Analyze-Fuse versus Fuse-Analyze in Multi-Channel Emitter Detection

Lauren Crider†, Raj Rao Nadakuditi‡ Douglas Cochran†

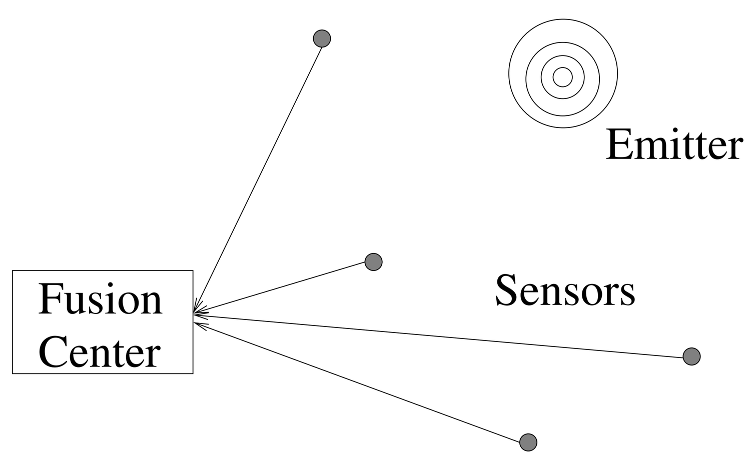
†Arizona State University ‡University of Michigan

Introduction

- Ongoing work at the University of Michigan under this MURI has shown that "analysis before fusion" can be advantageous in certain multi-source statistical signal processing situations [1]
- Here, we explicitly investigate the effect of pre-processing to censor weak channels prior to multi-channel processing on the performance of an established muti-channel signal detection method

Generalized Coherence-Based Detection

- Standard methods for detecting the presence of a common but unknown signal in data collected at several geographically distributed sensors rely on aggregation 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., $\to H_1$ / $\to H_0$) from data collected at more than one sensor
- In what follows, we demonstrate that detection performance of one such method can be substantially improved in some circumstances by pre-fusion analysis that leads to "censoring" certain (weak) channels from use in the multi-channel fusion detector

Generalized Coherence Detection

- Multiple-channel detection using the Generalized Coherence (GC) estimate formed from the channel data is a well-established method [2,3,4]
- 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

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

where $G(X_1, \ldots, X_M)$ is the $M \times M$ Gram matrix

$$G(X_1, \ldots, X_M) = \begin{bmatrix} \langle X_1, X_1 \rangle & \langle X_1, X_2 \rangle & \cdots & \langle X_1, X_M \rangle \\ \langle X_2, X_1 \rangle & \langle X_2, X_2 \rangle & \cdots & \langle X_2, X_M \rangle \\ \vdots & & \ddots & \vdots \\ \langle X_M, X_1 \rangle & \langle X_M, X_2 \rangle & \cdots & \langle X_M, X_M \rangle \end{bmatrix}$$

- The statistical properties and performance of the GC estimate as a multi-channel detection statistic have been studied extensively [2-8]

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Proposed Analyze-Fuse Approach

Note that computing the GC estimate entails evaluating inner products between segments of time series data collected at each pair of nodes in the network; this may be done at the fusion center using raw sensor data or locally at pairs of nodes that are in direct communication

- The availability of these pairwise correlations enables performance of a two-channel GC test on each pair X_i and X_j of data vectors
- Invariance properties given in [5,6] show that two-channel GC estimate will still follow its H_0 distribution even if one channel contains a strong signal, provided
  - The other channel contains only ZMWGN, and
  - The two channels are statistically independent

Analyze-Fuse algorithm

1. Test each pair (X_i, X_j), $i > j$ of data vectors using a two-channel GC detector with liberal threshold
2. Discard (censor) and channel that does not pass at least one pairwise test
3. Perform a GC test with the $K \leq M$ remaining channels

Experiments & Results

The effect of the Analyze-Fuse procedure on detection performance was examined experimentally as follows:

