Downlink Channel Covariance Estimation in Realistic FDD Massive MIMO Systems

Lorenzo Miretti[†], Renato L.G. Cavalcante[⋆], and Slawomir Stanczak[⋆]

Communication Systems Department, EURECOM[†]

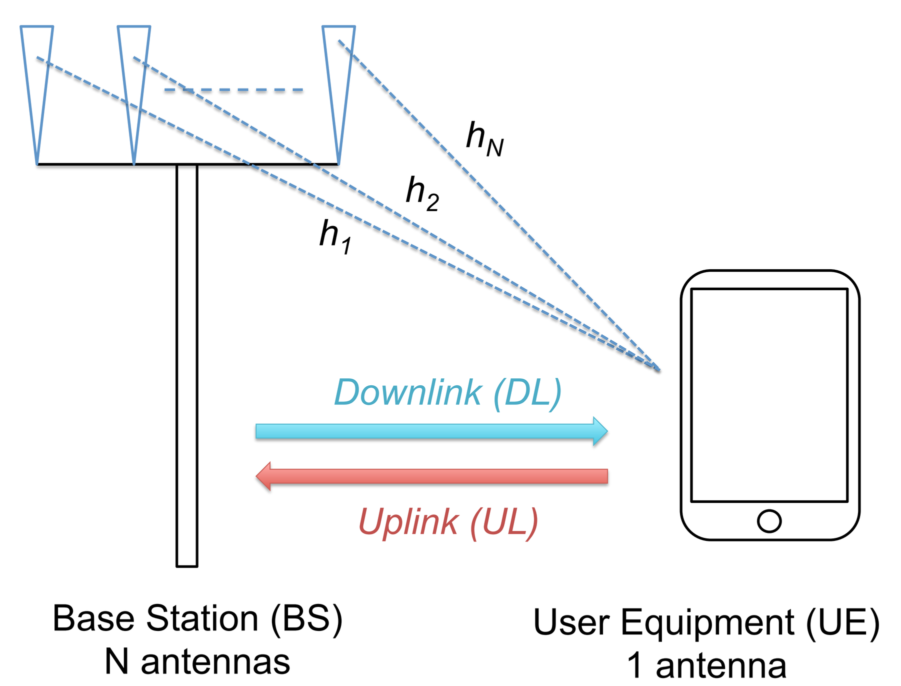
Fraunhofer Heinrich Hertz Institute and Technical University of Berlin[⋆]

Spatial Covariance Matrix

- Knowledge of $\boldsymbol{R}^d = \mathbb{E}[\boldsymbol{h}^d(\boldsymbol{h}^d)^H]$ at the base station:
- Crucial for many DL CSI acquisition and beamforming algorithms in FDD Massive MIMO systems.
- ➡ However, difficult to obtain in practical FDD Massive MIMO systems.

DL Covariance Estimation

- Conventional techniques based on DL training and feedback unfeasible in Massive MIMO.
- At the BS, $\boldsymbol{R}^u$ is generally easier to estimate.
- In FDD systems, $\boldsymbol{R}^d \neq \boldsymbol{R}^u$.
- ➡ However, a weaker form of channel reciprocity in the angular domain can be assumed.



FDD UL/DL Covariance Conversion Problem

- ➡ Estimation of $\boldsymbol{R}^d$ from $\boldsymbol{R}^u$.

Existing Approaches: Issues

- Most of the available solutions rely on simple channel models and/or require specific array geometries (e.g. ULA).
- ➡ They often fail to address important effects such as propagation in 3D environments, polarization, and non-ideal array geometries.

