Distributed Multicell and Multiantenna Precoding

Characterization and Performance Evaluation

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Content

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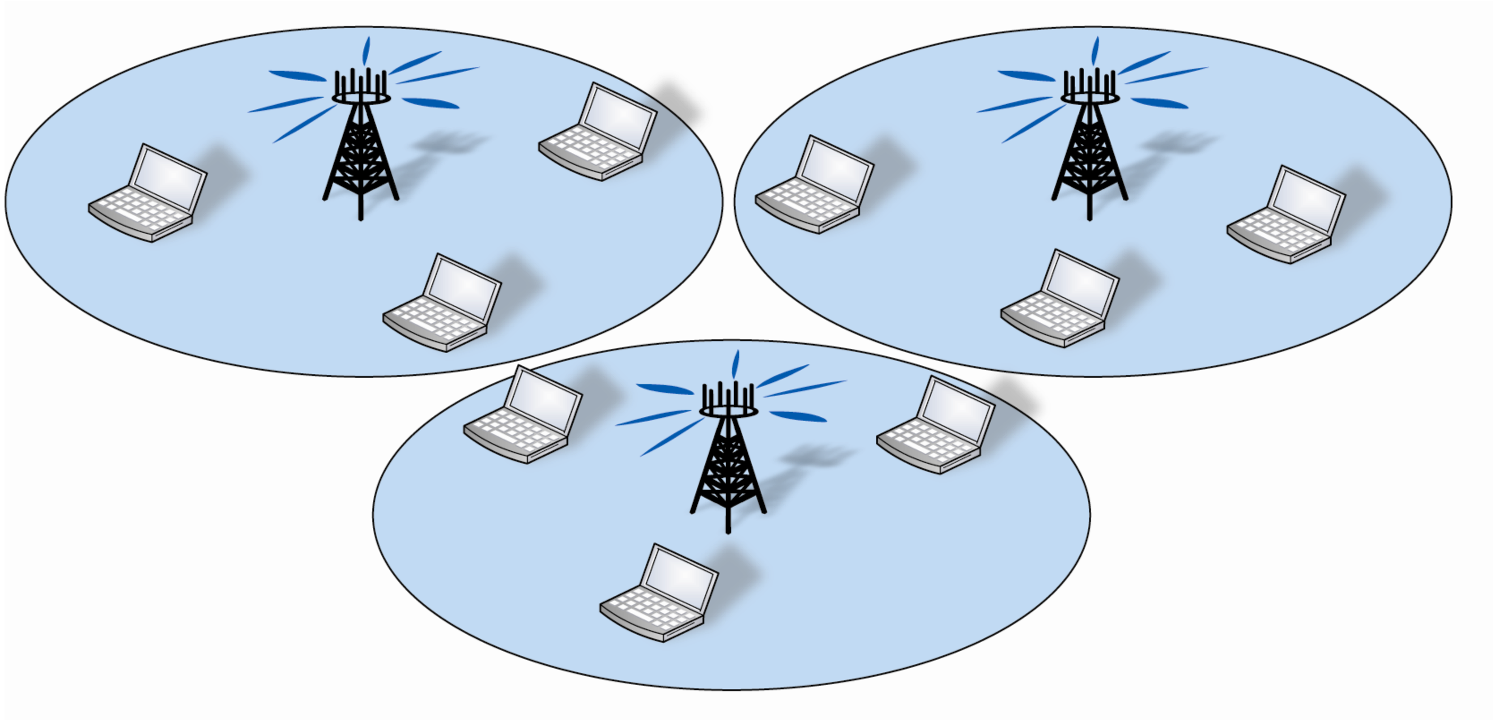
- Multicell Precoding
  - Users served by multiple cooperating base stations
  - Goal: Control interference with full frequency reuse
  - Also known as:

    Network MIMO,

    Coordinated Multipoint transmission (CoMP)
- Characterization of Optimal Precoding
  - Instantaneous/statistical channel information (CSI)
- Distributed Precoding Design
  - Motivation and performance evaluation

Intro: No Cooperation



- Non-Cooperative Multicell Downlink
  - Conventional single cell processing
  - Interference at cell edge users uncontrollable
  - Can be improved by coordinating interference

