Rate Optimization in mmWave Reconfigurable Intelligent Surface-assisted System

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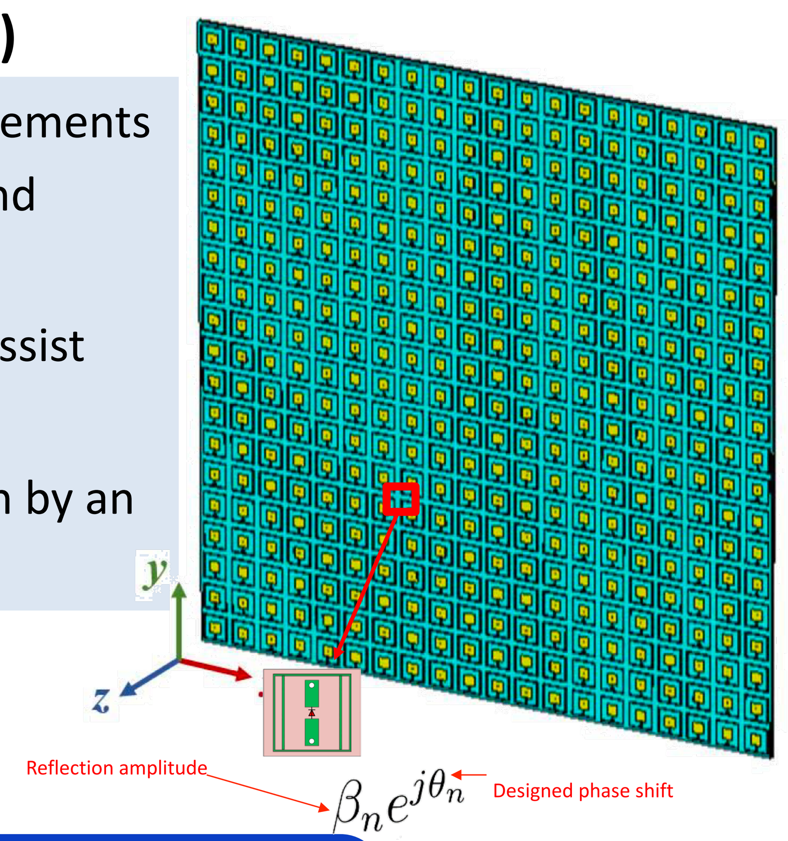
I MOTIVATION

Reconfigurable Intelligent Surfaces (RIS)

- Metasurface comprised of many passive elements consisting of tunable discrete amplitude and phase shifts of each RIS element
- Reconfigure propagation environment to assist communication
- Passive RIS enables "square-law" array gain by an N- element RIS



Goal

Design RIS phase shifts and per-subcarrier power allocation matrices in a wideband mmWave MIMO single-cell problem

Spectral Efficiency and impact of blockage and pathloss analysis

II MODELS & ASSUMPTIONS

Channel Models

Rician channel models with a geometric channel component

$$\mathsf{H}_i[l] = \sqrt{\frac{\bar{K}}{\bar{K}+1}}\bar{\mathsf{H}}_i[l] + \sqrt{\frac{1}{\bar{K}+1}}\tilde{\mathsf{H}}_i[l] \quad i = 1,2,3$$

$$\bar{\mathsf{H}}_i[l] = \sqrt{\frac{N_{\mathrm{RX}}N_{\mathrm{TX}}}{RC}}\sum_{c=0}^{C-1}\sum_{r=0}^{R-1}\beta_{rc}\mathbf{a}_{\mathrm{r}}(\phi^{\mathrm{r}}_{c,r},\varphi^{\mathrm{r}}_{c,r})\mathbf{a}^*_{\mathrm{t}}(\phi^{\mathrm{t}}_{c,r},\varphi^{\mathrm{t}}_{c,r})$$

Pathloss/Blockage Model

Probability of LOS predicts the likelihood that a UE is within a clear LOS of the receiver

$$P_{\mathrm{LOS}} = e^{-(\sqrt{D^2+(l_{\mathrm{t}}-l_{\mathrm{r}})^2}-10)/50}$$ Probability of direct path being LOS

Bernoulli pathloss model for direct path

$$\rho_{\mathrm{direct}} = \begin{cases} K_0\left(\frac{d_0}{\sqrt{D^2+(l_{\mathrm{t}}-l_{\mathrm{r}})^2}}\right)^{\alpha_{\mathrm{LOS}}} & \text{if LOS} \\ K_0\left(\frac{d_0}{\sqrt{D^2+(l_{\mathrm{t}}-l_{\mathrm{r}})^2}}\right)^{\alpha_{\mathrm{NLOS}}} & \text{if NLOS} \end{cases}$$

