Downlink Multi-User MIMO for IEEE 802.16m

Sivakishore Reddy
Naga Sekhar

Centre of Excellence in Wireless Technology

2013

Outline

Outline

MIMO Introduction

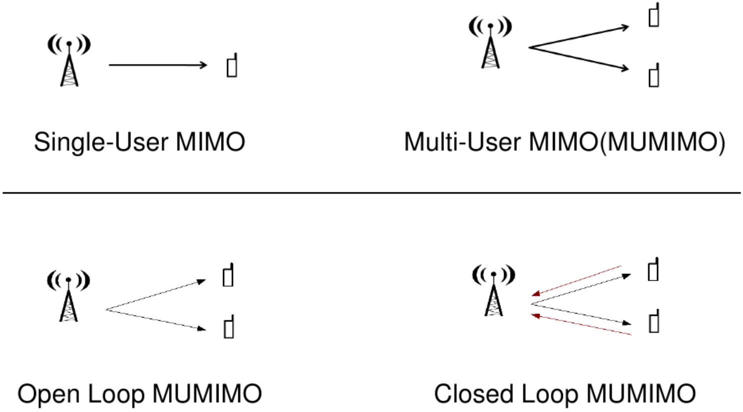


Figure: MIMO Systems

SU-MIMO vs MU-MIMO

Single User MIMO :

- Promises reliability and channel capacity through diversity gain and rate maximization.
- Mainly acts as physical(PHY) layer performance booster.

Multi User MIMO :

- Uses spatial degrees of freedom to schedule multiple users to simultaneously share the spatial channel.
- Optimum design strategy to increase the system capacity.

Requirements of MU-MIMO :

- Requires Channel State Information.
    - Partial CSI.
    - Codebook based precoding.
- Requires more complex scheduling algorithms.
- Requires advanced transceiver methodologies.

Outline

System model

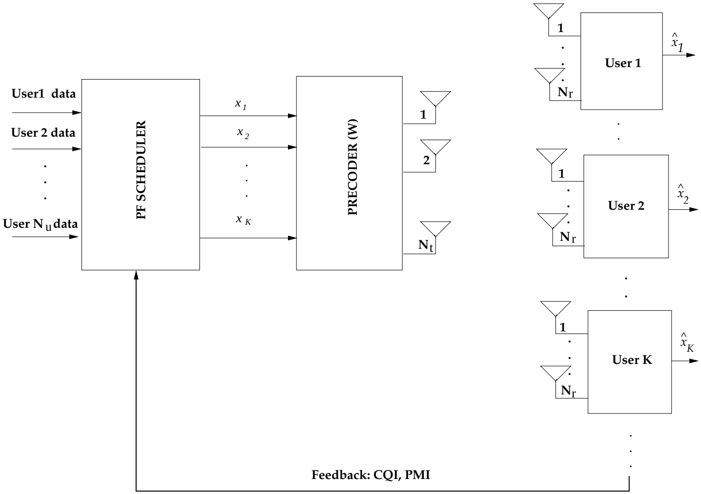


Figure: MU-MIMO System model

Notation

- N_t : No.of antennas at the BS.
- N_r : No.of antennas at the MS/user.
- N_u : No.of users contending for resource unit.
- K : No.of users served per resource unit.
- **H** : $N_r \times N_t$ desired channel matrix.
- **G** : $N_r \times N_t$ interfering co-channel matrix.
- **W** : $N_t \times K$ precoder.
- **v** : $N_t \times 1$ precoding vector chosen from codebook.
- I : Number of strong interferers.

