Map-Reduce Based Hybrid Beamforming: Trade-Off between Complexity and Cost

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Introduction

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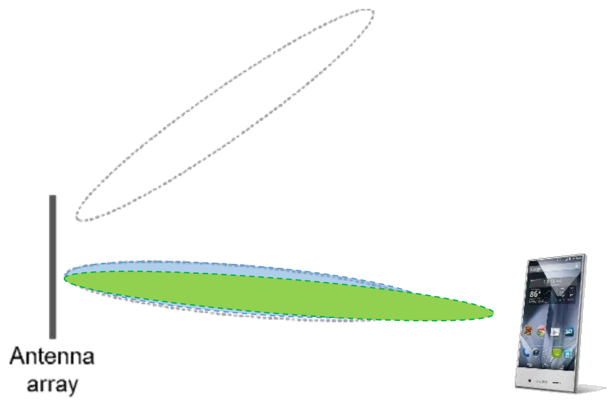
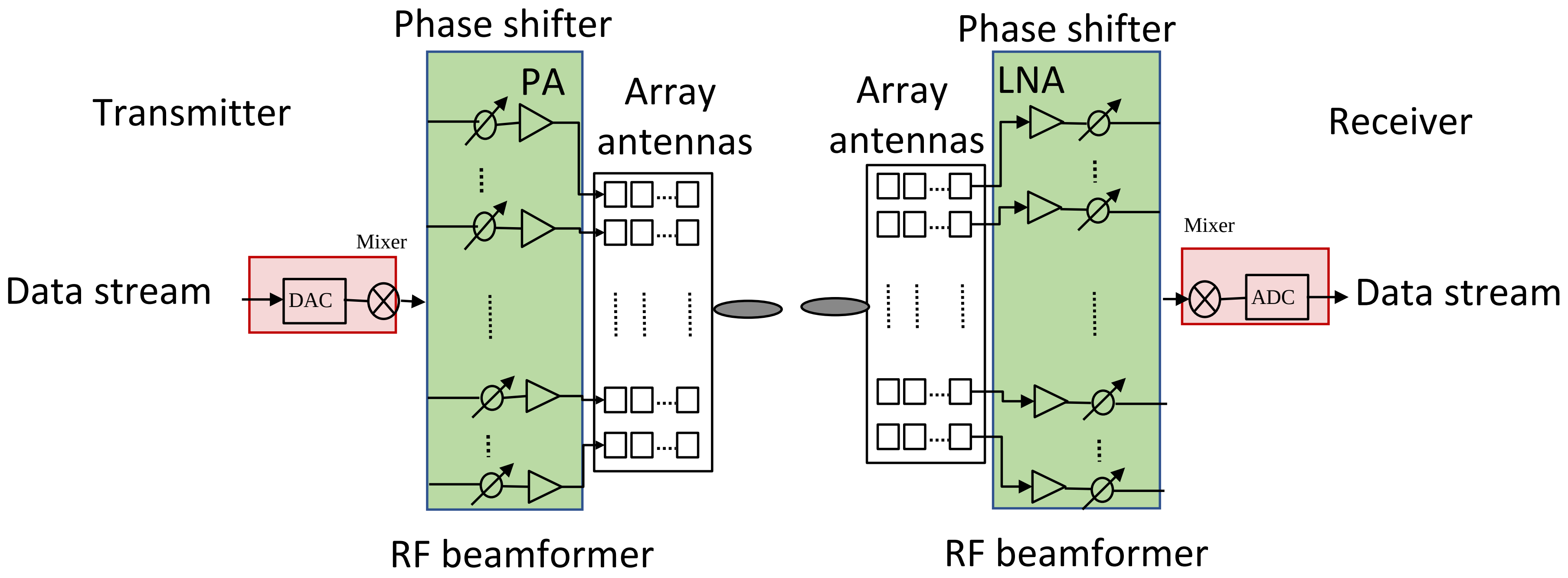
Beamforming

- With beamforming:
  - Direct the antenna pattern to the preferable propagation path.
  - Steer null to the interferer.



