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How Accurately Should We Calibrate a Massive MIMO TDD System?

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Introduction

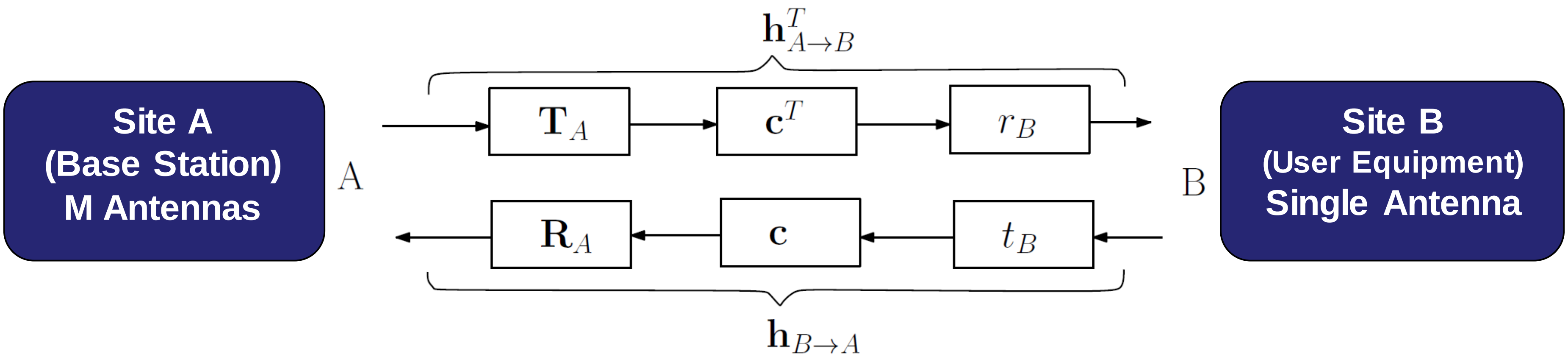
- **CSIT acquisition in Massive MIMO**
  - Large overhead if feedback CSIT from UE
  - Exploiting channel reciprocity in TDD system
  - Tx/Rx RF chains are not symmetric

- **TDD calibration**
  - Calibration stage: estimate calibration matrix
  - Beamforming stage: apply the calibration matrix on instantly measured UL channel to obtain CSIT

- **CSIT accuracy**
  - What are the joint impact of calibration matrix and UL CSI on CSIT?
  - What are their joint impact of on beamforming performance?
  - How accurately should we calibrate a Massive MIMO TDD system?

Calibration System Model

- **Mx1 MISO system**



$$\mathbf{h}_{A\to B}^T = r_B \mathbf{c}^T \mathbf{T}_A$$
$$\mathbf{h}_{B\to A} = \mathbf{R}_A \mathbf{c} t_B$$

