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Wireless Intelligence Lab

Integrated Imaging And Communication with Reconfigurable Intelligent Surfaces

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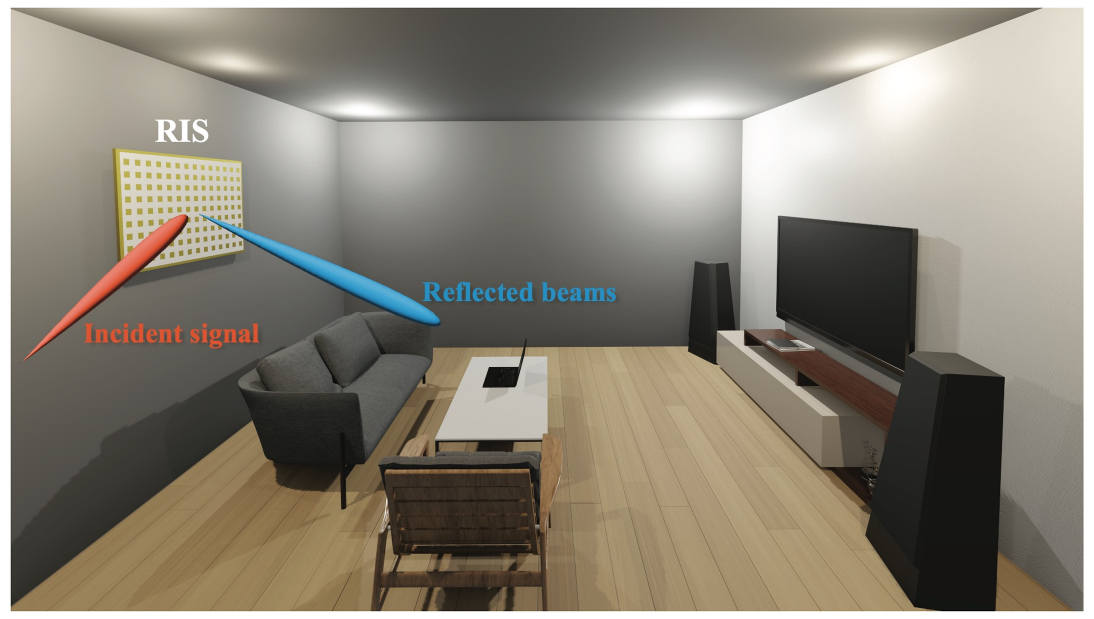
RIS Beam Training is a Key Challenge

