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SPREAD-SPECTRUM COMMUNICATIONS
IN NON-GAUSSIAN CHANNELS

Final Report
by
H. Vincent Poor, Principal Investigator

May 27, 1990

U.S. ARMY RESEARCH OFFICE

Contract No. DAAL03-86-0093

Coordinated Science Laboratory
University of Illinois at Urbana-Champaign

PROJECT SUMMARY

ARO CONTRACT DAAL03-86-0093

(June 15, 1986 - September 30, 1989)

The overall purpose of this research project was to seek new methods for improving the robustness and efficiency of spread-spectrum communications systems operating over non-Gaussian channels. This study was motivated in large part by the fact that modern military radio networks must operate in complex and variable noise environments that are often dominated by impulsive, non-Gaussian man-made noise sources.

The research under this contract progressed in three basic areas:

1.) optimum multiuser demodulation techniques;

2.) direct-sequence spread-spectrum multiple-access (DS/SSMA) signaling through impulsive channels; and

3.) improved suppression of narrowband interferers from spread-spectrum signals.

The common thread binding these three disparate multiuser-communications research topics is the fact that each involves the processing of signals in non-Gaussian interference. In the first case, the non-Gaussian interference is the multiuser noise interfering with the demodulation of a given user; in the second case, the non-Gaussian interference is the impulsive noise dominating the channel; and in the third case, the non-Gaussian interference is the spread-spectrum signal itself as it interferes with the prediction and consequent excision of the narrowband interferer.

Our progress in these areas is described briefly in the following paragraphs; details can be found in the appended list of publications supported by this contract.

1.) *Optimum Multiuser Demodulation Techniques:* The work in this area was an outgrowth and continuation of work begun under the predecessor to this contract, ARO Contract

DAAG-81-K-0062: SIGNAL DETECTION IN MULTIUSER DETECTION (May 21, 1981 - May 20, 1984). In this earlier study, the field of multiuser detection was established, including the development of demodulation algorithms and performance bounds for coherent symbol-asynchronous multiple-access channels. (The works [15-16], which were supported under this earlier effort, describe key progress in this area.) During the period covered by this report, three works were published in this general area [8, 9, 13]. Reference [8] treats the problem treated in [15-16], but for the situation in which the observations are point processes. This work is applicable to the important emerging problem of optical multiuser communications, and the results have since been applied in this field. In [9], a criterion for assessing the multi-access noise limitation of various multiuser systems. This criterion, known as the *multiuser asymptotic efficiency*, is a measure of the equivalent SNR of a multiuser receiver relative to the actual SNR, in the limit of vanishing background noise level. This quantity describes the effectiveness of the receiver in dealing with the multiple-access (MA) interference. It is well-known, for example, that conventional DS/SSMA receivers can become MA-noise limited, which implies an asymptotic efficiency of zero. On the other hand, the centralized maximum-likelihood MA receivers of [15-16] can have unit asymptotic efficiency, as reported in [9]. Since the appearance of [9], this efficiency criterion has since found widespread application in the analysis and development of a number of other types of multiuser receiver algorithms.

2.) DS/SSMA Communications in Impulsive Channels: In this area, we carried out a study of the performance characteristics of (linear and nonlinear) correlation receivers for use in DS/SSMA reception in impulsive channels. The results of this study, reported in [1-4], allow for the performance comparison of correlation receivers on channels subjected to both impulsive and MA noises. Particular emphasis was placed on the analysis of linear, hardlimiting, and smoothlimiting correlation receivers. The first two of these three receivers can be studied via exact performance analyses. Of these two, the linear correlator is most effective against MA noise, while the hardlimiting correlator is most effective against the impulsive noise. This performance pattern suggests the use of a compromise receiver that uses a smoothlimiting correlator. Unlike the other two receivers studied, the analysis of the smoothlimiting correlator is possible only through approximation and simulation. Several performance approximations have been developed and exploited for general nonlinear direct-sequence correlators, and an extensive computer simulation was carried out for the smoothlimiting case. These results (reported in [4]) indicate that the smoothlimiting correlator combines the attractive features of both linear and hardlimiting correlation, and thus is an effective receiver design for signaling through channels subjected to the combined effects of impulsive and MA noises. Reference [4] also reports an analysis of general nonlinear spread-spectrum correlators, in which the error-probability behavior is considered asymptotically as the lengths of the spreading codes increase without bound; and conditions on the spreading sequences have been obtained that assure asymptotic achievement of single-user performance in a multiuser system. Long-spreading-sequence approximations to the average error probabilities of general nonlinear correlators were also derived using this same mode of analysis.

3.) *Improved Narrowband Interference Suppression*: It is known that the narrow-band interference suppression capability of a direct-sequence spread-spectrum system can be enhanced considerably by passing the received signal through a prediction error filter prior to correlating it with the PN sequence. Previous work on this problem has centered around the use of linear prediction filters for this purpose. In this study, as reported in [10-12], we have exploited the binary nature of the direct-sequence signal to obtain nonlinear filters that outperform the linear filters hitherto employed for this purpose. The case of a Gaussian interferer with known autoregressive parameters was considered first. Using simulations, it was shown that an approximate conditional mean (ACM) filter of the Masreliez type performs significantly better than the optimum (Kalman-Bucy) filter. For the case of interferers with unknown parameters, the nature of the nonlinearity in the ACM filter was used to obtain an adaptive filtering algorithm which is identical to the linear transversal filter except that the previous prediction errors are transformed nonlinearly before being incorporated into the linear prediction. Two versions of this filter were considered, one in which the filter coefficients are updated using the Widrow LMS algorithm, and another in which the coefficients are updated using an approximate gradient algorithm. Simulations show that the nonlinear filter with LMS updates performs substantially better than the linear filter for both narrow-band Gaussian and single-tone interferers, whereas the gradient algorithm gives slightly better performance for Gaussian interferers but is rather ineffective in suppressing a sinusoidal interferer. Other aspects of this problem include the connection of this work with decision feedback systems and the further adaptivity to signal level (reported in [7]), and the design and performance analysis of systems for interference suppression in impulsive channels (reported in [[5,6]).

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