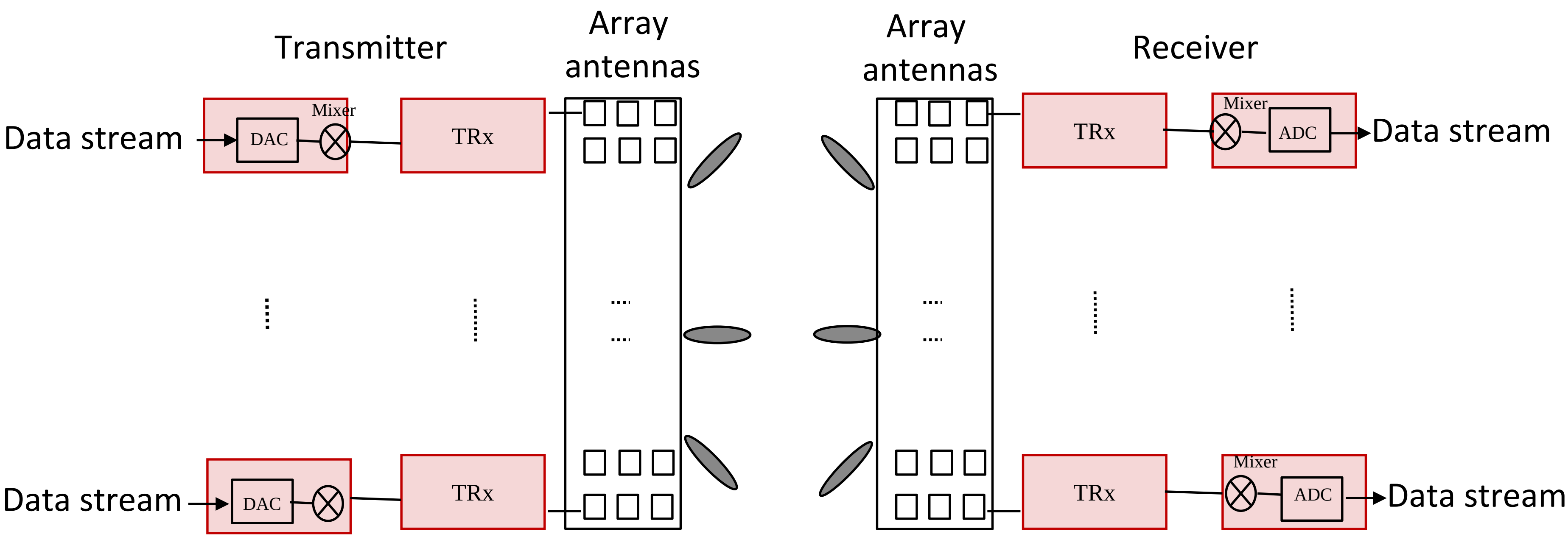
Analog Beamforming



Pro: Cost-effective

Con: Handles one data stream and generates one signal beam at a time

Digital Beamforming



Pro: Handles multiple data streams and generates multiple beams simultaneously

Con: Large number of RF chains and mixed signal components

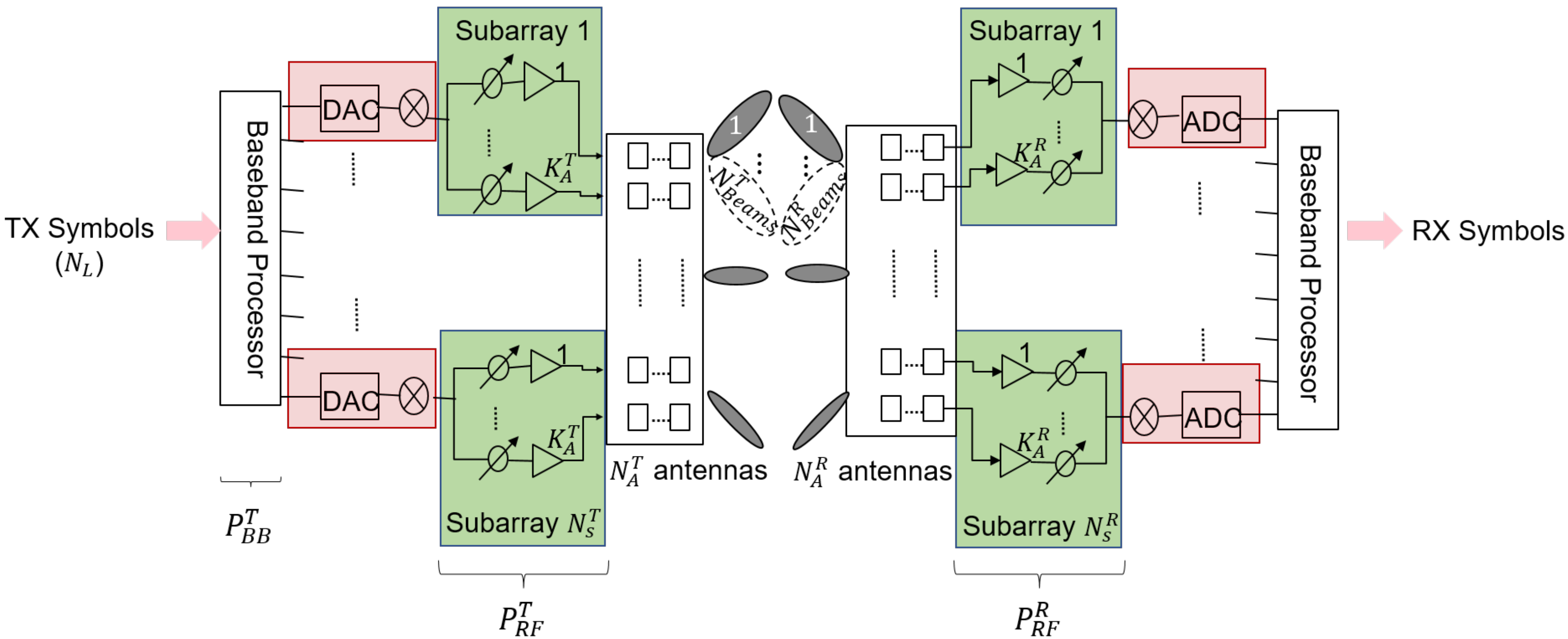
Hybrid Beamforming

- Combines analog beamformers in RF domain and digital beamformers in baseband.

