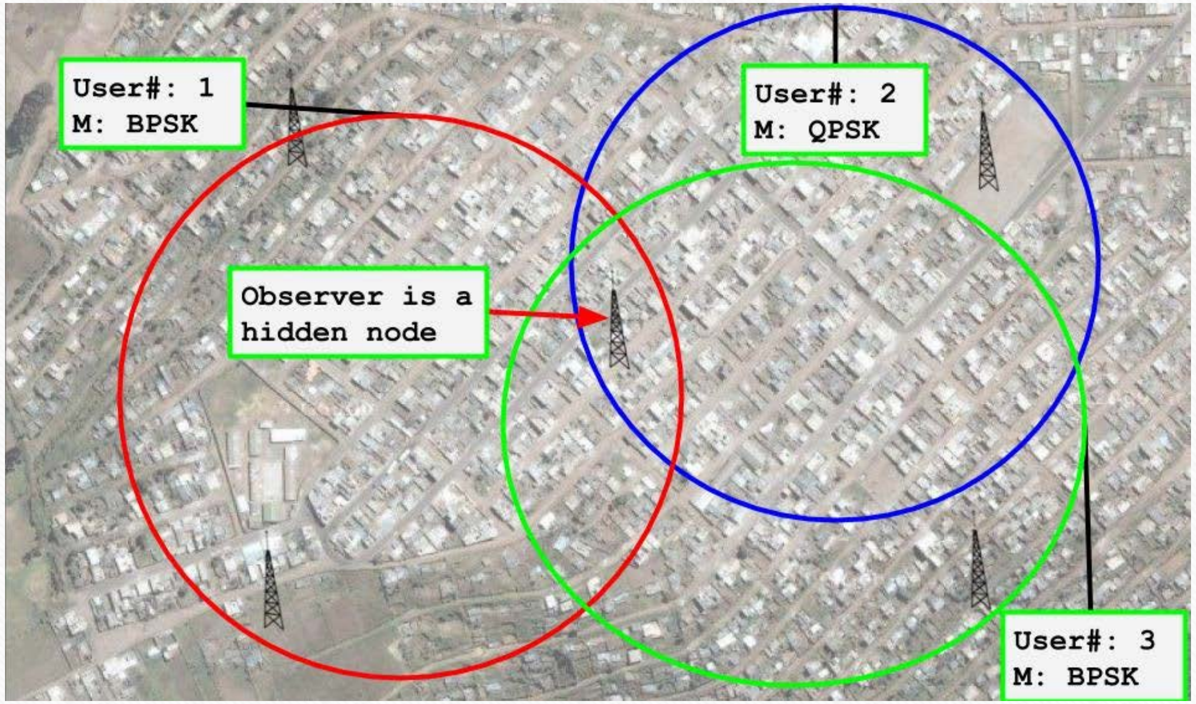
Multi-Receiver Modulation Classification for Non-Cooperative Scenarios

Agenda

- Non-Cooperative Scenarios
- Blind Source Separation
- Modulation Classification
- Simulation/Results
- Conclusions

Non-Cooperative Scenarios

A Common Scenario



Models

- **Several incoming signals can be modeled:**

$$\alpha_i e^{j2\pi\Delta_i f t} e^{j\theta_i} \sum_{k=1}^{K} e^{\phi_k} s_k g(t - (k-1)T - \epsilon T)$$

- α_i -- Amplitude of i^{th} signal
- Δ_i, θ_i -- Frequency and phase offset
- ϕ_k -- phase jitter
- ϵ – timing offset
- $g(t)$ -- convolution of impulse response and pulse
- T – Symbol period
- s_k -- k^{th} symbol

Issues

- Not certain how many users are actually transmitting.
- This is not a regular MIMO system, so transmitters are out of sync.
- Signal strengths are likely very different, making the ADC dynamic range an issue.

Solutions

- Digital or Analog Beamforming
  - Modulation Classification is generally a secondary function of a radio.
  - Beamforming generally uses knowledge of the signal like training symbols
- MIMO-system channel classification
  - What if one of the signals is analog? What if not all of their modulations are the same?
- **Blind Source Separation**
  - Only assumes statistical properties of incoming signals.

