QUADRATIC DETECTION IN NONCOHERENT MASSIVE SIMO SYSTEMS OVER CORRELATED CHANNELS

Signal Processing & Communications

Marc Vilà-Insa, Aniol Martí, Jaume Riba, and Meritxell Lamarca

Signal Processing and Communications Group (SPCOM), Departament de Teoria del Senyal i Comunicacions

Universitat Politècnica de Catalunya (UPC)

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Motivation

- **Industrial IoT (IIoT) requirements:**
  - High reliability and stringent latency constraints
  - Limited traffic volume
  - High density of low-power/low-complexity terminals
- **Proposed implementation:**
  - Leverage mMTC and URLLC from 5G (& beyond)
  - Noncoherent massive SIMO with *one-shot* transmission
  - Statistical CSI at Rx, low-complexity Tx

Problem statement

- Massive Rx array with N antennas
- Equiprobable M-ary constellation $\mathcal{X}$, decoding after a single channel use
- Correlated Rayleigh fading ($\mathbf{h}$) and correlated additive Gaussian noise ($\mathbf{z}$)

Signal model at Rx: $\mathbf{y} = \mathbf{h}x + \mathbf{z}, \quad x \in \mathcal{X}$

ML detection

- Rx only perceives energy information from $\mathbf{y}$.
- Unipolar PAM constellation: $\mathcal{X} = \{\sqrt{\varepsilon_1} \triangleq 0 < \sqrt{\varepsilon_2} < \cdots < \sqrt{\varepsilon_M}\}$.

Asymptotic performance

Uniquely identifiable constellation (UIC): $|x_a|^2 \neq |x_b|^2, \ \forall x_a, x_b \in \mathcal{X}$

Theorem 1: UICs are asymptotically error-free for $N \to \infty$.

Theorem 2: UICs have an error floor at high SNR for $M > 2$.

Under white noise and isotropic channel, ML detection can be decomposed as:

1. Computation of a quadratic statistic of data: $\hat{\varepsilon}(\mathbf{y})$.
2. One-dimensional decision problem: $\hat{x}(\hat{\varepsilon})$.

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Energy statistic

Quadratic framework: $\hat{\varepsilon}(\mathbf{y}) \triangleq \mathbf{y}^{\mathrm{H}}\mathbf{A}\mathbf{y} + c$

Studied implementations:

- **Information-theoretic design criteria:**
  - **Best quadratic unbiased estimator (BQUE):** Obtained by minimizing $\mathrm{MSE}(\hat{\varepsilon})|\varepsilon$. It achieves the CRB but is unrealizable.
  - **Quadratic minimum mean squared error (QMMSE):** Obtained by minimizing $\mathrm{E}[\mathrm{MSE}(\hat{\varepsilon})|\varepsilon]$.
- **High-SNR (HSNR):** Derived from a high SNR approximation of the ML detector.
- **Energy detector (ED):** Low-complexity technique that is well-known in the literature.

All these methods are equivalent under isotropic fading and white noise.

Symbol detection

Detection regions:

- Have to be obtained numerically.
- The use of a massive array can be exploited to derive a simpler approximation through the central limit theorem.
- This results in an analytic expression for the (approximate) error probability.

Assisted BQUE (ABQUE)

Decision-directed detection scheme with close to ML performance in many regimes. Implemented in two phases:

1. An energy statistic is obtained from ED.
2. The previous estimate is used to enable the genie-aided BQUE detection.

Summary of detection schemes

	Complexity	Performance	Graceful degradation	Tractable	Realizable	CSIR agnostic
ML	$O(N^2)+O(MN)$	Optimal	✓	✗	✓	✗
ED	$O(N)+O(M)$	High loss ($\rho \neq 0$)	✗	✓	✓	✓
BQUE	$O(N^2)+O(M)$	Low loss	✓	✓	✗	✗
QMMSE	$O(N^2)+O(M)$	Low loss (moderate SNR)	✓ ($\rho < 0.99$)	✓	✓	✗
ABQUE	$O(N^2)+O(M)$	Low loss	✓	✗	✓	✗