Indirect path pathloss

$$\rho_{\mathrm{indirect}} = \frac{256 G_{\mathrm{t}} G_{\mathrm{r}} \pi^2 d_1^2 d_2^2}{\lambda^4 (l_{\mathrm{t}}/d_1 + l_{\mathrm{r}}/d_2)^2}$$

Equivalent Channel

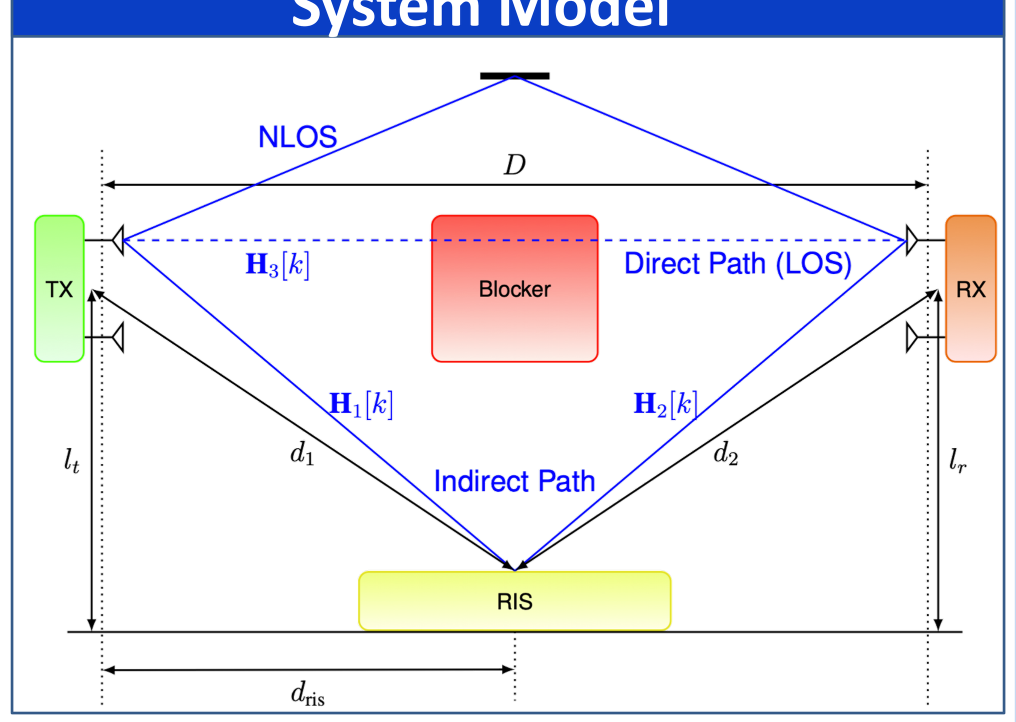
$$\mathbf{H}_{\mathrm{eq}}[k] = \sqrt{\rho_{\mathrm{direct}}}\mathbf{H}_3[k] + \sqrt{\rho_{\mathrm{indirect}}}\mathbf{H}_2[k]\mathbf{\Phi}\mathbf{H}_1[k], \forall k$$

Received Signal Model

$$\mathbf{y}[k] = \mathbf{H}_{\mathrm{eq}}[k]\mathbf{x}[k] + \mathbf{v}[k] \longrightarrow \mathcal{CN}(0, \sigma_{\mathrm{n}}^2\mathbf{I})$$

RIS Matrix: $\mathbf{\Phi} = \mathrm{diag}\{e^{j\phi_1}, \ldots, e^{j\phi_{N_{\mathrm{RIS}}}}\}$

System Model



III OPTIMIZATION

Problem Formulation

$$\max_{\mathbf{\Phi},\{\mathbf{Q}[k]\}_{k=1}^{K}} \quad \frac{1}{K}\sum_{k=1}^{K}\log_2\det\left(\mathbf{I}_{N_{\mathrm{r}}} + \frac{1}{\sigma_{\mathrm{n}}^2}\mathbf{H}_{\mathrm{eq}}[k]\mathbf{Q}[k]\mathbf{H}_{\mathrm{eq}}[k]^{\mathrm{H}}\right)$$

$$\text{s.t.} \quad |\mathbf{e}_i^T\mathbf{\Phi}\mathbf{e}_i| = 1, \quad i = 1\ldots N_{\mathrm{RIS}}$$

$$\sum_{\mathrm{k=1}}^{K}\sum_{\mathrm{g=1}}^{N_{\mathrm{s}}} P_{k,g} \leq P_{\mathrm{t}}$$

