ICML International Conference On Machine Learning

Paper

Code

UCLA Samueli Computer Science

ICON LAB

NeWRF: A Deep Learning Framework for Wireless Radiation Field Reconstruction and Channel Prediction

Haofan Lu, Christopher Vattheuer, Baharan Mirzasoleiman, Omid Abari

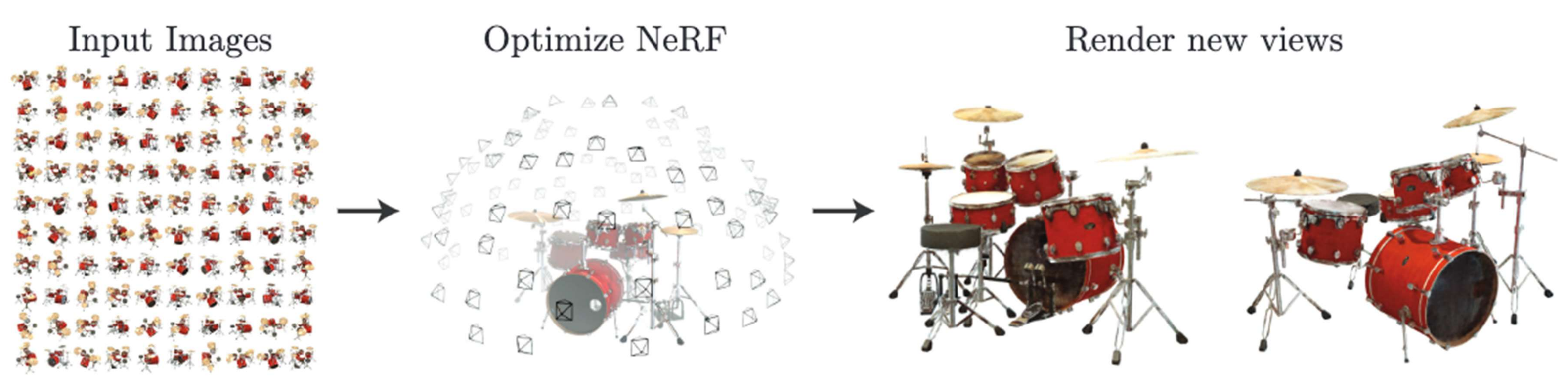
Motivation

Today's wireless deployments suffer from **dead zones**, requiring costly fine-grained measurements to resolve.

Can Neural Radiance Fields (NeRF), a recent advancement from Computer Vision, be adapted to the wireless domain to identify dead zones?

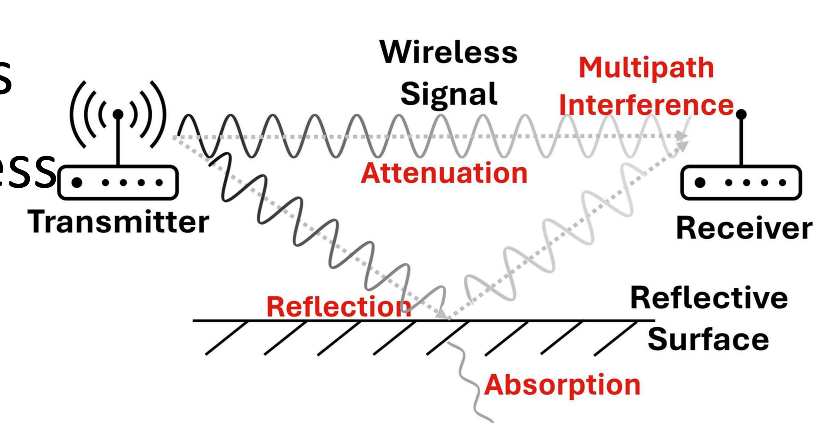
Background

NeRF is a deep learning technique where a model learns to synthesize novel-view images of a 3D scene given a set of photos.