About Codebook based precoding

- In 16m Codebook is defined for a given MIMO setup.
- $\mathbf{W} = \begin{bmatrix} \mathbf{v}_1 & \mathbf{v}_2 & \dots & \mathbf{v}_K \end{bmatrix}_{N_t \times K}$
- The $N_r \times 1$ received signal vector at the k^{th} MS :

$$\begin{aligned} \mathbf{y}_k &= \mathbf{H}_k \mathbf{W} \mathbf{x} + \mathbf{n}_k \ , \qquad k \in \{1, 2, \dots, K\} \\ &= \sqrt{\frac{P}{K}} \mathbf{H}_k \mathbf{v}_k x_k + \sqrt{\frac{P}{K}} \sum_{i \neq k, i=1}^{K} \mathbf{H}_k \mathbf{v}_i x_i + \mathbf{n}_k \end{aligned}$$

Desired signal IUI Noise

$$\mathbf{x} = \begin{bmatrix} \sqrt{\frac{P}{K}} x_1 & \sqrt{\frac{P}{K}} x_2 & \dots & \sqrt{\frac{P}{K}} x_K \end{bmatrix}_{K \times 1}^T$$

CL-MUMIMO PROBLEM STATEMENT

- How should each user make his choice for the **PMI**?
- How should each user model his **CQI**?
- How should the BS use this **feedback-info** to **schedule multiple users** per data region?

Choose PMI to minimize MSE

MUMIMO Equation :

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{W}\mathbf{x} + \sum_{i=1}^{I} \mathbf{G}_i \mathbf{W}'_i \mathbf{z}_i + \mathbf{n}_k$$

MSE for i^{th} precoding vector is :

$$\begin{aligned} MSE_i &= E(x_s - \hat{x_s})^2 \\ &= \sigma_{x_s}^2 - \mathbf{v}_i^* \mathbf{H}_k^* \left[\mathbf{H}_k \mathbf{W}\mathbf{W}^* \mathbf{H}_k^* + \mathbf{I}_{cov} + \sigma^2 \mathbf{I} \right]^{-1} \mathbf{H}_k \mathbf{v}_i \end{aligned}$$

$$\mathbf{I}_{cov} = \sum_{i=1}^{I} \mathbf{G}_i \mathbf{W}'_i \mathbf{W}'^*_i \mathbf{G}_i^*$$

If **W** is unitary,

$$\begin{aligned} MSE_i &= \sigma_{x_s}^2 - \mathbf{v}_i^* \mathbf{H}_k^* \left[\mathbf{H}_k \mathbf{H}_k^* + \mathbf{I}_{cov} + \sigma^2 \mathbf{I} \right]^{-1} \mathbf{H}_k \mathbf{v}_i \\ \mathbf{PMI} &= arg \min_i \left(\sum_{\forall subcarriers} MSE_i \right) \end{aligned}$$

CQI modeling

Receiver uses an MMSE filter **b**,

$$\mathbf{b}_k^*\mathbf{y}_k = \mathbf{b}_k^*\mathbf{H}_k\mathbf{v}_k x_k + \sum_{i\neq k, i=1}^{K} \mathbf{b}_k^*\mathbf{H}_k\mathbf{v}_i x_i + \sum_{i=1}^{I} \mathbf{b}_k^*\mathbf{G}_i\mathbf{W}_i'\mathbf{z}_i + \mathbf{b}_k^*\mathbf{n}_k$$

$$\mathbf{CQI} = \frac{|\mathbf{b}_k^*\mathbf{H}_k\mathbf{v}_k|^2}{\sum_{i\neq k, i=1}^{K} |\mathbf{b}_k^*\mathbf{H}_k\mathbf{v}_k|^2 + \mathbf{b}_k^*(I_{cov} + \sigma^2 I)\mathbf{b}_k}$$

where $\mathbf{I}_{cov} = \sum_{i=1}^{I} \mathbf{G}_i\mathbf{W}_i'\mathbf{W}_i'^*\mathbf{G}_i^* = \sum_{i=1}^{I} \mathbf{G}_i\mathbf{G}_i^*$

MUMIMO PF-Scheduler

- Find all possible pairs of users who have reported orthogonal PMI.
- Find sum-PF-metric for each pair.
- Schedule pair with maximum sum-PF-metric.

