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Hybrid Transceivers for Massive MIMO - Some Recent Results

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What is massive MIMO

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

-> 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

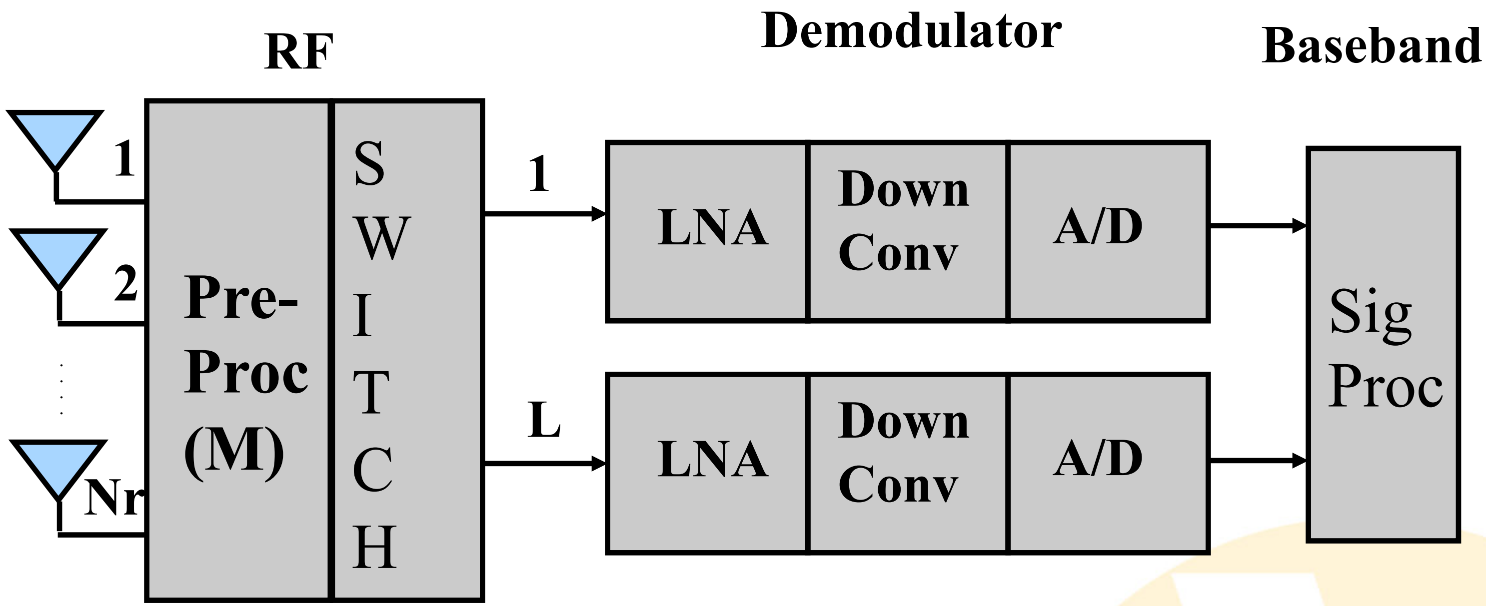
- Main benefits
  - Higher spectral efficiency
  - Reduced signal processing complexity
    - Conjugate beamforming instead of zero forcing
  - Reduced energy consumption
    - At least for TX energy, due to improved array gain

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

$$C_{\text{sum}} \propto \mathrm{B} \cdot T_{\text{co}} \log\left(\mathrm{SNR}\right)$$

Contents

Principle of hybrid transceivers



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

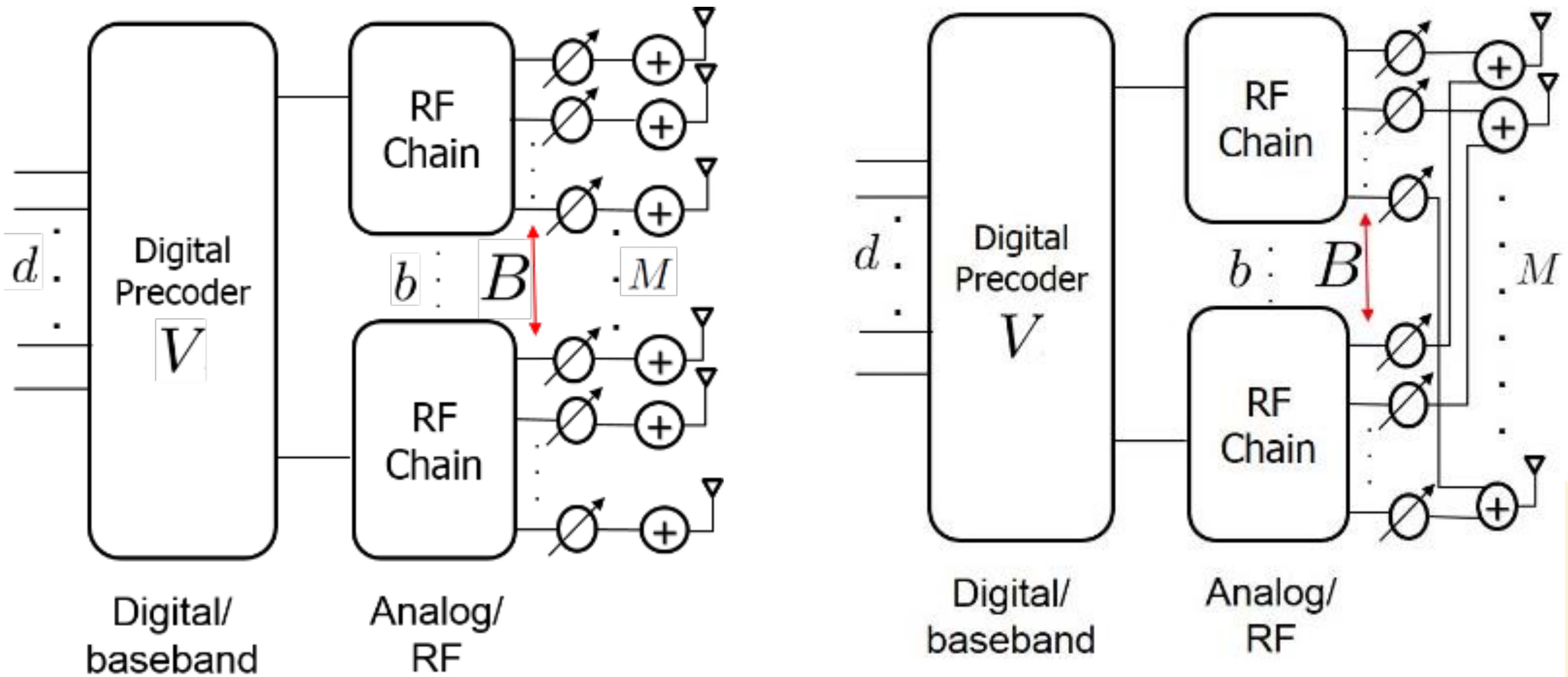
A. F. Molisch and X. Zhang, „FFT-based Hybrid Antenna Selection Schemes for spatially correlated MIMO channels*", IEEE Comm. Lett*., 8, 36-38 (2004).

