Finally research will continue to develop comparison performance of the various excision techniques described herein.

References

[1] J. Ketchum and J. Proakis, " Adaptive algorithms for estimating and suppressing narrow band interference in PN spread spectrum systems", IEEE Transactions on Communications, May 1982.

[2] S. Theodoridis, N. Kalouptsidis, J. Proakis and G. Koyas," Interference rejection in PN spread spectrum systems with linear phase FIR filters", IEEE Transactions on Communications, vol. 37, no. 9, September 1989.

[3] R. Iltis, J. Ritcey ,and L. Milstein, "Interference rejection in FFH systems using least squares estimation techniques", IEEE Transact. on Communications, vol. 38, Dec. 1990.

[4] M. Medley, G. Saulnier, and P. Das, "Applications of the wavelet transform in spread spectrum communications systems", SPIE, Wavelet Applic., Orlando, Florida, April 1994.

[5] S. Hosur and A. Tewfik, "Wavelet transform domain LMS algorithm," Proceedings of ICASSP, vol. III, April 1993.

[6] M. Doroslovacki and H. Fan, "Wavelet-based adaptive filtering," Proceedings of ICASSP, vol. III, April 1993.

[7] N. Erdol and F. Basbug, " Performance of wavelet transform based on adaptive filters," Proceedings of ICASSP, vol. III, April 1993.

[8] K. Anadakumar and S. Kassam, "Adaptive filtering based on wavelet decomposition," Preprint, Proceedings, of Inter. Symp. on TF/TS Analysis, Philadelphia, Pa, Oct. 1994.

[9] M. Amin, "Interference excision in spread spectrum communication systems using time-frequency distributions," Technical Report, AFOSR, RDL, Rome Lab, Sept. 1994