Downlink Multicell Cooperative Transmission With Imperfect CSI Sharing

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Outline

- Introduction
- System Model
- Decentralized Multicell Cooperation
  - Base Station-processing Strategy
  - Decentralized Multicell Precoder
- Simulation Results
- Conclusions

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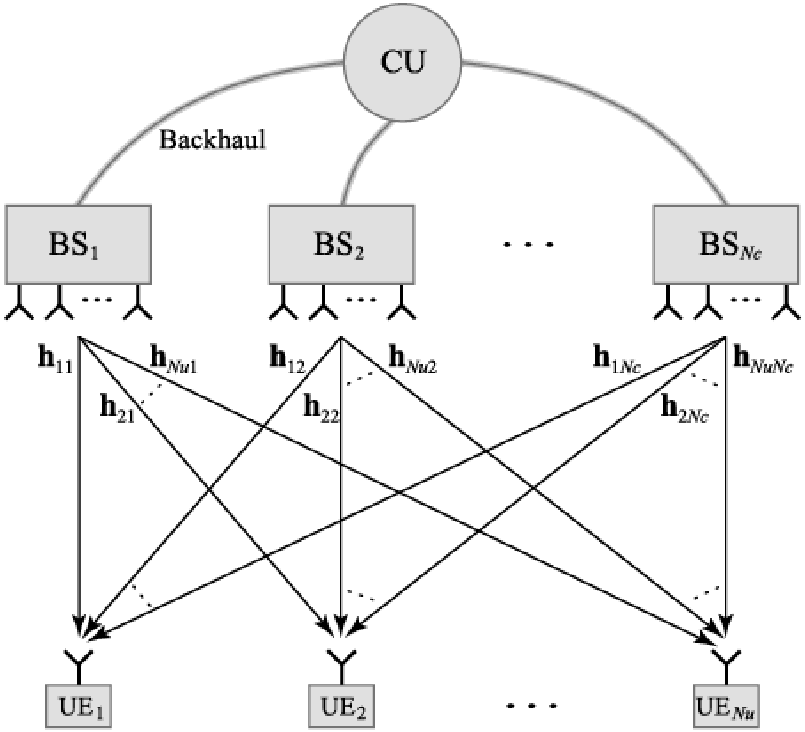
- Inter-cell interference is a major bottleneck for achieving high spectral efficiency in universal frequency reuse cellular networks.
- Multicell cooperative transmission, also known as coordinated multi-point (CoMP) transmission, is a promising solution.
- Typical coherent CoMP transmission:

General procedure in TDD systems

1. Each BS estimates channels from all users with UL-DL reciprocity.
2. Each BS forwards channel estimates to the central unit (CU).
3. CU computes precoders for all BSs, and broadcasts them to all BSs.
4. All BSs jointly transmit to all users.

CU-processing strategy



- Performance gain of coherent CoMP comes at a cost of various overhead and expensive backhaul networks for data and channel sharing.
- Recent work on imperfect channel state inforamtion (CSI) sharing
  - Imperfect CSI sharing due to estimation errors is considered in [1], where its impact on CoMP capacity region is investigated.
  - The cases without CSI sharing are considered in [2, 3] assuming full data sharing, where distributed precoders are proposed.

[1] P. Marsch and G. Fettweis, “On downlink network MIMO under a constrained backhaul and imperfect channel knowledge,” in Proc *IEEE GLOBECOM, 2009.*

[2] R. Zakhour and D. Gesbert, “Distributed multicell-MISO precoding using the layered virtual SINR framework,” *IEEE Trans. Wireless Commun., pp. 1–5, 2010.*

[3] E. Bjornson, R. Zakhour, D. Gesbert, and B. Ottersten, “Cooperative multicell precoding: Rate region characterization and distributed strategies with instantaneous and statistical CSI,” *IEEE Trans. Signal Processing, vol. 58,* pp. 4298–4310, 2010.