X. Zhang, A. F. Molisch, and S. Y. Kung, "Variable-phase-shift-based RF-baseband codesign for MIMO antenna selection", IEEE Trans. Signal Proc., 53, 4091-4103 (2005).

P. Sudarshan, N. B. Mehta, A. F. Molisch, and J. Zhang, „Channel Statistics-Based Joint RF-Baseband Design for Antenna Selection for Spatial Multiplexing",
IEEE Trans. Wireless Comm. 5, 3501-3511, (2006)

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

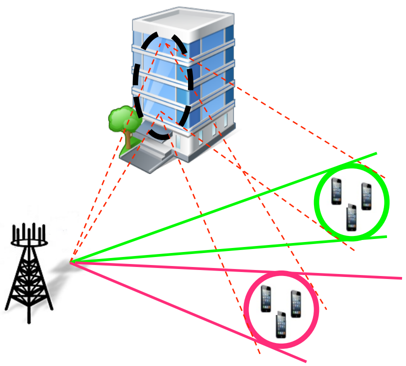
- The flow chat of layered framework for optimization

Contents

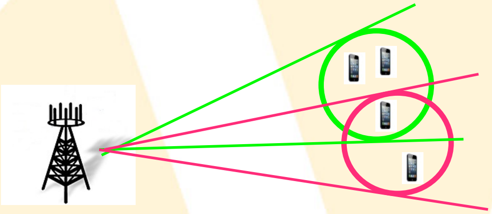
- Motivation and basic principle
- JSDM principle
- Generalizations of JSDM
- Fundamental description

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



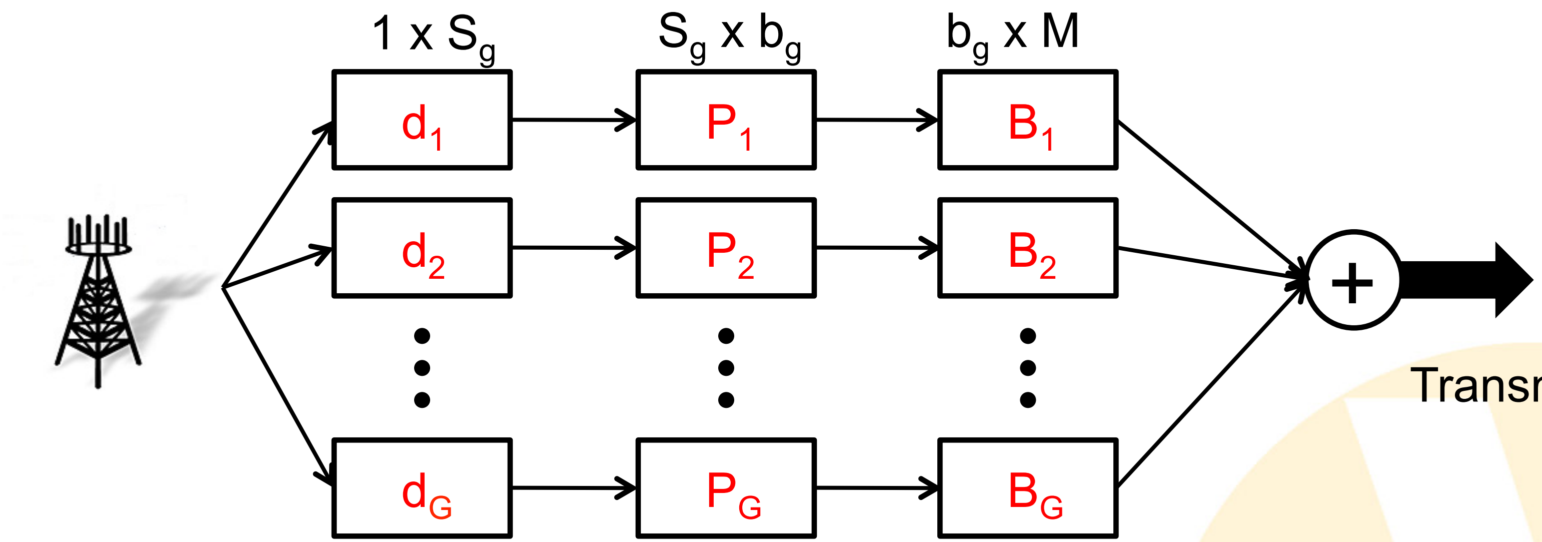
- UE has single antenna only

-> JSDM

JSDM (Joint Spatial Division and Multiplexing)

