A Knowledge-Based Approach to Interference Rejection For Direct-Sequence Spread Spectrum (DSSS) Systems

Ilteris Demirkiran ♣, Donald D. Weiner ♠ , Pramod Varshney ♠
Andrew Drozd $*$
♣ Electrical Engineering, Embry-Riddle Aeronautical University,
Daytona Beach, FL 32114, USA. Email=demir4a4@erau.edu
♠ Electrical Engineering and Computer Science, Syracuse University,
Syracuse, N.Y. 13244, USA. Email={ddweiner and varshney}@ecs.syr.edu
$*$ Andro Computational Solutions, LLC ,Rome, NY 13440-2067
Email= androcs@androcs.com

Abstract- *Interference rejection techniques need to be employed to insure the proper operation of electronic systems used in a severe electromagnetic interference environment. This paper discusses a knowledge-based interference rejection approach for DSSS systems. This innovative approach uses an expert system so as to monitor the signal environment to determine the interfering signal and select suitable interference rejection schemes from a library of preselected techniques. The effectiveness of the approach is demonstrated by means of computer simulations.*

Index Terms- *Knowledge-based interference rejection, Spread spectrum.*

1 Introduction

With the ever-increasing signal density of the available electro-magnetic spectrum, the desired signal of one channel or system becomes the undesired signal or interference of another. When the number and nature of interference signals, including their frequency spectra or waveforms, are not known a priori, communications becomes quite difficult. In military communication environments, the interference that affects the communication could also be intentional and hostile. Another problem is that transmitted information may be intercepted by unintentional users. Therefore, additional signal processing techniques are required in communication systems both to mitigate the effects of intentional interference and to lower the probability of interception. Advanced modulation schemes employing spread-spectrum and coding techniques are commonly used in communication systems to decrease their vulnerability to interference and to lower their probability of interception.

In this paper we focus on interference suppression in direct-sequence spread-spectrum communication systems. An effective technique used in spread-spectrum systems to minimize the effects of jamming is to pseudo-randomly distribute the information to be transmitted over a range of parameters (time, frequency and phase). Jamming protection is achieved because the jammer does not know the pseudo-random pattern and must distribute its limited resources (power) over many alternatives. This pseudo-random distribution of information also serves to conceal the information and thus prevents it from being intercepted. The inherent interference immunity displayed by a spread-spectrum system is not sufficient to combat all types of interference encountered in a communication environment. Additional interference mitigation techniques are, therefore, needed to ensure effective and secure information transfer. A significant number of interference cancellation schemes have been introduced in the literature [1-4]. While these schemes are able to provide effective cancellation for specific types of interference, no single scheme is able to suppress all types of interference that is encountered by the spread-spectrum system. We present a novel advanced knowledge-based interference cancellation scheme for direct-sequence spread-spectrum systems. This innovative approach utilizes

- IPUS [5], an expert system for the Integrated Processing and Understanding of Signals, to monitor the communication signal environment in order to determine the parameters of interfering signals within a pre-specified accuracy, and
- Expert system rules to select from a library of preselected techniques suitable interference rejection schemes based upon the knowledge obtained from monitoring the signal environment.

The effectiveness of the knowledge-based interference rejection capability is demonstrated using computer simulations.

Section 2 describes the knowledge-based interference rejection framework. Section 3 explains how IPUS is used to monitor the signal environment. In Section 4 the knowledge-based approach to interference rejection is illustrated for two interference scenarios in a DSSS application. Section 5 discusses the summary and conclusions.

2 Knowledge-Based Interference Rejection Framework

As mentioned before, there is no single interference cancellation scheme that is best able to effectively suppress all types of interference. Accurate knowledge of the time-frequency characteristics of the interference embedded in the received spread spectrum signal is required in order to apply suitable cancellation techniques. This knowledge is obtained through the knowledge-based system.

The overall knowledge-based framework for interference rejection is shown below in Figure 1 . The transmitted spread-spectrum signal is assumed to be corrupted by additive thermal noise and a number of interference signals prior to its reception at the receiver. The received signal is processed by the expert system called $IPUS$ which carries out the environmental monitoring function. It determines the types of interference signals (from a specified list of interference types) present in the received signal along with their parameters. If an interference type is not on the specified list, $IPUS$ can be extended to include new interference types. Based on the information generated by $IPUS$ (time-frequency locations of the isolated interferers), the most appropriate filters from a library of available interference cancellation filters is employed to eliminate interference from the received signal. This selection is based on a set of rules that have been developed. Additional rules can always be added when needed. Two switches are included to allow for either selection of an appropriate interference cancellation filter from the filter bank or for bypassing the interference cancellation stage when $IPUS$ determines that no interference is present. Finally, the spread-spectrum receiver demodulates its input and recovers the transmitted information.