A Novel Covariance Model for Dual-polarized Arrays

$$\boldsymbol{R} = \mathbb{E}[\boldsymbol{h}\boldsymbol{h}^H] = \int_\Omega \rho_V(\boldsymbol{\theta})\boldsymbol{a}_V(\boldsymbol{\theta})\boldsymbol{a}_V(\boldsymbol{\theta})^H d\boldsymbol{\theta} + \int_\Omega \rho_H(\boldsymbol{\theta})\boldsymbol{a}_H(\boldsymbol{\theta})\boldsymbol{a}_H(\boldsymbol{\theta})^H d\boldsymbol{\theta}$$

- $\Omega = [-\pi, \pi] \times [0, \pi]$ is a spherical coordinate system.
- $\boldsymbol{a}_V, \boldsymbol{a}_H : \Omega \to \mathbb{C}^{N\times 1}$ are the BS antenna array responses for the vertical and for the horizontal polarizations.
- $\rho_V, \rho_H : \Omega \to \mathbb{R}^+$ are the frequency invariant angular power spectra for the vertical and for the horizontal polarizations (V-APS, H-APS).
- ➡ It can be derived from 3GPP-3D-like channel models, both for narrow-band and wide-band OFDM systems.

Covariance Conversion using Projection Methods

$$\boldsymbol{R}^u = \int_\Omega \rho_V(\boldsymbol{\theta})\boldsymbol{a}_V^u(\boldsymbol{\theta})\boldsymbol{a}_V^u(\boldsymbol{\theta})^H d\boldsymbol{\theta} + \int_\Omega \rho_H(\boldsymbol{\theta})\boldsymbol{a}_H^u(\boldsymbol{\theta})\boldsymbol{a}_H^u(\boldsymbol{\theta})^H d\boldsymbol{\theta} \quad (1)$$

$$\boldsymbol{R}^d = \int_\Omega \rho_V(\boldsymbol{\theta})\boldsymbol{a}_V^d(\boldsymbol{\theta})\boldsymbol{a}_V^d(\boldsymbol{\theta})^H d\boldsymbol{\theta} + \int_\Omega \rho_H(\boldsymbol{\theta})\boldsymbol{a}_H^d(\boldsymbol{\theta})\boldsymbol{a}_H^d(\boldsymbol{\theta})^H d\boldsymbol{\theta} \quad (2)$$

1. We obtain an estimate $(\hat{\rho}_V, \hat{\rho}_H)$ of (ρ_V, ρ_H) based on the knowledge of $\boldsymbol{R}^u$, expression (1), and known properties of (ρ_V, ρ_H).
2. We compute an estimate of $\boldsymbol{R}^d$ from (2), and by substituting (ρ_V, ρ_H) with its estimate $(\hat{\rho}_V, \hat{\rho}_H)$.

Core idea: Joint V-APS and H-APS estimation formalized as a convex feasibility problem: very effective solutions based on projection methods on an infinite-dimensional Hilbert space.

Proposed Covariance Conversion Scheme

- ➡ Extension of the ideas in [1] to the considered realistic covariance model.
- Derived by focusing on the Hilbert space $\mathcal{H} = L^2[\Omega] \times L^2[\Omega]$ equipped with the inner product $\langle (f_V, f_H), (g_V, g_H) \rangle := \int_\Omega f_V(\boldsymbol{\theta}) g_V(\boldsymbol{\theta}) d^2\boldsymbol{\theta} + \int_\Omega f_H(\boldsymbol{\theta}) g_H(\boldsymbol{\theta}) d^2\boldsymbol{\theta}$.
- We estimate $(\rho_V, \rho_H) \in \mathcal{H}$ by solving

$$\text{find } (\rho_V, \rho_H)^* \in V := \cap_{m=1}^M V_m,$$

where

$$V_m := \{\langle (\rho_V, \rho_H), (g_{V,m}^u, g_{H,m}^u) \rangle = r_m^u\}.$$

- r_m^u is the mth element of $\mathrm{vec}\left(\left[\Re\{\boldsymbol{R}^u\}\ \Im\{\boldsymbol{R}^u\}\right]\right)$.
- $g_{(\cdot),m}^u$ is the mth element of $\mathrm{vec}\left(\left[\Re\{\boldsymbol{a}_{(\cdot)}^u(\theta)\boldsymbol{a}_{(\cdot)}^u(\theta)^H\}\ \Im\{\boldsymbol{a}_{(\cdot)}^u(\theta)\boldsymbol{a}_{(\cdot)}^u(\theta)^H\}\right]\right)$.
- ➡ Among the solutions, we choose the projection onto the linear variety $P_V(0)$ (Algorithm 1).
- Closed-form solution available in terms of inner products of the type $\langle (g_{V,m}^u, g_{H,m}^u), (g_{V,l}^u, g_{H,l}^u) \rangle$.
- A more accurate but more complex variant (Algorithm 2) is available, which takes into account the positivity of the APS.