Form G groups of users

- Colocated users (airport, café)
- User grouping



Users in *group g* get

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

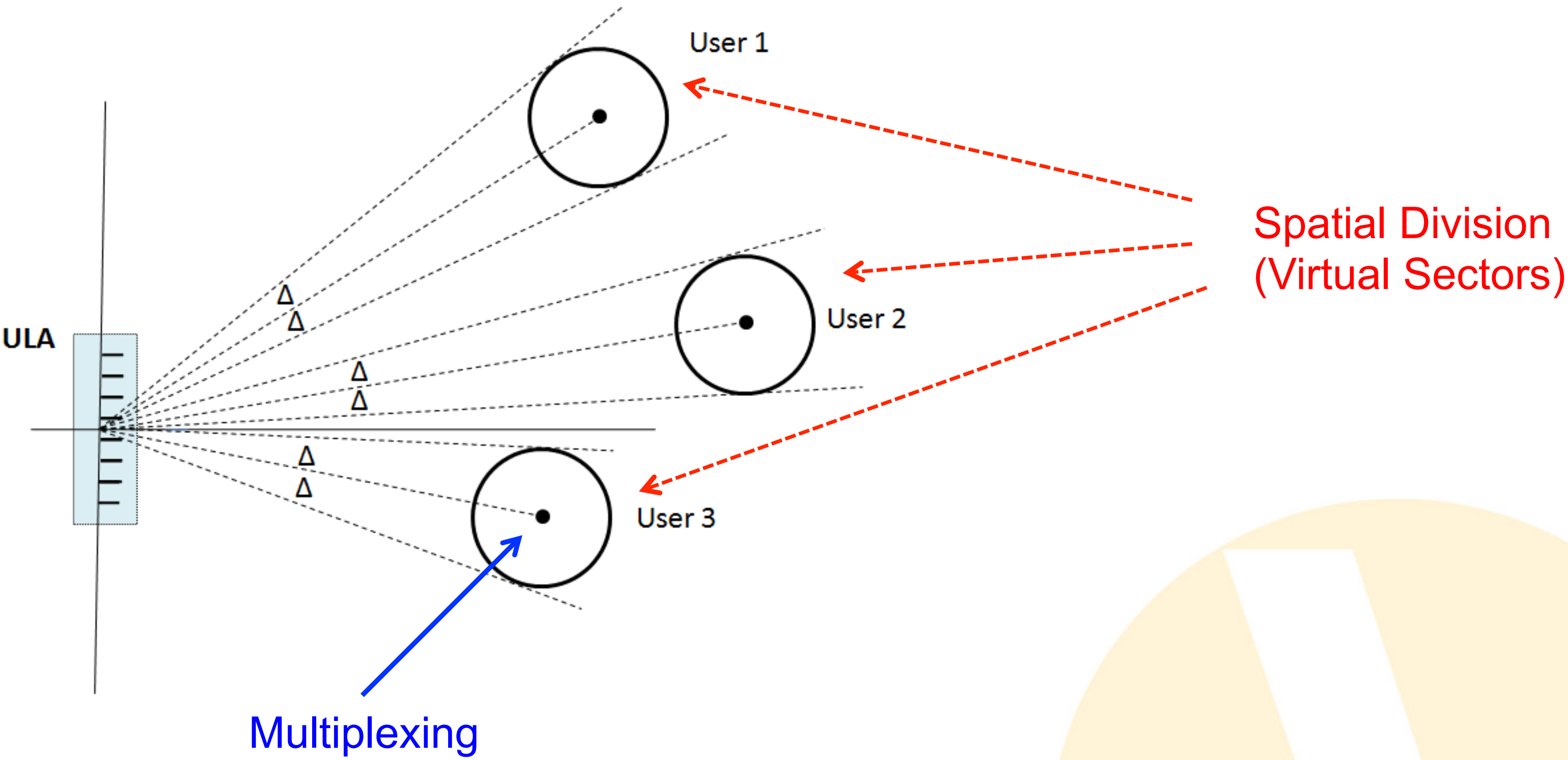
Useful Group Signal

Inter group Interference

(Use Block Diagonalization)

A. Adhikary, J. Nam, J.-Y. Ahn, and G. Caire, "Joint Spatial Division and Multiplexing: The Large-Scale Array Regim
Information Theory, IEEE Transactions on, vol. 59, no. 10, pp. 6441–6463, 2013.

Pictorial View of JSDM



JSDM is asymptotically optimal. When number of antennas is "large",

B ⟹ F_S ← Subset of Columns of a Fourier Matrix

⇑

Serve user groups with "disjoint angular support"

Why JSDM ?

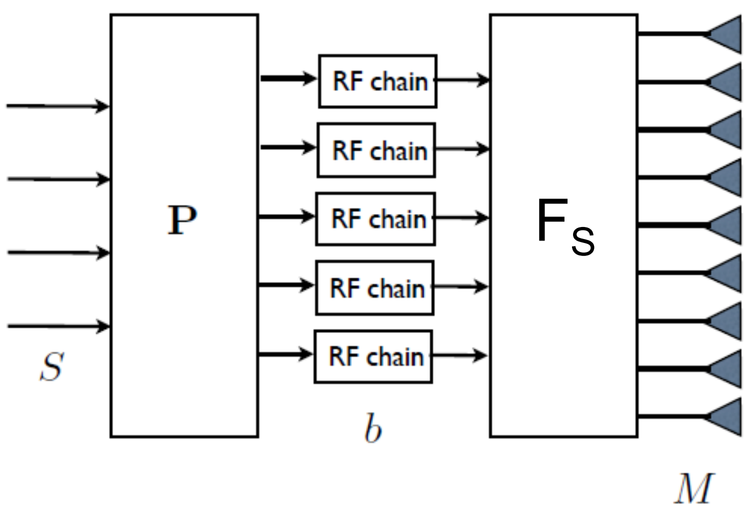
Reduced CSIT Requirements (K users, G groups, M antennas)

No of Channel Coefficients	No of resources required in TDD		No of resources required in FDD	
MK	K (No JSDM)	K/G (JSDM)	M (No JSDM)	b/G (JSDM)

