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## 1 Introduction

We consider a multi-user multi-input-multi-output (MU-MIMO) downlink channel where the eNodeB may schedule several user terminals on the same sub-band. As per the dimensioning agreement [1], each scheduled user is served a single data stream using beamforming or two data streams using rank-2 precoding. Each active user reports a preferred matrix index (PMI) (per sub-band) to the eNodeB, which is an index that identifies either a particular vector in a codebook of unit norm vectors or a particular matrix in a codebook of semi-unitary matrices. In addition, as per the double codebook structure the user can also report a wideband PMI [1]. The codebooks are known in advance to the eNodeB as well as all users. Each user also reports up-to two channel quality indices (CQIs) (per sub-band) which are its estimates of the signal-to-interference-plus-noise ratios (SINRs) on that sub-band. The reported PMIs and CQIs are then employed by the eNodeB to determine a suitable set of scheduled users, their transmit precoders and their assigned rates. The key practical problem in MU-MIMO is that when computing its PMI and CQIs, a user does not have an accurate estimate of the interference it might see (if scheduled) from the signals intended for the other co-scheduled users. This results in a mismatch between the user reported SINRs and the ones it actually observes in the aftermath of scheduling. In [2] it is shown that reducing this mismatch is critical for achieving MU-MIMO gains.

*To alleviate this problem we consider informing each user (in a slow or semi-static manner) about an estimate of (or an upper bound on) the total number of streams that the*

*eNodeB expects to co-schedule on a sub-band.* A related proposal [6] suggests reference rank indication for improving the accuracy of CQI computation. In addition, the indication of the expected total number of streams to a user can also be accompanied by a suggested rank for that user. We recall that slow rank adaptation was also recommended in [9] for MU-MIMO. We suggest useful SINR formulas that can use such parameters and show that the mismatch problem is mitigated to a large extent. In this context, we note that [7] (see also [8]) proposed a modified CQI calculation for MU-MIMO which always assumes a unitary matrix as the eNodeB (transmit) precoder. Further, we also consider best-companion PMI feedback that was suggested in [11] to reduce the post-scheduling interference seen by the user.

This document is an updated re-submission of [12].

## 2 PMI Selection and CQI computation Rules

Consider the narrowband received signal model at a user terminal of interest that is equipped with  $N$  receive antennas and where the eNodeB has  $M$  transmit antennas,

$$\mathbf{y} = \mathbf{H}^\dagger \mathbf{x} + \boldsymbol{\eta}, \quad (1)$$

where  $\mathbf{H} \in \mathbb{C}^{M \times N}$  is the channel matrix and  $\boldsymbol{\eta} \sim \mathcal{CN}(\mathbf{0}, \mathbf{I})$  is the additive noise. The signal vector  $\mathbf{x}$  transmitted by the eNodeB can be expanded as

$$\mathbf{x} = \sum_{k \in \mathcal{U}} \mathbf{V}_k \mathbf{s}_k \quad (2)$$

where  $\mathcal{U}$  is the set of users that are scheduled.  $\mathbf{V}_k$  is an  $M \times r_k$  semi-unitary matrix with  $\mathbf{V}_k^\dagger \mathbf{V}_k = \mathbf{I}_{r_k}$  and  $\mathbf{s}_k$  is the  $r_k \times 1$  symbol vector corresponding to user  $k \in \mathcal{U}$ . Further, let  $S = \sum_{k \in \mathcal{U}} r_k$  be the total number of streams that are co-scheduled. Each scheduled stream is assigned an identical power  $\rho'$ . The set of precoding matrices or vectors  $\{\mathbf{V}_k\}_{k \in \mathcal{U}}$  are

determined by first selecting a set  $\mathcal{U}$  of users that have reported mutually (near-)orthogonal matrices or vectors  $\{\mathbf{G}_k\}_{k \in \mathcal{U}}$  and which also yield a high weighted sum rate. The eNodeB can then either set  $\mathbf{V}_k = \mathbf{G}_k \forall k \in \mathcal{U}$  or it can perform a modified version of the block diagonalization technique proposed in [3] on  $\{\mathbf{G}_k\}_{k \in \mathcal{U}}$  to determine  $\{\mathbf{V}_k\}_{k \in \mathcal{U}}$ .

