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Decentralized Coordinated Beamforming for Weighted Sum Energy Efficiency Maximization in Multi-Cell MISO Downlink

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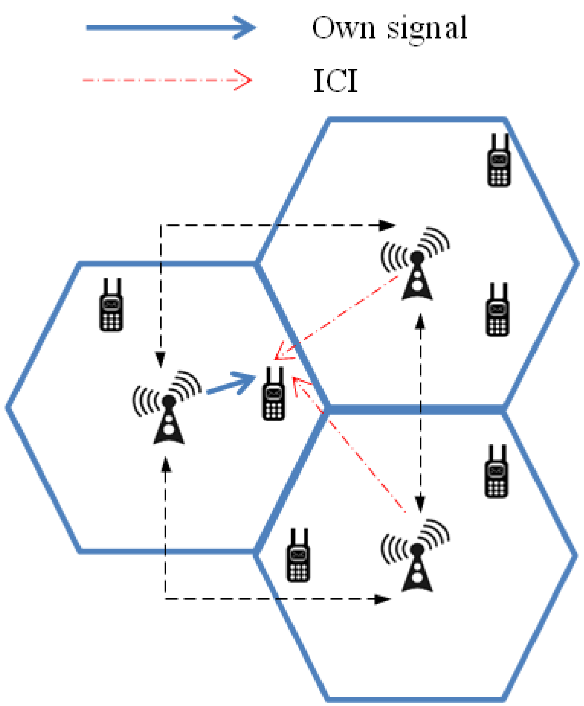
Content

- System assumptions and scope
- Problem Formulation
- Problem Solution
- Results

System model

- Multi-cell multiuser MISO
  - Downlink
  - Multi-antenna base stations (BS) and single-antenna users (UT)
  - Mutually interfering adjacent cells
- Coordinated beamforming
  - Interference coordination
- Assumptions:
  - BSs require local CSI (towards all the users) → TDD DL-UL reciprocity
  - Ideal backhaul between the BSs (scalars exchanged)



Scope

- Beam coordination to cope with inter-cell interference
- Provide energy-efficient beamforming strategy with decentralized optimization
  - Only local CSI needed
  - Scalar backhaul information exchange

Problem formulation

- Received signal of terminal k of cell b at

channel data

$$y_k = \mathbf{h}_{b_k,k}\mathbf{w}_k s_k + \sum_{j\in\mathcal{K}_{b_k}\setminus\{k\}} \mathbf{h}_{b_k,k}\mathbf{w}_j s_j + \underbrace{\sum_{m\in\bar{\mathcal{B}}_{b_k}} \sum_{j\in\mathcal{K}_m} \mathbf{h}_{m,k}\mathbf{w}_j s_j + n_k}_{\text{inter-cell interference}}$$

noise

TX beamformers

inter-cell interference

Problem formulation

- In the literature, different energy-efficient metrics proposed:

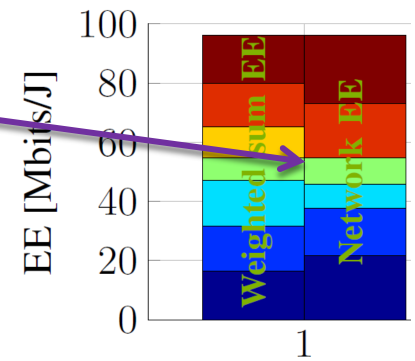
- Network energy efficiency:

$$\max_{\{\mathbf{w}_k\}_{k\in\mathcal{K}}} \quad \frac{\sum_{b\in\mathcal{B}} f_b(\mathbf{w})}{\sum_{b\in\mathcal{B}} g_b(\tilde{\mathbf{w}}_b)}$$

Rate of BS b

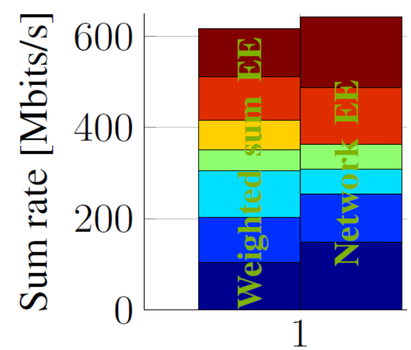
Total power of BS b

'Yellow' BS allocated with zero power



- **Weighted sum energy efficiency:**

$$\max_{\{\mathbf{w}_k\}_{k\in\mathcal{K}}} \quad \sum_{b\in\mathcal{B}} \omega_b \frac{f_b(\mathbf{w})}{g_b(\tilde{\mathbf{w}}_b)}$$