Reduction by G

Reduction by GM/b

Simplified Implementation



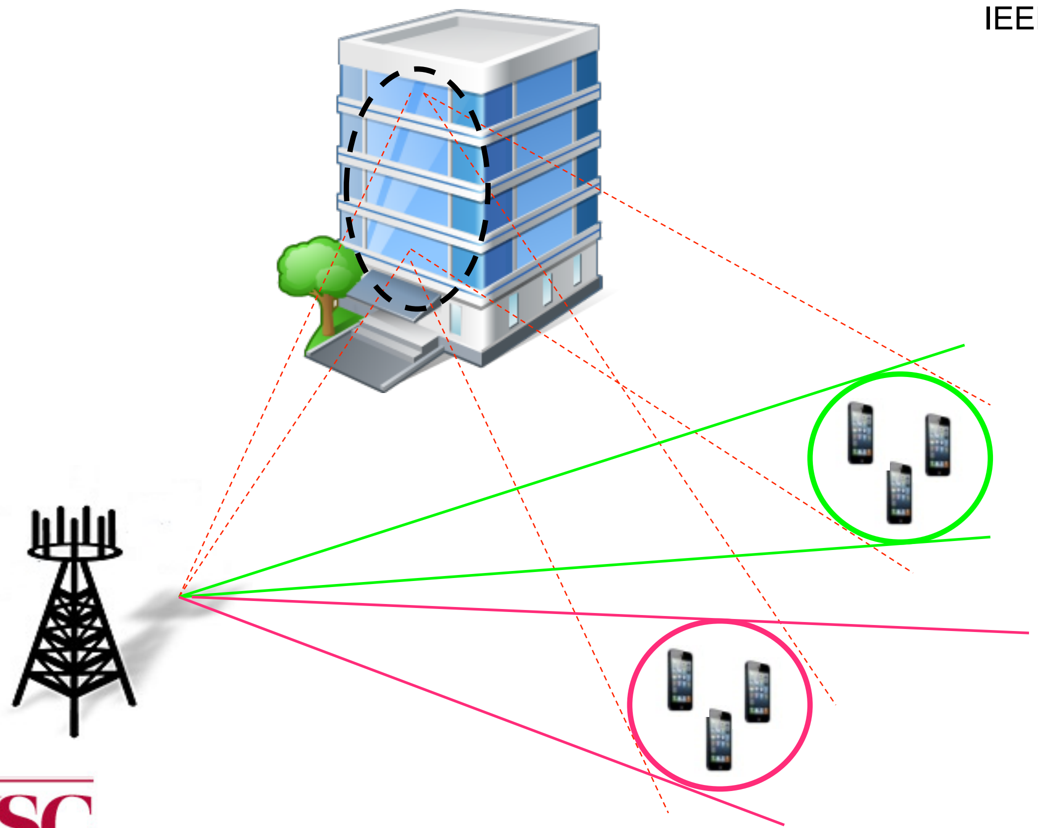
Hybrid Beamforming (b << M)

Contents

Common Scatterer Model

2 user groups, 1 common scatterer

A. Adhikary, E. Al-Safadi, M. Samimi, R. Wang, G. Caire, T. S. Rappaport, and A. F. Molisch, "Joint Spatial Division and Multiplexing for mm-Wave Channels", IEEE JSAC, 32, 1239- 1255 (2014).



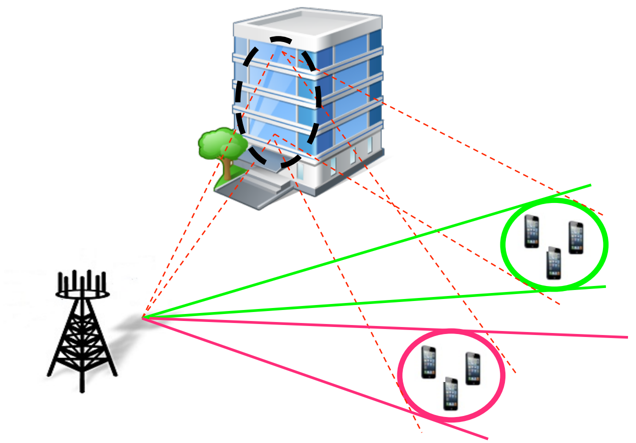
Need to modify JSDM to include common scatterers

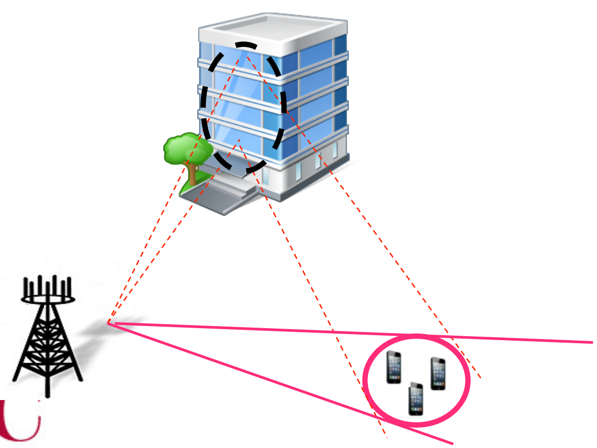
Handling common scatterers

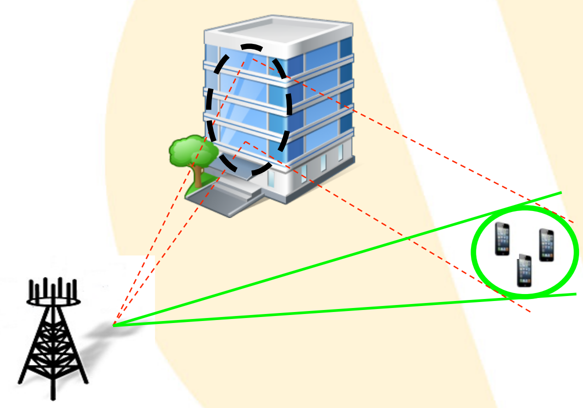
- Given a number of users with their second order statistics, how to perform user selection ?
- Two approaches
  - "Orthogonalization" (Algorithm 1)
    - Serve less users with higher beamforming gain
  - "Multiplexing" (Algorithm 2)
    - Serve more users with less beamforming gain
- Integer optimization Problems
  - Exponential Complexity with number of users
  - Greedy user selection → Linear complexity

How does “Orthogonalization” work ?

