A Novel Hybrid Precoder With Low-Resolution Phase Shifters and Fronthaul Capacity Limitation

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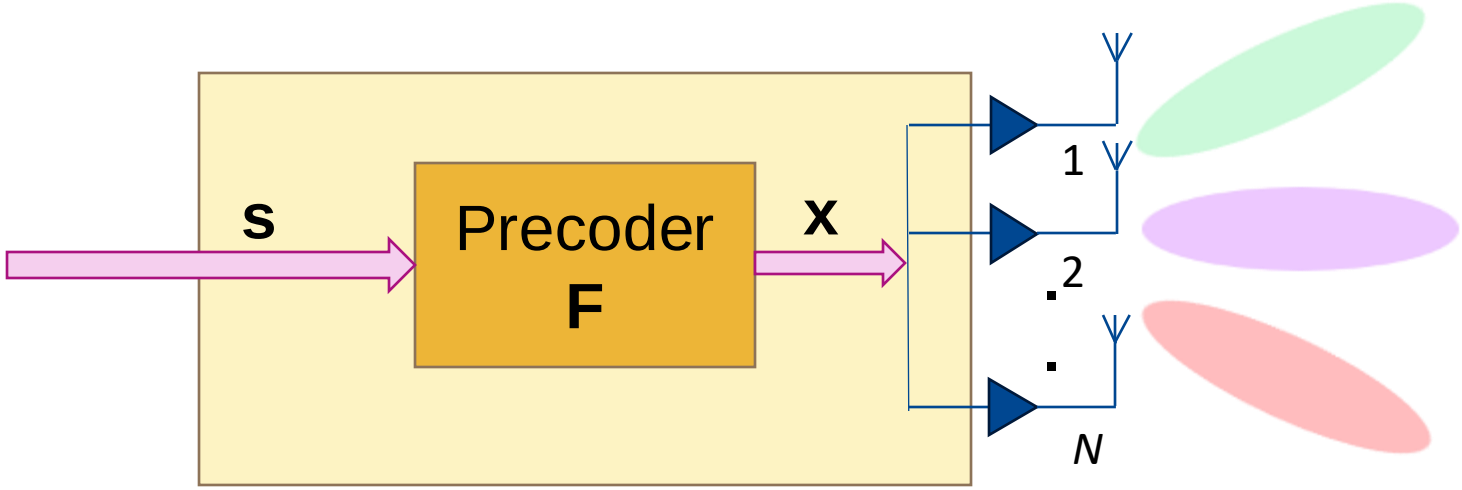
Precoding