  - ***balanced EEs and rates between the cells***
  - ***Adjustable EE's for different BS types (HETNET)***
  - ***tractable for decentralization***

Priority weights

Problem formulation

- Weighted sum energy efficiency maximization

$$\begin{aligned} \max_{\{\mathbf{w}_k\}_{k\in\mathcal{K}}} \quad & \sum_{b\in\mathcal{B}} \omega_b \frac{f_b(\mathbf{w})}{g_b(\tilde{\mathbf{w}}_b)} \\ \text{s.t.} \quad & \Gamma_k(\mathbf{w}) \geq \bar{\Gamma}_k, k \in \mathcal{K} \\ & \sum_{k\in\mathcal{K}_b} \|\mathbf{w}_k\|_2^2 \leq P_b, \forall b \in \mathcal{B} \end{aligned}$$

SINR constraints

TX power contraints

$$f_b(\mathbf{w}) \triangleq \sum_{k\in\mathcal{K}_b} R_k(\mathbf{w})$$

Sum rate of BS b

$$g_b(\tilde{\mathbf{w}}_b) \triangleq \frac{1}{\eta} \sum_{k\in\mathcal{K}_b} \|\mathbf{w}_k\|_2^2 + P_0$$

Total power of BS b

PA efficiency

Total circuit power of BS b (depends e.g. on number of UTs/antennas

Equivalent Transformation

$$\max_{\{t_b,\alpha_b\}_{b\in\mathcal{B}},\{\mathbf{w}_k,\gamma_k,\beta_k\}_{k\in\mathcal{K}}} \sum_{b\in\mathcal{B}} \omega_b t_b$$

$$\text{s.t.} \quad g_b(\tilde{\mathbf{w}}_b) \le \alpha_b^2/t_b, \forall b \in \mathcal{B}$$

$$\gamma_k \le |\mathbf{h}_{b_k,k}\mathbf{w}_k|^2/\beta_k, \forall k \in \mathcal{K}$$

other convex constraints

Jointly convex functions

First-order lower approximations at point $(\alpha_b^{(n)}, t_b^{(n)})$:

$$\frac{\alpha_b^2}{t_b} \ge \frac{2\alpha_b^{(n)}}{t_b^{(n)}}\alpha_b - \left(\frac{\alpha_b^{(n)}}{t_b^{(n)}}\right)^2 t_b \triangleq \phi^{(n)}(\alpha_b, t_b)$$

Sequential Convex Approximation

- Solve problem iteratively until convergence

$$\max_{\{t_b,\alpha_b\}_{b\in\mathcal{B}},\{\mathbf{w}_k,\gamma_k,\beta_k\}_{k\in\mathcal{K}}} \quad \sum_{b\in\mathcal{B}} \omega_b t_b$$

$$\text{s.t.} \quad g_b(\tilde{\mathbf{w}}_b) \leq \phi^{(n)}(\alpha_b, t_b), \forall b \in \mathcal{B}$$

$$\gamma_k \leq \psi^{(n)}(\mathbf{w}_k, \beta_k), \forall k \in \mathcal{K}$$

$$\frac{\mathbf{h}_{b_k,k}\mathbf{w}_k}{\sqrt{\bar{\Gamma}_k}} \geq \left(\mathcal{I}_k(\tilde{\mathbf{w}}_{b_k}) + \sum_{m\in\bar{\mathcal{B}}_{b_k}} \mathcal{I}_{m,k}(\tilde{\mathbf{w}}_m)\right)^{\frac{1}{2}}, \mathrm{Im}(\mathbf{h}_{b_k,k}\mathbf{w}_k) = 0$$

$$\beta_k \geq \mathcal{I}_k(\tilde{\mathbf{w}}_{b_k}) + \sum_{m\in\bar{\mathcal{B}}_{b_k}} \mathcal{I}_{m,k}(\tilde{\mathbf{w}}_m), \forall k \in \mathcal{K}$$

other convex constraints

Updated after each iteration

ICI couples all the cells (global CSI required)