Outline

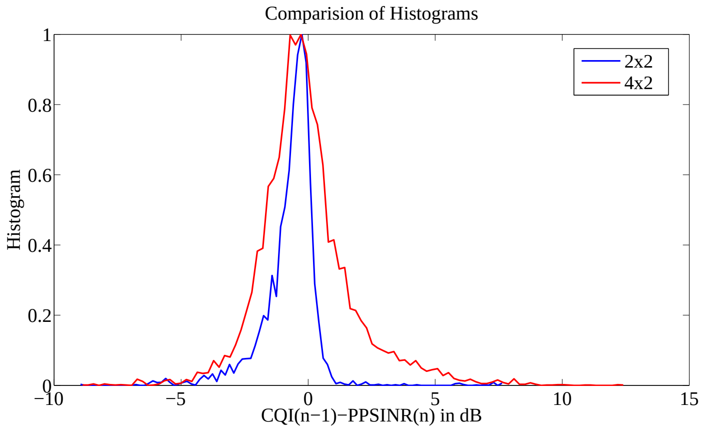
Unitary vs Non-Unitary Precoders

The covariance term which influence CQI :

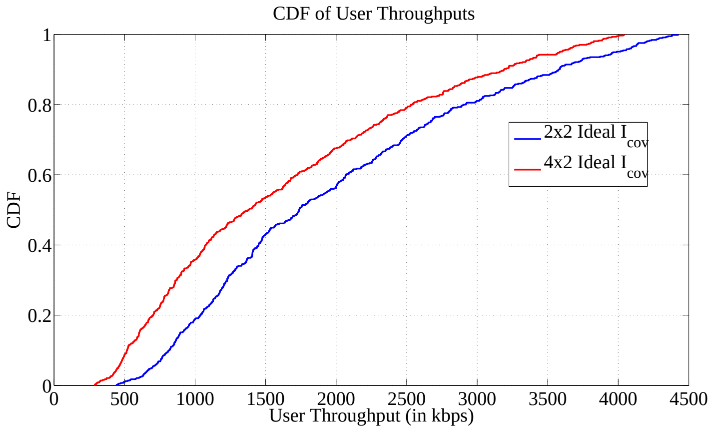
$$I_{cov} = \sum_{i=1}^{I} \mathbf{G}_i \mathbf{W}'_i \mathbf{W}'^*_i \mathbf{G}^*_i$$

- If the precoder **W** is not unitary, the interference level may change from one frame to another frame as the precoders used changes.
- So the CQI of 2x2 is stable compared to 4x2 as the precoders of 4x2 system are non-unitary.

CQI Stability



2x2 vs 4x2



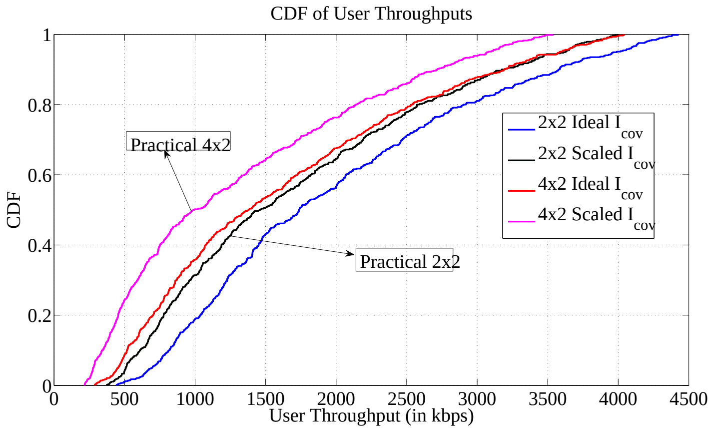
CDF of User Throughputs
1
0.8
0.6
0.4
0.2
0
CDF
0
500
1000
1500
2000
2500
3000
3500
4000
4500
User Throughput (in kbps)
2x2 Ideal I cov
4x2 Ideal I cov

