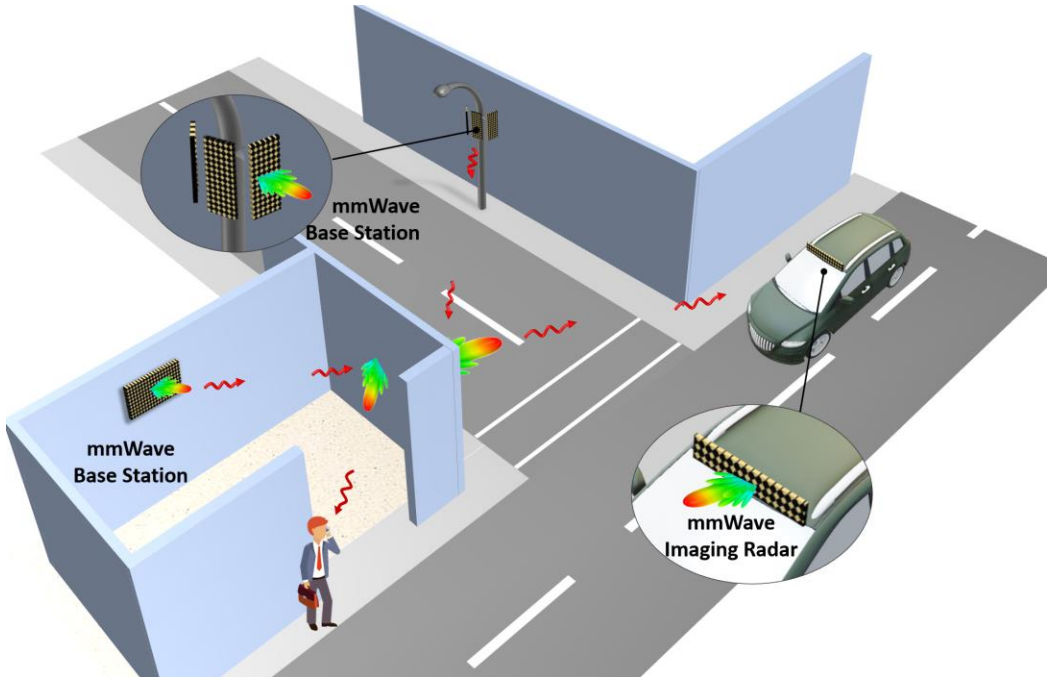
ARIZONA STATE UNIVERSITY

SWIFT: Synergy and Coexistence of Millimeter Wave Wireless Communications, Imaging, and Localization