$\Longrightarrow$

$$\mathbf{h}_{A\to B}^T = \mathbf{h}_{B\to A}^T \mathbf{F}$$

Calibration Matrix Measurement

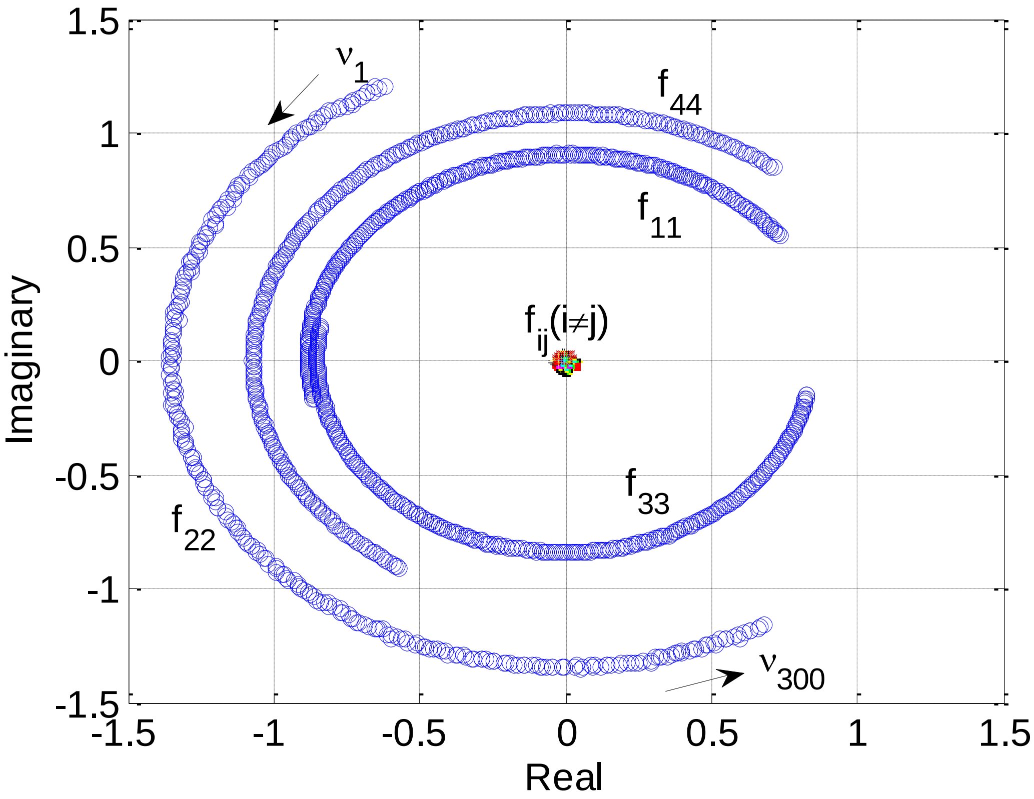
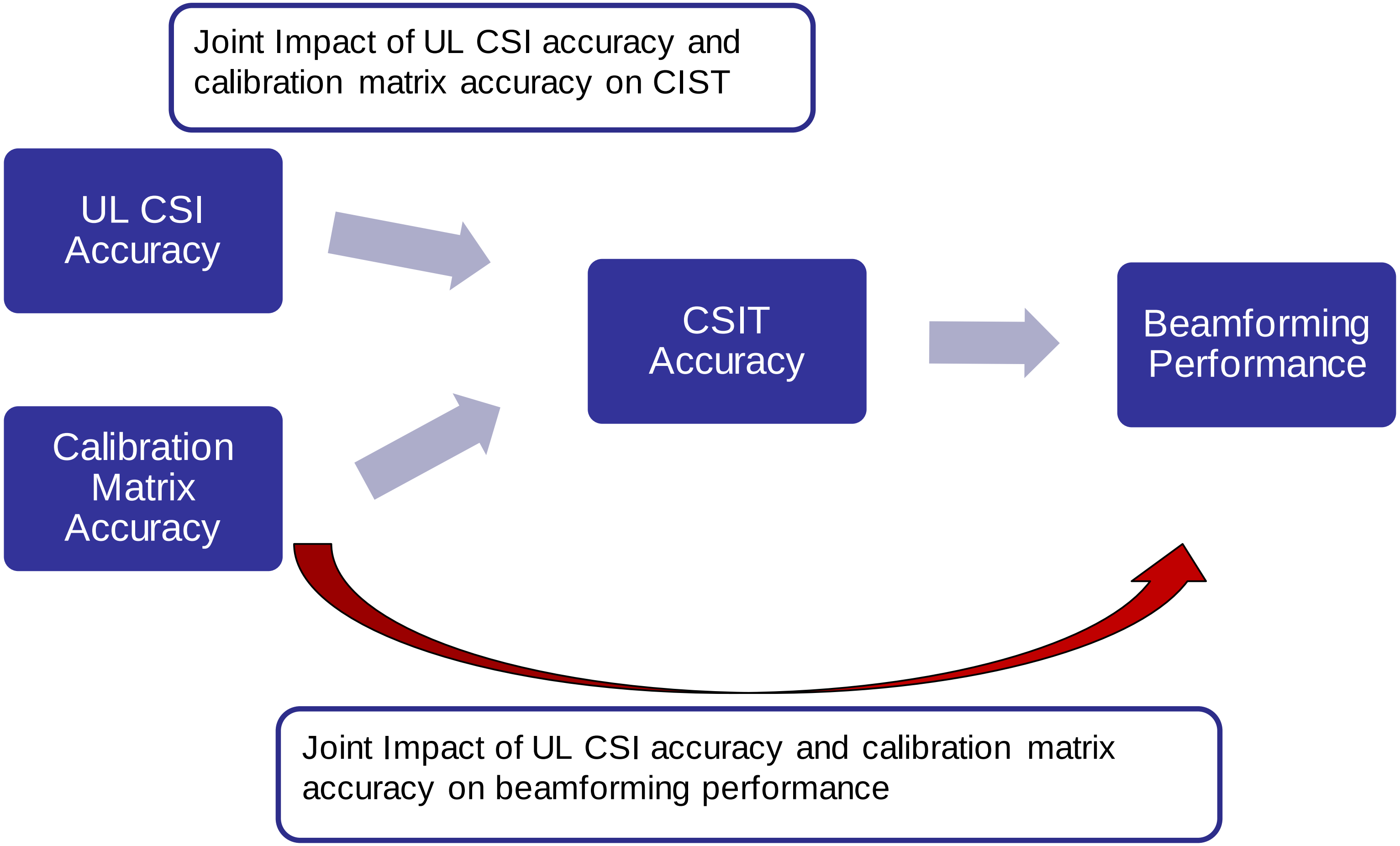


Figure 1: Measurement of **F** for a 4x1 MISO system on 300 different carriers.