Serve user groups in different time-frequency blocks

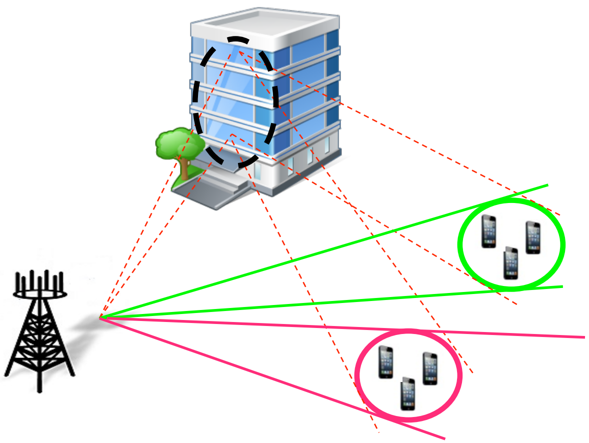




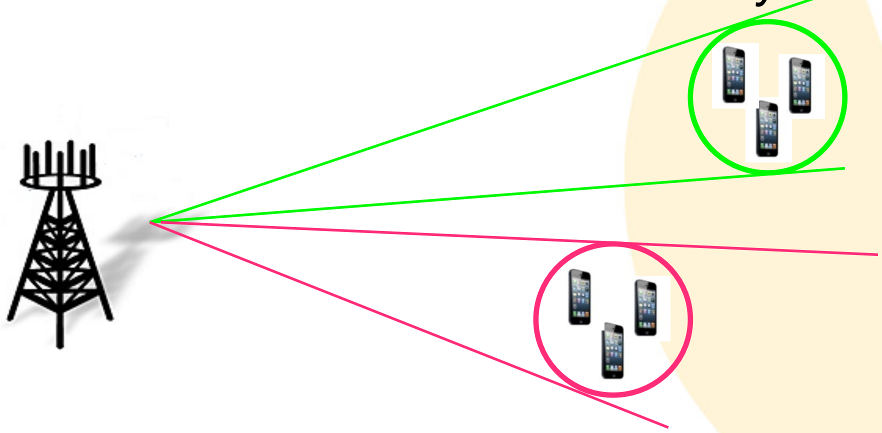


How does "Multiplexing" work ?

