Joint Demodulation of Low-Entropy Narrowband Cochannel Signals

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Introduction to Cochannel Signals: Many receivers today operate in an interference-limited environment. In a dense signal environment, the performance of a receiver is limited by interference from multiple signals at the receiver rather than signal-to-noise ratio. In the interference-limited environment, there is a diminishing return from investing additional resources into improving traditional receiver parameters such as noise figure. Advanced processing techniques exist that can help recover information that would otherwise be lost using a single-channel receiver.[1] This work investigates some of these techniques.

Interference may originate from many sources, such as users on the same or adjacent frequency band, unintended emissions, and intermodulation. This work investigates interference from cochannel information bearing signals. Cochannel interference is commonly defined as the reception of two or more signals at the receiver overlapping in frequency and in time.

AIS: The Automatic Identification System (AIS) is a ship- and land-based tracking and communications system operating in the very high frequency (VHF) maritime band. The primary function of AIS is to provide information for surveillance and the safe navigation of ships.[2,3] The AIS typically sends ship-based tracking messages indicating position and state information at intervals of 2 to 10 seconds. The International Maritime Organization (IMO) has ruled that all passenger ships, cargo ships greater than 500 gross tons, and all ships greater than 300 gross tons on an international voyage must carry an AIS transceiver by July 2008.[4] As a result, AIS provides an excellent means to monitor ship traffic entering U.S. waters and, thus, is of great interest to the Department of Homeland Security. Reception of AIS from a low Earth orbit (LEO) satellite, such as TACSAT-2, would provide an AIS monitoring capability at a greater distance than possible with coastal AIS receivers. However, because of the large field-of-view from LEO, the probability of cochannel interference while monitoring AIS is high.

This work uses the AIS signal as an example of a signal with the following properties: narrowband, cochannel, and low-entropy. The AIS signal is shown to have significant redundancy of information content from message to message. Analysis of the AIS data suggests a 168-bit AIS packet contains approximately 20 bits of new information. This research investigates the low-entropy property of the AIS signal and presents experimental results quantifying this property.

Joint Field-Based MAP: Although multiuser detection is a mature research field,[1] little prior research has focused on low-entropy signals. Optimal detection uses all the available information to make a decision. The optimal joint detection techniques are often dismissed due to the complexity of the receiver. Situations exist where this complexity is justified and is the most cost effective way to recover a signal. The field-based maximum *a posteriori* (MAP) joint detection algorithm uses the available *a priori* information to aid in jointly making a decision of what values are sent. Conceptually it is not difficult to understand; the idea is to select the combination of transmitted signals that maximize the *a posteriori* probability of a transmitted field. Let **A** be an $N \times N_s$ matrix of the transmitted symbol vectors $\mathbf{A} = \{\alpha_1 \alpha_2 \ldots \alpha_{N_s}\}$, where N_s is the number of signals and N is the length of each vector. The optimum receiver (minimizing the probability of incorrect **A**) is defined as the MAP receiver[5] that selects the most probable **A** given the received vector r. Finding the most likely set of transmitted signals, $\hat{\mathbf{A}}$, is now a combinatorics problem; try all 2^{NN_s} permutations of **A** and select the one that maximizes the *a posteriori* probability. This method is impractical for all but the shortest of messages. This research investigates *efficient* methods of incorporating the information available at a receiver in order to make a decision.

Results: This work develops the Joint Field-Based MAP algorithm in order to achieve the goals stated above. By incorporating *a priori* information from the signal sources, this detector outperforms maximum likelihood (ML)-based joint detectors. The field error rate (FER) performance gain is highly dependent on the specific signal characteristics. Here, results are presented for representative signals that show gains of approximately 3 to 18 dB over the current state of the art (joint symbol-by-symbol detection). Figure 3 illustrates this for the reception of the longitude field of an AIS message. FER is plotted for three different correlation coefficients, ρ. Even for highly correlated signals, the field-based MAP detector has acceptable performance. This gain does come at a cost. There must be a source of *a priori* information; this may be previous signal receptions or some other source of side information. Without knowledge of one or more of the cochannel signals, there will be no gain in performance. There is also a processing cost. Implementing the Joint Field-Based MAP detector is both more computationally costly and more difficult to set up than that of the joint ML detection. The complexity of the Joint Field-Based MAP detector is exponentially dependent

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on both the number of users and the field length. A complexity reduction is possible by recognizing that some field values occur with negligible probability. This technique significantly reduces the computational cost while incurring a small penalty in FER performance.