Large numbers of antennas | Narrow beams

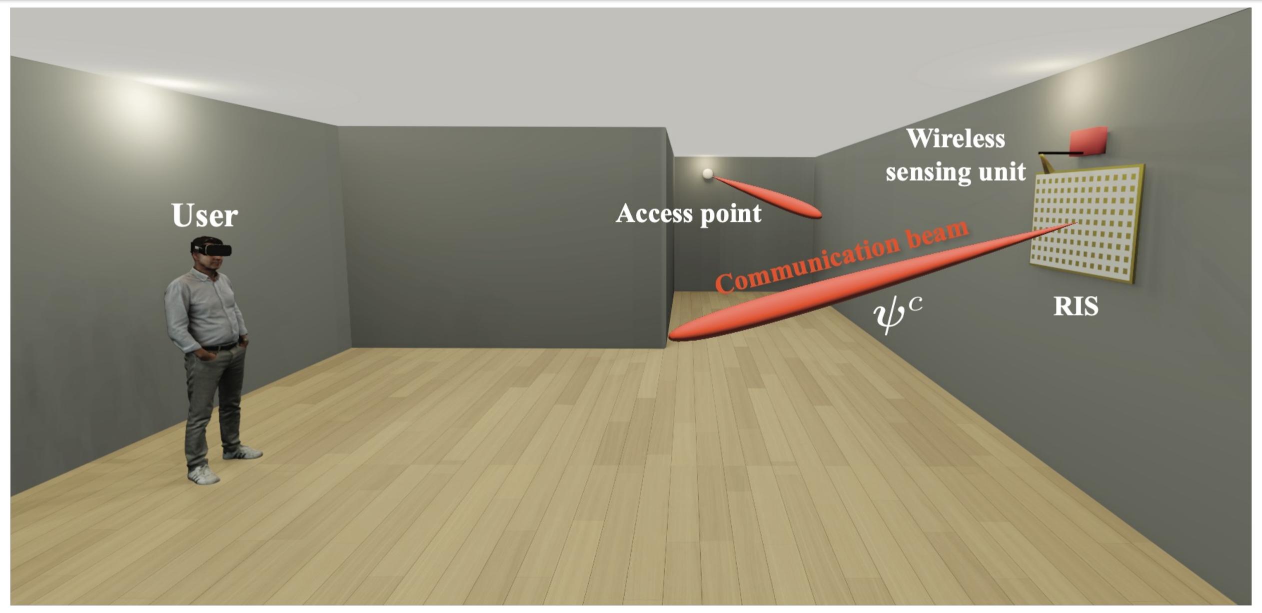


➤ RIS offers an opportunity for high spatial-resolution imaging

Can imaging assist RIS beam training for communication?

System Model

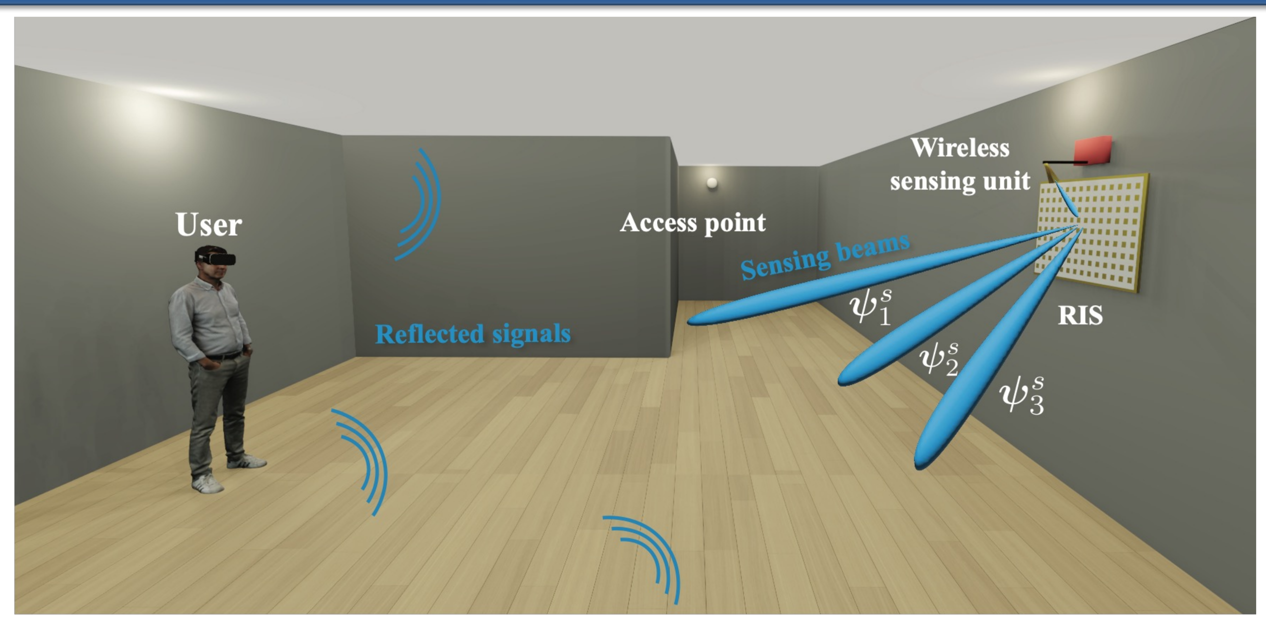
➤ Communication model



Received signal $y_c = (\mathbf{h}_R \odot \mathbf{h}_T)^T \boldsymbol{\psi}^c x_c + w_c$

