Journal Watch: Transactions on Wireless Communications

Anubhab Chowdhury

SPC Lab.
Indian Institute of Science

February 1, 2020

Multi-Cell Interference Exploitation: Enhancing the Power Efficiency in Cell Coordination.: Zhongxiang Wei et al.

- **Goal:** Improve system performance exploiting inter-cell and intra-cell interference effectively.
- **Challenges:**
  1. Full BS cooperation leads to high coordination overhead cost.
  2. Low-level coordination fails to exploit inter-cell interference to meet the users' SINR requirement.
  3. Practical scenario: CSI is imperfect.
- **Key Contributions:**
  1. Proposes a Partial-CI scheme to utilize multi-user interference while suppressing inter-cell interference by joint precoding design.
  2. To strike a trade-off between system performance and coordination overhead, low-complexity algorithms are proposed to minimize transmit power consumption.
  3. Incorporates CSI uncertainties.

- **System Model: CBF vs. CoMP**
  - N_{BS} coordinated BSs and K users in each cell. The received signal by the k -th user located in the i -th cell

$$y_{ik} = \boldsymbol{h}_{iik}^T \sum_{n=1}^{K} \boldsymbol{w}_{in} s_{in} + \sum_{j \neq i}^{N_{BS}} \sum_{m=1}^{K} \boldsymbol{h}_{jik}^T \boldsymbol{w}_{jm} s_{jm} + n_{ik}.$$

  - **Coordinated Beamforming**

$$\Gamma_{ik}^{\mathrm{CBF}} = \frac{\left|\boldsymbol{h}_{iik} \boldsymbol{w}_{ik}\right|^2}{\sum_{k' \neq k, k' \in \mathbb{I}} \left|\boldsymbol{h}_{iik} \boldsymbol{w}_{ik'}\right|^2 + \sum_{j \neq i}^{N_{BS}} \sum_{m=1}^{K} \left|\boldsymbol{h}_{jik} \boldsymbol{w}_{jm}\right|^2 + \sigma_n^2}.$$

  - **CoMP**

$$\Gamma_{ik}^{\mathrm{CoMP}} = \frac{\sum_{j=1}^{N_{BS}} \left|\boldsymbol{h}_{jik} \boldsymbol{w}_{ik}\right|^2}{\sum_{j=1}^{N_{BS}} \sum_{k' \neq k, k' \in \mathbb{J}} \left|\boldsymbol{h}_{jik'} \boldsymbol{w}_{ik'}\right|^2 + \sigma_n^2}.$$

  - **Key Idea:** In contrast to common practice where knowledge of the interference is used to eliminate it, the main idea proposed here is to use this knowledge to glean benefit from the interference.

- **Constructive Interference:**

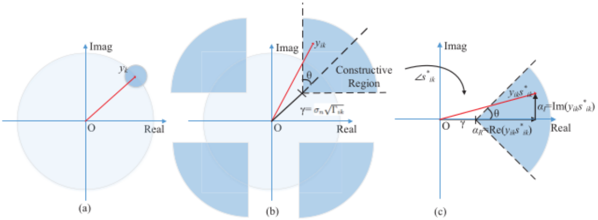


Figure: Optimization region for constructive interference exploitation, QPSK

- **Procedure:**
  1. $s_{ik} = d_{ik}e^{j(\phi_{ik})}$ replace with $s_{in} = s_{ik}e^{j(\phi_{in}-\phi_{ik})}$.
  2. Equivalent received signal: $y_{ik} = \sum_{j=1}^{N_{BS}} \tilde{\boldsymbol{h}}_{jik}^T \boldsymbol{w}_j s_{ik} + n_{ik}$, with $\tilde{\boldsymbol{h}}_{jik} = \boldsymbol{h}_{jik}e^{j(\phi_{11}-\phi_{ik})}$ and $\boldsymbol{w}_j = \sum_{m=1}^{K} \boldsymbol{w}_{jm}e^{j(\phi_{jm}-\phi_{11})}$, $\forall j \in N_{BS}$.
  3. **Condition for CI:**

$$|\Im\left(\sum_{j=1}^{N_{BS}} \tilde{\boldsymbol{h}}_{jik}^T \boldsymbol{w}_j\right)| \leq \left(\Re\left(\sum_{j=1}^{N_{BS}} \tilde{\boldsymbol{h}}_{jik}^T \boldsymbol{w}_j\right) - \sigma_n\sqrt{\Gamma_{ik}}\right)\tan\theta, \forall\ \mathrm{U}_{ik}.$$

Joint User Selection, Power Allocation, and Precoding Design With Imperfect CSIT for Multi-Cell MU-MIMO Downlink Systems: Choi et al.