- Number of RF chains is lower-bounded by the number of data streams.

- Beamforming gain depends on the number of antenna elements.

System Model



- N_S^R vector of symbols received across the receiver subarrays:

$$y = {P_{RF}^R}^* H P_{RF}^T P_{BB}^T x + {P_{RF}^R}^* \mathrm{w}$$

Optimization Metrics for Hybrid Precoder Design

- Channel capacity
- Mutual information
- Signal-to-noise ratio (SNR)
- Total throughput (Sum rate)

Hybrid Precoder Design based on Mutual Information

- Let define $\widetilde{H}$ as:

$$\widetilde{H} = {P_{RF}^{R}}^{*} H P_{RF}^{T} P_{BB}^{T}$$

- RF and baseband precoders are computed with joint optimization:

$$\underset{P_{B}^{T} \in C_{BB}^{T} P_{RF}^{T} \in (C_{RF}^{T})^{N_S^T} P_{RF}^{R} \in (C_{RF}^{R})^{N_S^R}}{\operatorname{argmax}} log_2 \det(I + \frac{1}{\sigma^2} \widetilde{H}^{*} \widetilde{H})$$

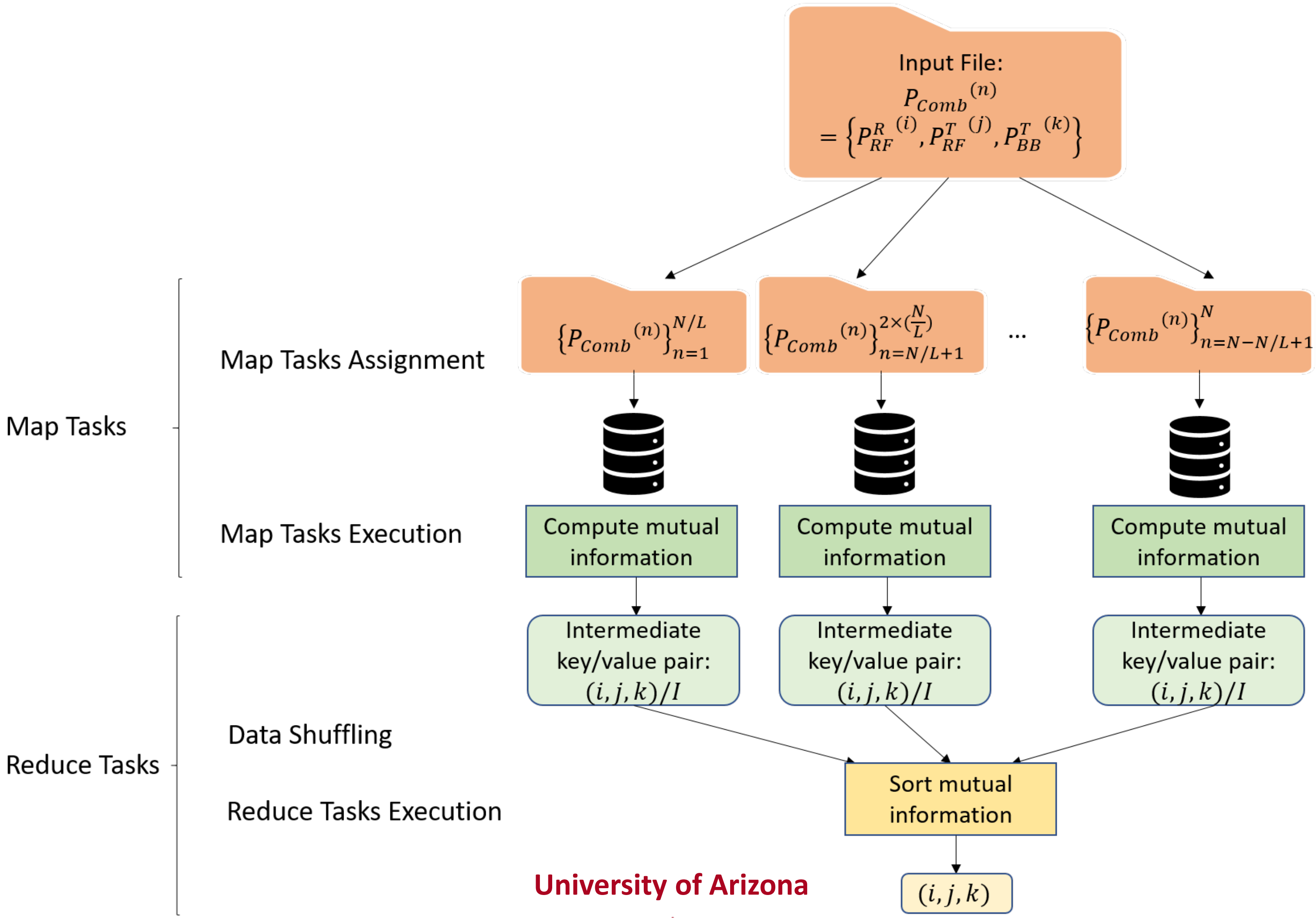
Hybrid Precoder Design Issues

- $P_{RF}^{T\,(i)} \in C_{RF}^{T} = \left\{(\emptyset_1^T, \theta_1^T), (\emptyset_2^T, \theta_2^T), \dots, \left(\emptyset_{N_{Beams}^T}^T, \theta_{N_{Beams}^T}^T\right)\right\}, i = 1, \dots, N_S^T$
- $P_{RF}^{R\,(j)} \in C_{RF}^{R} = \left\{(\emptyset_1^R, \theta_1^R), (\emptyset_2^R, \theta_2^R), \dots, \left(\emptyset_{N_{Beams}^R}^R, \theta_{N_{Beams}^R}^R\right)\right\}, j = 1, \dots, N_S^R$
- $P_{BB}^{T} \in C_{BB}^{T} = \left\{P_{BB}^{T\,(1)}, P_{BB}^{T\,(2)}, \dots, P_{BB}^{T\,(N_B^T)}\right\}$
- The total number of precoder combinations:

