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## 1 Introduction

In the RAN-1 meetings during Rel.10 and Rel.11, CQI/PMI reporting enhancements targeting DL MU-MIMO operations were considered by several companies [1]. In this contribution we briefly describe simple enhanced channel state information (CSI) reporting schemes that target an improvement in DL MU-MIMO performance. In particular, we first examine enhanced CSI reporting that includes an additional residual error norm feedback. This residual error norm captures the energy of the channel seen by a user that remains in the orthogonal complement of its reported precoder. Hence it is indicative of the interference that can potentially be caused to the user if it is co-scheduled with one or more other users. We then consider another enhanced CSI reporting scheme that includes additional CQI/PMI computed under the assumption of post-scheduling intra-cell interference (a.k.a. MU-CQI/PMI). The corresponding simulation results and implementation details are in [4].

## 2 Enhanced MU-MIMO operation via Residual Error Norm Feedback

Under this scheme when configured by the eNB, the user **reports SU-MIMO CSI plus a residual error term**. The eNB can configure a user (to report the additional feedback) in a semi-static manner. We consider a simple form of residual error referred to as the residual error norm. Using SU-MIMO rules the user of interest first determines the SU-MIMO CSI comprising of a PMI  $\hat{\mathbf{V}}$  of some rank  $r$  along with  $r$  quantized SINRs  $\{\text{SINR}_i^r\}_{i=1}^r$ . The *residual error norm is determined by the user as*  $\tilde{\epsilon} = \sqrt{\text{tr}(\mathbf{F}\mathbf{H}^\dagger\mathbf{P}\mathbf{H}\mathbf{F}^\dagger)}$ , where  $\text{tr}(\cdot)$  denotes the trace operation,  $\mathbf{H}^\dagger$  denotes the channel matrix seen in the DL by the user of interest and  $\mathbf{F}$  denotes the filter matrix it computes for SU-MIMO CSI generation and  $\mathbf{P} = (\mathbf{I} - \hat{\mathbf{V}}\hat{\mathbf{V}}^\dagger)$  is a projection matrix. Note that  $\tilde{\epsilon}$  represents the residual total energy in the component of the filtered channel that lies in the orthogonal complement of the reported precoder  $\hat{\mathbf{V}}$ . The user reports the usual SU-MIMO CSI along with the residual error norm  $\tilde{\epsilon}$  or a *normalized residual error norm  $\epsilon$  computed using*  $\epsilon = \sqrt{\text{tr}(\mathbf{F}\mathbf{H}^\dagger\mathbf{P}\mathbf{H}\mathbf{F}^\dagger\tilde{\mathbf{D}}^{-1})}$ , where  $\tilde{\mathbf{D}} = \text{diag}\{\text{SINR}_1^r, \dots, \text{SINR}_r^r\}$ . The eNB can use the residual error norms reported by the users to determine accurate SINRs for any choice of user pairing in MU-MIMO. To achieve this, consider the case when the pairing includes the user of interest. The eNB employs a finer approximation of the filtered channel matrix ( $\mathbf{F}\mathbf{H}^\dagger$ ) of the user given by  $\mathbf{F}\mathbf{H}^\dagger \approx \hat{\mathbf{D}}^{1/2}(\hat{\mathbf{V}}^\dagger + \mathbf{R}^\dagger\mathbf{Q}^\dagger)$ , where  $\mathbf{Q} \in \mathbb{C}^{M \times M-r}$  is a semi-unitary matrix whose columns lie in the orthogonal complement of  $\hat{\mathbf{V}}$ , i.e.  $\mathbf{Q}^\dagger\hat{\mathbf{V}} = \mathbf{0}$  and  $\mathbf{R} \in \mathbb{C}^{M-r \times r}$  is a matrix which satisfies the Frobenius-norm constraint  $\|\mathbf{R}\|_F^2 = \frac{\rho}{r}\epsilon^2$ , where  $\epsilon > 0$  is the normalized residual error norm reported by the user and  $\rho$  denotes the energy per resource element (EPRE) or equivalently an average transmit power bound configured for that user, while  $\hat{\mathbf{D}} = \frac{r}{\rho}\text{diag}\{\text{SINR}_1^r, \dots, \text{SINR}_r^r\}$ . Then, suppose the transmit precoder selected by the eNB,  $\mathbf{U}$ , is parsed as