Summary: Figure 4 presents a "big picture" view of the objective in this work as applied to remote reception of the AIS. The algorithm begins with some knowledge about existing ships — this could be very specific information such as a previous position report or very general, such as "Ship A left Port B at 1300 yesterday." At the receiver, two or more signals are received overlapping in frequency and time. The signal parameters for each of the overlapping signals are estimated. This reception is passed through multiple matched filters, and each filter is matched to a specific pulse with estimated parameters. The resulting decision statistics are then passed to the Joint Field-Based MAP detector, along with *a priori* information derived from previous receptions or other sources. The output of the decisions from the joint detector is then passed to prediction algorithms for future receptions.

This work focuses on advanced reception techniques that are of particular relevance to the military. Most of these techniques are applicable when there is sufficient extra processing capability available. These techniques are tailored toward asymmetric communications; the scenario where there are existing transmitters and an advanced receiver platform. Although this work uses the AIS signal as an example, it is envisioned that with adequate processing resources, these algorithms can be used to improve the bit error rate (BER) performance of many other systems. This work presents simulation and analytical bounds demonstrating the benefit of using these advanced detection techniques on cochannel signals.

[Sponsored by USAF]

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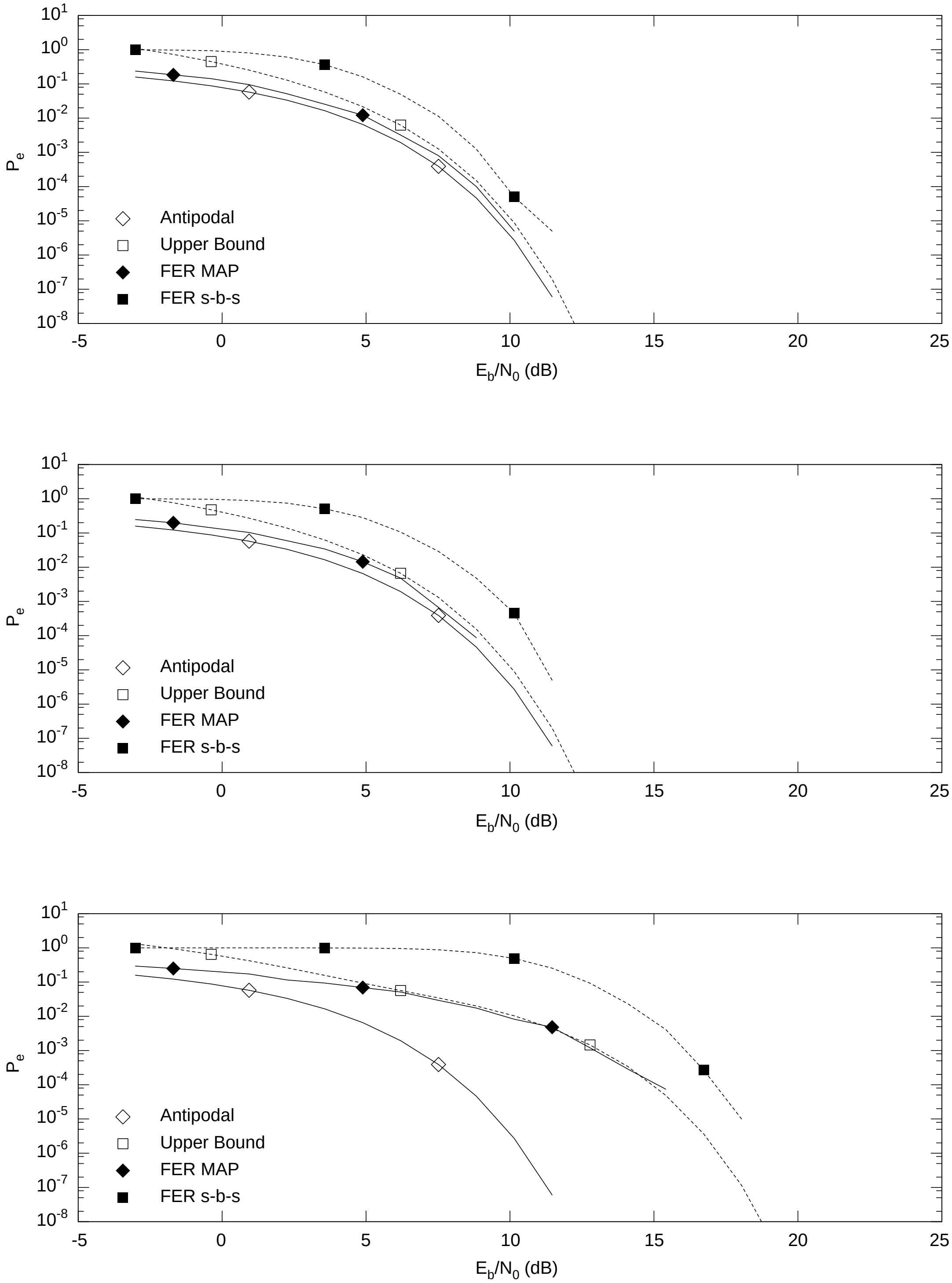

