SUPERVISED LEARNING BASED SPARSE CHANNEL ESTIMATION FOR RIS AIDED COMMUNICATIONS

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Introduction

- Frequent LoS compromise in mmWave: Use RIS to establish LoS
- Uplink channel estimation for RIS aided LoS in NLoS
- Consider the sparse angular domain channel by discretizing AoAs at the BS
- Consider 2 cases
  - on-grid: AoAs lie exactly on the discrete grid
  - off-grid: AoAs can take any continuous value deviating from discrete grid
- OMP [1] based algorithm in the on-grid case
- Neural networks trained based on supervised learning is used to estimate the residual angles in the off-grid case

System Model I

- M antennas at BS
- A single antenna user in NLoS with BS
- RIS with N reflecting elements
- $\mathbf{\Theta} = \text{diag}(\boldsymbol{v}) = \text{diag}([e^{j\alpha_1}, e^{j\alpha_2}, ..., e^{j\alpha_N}]^T)$ denote the reflection matrix of the RIS

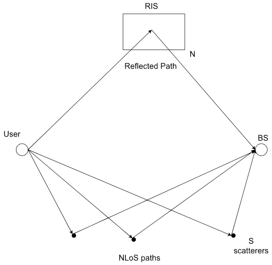

Figure 1: Illustration of the system model.

System Model II

$$\boldsymbol{h}_v = c_v \boldsymbol{a}_{RIS}(\theta_R^{RIS}), \tag{1}$$

and

$$\boldsymbol{H}_r = c_r \boldsymbol{a}_{BS}(\theta_R^{BS}) \left[\boldsymbol{a}_{RIS}(\theta_T^{RIS})\right]^H, \tag{2}$$

$$\begin{aligned} \boldsymbol{g} &= \boldsymbol{H}_r \boldsymbol{\Theta} \boldsymbol{h}_v \\ &= c_r \boldsymbol{a}_{BS}(\theta_R^{BS}) \left[\boldsymbol{a}_{RIS}(\theta_T^{RIS})\right]^H c_v \boldsymbol{\Theta} \boldsymbol{a}_{RIS}(\theta_R^{RIS}) \\ &= \boldsymbol{a}_{BS}(\theta_R^{BS}) \left(\sum_{n=1}^{N} \gamma_n^* e^{j\alpha_n} \right) \\ &= \boldsymbol{a}_{BS}(\theta_R^{BS}) \boldsymbol{\gamma}^H \boldsymbol{v}, \end{aligned} \tag{3}$$

On-Grid AoAs

- The effective channel,

$$\begin{aligned}\boldsymbol{h}_{t,i} &= \boldsymbol{g}_{t,i} + \sum_{q=1}^{S} \beta_{t,q} \boldsymbol{a}_R(\theta_{t,q}) \\ &= \boldsymbol{a}_R(\theta_{t,0}) \gamma_t^H \boldsymbol{v}_{t,i} + \sum_{q=1}^{S} \beta_{t,q} \boldsymbol{a}_R(\theta_{t,q}),\end{aligned} \tag{4}$$

- The angular dictionary can be defined as,

$$\boldsymbol{A}_R = \begin{bmatrix} \boldsymbol{a}_R(\tilde{\theta}_0) & \boldsymbol{a}_R(\tilde{\theta}_1) & \cdots & \boldsymbol{a}_R(\tilde{\theta}_K) \end{bmatrix}. \tag{5}$$

- Compact received signal matrix,

$$\boldsymbol{Y} = \boldsymbol{A}_R \tilde{\boldsymbol{Q}} \tilde{\boldsymbol{V}} + \boldsymbol{N}. \tag{6}$$

Solving On-Grid Case

- Using the orthogonality of the augmented codebook (based on [2]),

$$\begin{aligned} \boldsymbol{Y}\tilde{\boldsymbol{v}}_0^* &= \boldsymbol{A}_r\tilde{\boldsymbol{q}}_0\tilde{\boldsymbol{v}}_0^T\tilde{\boldsymbol{v}}_0^* + \boldsymbol{N}\tilde{\boldsymbol{v}}_0^* \\ \boldsymbol{y}' &= \boldsymbol{A}_r\bar{\boldsymbol{z}} + \boldsymbol{n}', \end{aligned} \tag{7}$$

  which can be solved with OMP.
- Next, we remove effect of direct channel,

$$\boldsymbol{Y}_{\text{RIS}} = \boldsymbol{Y} - \boldsymbol{A}_r\bar{\boldsymbol{z}}\tilde{\boldsymbol{v}}_0^T. \tag{8}$$