- Backhaul latency in current deployed cellular systems is in an order of 10 to 20 milliseconds [4].
- Channel delay in CU-processing strategies: double backhaul latency due to the BS-CU-BS transfer.
- In this talk, imperfect channel sharing led by backhaul latency is considered, and a new CoMP strategy is proposed to alleviate the performance loss led by backhaul latency.

[4] 3GPP TSG TS 36.420, “Evolved universal terrestrial radio access network (e-utran): X2 general aspects and principles,” 2009.

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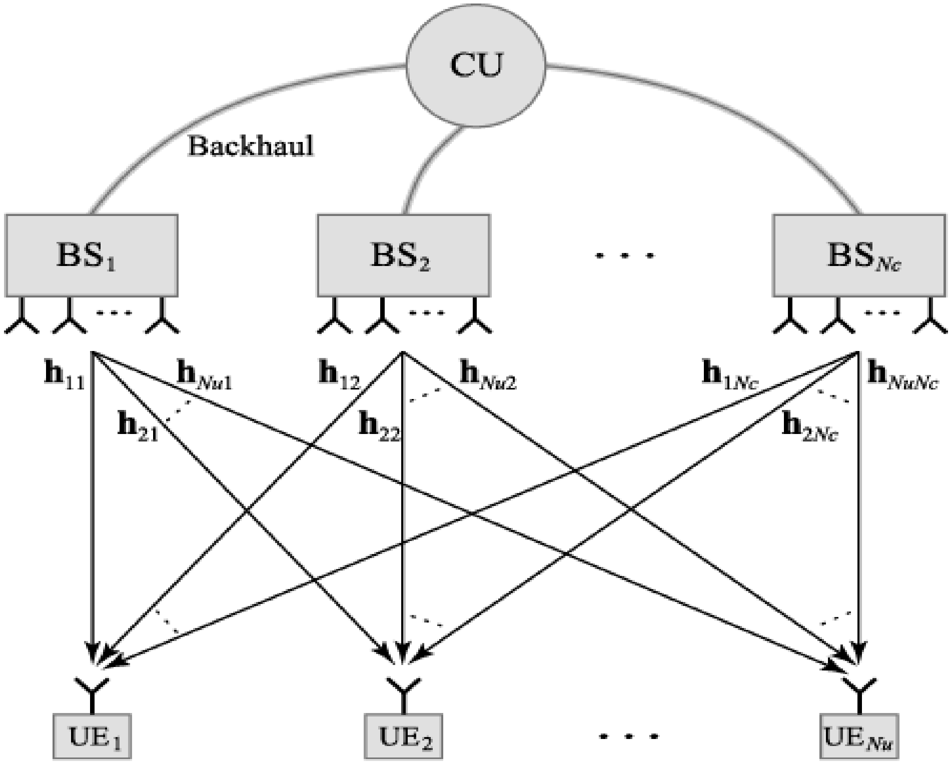

- Consider a TDD-CoMP system with full data sharing among BSs
- The CU is connected to all cooperative BSs via backhaul links
- *Nc* BSs each equipped with *Nt* antennas
- *Nu* UEs each equipped with *1* antennas

- Received signal of user *i*

$$y_i = \mathbf{h}_i \mathbf{w}_i^H x_i + \mathbf{h}_i \sum_{j \neq i} \mathbf{w}_j^H x_j + z_i$$

  - x_i is the data symbol for user *i* shared among the BSs
  - $\mathbf{h}_i = [\mathbf{h}_{i1}, \ldots, \mathbf{h}_{iN_c}] \in \mathbb{C}^{1 \times N_c N_t}$ is the global channel from *Nc* BSs to user *i*
  - $\mathbf{w}_i = [\mathbf{w}_{i1}, \ldots, \mathbf{w}_{iN_c}] \in \mathbb{C}^{1 \times N_c N_t}$ is the precoding vector of user *i*
  - z_i is the additive white Gaussian noise with zero mean and variance σ^2

- Consider that the BSs esitmate channels at time $t-\tau$, and perform downlink transmission at time t, where τ is the channel delay led by backhaul latency.
- Assuming a priori knowledge of channel statistics and with Weiner filtering, the channel is modeled as

$$\mathbf{h}_{ik} = \hat{\mathbf{h}}_{ik} + \mathbf{e}_{ik}$$

  - $\mathbf{h}_{ik}$ and $\hat{\mathbf{h}}_{ik}$ are the real channel and its estimate at the BS.
  - $\mathbf{e}_{ik} \sim CN\left(0, \sigma_{ik}^2 \mathbf{I}\right)$ is the channel estimation error, where σ_{ik}^2 increases with the growth of backhaul latency.