$$N_{Comp} = (N_{Beams}^R)^{N_S^R} \times (N_{Beams}^T)^{N_S^T} \times N_B^T$$

Map-Reduce Based Hybrid Beamforming

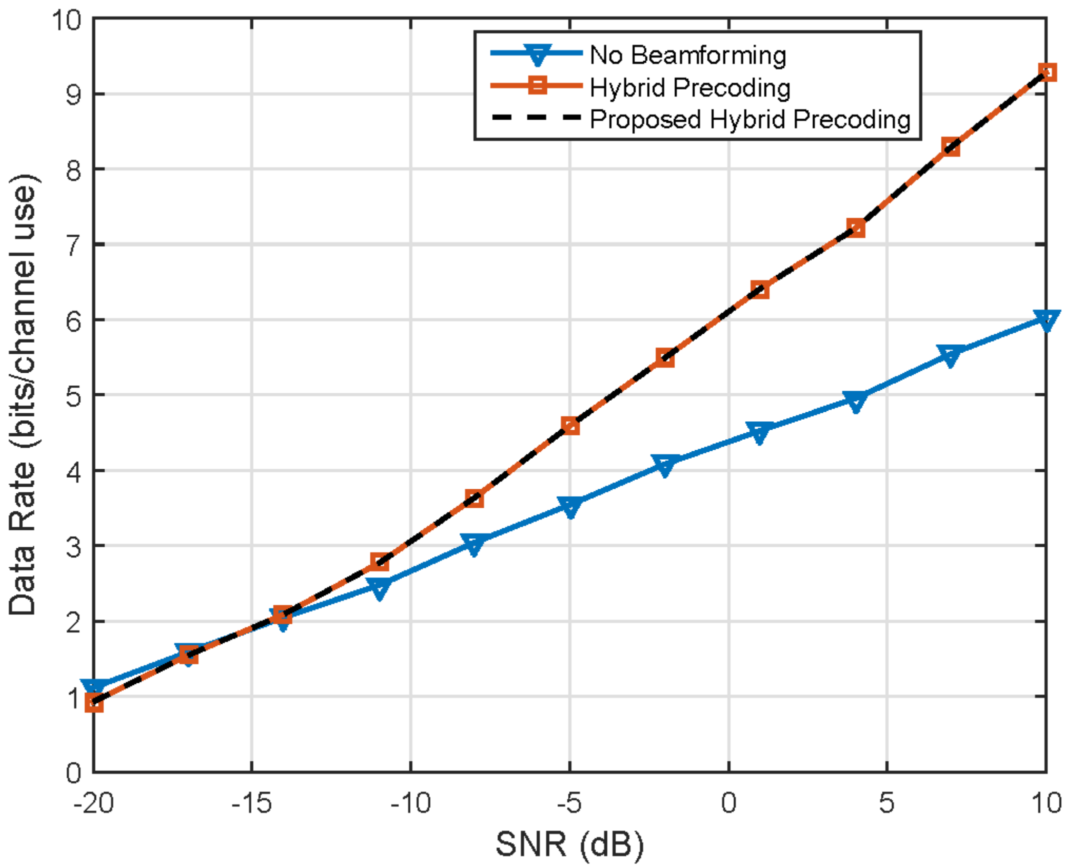
Map-Reduce Based Hybrid Beamforming



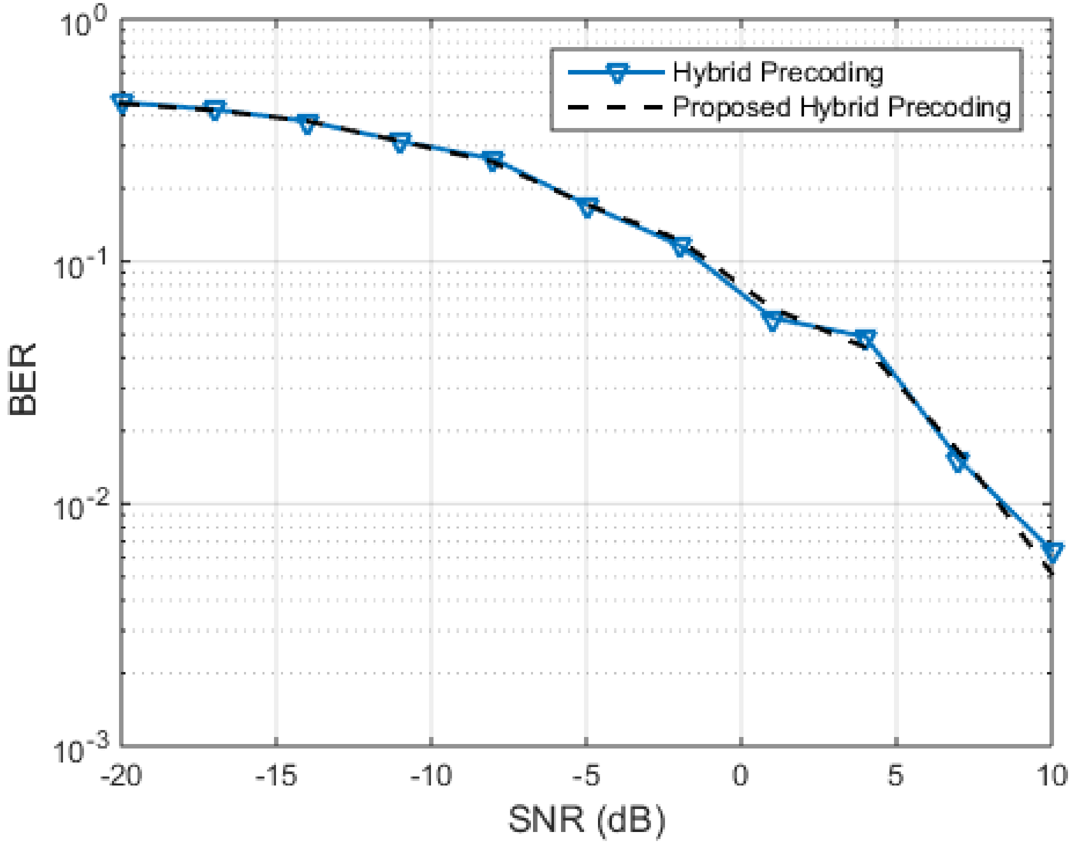
Simulation Scenario for Map-Reduce Based Hybrid Beamforming

Parameter	Value
Carrier Frequency	30 GHz
Number of Transmitter Antennas	16
Number of Receiver Antennas	8
Number of Subarrays at Transmitter	2
Number of Subarrays at Receiver	2
Number of Beams at each Transmitter Subarray	12
Number of Beams at each Receiver Subarray	8

Results of Map-Reduce Based Hybrid Beamforming

