Robust Location-Aided Beam Alignment in mmWave Massive MIMO

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Beam Alignment in mmWave

- Unfeasible pilot, power and time resource overhead in Massive MIMO settings to establish communication
- One approach to reduce alignment overhead consists in exploiting **location** information [2, 3]
  - ▷ Possible acquisition through GNSSs, radars, ...
- **Noise** in the acquisition/estimation process
- **Unequal degrees** of information accuracies

Transmission Scenario

- Dual Massive MIMO setup
- Analog beamforming through codebooks $\mathcal{V}_{TX}$ and $\mathcal{V}_{RX}$
- Pilot training over small subsets of the codebooks

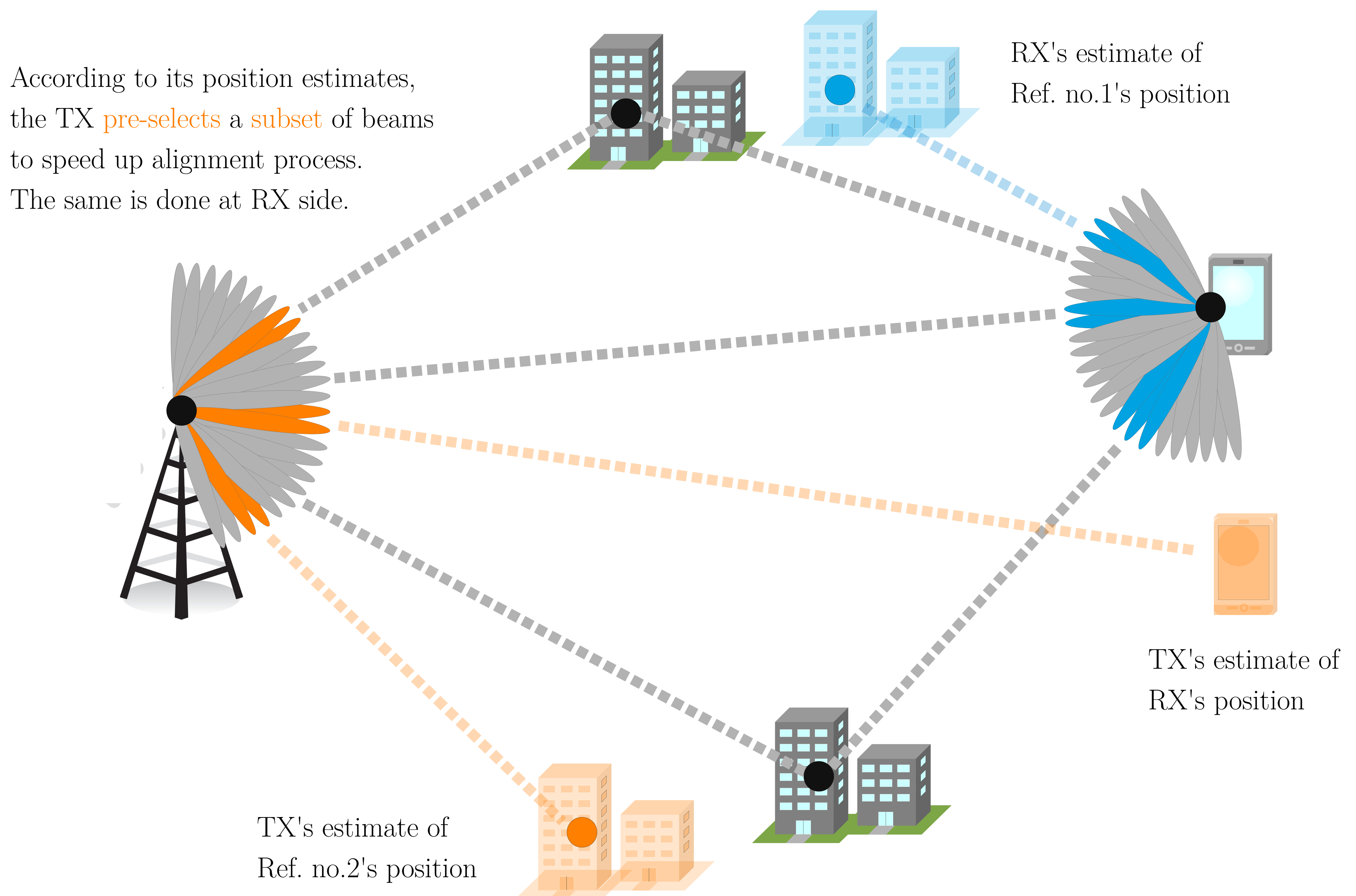
Information Model

- Distributed model which emphasizes the decentralized nature of information available at TX and RX sides
- Position information at the TX and the RX:

$$\hat{\mathbf{P}}^{(TX)} = \mathbf{P} + \mathbf{E}^{(TX)}$$

$$\hat{\mathbf{P}}^{(RX)} = \mathbf{P} + \mathbf{E}^{(RX)}$$

- Shared statistical long-term information



Coordinated Beam Alignment Methods

Goal: Design $\mathcal{D}_{TX}$ and $\mathcal{D}_{RX}$, i.e. the sets of D_{TX} and D_{RX} pre-selected beams at the TX and the RX