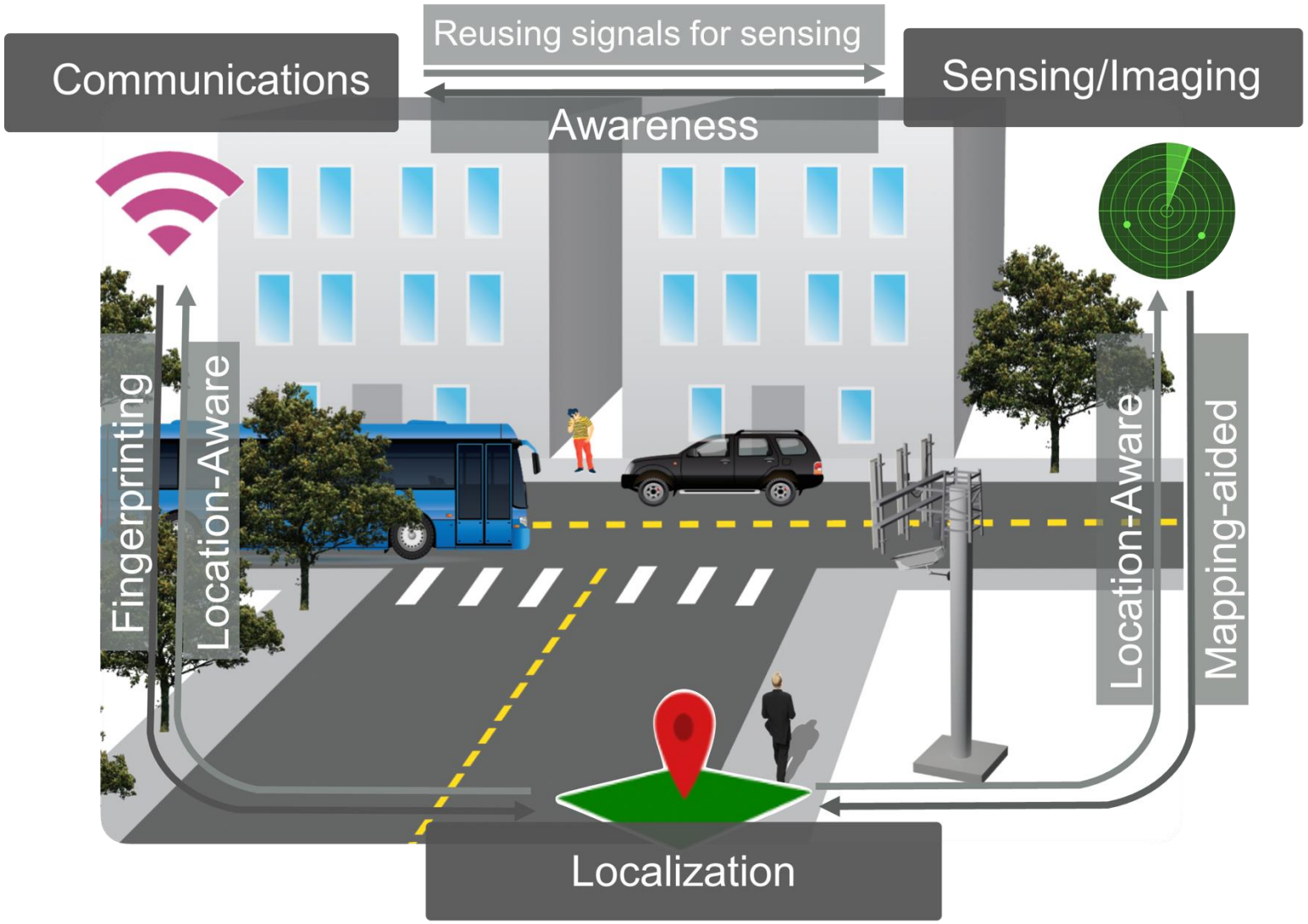
PI: Georgios (George) Trichopoulos

CoI: Ahmed Alkhateeb

School of Electrical, Computer, and Energy Engineering, Arizona State University

gtrichop@asu.edu, aalkhateeb@asu.edu

Award #: 2229530



Project Objectives

- Seeing the surroundings through a wireless communication system
- Develop imaging-based NLoS localization solutions for mmWave systems
- Develop localization and mapping-based fast mmWave ***beam tracking*** and ***channel estimation*** strategies.

Significance

- Rapid channel estimation/beam training
- Spectrum efficiency: provide sensing and localization

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Non-Line-of-Sight Imaging Using mmWaves

MmWave Imaging from a Single Viewpoint:

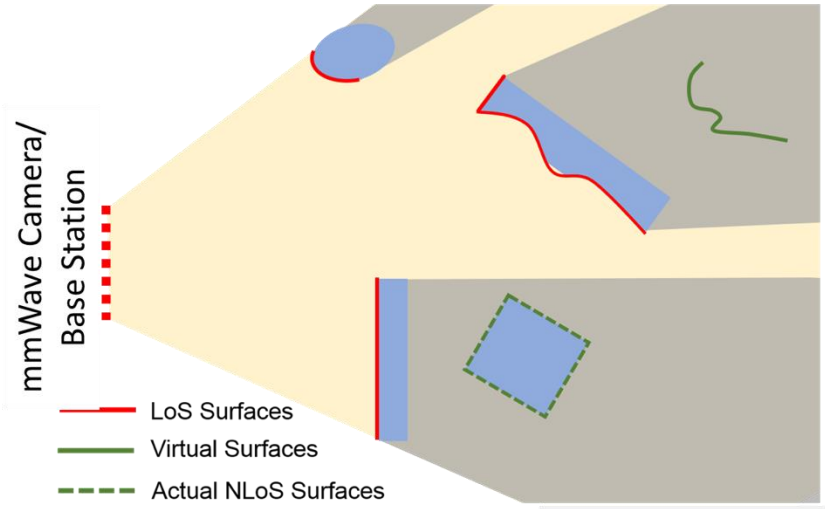
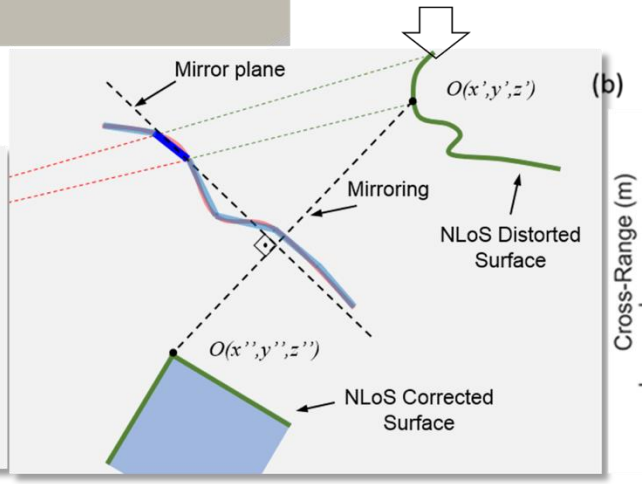


