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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 $\rightarrow$ many RF-chains
- **Problem:** RF-chains are bulky and costly

MIMO Point-to-Point (P2P) system:

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

  Precoder: $\mathbf{F}_{\mathrm{opt}} = \mathbf{V}\mathbf{\Gamma}$
  Postcoder: $\mathbf{W}_{\mathrm{opt}} = \mathbf{U}^H$

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

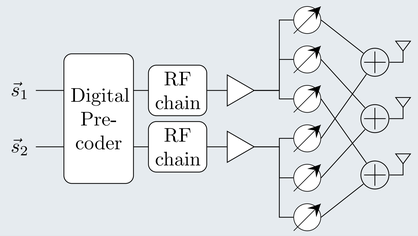
  $$\mathbf{F} = \mathbf{F}_{\mathrm{A}}\mathbf{F}_{\mathrm{D}} \qquad \mathbf{W} = \mathbf{W}_{\mathrm{D}}\mathbf{W}_{\mathrm{A}}$$

  - limited flexibilty of $\mathbf{F}_{\mathrm{A}},\ \mathbf{W}_{\mathrm{A}}$ 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)?

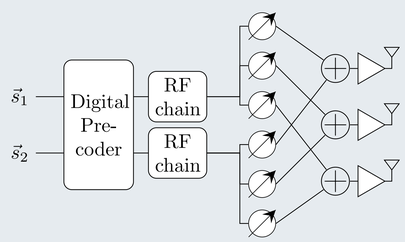
Hybrid Beamforming Architectures

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



- **Scheme from [Sohrabi, Yu]:**
  - Algorithm to determine $\mathbf{F}_{\mathrm{A}}$ (phase shifters)
  - $\mathbf{F}_{\mathrm{D}}$ given based on $\mathbf{F}_{\mathrm{A}},\ \mathbf{H}$ and $\mathbf{\Gamma}$

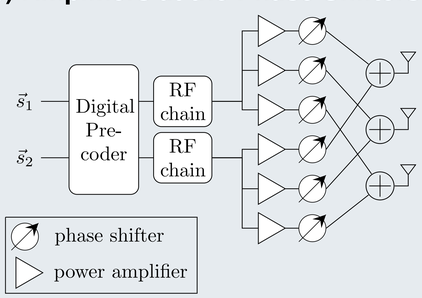
(b) Amplifiers at the Antennas $\longrightarrow N_{\mathrm{t}}$ amplifiers



- **Proposed scheme:**
  - Phase shifter matrix $\mathbf{F}_{\mathrm{PS}}$ and $\mathbf{F}_{\mathrm{D}}$ as in [Sohrabi, Yu]
  - Precoder: $\mathbf{F} = \begin{pmatrix} \beta_1 & 0 & 0 \\ 0 & \beta_2 & 0 \\ 0 & 0 & \beta_3 \end{pmatrix} \mathbf{F}_{\mathrm{PS}}\mathbf{F}_{\mathrm{D}}$

    $\rightarrow$ Independent scaling of rows of $\mathbf{F}$ by β
  - determine $\beta \longrightarrow \|\mathbf{f}_i\| = \|\mathbf{v}_{\mathrm{c},i}\|$

(c) Amplifiers at the Phase Shifters $\longrightarrow N_{\mathrm{RF}}N_{\mathrm{t}}$ amplifiers



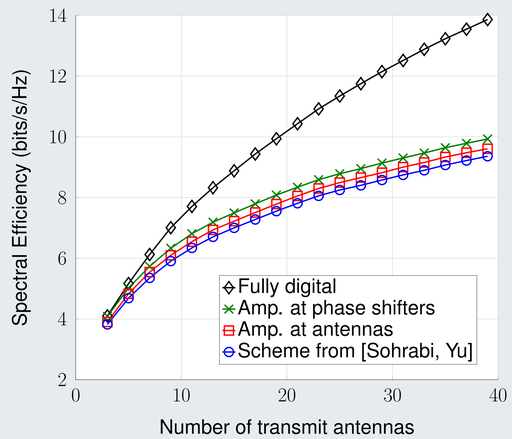
- **Optimal hybrid scheme:**
  - High analog precoder design flexibility: amplitude and phase
  - determine phase shifters and amp. gains such that

    $$\mathbf{F} = \mathbf{V}_c\mathbf{\Gamma},$$

Numerical Results

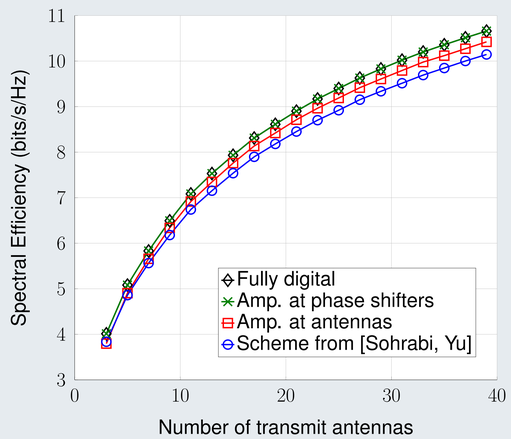
- **P2P-MIMO system** with 8 receive antennas, 2 RF-chains, geometric channel model, Kronecker model for rank-deficient channel

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

[Sohrabi, Yu] F. Sohrabi and W. Yu, "Hybrid Digital and Analog Beamforming Design for Large-Scale Antenna Arrays", *IEEE Journal of Selected Topics in Signal Processing*, 2016

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