Blind Source Separation

Independent Component Analysis

- JADE (Joint-Approximate Diagonalization of Eigenmatrices)
  - Separate the incoming signals by intelligently guessing the separation matrix
- Others
  - Separate by maximizing the entropy of several separated signals
  - Separate by minimizing the cumulants of a signal

Issues

- We cannot know how many signals are present
  - One option: guess that there are 10 signals. If there is only 1 signal, the rest can be considered noise.
  - Many ICA algorithms are limited in the number of Gaussian signals they can separate.

Modulation Classification

Three Stages

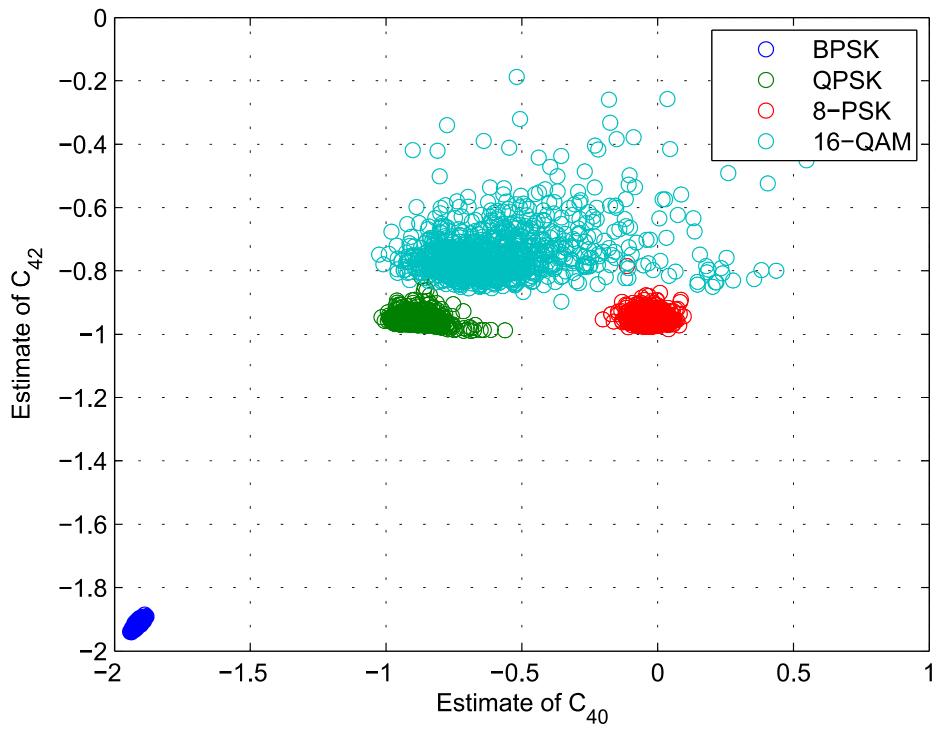
- Modulation Classification can be separated into three problems
  - Preprocessing
  - Feature Extraction
  - Classification
- We propose novel additions to each problem

Approach

- Preprocessing
  - **Blind Source Separation:** fastICA, Gonen, and JADE algorithms are compared for both single and multi-user scenarios to see which is better overall
- Feature Extraction
  - **Fourth-Order Cumulants:** A variant of the Fourth-order cumulants is considered
- Classification
  - **Support-Vector Machine:** Two fourth-order cumulant values

Fourth-Order Cumulants

- $\hat{C}_{20} = \frac{1}{N}\sum_N y^2(n)$
- $\hat{C}_{21} = \frac{1}{N}\sum_N |y(n)|^2$
- $\hat{C}_{40} = \frac{1}{N}\sum_N y^4(n) - 3\,\hat{C}_{20}^2$
- $\hat{C}_{42} = \frac{1}{N}\sum_N |y(n)|^4 - \left|\hat{C}_{20}\right|^2 - 2\hat{C}_{21}^2$