- **Goal:** Formulate optimization framework for the joint design of user selection, power allocation, and precoding in MU-MIMO with imperfect CSIT.
- **Challenges:**
  1. The joint optimization of user-cell association, power allocation, and precoding vectors in order to maximize the weighted sum-spectral efficiency is known to be NP-hard.
  2. The sum-SE maximization subject to a total power constraint under linear precoding is non-convex, even in the case of perfect CSIT.
- **Key Contributions:**
  1. GPIP (generalized power iteration pre-coding)
  2. Extension to multi-cell cooperation.
  3. Lower bound on WSSE by generalized mutual information (GMI).

- **System Model**
  1. **Correlation Model:**

$$[\mathbf{R}_{j,\ell,k}]_{n,m} = \frac{\beta_{j,\ell,k}}{2\Delta_{j,\ell,k}} \int_{\theta_{j,\ell,k}-\Delta_{j,\ell,k}}^{\theta_{j,\ell,k}+\Delta_{j,\ell,k}} e^{-j\frac{2\pi}{\lambda}\Psi(\alpha)(\mathbf{r}_{j,n}-\mathbf{r}_{j,m})}\mathrm{d}\alpha.$$

  2. **Quality of CSI:** (the amount of feedback bits to quantize the downlink channel)

$$\hat{\mathbf{h}}_{\ell,\ell,k} = \mathbf{U}_{\ell,\ell,k}\mathbf{\Lambda}_{\ell,\ell,k}^{\frac{1}{2}}\left(\sqrt{1-\kappa_{\ell,\ell,k}^2}\,\mathbf{g}_{\ell,\ell,k} + \kappa_{\ell,\ell,k}\mathbf{v}_{\ell,\ell,k}\right).$$

- **WSSE maximization problem:**

$$\underset{\mathbf{f}_{\ell,\pi_{\mathcal{S}_{\ell,j}}(1)},\ldots,\mathbf{f}_{\ell,\pi_{\mathcal{S}_{\ell,j}}(|\mathcal{S}_{\ell,j}|)}}{\arg\max} \quad \underset{\mathcal{S}_{\ell,j}\in\mathcal{P}(\mathcal{K}_\ell)\setminus\emptyset}{\arg\max} \quad g\left(\mathcal{S}_{\ell,j}\right) = \sum_{i=1}^{|\mathcal{S}_{\ell,j}|} w_{\ell,\pi_{\mathcal{S}_{\ell,j}}(i)} R_{\ell,\pi_{\mathcal{S}_{\ell,j}}(i)}\left(\hat{\mathbf{H}}_{\ell,\ell}(\mathcal{S}_{\ell,j})\right)$$

$$\text{subject to} \quad \sum_{i=1}^{|\mathcal{S}_{\ell,j}|} \|\mathbf{f}_{\ell,\pi_{\mathcal{S}_{\ell,j}}(i)}\|_2^2 \leq 1.$$

- **Maximization of the lower bound:**

$$\underset{\mathbf{f}_{\ell,1},\dots,\mathbf{f}_{\ell,K}}{\arg\max}\prod_{k=1}^{K}\times\left[\frac{\sum_{i=1}^{K}\mathbf{f}_{\ell,i}^{\mathsf{H}}\left(\hat{\mathbf{h}}_{\ell,\ell,k}\hat{\mathbf{h}}_{\ell,\ell,k}^{\mathsf{H}}+\mathbf{\Phi}_{\ell,\ell,k}\right)\mathbf{f}_{\ell,i}+\frac{\tilde{\sigma}_{\ell,k}^{2}}{P}}{\sum_{i\neq k}^{K}\mathbf{f}_{\ell,i}^{\mathsf{H}}\hat{\mathbf{h}}_{\ell,\ell,k}\hat{\mathbf{h}}_{\ell,\ell,k}^{\mathsf{H}}\mathbf{f}_{\ell,i}+\sum_{i=1}^{K}\mathbf{f}_{\ell,i}^{\mathsf{H}}\mathbf{\Phi}_{\ell,\ell,k}\mathbf{f}_{\ell,i}+\frac{\tilde{\sigma}_{\ell,k}^{2}}{P}}\right]^{w_{\ell,k}}$$

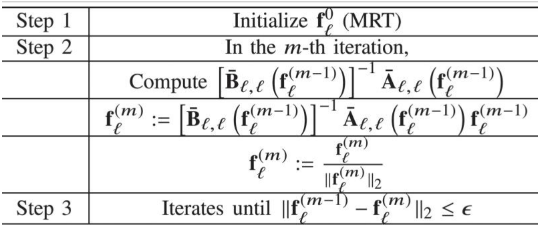
$$\text{subject to}\sum_{i=1}^{K}\|\mathbf{f}_{\ell,i}\|_2^2\leq 1.$$