[Ref] X. Jiang, M. Cˇirkic´, F. Kaltenberger, G. L. Larsson, L. Deneire, and R. Knoppe, “MIMO-TDD reciprocity and hardware imbalances: Experimental results,” in Proc. IEEE International Conference on Communications (ICC), London, United Kingdom, Jun. 2015.

CSIT Accuracy and Beamforming Performance



CSIT Accuracy

$$\overline{\text{MSE}} = \frac{1}{M}\mathbb{E}_{\mathbf{h}_{B\to A},\mathbf{s}_B,\mathbf{N}_A}\left[\left\|\hat{\mathbf{F}}^T\hat{\mathbf{h}}_{B\to A} - \mathbf{h}_{A\to B}\right\|^2\right]$$

$$= \frac{\sigma_{n,A}^2}{ML_B}\text{Tr}\left\{\mathbf{F}^T\mathbf{F}^*\right\} + \frac{1}{M}\text{Tr}\left\{\Delta\mathbf{F}^T\left(\mathbf{V} + \frac{\sigma_{n,A}^2}{L_B}\mathbf{I}\right)\Delta\mathbf{F}^*\right\} + \frac{\sigma_{n,A}^2}{MT_B}\text{Tr}\left\{\mathbf{F}^T\Delta\mathbf{F}^* + \Delta\mathbf{F}^T\mathbf{F}^*\right\}$$

where $\mathbf{V} = \mathbb{E}\left[\mathbf{h}_{B\to A}\mathbf{h}_{B\to A}^H\right]$

$\hat{\mathbf{F}} = \mathbf{F} + \Delta\mathbf{F}$

$\sigma_{n,A}^2$ is the variance of circular-symmetric complex Gaussian noise at A.

L_B is the number of symbols used for UL channel estimation.