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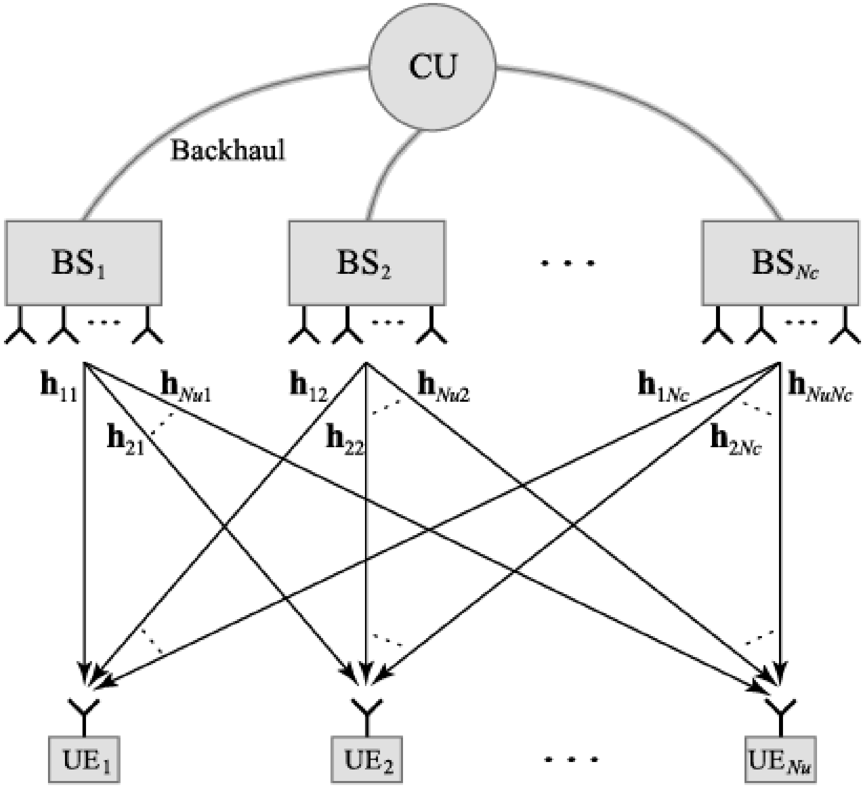
BS-processing Strategy

1. Each BS estimates channels from all users with UL-DL reciprocity.
2. Each BS forwards channel estimates to the CU.
3. The CU broadcasts collected channels to all BSs.
4. Each BS re-estimates channels from all users, and computes its own precoder with all available channels.
5. All BSs jointly transmit to all users.



- Features of BS-processing strategy
  - Precoders at different BSs are designed individually.
  - Channels at different BSs are different but correlated, for instance, channels at BS *k* includes:
    - Coarse own channel esitmates $\bar{\mathbf{H}}_{L,k}$
    - Coarse shared channel estimates $\hat{\mathbf{H}}_{C,k}$
    - Fine own channel esitmates $\hat{\hat{\mathbf{H}}}_{L,k}$
  - Goals of cooperative BSs are the same.
- The precoder design problem falls into the framework of team decision theory [5, 6].

[5] Y.-C. Ho, “Team decision theory and information structures,” *Proc. IEEE, vol. 68, pp. 644–654, 1980.*

[6] R. Zakhour and D. Gesbert, “Team decision for the cooperative MIMO channel with imperfect CSIT sharing,” in *IEEE Information Theory and Applications Workshop, 2010.*

- Person-by-person optimization
  - A suboptimal solution to team decision making problem, where
  - One decision maker optimizes its decision variables given that other team members' decision variables are fixed.
  - Decision variables sharing is required.
- Sharing of decision variables is not preferred
  - It eventually results in an iterative precoder design method.
  - The shared decision variables become useless when the backhaul latency is large.