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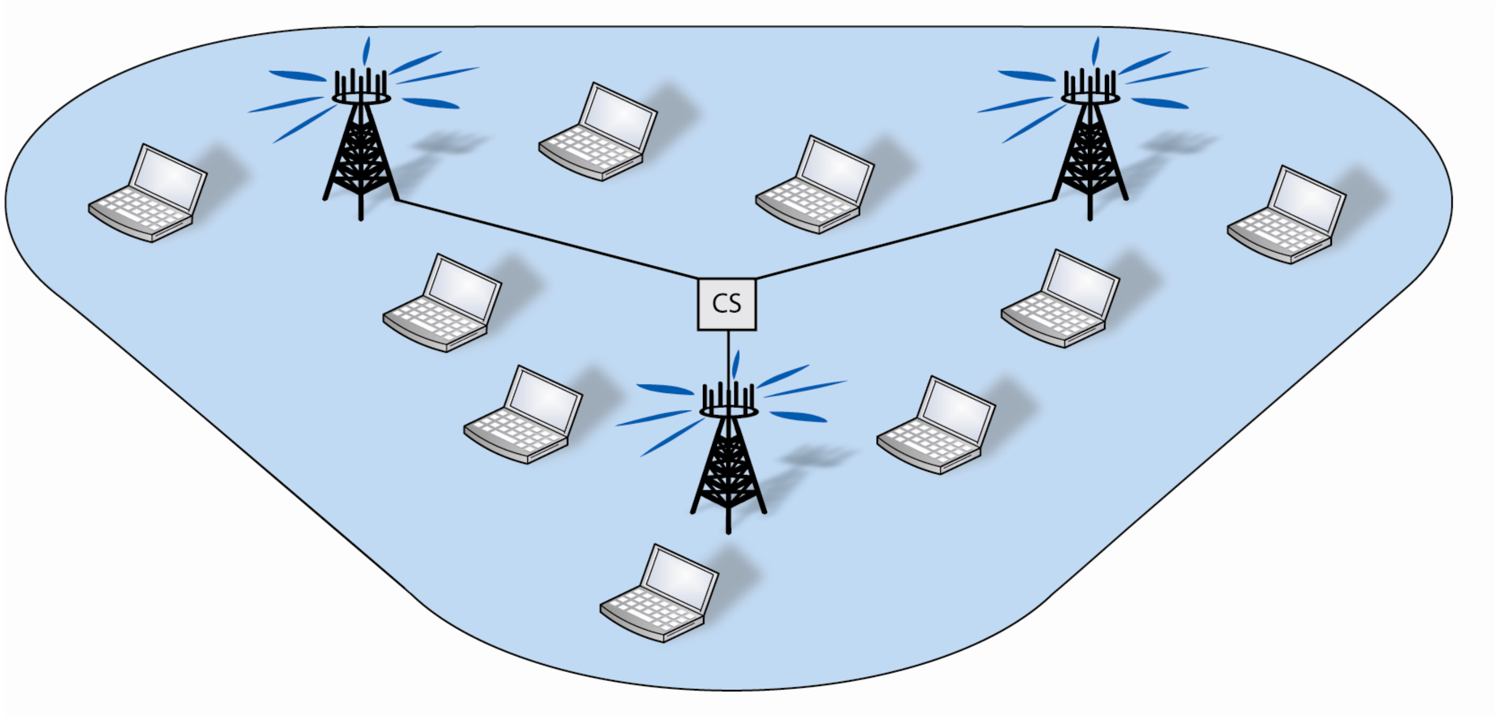
Intro: Full Cooperation



- Centralized Cooperative Multicell Downlink
  - Backhaul network and central station (CS)
  - Centralized processing as “one cell”
  - Capacity in [Yu06], [Weingarten06]
    (MIMO broadcast, special power constraints)