Phase-Correction

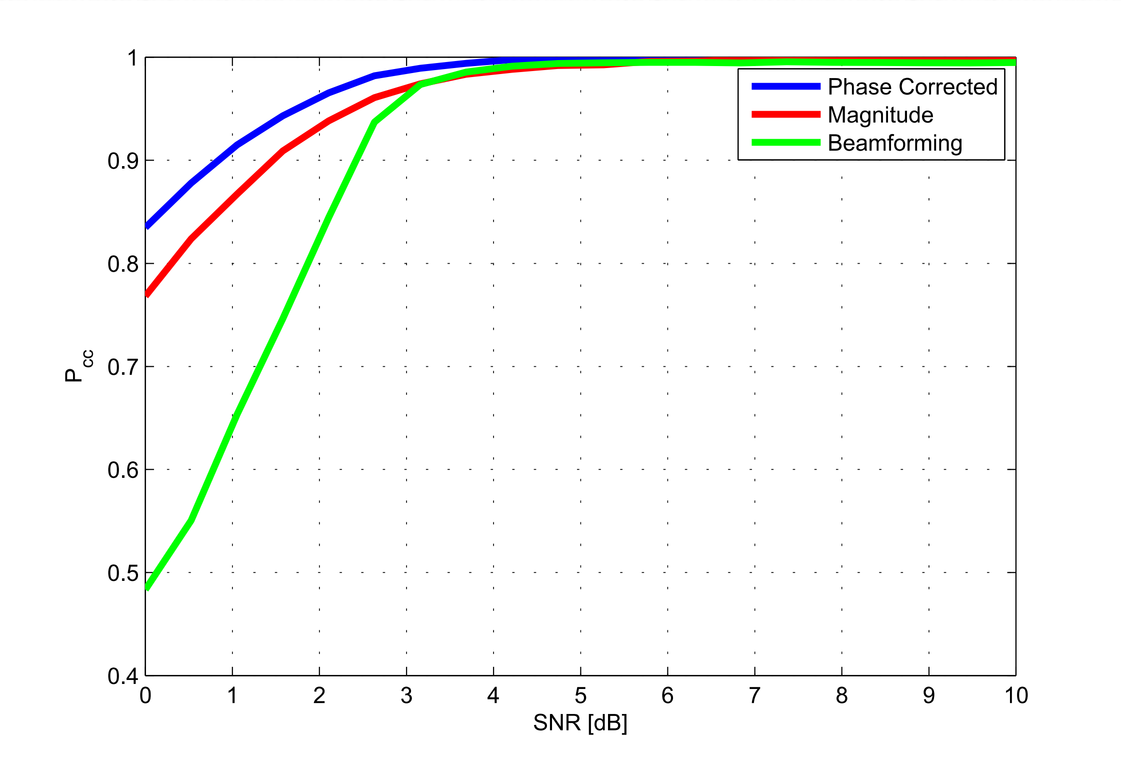
- BSS techniques introduce a phase ambiguity, making the cumulant estimates also have a phase ambiguity
  - Take the magnitude, then compare.
  - Attempt to correct the phase by maximizing the average magnitude of the imaginary component
- The latter shows better results, even in low-SNR (0 dB) environments

BSS Algorithms

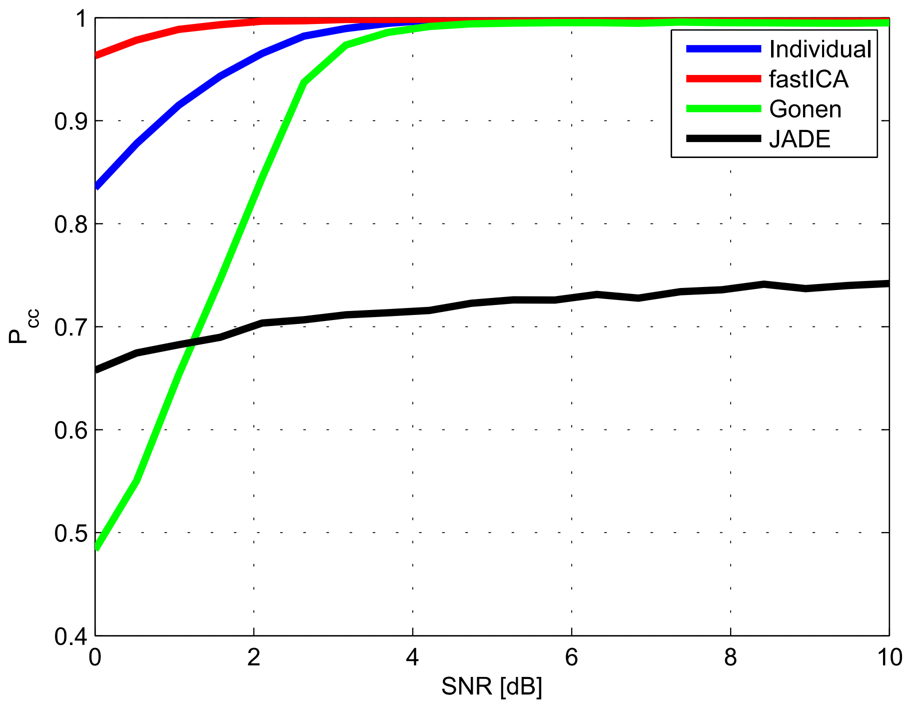
- JADE [1]
  - Fails to separate more than two Gaussian sources
- Gonen [2]
  - Based on cumulants, so noise and interferences are suppressed. Suffers in Single-user cases
- fastICA [3]
  - Computationally efficient. Handles many sources.