$$\mathbf{x} = \mathbf{F}\mathbf{s}$$

Precoded signal to be transmitted

Precoding Matrix

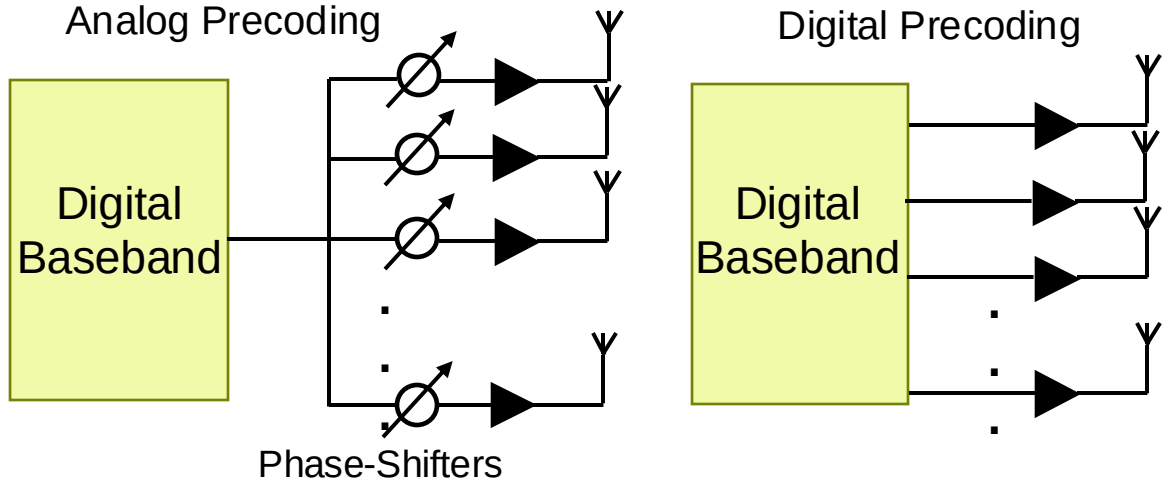
Input data symbols

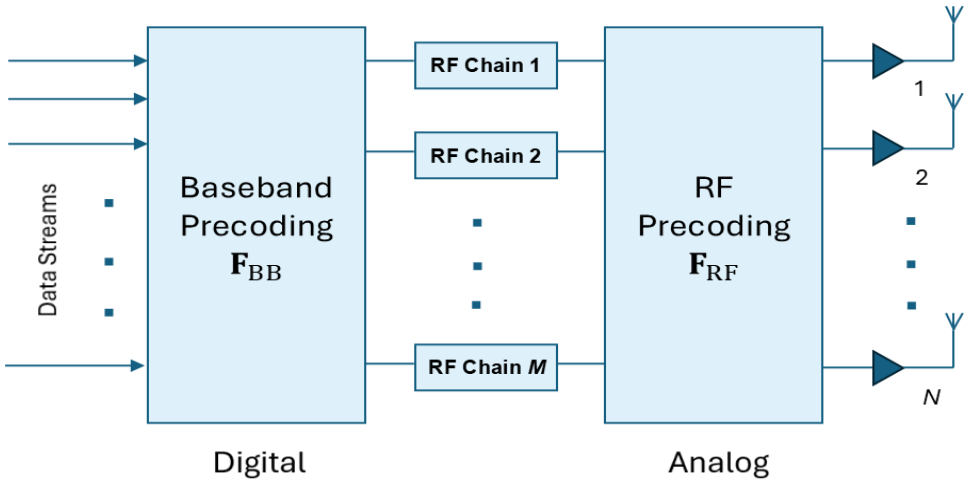
Precoding is a signal processing technique used in MIMO wireless systems where the transmitter pre-processes the signals before transmission to

1. Combat channel effects
2. Enable spatial multiplexing

Hybrid Precoding

- **Analog Precoding** is implemented using phase shifters, which adjust only the phase of the transmitted signals without altering their amplitude.
- **Digital Precoding** allows for precise control over signal phases and amplitudes but requires a separate RF chain for each antenna.
- **Hybrid Precoding** reduces the number of RF chains, enabling large antenna arrays with lower cost and power consumption.

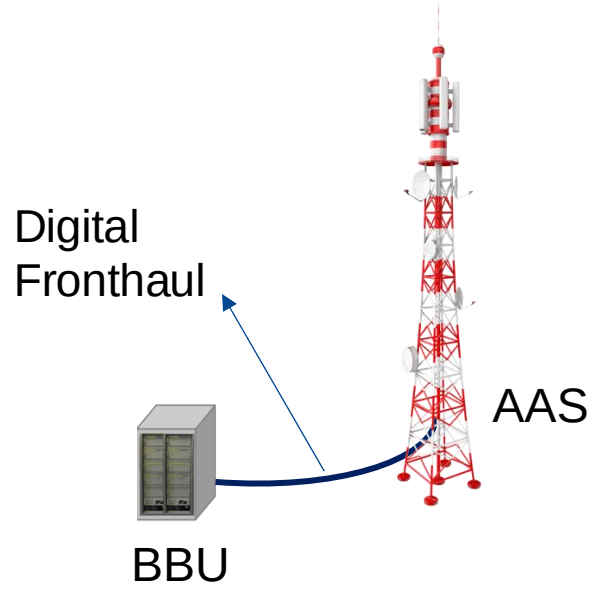




Practical Constraints

- The phase shifters used in analog precoders typically have limited resolution which means that we can only select phase shifts from a discrete set.
- Another practical constraint is the fronthaul capacity limitation which means that the entries of the digital precoder must belong to a discrete set.
- Our objective is to design the analog and digital precoders while taking into account these practical constraints.

