Qualcomm

ICLR 2023

WiNeRT: Towards Neural Ray Tracing for Wireless Channel Modelling and Differentiable Simulations

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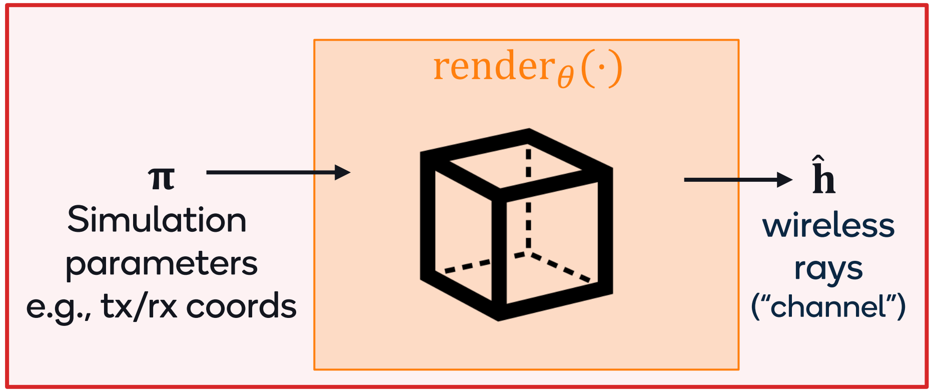
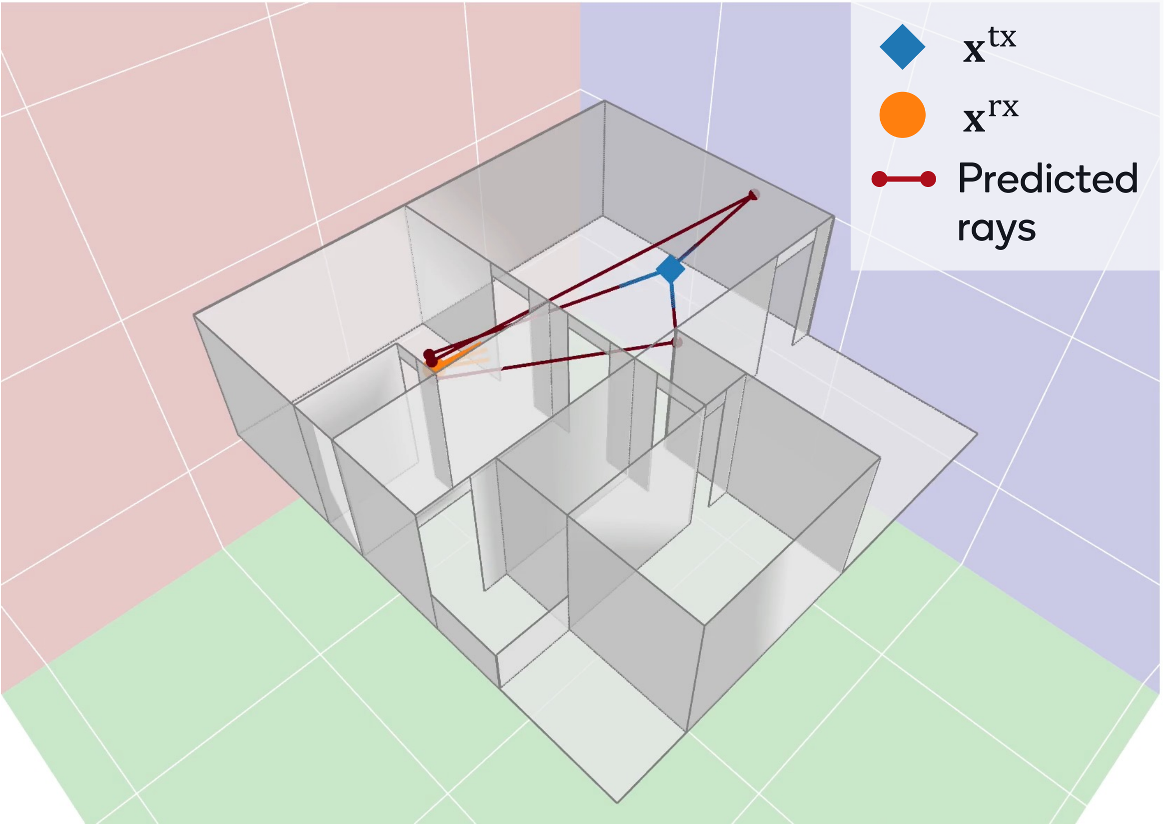
† Qualcomm AI Research is an initiative of Qualcomm Technologies, Inc