- Basic idea of the proposed precoder
  - Each BS first estimates other BSs' precoders, then optimizes its own precoder.
- Usage of channels: shared coarse $\bar{\mathbf{H}}_{L,k}$ or private fine $\hat{\mathbf{H}}_{L,k}$?
  - Just simply use the private fine $\hat{\mathbf{H}}_{L,k}$ and other BSs' channels $\hat{\mathbf{H}}_{C,k}$.

→ The precoder design at each BS turns into the problem of Bayesian robust design with the channel $\hat{\mathbf{H}}_k = \left[\hat{\mathbf{H}}_{L,k} \quad \hat{\mathbf{H}}_{C,k} \right]$.

- Performance Utility: weighted average sum rate

$$\bar{R}_s = \sum_{i=1}^{N_u} \alpha_i \bar{R}_i$$

  - $\bar{R}_i$ is the average data rate of user *i*:

$$\bar{R}_i = \mathbb{E}\left\{ \log\left(1 + \frac{\mathbf{w}_i \mathbf{h}_i^H \mathbf{h}_i \mathbf{w}_i^H}{\sigma^2 + \sum_{\substack{j=1 \\ j \neq i}}^{N_u} \mathbf{w}_j \mathbf{h}_i^H \mathbf{h}_i \mathbf{w}_j^H}\right) \right\}$$

$$\approx \log\left(1 + \frac{\mathbf{w}_i \mathbb{E}\{\mathbf{h}_i^H \mathbf{h}_i\} \mathbf{w}_i^H}{\sigma^2 + \sum_{\substack{j=1 \\ j \neq i}}^{N_u} \mathbf{w}_j \mathbb{E}\{\mathbf{h}_i^H \mathbf{h}_i\} \mathbf{w}_j^H}\right)$$

- Problem formulation:

$$\max_{\mathbf{w}_{ik}} \bar{R}_s,\ i=1,\ldots,N_u,\ k=1,\ldots,N_c$$
$$s.t.\ \operatorname{Tr}\left(\mathbf{W}_k\mathbf{W}_k^H\right)\le P_0,\ k=1,\ldots,N_c$$

  - $\mathbf{W}_k=[\mathbf{w}_{1k}^H,\ldots,\mathbf{w}_{N_uk}^H]$ is the precoding matrix at BS *k*.
  - The constraints reflect the per-BS power constraints (PBPC).
- Problem reformulation with rate profile $\beta_i=\alpha_i\bar{R}_i/\bar{R}_s$ [7]

$$\max_{\mathbf{w}_{ik}} \bar{R}_s,\ i=1,\ldots,N_u,\ k=1,\ldots,N_c$$
$$s.t.\ \bar{R}_i\ge\frac{\beta_i}{\alpha_i}\bar{R}_s,\ i=1,\ldots,N_u,$$
$$\operatorname{Tr}\left(\mathbf{W}_k\mathbf{W}_k^H\right)\le P_0,\ k=1,\ldots,N_c.$$

- Define $\mathbf{X}_i = \mathbf{w}_i^H \mathbf{w}_i$, the optimization problem is rewritten as

$$\begin{aligned}
&\max_{\mathbf{X}_i} \ \bar{R}_s, \ i = 1, \ldots, N_u \\
&s.t. \ \operatorname{Tr}(\mathbf{R}_i \mathbf{X}_i) - c_i \sum_{j \neq i} \operatorname{Tr}(\mathbf{R}_i \mathbf{X}_j) \geq c_i \sigma^2, \\
&\qquad \sum_{i=1}^{N_u} \operatorname{Tr}(\mathbf{B}_k \mathbf{X}_i) \leq P_0, \ k = 1, \ldots, N_c, \\
&\qquad \mathbf{X}_i \succeq 0, \ \boxed{\operatorname{rank}(\mathbf{X}_i) = 1}, \ i = 1, \ldots, N_u,
\end{aligned}$$

  - c_i is a scalar as a function of $\bar{R}_s$ and β_i .
  - $\mathbf{B}_k$ is a properly defined row-selection matrix to ensure the PBPC.
- Semi-definite relaxation (SDR) [8] is used to obtain a semi-definite programming (SDP) feasibility problem by omitting the only non-convex rank-one constraints.