- Given $M = 7$ complex data channels, define

$$A = \begin{bmatrix} | & | & \cdots & | \\ X_1 & X_2 & \cdots & X_M \\ | & | & \cdots & | \end{bmatrix}$$

to satisfy conditions for *two* experiment designs:

1 Channel with Varying SNR

A is constructed such that

1. X_1, X_2 and X_3 carry a *strong* signal, with SNR = -3 dB
2. X_4, X_5 and X_6 contain only ZMWGN
3. X_7 has a *varying* SNR ranging from -3 to -57 dB

4 Channels with Varying SNR

A is constructed such that

1. X_1, X_2 and X_3 carry a *strong* signal, with SNR = -3 dB
2. X_4, X_5, X_6 and X_7 have equal SNRs *varying* from -3 to -57 dB

- With appropriately constructed data, perform a seven-channel GC test with threshold corresponding to $P_f = 0.1$
- Test each data channel pair (X_i, X_j), $i > j$ using a two-channel GC detector against a more liberal threshold $(P_f = 0.25)$
  - Discard all channels that do not pass the two-channel test at least once
  - Perform a $K-$channel GC estimate compare against the moderate threshold with $K \leq M$ remaining channels
- Plot the probability of detection as a function of the varying SNR values
- Compare the 7-channel test with the K-channel test

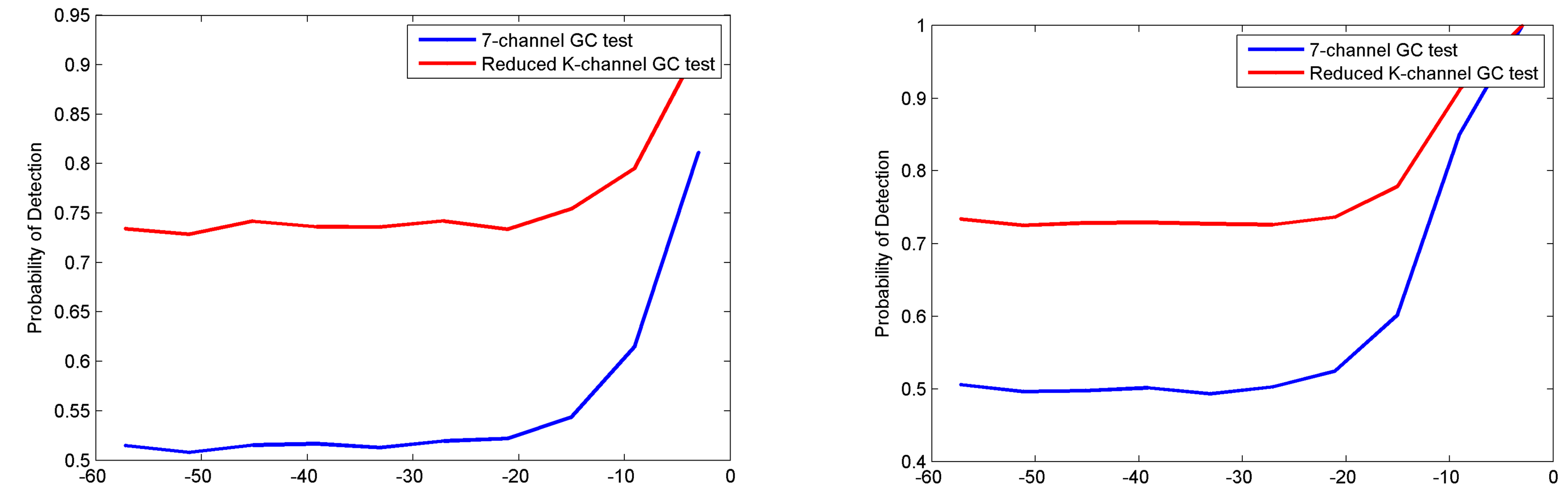

Figure : (Left) Empirical probability of detection (P_d) as a function of the varying SNR on channel 7. (Right) P_d as a function of the varying SNR on channels 4, 5, 6 and 7. The red lines show results from the full 7-channel GC detector, blue lines show results with censoring prior to the GC detector. P_f is held constant at 0.1.

