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

Transmitted Scenario

- Dual Massive MIMO setup
- Analog beamforming through codebooks $V_{TX}$ and $V_{RX}$
- 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:
  \[
  \hat{P}_{TX} = P + E_{TX} \\
  \hat{P}_{RX} = P + E_{RX}
  \]
- Shared statistical long-term information

Coordinated Beam Alignment Methods

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

- Figure of merit $E[R(D_{TX}, D_{RX}, P)]$, where:
  \[
  R(D_{TX}, D_{RX}, P) = \max_{P \in D_{TX}, Q \in D_{RX}} \log_2 \left( 1 + \frac{G_{q,p}(P)}{N_0} \right)
  \]

Optimal Bayesian Beam Alignment

Decentralized beam pre-selection, based on local position information

- Beam pre-selection function at the TX and the RX:
  \[
  d_{TX} : \mathbb{R}^{2s(L+1)} \rightarrow V_{TX} \\
  \hat{P}_{TX} = d_{TX}(\hat{P}_{TX}) \\
  d_{RX} : \mathbb{R}^{2s(L+1)} \rightarrow V_{RX} \\
  \hat{P}_{RX} = d_{RX}(\hat{P}_{RX})
  \]

Formulation as a Team Decision problem:

\[
(d_{TX}, d_{RX}) = \arg\max_{d_{TX}, d_{RX}} E_{P, \hat{P}_{TX}, \hat{P}_{RX}} \left[ R(d_{TX}(\hat{P}_{TX}), d_{RX}(\hat{P}_{RX}), P) \right]
\]

Naïve Beam Alignment

- TX and RX treat local information as perfect and global, i.e. it is optimal with perfect information,
- $d_{TX}^{\text{opt}}(\hat{P}_{TX}) = \arg\max_{D_{TX}} R(D_{TX}, D_{RX}, \hat{P}_{TX})$
- $d_{RX}^{\text{opt}}(\hat{P}_{RX}) = \arg\max_{D_{RX}} R(D_{TX}, D_{RX}, \hat{P}_{RX})$
- Misalignments occur in case of imperfect information

Simulations

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

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

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

\[
(d_{TX}^{\text{opt}}(\hat{P}_{TX}), d_{RX}^{\text{opt}}(\hat{P}_{RX})) = \arg\max_{D_{TX} \subset V_{TX}, D_{RX} \subset V_{RX}} E_{P, \hat{P}_{TX}, \hat{P}_{RX}} \left[ R(d_{TX}(\hat{P}_{TX}), D_{RX}, P) \right]
\]

References