- Procedure:
  - Rewrite the problem as

$$\underset{\mathbf{f}_{\ell}\in\mathbb{C}^{NK\times 1}}{\arg\max}\quad\prod_{k=1}^{K}\left[\frac{\mathbf{f}_{\ell}^{\mathsf{H}}\mathbf{A}_{\ell,\ell,k}\mathbf{f}_{\ell}}{\mathbf{f}_{\ell}^{\mathsf{H}}\mathbf{B}_{\ell,\ell,k}\mathbf{f}_{\ell}}\right]^{w_{\ell,k}}$$

$$\text{subject to}\quad\|\mathbf{f}_{\ell}\|_2^2\leq 1.$$

  - Algo:



Step 1	Initialize $\mathbf{f}_{\ell}^{0}$ (MRT)
Step 2	In the m-th iteration,
	Compute $\left[\bar{\mathbf{B}}_{\ell,\ell}\left(\mathbf{f}_{\ell}^{(m-1)}\right)\right]^{-1}\bar{\mathbf{A}}_{\ell,\ell}\left(\mathbf{f}_{\ell}^{(m-1)}\right)$
	$\mathbf{f}_{\ell}^{(m)} := \left[\bar{\mathbf{B}}_{\ell,\ell}\left(\mathbf{f}_{\ell}^{(m-1)}\right)\right]^{-1}\bar{\mathbf{A}}_{\ell,\ell}\left(\mathbf{f}_{\ell}^{(m-1)}\right)\mathbf{f}_{\ell}^{(m-1)}$
	$\mathbf{f}_{\ell}^{(m)} := \frac{\mathbf{f}_{\ell}^{(m)}}{\|\mathbf{f}_{\ell}^{(m)}\|_2}$
Step 3	Iterates until $\|\mathbf{f}_{\ell}^{(m-1)}-\mathbf{f}_{\ell}^{(m)}\|_2\leq\epsilon$

Making Cell-Free Massive MIMO Competitive With MMSE Processing and Centralized Implementation: Bjrnson & Sanguinetti

- **Goal:** To provide the first comprehensive analysis of this technology under different degrees of cooperation among the APs.
- **Challenges:**
  1. Front-haul signalling load.
  2. Can we apply channel hardening?
- **Key Contributions:**
  1. Achievable SE expressions for spatially correlated fading and multi-antenna APs.
  2. Effect of AP coordination on system performance.
  3. Non-linear decoding.

- **Cooperation Levels:**
  1. **Level 1** (fully distributed network) : the detection is performed locally at the APs by using only local channel estimates and one AP serves each UE, and nothing is exchanged with the CPU.
  2. **Level 2**: the CPU performs detection in the second stage by simply taking the average of the local estimates. This dispenses the CPU from knowledge of the channel statistics and thus reduces the amount of information to be exchanged.
  3. **Level 3** (LSFD): In the first stage, each AP locally estimates the channels and applies an arbitrary receive combiner to obtain local estimates of the UE data. These are then gathered at the CPU where they are linearly processed to perform joint detection.
  4. **Level 4**(fully centralized network): the pilot and data signals received at all APs are gathered (through the fronthaul links) at the CPU, which performs channel estimation and data detection.

- **Key findings:**
  1. A centralized implementation, with all the signal processing taking place at CPU, is highly preferable compared to distributed alternatives.
  2. Linear processing is sufficient at Level 4 since non-linear processing provides negligible gains due to the favorable propagation property.
  3. A centralized implementation with optimal MMSE processing not only maximizes the SE but largely reduces the fronthaul signaling compared to the standard distributed approach.

- **Corollary 1:** The instantaneous SINR for UE k is maximized by the MMSE combining vector

$$\mathbf{v}_k = p_k \left(\sum_{i=1}^{K} p_i \left(\hat{\mathbf{h}}_i \hat{\mathbf{h}}_i^{\mathrm{H}} + \mathbf{C}_i \right) + \sigma^2 \mathbf{I}_{LN} \right)^{-1} \hat{\mathbf{h}}_k,$$

which leads to the maximum value

$$\mathrm{SINR}_k^{(4)} = p_k \hat{\mathbf{h}}_k^{\mathrm{H}} \left(\sum_{i=1, i\neq k}^{K} p_i \hat{\mathbf{h}}_i \hat{\mathbf{h}}_i^{\mathrm{H}} + \sum_{i=1}^{K} p_i \mathbf{C}_i + \sigma^2 \mathbf{I}_{LN} \right)^{-1} \hat{\mathbf{h}}_k.$$

Other interesting papers!

Felipe Gmez-Cuba and Andrea J. Goldsmith
Compressed Sensing Channel Estimation for OFDM With Non-Gaussian Multipath Gains.

G. Alfano, C.-F. Chiasserini, and A. Nordio
SINR and Multiuser Efficiency Gap Between MIMO Linear Receivers.

Victor Perim et al.
Asymptotically Exact Approximations to Generalized Fading Sum Statistics.

Sicong Liu, Li-Chun Wang, and H. Vincent Poor
Reinforcement Learning-Based Downlink Interference Control for Ultra-Dense Small Cells.

Harald Haas, and Lajos Hanzo
Spatial Modulated Multicarrier Sparse Code-Division Multiple Access.