Serve user groups by removing the common scatterer effect

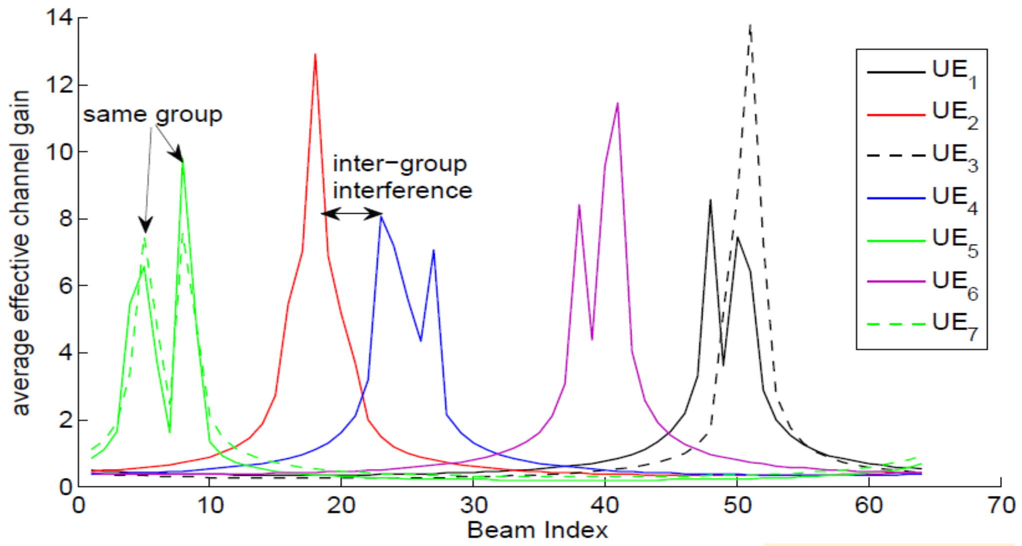


Maximize number of users that can be served without *any* overlap



Overlapping Angular Power Spectra

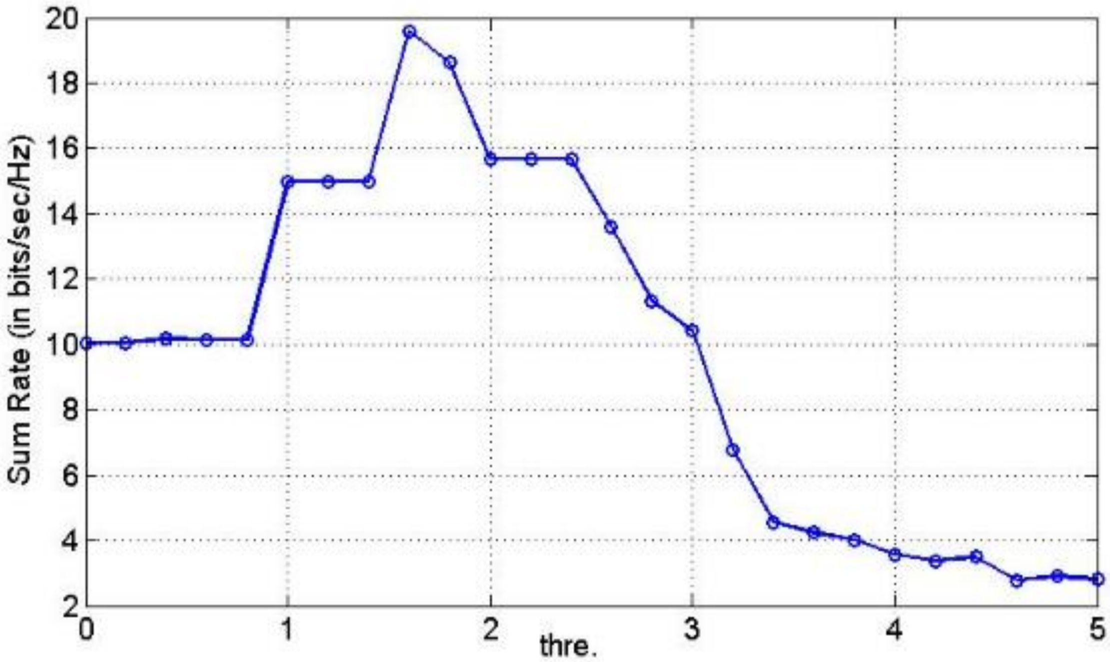
- Average amplitude spectrum of multiple UEs based on 64-by-64 Fourier beamforming codebook
  - Average over small scale fading



- 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

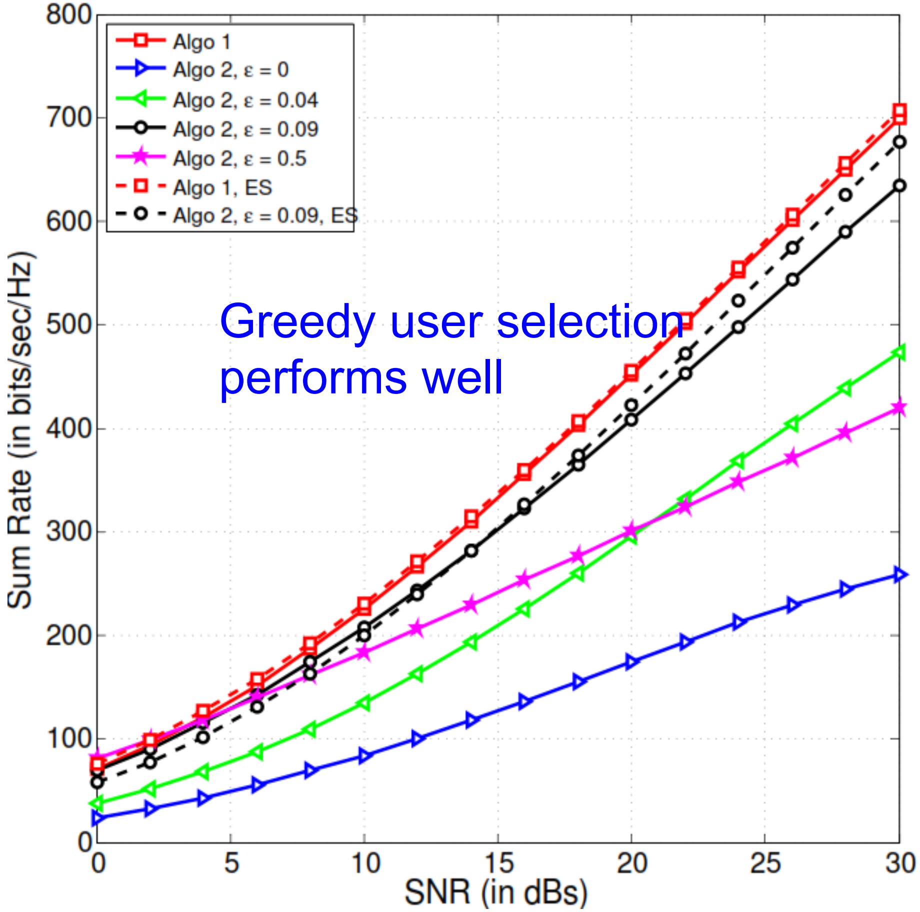
Advantage : No need for instantaneous CSIT, only second order statistics