Source: Ben Mildenhall et al. 2021. NeRF: representing scenes as neural radiance fields for view synthesis. Commun. ACM 65, 1, 99–106. https://doi.org/10.1145/3503250

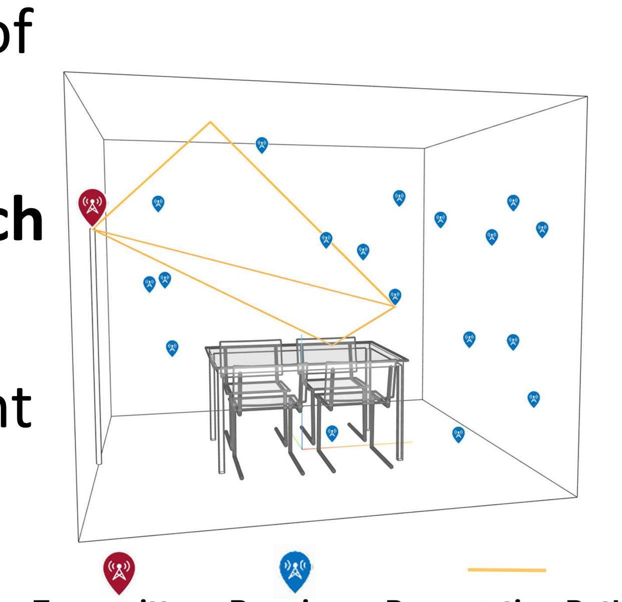
Wireless Channel describes the total distortion a wireless signal experiences as it propagates to the receiver.



Problem Formulation

Given an environment with a fixed transmitter location:

- Perform **sparse measurements** of the channel at several locations
- Utilize an **NeRF-inspired approach to predict the channel** at any other location in the environment
- Identify dead zones through estimated channels



