Hybrid Beamforming: Where Should the Analog Power Amplifiers be Placed?

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Too many antennas - not enough RF-chains

mmWave Communication and massive MIMO:

- Fully digital beamforming: one RF-chain (DAC/ADC) per antenna
- Massive antenna array → many RF-chains
- Problem: RF-chains are bulky and costly

MIMO Point-to-Point (P2P) system:

- Optimal Beamforming: derived from SVD of the channel $H = U\Sigma V^H$
  and waterfilling matrix $\Gamma = \text{diag}(\sqrt{p_1}, \ldots, \sqrt{p_d})$

  - Precoder: $F_{\text{opt}} = VM$
  - Postcoder: $W_{\text{opt}} = U^H$

Hybrid Beamforming (HB): limited number of RF-chains, combination of digital and analog beamforming

$F = F_A F_D$  $W = W_D W_A$

- limited flexibility of $F_A$, $W_A$ depending on HB architecture
- DoF is limited to the number of RF-chains

How do different placements of analog amplifiers in the HB architecture affect the spectral efficiency (SE)?

Hybrid Beamforming Architectures

(a) Amplifiers at the RF-chains $\rightarrow N_{RF}$ amplifiers

- Scheme from [Sohrabi, Yu]:
  - Algorithm to determine $F_A$ (phase shifters)
  - $F_D$ given based on $F_A$, $H$ and $\Gamma$

(b) Amplifiers at the Antennas $\rightarrow N_t$ amplifiers

- Proposed scheme:
  - Phase shifter matrix $F_{PS}$ and $F_D$ as in [Sohrabi, Yu]
  - Precoder: $F = \begin{bmatrix} \beta_1 & 0 & 0 \\ 0 & \beta_2 & 0 \\ 0 & 0 & \beta_3 \end{bmatrix} F_{PS} F_D$
  - Independent scaling of rows of $F$ by $\beta$
  - determine $\beta \rightarrow \|f\| = \|v_{c,i}\|$ for rows of $F$

(c) Amplifiers at the Phase Shifters $\rightarrow N_{RF} N_t$ amplifiers

- Optimal hybrid scheme:
  - High analog precoder design flexibility: amplitude and phase
  - determine phase shifters and amp. gains such that
    $F = VM$,

Numerical Results

- P2P-MIMO system with 8 receive antennas, 2 RF-chains, geometric channel model, Kronecker model for rank-deficient channel

Full rank channel:

- increasing gap between fully digital and hybrid beamforming due to limited DoF

Rank-deficient channel:

- same DoF with both digital and hybrid beamforming

- Additional amplifiers increase SE due to improved SNR at the receiver
- Proposed scheme (b) reduces the gap to the optimal HB scheme

References