Intro: Four Main Approaches

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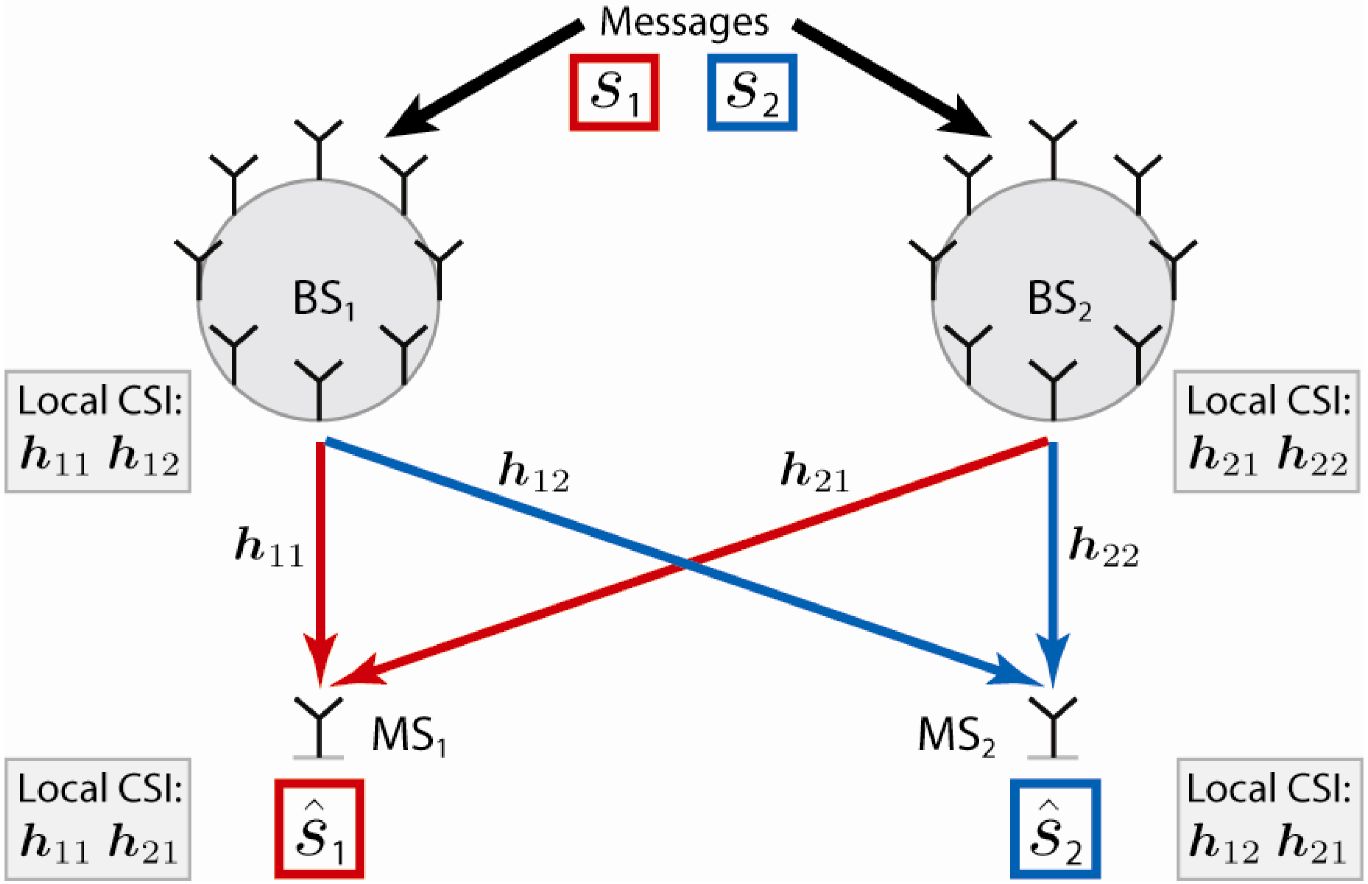
Available CSI / ***Available Data Messages***	Local	Global
Global	**Interference Channel** (Centralized) *Handle interference by beamforming, scheduling, interference alignment* *Game Theory is useful*	**Network MIMO** (Centralized Precoding) *Mimic single-cell MIMO broadcast channel with centralized control*
Local	**Interference Channel** (Distributed) *Iterative implementations of centralized approaches* *Heuristic solutions*	**Network MIMO** (Distributed Precoding) ? *Considered in our paper*

System Model

- K_t multi-antenna base stations
- K_r single-antenna user terminals
- $\mathbf{h}_{jk}$ channel vector from BS_j to MS_k

$K_t = K_r = 2$

General case in [Björnson2010]



Local CSI

(estimated on reverse links)

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Multicell Precoding

- Symbol $s_k \in \mathcal{CN}(0,1)$ Intended for MS_k
  - Available at all transmitters
  - Enables cooperative multicell precoding
- Signal from BS_j: $$\mathbf{x}_j = \sum_{k=1}^{K_r} \underbrace{\boxed{\sqrt{p_{jk}}}}_{\text{Power allocation}} \underbrace{\boxed{\mathbf{w}_{jk}}}_{\text{Beamformer (unit norm)}} s_k$$

Power allocation
$\sum_{k=1}^{K_r} p_{jk} \leq P_j$

Beamformer
(unit norm)