$$\text{minimize}_{\mathbf{F}_{\text{RF}},\mathbf{F}_{\text{BB}}} \|\mathbf{F}_{\text{FD}} - \mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}\|_F^2$$
$$\mathbf{F}_{\text{RF}} \in \mathcal{A}^{N\times M}$$
$$\mathbf{F}_{\text{BB}} \in \mathcal{B}^{M\times KS}$$



N: Number of antennas
K: Number of users
$\mathcal{A}$: Set of phase shift values
M: Number of RF chains
S: Number of sub-carriers
$\mathcal{B}$: Set of digital precodeing values

Sphere Decoding-Based Hybrid Precoder Design

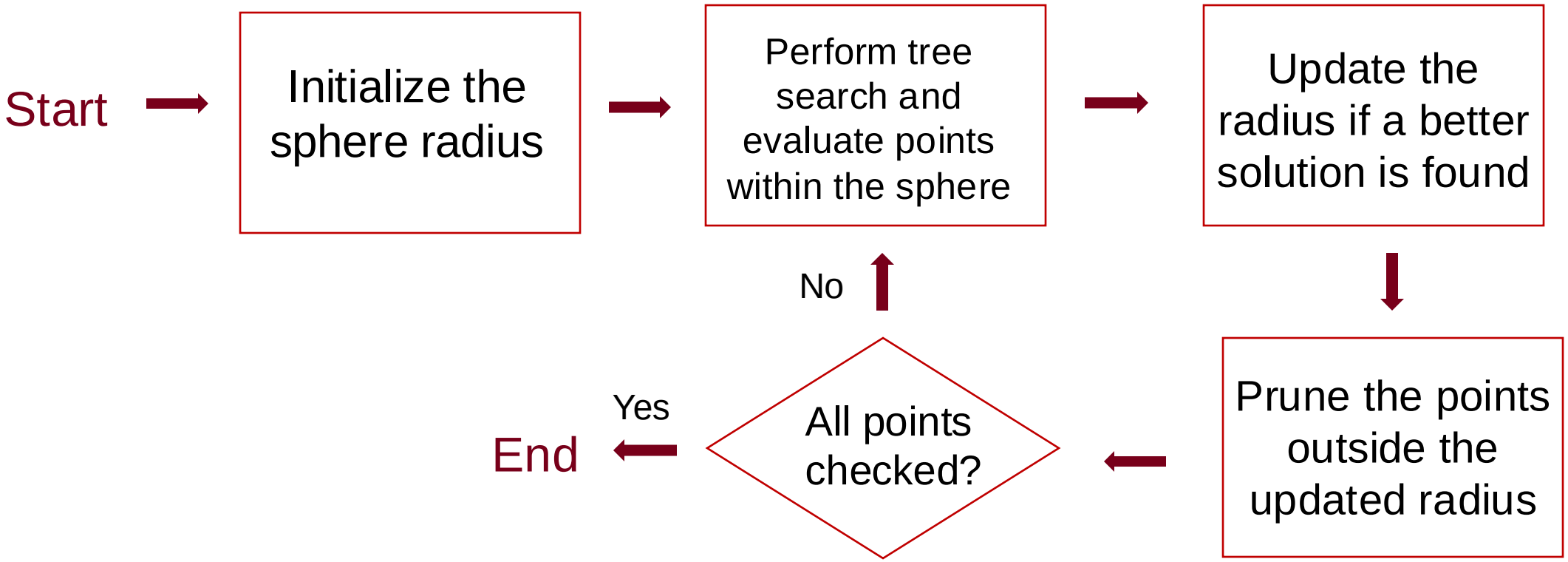
- The common approach in the literature is to solve the problem by first disregarding the discrete constraint and then map optimized continuous values to the nearest discrete ones:
- This solution is sub-optimal and leads to poor performance in multi-user scenarios.
- We propose to solve the above problem **optimally** by using sphere decoding

