1 bit Massive MIMO Transmitter

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Motivation

- Massive MIMO provides significant advantages
  1. High spectral efficiency
  2. Relaxed Scheduling
  3. Spatial Multiplexing - Diversity - Beamforming

Why no massive MIMO implementation yet [1]?

1. Cost
   - Each antenna requires own RF chain
2. Size
   - $\lambda/2$ distance between antennas
3. Power Consumption
   - Increases with number of RF chains

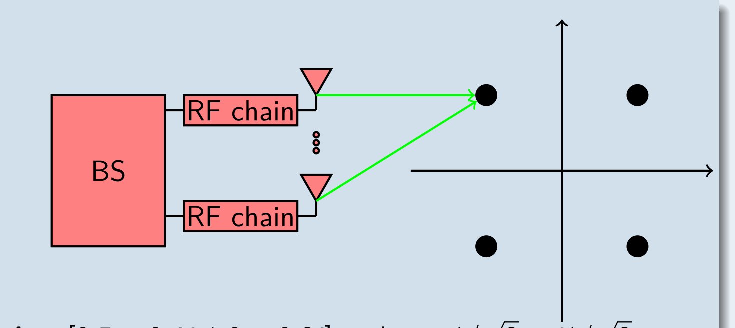
1 bit massive MIMO

1. Very low cost RF chain
2. Can be added to boost existing systems

System Model

General Idea

As each antenna is connected to an RF chain, we aim to reduce the cost of the overall system by simplifying the RF chain. We only use one bit for the amplitude (0,a) and few bits (0-3) for additional phase information. In order to reliably transmit, we propose to modulate the symbol over the air, e.g., the channel coefficients add up to the desired symbol.



Example: $\boldsymbol{h} = [0.5 - 0.4i \;\; 1.0 + 0.8i]$ and $u = 1/\sqrt{2} + i1/\sqrt{2}$ then $\boldsymbol{x} = [0 \;\; 1]$

Optimization Problem

We optimize the MSE between the received and desired symbol to show the possibilities of the scheme without noise:

$$\text{minimize} \quad \|\boldsymbol{Hx} - \boldsymbol{u}\|^2$$
$$\text{subject to} \quad \boldsymbol{x} \in \left\{0, \frac{1}{\sqrt{M}}\right\}^M$$

Where $\boldsymbol{H} \in \mathbb{C}^{K\times M}$ is the channel matrix, $\boldsymbol{x}$ is the transmit vector and $\boldsymbol{u} \in \mathbb{C}^{K\times 1}$ the vector containing the desired symbols of the UEs.

- With phase information only the constraint on $\boldsymbol{x}$ changes

Suboptimal Algorithm

- Motivated by the knapsack problem
- Achieves close to exhaustive search results
- Best channel coefficients are chosen sequentially

Basic Algorithm

$\boldsymbol{H} = \boldsymbol{H}/\sqrt{M}$
$\boldsymbol{err} = \boldsymbol{u}$
for $i = 1 : M$ **do**
  $j^* = \text{argmin}\, \|\boldsymbol{err} - \boldsymbol{H}(:,j)\|$
  if $\|\boldsymbol{err}\| < \|\boldsymbol{err} - \boldsymbol{H}(:,j^*)\|$ **then** stop;
  $\boldsymbol{err} = \boldsymbol{err} - \boldsymbol{H}(:,j^*)$
  $x_j = \frac{1}{\sqrt{M}}$
  $\boldsymbol{H}(:,j^*) = NaN$
end

Algorithm with Phase

When phase is added, only a few changes have to be made:

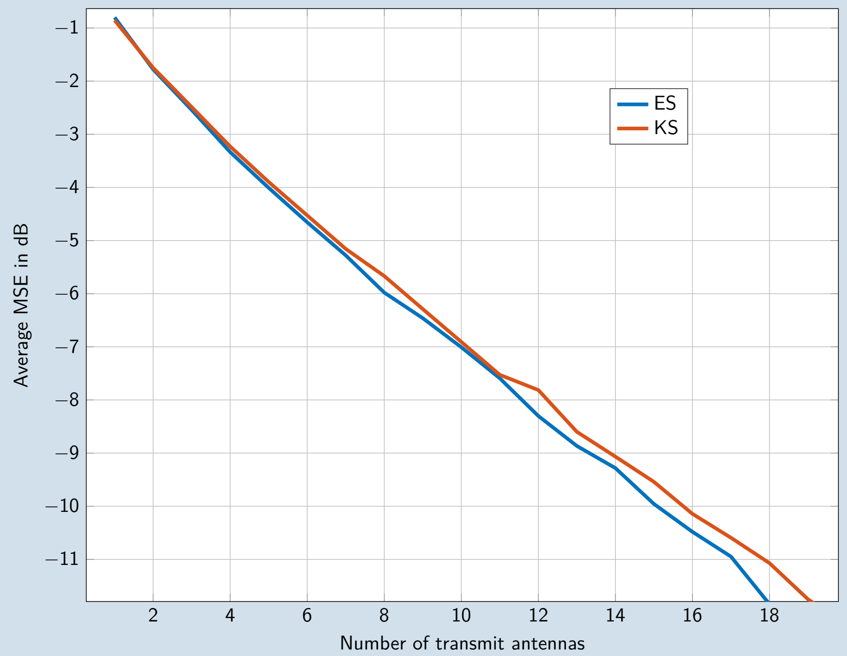
1. Create the row vector with all possible phase values $\boldsymbol{o}_{ph}$
2. Compute $\boldsymbol{H} = \boldsymbol{o}_{ph} \otimes \boldsymbol{H}$, where $\otimes$ denotes the Kronecker product
3. Plug $\boldsymbol{H}$ into the basic algorithm

Simulation Results

Simulation Settings

# BS	1
# BS antennas (M)	1-120
BS sum power constraint (P)	1
# UE (K)	1-10
# UE antennas	1
Input alphabet	256 QAM
Quantization scheme	1 bit amplitude, 1-6 bit phase
Channel model	Rayleigh, WINNER [2]