Decentralied Multicell Precoder

1. At each BS, given a rate profile $\boldsymbol{\beta} = [\beta_1, \ldots, \beta_{Nu}]$, solve the relaxed SDP problem by the bisection method and obtains the optimal $\mathbf{X}_i$.
2. If $\mathbf{X}_i$ is of rank-one, obtain $\mathbf{w}_i$ by eigenvalue decomposition. Otherwise, the randomization method [8] can be employed to obtain a suboptimal $\mathbf{w}_i$.
3. Repeat step 1 and step 2 for all possible rate profiles, and find the optimal $\mathbf{w}_i$ corresponding to the maximal weighted average sum rate.
4. Perform phase adjustment to the obtained precoders to ensure $\Im(\hat{\mathbf{h}}_i \mathbf{w}_i^H) = 0$, where $\Im(\cdot)$ denotes the imaginary part of a complex number.

[7] M. Mohseni, R. Zhang, and J. M. Cioffi, “Optimized transmission for fading multiple-access and broadcast channels with multiple antennas,” *IEEE J. Select. Areas Commun., vol. 24, no. 8, pp. 1627–1639, 2006.*

[8] Z. quan Luo, W. kin Ma, A. M.-C. So, Y. Ye, and S. Zhang, “Semidefinite relaxation of quadratic optimization problems,” *IEEE Signal Processing Mag., vol. 27, no. 3, pp. 20–34, 2010.*