ADMM-based Decentralized Solution

- Introduce inter-cell interference variable $z_{b,j}$

$$z_{b,j}^2 \geq \sum_{k \in \mathcal{K}_b} |\mathbf{h}_{b_k,j}\mathbf{w}_k|^2, \forall b \in \mathcal{B}, j \in \bar{\mathcal{K}}_b$$

$$\frac{\mathbf{h}_{b_k,k}\mathbf{w}_k}{\sqrt{\bar{\Gamma}_k}} \geq \left(\mathcal{I}_k(\tilde{\mathbf{w}}_{b_k}) + \sum_{m \in \bar{\mathcal{B}}_{b_k}} z_{m,k}^2\right)^{\frac{1}{2}}$$

$$\beta_k \geq \mathcal{I}_k(\tilde{\mathbf{w}}_{b_k}) + \sum_{m \in \bar{\mathcal{B}}_{b_k}} z_{m,k}^2, \forall k \in \mathcal{K}$$

Convex

- Introduce 'local copies' for each $z_{b,j}$

$\tilde{z}_{m,k}^{b}$ ICI from BS m to user k optimized by BS **b**

$\tilde{z}_{m,k}^{m}$ ICI from BS m to user k optimized by BS **m**

ADMM-based Decentralized Solution

- Define local feasible set

Local optimization variables

$$\mathcal{S}_b = \Big\{ (\tilde{\mathbf{w}}_b, \boldsymbol{\gamma}_b, \alpha_b, t_b, \boldsymbol{\beta}_b, \tilde{\mathbf{z}}_b) \Big| \\
\sum_{k\in\mathcal{K}_b} ||\mathbf{w}_k||_2^2 \le P_b \\
\mathrm{Im}(\mathbf{h}_{b_k,k}\mathbf{w}_k) = 0, \forall k \in \mathcal{K}_b \\
\sum_{k\in\mathcal{K}_b} \log(1+\gamma_k) \ge \alpha_b^2 \\
g_b(\tilde{\mathbf{w}}_b) \le \phi^{(n)}(\alpha_b, t_b) \\
\gamma_k \le \psi^{(n)}(\mathbf{w}_k, \beta_k), \forall k \in \mathcal{K}_b \\
\frac{\mathbf{h}_{b_k,k}\mathbf{w}_k}{\sqrt{\Gamma_k}} \ge (\mathcal{I}_k(\tilde{\mathbf{w}}_b) + \sum_{m\in\bar{\mathcal{B}}_{b_k}} (\tilde{z}_{m,k}^b)^2)^{\frac{1}{2}}, \forall k \in \mathcal{K}_b \\
\beta_k \ge \mathcal{I}_k(\tilde{\mathbf{w}}_b) + \sum_{m\in\bar{\mathcal{B}}_b} (\tilde{z}_{m,k}^b)^2, \forall k \in \mathcal{K}_b \\
(\tilde{z}_{b,j}^b)^2 \ge \sum_{k\in\mathcal{K}_b} |\mathbf{h}_{b,j}\mathbf{w}_k|^2, \forall j \in \bar{\mathcal{K}}_b \Big\} \quad (15)$$

Local convex constraints

ADMM-based Decentralized Solution

- Equivalent Transformation

$$\max \quad \sum_{b \in \mathcal{B}} \omega_b t_b$$

$$\text{s. t.} \quad (\tilde{\mathbf{w}}_b, \boldsymbol{\gamma}_b, \alpha_b, t_b, \boldsymbol{\beta}_b, \tilde{\mathbf{z}}_b) \in \mathcal{S}_b, \forall b \in \mathcal{B}$$ Local constraints