Distribution of K

- Recording the number K of channels used in each second-stage test provides a sample distribution of K
  - In the experiment with 1 channel of varying SNR, there is a slight tendency to include more channels in the second-stage test for high SNR
  - In the experiment with 4 channels of varying SNR, all 7 channels are always used once the SNR is sufficiently high; all channels have strong signal present in this case. In the low SNR regime, the distribution of K is broader
- Caution is warranted in censoring: results in [7,8] show that multi-channel detection is possible for signals too weak to be detected on any pair of channels

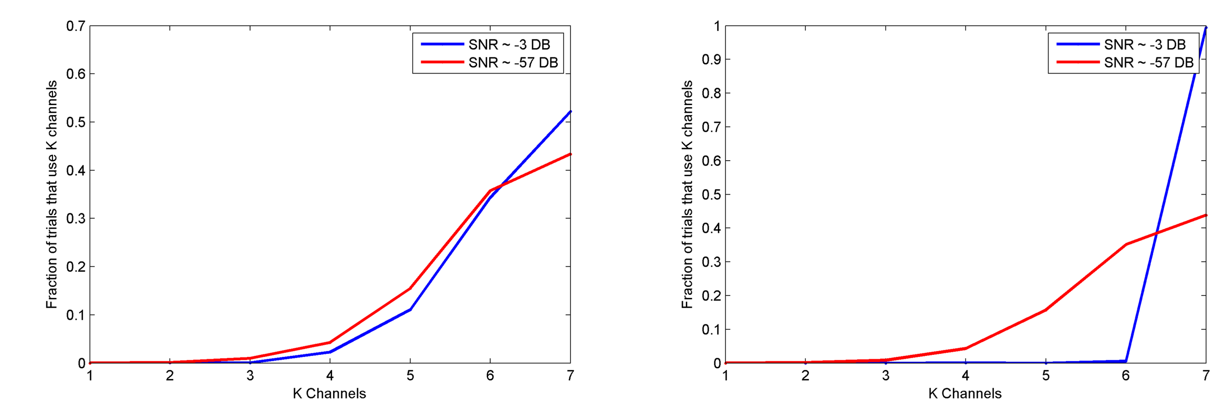

Figure : Sample distributions of K, the number of channels used in the second (fusion) stage. (Left) Representative of the experiment with onn channel of varying SNR. (Right) Representative of the experiment with 4 varying channels.

Discussion and Future Work

These results, though preliminary, indicate that pre-fusion processing to censor non-contributing sensors can yield substantial payoff in detection performance. Some directions for extension of this work are evident:

- Analytical treatment of the problem, including optimization of thresholds at the censoring stage
- Network instantiation using maximum-entropy surrogation, as described in [9]

References

[1] R. R. Nadakuditi, "Fundamental finite-sample limit of canonical correlation analysis based detection of correlated high-dimensional signals in white noise," *Proceedings of the IEEE Statistical Signal Processing Workshop*, 2011.

[2] H. Gish and D. Cochran, "Generalized coherence," *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*, April 1988.

[3] D. Cochran, H. Gish, and D. Sinno, "A geometric approach to multiple-channel signal detection," *IEEE Transactions on Signal Processing*, September 1995.

[4] S. Sirianunpiboon, S. D. Howard, and D. Cochran, "A Bayesian derivation of the generalized coherence detectors," *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*, April 2012.

[5] A. H. Nuttall, "Invariance of distribution of coherence estimate to second-channel statistics," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, 1981.

[6] H. Gish and D. Cochran, "Invariance of the magnitude-squared coherence estimate with respect to second channel statistics," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, December 1987.

[7] A. Clausen and D. Cochran, "An invariance property of the generalized coherence estimate," *IEEE Transactions on Signal Processing*, 1997.

[8] K. Beaudet and D. Cochran,"Multiple-channel detection in active sensing," *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*, June 2013.

[9] K. Beaudet, L. Crider, and D. Cochran, "Detection in networked radar," *Proceedings of the SPIE Defense, Security, and Sensing Conference*, May 2013.