The user of interest can estimate  $\rho' \mathbf{H}$ . We will assume that the user of interest also has an estimate of  $S$  available. In practise, the eNodeB can convey an estimate of  $S$  (or an upper bound on  $S$ ) to a user in a semi-static manner and such an estimate can be user-specific. The user then uses its estimates of  $\rho' \mathbf{H}$  and  $S$  in the following formulas to select PMIs and compute SINRs.

### 3 PMI Selection and SINR computation

We first consider the case when the user reports one PMI along with one or more CQIs per sub-band (each based on a computed SINR). In general the PMI can correspond to a precoder of rank  $r$ , where  $1 \leq r \leq \min\{M, N\}$ . In the scenario where fast-rank adaptation is allowed in MU-MIMO, the user can determine the best precoder for each value of  $r$  and then select the one which yields the overall highest rate. In the case where only slow rank adaptation is allowed, the user selects precoder matrices of a common rank for several consecutive frames and the eNodeB can possibly inform the user about a suitable rank in a semi-static manner.

Next, in order to determine a suitable semi-unitary matrix  $\hat{\mathbf{G}}_r$  from a set or codebook of rank- $r$  semi-unitary matrices,  $\mathcal{C}_r$ , along with up-to  $r$  SINRs, the user of interest can use the following rules. The key feature of the rules derived below is that they attempt to account for the interference due to signals intended for the co-scheduled users and maximize a bound on the expected SINR or the expected capacity. These rules are derived by leveraging some key random matrix distribution results developed in [3]. Note that the codebook of semi-unitary matrices could itself be obtained after transformation of a base codebook [10].

- Capacity Metric: The PMI is selected as follows:

$$\begin{aligned}\hat{\mathbf{G}}_r &= \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \ln \left| \mathbf{I} + \rho' \mathbf{G}^\dagger \mathbf{H} (\mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H})^{-1} \mathbf{H}^\dagger \mathbf{G} \right| \right\} \\ &= \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right| - \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} \right| \right\}\end{aligned}\quad (3)$$

where  $\tilde{\rho} = \frac{\rho'(S-r)}{M-r}$ .

- MMSE based receiver: A PMI is selected after determining  $r$  SINRs for each matrix in  $\mathcal{C}_r$ . We let  $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_r]$ .

$$\hat{\mathbf{G}}_r = \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \sum_{j=1}^r \ln \left( 1 + \text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}) \right) \right\} \quad (4)$$

where

$$\text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}) = \frac{\rho' \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger \mathbf{H} + (\rho' - \tilde{\rho}) \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j}{1 - \rho' \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger \mathbf{H} + (\rho' - \tilde{\rho}) \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j} \quad (5)$$

- SIC receiver: A PMI is selected after determining  $r$  SINRs for each matrix in  $\mathcal{C}_r$ . We let  $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_r]$  and suppose the order of decoding to be  $\{1, \dots, r\}$ .

$$\hat{\mathbf{G}}_r = \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \sum_{j=1}^r \ln \left( 1 + \text{SINR}_{j,r}^{\text{SIC}}(\mathbf{G}) \right) \right\} \quad (6)$$

where

$$\text{SINR}_{j,r}^{\text{SIC}}(\mathbf{G}) = \frac{\rho' \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} + \rho' \mathbf{H}^\dagger \sum_{q=j}^r \mathbf{g}_q \mathbf{g}_q^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j}{1 - \rho' \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} + \rho' \mathbf{H}^\dagger \sum_{q=j}^r \mathbf{g}_q \mathbf{g}_q^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j} \quad (7)$$

Note that using the chain rule

$$\sum_{j=1}^r \ln \left( 1 + \text{SINR}_{j,r}^{\text{SIC}}(\mathbf{G}) \right) = \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right| \\ - \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{G} \mathbf{G}^\dagger) \mathbf{H} \right|$$

so that an optimal PMI can be computed using (3) and then  $r$  SINRs can be computed for the  $\hat{\mathbf{G}}_r$  so determined.