Tl;dr. WiNeRT = Wireless Neural Ray Tracer

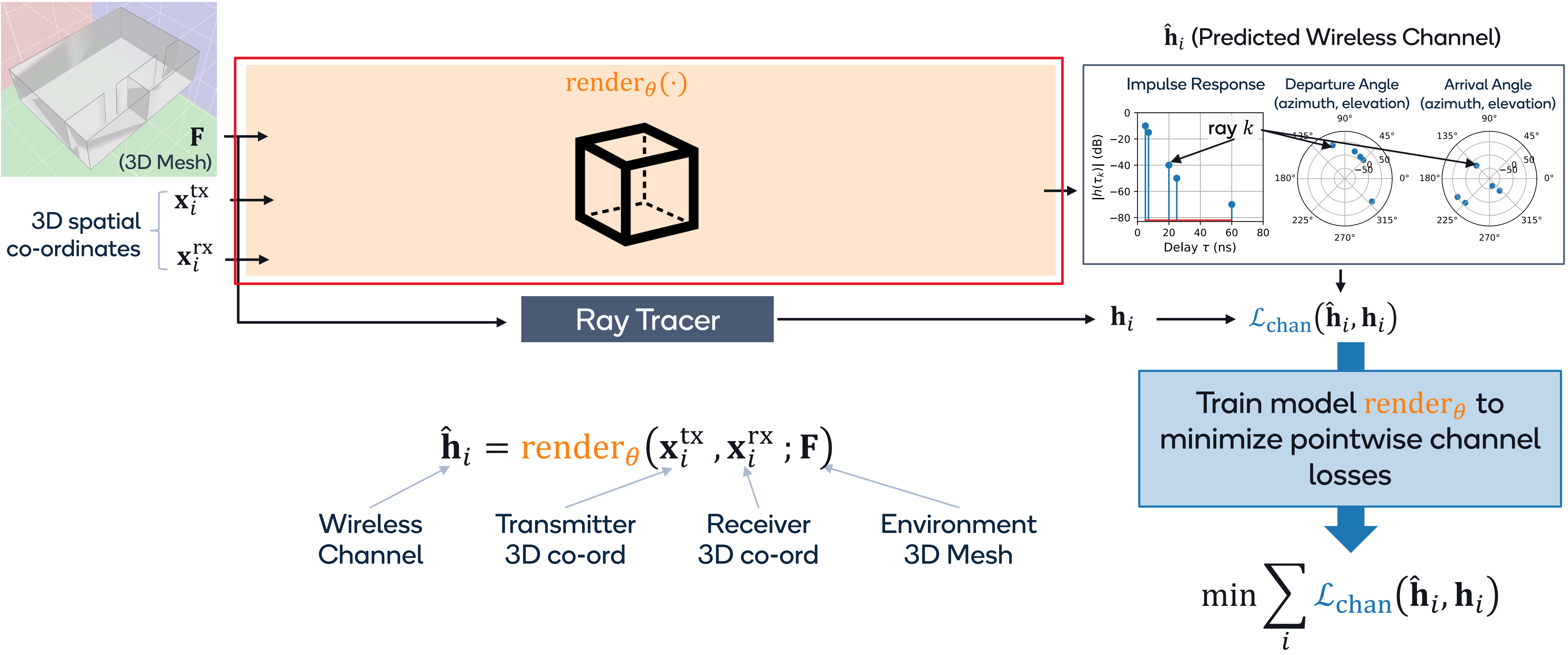


- Neural Data-driven Differentiable Ray Tracer
- Motivation: Benefits over classical ray tracers e.g.,
  - Differentiability
  - Faster Simulation times
- Approach: NeRF[1]-like. Combination of:
  - Incidence-dependent MLP evaluations at spatial co-ordinates
  - Classical rendering (wireless ray tracing)
- Results
  - Evaluated on simulated data (Insite[2]/Pylayers[3])
  - Avg. delay MAE: 0.82 – 1.8 ns
  - Bonus: 6-22X faster than simulators, Generalization, Positioning via Inverse Rendering