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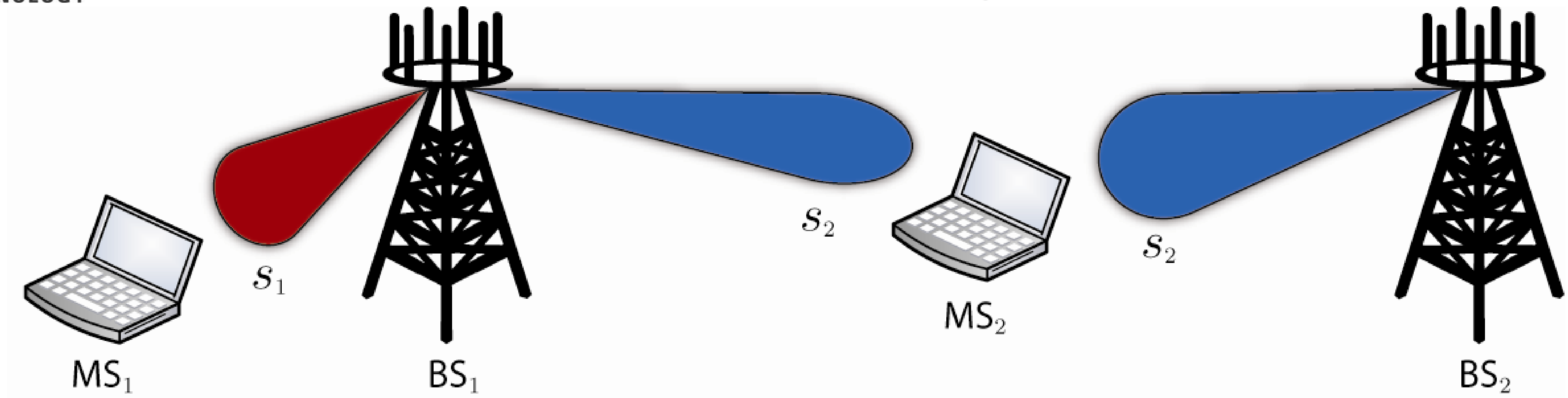

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Beamformer
(unit norm)

- SINR at MS$_k$:

$$\mathrm{SINR}_k = \frac{\left| \sum_{j=1}^{K_t} \sqrt{p_{jk}} \mathbf{h}_{jk}^H \mathbf{w}_{jk} \right|^2}{\sum_{\substack{\bar{k}=1 \\ \bar{k}\neq k}}^{K_r} \left| \sum_{j=1}^{K_t} \sqrt{p_{j\bar{k}}} \mathbf{h}_{jk}^H \mathbf{w}_{j\bar{k}} \right|^2 + \sigma^2}$$

(perfect synchronization)

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Achievable Rate Region

- Precoding Design
  - Feasible selection of $\mathbf{w}_{jk}$ and p_{jk} for all j, k
- Rates: $R_k = \log_2(1 + \mathrm{SINR}_k)$
- Achievable Rate Region
  - Pairs (R_1, R_2) achieved by some precoding design
  - Upper boundary: Pareto boundary
- Rate Pairs (R_1, R_2) on Pareto Boundary
  - Cannot increase R_k without decreasing $R_{\bar{k}}$, $\bar{k} \neq k$
  - Maximizes some weighted sum rate
  - Non-constructive

