# Journal Watch
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# Joint Unicast and Multi-Group Multicast Transmission in Massive MIMO Systems - Meysam Sadeghi et al.

## Goal

- To maximize the weighted spectral efficiency of the unicast user terminals (UT) and minimum spectral efficiency (SE) of the multicast UTs

## Contributions

- Closed form expressions for the achievable SE of each unicast and multicast UTs in the system
- Formulate the problem of maximizing the SSE of the unicast UTs and the max-min fairness (MMF) problem for the multicast UTs
- MMF and SSE problems are coupled in a conflicting manner. Hence, a multiobjective optimization problem (MOOP) is formulated for the joint unicast and multicast transmission
- Derive the pareto boundary of the MOOP analytically

## System Model

- Single cell with $N$ antenna base station (BS)
- $U$ single antenna unicast UTs and $G$ multicasting groups (group $g$ contains $K_g$ single antenna UTs)
- Block fading channel model
- Orthogonal pilots for unicast UTs and multicast groups (one pilot per group)

- MMSE channel estimation
  - No pilot contamination of unicast UT channels
  - For multicast UTs, the channel estimates are equivalent up to a scalar coefficient
- Achievable spectral Efficiencies for MRT and ZF precoding

$$\mathrm{SINR}_{m,un}^{\mathrm{MRT}} = \frac{Np_m^{dl}\vartheta_m}{1+\beta_m(P_{un}+P_{mu})}.$$

$$\mathrm{SINR}_{jk,mu}^{\mathrm{MRT}} = \frac{Nq_j^{dl}\xi_{jk}}{1+\eta_{jk}(P_{mu}+P_{un})}.$$

$$\mathrm{SINR}_{m,un}^{\mathrm{ZF}} = \frac{(N-G-U)p_m^{dl}\vartheta_m}{1+(\beta_m-\vartheta_m)\left(P_{un}+P_{mu}\right)}.$$

$$\mathrm{SINR}_{jk,mu}^{\mathrm{ZF}} = \frac{(N-G-U)q_j^{dl}\xi_{jk}}{1+(\eta_{jk}-\xi_{jk})(P_{un}+P_{mu})}.$$

- Optimal Resource Allocation

$$\mathcal{P}1: \underset{\{q_j^{dl}\},\{q_{jk}^{up}\},\tau}{\text{maximize}} \ \min_{j\in\mathcal{G},k\in\mathcal{K}_j} \mathrm{SE}_{jk,mu}^{\dagger}$$

$$s.t. \ \sum_{j=1}^{G} q_j^{dl} \leq P - P_{un}$$

$$0 \leq q_j^{dl}$$

$$0 \leq \tau q_{jk}^{up} \leq E_{jk}$$

$$\tau \in \{U+G,\ldots,T\}$$

$$\mathcal{P}2: \underset{\{p_m^{dl}\},\{p_m^{u}\},\tau}{\text{maximize}} \ \sum_{m=1}^{U} \alpha_m \mathrm{SE}_{m,un}^{\dagger}$$

$$s.t. \ \sum_{m=1}^{U} p_m^{dl} \leq P - P_{mu}$$

$$0 \leq p_m^{dl}$$

$$0 \leq \tau p_m^{up} \leq E_m$$

$$\tau \in \{U+G,\ldots,T\}$$

- Theorems to prove that, at the optimal point, all the multicast UTs attain the same SE

- Solutions to $\mathcal{P}1$ and $\mathcal{P}2$ are coupled in a conflicting manner
- To balance the two objectives, a MOOP is formulated

$$\mathcal{M}: \max_{\mathbf{x}} [O_{mu}(\mathbf{x}), O_{un}(\mathbf{x})]^T$$
$$s.t. \ \mathbf{x} \in \mathcal{X}$$

where

$$\mathcal{X} = \Big\{ \Big(\{q_j^{dl}\}, \{q_{jk}^{up}\}, \{p_m^{dl}\}, \{p_m^{up}\}, \tau\Big) \mid 0 \leq q_j^{dl}, 0 \leq \tau q_{jk}^{up} \leq E_{jk}, 0 \leq p_m^{dl}, \ 0 \leq \tau p_m^{up} \leq E_m,$$
$$P_{un} + P_{mu} \leq P, \tau \in \{U+G, \ldots, T\} \Big\}.$$

- Pareto boundary (System designer can choose any point based on the requirement)

### Theorem

*The MOOP (45) of the considered joint unicast and multi-group multicast massive MIMO system with either MRT or ZF precoding, does not have any weak Pareto optimal points and its strong Pareto boundary is analytically described by*

$$\mathcal{B}_s = \Big\{ (O_{mu}^*(P_{un}), O_{un}^*(P_{mu})) \mid P_{mu} + P_{un} = P, 0 \leq P_{mu} \leq P, 0 \leq P_{un} \leq P \Big\}.$$