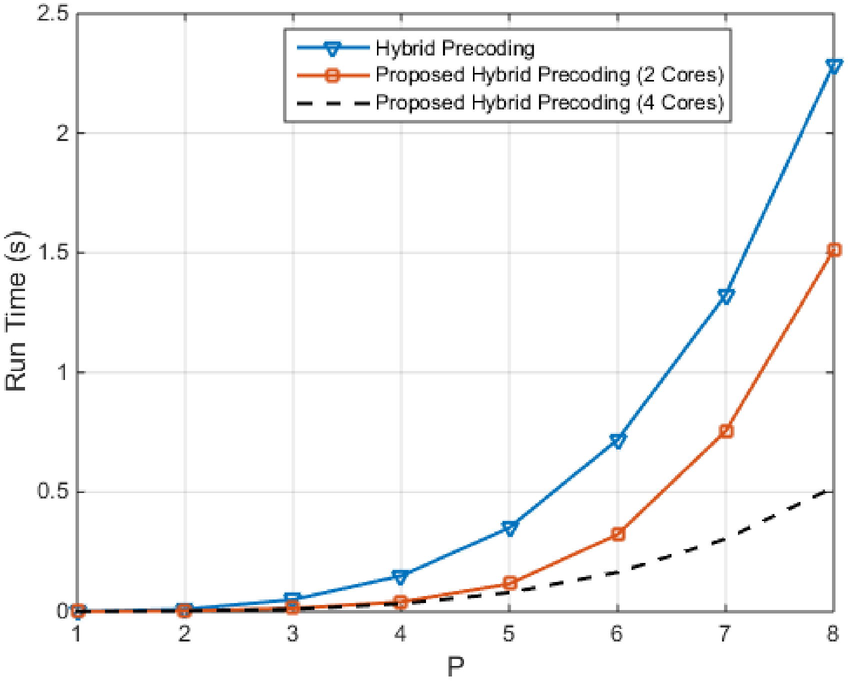


Results of Map-Reduce Based Hybrid Beamforming



Results of Map-Reduce Based Hybrid Beamforming

P: Number of available beams at the transmitter and the receiver



Issues on Map-Reduce Based Hybrid Beamforming Algorithm

- The communication load:

$$CommLoad \ = QN\left(1 - \frac{1}{L}\right)$$

grows linearly with

$$N = (N_{Beams}^{R})^{N_S^R} \times (N_{Beams}^{T})^{N_S^T} \times N_B^T .$$

Optimized Map-Reduce Based Hybrid Beamforming

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Optimized Map-Reduce for Reduced Complexity Hybrid Beamforming

