Design and Performance of a Noncoherent Massive SIMO System

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Motivation

- Higher carrier frequencies, larger number of antennas ☺
- Large MIMO systems have large channel estimation overhead ☹
- What can we do without CSI at either transmitter or receiver ?

Communication in Massive MIMO: Challenges

- Non coherent schemes:
  - Multiuser Grassman manifold codebook optimization is tough for moderate SNRs
  - Encoding complexity and decoder complexity
- Coherent (pilot based) schemes:
  - FDD: Impractical due to the large number of antennas
  - TDD: Pilot Contamination

System Model

1 receiver with n antennas and 1 transmitter with single antenna:

$$\mathbf{y} = \mathbf{h}x + \boldsymbol{\nu},$$

where $\mathbf{y} \in \mathbb{R}^n$, h_i i.i.d. $\sim f(h)$, ν_i i.i.d. $\sim \mathcal{N}(0, \sigma^2)$, $x \in \mathcal{P}$

Proposed Approach

- Use **only** the knowledge of the channel statistics in the system model and the asymptotics of n
- Energy measurements at the receiver:

$$\frac{||\mathbf{y}||^2}{n} = \frac{\sum_{k=1}^{n} |y_i|^2}{n} \in \mathbb{R}^+$$

- Non-intersecting decoding intervals: $\{\mathcal{I}_p\}_{p \in \mathcal{P}}$
- Estimate the transmitted symbol as: $\hat{p} \in \{p : \frac{||\mathbf{y}||^2}{n} \in \mathcal{I}_p\}$

Aim

Design $\mathcal{P}$ and $\{\mathcal{I}_p\}_{p \in \mathcal{P}}$ to get a low probability of symbol error

Our Previous Results

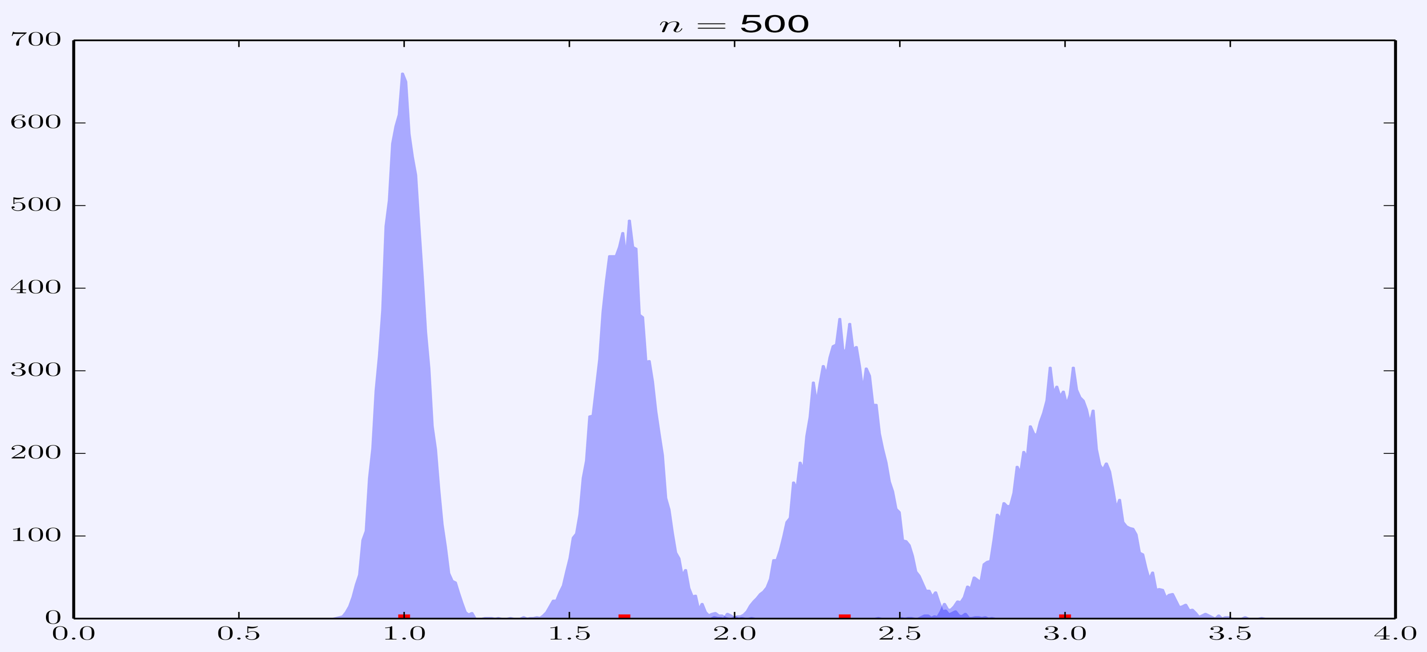
- Positive rate achievability with **vanishing** error
- Low encoding and decoding complexity
- Knowing $\mathbf{h}$ perfectly doesn't improve the scaling behavior with large n
- Multiple-transmitter constellations can also be designed similarly