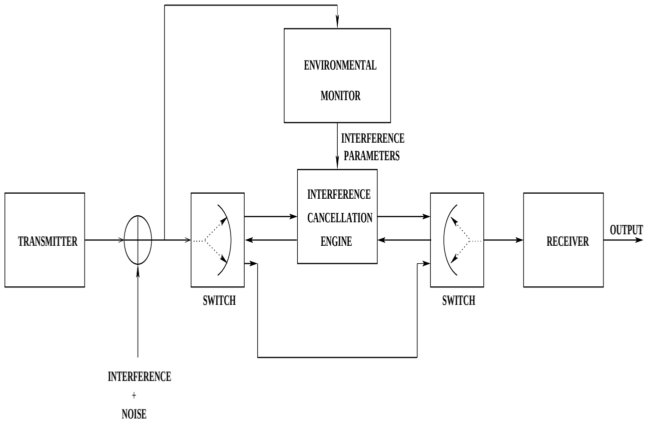

Figure 1: Block Diagram of the Knowledge-Based Interference Cancellation System.

The problem of interference cancellation in direct-sequence spread-spectrum systems may be formally described by considering received signals of the form:

$$r(t) = s(t) + \sum_{k=1}^{N} j_k(t). \tag{1}$$

where $s(t)$ is the information-bearing spread spectrum signal and $j_k(t)$, k=1,2,..., are different types of jamming signals that may be simultaneously present on the channel. They have the form

$$j_k(t) = a_k \cos[\int_0^t \omega_k(\tau) d\tau + \phi_k]. \qquad (2)$$

Our objective is to sufficiently attenuate all the interferers $j_k(t)$ such that the original spread-spectrum signal $s(t)$ can be successfully demodulated due to the inherent processing gain of the system. In the prototype that we have developed to demonstrate the proof of concept for our advanced knowledge-based approach, we have restricted the types of interferers to be:

(1) Multiple tone interferers operating in a continuous wave (CW) mode,

(2) Linear-FM (or chirp) interfering signals,

(3) Multiple CW tones operating in an ON/OFF mode with or without frequency hopping.

This selection was made on the basis that scenarios limited to having combinations of these interfering signal types offer ample scope for demonstrating the benefits of the knowledge-based approach. While CW interferers are common in a spread spectrum communication environment, chirp and frequency hopped interferers also occur frequently. Reduction of these interferers necessitates some form of adaptive filtering by the receiver.

3 Knowledge-Based Interference Isolation

The isolation of individual interference signals from the contaminated spread spectrum signal is carried out through time-frequency analysis performed using a filter-bank. Individual filters in the filter-bank are adapted in a data-dependent fashion to separately resolve individual interference signals. This knowledge-based filter adaptation strategy follows the IPUS blackboard paradigm. IPUS takes into consideration the distortions that can result when attempting to make signal measurements. For example, use of a Fast Fourier Transform (FFT) with inadequate resolution on two signals that are closely spaced in frequency will result in their incorrect detection as a single signal. Use of an amplifier with inadequate dynamic range will result in distortion of a strong signal due to nonlinear effects. Use of a receiver with inadequate bandwidth will result in distortion of a signal whose spectrum is wider than the receiver bandwidth. Nevertheless, traditional signal processing systems typically accept measured signals without questioning whether or not they may have been distorted by the front-end stages of the receiver. IPUS not only allows the receiver to interpret the essential characteristics of monitored signals, but also recognizes when uncertainties and/or distortions exist and reprocesses the monitored signals so as to reduce the uncertainties and/or distortions.

IPUS achieves its objective by detecting one or more of the three kinds of discrepancies defined below:

- Violation - A violation occurs when a monitored signal is identified as having characteristics different from those included in the class of possible signals chosen a priori for the application domain.
- Conflict - As IPUS monitors signals in a particular time interval, various expectations are created for the next time interval.
- Fault- A fault occurs when two different signal processing algorithms applied to the same observed data result in different conclusions.