$$\mathbf{Q}[k] \succeq \mathbf{0}, k = 1, \ldots, K$$

Non-convex problem due to the unit-modular constraints on each RIS element

Approach

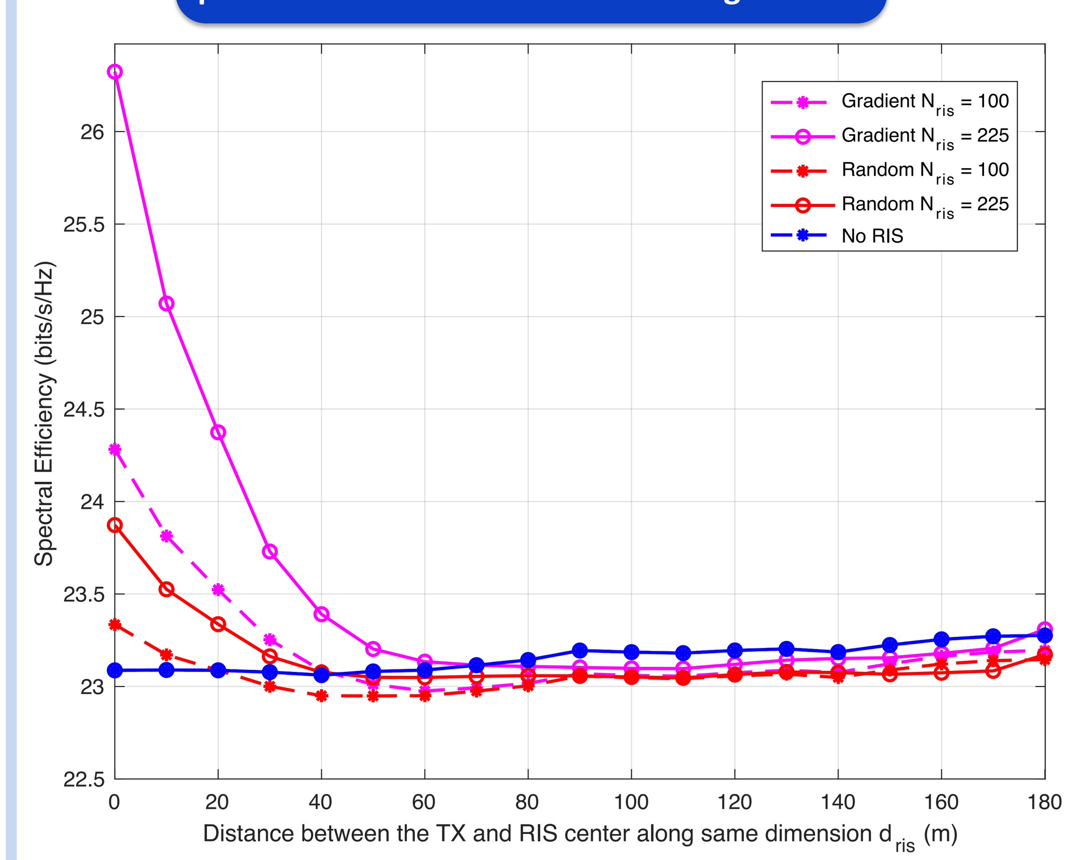
- **Projected Gradient Ascent to update phases of RIS**
- **Spatial-Frequency Waterfilling to optimize per-subcarrier power allocation matrices**

1: **Initialize** $\mathbf{\Phi}$ **with random phases taken from** $\mathcal{U}[0, 2\pi]$
2: **Set** $n = 0$
3: **Evaluate** $\mathcal{R}_n(\mathbf{Q}[k], \mathbf{\Phi})$ **using** $\mathbf{Q}[k]$, $\mathbf{\Phi}$
4: **while** $|\mathcal{R}_{n+1}(\mathbf{Q}[k], \mathbf{\Phi}) - \mathcal{R}_n(\mathbf{Q}[k], \mathbf{\Phi})| \geq \epsilon$ **do**
5: **Calculate** $\nabla_{\mathbf{\Phi}_n}\mathcal{R}(\mathbf{Q}[k], \mathbf{\Phi})$
6: **Update** $\mathrm{diag}(\mathbf{\Phi}_{n+1})$ **as:**
7: $\mathrm{diag}(\mathbf{\Phi}_{n+1}) = \mathrm{diag}(\mathbf{\Phi}_n) + \mu\,\mathrm{diag}(\nabla_{\mathbf{\Phi}_n}\mathcal{R}(\mathbf{Q}[k], \mathbf{\Phi}))$
8: **Project phase shifts in** $\mathbf{\Phi}_{n+1}$ **back to feasible set**
9: **Update each transmit covariance matrix** $\mathbf{Q}_{n+1}[k]$
10: **Evaluate** $\mathcal{R}_{n+1}(\mathbf{Q}[k], \mathbf{\Phi})$ **using** $\mathbf{Q}_{n+1}[k]$, $\mathbf{\Phi}_{n+1}$
11: **if** $\mathcal{R}_{n+1}(\mathbf{Q}[k], \mathbf{\Phi}) \leq \mathcal{R}_n(\mathbf{Q}[k], \mathbf{\Phi})$
12: **Update learning rate** μ **as** $\mu = \mu/10$
13: **end while**
14: **Evaluate the optimized** $\mathcal{R}(\mathbf{Q}[k]^\star, \mathbf{\Phi}^\star)$

