Interference Management via User Clustering in Two-Stage Precoder Design

Ayswarya Padmanabhan, Antti Tölli

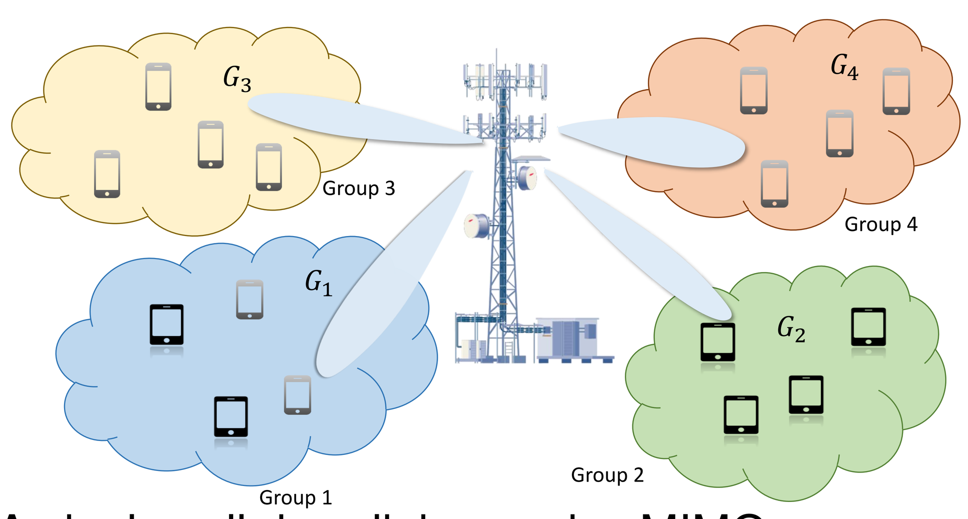
Centre for Wireless Communications (CWC), University of Oulu, Finland - FI-90014

ayswarya.padmanabhan@oulu.fi, antti.tolli@oulu.fi

1. Introduction and Motivation

- Massive MIMO is the key for efficient future communications.
- Downside of Massive MIMO is its Computational complexity.
- Focus: Fully Digital Two Stage Beamforming with outer beamformer (OBF) and an inner beamformer (IBF) [1].
- OBF forms pre-beams to different users propagation paths by effectively reducing channel dimensions.
- IBF applies spatial multiplexing on effective channel reduced dimension.

2. System Model



A single cell downlink massive MIMO

- N_T transmit antennas in ULA model.
- K single antennas users are clustered into G groups based on user statistics.
- $\mathcal{G} = \{1, \dots, G\}$ is the set of groups.
- $\mathcal{U}_g$ set of users in $g \in \mathcal{G}$
- $\mathcal{U} = \sum_{g \in \mathcal{G}} \mathcal{U}_g$

3. Outer beamformer (OBF) Design

1. Eigen Selection
   - Slow fading scenario where channel is constant for a period.
   - Eigen Vectors of channel covariance matrix forms the OBF.
     - Channel covariance matrix: $\mathbf{R} = \mathbb{E}[\mathbf{H}\mathbf{H}^{\mathrm{H}}]$.
     - Decomposing $\mathbf{R}$ using EVD: $\mathbf{R} = \mathbf{U}\mathbf{\Lambda}\mathbf{U}^{\mathrm{H}}$.
     - Choosing S_g columns of $\mathbf{U}$ denoted by $\mathbf{U}(S_g)$ and S_g largest Eigen values in diag$(\mathbf{\Lambda})$.

$$\mathbf{B}_g = \mathbf{U}(S_g) \in \mathbb{C}^{N_T \times S_g} \qquad (1)$$

     - OBF consists of S_g predominant spatial signature to user distribution.
2. Greedy Energy Maximization
   - As number of users increases the probability of finding a user in azimuthal direction follows uniform distribution $\theta_k \in [-\pi, \pi]$.
     - DFT beams helps multiplexing data in multiple high directional beams *i.e.,* N_T dimensional orthogonal basis Eigen vectors.
     - DFT matrix

$$\mathbf{D} = \frac{1}{\sqrt{N_T}} \left[\mathbf{1}, \mathbf{a}\left(\frac{2\pi}{N_T}\right) \dots, \mathbf{a}\left(\frac{2\pi \times (N_T - 1)}{N_T}\right) \right]. \qquad (2)$$

     - Using $\mathbf{D}$ OBF matrix $\mathbf{B}$ is designed by replacing the precise estimation of actual channel covariance $\mathbf{U}$.