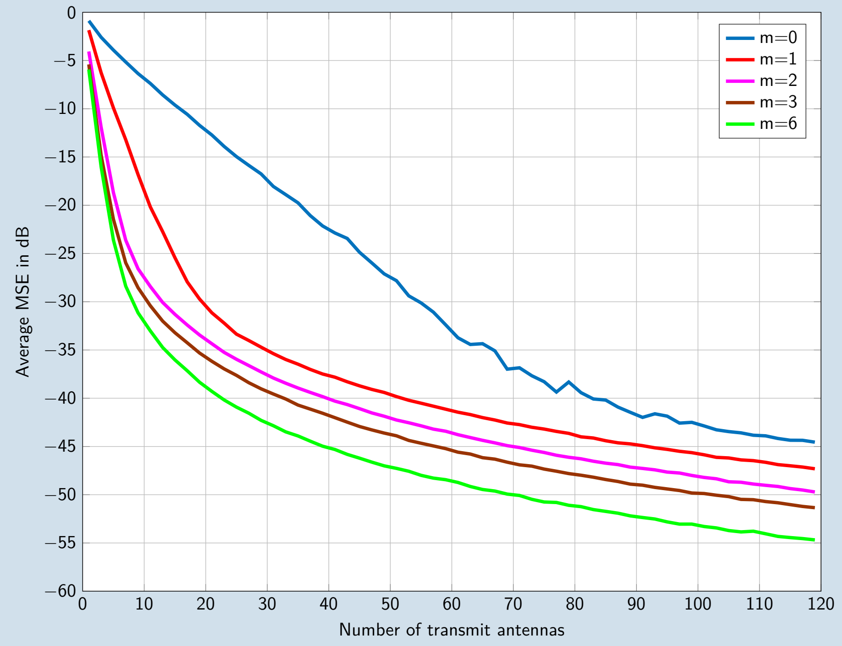
Knapsack and Exhaustive Search



Simulation Results

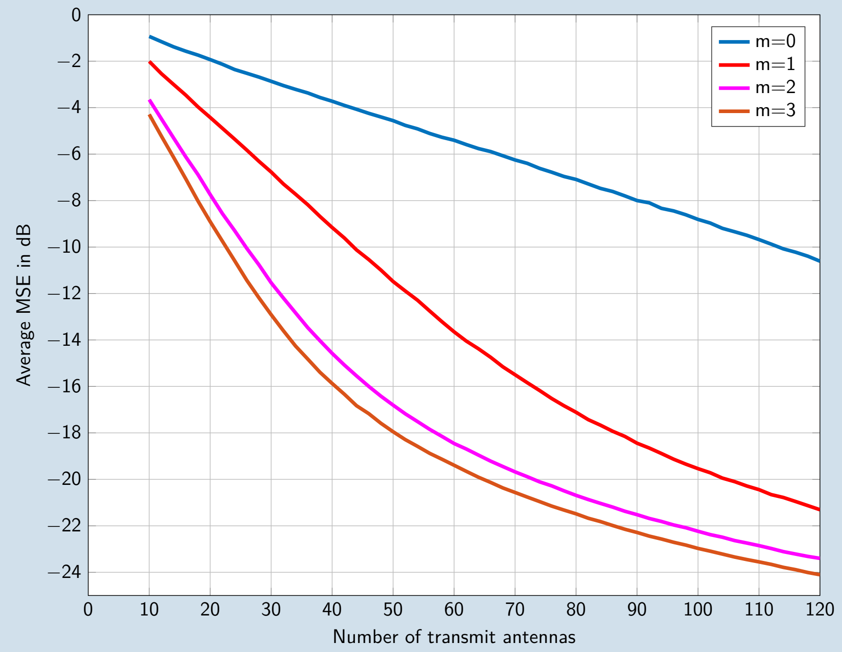
- Behavior of the MSE for an increasing number of antennas
- No noise is assumed
- For 256 QAM the target is -20 dB

Single UE



MSE averaged over multiple channel realizations and for a different number of bits for the phase information (m) with the Rayleigh channel model

10 UEs



MSE averaged over multiple channel realizations and UEs and for a different number of bits for the phase information (m) with the Rayleigh channel model

Results

- MSE goes down exponentially at first
- Linear decrease at some point depending on the number of UEs
- Phase information is important
- Large amount of antennas needed for multi user systems

Combination with Full RF

- The WINNER 2 Urban Macro channel model is implemented with Quadriga [3]

WINNER Channel Settings

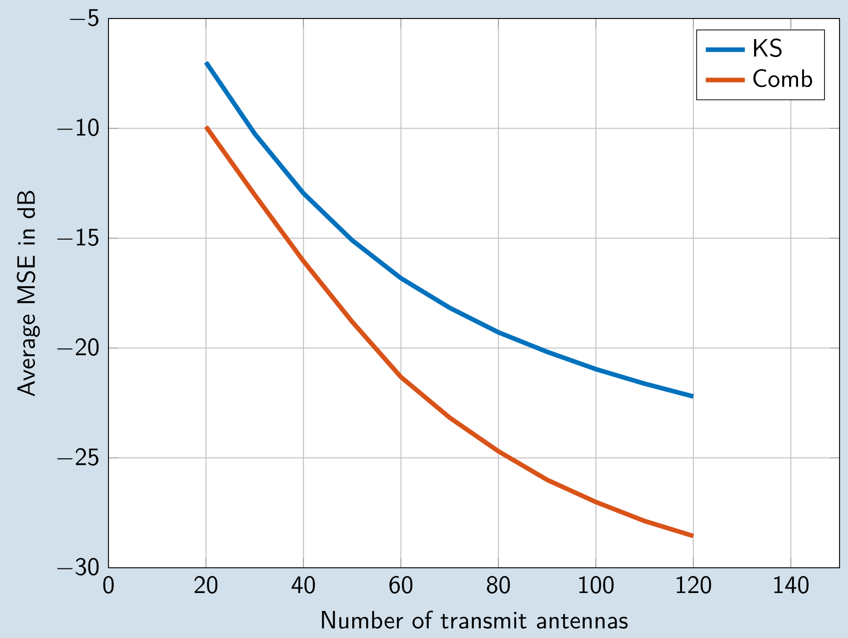
BS height	25 m
Antenna array	ULA
Antenna distance	$\lambda/2$
UE distribution	Uniform in 200 m radius
Center frequency	2,5 GHz

Combining with full RF

1. Minimize the distance to the desired symbol with the low complexity RFs
2. Minimize the remaining error with the full RF chains by utilizing the least squares solution

- The antennas connected to full RF chains should be distributed throughout the array to avoid high correlation

10 UEs and 8 full RF



Challenges and Future Work

1. Channel estimation
2. Reducing complexity
3. Theoretical Bounds

References

[1] E. Larsson, O. Edfors, F. Tufvesson, and T. Marzetta, "Massive mimo for next generation wireless systems," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186–195, February 2014.

[2] P. Kyösti, J. Meinilä, and L. Hentilä, "Simulation winner ii d1.1.2 v.1.1: Winner ii channel models," *WINNER, Tech. Rep.*, 2007.

[3] S. Jaeckel, L. Raschkowski, K. Borner, and L. Thiele, "Quadriga: A 3-d multi-cell channel model with time evolution for enabling virtual field trials," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 6, pp. 3242–3256, June 2014.

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