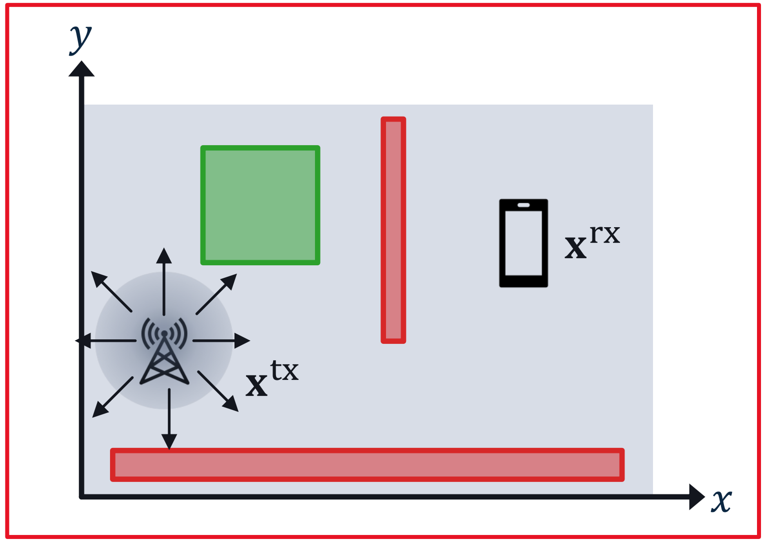


[1] Mildenhall et al., "Nerf: Representing scenes as neural radiance fields for view synthesis." ECCV '20
[2] Remcom Wireless InSite with Ray Tracer X3D
[3] Amiot et al., "Pylayers: An open source dynamic simulator for indoor propagation and localization." ICC '13

Problem Statement: Surrogate Neural Ray Tracing

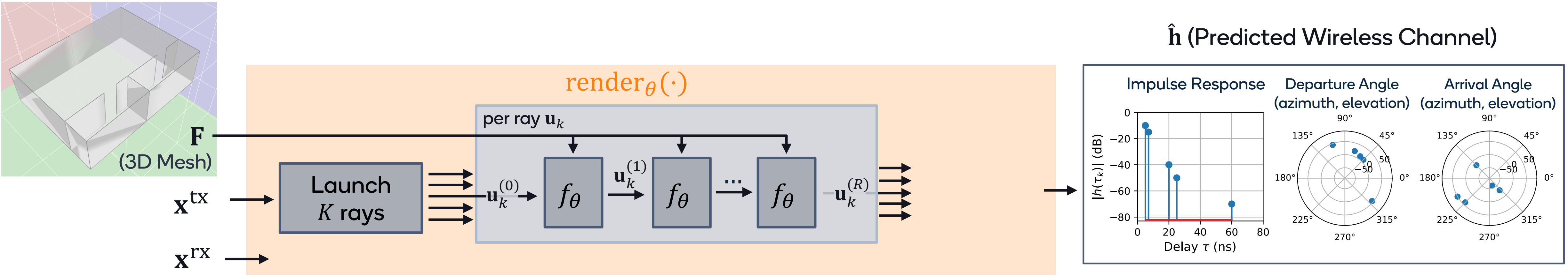


WiNeRT: Approach (1/4)