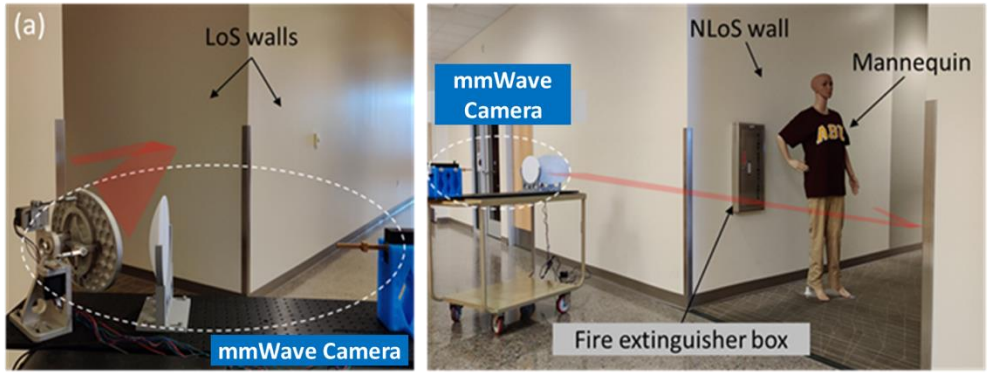
Image Correction Steps

1. Mirror surface is identified and discretized
2. Virtual object is assigned to the discretized segment
3. Mirroring is applied
4. Object location and shape are corrected

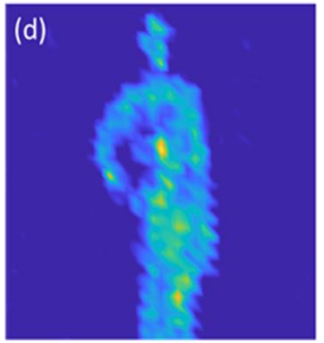
Virtual Object Correction (Mirroring)



