Effects of Mutual Coupling on Lattice Reduction-Aided Millimeter Wave Hybrid Beamforming

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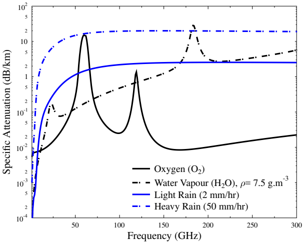
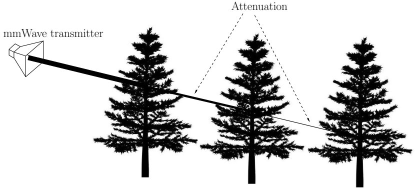
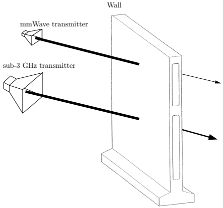
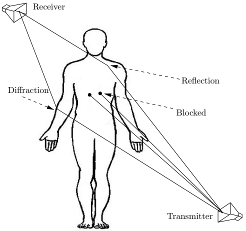
Overview

mmWave Challenges







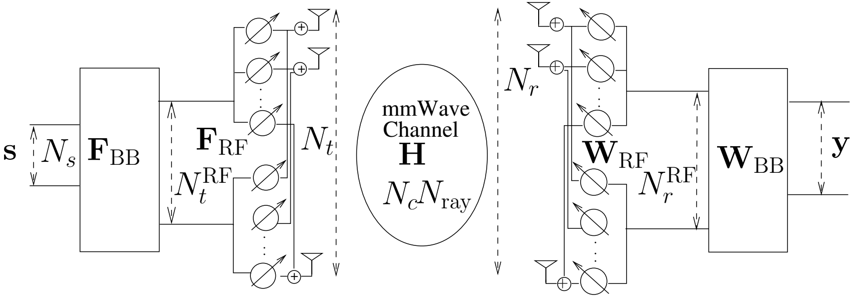


I. A. Hemadeh, **K. Satyanarayana**, M. El-Hajjar, L. Hanzo "Millimeter-Wave Communications: Physical Channel Models, Design Considerations, Antenna Constructions and Link-Budget" IEEE Communications Surveys & Tutorials 2018.

mmWave Challenges

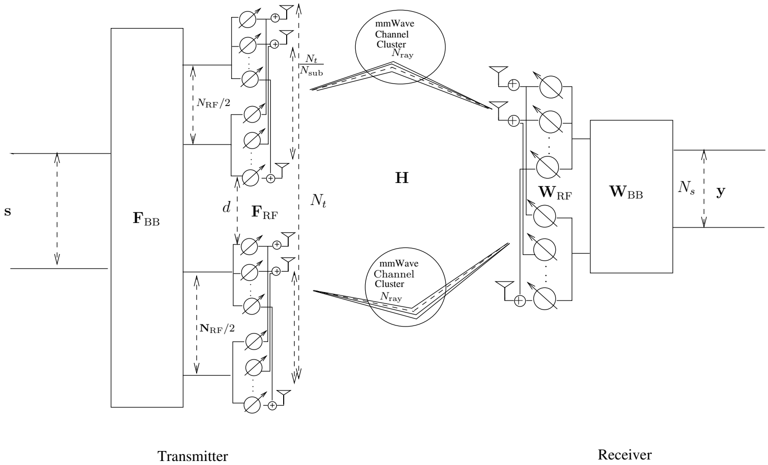
- Directional transmission is employed to mitigate the losses
- Conventional MIMO relies heavily on digital signal processing
  - Dedicated RF chains (ADCs) for every antenna element
- Large number of antennas are employed at mmWave frequencies
  - Dedicating RF chains per antenna would incur more cost and complexity
- Analog signal processing along with digital processing, termed hybrid beamforming is a plausible solution [X. Zhang '05]
- State-of-the-art hybrid beamforming designs include fully-connected architecture and sub-array-connected architecture

Fully-Connected Architecture



- The phase shifters of each RF chain are connected to all the transmit antennas
- Number of phase shifters required is equal to $N_t N_t^{\mathrm{RF}}$