- Divides precoder matrices into submatrices.

$$\left[\begin{array}{c|c} {P_{RF}^{T}}^{(1)} & {P_{RF}^{T}}^{(2)} \end{array}\right] \quad \left[\begin{array}{c|c} {P_{RF}^{R}}^{(1)} & {P_{RF}^{R}}^{(2)} \end{array}\right] \quad \left[\begin{array}{c|c} {P_{BB}^{T}}^{(1)} & {P_{BB}^{T}}^{(2)} \end{array}\right]$$

$$\left[\begin{array}{c} {P_{RF}^{T}}^{(1)} \\ \hline {P_{RF}^{T}}^{(2)} \end{array}\right] \quad \left[\begin{array}{c} {P_{RF}^{R}}^{(1)} \\ \hline {P_{RF}^{R}}^{(2)} \end{array}\right] \quad \left[\begin{array}{c} {P_{BB}^{T}}^{(1)} \\ \hline {P_{BB}^{T}}^{(2)} \end{array}\right]$$

Optimized Map-Reduce for Reduced Complexity Hybrid Beamforming

- If the following partitioning

$$P_{RF}^{T} = \left[{P_{RF}^{T}}^{(1)} \quad {P_{RF}^{T}}^{(2)} \quad \cdots \quad {P_{RF}^{T}}^{(N_S^T)} \right]_{N_A^T \times N_S^T}$$

$$P_{RF}^{R} = \left[{P_{RF}^{R}}^{(1)} \quad {P_{RF}^{R}}^{(2)} \quad \cdots \quad {P_{RF}^{R}}^{(N_S^R)} \right]_{N_A^R \times N_S^R}$$

$$P_{B}^{T} = \left[{P_{B}^{T}}^{(1)} \quad {P_{B}^{T}}^{(2)} \quad \cdots \quad {P_{B}^{T}}^{(N_L)} \right]_{N_S^T \times N_L}$$

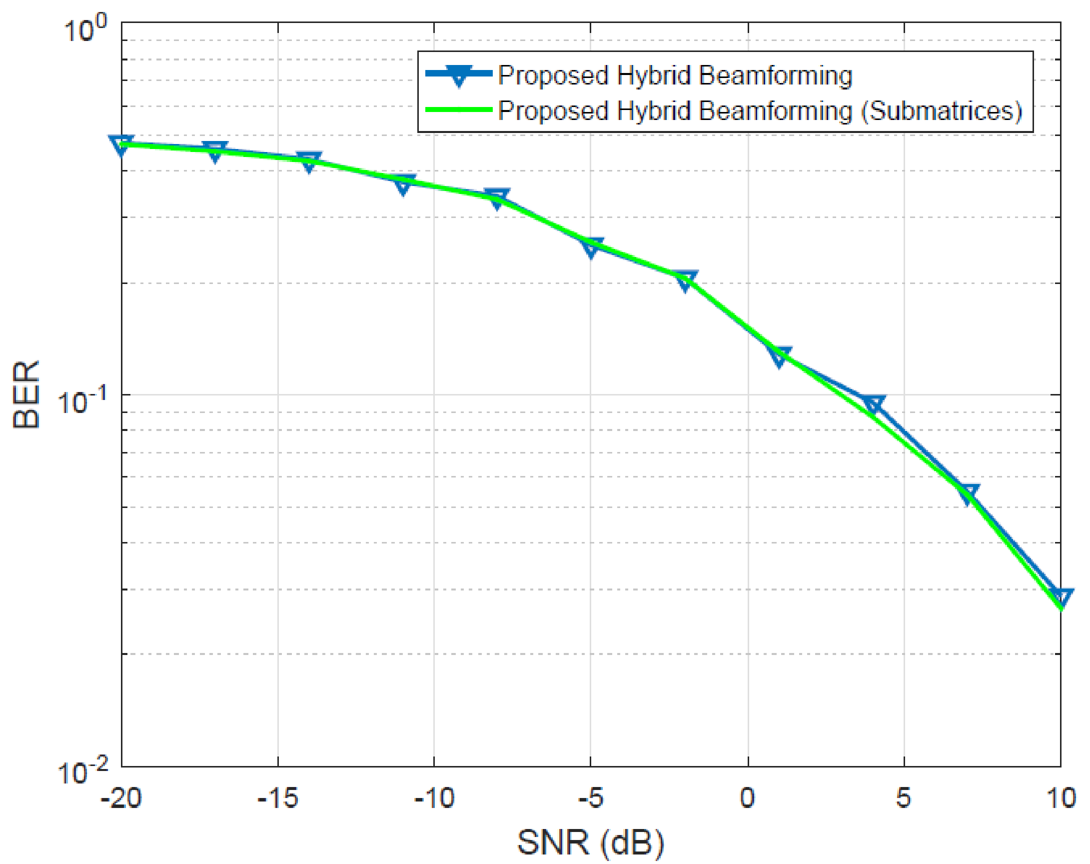
is used, the total number of precoder combinations becomes:

$$N_{Comp} = N_S^R \times N_S^T \times N_{Beams}^R \times N_{Beams}^T \times N_B^T$$