Disadvantage : Reduced Spatial Multiplexing

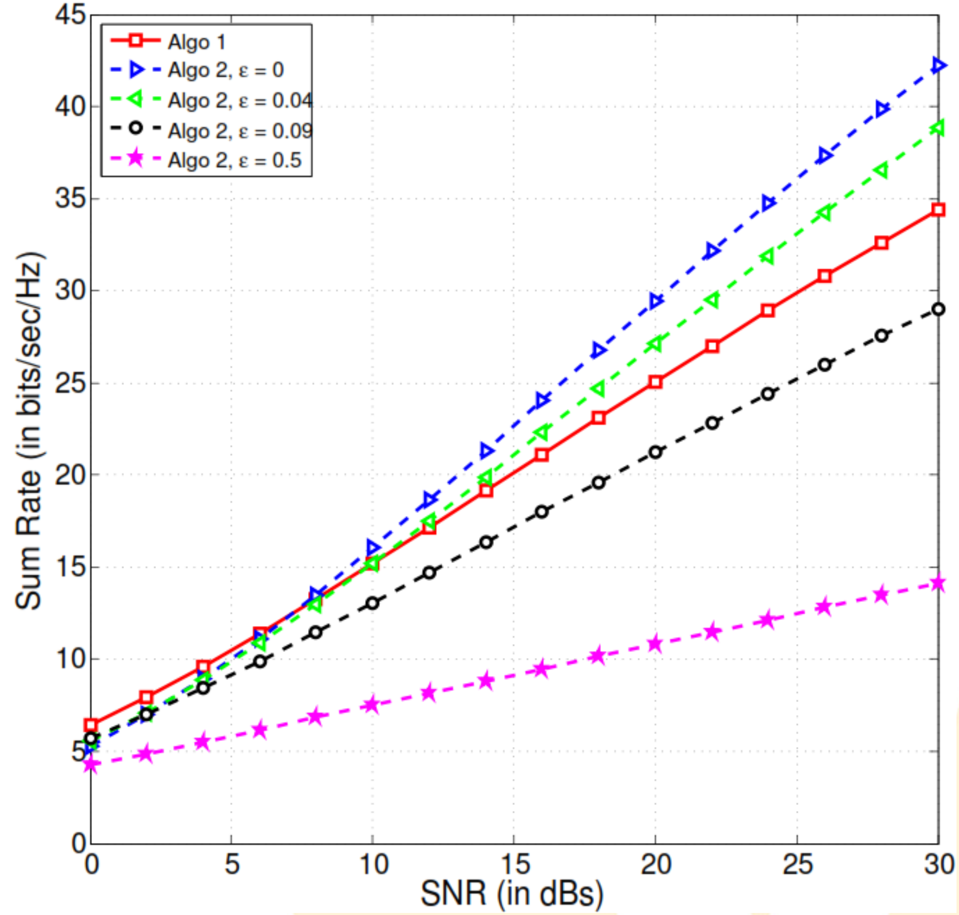
Numerical Results

5 user groups with multiple scattering clusters

ε controls spatial multiplexing



Greedy user selection performs well



JSDM → Covariance based JSDM

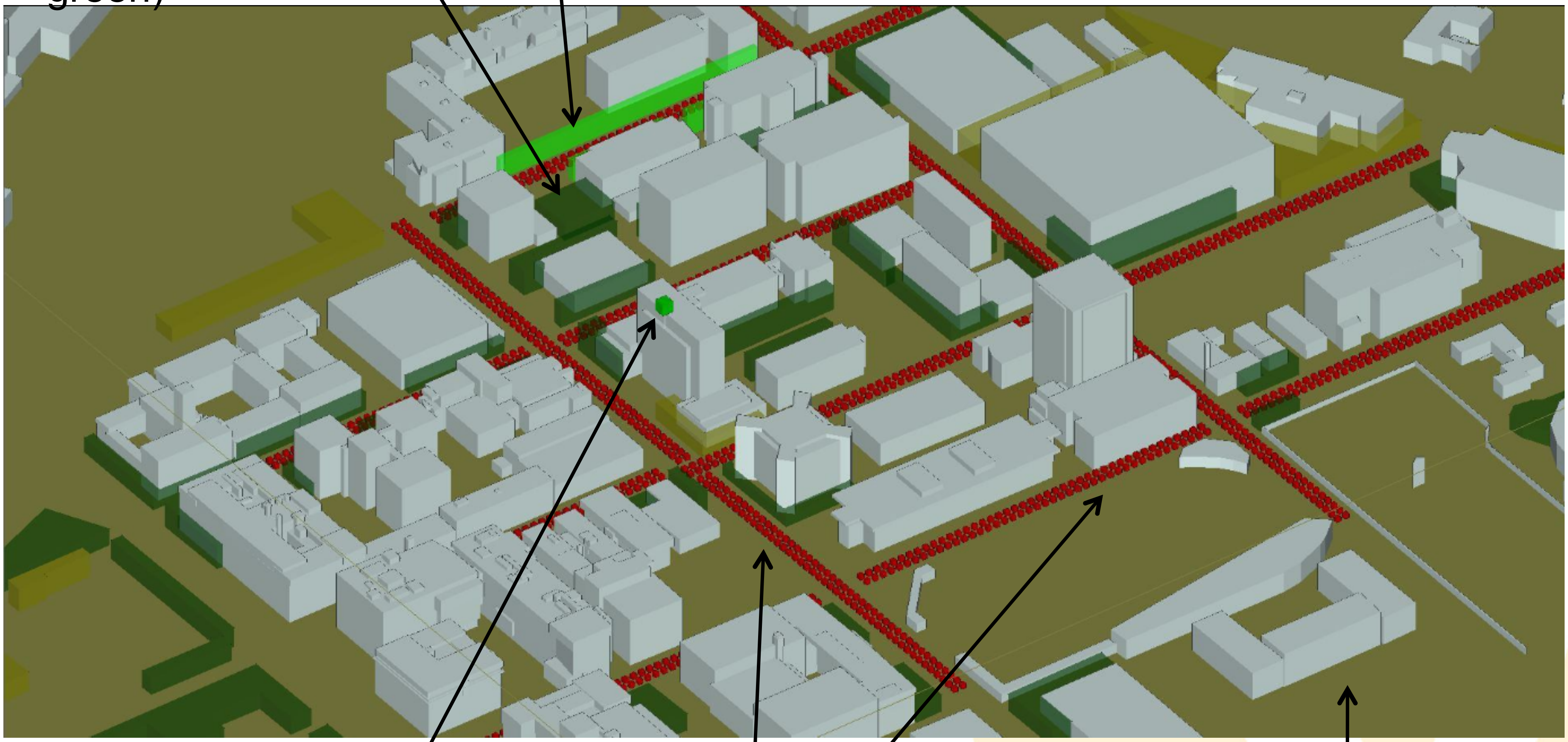
Reduced Spatial Multiplexing

mm-Wave channels

- High Frequencies → 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

mm-Wave channels

Foliage (Dense foliage → Dark green, Sparse foliage → Light green)