Practical Implications in Closed loop system

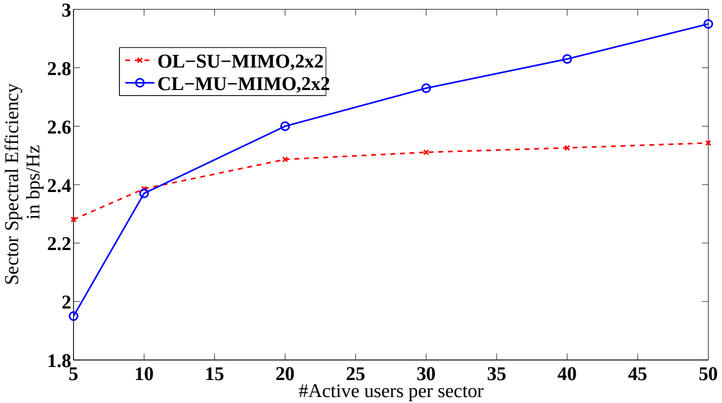
- The mimo modes of interfering users can change in closed loop region.
- The calculation of CQI which involves I_{cov} cannot be perfectly determined.
- The PMI decision term also involves I_{cov} is also not perfect.
- In demodulation, if the mimo mode of CCI is different it is difficult to even estimate the interference covariance at the reciever. Thus degrading the performance further.

The PMI and CQI fedback are IMPERFECT and reduces the capacity.

CL-MUMIMO

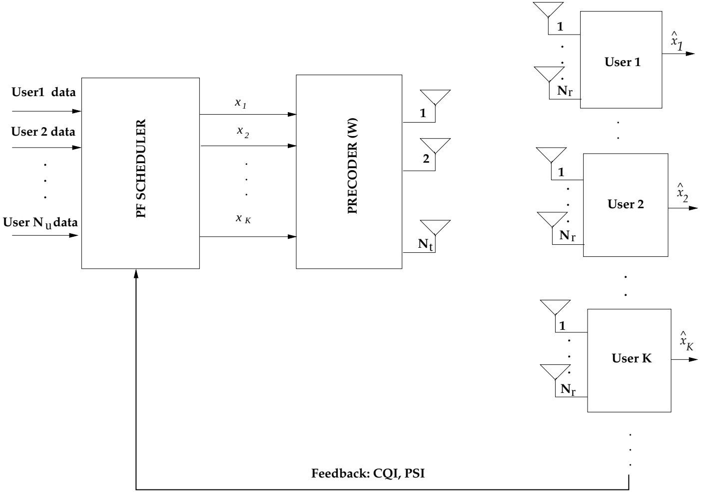

CDF of User Throughputs
CDF
User Throughput (in kbps)
0
0.2
0.4
0.6
0.8
1
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Practical 4x2
Practical 2x2
2x2 Ideal I cov
2x2 Scaled I cov
4x2 Ideal I cov
4x2 Scaled I cov

CL-MU-MIMO vs OL-SU-MIMO



Outline

Open Loop MU-MIMO System Model



Open Loop Multi-User MIMO

- Precoders are fixed a priori.
- $\mathbf{W} = \begin{bmatrix} \mathbf{v}_1 & \mathbf{v}_2 & \dots & \mathbf{v}_K \end{bmatrix}_{N_t \times K}$
- Each user feedbacks preferred stream index (PSI) and CQI.
- $PSI \in \{1, 2, \dots, K\}$.
- PF scheduler will serve set of K users who feedback $PSIs$ $\{1, 2, \dots, K\}$.

Open Loop Region

Inside Open Loop Region :

- All the base stations will use same MIMO mode.
- Creates stable interference environment.
- Estimation of CCI is easy and accurate.
- Covariance matrix is calculated using estimated precoded channels.