$$\mathbf{D} = [\mathbf{d}_1, \dots, \mathbf{d}_S] \in \mathbb{C}^{N_T \times S}, S = \sum_{g \in \mathcal{G}} S_g. \qquad (3)$$

     - Energy is maximized by constructing one vector at a time from DFT vectors $\mathbf{D}$.
     - Aligning the precise channel covariance provides the strongest signal direction.

$$k = \underset{i}{\text{argmax}} \, (\mathbf{d}_i^{\mathrm{H}} \mathbf{R}_g \mathbf{d}_i), \; \forall i \in \mathcal{D}$$
$$\mathcal{B}_g = \mathcal{B}_g \cup \{k\}, \quad \mathcal{D} = \mathcal{D} \backslash \mathcal{B}_g. \qquad (4)$$

     - OBF matrix: $\mathbf{B}_g = [\mathbf{d}_{\mathcal{B}(1)}, \dots, \mathbf{d}_{\mathcal{B}(|\mathcal{B}|)}]$ provides orthogonal DFT beams.

4. IBF Design

To design IBF for each group with reduced dimensions

$$\underset{\mathbf{w}_k, \gamma_k}{\text{maximize}} \quad \sum_{g \in \mathcal{G}} \prod_{k \in \mathcal{U}_g} (1 + \gamma_k)^{\alpha_k} \qquad (5a)$$
$$\text{subject to} \quad \sum_{g \in \mathcal{G}} \sum_{k \in \mathcal{U}_g} \|\mathbf{B}_g \mathbf{w}_k\|^2 \le P_{tot} \qquad (5b)$$

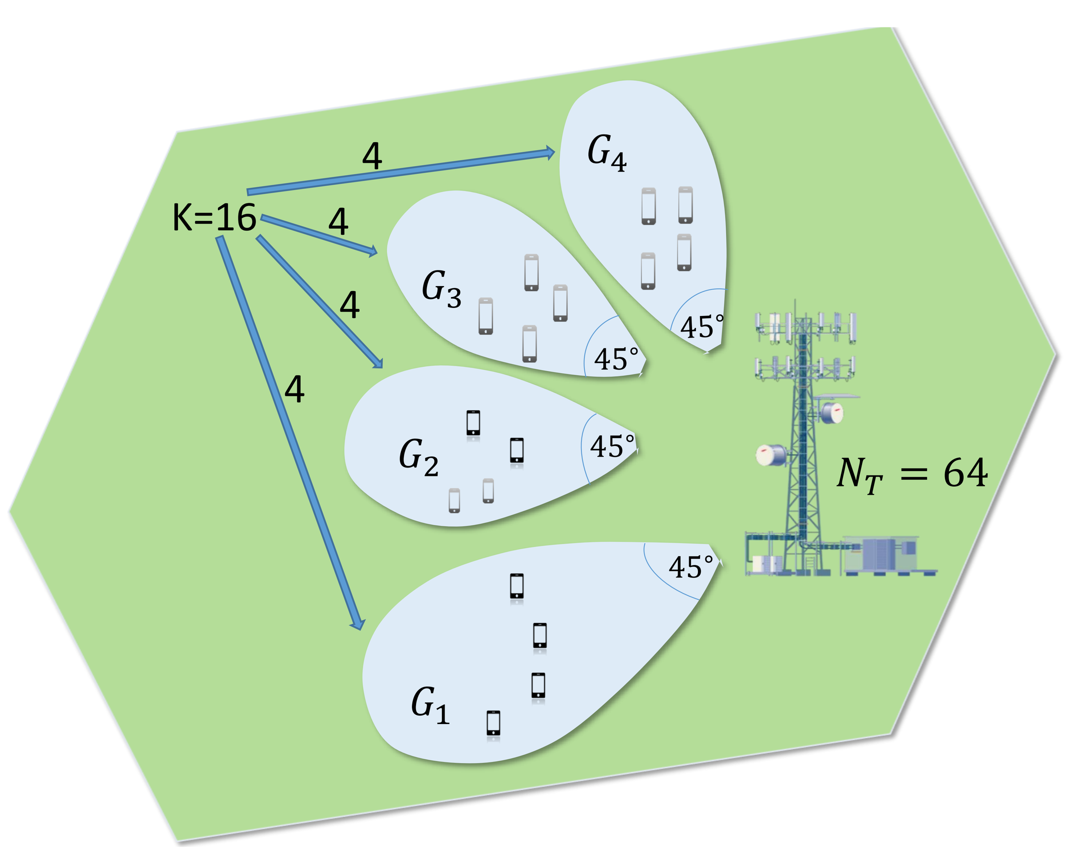
1. Centralized Design

   The inter group interference (IGI) terms from adjacent groups are treated as variables.