*Moreover,* $(O_{mu}^*(P_{un}), O_{un}^*(P_{mu})) \in B_s$ *is achieved when* $(q_j^{dl*}, q_{jk}^{up*}, p_m^{dl*}, p_m^{up*}, \tau^*)$ *are obtained either from Theorems 1 and 3 for MRT precoding, or from Theorems 2 and 4 for ZF precoding.*

# Low-Complexity Statistically Robust Precoder/Detector Computation for Massive MIMO Systems - Mahdi Nouri Boroujerdi et al.

## Goal

- To design the precoder/detector in a massive MIMO system without the knowledge of the channel statistics

## Contributions

- Proposed a novel technique for designing precoding/detection matrices in a massive MIMO system based on the randomized Kaczmarz algorithm (KA)
- Extension of the randomized KA (used to solve the overdetermined (OD) set of linear equations (SLE)) to solve the underdetermined (UD) SLE and used it for massive MIMO applications
- Theoretical performance analysis
- Comparison of the performance with techniques based on random matrix theory and approximate message passing via numerical simulations
  - Comparable performance with low complexity
  - No knowledge of channel statistics

## Problem Statement

- To reduce the complexity of the detector/precoder computation in the massive MIMO system

- Kaczmarz Algorithm to solve $\mathbf{Aw} = b$

**Algorithm 1** Kaczmarz Algorithm

Initialize $\mathbf{w}^0$.
**for** $t = 0, 1, \ldots, T-1$ **do**
    Pick a row $r(t)$ of $\mathbf{A}$ denoted by the row vector $\mathbf{a}_{r(t)}^{\mathsf{H}}$.
        ▷ In [27], each row $i$ of the matrix $\mathbf{A}$ is selected randomly with the probability $\frac{\|\mathbf{a}_i\|^2}{\|\mathbf{A}\|_{\mathsf{F}}^2}$.
    Update $\mathbf{w}^t$ as $\mathbf{w}^{t+1} = \mathbf{w}^t + \frac{b_{r(t)} - \langle \mathbf{a}_{r(t)}, \mathbf{w}^t \rangle}{\|\mathbf{a}_{r(t)}\|^2} \mathbf{a}_{r(t)}$.
        ▷ After the update, $\langle \mathbf{a}_{r(t)}, \mathbf{w}^{t+1} \rangle = b_{r(t)}$, and $r(t)$-th equation is fulfilled.
**end for**

- Each Kaczmarz update obeys the minimum energy perturbation principle
    - At each iteration $t$, KA finds the closest vector $\mathbf{w}$ to the current solution $\mathbf{w}^t$ that satisfies the slected equation

$$\mathbf{w}^{t+1} = \arg\min_{\mathbf{w}} ||\mathbf{w} - \mathbf{w}^t||^2 \quad \text{s.t} < \mathbf{a}_{r(t)}, \mathbf{w} >= b_{r(t)} \tag{1}$$

Unified Mathematical Framework:

- Unified approach to analyze the performance of all variants of KA studied in this paper
- Convergence rate of KA depends on the choice of the probability distribution with which we choose the rows in each iteration
- Optimal probability distribution depends on the average gain of the matrix $\mathbf{A}$ (more details in the paper). But solving this is an SDP, whose complexity is of the same order as computing the precoder/detector matrices directly
- Suboptimal probability distribution chosen as $p_i = ||\mathbf{a}_i||^2/||\mathbf{A}||_F^2$
  - Convergence rate depends on the normalized minimum gain of the matrix $\mathbf{A}$ along the subspace spanned by the columns of $\mathbf{A}^H$

$$\kappa_{\mathcal{X}}(\mathbf{A}) = \min_{\mathbf{x}\in\mathcal{X},\mathbf{x}\neq 0} \frac{\|\mathbf{A}\mathbf{x}\|^2}{\|\mathbf{A}\|_F^2\|\mathbf{x}\|^2}$$

$$\mathbb{E}\left[\|\mathbf{x}^t - \mathbf{x}^*\|^2\right] \leq (1-\kappa_{\mathcal{X}}(\mathbf{A}))^t\|\mathbf{x}^0 - \mathbf{x}^*\|^2$$

Kaczmarz Algorithm for MMSE/ZF Detection:

- $\ell_2$ regularized least squares cost function $||\mathbf{Q}\mathbf{w}-\mathbf{y}||^2 + \xi||\mathbf{w}||^2$ can be written as $||\mathbf{B}\mathbf{w}-\mathbf{y}_0||^2$, where $\mathbf{B} = [\mathbf{Q}; \sqrt{\xi}\mathbf{I}_K]$ and $\mathbf{y}_0 = [\mathbf{y}; \mathbf{0}]$
- Inconsistent equations due to noise in the observations. Randomized KA will result in residual errors. To avoid that:

$$\widehat{\mathbf{y}}_0 = \mathbf{B}\widehat{\mathbf{s}} \overset{(i)}{=} \mathbf{B}(\mathbf{B}^H\mathbf{B})^{-1}\mathbf{B}^H\mathbf{y}_0 = \mathbf{B}(\mathbf{B}^H\mathbf{B})^{-1}\mathbf{Q}^H\mathbf{y}$$

$$\mathbf{B}^H\widehat{\mathbf{y}}_0 = (\mathbf{B}^H\mathbf{B})(\mathbf{B}^H\mathbf{B})^{-1}\mathbf{Q}^H\mathbf{y} = \mathbf{Q}^H\mathbf{y}, \tag{21}$$

- Solve the OD SLE $\mathbf{B}\hat{\mathbf{s}} = \hat{\mathbf{y}}_0$ to get the estimate $\hat{\mathbf{s}}$

# Downlink Performance of Superimposed Pilots in Massive MIMO Systems - Karthik Upadhya et al.

## Goal

- To investigate the downlink throughtput performance of a massive MIMO system that employs superimposed pilots (SP)[1] for channel estimation

## Contributions

- Closed-form expressions for the DL achievable rate when the LS channel estimates obtained from SP are employed in a matched filter (MF) precoder at the base station (BS)
- Relationship between staggered pilots and SP and derived the DL rate for the former scheme
- Derived expressions for the NMSE and compared it against the Bayesian-CRLB
- Hybrid system design (UEs transmit both regular pilots and SP) for the DL by minimizing the UL and DL interference

**System Model**: TDD, $L$ cells, $K$ single-antenna users per cell, BS with $M$ antennas

- Uplink

$$\boldsymbol{Y}_j = \sum_{\ell=0}^{L-1} \sum_{k=0}^{K-1} \sqrt{\mu_{\ell k}} \boldsymbol{h}_{j\ell k} \boldsymbol{s}_{\ell k}^T + \boldsymbol{W}_j$$

- Downlink

$$\widehat{d}_{jm} = \sqrt{\gamma} \sum_{\ell=0}^{L-1} \boldsymbol{h}_{\ell jm}^H \sum_{k=0}^{K-1} \sqrt{\nu_{\ell k}} \boldsymbol{g}_{\ell k} d_{\ell k} + w_{jm}$$

[1] Both pilots and data transmitted together

- Effect of pilot contamination on the downlink
  - Regular Pilots (Orthogonal pilots+non overlapping data)
    - Both the LS channel estimate NMSE and DL SINR (with MF precoding) doesn't depend asymptotically on the number of BS antennas (M)
  - Superimposed Pilots (Orthogonal pilots+overlapping data during the whole frame)
    - With an optimized pilot and data power allocation, NMSE reduces proportional to $\sqrt{M}$ and if cell reuse factor is more than that of the RP case, then the DL SINR is higher than that of DL SINR with RP (asymptotically)
  - Staggered Pilots (Orthogonal pilots+overlapping data only for the pilot duration)
    - Can achieve the asymptotic DL performance of RP with a reuse factor of SP with an overhead equivalent to that of RP (with a reuse factor of RP)
    - UL spectral efficiency of RP
- Hybrid System
  - RP outperforms SP when the UEs are close to the BS
  - Two sets of users that transmit RP and SP
  - Assumption is that users in RP and SP groups do not interfere with each other (Interference cancellation of RP users needs to be done if this assumption does not hold)
  - Optimization problem to partition the users into RP and SP groups (to minimize the UL and DL interference)
  - Greedy algorithm from an earlier reference extended to solve this problem

# Other Interesting Papers

1. Distributed Precoding Systems in Multi-Gateway Multibeam Satellites: Regularization and Coarse Beamforming
2. Sum-Rate Maximization Methods for Wirelessly Powered Communication Networks in Interference Channels
3. Bandwidth and Energy-Aware Resource Allocation for Cloud Radio Access Networks
4. A NOMA Scheme for a Two-User MISO Downlink Channel With Unknown CSIT
5. An Efficient Uplink Multi-Connectivity Scheme for 5G Millimeter-Wave Control Plane Applications
6. Interference Coordination for 3-D Beamforming-Based HetNet Exploiting Statistical Channel-State Information
7. Achievable Rate With 1-Bit Quantization and Oversampling Using Continuous Phase Modulation-Based Sequences