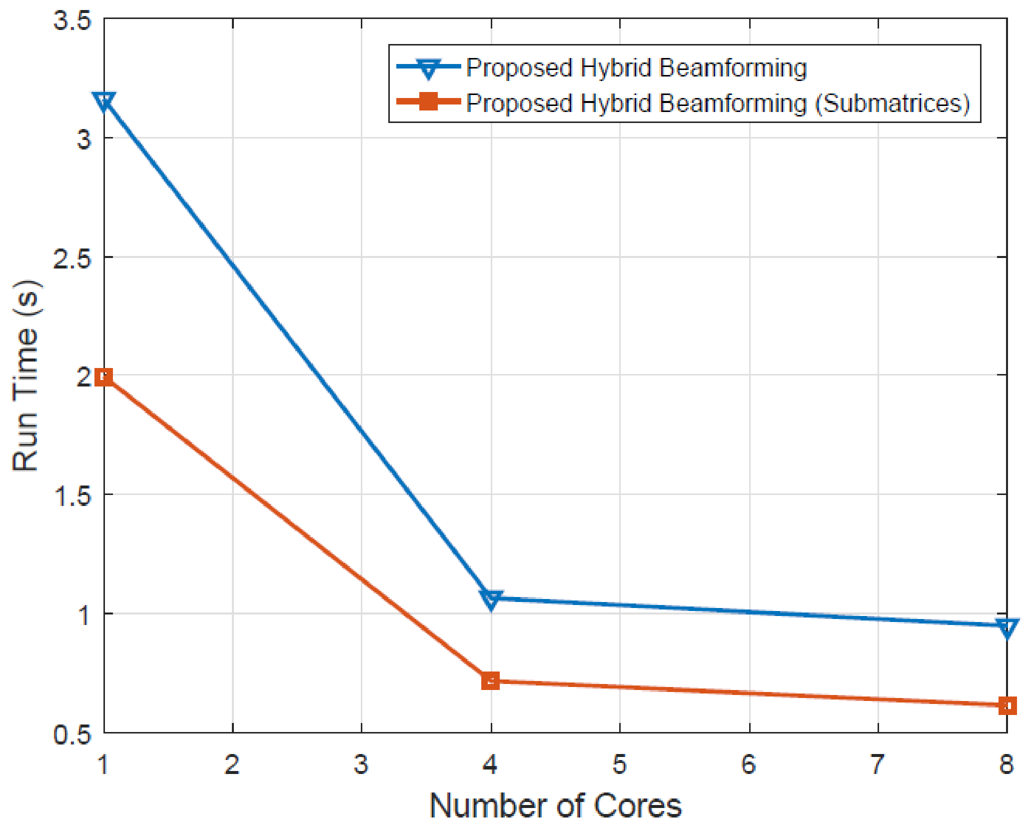
Simulation Scenario for Optimized Map-Reduce Based Hybrid Beamforming

Parameter	Value
Carrier Frequency	30 GHz
Number of Transmitter Antennas	16
Number of Receiver Antennas	8
Number of Subarrays at Transmitter	2 and 4
Number of Subarrays at Receiver	2 and 4
Number of Beams at each Transmitter Subarray	6
Number of Beams at each Receiver Subarray	4