- Now we can find γ by minimizing,

$$\|\boldsymbol{Y}_{\text{RIS}} - \boldsymbol{a}_R(\tilde{\theta}_0)\boldsymbol{\gamma}^H\boldsymbol{V}\|_2^2. \tag{9}$$

Off-Grid AoAs

- residual AoA vector $\boldsymbol{\delta} = \begin{bmatrix} \delta_0 & \delta_1 & \cdots & \delta_K \end{bmatrix}$ such that

$$\delta_k = \begin{cases} \theta_q - \tilde{\theta}_{k_q}, & q = k_q, \text{ for } q = 0, 1, \cdots, S, \text{ and } k \neq 0 \\ 0, & \text{otherwise,} \end{cases}$$

- Modified array response dictionary $\boldsymbol{A}_R(\boldsymbol{\delta})$
- Now the Equation (6) can be modified

$$\boldsymbol{Y} = \boldsymbol{A}_R(\boldsymbol{\delta}) \tilde{\boldsymbol{Q}} \tilde{\boldsymbol{V}} + \boldsymbol{N}. \tag{10}$$

Neural Network for Off-Grid Estimation

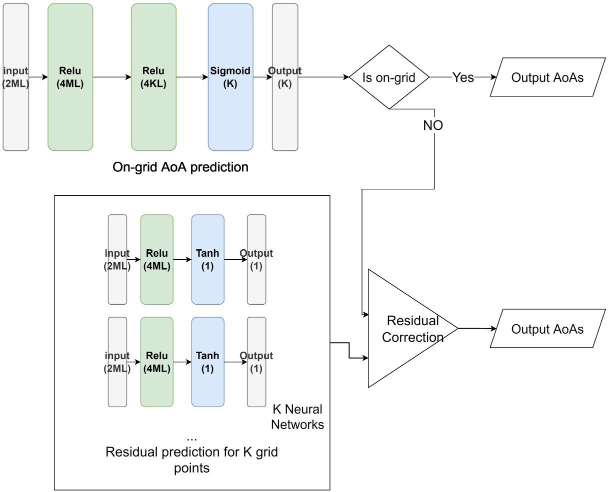

Figure 2: NN architecture for residual AoA prediction..

Results (On-Grid)

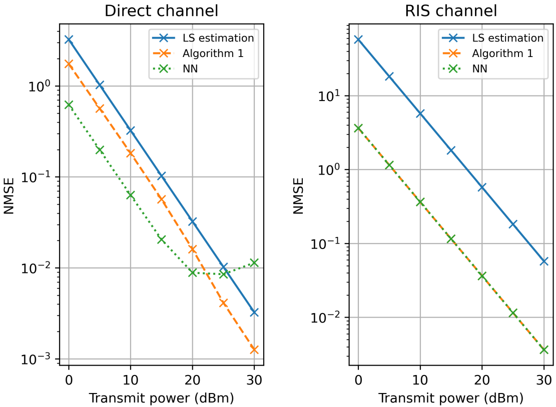

Figure 3: Channel estimation with on-grid AoAs.

Results (Off-Grid)

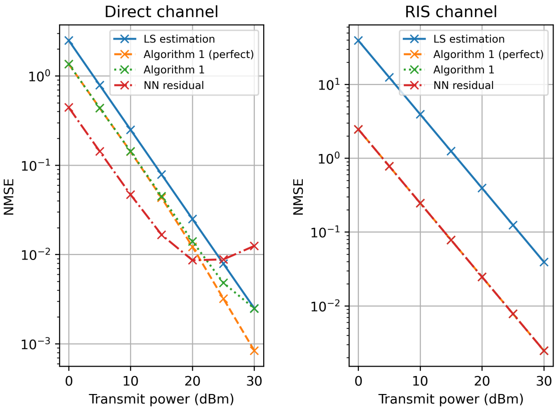

Figure 4: Channel estimation with off-grid AoAs.

References I

[1] J. A. Tropp and A. C. Gilbert, “Signal Recovery From Random Measurements Via Orthogonal Matching Pursuit,” *IEEE Transactions on Information Theory*, vol. 53, no. 12, pp. 4655–4666, 2007.

[2] T. L. Jensen and E. De Carvalho, “An Optimal Channel Estimation Scheme for Intelligent Reflecting Surfaces Based on a Minimum Variance Unbiased Estimator,” in *ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2020, pp. 5000–5004.

The End.

Thank You!