Received signal

The $N_r \times 1$ received signal vector at the k^{th} MS :

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{W} \mathbf{x} + \sum_{i=1}^{8} \mathbf{G}_{ik} \mathbf{W} \mathbf{x}'_{ik} + \mathbf{n}_k \;, \qquad k \in \{1, 2, \ldots, K\}$$

$$= \sqrt{\frac{P}{K}} \mathbf{H}_k \mathbf{v}_k x_k + \sqrt{\frac{P}{K}} \sum_{i \neq k, i=1}^{K} \mathbf{H}_k \mathbf{v}_i x_i + \sum_{i=1}^{8} \mathbf{G}_{ik} \mathbf{W} \mathbf{x}'_{ik} + \mathbf{n}_k$$

Desired signal — IUI — CCI — Noise

$$\mathbf{x} = \begin{bmatrix} \sqrt{\frac{P}{K}} x_1 & \sqrt{\frac{P}{K}} x_2 & \ldots & \sqrt{\frac{P}{K}} x_K \end{bmatrix}^T_{K \times 1}$$

Covariance matrix and MMSE filter

- The Covariance matrix of CCI $(\mathbf{K}_{CCI})$:

$$\mathbf{K}_{CCI} = \left(\frac{P}{K}\right) \sum_{i=1}^{8} \mathbf{G}_{ik} \mathbf{W}\mathbf{W}^{*} \mathbf{G}_{ik}^{*}$$

- $1 \times N_r$ MMSE filter equation for k^{th} user :

$$\mathbf{b}_k = (\mathbf{H}_k \mathbf{v}_k)^* \left[\tilde{\mathbf{H}}_k \tilde{\mathbf{H}}_k^* + \frac{K}{P} \mathbf{K}_{CCI} + \frac{K N_o}{P} \mathbf{I}_{N_r} \right]^{-1}$$

where $\tilde{\mathbf{H}}_k = \mathbf{H}_k \mathbf{W}$.

SINR Calculation

$$\hat{x}_k = \mathbf{b}_k \mathbf{y}_k$$
$$= \sqrt{\frac{P}{K}} \mathbf{b}_k \mathbf{H}_k \mathbf{v}_k x_k + \sqrt{\frac{P}{K}} \sum_{i \neq k, i=1}^{K} \mathbf{b}_k \mathbf{H}_k \mathbf{v}_i x_i + \sum_{i=1}^{8} \mathbf{b}_k \mathbf{G}_{ik} \mathbf{W} \mathbf{x}'_{ik} + \mathbf{b}_k \mathbf{n}_k$$

$$SINR_k = \frac{\left(\frac{P}{K}\right) |\mathbf{b}_k \mathbf{H}_k \mathbf{v}_k|^2}{IUI_k + CCI_k + \|\mathbf{b}_k\|^2 N_o}$$

$$IUI_k = \left(\frac{P}{K}\right) \sum_{i \neq k, i=1}^{K} |\mathbf{b}_k \mathbf{H}_k \mathbf{v}_i|^2$$

$$CCI_k = \mathbf{b}_k \mathbf{K}_{CCI} \mathbf{b}^*_{k,l}$$

CQI and PSI Computation

$$\mathbf{W} = \begin{bmatrix} \mathbf{v}_1 & \mathbf{v}_2 & \dots & \mathbf{v}_K \end{bmatrix}_{N_t \times K}$$

$$SINR_{k,l} = \frac{\left(\frac{P}{K}\right) |\mathbf{b}_k \mathbf{H}_k \mathbf{v}_l|^2}{IUI_l + CCI_k + \|\mathbf{b}_k\|^2 N_o}$$