Once discrepancies are detected, IPUS selects strategies to reprocess the data by changing the parameters of the signal processing algorithms and/or selecting new algorithms. The process iterates until interpretations have been generated that resolve the discrepancies. This approach is well suited to determining the characteristics of incompletely unknown interfering signals. Problem-solving in an IPUS based system takes place on a data blackboard which is operated upon by a variety of knowledge sources. It is implemented in the C++ environment which provides a convenient facility for developing IPUS applications. In the next section It is seen that the *IPUS*-based interference cancellation approach shows improved performance over that achieved with a single fixed interference when the desired DSSS signal is contaminated by multiple interferers.

4 DSSS Interference Cancellation System

This section presents the results of simulations for two different scenarios to demonstrate the performance improvement achieved by our knowledge-based interference cancellation scheme over that of the adaptive transversal filter. Performance is characterized in terms of the bit error rate (BER). The BER curves were obtained assuming perfect synchronization. Different combinations of jamming signals are used in the two scenarios where the power of each jammer by itself is of a magnitude sufficiently large to over ride the processing gain of the spread-spectrum system so as to result in significant errors at the demodulator output.

Scenario-1: In this scenario the received signal consists of the transmitted direct-sequence spread spectrum signal plus two CW jammers and two ON/OFF jammers. The desired DSSS signal has a processing gain of 15 dB, a bandwidth of 6400Hz., and a carrier frequency of 4800 Hz. The time-frequency distribution of the jamming signals for a short time segment is shown in Figure 2. In this time segment the 4500 Hz jammer turns OFF when the 5500 Hz jammer turns ON. However, the ON/OFF times are randomly chosen and in other time segments both jammers may be either ON or OFF at the same time. Each interferer contributes an interfering signal power of approximately 30 dB over the interfering signal power that can be handled by the system processing gain. *IPUS* provides the time-frequency locations of each interferer embedded in the received spread-spectrum signal. The time-frequency estimation information shown in Figure 3, provides a good estimate of the true time-frequency profile. For each interfering signal, cancellation is achieved by placing an adaptive notch filter at its estimated frequency location. In the case of interferers that are found to be operating in an ON/OFF mode, the cancellation stage employs a switching mechanism which ensures that the received signal is filtered only in the interval during which the tone is ON. The BER curves are shown in Figure 4 for both the adaptive transversal filter of order 20 and the knowledge-based notch filter. This plot shows that the knowledge- based notch filter outperforms the adaptive transversal filter.

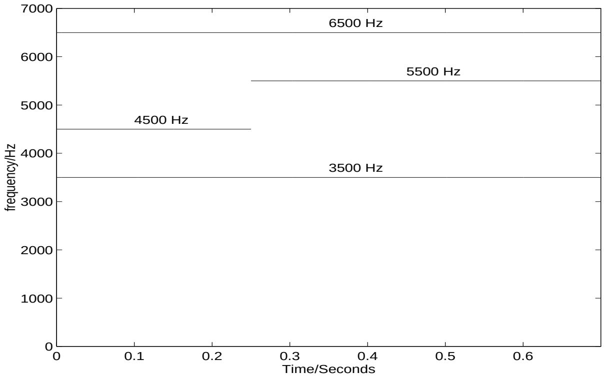

Figure 2: Actual Time-Frequency Track of Two ON/OFF and Two CW Jamming Signals in Scenario-1

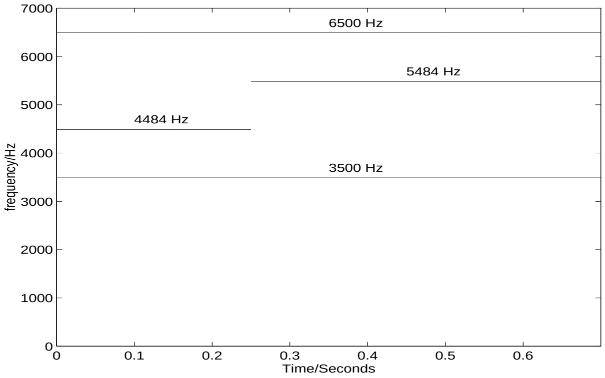

Figure 3: Estimated Time-Frequency Track of Two ON/OFF and Two CW Jamming Signals generated by IPUS for Scenario-1

Scenario-2: This scenario consists of a linear chirp jammer plus three CW jammers in addition to the transmitted spread-spectrum signal whose parameters are identical to those given in scenario-1. Each interferer contributes an interfering signal power of approximately 30 dB over the interfering signal that can be handled by the system processing gain. The actual time-frequency track of the LFM jammer is shown in Figure 5 along with the piece-wise constant estimate provided by *IPUS*. The frequency estimates are used to adaptively control the center frequency of a Chebyshev Type II IIR band-stop filter. As shown in Figure 6, the knowledge-based notch filter, once again, outperforms the adaptive transversal filter of order 20.