- Single unified SINR for MMSE receiver when  $r > 1$ : A PMI is selected after determining one SINR for each matrix in  $\mathcal{C}_r$ . We let  $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_r]$ .

$$\hat{\mathbf{G}}_r = \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \ln \left( 1 + \text{SINR}_r^{\text{MMSE}}(\mathbf{G}) \right) \right\} \quad (8)$$

where

$$\ln \left( 1 + \text{SINR}_r^{\text{MMSE}}(\mathbf{G}) \right) = \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger \mathbf{H} + (\rho' - \tilde{\rho}) \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right| \\ - \ln \left| \mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger \mathbf{H} + \left( \frac{\rho'(r-1)}{r} - \tilde{\rho} \right) \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} \right|$$

The following two special cases are particularly important

- Rank-1 or beamforming with  $r = 1$ . In this case an optimal vector  $\hat{\mathbf{g}}_1 \in \mathcal{C}_1$  is selected and only one SINR (per vector) is computed. Specializing either (4) or (6) to this case, we have

$$\hat{\mathbf{g}}_1 = \arg \max_{\mathbf{g} \in \mathcal{C}_1} \left\{ \text{SINR}_{1,1}^{\text{MMSE}}(\mathbf{g}) \right\} \quad (9)$$

where

$$\text{SINR}_{1,1}^{\text{MMSE}}(\mathbf{g}) = \rho' \mathbf{g}^\dagger \mathbf{H} (\mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger (\mathbf{I} - \mathbf{g} \mathbf{g}^\dagger) \mathbf{H})^{-1} \mathbf{H}^\dagger \mathbf{g}$$

with  $\tilde{\rho} = \frac{\rho'(S-1)}{M-1}$ . The rule given in (9) was derived in [4] and was shown to be very effective in [5]. It can be shown that the rule in (9) is equivalent to the following rule that is much simpler to compute.

$$\hat{\mathbf{g}}_1 = \arg \max_{\mathbf{g} \in \mathcal{C}_1} \left\{ \mathbf{g}^\dagger \mathbf{H} (\mathbf{I} + \tilde{\rho} \mathbf{H}^\dagger \mathbf{H})^{-1} \mathbf{H}^\dagger \mathbf{g} \right\} \quad (10)$$

- Rank-2 or precoding with  $r = 2$ . In this case an optimal matrix  $\hat{\mathbf{G}}_2 \in \mathcal{C}_2$  can be selected using the SIC formula in (6) with  $r = 2$  and 2 CQIs based on the computed SINRs can be fed back in the form of a base-CQI and a delta-CQI. Expanding  $\hat{\mathbf{G}}_2 = [\hat{\mathbf{g}}_{1,2}, \hat{\mathbf{g}}_{2,2}]$ , we note that in this case the CQI computed using first SINR,  $\text{SINR}_{1,2}^{\text{SIC}}(\hat{\mathbf{G}}_2)$ , is the base CQI. The second CQI is equal to the base-CQI plus delta-CQI and corresponds to the second SINR,  $\text{SINR}_{2,2}^{\text{SIC}}(\hat{\mathbf{G}}_2)$ . This allows the eNodeB to perform a rank-override in which the user is scheduled as a rank-1 MU-MIMO user based on the pair  $(\text{SINR}_{2,2}^{\text{SIC}}, \hat{\mathbf{g}}_{2,2})$ .