RIS-UE channel; AP-RIS channel; RIS interaction vector for communication

➤ Imaging model (based on beamformed FMCW)



Received baseband digital signal

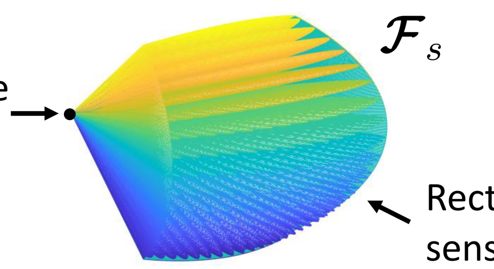
$$z[u,v] = \sum_{k=1}^{K}\sum_{\ell=1}^{L_k} \sqrt{\rho_{k,\ell}}\, e^{-j\vartheta_{k,\ell}} e^{+j\Xi_{k,\ell}} + w_s[u,v] e^{j\chi[u]}$$

u^{th} ADC sample; v^{th} sensing beam (chirp); Path gain and phase; Contain range information

Problem Formulation

➤ RIS-aided depth estimation

Sensing codebook



Depth estimation function

$$\mathbf{D}_{\text{map}} = \mathbf{p}_d(\mathbf{Z}; \mathcal{F}_s)$$

Received signal matrix after sensing beam sweeping

[Taha'23] A. Taha, H. Luo, and A. Alkhateeb, "Reconfigurable Intelligent Surface Aided Wireless Sensing for Scene Depth Estimation," in IEEE ICC, 2023.

➤ RIS beam selection problem with a predefined codebook

User detection function

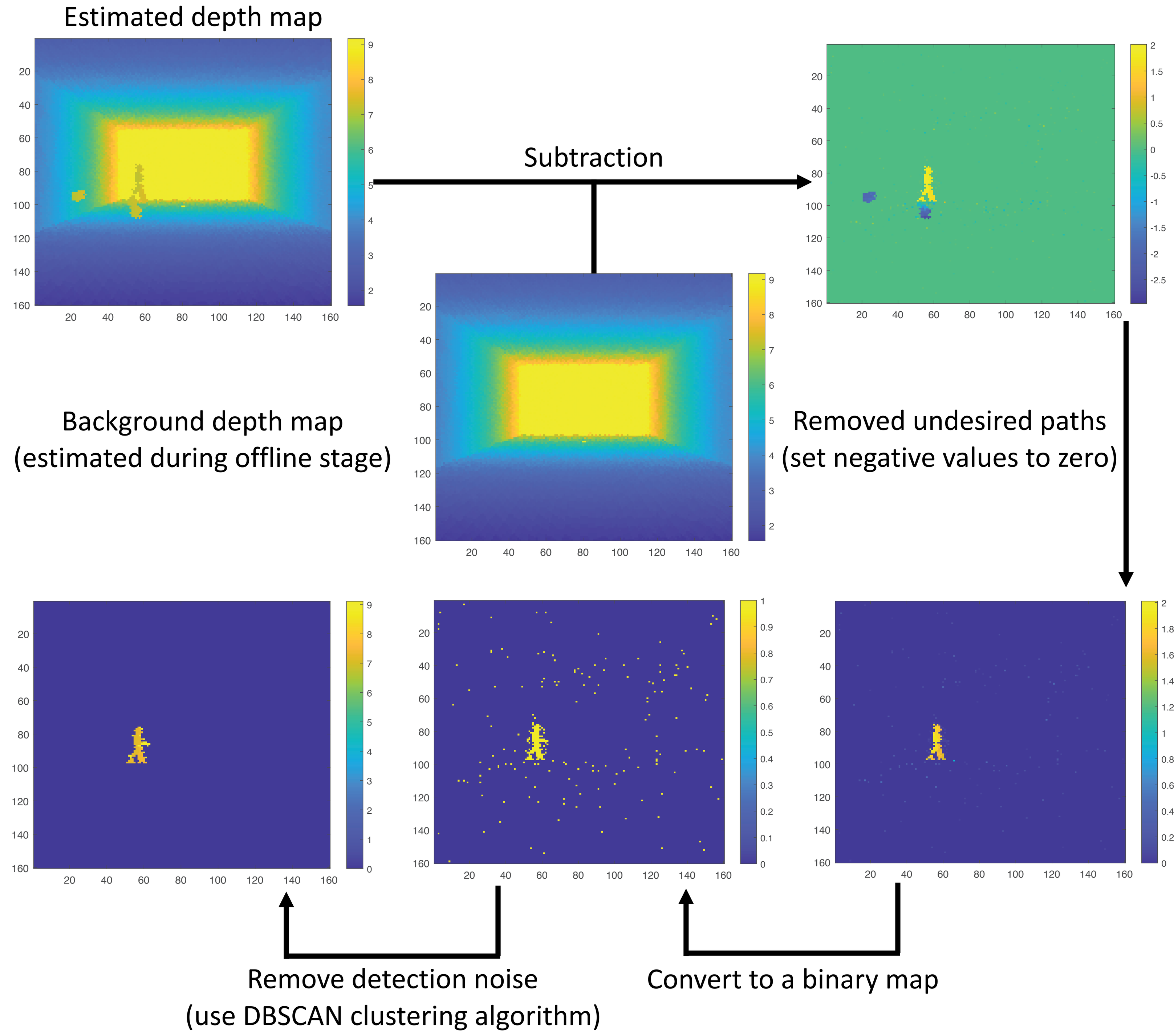
$$(\tilde{\theta}^{\text{az}}_{\text{UE}}, \tilde{\theta}^{\text{ze}}_{\text{UE}}) = \mathbf{p}_u(\mathbf{D}_{\text{map}})$$