Dual-Function Hybrid Architecture

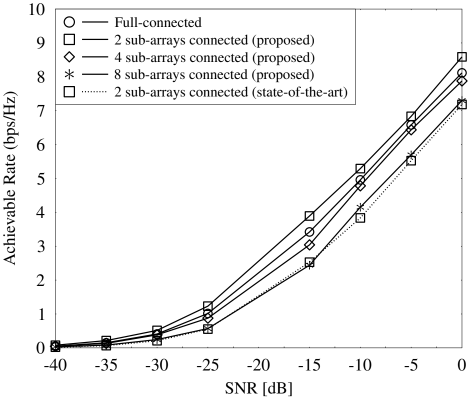


- Beamforming + Diversity
- Number of phase shifters required is equal to $N_t N_{\text{sub}}^{\text{RF}}$

K. Satyanarayana, et al., "Dual-Function Hybrid Beamforming and Transmit Diversity Aided Millimeter Wave Architecture", IEEE TVT 2017.

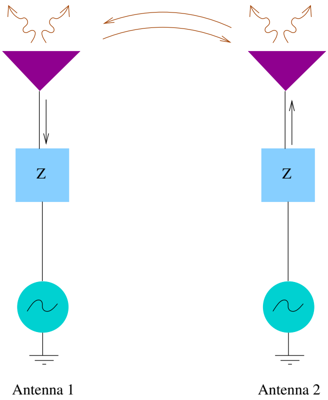
Dual-Function Hybrid Architecture

- Beamforming gain is halved for every sub-array partition
- Diversity gain is achieved instead, which is more than the reduction in BF loss for 2 sub-arrays. However, diversity gain diminishes with the increase in the number of sub-arrays

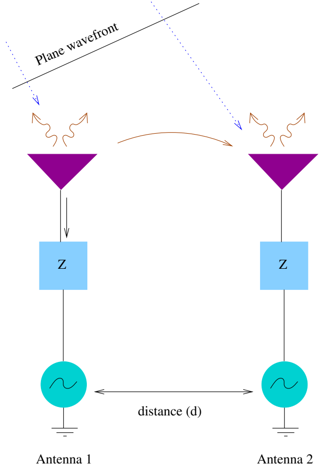


Mutual Coupling

- Transmitting mode



- Receiving mode



System Model

The received signal vector y after hybrid precoding and combining is given by

Received Signal Vector

$$\mathbf{y} = \sqrt{P}\mathbf{W}_{\mathrm{BB}}^{H}\mathbf{W}_{\mathrm{RF}}^{H}\mathbf{H}\mathbf{C}\mathbf{F}_{\mathrm{RF}}\mathbf{F}_{\mathrm{BB}}\mathbf{s} + \mathbf{W}_{\mathrm{BB}}^{H}\mathbf{W}_{\mathrm{RF}}^{H}\mathbf{n} \quad (1)$$

Channel Model

$$\mathbf{H} = \sqrt{\frac{N_r N_t}{N_c N_{\mathrm{ray}}}} \sum_{n_c=1}^{N_c} \sum_{n_{\mathrm{ray}}=1}^{N_{\mathrm{ray}}} \alpha_{n_c}^{n_{\mathrm{ray}}} \mathbf{a}_r(\phi_{n_c}^{n_{\mathrm{ray}}}) \mathbf{a}_t^T(\phi_{n_c}^{n_{\mathrm{ray}}}) \quad (2)$$

Coupling Matrix

$$\mathbf{C} = (Z_A + Z_T)\left(\mathbf{Z} + Z_T \mathbf{I}_{N_t}\right)^{-1} \quad (3)$$

where Z_A is the antenna impedance and Z_T is the load impedance.

Achievable Rate (1/2)

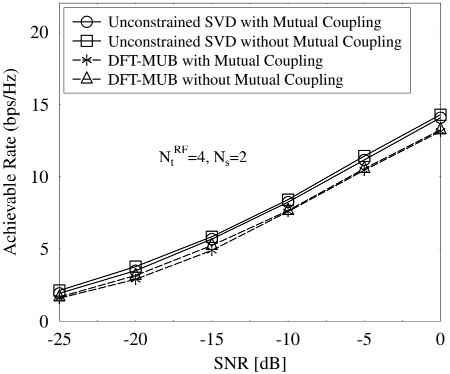


Figure: 64×32 MIMO while d is 2λ.

Table: Simulation parameters.