Our New Results

- Better constellation design if statistics of $\mathbf{h}$ and $\boldsymbol{\nu}$ are perfectly known
- Robust constellation design if statistics of $\mathbf{h}$ are not perfectly known

Error Probability Upper Bound and Rate Function

- P_e is upper bounded by $e^{-nI_p(d)}$ where $I_p(d)$ is the rate function



Useful Lemma

The rate function $I_p(d)$ satisfies

$$\lim_{d \to 0} \frac{I_p(d)}{d^2} = \frac{1}{s(p)}$$

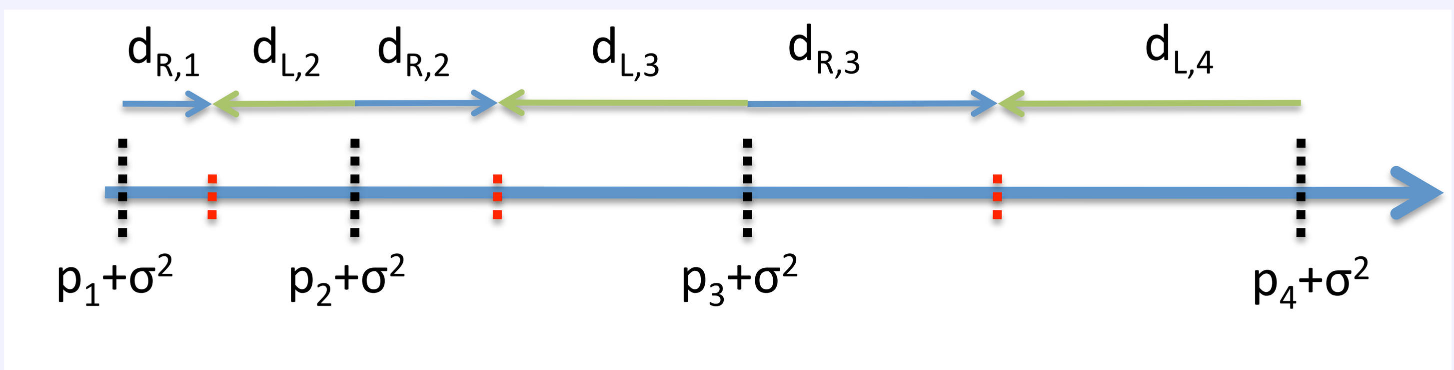
Constellation Design Problem

Perfect Knowledge of Channel Statistics

Using the Lemma, the constellation design problem can be approximated as

$$\underset{\mathcal{P}, \{d_{L,p}, d_{R,p}\}_{p \in \mathcal{P}}}{\text{maximize}} \quad \min \frac{d_{L,p}^2}{s(p)}, \frac{d_{R,p}^2}{s(p)}$$

$$\frac{1}{L} \sum_{i=1}^{L} p_i \leq 1, \ 0 \leq p_i$$



Intuition: Solve a weighted minimum distance problem

Channel Statistics Uncertainty

- We consider the case that

$$\sigma^2 \in [\sigma_l^2 \ \ \sigma_u^2], \text{ and } \alpha \in [\alpha_l \ \ \alpha_u].$$

- We would like to guarantee a vanishing error probability under channel statistics uncertainty

Robust Constellation Design

Find maximum t^* such that:

$$\frac{d_{R,p}^2}{s(p)} \geq t^*, \frac{d_{L,p}^2}{s(p)} \geq t^*, \ \forall p \in \mathcal{P}$$