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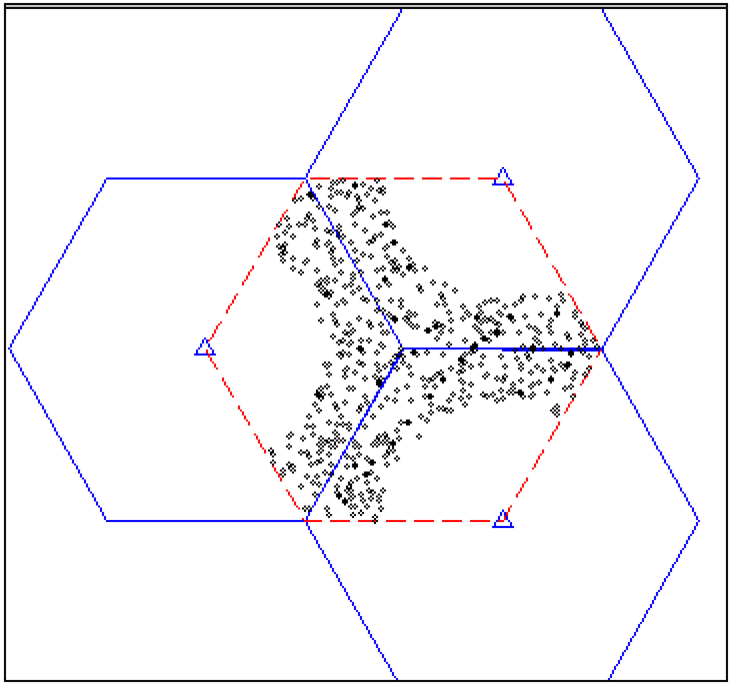
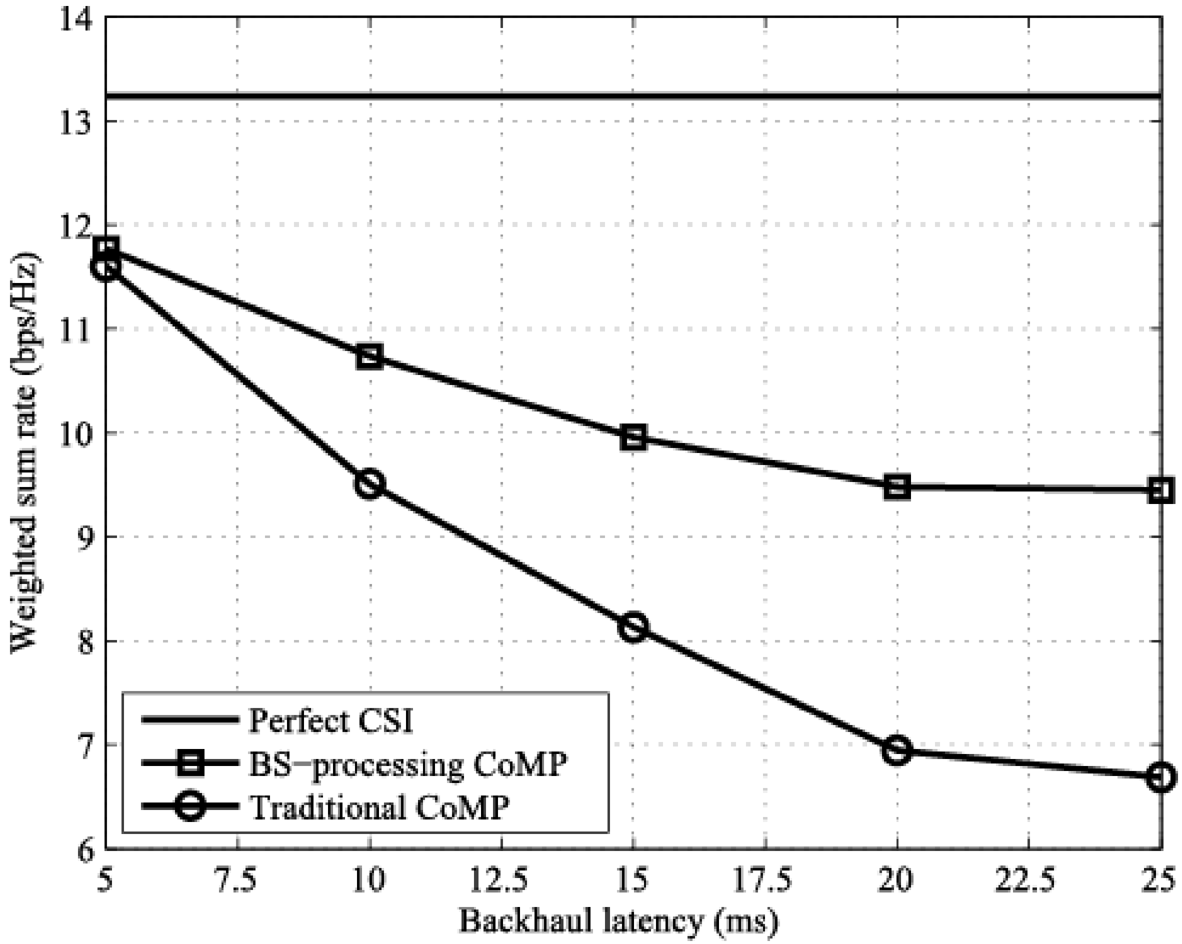
Cooperative cell #	3
Total User #	2
BS and user antenna #	2, 1
Inter-BS distance	500 m
BS-UE min distance	150 m
Large-scale fading	$-35.3-37.6\log(d_{im})$
SNR at cell edge	10 dB
Small-scale fading	i.i.d. Rayleigh
Time-varying channel	Jakes' model Moving speed of 3km/h Carrier frequency of 2 GHz
Uplink training period	5 ms
Rate weighting factors	[1,...,1]





- The BS-processing CoMP with the decentralized multicell precoder effectively alleviates the performance loss led by backhaul latency.

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- Proposed a new downlink multicell cooperation framework, the BS-processing strategy, which alleviates the performance degradation led by backhaul latency.
- The proposed decentralized multicell precoder is mainly intended for providing a performance benchmark for the BS-processing strategy.
- In future, the design of low-complexity precoders and efficient usage of the available channel state information at the BS will be studied.

Thank you for your attention!