Parameters	*Values*
N_c	4
N_{ray}	6
N_t	64, 8
N_r	32, 8
N_t^{RF}	4
N_r^{RF}	2
$\phi_{n_c}^{n_{ray}}$	$\sim \mathcal{U}[0, 2\pi)$

K. Satyanarayana, et al., "Millimeter Wave Hybrid Beamforming with DFT-MUB Aided Precoder Codebook Design," in Proc. VTC 2017.

Achievable Rate (2/2)

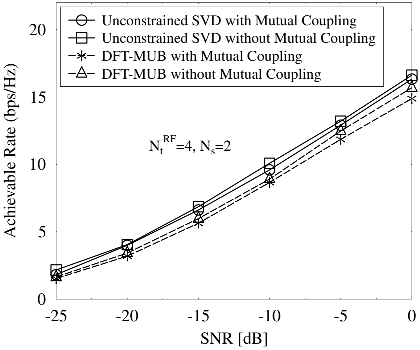


Figure: d is $\lambda/2$.

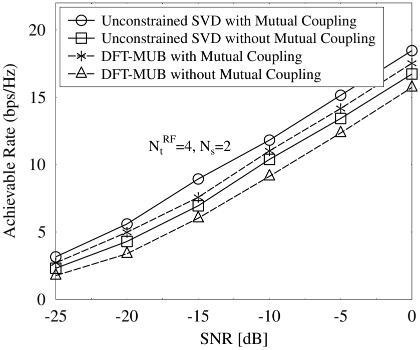
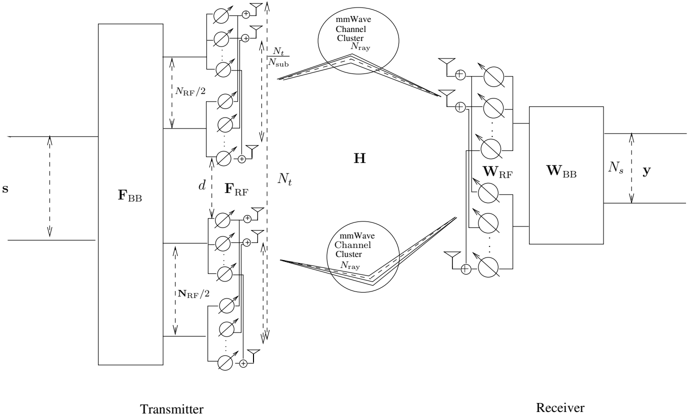


Figure: d is $\lambda/4$.

Bit Error Ratio (BER) (1/2)



- At the receiver side, element-based lattice reduction (ELR)-aided detection is employed owing to its low complexity

O. H. Toma and M. El-Hajjar, "Element-based lattice reduction aided K-best detector for large-scale MIMO systems," in Proc. SPAWC 2016.

Bit Error Ratio (BER) (2/2)

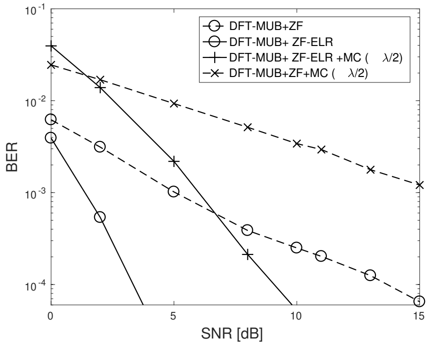


Figure: 8 × 8 MIMO, ELR-Aided BER

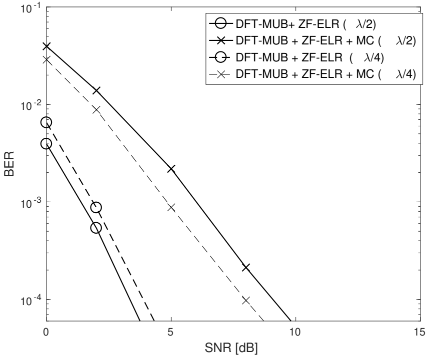


Figure: BER when d is $\lambda/2$, $\lambda/4$.

Conclusions

- Mutual coupling is not always detrimental
- For very small values of d, mutual coupling is beneficial, while for large values of d mutual coupling has no effect
- For small-to-moderate spacing between antennas, mutual coupling has detrimental effects

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