Optimal beam index

$$m^\star = \underset{\boldsymbol{\psi}^c_m \in \mathcal{F}_c}{\arg\max} \left|(\mathbf{h}_R \odot \mathbf{h}_T)^T \boldsymbol{\psi}^c_m\right|$$

➤ Objective: Find the optimal beam based on user detection

User Detection in RIS-based Depth Map



➤ **To determine the azimuth and zenith angles towards the user**
- **Find the mean of the user's pixel coordinates**
- **Each pixel is estimated by a sensing beam of a predefined reflected direction**

RIS Beam Selection

➤ Decomposition of RIS interaction vector

RIS interaction vector $\tilde{\boldsymbol{\psi}}^c = \tilde{\boldsymbol{\psi}}^c_{\text{AP}} \odot \tilde{\boldsymbol{\psi}}^c_{\text{UE}}$ — Far-field array response vector

AP-side beam $\tilde{\boldsymbol{\psi}}^c_{\text{AP}} = \mathbf{a}^*(\theta_{\text{AP}})$ — Angles towards the AP (known)

UE-side beam $\tilde{\boldsymbol{\psi}}^c_{\text{UE}} = \mathbf{a}^*(\theta_{\text{UE}})$ — Angles towards the user

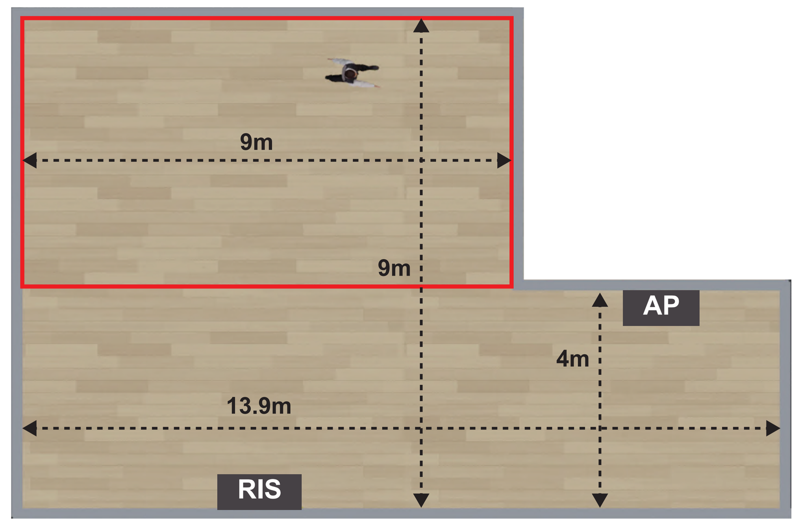
➤ Similarities between estimated beam and codebook beams