Alternatively, an optimal matrix  $\hat{\mathbf{G}}_2 \in \mathcal{C}_2$  can be selected using the unified formula in (8) with  $r = 2$ . The base CQI can correspond to  $\text{SINR}_2^{\text{MMSE}}(\hat{\mathbf{G}}_2)$ . The second CQI is equal to the base-CQI plus delta-CQI and corresponds to the following SINR

$$\frac{\rho' \hat{\mathbf{g}}_{2,2}^\dagger \mathbf{H} (\mathbf{I} + \hat{\rho} \mathbf{H}^\dagger \mathbf{H})^{-1} \mathbf{H}^\dagger \hat{\mathbf{g}}_{2,2}}{1 - \hat{\rho} \hat{\mathbf{g}}_{2,2}^\dagger \mathbf{H} (\mathbf{I} + \hat{\rho} \mathbf{H}^\dagger \mathbf{H})^{-1} \mathbf{H}^\dagger \hat{\mathbf{g}}_{2,2}} \quad (11)$$

with  $\hat{\rho} = \frac{\rho'(S-1)}{M-1}$ . This allows the eNodeB to perform a rank-override in which the user is scheduled as a rank-1 MU-MIMO user based on  $\hat{\mathbf{g}}_{2,2}$  and the SINR given in (11).

### 3.1 Alternate PMI Selection and CQI computation Rules

In this section we consider two alternate rules.

- The user can first select a matrix from  $\mathcal{C}_r$  by quantizing the  $r$  dominant right singular vectors of  $\mathbf{H}^\dagger$ . In particular, let  $\mathbf{H}^\dagger = \mathbf{U} \mathbf{\Lambda} \tilde{\mathbf{V}}^\dagger$  be the SVD of  $\mathbf{H}^\dagger$  where  $\tilde{\mathbf{V}}$  is a  $M \times N$

semi-unitary matrix. Let  $\tilde{\mathbf{V}}_{(r)}$  denote the matrix formed by the first  $r$  columns of  $\tilde{\mathbf{V}}$  which are the  $r$  dominant right singular vectors of  $\mathbf{H}^\dagger$ . Then, the user can select a matrix from  $\mathcal{C}_r$  by using

$$\hat{\mathbf{G}}_r = \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \text{tr}(\tilde{\mathbf{V}}_{(r)}^\dagger \mathbf{G}_r \mathbf{G}_r^\dagger \tilde{\mathbf{V}}_{(r)}) \right\} \quad (12)$$

Once such a  $\hat{\mathbf{G}}_r$  is determined we can compute the  $r$  SINRs corresponding to  $\hat{\mathbf{G}}_r$  using either (5) or (7).

- SU-MIMO Based Rule: To determine a suitable precoding matrix from  $\mathcal{C}_r$  along with corresponding SINRs, the user of interest can use the following SU-MIMO rules which completely neglect the interference that will be caused due to other co-scheduled streams. For convenience, we only consider the MMSE based receiver. Then, a PMI is selected after determining  $r$  SINRs for each matrix in  $\mathcal{C}_r$ . We let  $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_r]$ .

$$\hat{\mathbf{G}}_r = \arg \max_{\mathbf{G} \in \mathcal{C}_r} \left\{ \sum_{j=1}^r \ln \left( 1 + \text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}) \right) \right\} \quad (13)$$

where

$$\text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}) = \frac{\rho}{r} \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \frac{\rho}{r} \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} - \frac{\rho}{r} \mathbf{H}^\dagger \mathbf{g}_j \mathbf{g}_j^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j$$

with  $\rho$  denoting the total power that is equally divided among all streams.

## 4 PMI, Best-Companion-PMI Selection and CQI computation

The user of interest must now feed-back to its serving eNodeB, a PMI along with a best-companion PMI, with the understanding that the codeword corresponding to such a companion PMI generates the least amount of interference for the user. In addition to  $S$  (and

possibly  $r$ ), we assume that the user of interest knows (or has been informed about)  $r^c$ , the rank of the codeword to be selected as the companion.