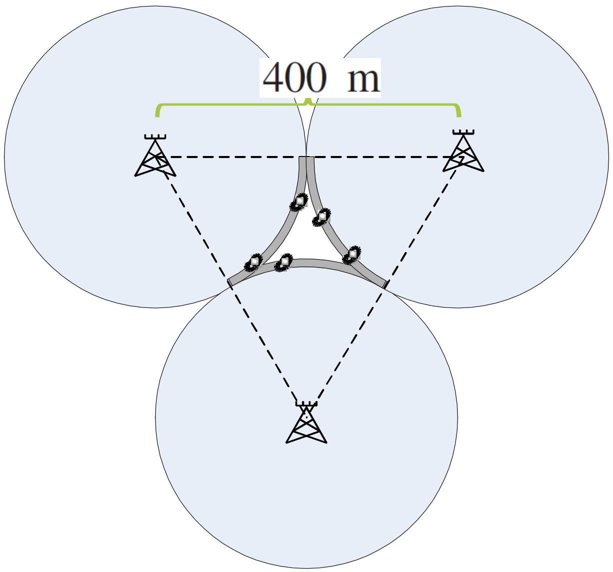
$$\tilde{\mathbf{z}}_b = \mathbf{z}_b, \forall b \in \mathcal{B}$$ Global constraints (ensures that local copies equal to global variables)

→ **general global consensus problem → can be solved using well-known ADMM**

Each base station needs to share local interference variables to other BSs ($2K_b$ real scalars)

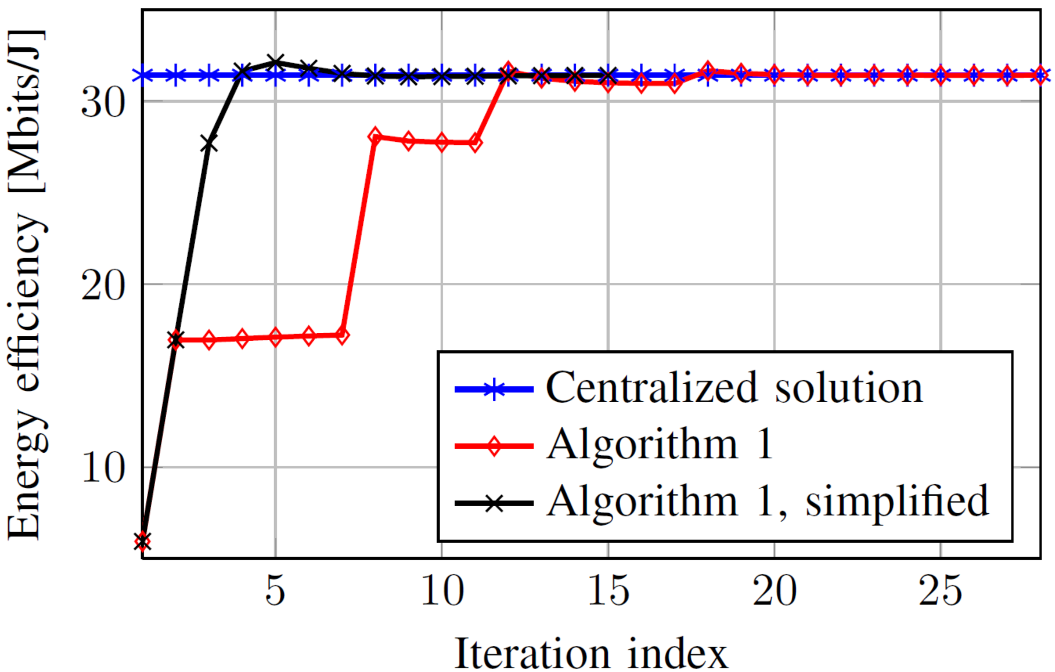
Simulation modeling

- 3 BSs
- 9 users at the center area of the BSs (3 per cell)



Numerical results

- Algorithm 1:
  - Until convergence {
    1. Perform SCA step
    2. Use ADMM until convergence
- Algorithm 1, simplified:
  - Until convergence {
    1. Perform SCA step
    2. Perform ADMM step



$B = 3$, $W = 20$ MHz, $P_{\mathrm{FIX}} = 18$ Watts, $P_{\mathrm{BS}} = 1$ Watt

$P_{\mathrm{SYN}} = 2$ Watts, $\rho = 0.04$, $\bar{\Gamma}_k = \bar{\Gamma} = 0$ dB, $P_b = 46$ dBm

$\eta = 0.39$, $W N_0 =$ -96 dBm, $N = 9$, $K_b = K = 3$

Conclusions

- Coordinated beamforming for energy-efficient transmission
  - Decentralized solution
  - Optimization based on local CSI and scalar backhaul information exchange