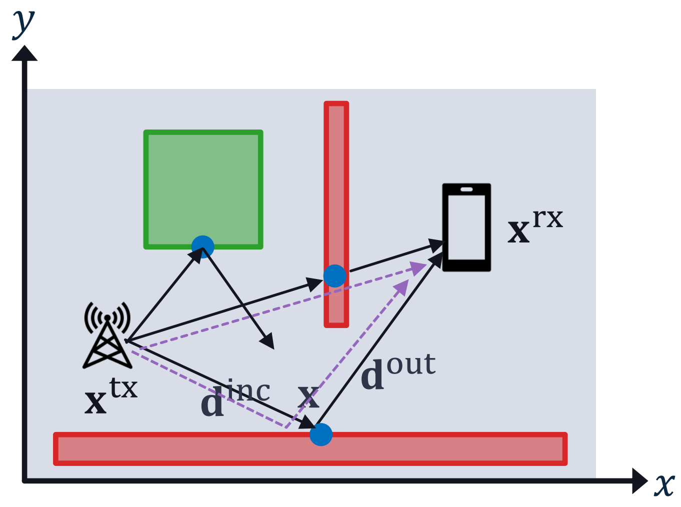


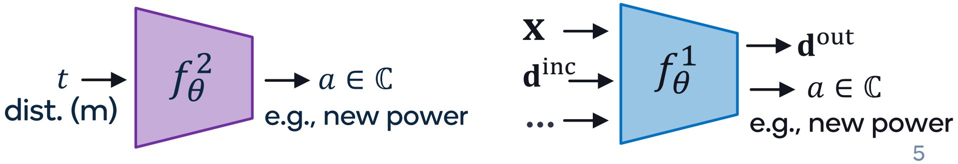
- Step 1: Ray Launching
  - Launch K rays $\{\mathbf{u}_k^{(r=0)}\}$ uniformly in all directions
    - $K \approx$ 10K (vertices of ico-sphere, with 5 divisions)
  - Ray $\mathbf{u}_k^{(r)}$ contains geometric, wireless, and state attributes
    - E.g., Origin, direction, Gain a_k, Delay τ_k (time-of-flight)

WiNeRT: Approach (2/4)

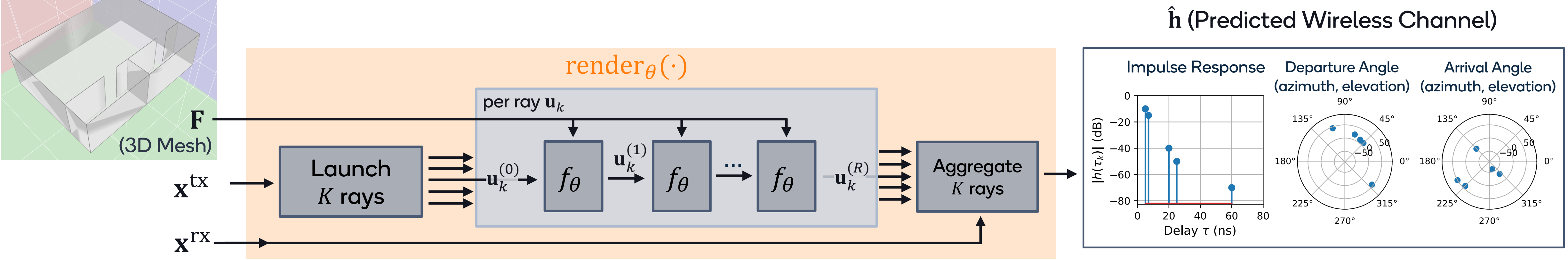


- Step 2: Ray Marching
  - Core Idea: f_θ updates the ray attributes as it interacts (reflects/transmits) with surfaces in the environment
  - Leverage simple ReLU MLP f_θ^1 to learn ray-surface interactions
    - Independently evaluate MLP for each ray $\mathbf{u}_k^{(r)}$ at each step r
  - Finally apply distance-dependent free-space path loss f_θ^2

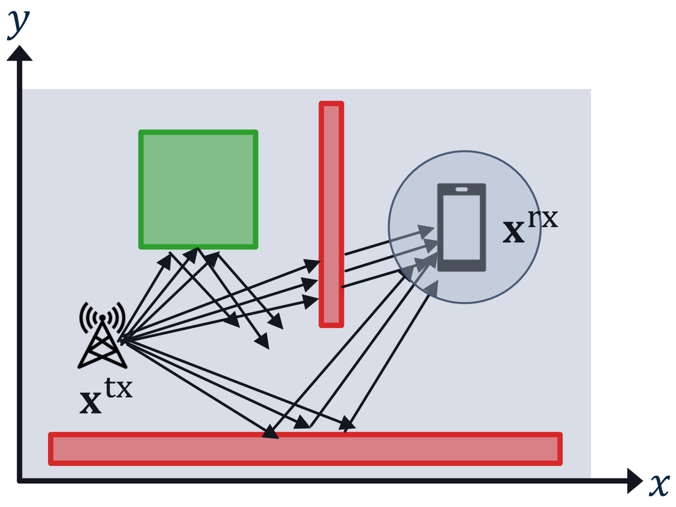




WiNeRT: Approach (3/4)