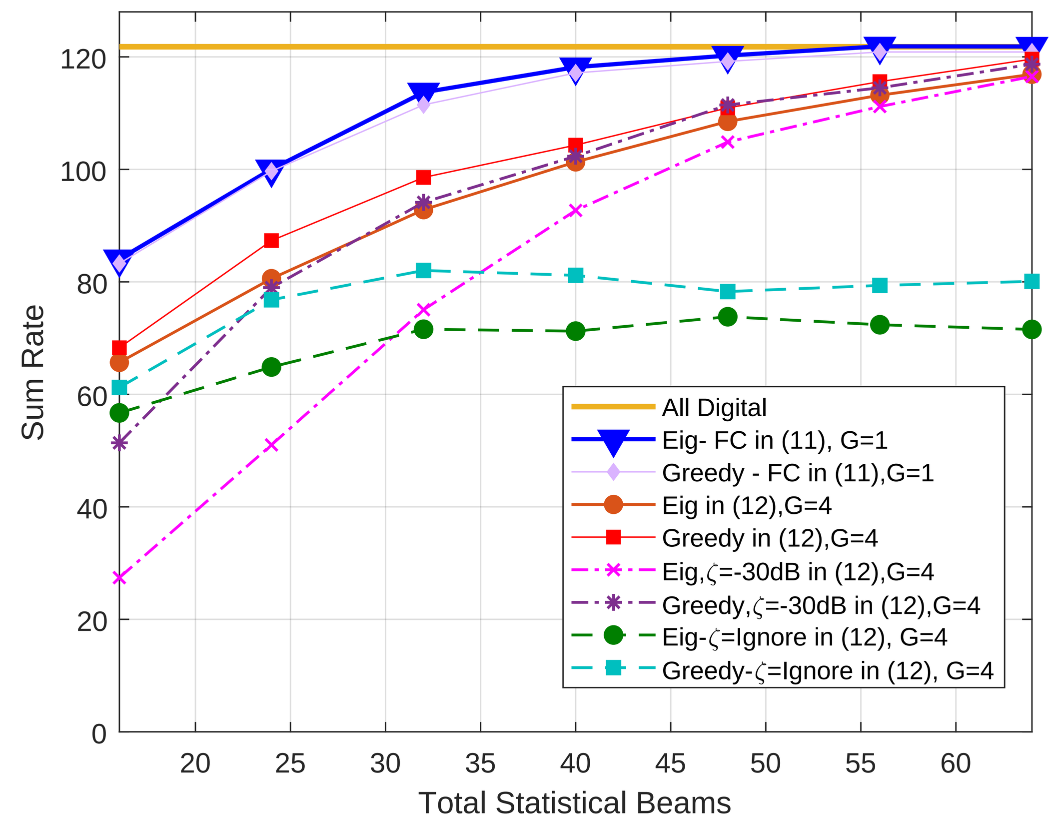
$$\underset{t_k, b_k, \mathbf{w}_k, \zeta_g}{\text{maximize}} \quad \sum_{g \in \mathcal{G}} \prod_{k \in \mathcal{U}_g} t_k \approxeq \prod_{k \in \mathcal{U}} t_k \qquad (6a)$$
$$\text{subject to} \quad \frac{|\mathbf{h}_k^{\mathrm{H}} \mathbf{B}_g \mathbf{w}_k|^2}{b_k} \ge t_k^{\frac{1}{\alpha_k}} - 1 \qquad (6b)$$
$$\sum_{i \in \mathcal{U}_g \backslash \{k\}} |\mathbf{h}_k^{\mathrm{H}} \mathbf{B}_g \mathbf{w}_k|^2 + \sum_{\bar{g} \in \mathcal{G} \backslash \{g\}} \zeta_{\bar{g}} + N_0 \le b_k \qquad (6c)$$
$$\sum_{j \in \mathcal{U}_{\bar{g}}} |\mathbf{h}_k^{\mathrm{H}} \mathbf{B}_{\bar{g}} \mathbf{w}_j|^2 \le \zeta_{\bar{g}}, \; \forall \bar{g} \in \mathcal{G} \backslash \{g\} \qquad (6d)$$
$$\sum_{g \in \mathcal{G}} \sum_{k \in \mathcal{U}_g} \|\mathbf{B}_g \mathbf{w}_k\|^2 \le P_{tot} \qquad (6e)$$