Main Advantages

- *Algorithm 1* is a simple matrix/vector multiplication $\hat{\boldsymbol{r}}^d = \boldsymbol{F}\boldsymbol{r}^u$ over vectorized covariances.
- $\boldsymbol{F}$ depends only on the array geometry and it is computed once for the entire system lifetime.
- It takes into account polarization and 3D propagation.
- No specific array geometry is required.

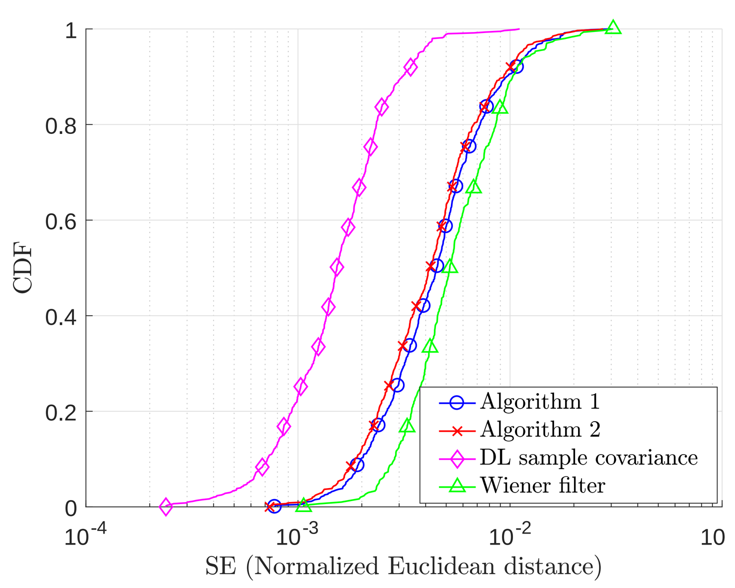


Figure: CDF of the DL covariance estimation error.

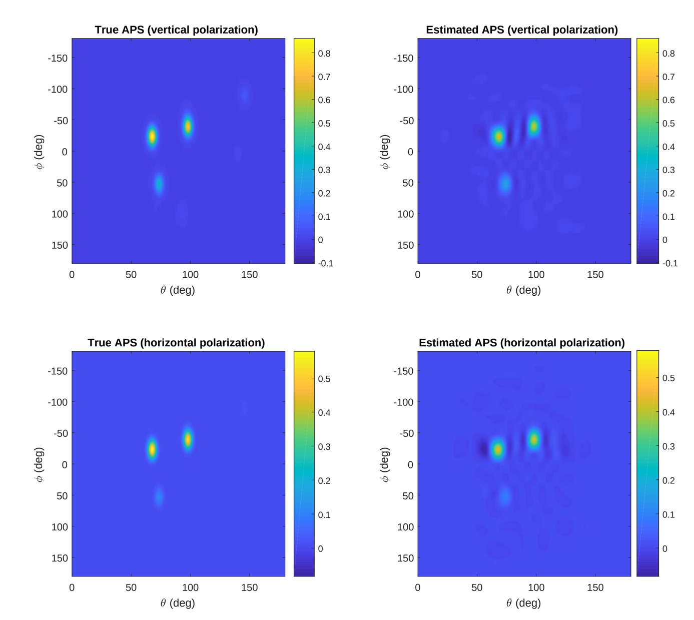


Figure: Example of joint V-APS and H-APS estimation.

[1] L. Miretti, Renato L.G. Cavalcante and Slawomir Stanczak, "FDD massive MIMO channel spatial covariance conversion using projection methods", *IEEE ICASSP*, 2018

[2] L. Miretti, Renato L.G. Cavalcante and Slawomir Stanczak, "Downlink channel spatial covariance estimation in realistic FDD massive MIMO systems", *IEEE GlobalSIP*, 2018