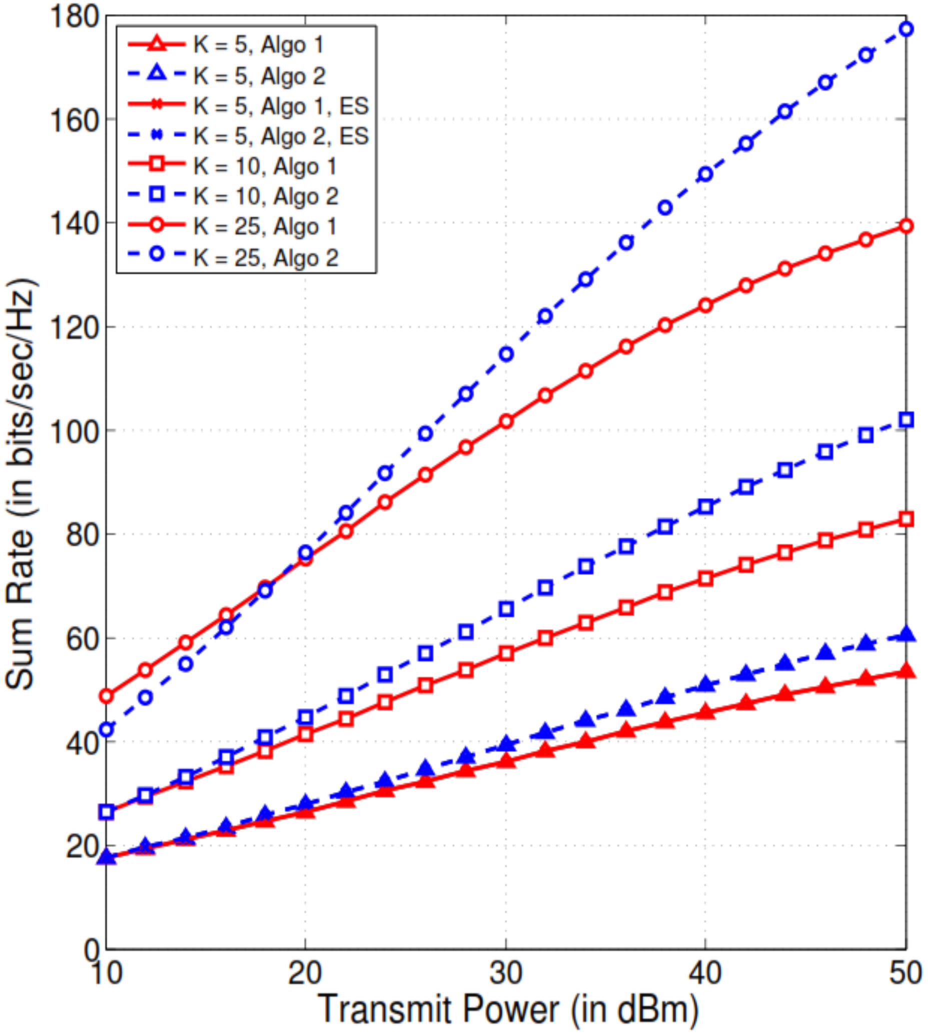


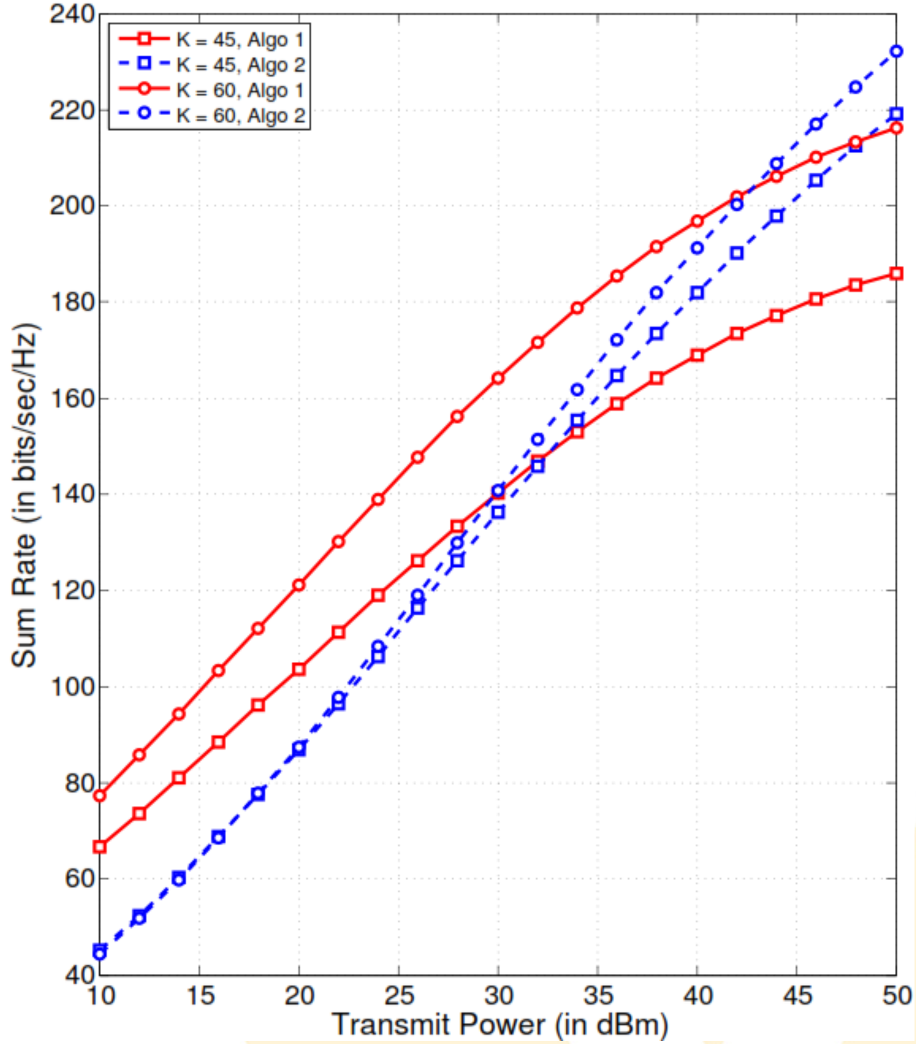
BS

MS (Red)

Buildings (White)

Covariance based JSDM for mm-Wave channels





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?

Contents

Fundamental problem

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

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