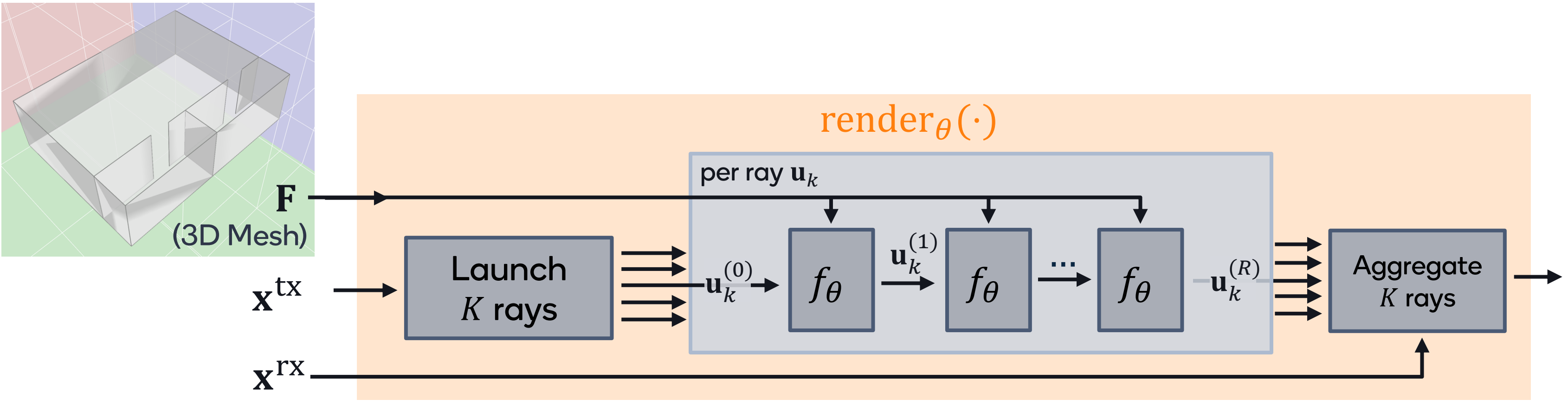


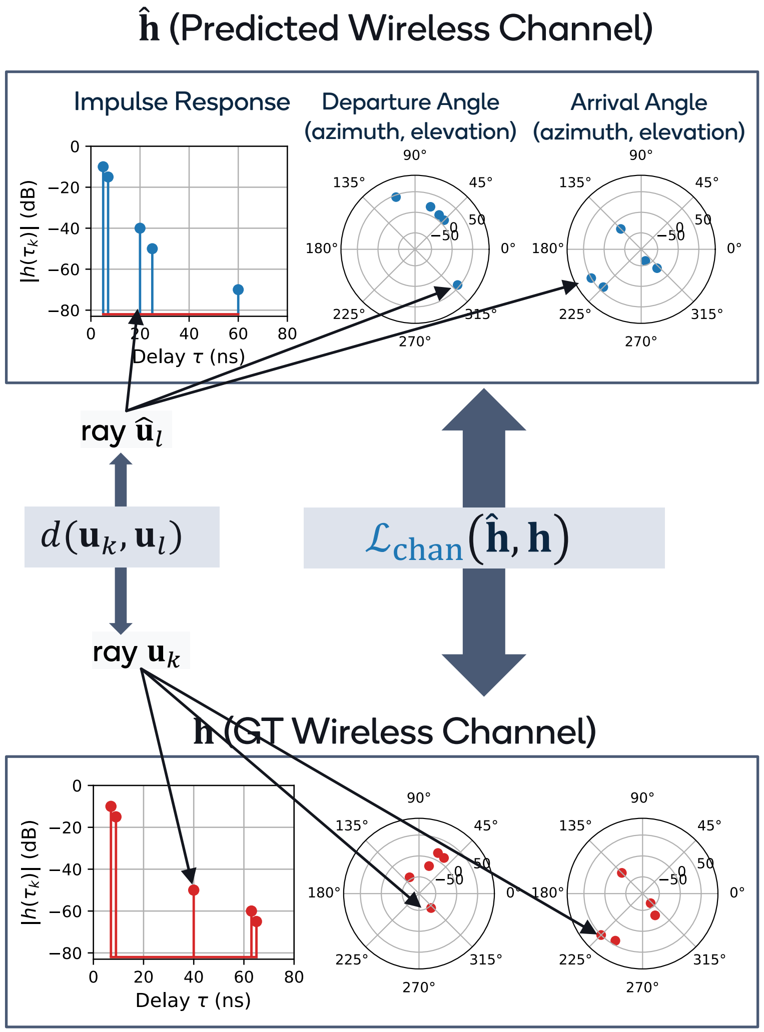
- Step 3: Reception and Aggregation
  - Which rays are received?
    - Model fixed-size reception sphere centered at $\mathbf{x}^{\text{rx}}$ and find subset of rays that impinge on sphere surface
  - Dealing with double counting
    - Ray abstracts a spherical wavefront
    - Fermat's principle of least time: consider the shortest ray



