IEEE Globecom, Dec. 2015

Hybrid Transceivers for Massive MIMO - Some Recent Results

Andreas F. Molisch
Wireless Devices and Systems (WiDeS) Group
Communication Sciences Institute
University of Southern California (USC)
What is massive MIMO

- MIMO is key for enhancing spectral efficiency
- Capacity increases with number of antenna elements

\[ \text{Massive MIMO: let number of antennas grow large} \]

- [Marzetta 2010], [Larson et al. 2014]

**Definitions in the literature**

- Pilot contamination dominates performance?
  - Recent methods get rid of pilot contamination
- Number of antennas tends to infinity and
  - Number of users constant
  - Ratio of antennas to users constant and large
Pros and cons

• Main benefits
  – Higher spectral efficiency
  – Reduced signal processing complexity
    • Conjugate beamforming instead of zero forcing
  – Reduced energy consumption
    • At least for TX energy, due to improved array gain

• Main challenges
  – Large number of RF chains (cost and energy consumption)
  – Array size (especially at low frequencies)
  – Training overhead

\[ C_{\text{sum}} \propto B \cdot T_{\text{co}} \log (\text{SNR}) \]
Contents

• Motivation and basic principle
• JSDM principle
• Generalizations of JSDM
• Fundamental description
**Principle of hybrid transceivers**

- **Preprocessing in RF domain**
- **Reduced number of up/downconversion chains**


Classification of hybrid transceivers

- Module-based versus fully connected
  - Complex matrix entries versus phase shifters only
    - Pure phase shifter arrays easier to manufacture
    - Harder to evaluate analytically
Classification based on CSI

- **Channel-independent solution**
  - Fixed matrix (FFT Butler matrix)

- **Time-variant solution**
  - Elements of pre-processing matrix tuned to instantaneous channel state

- **Time-invariant solution**
  - Elements of pre-processing matrix based only on second order channel-statistics

- **Digital processing in all cases based on instantaneous CSI**
Fundamental problem

- The flow chat of layered framework for optimization
• Motivation and basic principle

• JSDM principle

• Generalizations of JSDM

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Simplifications

- Each user “sees” only one beam
  - In reality: common far scatterers

- User groups are orthogonal
  - In reality: overlap of power angular spectra
  - FIGURE: overlapped scatterer circles

- UE has single antenna only
  -> JSDM
JSDM (Joint Spatial Division and Multiplexing)

Form $G$ groups of users
- Colocated users (airport, café)
- User grouping

Users in group $g$ get

$$y_g = H_g^H B_g P_g d_g + \sum_{m \neq g} H_g^H B_m P_m d_m + z_g$$

Useful Group Signal
Inter group Interference (Use Block Diagonalization)

JSDM is asymptotically optimal. When number of antennas is “large”,

Serve user groups with “disjoint angular support”
Why JSDM?

Reduced CSIT Requirements (K users, G groups, M antennas)

<table>
<thead>
<tr>
<th>No of Channel Coefficients</th>
<th>No of resources required in TDD</th>
<th>No of resources required in FDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK</td>
<td>K (No JSDM)</td>
<td>K/G (JSDM)</td>
</tr>
<tr>
<td></td>
<td>M (No JSDM)</td>
<td>b/G (JSDM)</td>
</tr>
</tbody>
</table>

Reduction by $G$

Simplified Implementation

<table>
<thead>
<tr>
<th>P</th>
<th>RF chain</th>
<th>FS</th>
<th>RF chain</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RF chain</td>
<td></td>
<td></td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>RF chain</td>
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</table>

Hybrid Beamforming ($b << M$)
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2 user groups, 1 common scatterer

Given a number of users with their second order statistics, how to perform user selection?

Two approaches

- “Orthogonalization” (Algorithm 1)
  - Serve less users with higher beamforming gain
- “Multiplexing” (Algorithm 2)
  - Serve more users with less beamforming gain

Integer optimization Problems

- Exponential Complexity with number of users
- Greedy user selection → Linear complexity
How does “Orthogonalization” work?

Serve user groups in different time-frequency blocks
How does “Multiplexing” work?

Serve user groups by removing the common scatterer effect.

Maximize number of users that can be served without any overlap.
• Average amplitude spectrum of multiple UEs based on 64-by-64 Fourier beamforming codebook
  – Average over small scale fading

• Solution approaches:
  – Live with inter-beam interference
  – Reduce inter-beam interference by digital beamforming
  – Orthogonalization (in time) of beams with too much overlap
Impact of threshold

• For orthogonalization: what is “too much overlap”
• Strike transmit-receive beam pairs below threshold
  – Reduction of training overhead cost vs. loss of DoF
Further reduction of CSI requirements

Scheme: Covariance based JSDM

Idea: No multiplexing in stage 2

Advantage: No need for instantaneous CSIT, only second order statistics

Disadvantage: Reduced Spatial Multiplexing
Numerical Results

5 user groups with multiple scattering clusters
$\varepsilon$ controls spatial multiplexing

Greedy user selection performs well
mm-Wave channels

• High Frequencies $\rightarrow$ Smaller wavelengths
  – Suitable for massive MIMO

• Highly directional
  – Small number of multi-path components
  – Different users are coupled by “common scatterers”

• Hybrid beamforming
  – JSDM approach
    • Stage 1 as analog beamforming (using phase shifters)
    • Stage 2 in baseband
Foliage (Dense foliage → Dark green, Sparse foliage → Light green)

mm-Wave channels

BS

MS (Red)

Buildings (White)
Observe Tradeoff between orthogonalization and multiplexing
Multiple antennas at MS

- **UE could have**
  - Multiple antenna elements
  - Hybrid transceivers

- **Use of second-order statistics for UE**
  - Could be used to suppress inter-group interference
  - Depends on channel statistics: Kronecker model applicable or not?
• Motivation and basic principle

• JSDM principle

• Generalizations of JSDM

• Fundamental description
For material from this section, please see

Z. Li, S. Han, and A. F. Molisch, submitted.

(sorry, no publicly available version yet)
Summary

- Massive MIMO promising solution for future cellular systems
- Hybrid transceivers provide low complexity for massive MIMO in correlated channels with good performance
- JSDM algorithm provides good performance under idealized circumstances
- Far scatterers, waveguiding, finite number of scatterers, and non-Kronecker structure need to be taken into account
- General solution via iterative approaches
Questions?

Thanks to: Zheda Li, Shenqian Han, Giuseppe Caire, Ansuman Adhirkari

Contact information

Andreas F. Molisch

Ph.D., FIEEE, FAAAS, FIET, MAASc.
Head, Wireless Devices and Systems (WiDeS) Group
Director, Communications Sciences Institute,
Ming Hsieh Dpt. Of Electrical Engineering
Viterbi School of Engineering
University of Southern California (USC)
Los Angeles, CA, USA

Email: molisch@usc.edu
Website: wides.usc.edu