- Capacity Metric: a matrix  $\hat{\mathbf{G}}_r$  is selected along with the best-companion matrix,  $\hat{\mathbf{G}}_{r^c}$ .

$$\{\hat{\mathbf{G}}_r, \hat{\mathbf{G}}_{r^c}\} = \arg \max_{\mathbf{G} \in \mathcal{C}_r, \mathbf{G}_{r^c} \in \mathcal{C}_{r^c}} \left\{ \ln \left| \mathbf{I} + \check{\rho} \mathbf{H}^\dagger \mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G} \mathbf{G}^\dagger \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G}_{r^c} \mathbf{G}_{r^c}^\dagger \mathbf{H} \right| \right. \\ \left. - \ln \left| \mathbf{I} + \check{\rho} \mathbf{H}^\dagger \mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G}_{r^c} \mathbf{G}_{r^c}^\dagger \mathbf{H} \right| \right\}$$

where  $\check{\rho} = \frac{\rho'(S-r-r^c)}{r'}$ ,  $\mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp = \mathbf{I} - [\mathbf{G}, \mathbf{G}_{r^c}][\mathbf{G}, \mathbf{G}_{r^c}]^+$  is a projection matrix and  $r' = \text{Rank}(\mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp)$ . Note that since both  $\mathbf{G}, \mathbf{G}_{r^c}$  are semi-unitary matrices, when  $\mathbf{G}_{r^c}^\dagger \mathbf{G} = \mathbf{0}$ , we can also write  $\mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp = \mathbf{I} - \mathbf{G} \mathbf{G}^\dagger - \mathbf{G}_{r^c} \mathbf{G}_{r^c}^\dagger$  and in this case  $r' = M - r - r^c$ .

- MMSE based receiver: a matrix  $\hat{\mathbf{G}}_r$  is selected after determining  $r$  SINRs for each matrix in  $\mathcal{C}_r$ . Also selected is the best-companion matrix,  $\hat{\mathbf{G}}_{r^c}$ . We let  $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_r]$ .

$$\{\hat{\mathbf{G}}_r, \hat{\mathbf{G}}_{r^c}\} = \arg \max_{\mathbf{G} \in \mathcal{C}_r, \mathbf{G}_{r^c} \in \mathcal{C}_{r^c}} \left\{ \sum_{j=1}^r \ln \left( 1 + \text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}, \mathbf{G}_{r^c}) \right) \right\} \quad (14)$$

where

$$\text{SINR}_{j,r}^{\text{MMSE}}(\mathbf{G}, \mathbf{G}_{r^c}) = \rho' \mathbf{g}_j^\dagger \mathbf{H} \left( \mathbf{I} + \check{\rho} \mathbf{H}^\dagger \mathbf{P}_{\mathbf{G}, \mathbf{G}_{r^c}}^\perp \mathbf{H} + \rho' \mathbf{H}^\dagger \mathbf{G}_{r^c} \mathbf{G}_{r^c}^\dagger \mathbf{H} + \rho' \mathbf{H}^\dagger \sum_{k \neq j} \mathbf{g}_k \mathbf{g}_k^\dagger \mathbf{H} \right)^{-1} \mathbf{H}^\dagger \mathbf{g}_j \quad (15)$$

Note that the alternate rule derived in Section 3.1 can be readily extended to this scenario. In particular, the user first uses (12) to determine the matrix  $\hat{\mathbf{G}}_r$ . Next, it again uses (12) to determine the matrix  $\hat{\mathbf{G}}_{r^c}$ , but where the search is over  $\mathcal{C}_{r^c}$  and  $\tilde{\mathbf{V}}_{(r)}$  is replaced by  $\hat{\mathbf{V}}_{(r^c)}$ , with  $\hat{\mathbf{V}}_{(r^c)}$  denoting the  $M \times r^c$  matrix formed by the  $r^c$  right singular vectors of  $\mathbf{H}^\dagger$  that correspond to the  $r^c$  smallest singular values. Once  $\hat{\mathbf{G}}_r, \hat{\mathbf{G}}_{r^c}$  are determined, the user can compute the  $r$  SINRs corresponding to  $\hat{\mathbf{G}}_r, \hat{\mathbf{G}}_{r^c}$  using (15). Alternatively, the user can compute the best companion PMI using the