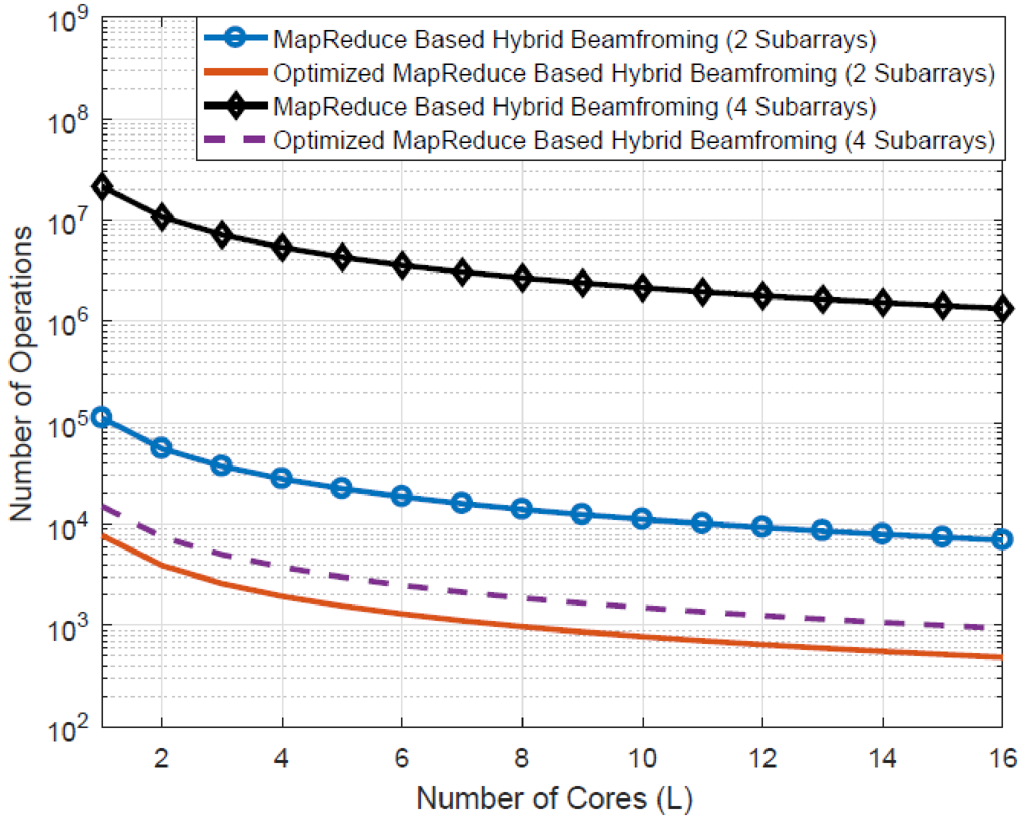
Results of Optimized Algorithm



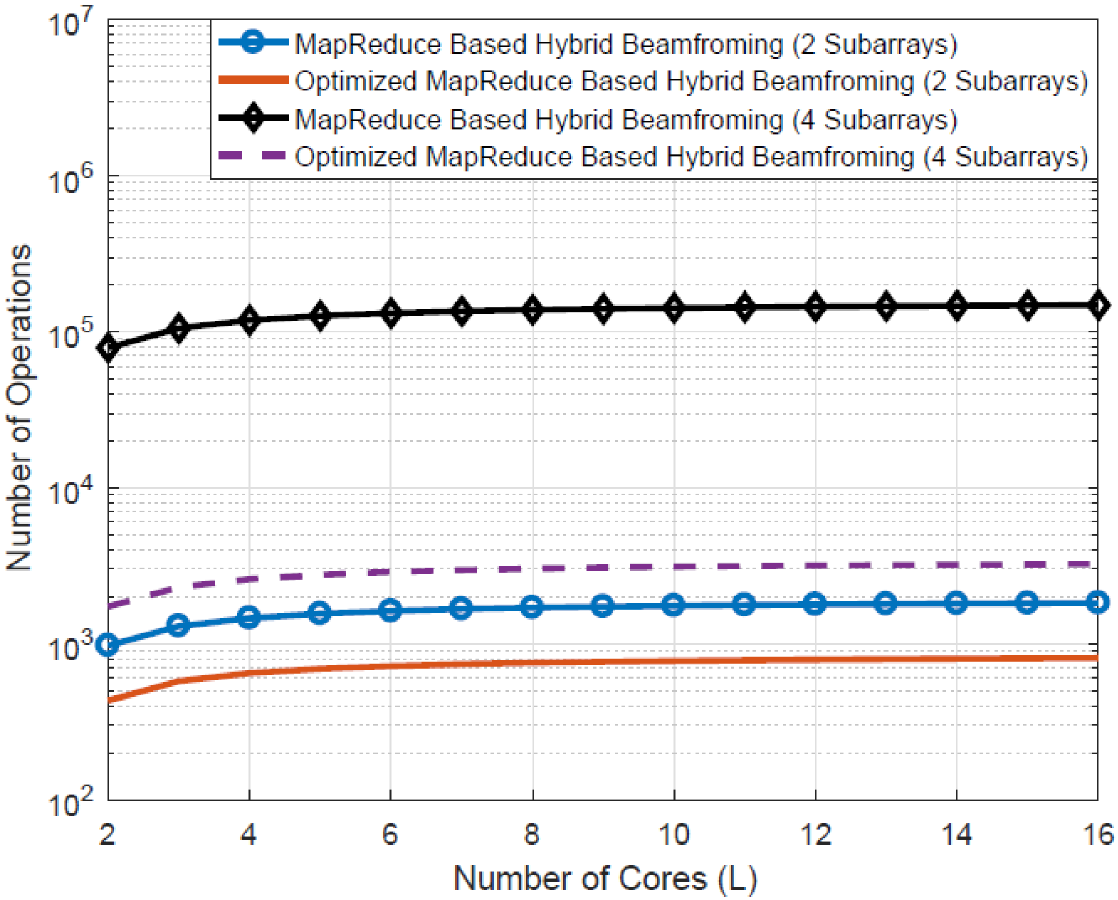
Results of Optimized Algorithm



Results of Optimized Algorithm



Results of Optimized Algorithm



Conclusion & Future Work

Conclusion

- We propose a novel hybrid beamforming algorithm that finds the optimal precoders with MapReduce framework.
- The complexity has been significantly reduced with MapReduce based hybrid beamforming algorithm.
- Both the computational complexity and the communication load are further reduced with the optimized algorithm.

Future Work

- We will study coded MapReduce for hybrid beamforming.
- We aim to show that coding reduces communication load of MapReduce based hybrid beamforming and speeding up the overall computations.

Questions?