Selected beam index $\tilde{m} = \underset{\boldsymbol{\psi}^c_m \in \mathcal{F}_c}{\arg\max} \left|(\tilde{\boldsymbol{\psi}}^c)^H \boldsymbol{\psi}^c_m\right|$

➤ Note: A set of candidate beams can be found by sorting the codebook based on the calculated similarities

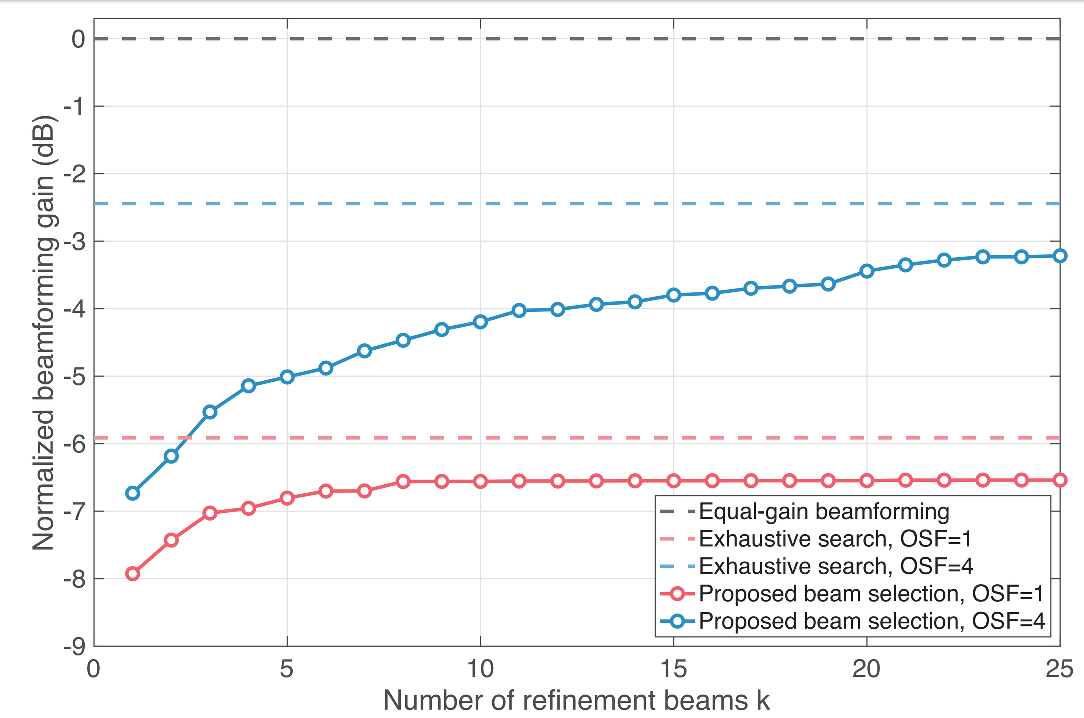
Simulation Results

➤ Simulation framework



- RIS structure: 40×40 UPA
- Operating band: 60 GHz
- Comm. codebook: Beamsteering
- Floor plan design: Blender
- Ray-tracing simulator: Wireless Insite
- User is in the NLoS area (red box)

➤ Results



Note: Normalized beamforming gain is the ratio of beamforming gain to equal-gain beamforming gain

➤ **Oversampled codebook provides better beamforming gain**

➤ **With oversampling factors of four in azimuth and zenith**
- **Achieve comparable performance to the exhaustive search**
- **Require 1000 times less beam training overhead**