IV RESULTS & CONCLUSIONS

"Non-symmetric" environment (Lt = 10m, Lr = 50m)/ No direct path

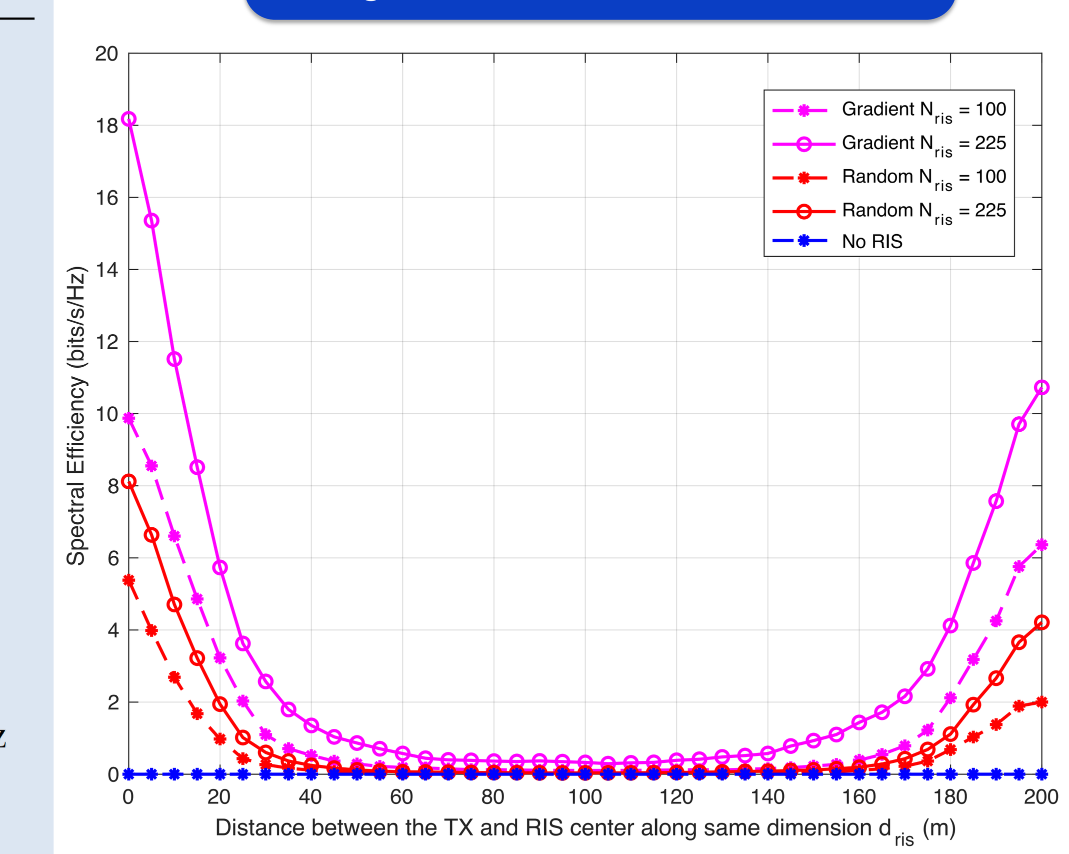
RIS position placement cutoff based on No RIS performance in comparison to RIS-performance in different Nris settings



Parameter	Value
D	200 m
l_{t}	10 m
l_{r}	50 m
H_{Tx}	12 m
H_{RIS}	12 m
H_{Rx}	2 m
LOS path loss exponent	2
NLOS path loss exponent	4
Number of subcarriers (K)	128
Number of taps (L_1, L_2, L_3)	3, 4, 5
Number of antennas at BS	32
Number of antennas at UE	4
Antenna Gain Tx	14 dBi
Antenna Gain Rx	5 dBi
Antenna inefficiency	3dB
Carrier Frequency	28 GHz
Bandwidth	100 MHz
Initial Learning Rate	.1
Convergence Error Threshold	.001

"Symmetric" environment (Lt = 10m, Lr = 10m)/Strong direct path

RIS performance in different positions in system and different Nris settings with blockage model enabled



Conclusions

- Validated that performance of RIS-assisted systems depends on strength of direct path between a transmitter and receiver
- Considered problem of RIS placement in a single-cell, single user setting
- Current work considering imperfect CSI and more practical settings

References

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