CSIT Accuracy

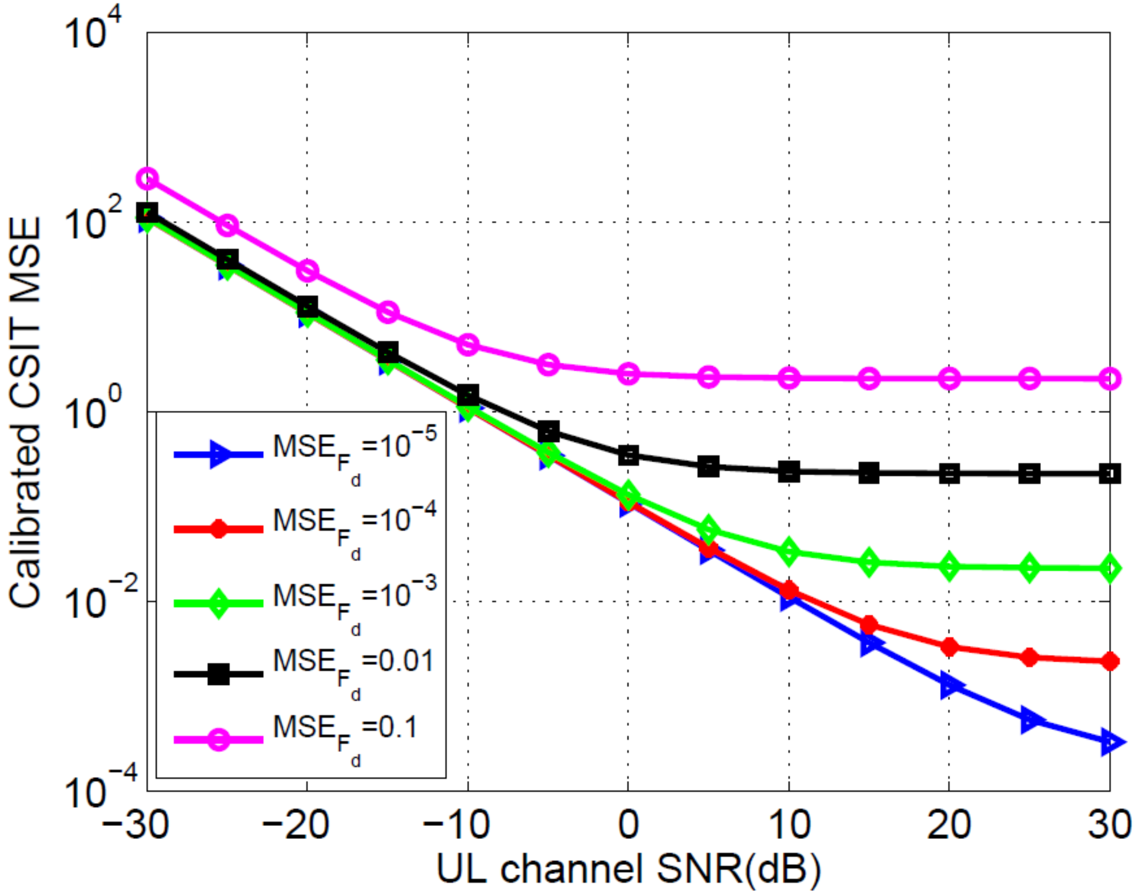


Figure 2: Calibrated CSIT averaged MSE as a function of UL CSI accuracy and calibration matrix accuracy in a 64x1 MISO system (LB = 10).

Beamforming Performance

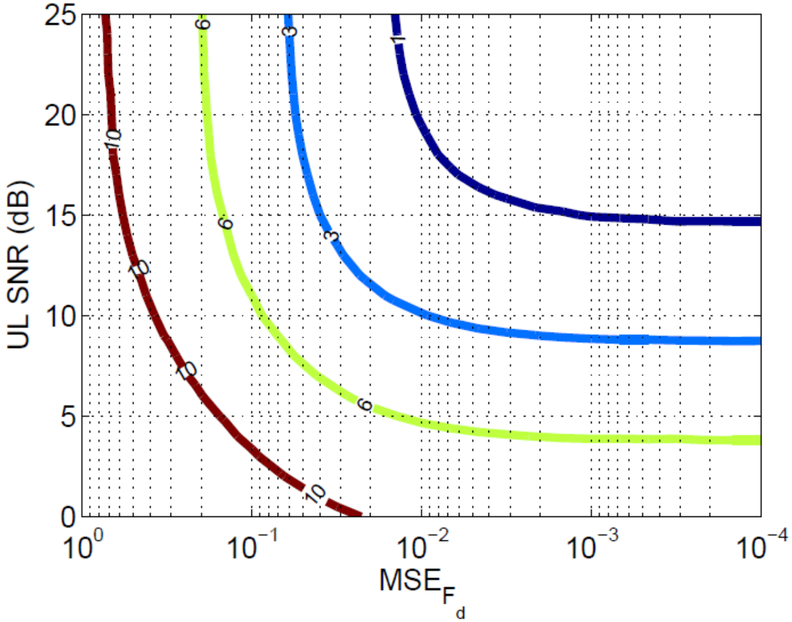


Figure 3: Conjugate beamforming SINR loss (in dB) due to joint impact of estimated **F** and UL channel estimation inaccuracy in a 64x8 system with DL SNR=0dB (LB = 10).

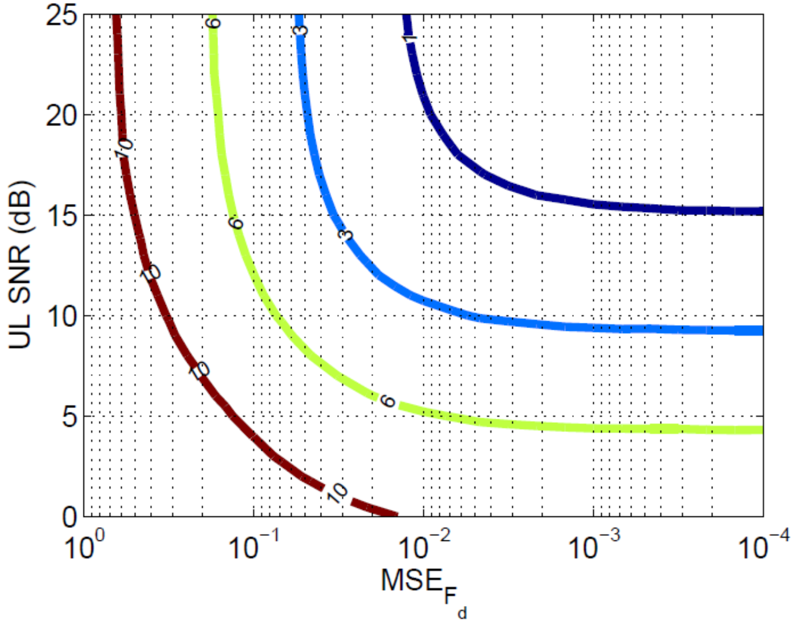


Figure 4: ZF beamforming SINR loss (in dB) due to joint impact of estimated **F** and UL channel estimation inaccuracy in a 64x8 system with DL SNR=0dB (LB = 10).