WiNeRT: Approach (4/4)

$$\min \sum_i \mathcal{L}_{\text{chan}}(\hat{\mathbf{h}}_i, \mathbf{h}_i)$$
$$\hat{\mathbf{h}}_i = \text{render}_\theta(\mathbf{x}_i^{\text{tx}}, \mathbf{x}_i^{\text{rx}}; \mathbf{F})$$

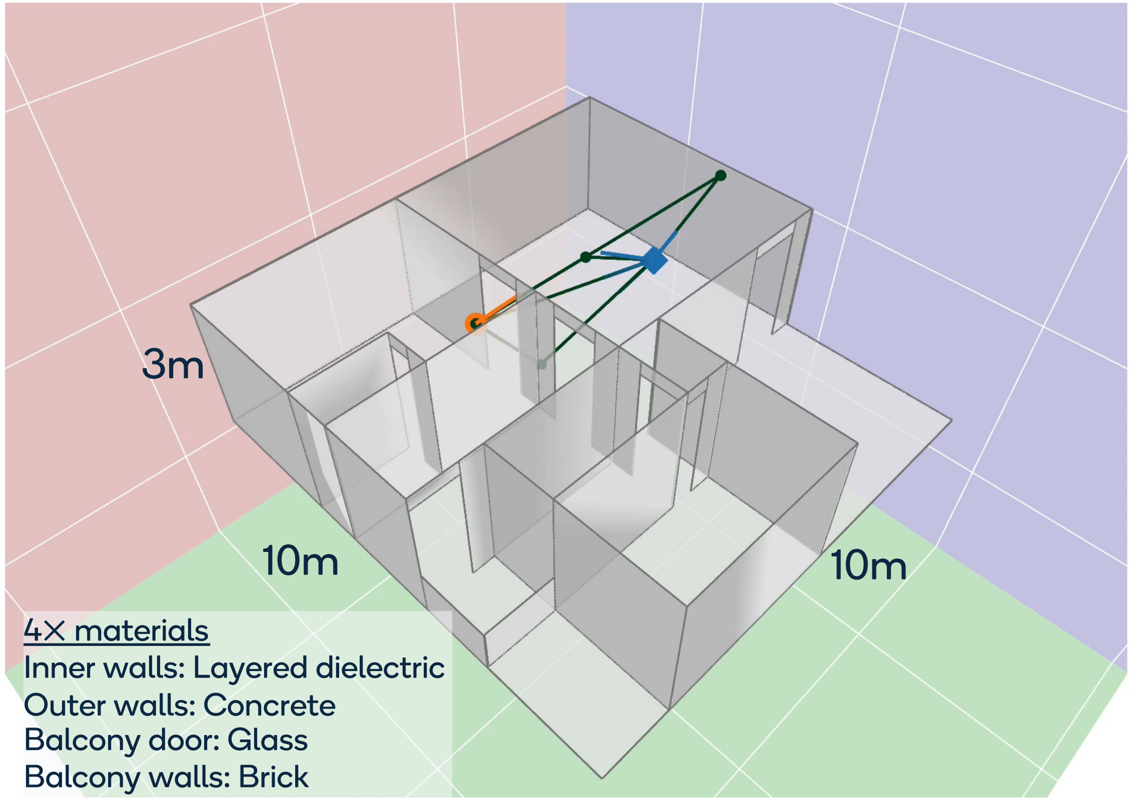




- Step 4: (Training) Loss evaluation
  - Comparing two time-angle impulse responses
  - Set-based loss over sets of rays
    - $\mathcal{L}_{\text{chan}}(\mathbf{h}, \hat{\mathbf{h}}) = \sum_k d(\mathbf{u}_k, \hat{\mathbf{u}}_{\Pi(k)})$
    - Π: Angle-of-departure based association
  - Comparing two wireless rays $d(\mathbf{u}_k, \mathbf{u}_l)$
    - MSE over individual attributes
    - Tricks: normalization, cartesian representation of angles, ...

