Value of Information Sharing in Network Signal Detection

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Introduction

• Standard methods for detecting the presence of a common but unknown signal in data collected at multiple geographically distributed sensors rely on total accumulation of the collected data for simultaneous analysis

• A typical application is detecting the presence of an uncharacterized emitter

• Processing performed on the aggregated data may be regarded as a data fusion mechanism: it provides a single global answer (i.e., → \( H_1 \) / \( H_0 \)) from data collected at more than one sensor

• Sensor scenarios that motivate this research involve incomplete data accumulation

• For a particular class of multiple-channel detectors, the value of a link in the network graph is measured in terms of the difference in detection performance with the link present between two nodes versus using a maximum-entropy surrogate for data shared between the nodes

• For example, the sensors collecting data may be networked in such a way that complete sharing of data between all pairs of sensors is not viable

• We demonstrate detection performance in such scenarios where maximum-entropy methods are used to “surrogate” information between sensors that may not be in direct communication, providing a mechanism for quantifying the value of information sharing within the network

Generalized Coherence Detection

• Multiple-channel detection using the Generalized Coherence (GC) estimate formed from the channel data is a well-established method [2,3]

• Given \( M \geq 2 \) complex data channels and finite samples \( X_1, \ldots, X_M \in \mathbb{C}^N \) from each channel, the GC estimate obtained from these measurements is

\[
\hat{\gamma}_M^2(X_1, \ldots, X_M) = 1 - \frac{\det G(X_1, \ldots, X_M)}{||X_1||^2 \cdots ||X_M||^2},
\]

where \( G(X_1, \ldots, X_M) = \begin{bmatrix} (X_1, X_1) & \cdots & (X_1, X_M) \\ \vdots & \ddots & \vdots \\ (X_M, X_1) & \cdots & (X_M, X_M) \end{bmatrix} \)

(1)

• In typical multiple-channel detection applications, \( \hat{\gamma}_M^2 \) is compared to a threshold to decide between signal-present \( (H_1) \) and signal-absent \( (H_0) \) hypotheses

• The statistical properties and performance of the GC estimate as a multi-channel detection statistic have been studied extensively, specifically when all information is shared [1-3]

References


Simulation Results

• The effect on detection performance of replacing missing data by maximum-entropy surrogate values has been examined experimentally [4,6]

• A link between sensors is precisely as valuable as the performance gain it enables over the use the maximum-entropy surrogate in place of its datum

• Detection performance for two incompletely connected topologies (each with two surrogate values) suggests that performance may be identical

Null Distribution of Surrogated Coherence

• Knowledge of the distribution of the data under the \( H_0 \) assumption that the \( x_{ij} \) are independent zero-mean white complex gaussian noise vectors ensures that detection thresholds that correspond to desired false alarm probabilities can be analytically determined

• Without surrogation, conditional distributions under the signal-present and signal-absent hypotheses have been studied [1,3]

• Recording the distribution of the surrogated \( \hat{\gamma}_M^2 \) given \( H_0 \) with 1,000 degrees of freedom provides empirical cumulative distribution functions for the two distinct sensor network topologies

Discussion

• Further empirical tests for various network sizes and topologies show that different network topologies on \( M \) sensors with equal numbers of surrogations give indistinguishable distributions of the generalized coherence estimate under \( H_0 \), hence:

• Conjecture: The null distribution of the surrogated coherence estimate does not depend on the network topology, only on the number of links present

• If this holds, it will only be necessary for the fusion center to store one set of detection thresholds for each number of possible surrogate values rather than one set for each possible network topology