Number of Antennas needed: Perfect Channel Statistics

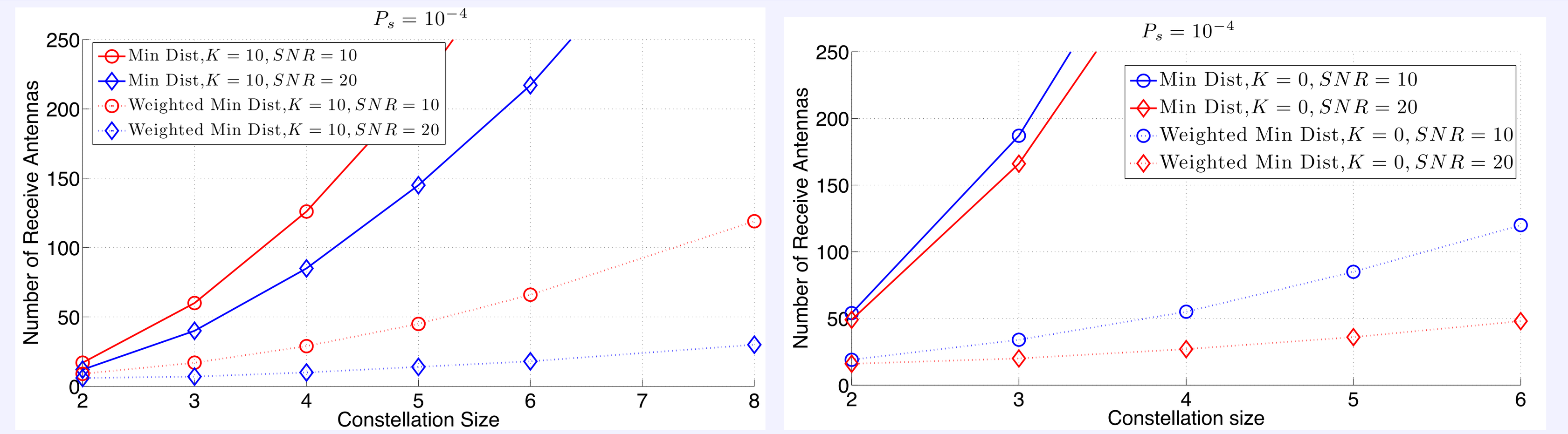


Figure : Minimum number of antennas to achieve $P_e \leq 10^{-4}$ in a Rician channel

SER Performance Results: Uncertain Channel Statistics

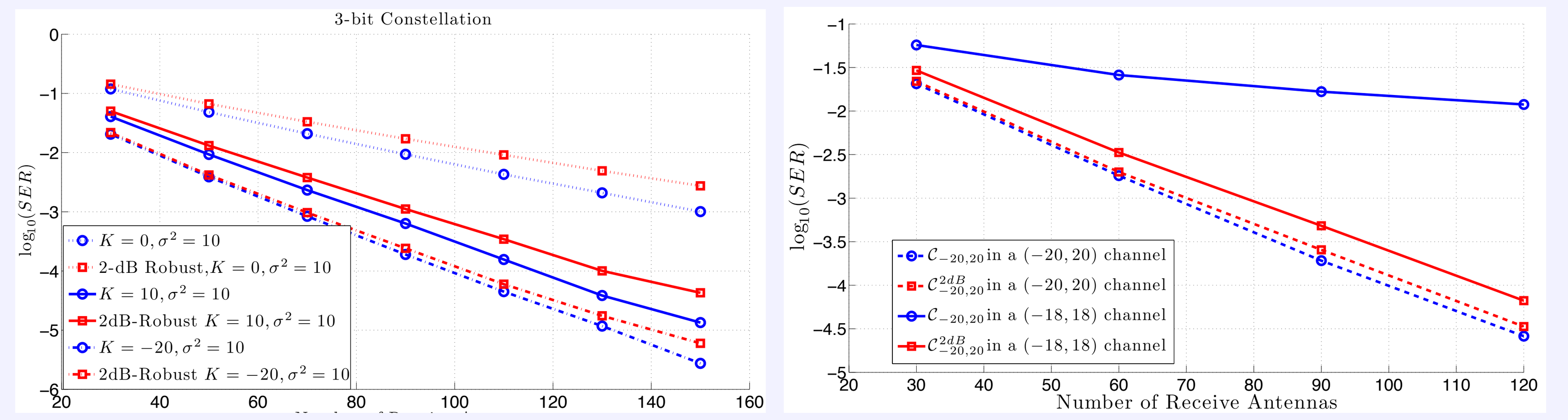


Figure : SER performance comparison between the constellations assuming perfect statistics knowledge and a 2 dB-uncertainty, with increasing number of receive antennas.

Conclusions

- Simple scheme for non coherent communication in SIMO channels with simple encoding, simple decoding (lookup table) and simple receiver architecture (energy measurements only)
- "Asymptotics" kick in even with 50-100 antennas
- Valid for general fading statistics (e.g. Rician, Nakagami) and to block fading models
- **Extensions: multiple users**
- **Current work: large coherence times, phase, downlink**

References

- Mainak Chowdhury, Alexandros Manolakos, Andrea Goldsmith, "Design and Performance of Noncoherent Massive SIMO Systems", IEEE CISS 2014.
- Alexandros Manolakos, Mainak Chowdhury, Andrea Goldsmith, "CSI is not needed for Optimal Scaling in Multiuser Massive SIMO Systems", accepted in IEEE ISIT 2014.

Main takeaway

With 128 receive antennas, we can design a 3-bit constellation that achieves uncoded symbol error probability less than 10^{-4} in Rician Fading with $K = 10$ and SNR=10 dB without any CSI knowledge.