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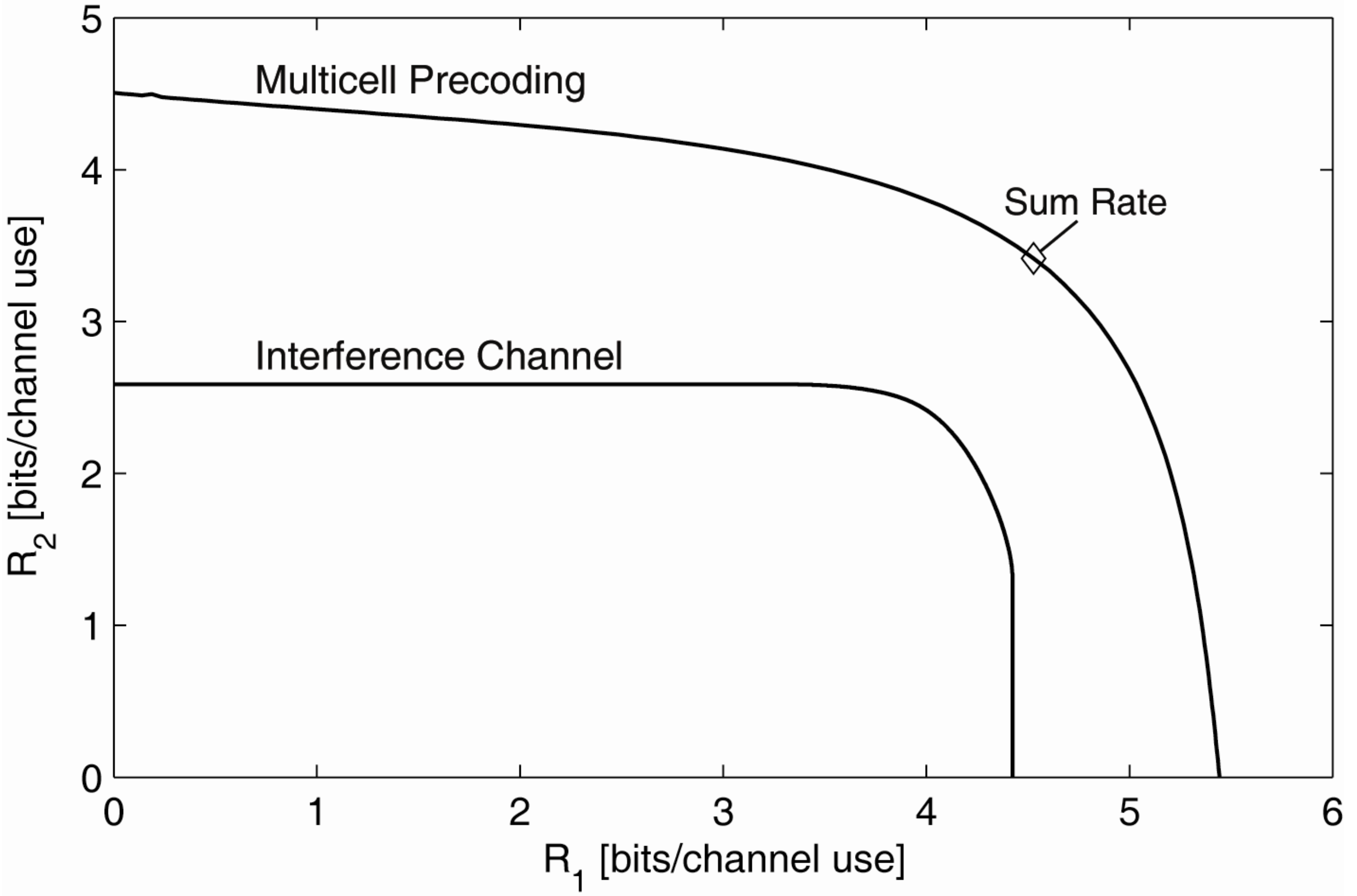
Achievable Rate Region (2)

- Example: Pareto Boundary



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Large Potential Gain of Data Sharing!

Achievable Rate Region (3)

- How to Attain the Pareto Boundary?
  - Achieved for certain $\mathbf{w}_{jk}$ and p_{jk}
  - Need strategy to find good ones!

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- Classical Beamforming Strategies:
  - Maximum Ratio Transmission: $\mathbf{w}_{jk}^{(\mathrm{MRT})} = \frac{\mathbf{h}_{jk}}{\|\mathbf{h}_{jk}\|}$
  - Zero-Forcing: $\mathbf{w}_{jk}^{(\mathrm{ZF})} = \frac{\mathbf{\Pi}^{\perp}_{\mathbf{h}_{j\bar{k}}} \mathbf{h}_{jk}}{\|\mathbf{\Pi}^{\perp}_{\mathbf{h}_{j\bar{k}}} \mathbf{h}_{jk}\|}$
  - Only require local transmit-side CSI

Achievable Rate Region (4)

- What is Optimal Beamforming?
  - MRT "optimal" at low SNR
  - ZF "optimal" at high SNR

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Theorem 1. *Each* (R_1, R_2) *on Pareto boundary can be achieved using full power and*

$$\mathbf{w}_{jk} = c_{jk}\mathbf{w}_{jk}^{(\mathrm{MRT})} + d_{jk}\mathbf{w}_{jk}^{(\mathrm{ZF})}, \text{ for some } c_{jk}, d_{jk} \in \mathbb{C}.$$

Generalization of [Jorswieck08]

- Conclusion:
  - Beamformer in span of $\mathbf{w}_{jk}^{(\mathrm{MRT})}, \mathbf{w}_{jk}^{(\mathrm{ZF})}$ (local CSI)
  - Precoding design means finding good c_{jk}, d_{jk}
  - Optimal solution requires global CSI

Distributed Precoding Design

- Local Precoding using Only Local CSI
  - Limited backhaul signaling and central processing
  - Cannot maximize any global performance measure
  - Only heuristic solutions possible