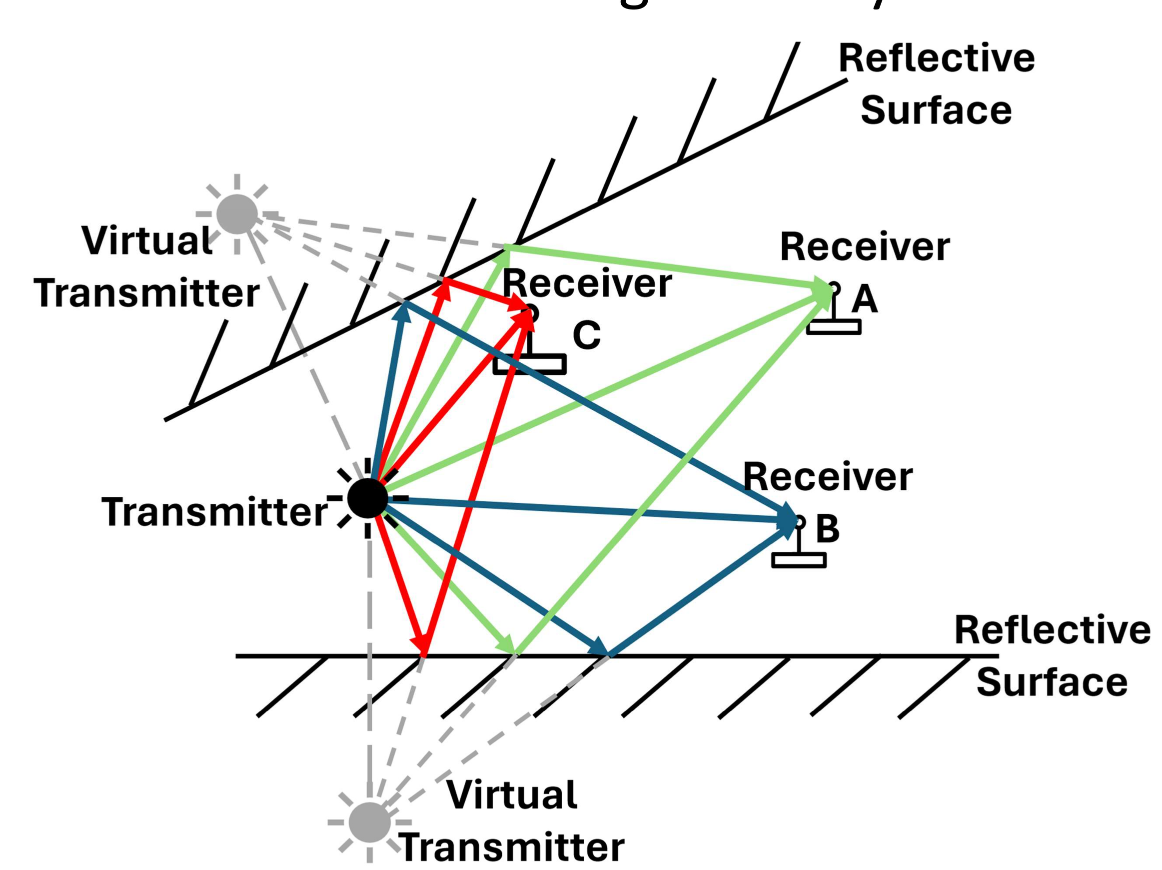
NeWRF: Neural Wireless Radiation Fields

Challenges in Adapting NeRF to Wireless

Challenge #1: Scene Complexity

Wireless scenes are typically large-scale, while channel measurements are less informative than images, reconstructing the scene with wireless measurements is hard

Solution: Identify a simple nature of wireless scenes: a wireless scene can be characterized by the locations of (virtual) transmitters and the signals they transmit



Challenge #2: Ambiguous Ray Direction

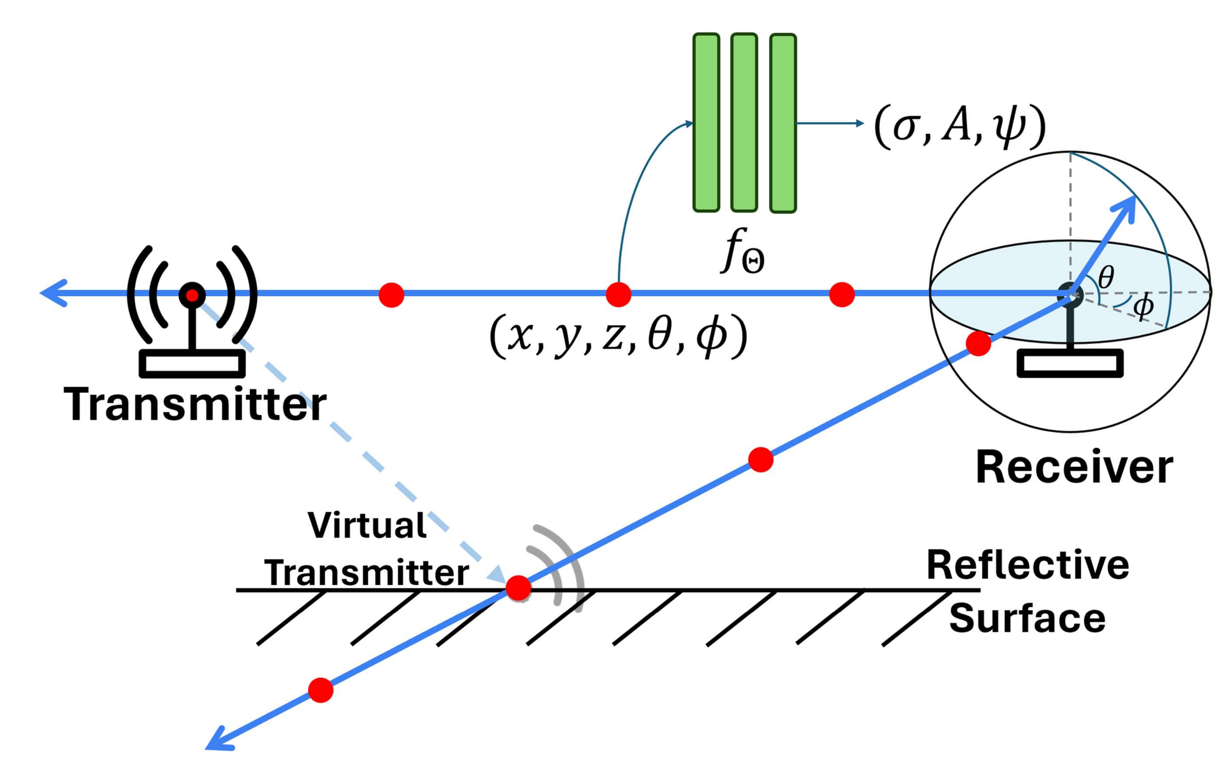
- Wireless antennas capture the sum of all signals received from all directions.
- The exhaustive grid-based ray tracing scheme enlarges the search space, making the model hard to converge