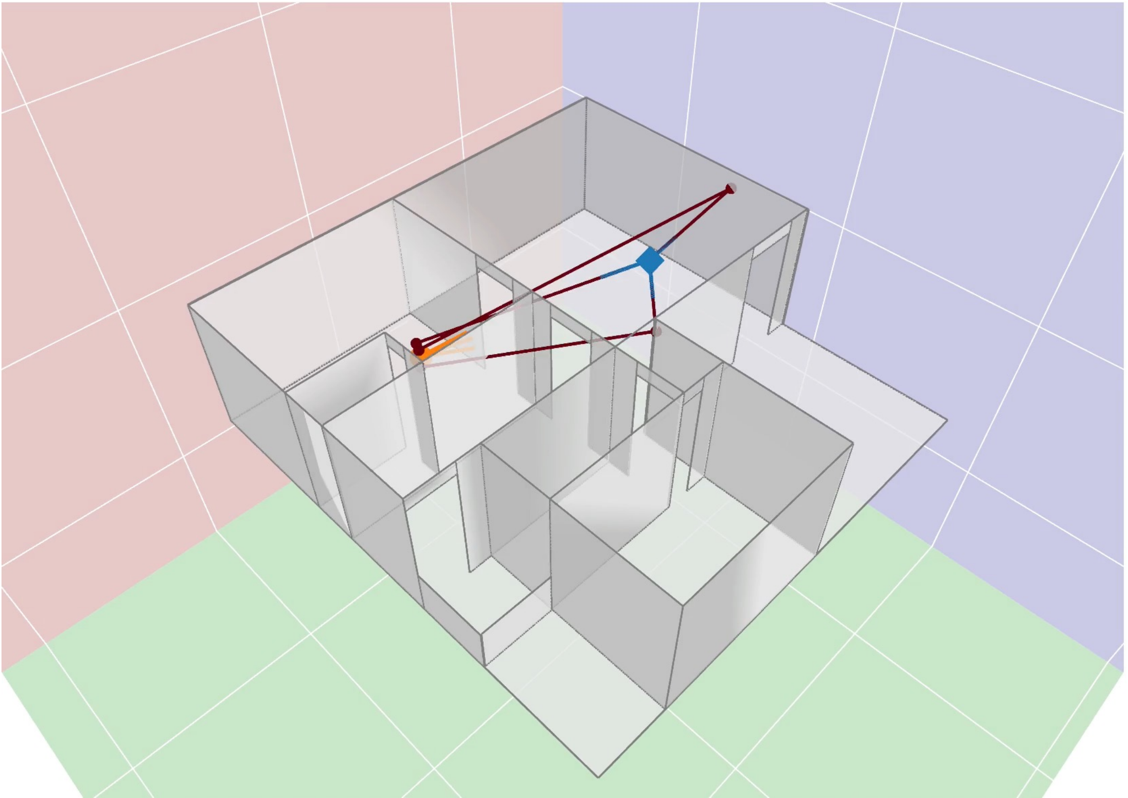
Results: Overall

Wireless Insite Ray-tracer (Ground truth)



Tx
Rx
GT paths
Predicted paths

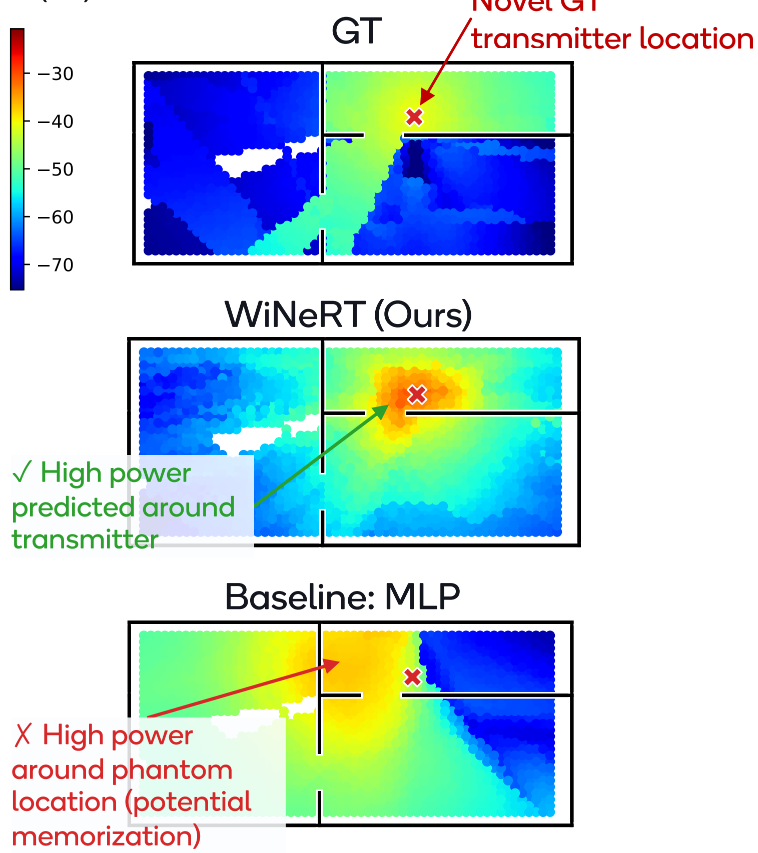
WiNeRT (Predictions)