2. Decoupling the Inter-group Interference
   - Decouple the IGI terms by letting ζ_g in (6d) to a constant value.
   - By doing so, the optimization is carried out independently per sub group.
   - IGI is used for final SINR calculation

5. Numerical Results

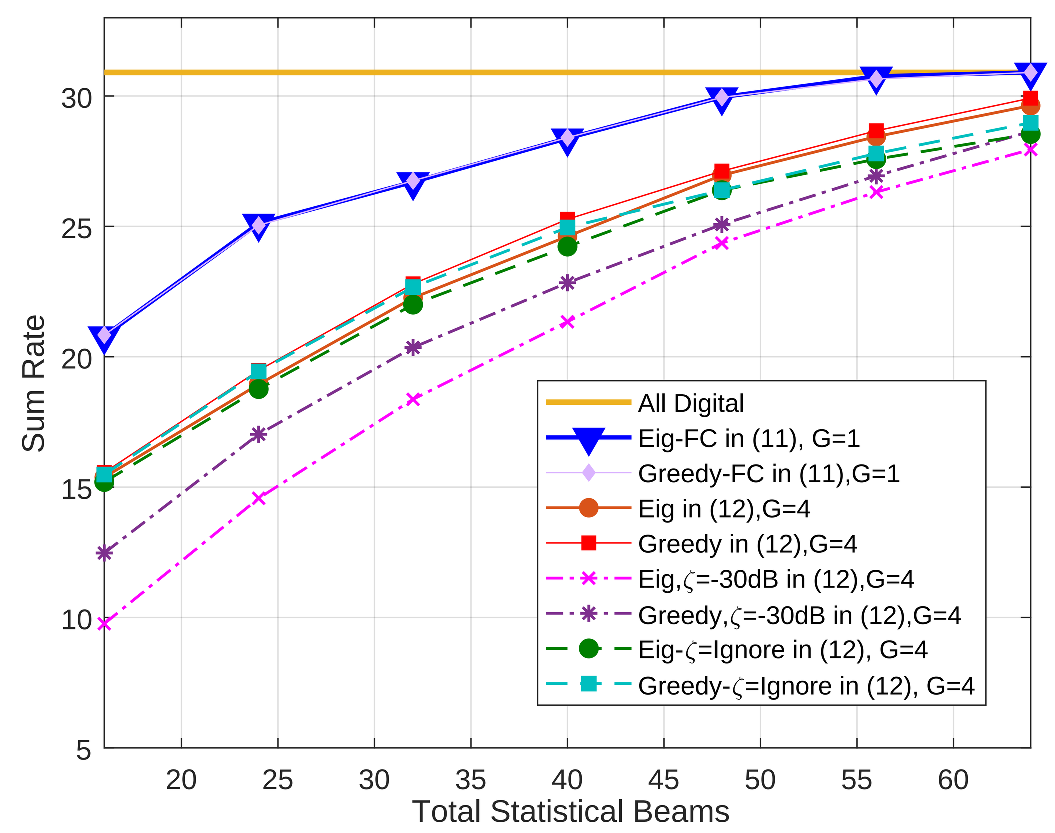


- The OBF is defined explicitly by the type of IBF.
  - The FC system is obtained by solving (6a), where all outer beams are utilized by IBF.
  - FC design: $G = 1$ and all group specific: $G = 4$.
  - $\zeta = -30$dB: IGI term is treated as constant.
  - ζ-ignore: ignoring IGI term.



Results

1. Figure. 3: A high power regime with 20dB
   - FC Eigen and greedy designs has superior performance.
   - $S_g = 16$: group specific beamformers and $S = 64$: FC almost similar performance.
   - Computational complexity is $(\frac{1}{(4)^3})$ of FC design.
   - Ignoring the IGI term the achievable sum rate is inferior.
   - Greedy maximization performs better in the group specific design compared to Eigen maximization.
2. Figure. 4: A low power regime with 0dB
   - Only a subset of users are served .
   - IGI has minimal impact on the total sum rate achieved.
   - All group specific schemes performs almost similar.
   - Difference from FC design is less.



6. Conclusion

- Interference management for fully digital two stage beamformer design was observed.
- Different methods to build the outer beamformer (OBF) namely, Eigen beam selection and greedy energy Maximization.
- Centralized and group specific IBF design discussed to manage the IGI.
- Greedy maximization performs better compared to the Eigen selection.

References

[1] A. Arvola, A. Tölli, and D. Gesbert, “Two-layer precoding for dimensionality reduction in massive MIMO,” in *24th European Signal Processing Conference (EUSIPCO), 2016.* IEEE, 2016, pp. 2000–2004.