Parameter	Assumption
Bandwidth	10.0 MHz
FFT size	1024
Number of sub-carriers for data	600
RB bandwidth	180 kHz (12 subcarriers)
Sub-band size	5 RB
PMI granularity	per-subband
CQI granularity	per-subband
UE Receiver	MMSE
Precoding codebook	LTE codebook (4 bits per rank)
Number of antennas at eNodeB	4
Number of antennas at UE	2
UE Speed	3 Kmph
Channel model	Urban Micro channel

Table 1: Simulation Parameters

aforementioned rules. It can then report the CQI(s) that are based on SINR(s) without the best companion (for instance using (5) with  $\hat{\mathbf{G}}_r$ ) along with a delta CQI that corresponds to the average difference between the SINRs without the best companion and those with the best companion ((15) with  $\hat{\mathbf{G}}_r, \hat{\mathbf{G}}_{r,c}$ ).

## 5 Simulation results

In this section, the CQI mismatch problem is investigated via simulations. We assume that the eNodeB has four transmit antennas whereas the user of interest (UE-1) has two receive antennas. UE-1 reports its preferred PMI (per sub-band) along with the corresponding CQI(s) to the eNodeB. On each sub-band, the eNodeB then serves UE-1 using its reported precoding vector or matrix. It also randomly picks another precoding vector or matrix per sub-band (that is near-orthogonal to the one reported by UE-1) meant for the co-scheduled user. The cdf of the difference between the UE-1 reported CQI (SINR) and the actual CQI (SINR) observed by UE-1 post-scheduling, is shown in the following figures. Other specific simulation parameters are listed in Table 1.

In Fig. 1, we compare the cdf obtained when UE-1 employs the SU-MIMO rule in (13)

to determine its rank-1 precoding vector and corresponding CQI (denoted by conventional scheme in the legend) with the one obtained when the UE employs the rule in (4) with  $r = 1$  &  $S = 2$  to determine its rank-1 precoding vector and corresponding CQI (denoted by S reference in the legend). As seen from the plot the S reference scheme considerably reduces the CQI mismatch. In Fig. 2 we compare the cdf of the conventional scheme and the S reference scheme when the eNodeB signals  $r = 2$  &  $S = 3$  to UE-1 in a semi-static manner. UE-1 accordingly reports back a precoding matrix of rank-2 and two CQIs using the rule in (13) in the conventional scheme and using the rule in (4) in the S reference scheme. Upon receiving the PMI from UE-1, the eNodeB then randomly picks a (near-orthogonal) vector as the beamforming vector used for the co-scheduled stream. Note that the conventional scheme does not require the eNodeB to signal  $S$  but since this signaling is done in a semi-static manner it results in negligible overhead. Fig. 3 is the same as Fig. 2 except that the eNodeB signals  $r = 2$  &  $S = 4$  to UE-1 in a semi-static manner and upon receiving the rank-2 matrix report from UE-1, it randomly picks a (near-orthogonal) rank-2 matrix as the precoding matrix used for the co-scheduled streams. Note that in both cases the CQI mismatch is considerably reduced in the S reference scheme.

## 6 Conclusions

In this contribution, we considered enhancements to the MU-MIMO operation which aim to reduce the mismatch between the user reported SINRs and the ones it actually observes in the aftermath of scheduling. Our observation is that indicating the expected total number of streams (that the eNodeB expects to co-schedule on a sub-band) to a user can substantially reduce this mismatch and hence help realize the benefits of MU-MIMO. In addition, the indication of the expected total number of streams to a user can also be accompanied by a suggested rank for that user.