$$\min_{\mathbf{F}_{\mathrm{RF}}\in\mathcal{A}^{N\times M}} \|\mathbf{F}_{\mathrm{FD}} - \mathbf{F}_{\mathrm{RF}}\mathbf{F}_{\mathrm{BB}}\|_F^2 \rightarrow \min_{\mathbf{F}_{\mathrm{RF}}\in\mathcal{A}^{N\times M}} \left\|\mathbf{F}_{\mathrm{FD}}^{\mathrm{T}} - \mathbf{F}_{\mathrm{BB}}^{\mathrm{T}}\mathbf{F}_{\mathrm{RF}}^{\mathrm{T}}\right\|_F^2 \rightarrow \min_{\mathbf{F}_{\mathrm{RF}}\in\mathcal{A}^{N\times M}} \sum_{n=1}^{N} \left\|\mathbf{f}_{\mathrm{FD,n}}^{\mathrm{T}} - \mathbf{F}_{\mathrm{BB}}^{\mathrm{T}}\mathbf{f}_{\mathrm{RF,n}}^{\mathrm{T}}\right\|^2$$

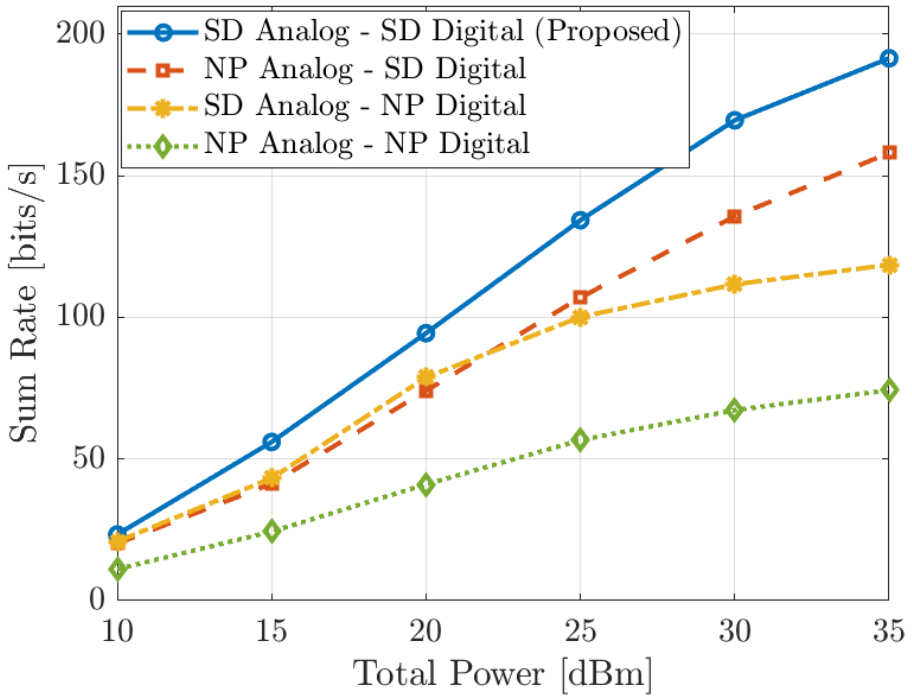
$$\rightarrow \min_{\mathbf{f}_{\mathrm{RF,n}}\in\mathcal{A}^{M}} \left\|\mathbf{f}_{\mathrm{FD,n}}^{\mathrm{T}} - \mathbf{F}_{\mathrm{BB}}^{\mathrm{T}}\mathbf{f}_{\mathrm{RF,n}}^{\mathrm{T}}\right\|^2$$

- This problem can be solved using the sphere decoding algorithm
- Instead of searching through all vectors, sphere decoding restricts the search to a smaller set within a sphere of a certain radius

Sphere Decoding



Performance Evaluation



- The design with sphere decoding-based analog and digital precoders performs the best because it better approximates the fully-digital precoder.
- At high transmit powers, the design with sphere decoding-based digital precoder outperforms the one with sphere decoding-based analog precoder, as the digital precoder controls both the phase and amplitude of the transmitted signal.

$N = 64, M = 8, K = 2, S = 16$

Resolution of analog and digital precoder: 1 bit

Thank you for your attention!