OPTIMUM RECEPTION IN AN IMPULSIVE INTERFERENCE ENVIRONMENT

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Since communications systems are seldom interfered with by classical white Gaussian noise, Middleton's recently developed physical-statistical model of impulsive interference is applied to real world communications channels.

The main impulsive interference models that have been proposed to date are summarized, and Middleton's model is specified in some detail, giving the statistics required for the solution of signal detection problems. Excellent agreement of these statistics with corresponding measured statistics is shown.

Middleton's model for narrow-band impulsive interference (a subset of the overall model) is applied to a class of optimal signal detection problems. Optimum detection algorithms are given for coherent and incoherent binary detection. The three basic digital signaling waveforms are considered; i.e., antipodal, orthogonal, and ON-OFF keying. Performance bounds are obtained for these signaling situations. Since it is known that in order to gain significant improvement over current receivers, the number of independent samples of the received interference waveform must be large, the performance results are given parametrically in the number of samples, or equivalently, the time-bandwidth product. Performance of the current suboptimum receivers is obtained and compared to the optimum performance. It is shown that substantial savings in signal power and/or spectrum space can be achieved.

Since physical realization of the completely optimum detection algorithms cannot, in general, be economically obtained, the corresponding locally optimum or threshold receivers are derived and their performance given. These threshold receiver structures are canonical in nature in that their structure is independent of the form of the interference. They are also adaptive in that they must be able to adjust to the changing interference environment. Locally optimum structures are given here for coherent and incoherent detection with constant signal levels and various kinds of fading. The case in which phase estimation is used (partially coherent reception) is also considered.

Key words: Impulsive interference, impulsive noise, interference models, man-made noise, optimum detection, threshold receivers.

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1. INTRODUCTION

Man-made electromagnetic interference (or noise) has become a problem of great concern in the telecommunications community, particularly in the face of available bandwidth resources. Such noise is also, and will become more and more so, a major limiting factor for the successful functioning of communication systems. There is now general recognition of the terrible price that is paid for the effects of man-made noise. The sources are virtually unlimited--incidential radiation from electrical devices of all sorts; complex out-of-band modulation products from radio communications systems, particularly where many independent users are crowded into small geographical areas; spurious emissions from radio frequency generators of various types; minor lobe radiation from directional antennas; and so on.

The usual means of combating such noise is the use of higher powers or greater bandwidths in the affected system in order to overcome the noise. But this increase in power and/or bandwidth may, in turn, raise the ambient interference level to other users and contribute to a never-ending cycle of increasing interference.

The receivers in general use today are those that are designed to be optimum when the interference is white Gaussian noise. Unfortunately, a communications system is seldom interfered with by white Gaussian noise. The interference is almost always far from being Gaussian, being instead, quite impulsive in nature. The general approach in the past has been to use various ad hoc techniques to make the real world interference appear to the receiver to be more Gaussian, thereby matching the receiver. Such techniques take the form of wide-band limiting, hole-punching, smear-desmear filtering, time-domain filtering, etc. All such techniques, in order to be effective, require large increases in bandwidth and are extremely wasteful of the limited spectrum resource. Only recently have there been efforts to design receivers to match the interference.

Effective analysis of system performance and design requirements demands tractable models of the interference mechanisms, so that the standard methods of Statistical Communication Theory can then be employed for the desired system evaluations. The models are necessarily statistical, on one hand, since the processes they describe are inherently random in time and space. On the other hand, since these processes are generated in the real world, for an adequate description we must also include the appropriate physics of propagation and reception.

In section 2 we start by reviewing the models for impulsive interference that have been proposed. As we will see, most of these models are either empirical in nature and, therefore, not suited for the determination of optimal detection algorithms, or are mathematically intractable and not related to the underlying physics. The only exception to date is the model recently developed by Middleton (1972) which is both tractable and related to the physics. This model is summarized in some detail in section 2, where the statistics we require in the determination of optimal detection algorithms and the performance of these algorithms are presented.

We distinguish two principle classes of interference generally:

Class A Noise: where the interference is spectrally less than the desired signal, and

Class B Noise: where the interference is spectrally very broad vis-a-vis the desired signal.

Middleton's model is the only general model to date that also covers the important case of class A interference.

Section 3 summarizes briefly the pertinent concepts from Statistical Decision Theory that we require and also summarize the past results of optimal detection in impulsive interference.

In section 4 we obtain, for class A interference, the optimum coherent detectors for a variety of signaling situations and analyze the performance of these receivers. The performance of the current suboptimum receivers (i.e., those optimum in white Gaussian noise) is obtained and compared with the optimum performance. It is seen that quite substantial improvement is possible. Corresponding locally optimum Bayes detectors (LOBD) are also derived and their performance obtained. The LOBD structures are canonical (do not depend on the form of the interference) and are much easier to realize physically than the completely optimum structures. Section 5 then treats the corresponding incoherent signal detection cases.

Finally, in section 6, we present a summary of results, point out which results are new, discuss these results, and give some indications of required next steps.