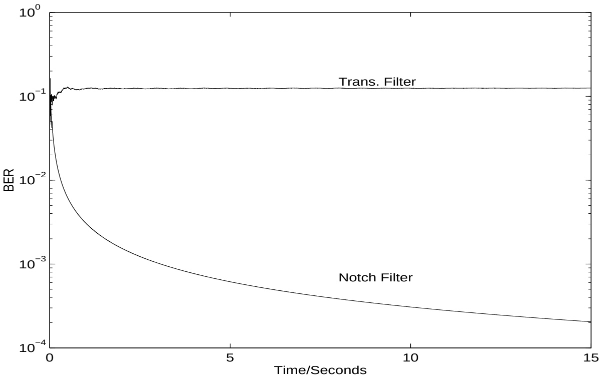

Figure 4: Performance Comparison for Scenario-2

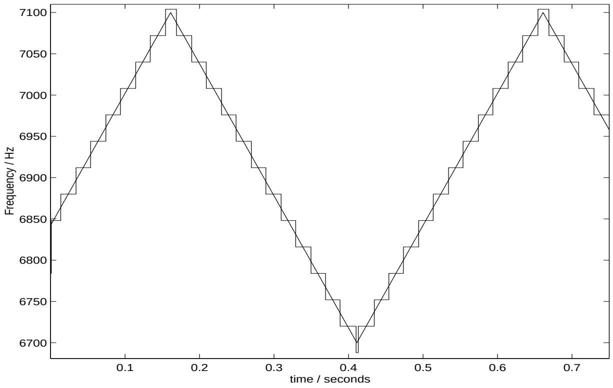

Figure 5: Actual and Estimated Time-Frequency Track of One LFM Jammer for Scenario-2

5 Summary and Conclusions

In this paper we presented a novel knowledge-based interference cancellation framework for spread-spectrum communication systems. This innovative knowledge-based interference cancellation technique utilizes IPUS to monitor the communication signal environment in order to determine the parameters of interfering signals within a prespecified accuracy. After having monitored the environment, the knowledge- based interference cancellation technique selects the most suitable cancellation filter from a library of cancellation filter banks in order to reduce the level of the interference signal in the received signal. Two interference scenarios were investigated and results demonstrated the superior performance of our knowledge-based interference cancellation scheme.

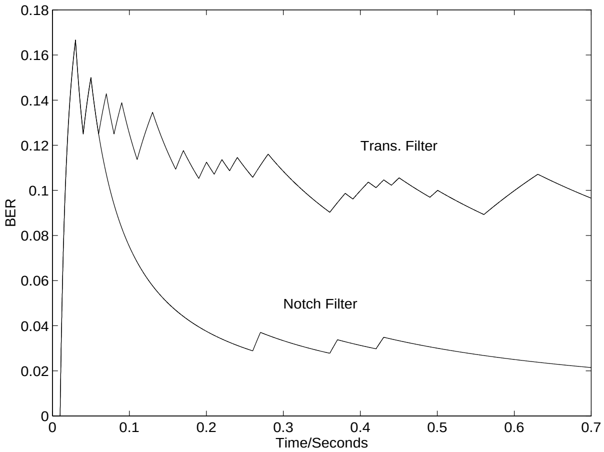

Figure 6: Performance Comparison for Scenario-2

References

[1] J.D. Laster and J.H. Reed, "Interference Rejection in Digital Wireless Communications", *IEEE Signal Processing magazine* , pp.37-62, May 1997.

[2] L.B. Milstein, "Interference Rejection techniques in Spread Spectrum Communications", *Proceedings of the IEEE*, vol. 76, no. 6, pp. 657-671, June 1988.

[3] L.B. Milstein and R.A. Iltis, "Signal Processing for Interference rejection in Spread Spectrum Communications", *IEEE ASSP magazine*, pp. 18-31, April 1986.

[4] J.W. Ketchum and J. G. Proakis, "Adaptive Algorithms for Estimating and Suppressing Narrowband Interference in PN Spread Spectrum System", *IEEE Trans. on Comm.*, vol.30, pp.913-924, May 1982.

[5] V. R. Lesser, S. H. Nawab, and F. I. Klassner, "IPUS: An Architecture for the Integrated Processing and Understanding of Signals", *Artificial Intelligence*, vol. 77, pp. 129-171, 1995.