Numerical results

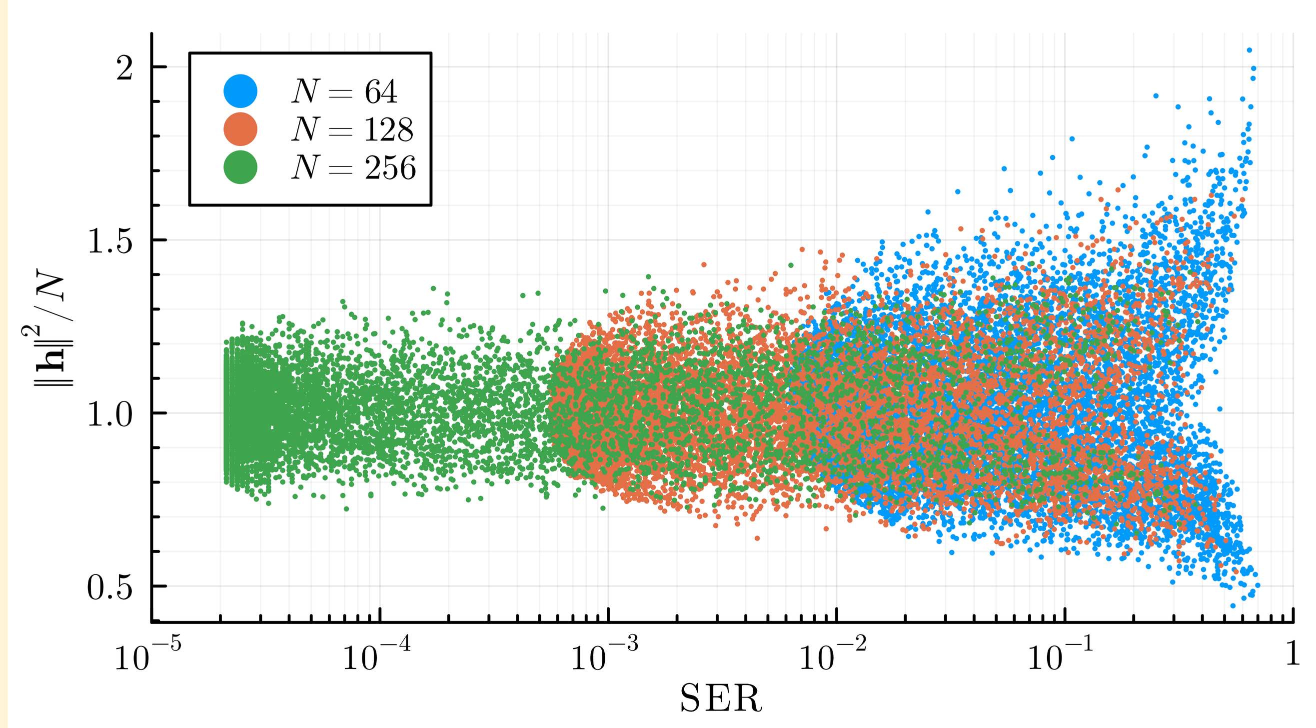

Figure 1. BQUE SER at SNR=10 dB with moderate channel correlation ($\rho = 0.7$).