FIGURE 3
Joint field-based MAP for 28-bit field values separated by 1.

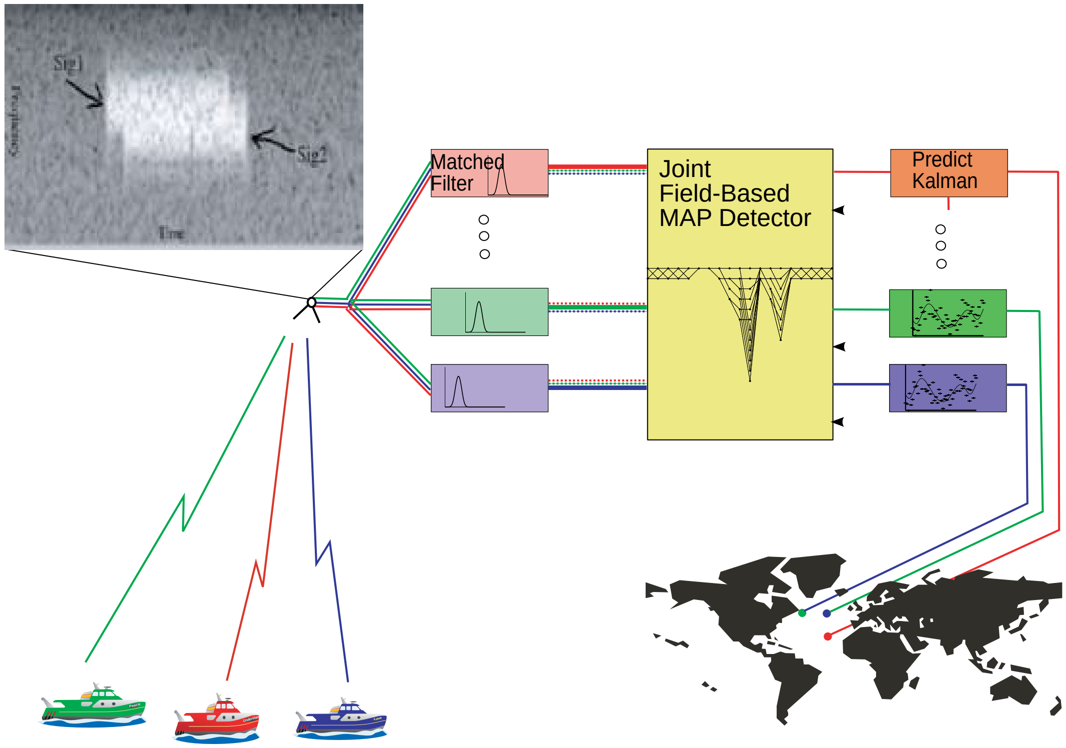

FIGURE 4
Application of joint field-based MAP.