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- Proposal 1: Maximize virtual SINR

$$\mathbf{w}_{jk}^{(\text{LVSINR})} = \arg\max_{\|\mathbf{w}\|=1} \frac{\boxed{|\mathbf{h}_{jk}^H \mathbf{w}|^2}}{\frac{\sigma^2}{p_{jk}} + \boxed{\sum_{\bar{k}\neq k} |\mathbf{h}_{j\bar{k}}^H \mathbf{w}|^2}}$$

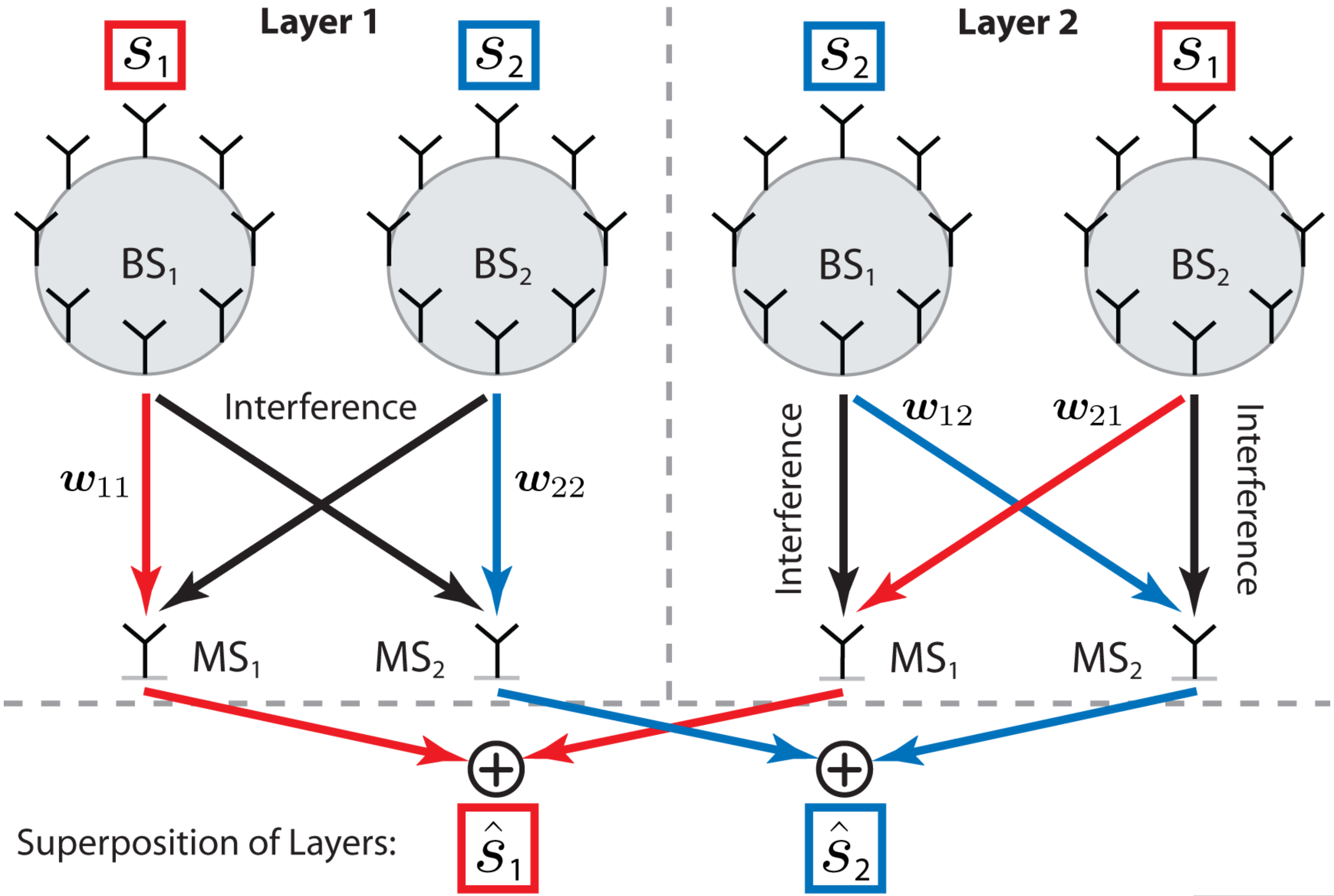
Signal Power

Interference at other users

  - Gives heuristic values on c_{jk}, d_{jk} (Rayleigh quotient)
  - Used for interference channels in [Zakhour09]

Distributed Precoding Design (2)

- Motivation: Layers of Interference Channels



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Summation of Outputs from two Interference Channels

Distributed Precoding Design (3)