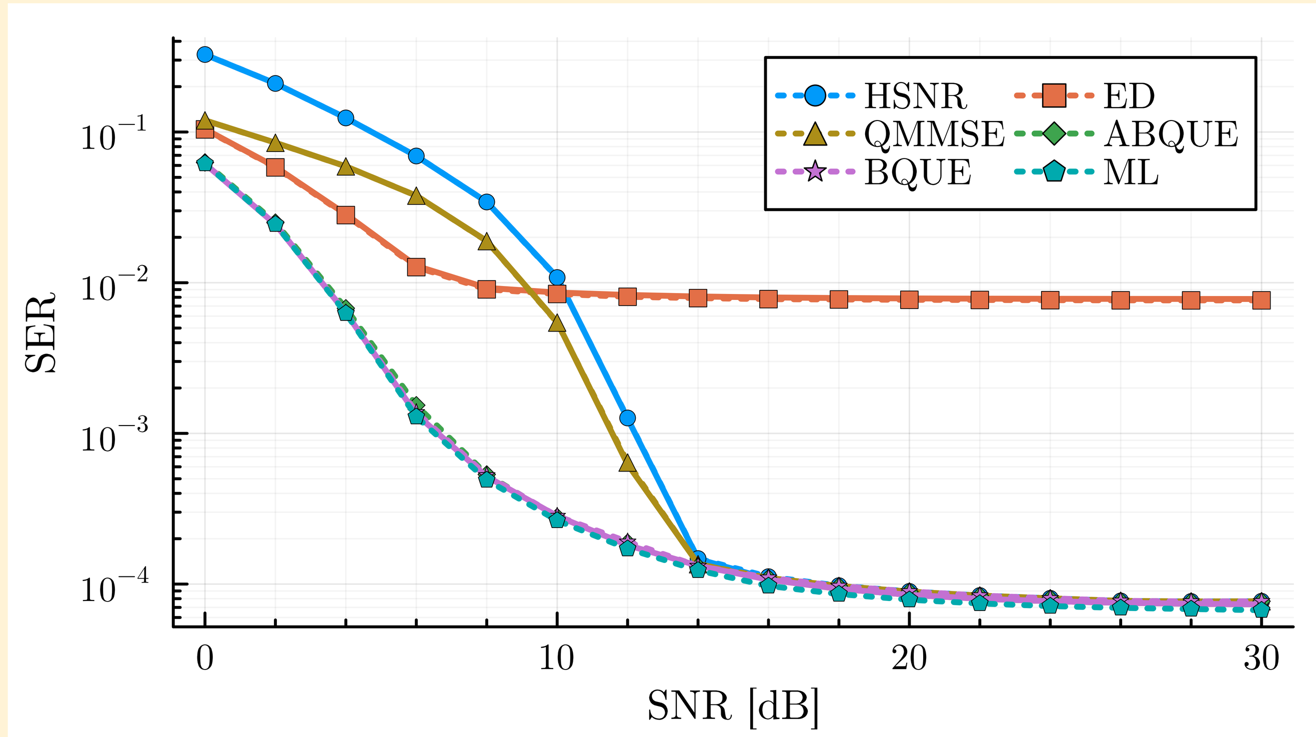

Figure 2. SER of presented detectors for $N = 512$ and moderate correlation ($\rho = 0.7$).

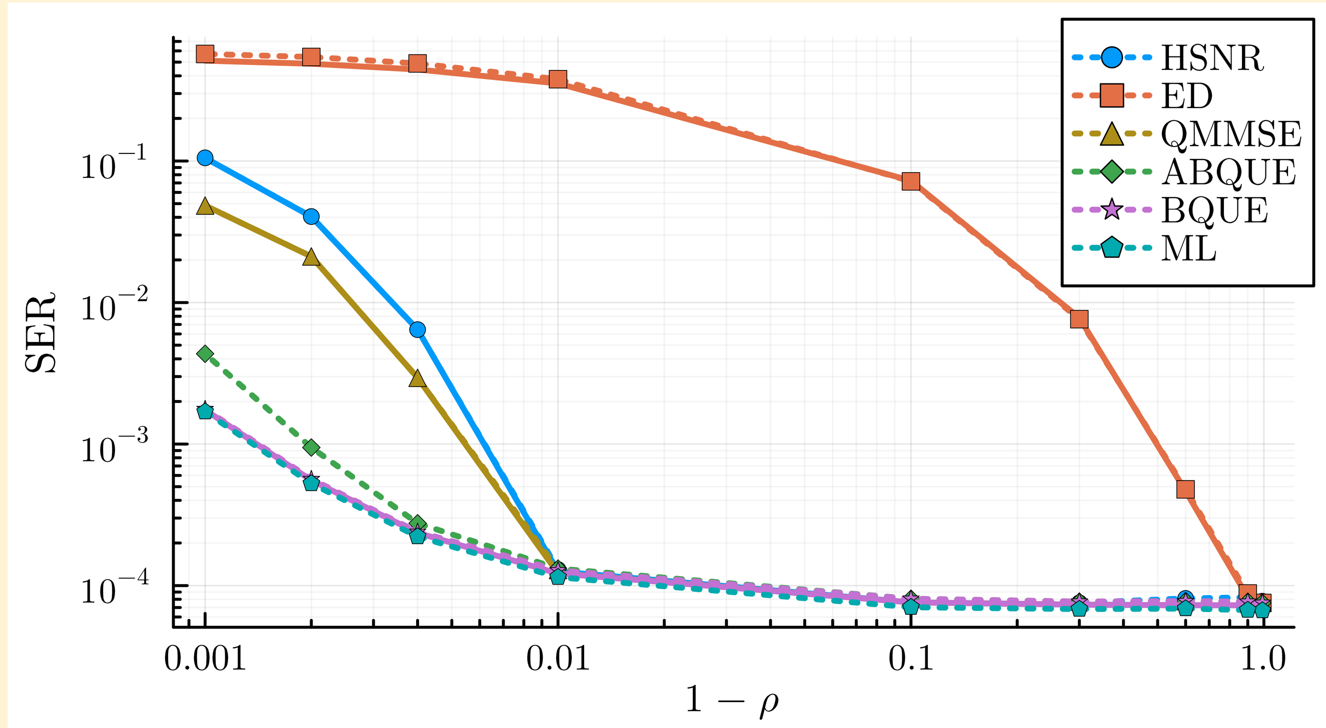

Figure 3. Error floor level of presented detectors for $N = 512$.

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{marc.vila.insa, aniol.marti, jaume.riba, meritxell.lamarca}@upc.edu