Solution: Utilize an **Antenna Array** to resolve direction of arrival DoA for channel measurements, enabling model convergence

Challenge #3: Complex Propagation Model

- Wireless signals have longer wavelength → signal phase affects channel
- Signal takes multiple paths to reach the receiver → const./destr. interference

Solution: a novel **Neural Channel Synthesis Algorithm**



Represent the wireless scene with an MLP

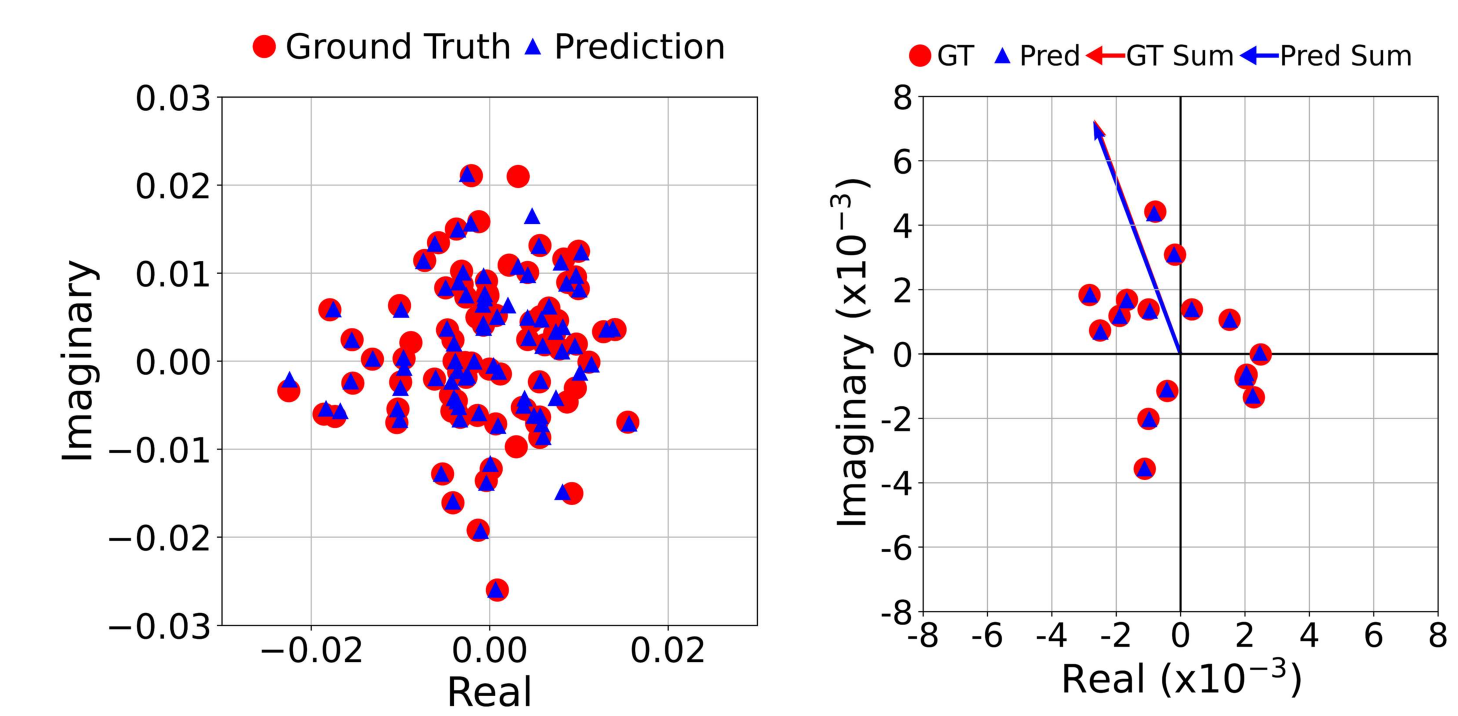
To synthesize channel at a receiver location:

- Backtrace and sample rays from receiver
- For each sample point and view direction (x, y, z, θ, ϕ), predict the probability of a (virtual) transmitter being present at this region, σ, as well as transmitted signal amplitude, A, and phase, ψ
- Incorporate free-space propagation laws to estimate the amplitude and phase of the signal as it reaches the target location
- Sum up all signals arrived at receiver

Experiment Setup

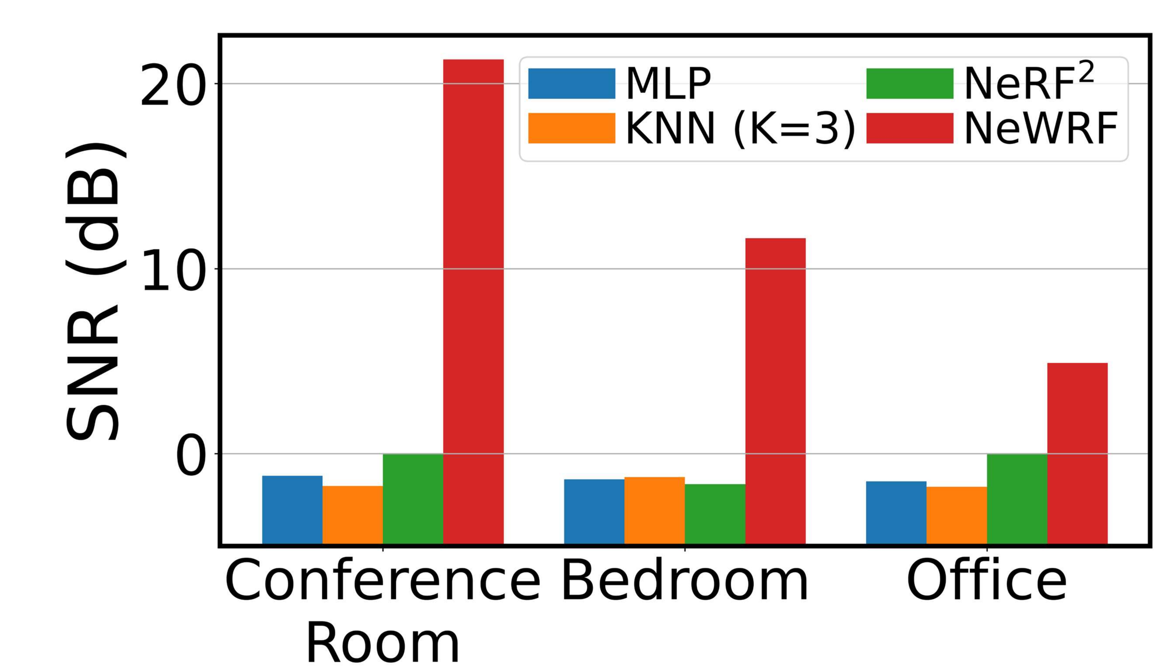
- Evaluated NeWRF in three different simulated environments (Bedroom, Office and Conference Room).
- Considered up to second-order reflections, diffractions, different signal frequencies and environment materials

Evaluation



(a) (b)

NeWRF can predict the channel (a) as well as each individual propagation path (b) for test locations accurately



NeWRF outperforms each baseline in all environments