- Heuristic Power Allocation
  - More power allocated to strong users

- Proposal 2: Based on percentage of total gain

$$p_{jk} = \frac{\|\mathbf{h}_{jk}\|^2}{\sum_{\bar{k}=1}^{K_r} \|\mathbf{h}_{j\bar{k}}\|^2} P_j$$

  - More advanced power allocation in [Björnson10]
  - Minor performance difference

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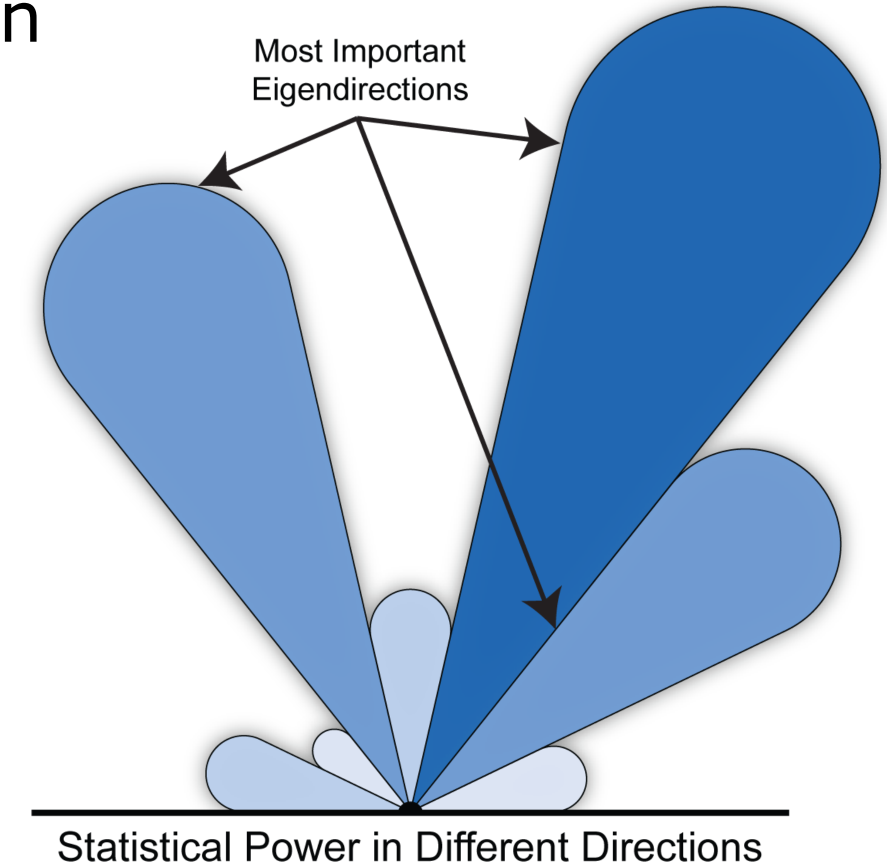
Generalization: Statistical CSI

- Similar Analysis with Local Statistical CSI
  - Especially with spatial correlation
- Pareto Characterization
  - Channel vectors not known exactly
  - Depends on dominating eigendirections
- Distributed Precoding
  - Proposed scheme is extendable



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Generalization: Arbitrary Dim.

- Arbitrary number of BSs and MSs
  - Analyzed in [Björnson2010]
- Characterization of Pareto Boundary
  - Linear combination of MRT and multiple ZF vectors
- Distributed Precoding Design
  - Definition directly extendable
  - Simulations show that it works well

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Numerical Example

- System Parameters
  - Uncorrelated channels: $\mathbf{h}_{jk} \in \mathcal{CN}(\mathbf{0}, \beta_{jk}\mathbf{I})$
  - Different average gains β_{jk} (path loss)
- Precoding Schemes
  - Optimal Beamforming and Power allocation
  - Maximum Ratio Transmission (MRT)
  - Zero-Forcing Beamforming (ZF)
  - Layered VSINR Beamforming (LVSINR)

Proposed Heuristic Power Allocation

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Numerical Example (2)

- Average Performance in Multicell Area
  - Scenarios with uniformly distributed users
  - Cell edge SNR defined in the center