Simulation and Results

Magnitude and Phase-Correction Algorithms

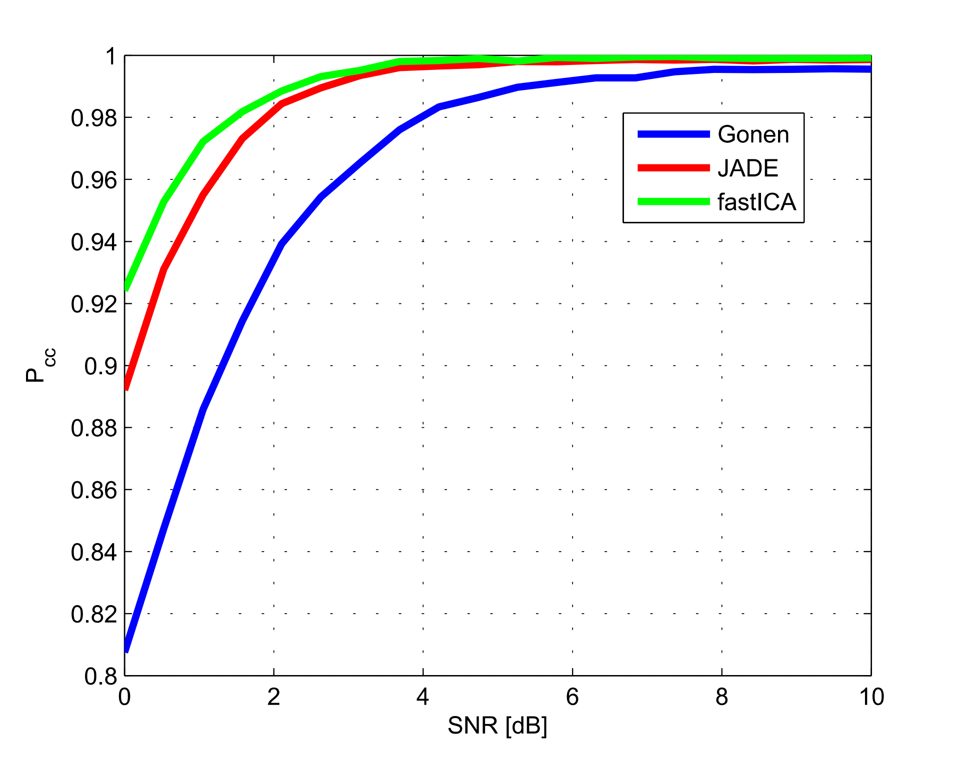


Single-User



Individual
fastICA
Gonen
JADE
P_{cc}
SNR [dB]
1
0.9
0.8
0.7
0.6
0.5
0.4
0
2
4
6
8
10

Multi-User Results



References

- [1] Cardoso, J., & Souloumiac, A. (1993). Blind beamforming for non-Gaussian signals. *IEE Proceedings F (Radar and Signal Processing)*, *140*(September). Retrieved from http://digital-library.theiet.org/content/journals/10.1049/ip-f-2.1993.0054
- [2] Gonen, E., & Mendel, J. (1997). Applications of cumulants to array processing. III. Blind beamforming for coherent signals. *IEEE Transactions on Signal Processing*, *45*(9), 2252–2264. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=622948
- [3] Hyvärinen, A. (1999). Fast and robust fixed-point algorithms for independent component analysis. *IEEE Transactions on Neural Networks*, *10*, 626–634. doi:10.1109/72.761722