MIMO - Final Project

Submission deadline: June 20, 23h59

For students assigned to **project-A**, please refer to the following papers:

[1] Q. Shi, M. Razaviyayn, Z. -Q. Luo and C. He, "An Iteratively Weighted MMSE Approach to Distributed Sum-Utility Maximization for a MIMO Interfering Broadcast Channel," in *IEEE Transactions on Signal Processing*, vol. 59, no. 9, pp. 4331-4340, Sept. 2011.

Basic assumptions and some parameters are given as follows (parameter settings are the same as in the paper):

- Number of transmit antennas T.
- Number of receive antennas R.
- Number of data streams d.
- Number of base stations K and serves I users per cell.
- Please implement the **WMMSE** algorithm.

Please answer the following questions.

(a) Plot the convergence properties, and discuss the simulation results. (Fig.1 in the paper)

  a) Consider the MIMO case $K = 4, T = 4, R = 2, I = 4, d = 4$, SNR = 30 dB.

  b) Consider the SISO case $K = 4, T = 1, R = 1, I = 4, d = 4$, SNR = 30 dB.

(b) Plot the average sum-rate versus SNR, where the SNR ranges from 5 to 30 in increments of 5. Please plot "WMMSE" and "WMMSE_10rand_int", each curve is averaged over 100 random channel realizations, and discuss the simulation results. (Fig.2 and Fig.3 in the paper)

  a) Consider the MIMO case $K = 3, T = 2, R = 2, I = 2, d = 4$.

  b) Consider the SISO case $K = 3, T = 1, R = 1, I = 2, d = 4$.

(c) Explain why the weighted sum-rate maximization problem and the sum-MSE minimization problem is equivalent .

(d) Consider the general utility maximization problem in the paper. What is the conditions of $u_{ik}(.)$, $c_{ik}(.)$, and $\gamma_{ik}(.)$. And according to the condition, please make an example of $u_{ik}(.)$.

(e) Based on this paper, what are some promising avenues for future research?

For students assigned to **project-B**, please refer to the following papers:

[2] O. E. Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi and R. W. Heath, ”Spatially Sparse Precoding in Millimeter Wave MIMO Systems,” in *IEEE Transactions on Wireless Communications*, vol. 13, no. 3, pp. 1499-1513, March 2014,

Basic assumptions and some parameters are given as follows (parameter settings are the same as in the paper):

- Number of clusters $N_{\mathrm{cl}} = 8$.
- Number of rays $N_{\mathrm{ray}} = 10$.
- Number of stream N_s.
- Angular spread: θ
- Number of RF chains at the transmitter and receiver, $N_{\mathrm{t}}^{\mathrm{RF}}, N_{\mathrm{r}}^{\mathrm{RF}}$.
- Please implement the comparison between **Sparse Precoding & Combining Algorithm** (Algorithm 1 & 2) and **Optimal Unconstrained Precoding**.

Perform the following simulations under different settings.

(a) Consider 64 × 16 mmWave system with planar arrays at the transmitter and receiver. Please compare the spectral efficiency (bit/s/Hz) as a function of SNR from -40dB to 0dB.

   a) Consider $N_s = 1, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4, \theta = 7.5°$
   b) Consider $N_s = 2, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4, \theta = 7.5°$
   c) Consider $N_s = 1, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 6, \theta = 7.5°$

(b) Please compare the spectral efficiency (bit/s/Hz) as a function of angle spread from $0° \sim 15°$.

   a) Consider 64 × 16 mmWave system with planar arrays at the transmitter and receiver. Consider $N_s = 1, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4,$ SNR = -5,0 dB, please plot in one figure.
   b) Consider 64 × 16, 256 × 64 mmWave system with planar arrays at the transmitter and receiver. Consider $N_s = 1, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4,$ SNR = 0 dB, please plot in one figure.
   c) Consider 64 × 16 mmWave system with planar arrays at the transmitter and receiver. Consider $N_s = 1, 2, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4,$ SNR = 0 dB , please plot in one figure.
   d) Consider 64 × 16 mmWave system with planar arrays at the transmitter and receiver. Consider $N_s = 1, N_{\mathrm{t}}^{\mathrm{RF}} = N_{\mathrm{r}}^{\mathrm{RF}} = 4, 6,$ SNR = 0 dB , please plot in one figure.

Please answer the following questions.

(a) Discuss all simulation results.

(b) Please explain why the authors assume the channel in this way, and draw a figure to illustrate

Algorithm 1 Spatially Sparse Precoding via Orthogonal Matching Pursuit

Require: $\mathbf{F}_{\text{opt}}$

$\mathbf{F}_{\text{RF}} = \text{Empty Matrix}$

$\mathbf{F}_{\text{res}} = \mathbf{F}_{\text{opt}}$

for $i \leq N_{\text{t}}^{\text{RF}}$ **do**

  $\boldsymbol{\Psi} = \mathbf{A}_t^* \mathbf{F}_{\text{res}}$

  $k = \arg\max_{\ell=1,\ \dots,\ N_{\text{cl}}N_{\text{ray}}} \left(\boldsymbol{\Psi}\boldsymbol{\Psi}^*\right)_{\ell,\ell}$

  $\mathbf{F}_{\text{RF}} = \left[\mathbf{F}_{\text{RF}} | \mathbf{A}_t^{(k)}\right]$

  $\mathbf{F}_{\text{BB}} = \left(\mathbf{F}_{\text{RF}}^* \mathbf{F}_{\text{RF}}\right)^{-1} \mathbf{F}_{\text{RF}}^* \mathbf{F}_{\text{opt}}$

  $\mathbf{F}_{\text{res}} = \frac{\mathbf{F}_{\text{opt}} - \mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}}{\|\mathbf{F}_{\text{opt}} - \mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}\|_F}$

end for

$\mathbf{F}_{\text{BB}} = \sqrt{N_{\text{s}}} \frac{\mathbf{F}_{\text{BB}}}{\|\mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}\|_F}$

return $\mathbf{F}_{\text{RF}}$, $\mathbf{F}_{\text{BB}}$

Fig. 1: Algorithm 1

the channel model:

$$\mathbf{H} = \gamma \sum_{i,\ell} \alpha_{i\ell} \Lambda_{\text{r}}(\phi_{i\ell}^{\text{r}}, \theta_{i\ell}^{\text{r}}) \Lambda_{\text{t}}(\phi_{i\ell}^{\text{t}}, \theta_{i\ell}^{\text{t}}) \mathrm{a}_{\text{r}}(\phi_{i\ell}^{\text{r}}, \theta_{i\ell}^{\text{r}}) \mathrm{a}_{\text{t}}(\phi_{i\ell}^{\text{t}}, \theta_{i\ell}^{\text{t}})^*, \quad (1).$$

(c) Answer the following questions about precoding algorithm:

a) Explain why the author can approximate problem (15) to problem (16).

b) Consider the algorithm in Fig. 1. Given the channel matrix $\mathbf{H}$. What is the optimal unconstrained unitary precoder for $\mathbf{H}$? Write the answer step-by-step. You can use python or MATLAB, but you need to provide the code.

$$H = \begin{bmatrix} 2.566 & 0.883 & 2.566 \\ 1.033 & 2.748 & 1.033 \\ -1.161 & -1.634 & -1.161 \end{bmatrix}$$

(d) Explain why algorithm 2 can solve problem (24).

(e) Based on this paper, what are some promising avenues for future research?