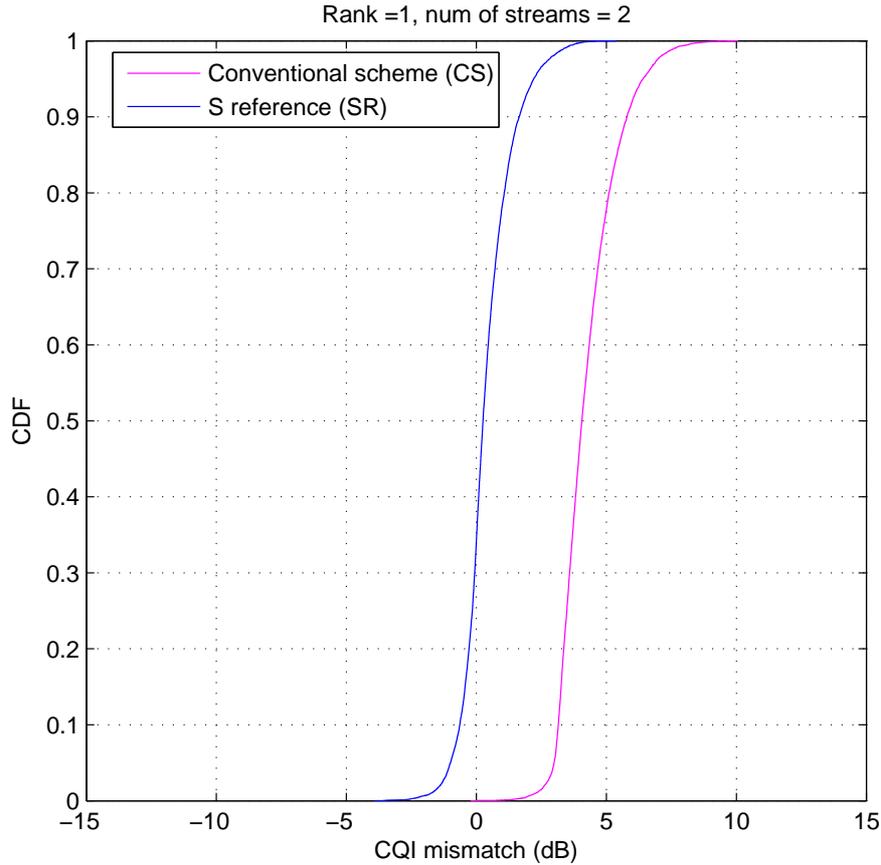


Figure 1: CDF of CQI mismatch for conventional scheme and the S reference scheme.

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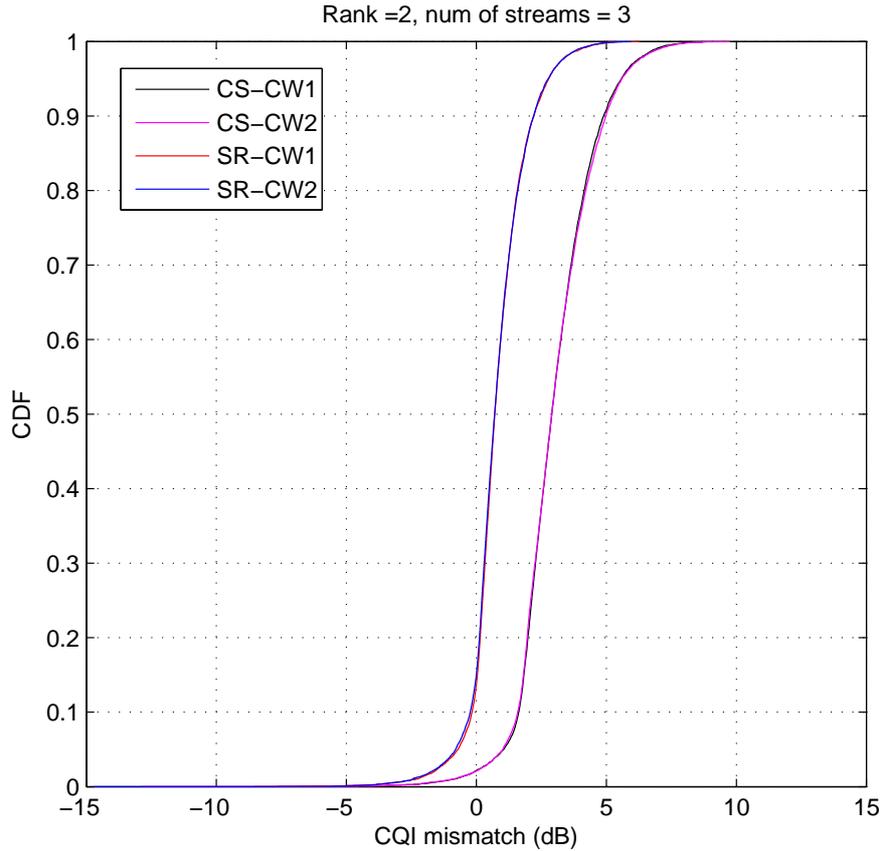