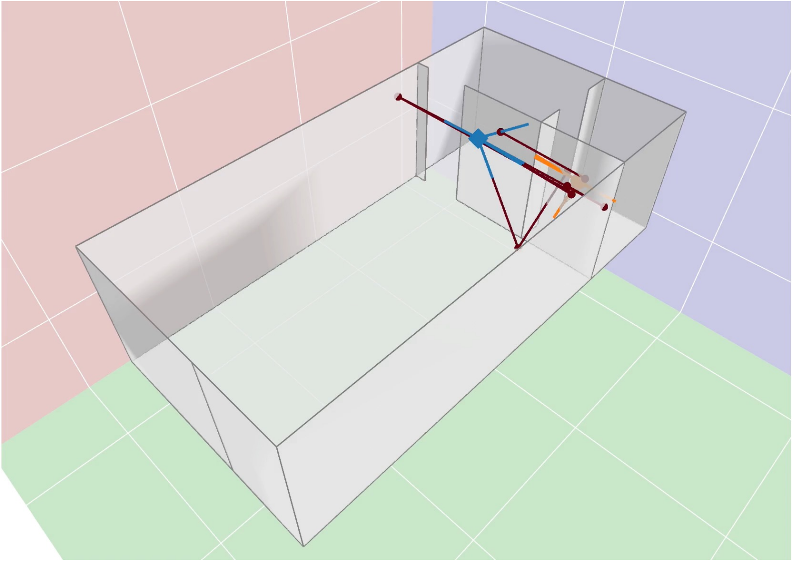
MAE – Average Delay	1.55 ns
MAE - RSRP	-106.74 dB
MAE – LOS ToF	3.97 ns
Hungarian distance	0.24

Results: Additional Analysis

Generalization

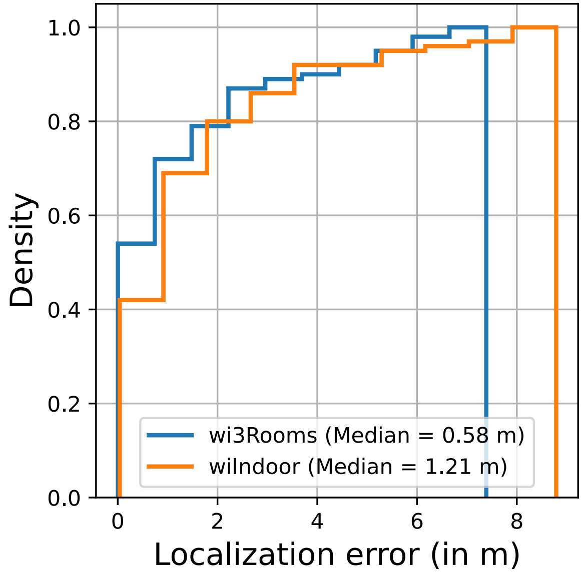


New re-configured Floormaps at test-time (Train on floor $\mathbf{F}$, Simulate on $\mathbf{F}'$)



Inverse Rendering Application: Localization

$$\nabla_{\mathbf{x}^{\mathrm{rx}}} \mathcal{L}(\mathrm{render}_\theta(\mathbf{x}^{\mathrm{rx}}, \dots), \boldsymbol{h}^{\mathrm{target}})$$



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3-May (Wednesday)
4.30pm – 6.30pm CAT

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