Beamforming Performance

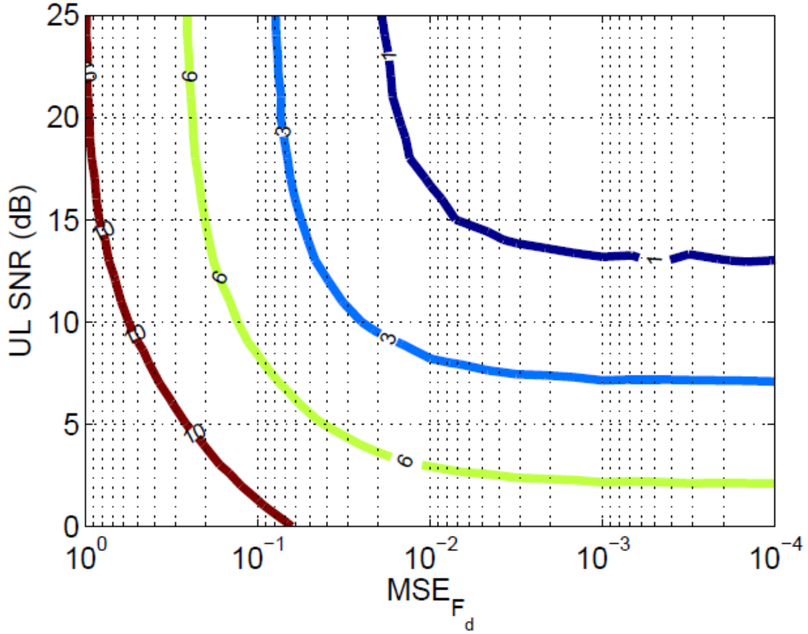


Figure 5: Conjugate beamforming SINR loss (in dB) due to joint impact of estimated **F** and UL channel estimation inaccuracy in a 64x8 system with DL SNR=20dB (LB = 10).

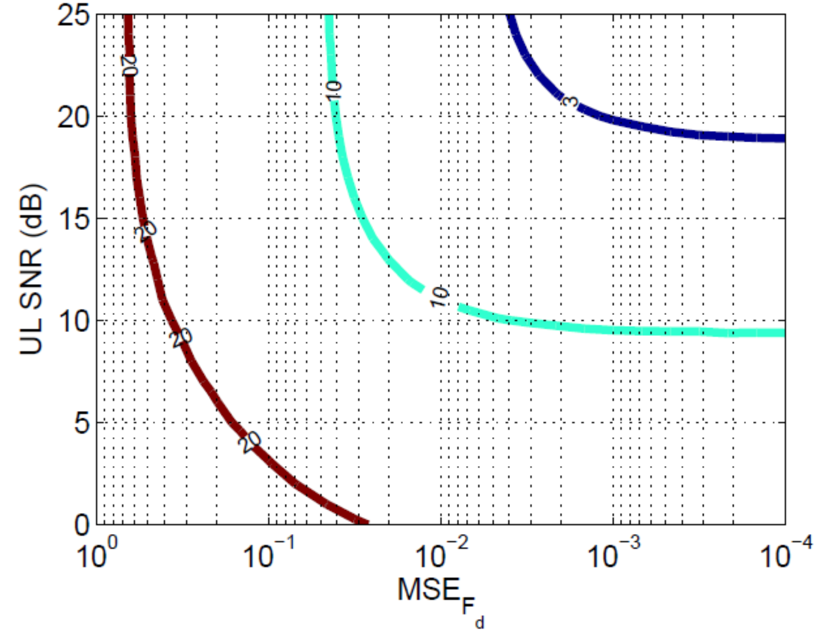


Figure 6: ZF beamforming SINR loss (in dB) due to joint impact of estimated **F** and UL channel estimation inaccuracy in a 64x8 system with DL SNR=20dB (LB = 10).

Conclusions

- **CSIT accuracy**
  - To improve CSIT, more resources should be allocated to the limiting factor

- **Conjugate vs. ZF beamforming**
  - ZF is more sensitive than conjugate beamforming to the inaccuracy of calibration matrix and UL channel estimation, especially in high DL SNR region

- **System design tool**
  - Given a certain beamforming SINR loss target, a calibration matrix and UL channel estimation accuracy can be derived