$\mathbf{U} = [\mathbf{U}, \bar{\mathbf{U}}]$ , where  $\bar{\mathbf{U}}$  includes columns of the transmit precoder matrix intended for the other co-scheduled (paired) users. For a well designed transmit precoder, the eNB can make the reasonable assumption that  $\mathbf{U}$  (almost) lies in the span of  $\hat{\mathbf{V}}$  whose columns represent the preferred directions along which the user wishes to receive its intended signal (so that  $\mathbf{Q}^\dagger \mathbf{U} \approx \mathbf{0}$ ). Accordingly, a model more tuned to MU-MIMO operation can be obtained in which the channel output seen by the user of interest post MU-MIMO scheduling is modeled as

$$\mathbf{y} = \hat{\mathbf{D}}^{1/2} \hat{\mathbf{V}}^\dagger \mathbf{U} \mathbf{s} + \hat{\mathbf{D}}^{1/2} (\hat{\mathbf{V}}^\dagger + \mathbf{R}^\dagger \mathbf{Q}^\dagger) \bar{\mathbf{U}} \bar{\mathbf{s}} + \boldsymbol{\eta}, \quad (1)$$

The model in (1) accounts for the fact that the component of  $\bar{\mathbf{U}}$  in the orthogonal complement of  $\hat{\mathbf{V}}$  can also cause interference to the user. Notice that when only SU-MIMO CSI along with the normalized residual error norm is reported by the users, in the model in (1) the eNB can only infer that the semi-unitary matrix  $\mathbf{Q}$  lies in the subspace determined by  $\mathbf{I} - \hat{\mathbf{V}} \hat{\mathbf{V}}^\dagger$  and  $\mathbf{R}$  is also not known except for the fact that  $\text{tr}(\mathbf{R}^\dagger \mathbf{R}) = \frac{\rho}{r} \epsilon^2$ . In [3] we describe how the eNB can utilize the model in (1) for more accurate MU-MIMO SINR computation.

### 3 Enhanced MU-MIMO operation via MU-MIMO CQI/PMI

Under this scheme the user itself assumes a post-scheduling model of the form

$$\mathbf{y} = \mathbf{H}^\dagger \hat{\mathbf{V}} \mathbf{s} + \mathbf{H}^\dagger \bar{\mathbf{U}} \bar{\mathbf{s}} + \boldsymbol{\eta}, \quad (2)$$

where  $\hat{\mathbf{V}}$  denotes the precoder under consideration (or determined a-priori using SU-MIMO rules) and  $\bar{\mathbf{U}}$  is assumed by the user to be isotropically distributed in the range of  $\mathbf{I} - \hat{\mathbf{V}} \hat{\mathbf{V}}^\dagger$ . Then, to compute MU-SINRs the user can be configured to assume a particular number of columns in  $\bar{\mathbf{U}}$  with an equal power per scheduled stream or to assume a non-uniform power allocation in which a certain fraction of EPRE is shared equally among all columns of  $\mathbf{U}$  with the remaining fraction being shared equally among all columns in  $\bar{\mathbf{U}}$  [2].

## 4 Conclusions

In this contribution, we considered enhancements to the DL MU-MIMO operation by enhancing the user CSI reporting which enables more accurate MU-MIMO SINR computation at the eNB. A companion contribution [4] shows that good system throughput improvements can be obtained by the suggested schemes.

## References

- [1] Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, AT&T, ETRI, Icera Inc., LG Electronics, Marvell, NEC, New Postcom, Pantech, Qualcomm, RIM, Samsung, Texas Instruments, "Way Forward on CQI/PMI reporting enhancement on PUSCH 3-1 for 2, 4 and 8 TX," *3GPP TSG RAN WG1 R1-105801* 62bis, Xian, China, Oct. 2010
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- [3] NEC Group, "DL MU-MIMO enhancement via Residual Error Norm feedback," *3GPP TSG RAN WG1 R1-113874*.
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