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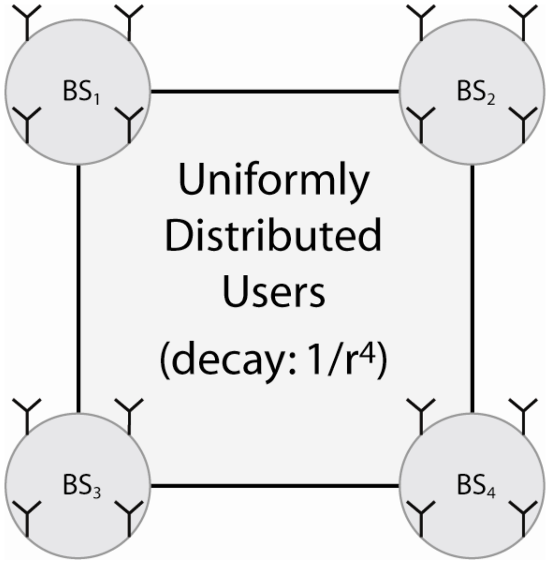
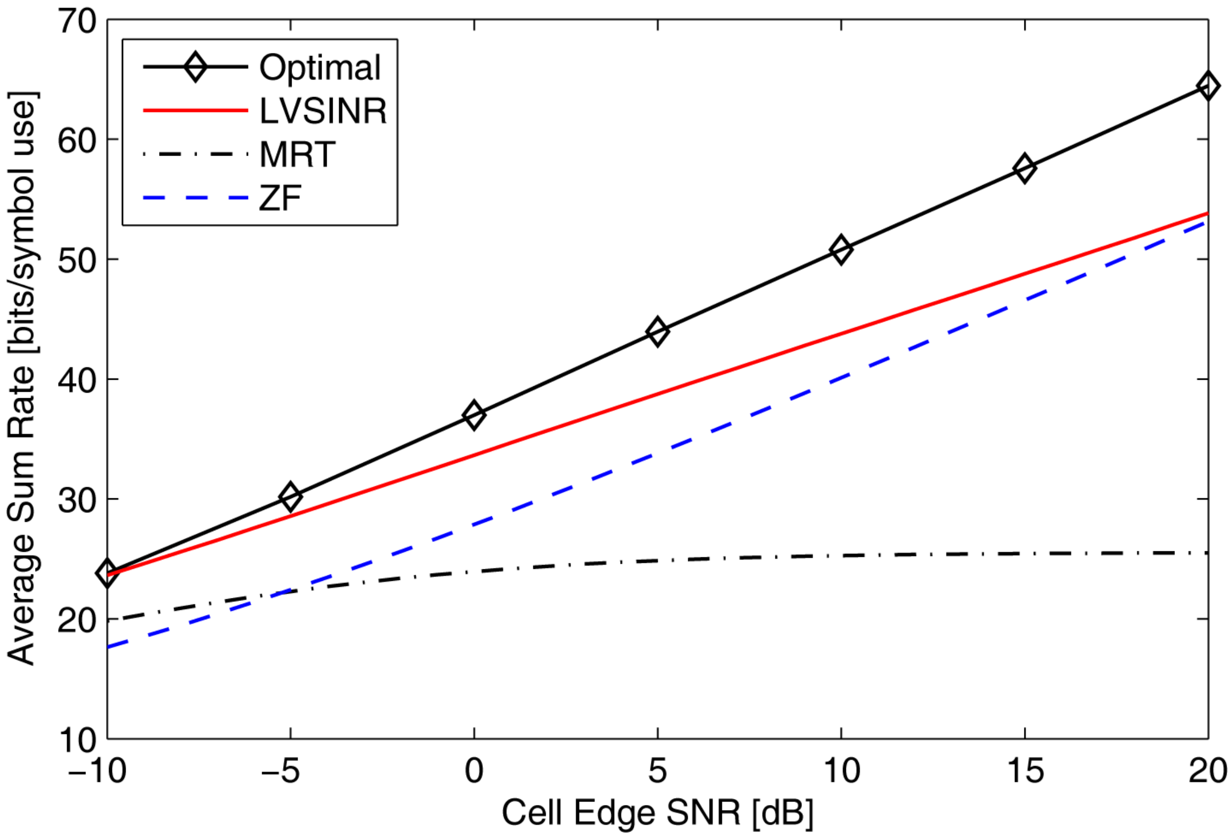


Parameters

4 BS, 4 MS
4 antennas/BS



Summary

- Interference Limits Multicell Performance
  - Managed by base station cooperation
  - Special case with data sharing and only local CSI

- Characterization of Pareto Boundary
  - Beamforming: Linear combination of MRT and ZF
  - Generalization of results on interference channels

- Distributed Precoding Design
  - Proposal 1: Maximization of virtual SINRs
  - Proposal 2: Heuristic power allocation
  - Finds reasonable linear combination of MRT and ZF
  - Good performance using only local CSI

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Thank You for Listening!

Questions?

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