$$PSI_k = arg \max_{l} SINR_{k,l}$$

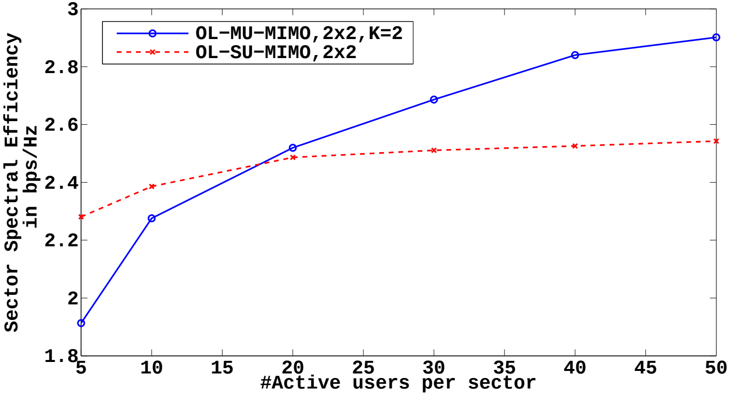
$$CQI_k = SINR_{k,PSI_k}$$

Open Loop Single-User MIMO

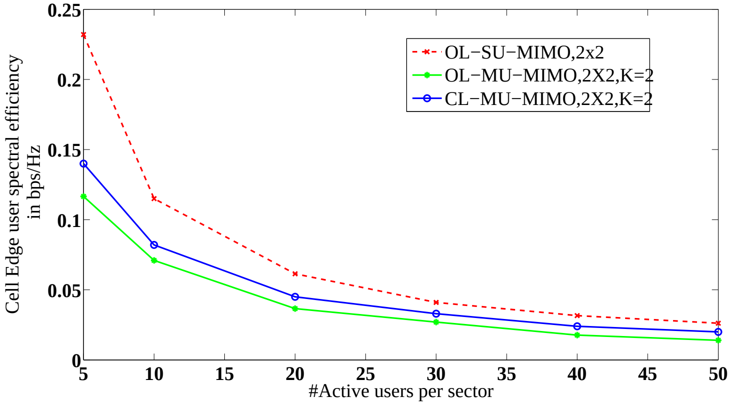
- Single user with single stream is scheduled.
- No orthogonal pairing problem.
- Better Cell edge user performance than MU-MIMO.

Outline

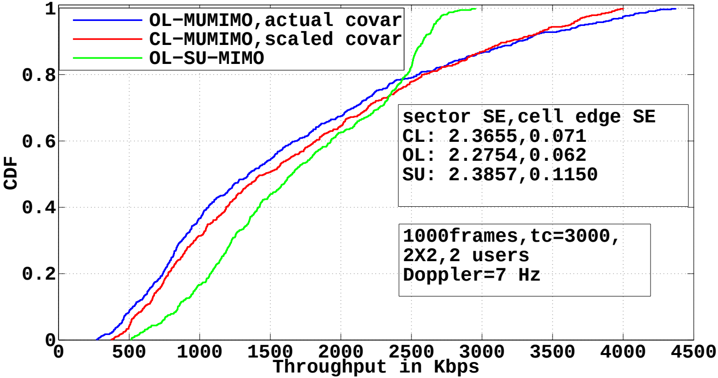
OL-MU-MIMO vs OL-SU-MIMO



OL-MU-MIMO vs OL-SU-MIMO contd...



OL-MU-MIMO, CL-MU-MIMO and OL-SU-MIMO Comparison



Sector Spectral Efficiency variation for OL-MU-MIMO :

N_u	$4 \times 4, K = 2$	$4 \times 4, K = 3$	$4 \times 4, K = 4$
5	4.1905	3.2062	2.2163
10	4.4942	3.9944	3.0491
50	4.9806	5.2304	5.4579

Table: Sector Spectral Efficiency for 4×4 OL-MU-MIMO.

Convergence of OL-MU-MIMO and CL-MU-MIMO

- When there are large number of active users per sector both OL-MU-MIMO and CL-MU-MIMO will perform similarly.

Outline

Conclusions

- MU-MIMO system achieves higher throughput when compare to single user system.
- MU-MIMO system has slightly more FER when compare to single user system.
- Optimum number of users (with single stream per user) that can be scheduled in a dataregion to achieve maximum throughput is equal to $min\,(N_t, N_r)$.
- FER and throughput of the system improves as $min\,(N_t, N_r)$ increases.

THANK YOU

ANY QUESTIONS ?