Figure 2: CDF of CQI mismatch for conventional scheme and the S reference scheme.

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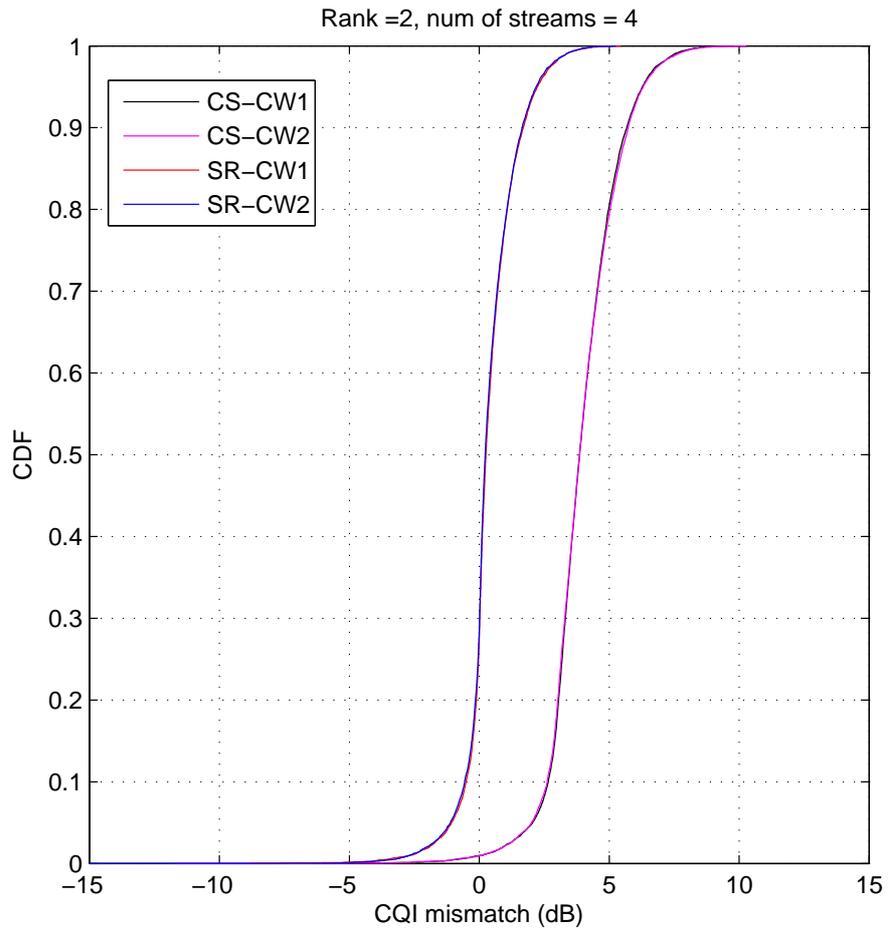


Figure 3: CDF of CQI mismatch for conventional scheme and the S reference scheme.