- Figure of merit $\mathbb{E}[R(\mathcal{D}_{TX}, \mathcal{D}_{RX}, \mathbf{P})]$, where:

$$R(\mathcal{D}_{TX}, \mathcal{D}_{RX}, \mathbf{P}) = \max_{p \in \mathcal{D}_{TX}, q \in \mathcal{D}_{RX}} \log_2 \left(1 + \frac{G_{q,p}(\mathbf{P})}{N_0}\right)$$

Optimal Bayesian Beam Alignment

Decentralized beam pre-selection, based on local position information

- Beam pre-selection function at the TX and the RX:

$$d_{TX}: \quad \mathbb{R}^{2\times(L+1)} \to \mathcal{V}_{TX}, \quad \hat{\mathbf{P}}^{(TX)} \mapsto d_{TX}(\hat{\mathbf{P}}^{(TX)}) \qquad d_{RX}: \quad \mathbb{R}^{2\times(L+1)} \to \mathcal{V}_{RX}, \quad \hat{\mathbf{P}}^{(RX)} \mapsto d_{RX}(\hat{\mathbf{P}}^{(RX)})$$

➥ Formulation as a **Team Decision** problem:

$$(d^*_{TX}, d^*_{RX}) = \operatorname*{argmax}_{d_{TX}, d_{RX}} \mathbb{E}_{\mathbf{P}, \hat{\mathbf{P}}^{(TX)}, \hat{\mathbf{P}}^{(RX)}} \left[R\left(d_{TX}(\hat{\mathbf{P}}^{(TX)}), d_{RX}(\hat{\mathbf{P}}^{(RX)}), \mathbf{P}\right)\right]$$

- Functional Stochastic Optimization problem (notoriously difficult to solve, need for approximations)

2-Step Robust Beam Alignment

We first introduce the Person-by-Person (PbP) optimal, a necessary optimality condition for the optimal BA

- Each node takes the best strategy given the strategy at the other node

$$d^{\text{PP}}_{TX}(\hat{\mathbf{P}}^{(TX)}) = \operatorname*{argmax}_{\mathcal{D}_{TX} \subset \mathcal{V}_{TX}} \mathbb{E}_{\mathbf{P}, \hat{\mathbf{P}}^{(RX)} | \hat{\mathbf{P}}^{(TX)}} \left[R\left(\mathcal{D}_{TX}, d^{\text{PP}}_{RX}(\hat{\mathbf{P}}^{(RX)}), \mathbf{P}\right)\right]$$

$$d^{\text{PP}}_{RX}(\hat{\mathbf{P}}^{(RX)}) = \operatorname*{argmax}_{\mathcal{D}_{RX} \subset \mathcal{V}_{RX}} \mathbb{E}_{\mathbf{P}, \hat{\mathbf{P}}^{(TX)} | \hat{\mathbf{P}}^{(RX)}} \left[R\left(d^{\text{PP}}_{TX}(\hat{\mathbf{P}}^{(TX)}), \mathcal{D}_{RX}, \mathbf{P}\right)\right]$$

- (Still) Complicated solution due to the **interdependence** between the mappings d^{PP}_{TX} and d^{PP}_{RX}

Main idea: Approximate the PbP optimal beam alignment by replacing the PbP mapping inside the expectation operator with the **naive mapping** as described above

$$d^{\text{2-s}}_{TX}(\hat{\mathbf{P}}^{(TX)}) = \operatorname*{argmax}_{\mathcal{D}_{TX} \subset \mathcal{V}_{TX}} \mathbb{E}_{\mathbf{P}, \hat{\mathbf{P}}^{(RX)} | \hat{\mathbf{P}}^{(TX)}} \left[R\left(\mathcal{D}_{TX}, d^{\text{1-s}}_{RX}(\hat{\mathbf{P}}^{(RX)}), \mathbf{P}\right)\right]$$

$$d^{\text{2-s}}_{RX}(\hat{\mathbf{P}}^{(RX)}) = \operatorname*{argmax}_{\mathcal{D}_{RX} \subset \mathcal{V}_{RX}} \mathbb{E}_{\mathbf{P}, \hat{\mathbf{P}}^{(TX)} | \hat{\mathbf{P}}^{(RX)}} \left[R\left(d^{\text{1-s}}_{TX}(\hat{\mathbf{P}}^{(TX)}), \mathcal{D}_{RX}, \mathbf{P}\right)\right]$$

Naïve Beam Alignment

- TX and RX treat local information as perfect and global, i.e. it is optimal with perfect information

$$d^{\text{1-s}}_{TX}(\hat{\mathbf{P}}^{(TX)}) = \operatorname*{argmax}_{\mathcal{D}_{TX} \subset \mathcal{V}_{TX}} \max_{\mathcal{D}_{RX} \subset \mathcal{V}_{RX}} R\left(\mathcal{D}_{TX}, \mathcal{D}_{RX}, \hat{\mathbf{P}}^{(TX)}\right)$$

$$d^{\text{1-s}}_{RX}(\hat{\mathbf{P}}^{(RX)}) = \operatorname*{argmax}_{\mathcal{D}_{RX} \subset \mathcal{V}_{RX}} \max_{\mathcal{D}_{TX} \subset \mathcal{V}_{TX}} R\left(\mathcal{D}_{TX}, \mathcal{D}_{RX}, \hat{\mathbf{P}}^{(RX)}\right)$$

- Misalignments occur in case of imperfect information

Simulations

- $L = 3$ dominant multipath components, of which 1 LoS
- 64 antennas (ULA), 64 beams in $\mathcal{V}_{TX}$ and $\mathcal{V}_{RX}$
- Uniform bounded error model for location information

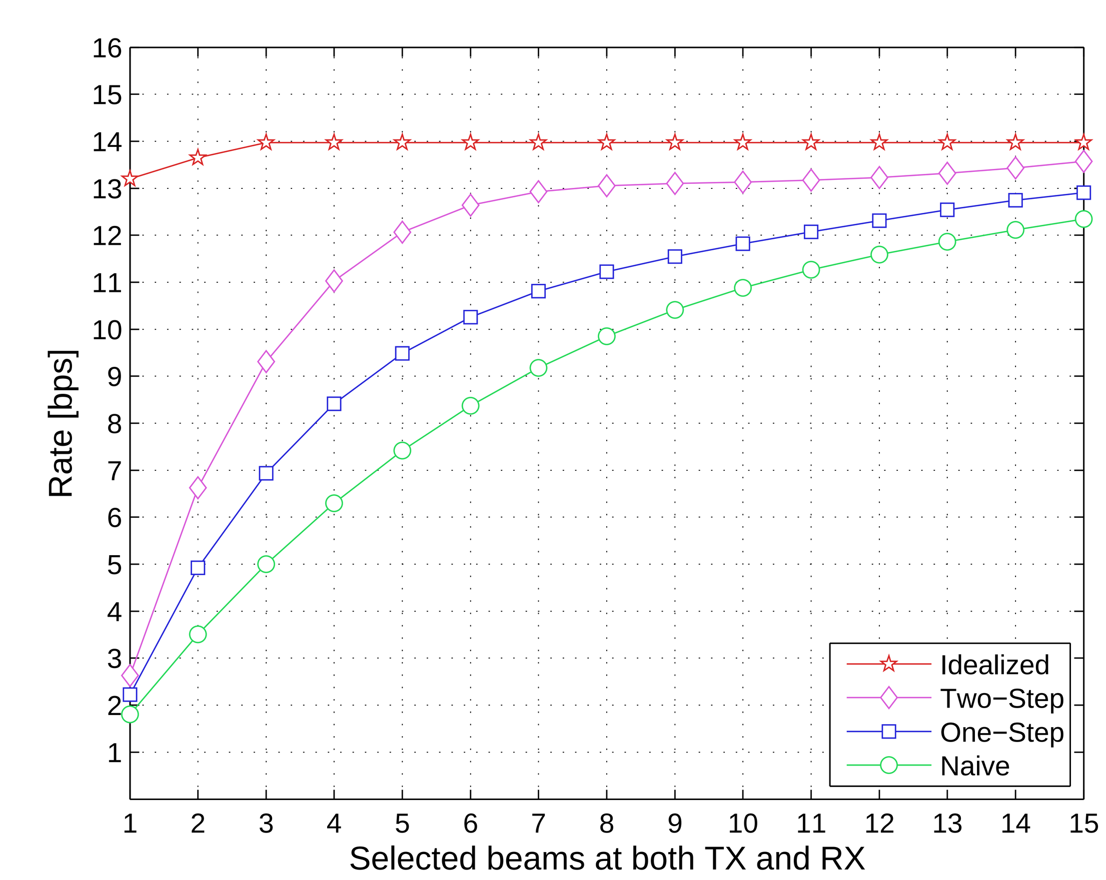


Figure : Rate vs # of selected beams at TX and RX, SNR = 10 dB.

References

[1] F. Maschietti, D. Gesbert, P. de Kerret and H. Wymeersch, "Robust Location-Aided Beam Alignment in Millimeter Wave Massive MIMO", 2017. [Online: arxiv.org/abs/1705.01002]

[2] N. Garcia, H. Wymeersch, E. G. Ström and D. Slock, "Location-Aided mmWave Channel Estimation for Vehicular Communication", IEEE SPAWC, 2016.

[3] A. Ali, N. González-Prelcic, R. W. Heath, "Millimeter Wave Beam-Selection using Out-of-Band Spatial Information", 2017. [Online: arxiv.org/abs/1702.08574]