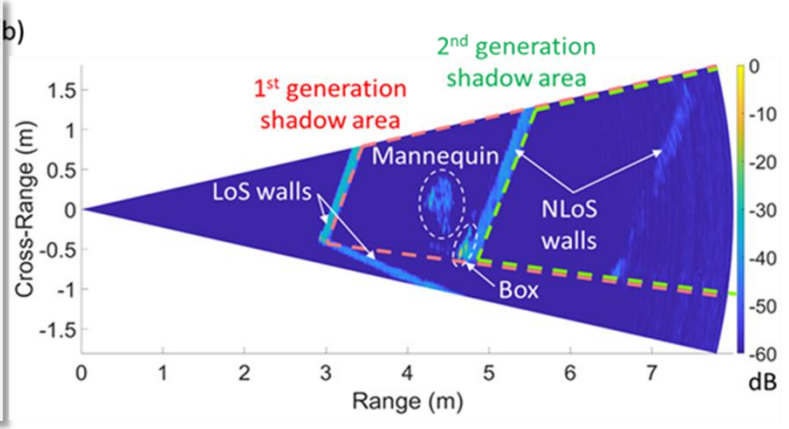
Experiment Setup (270-300 GHz



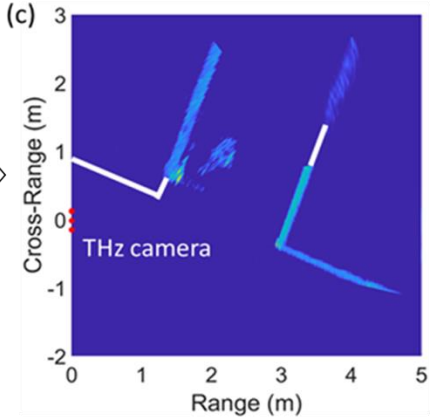
NLoS Mannequin



Raw mmWave Image



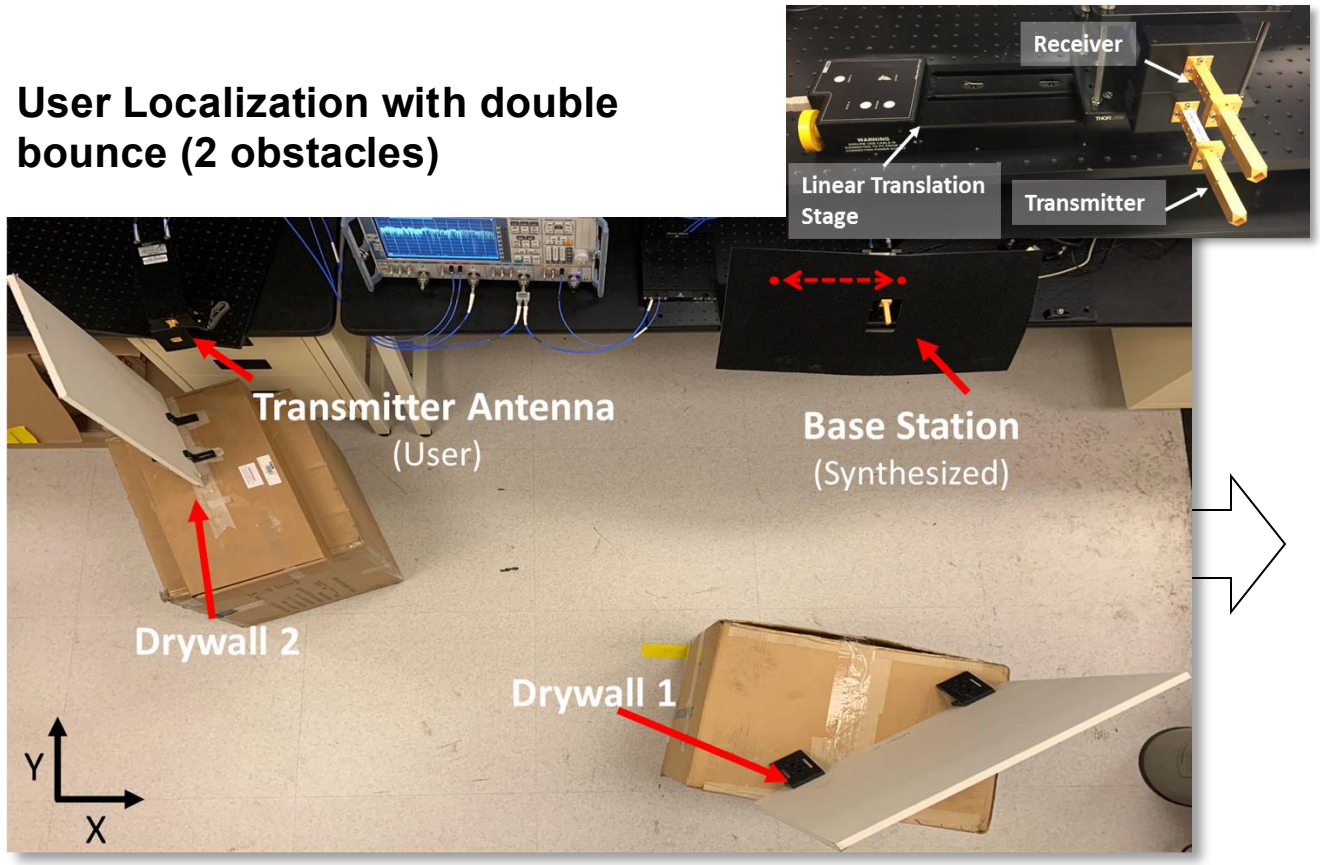
Corrected Image



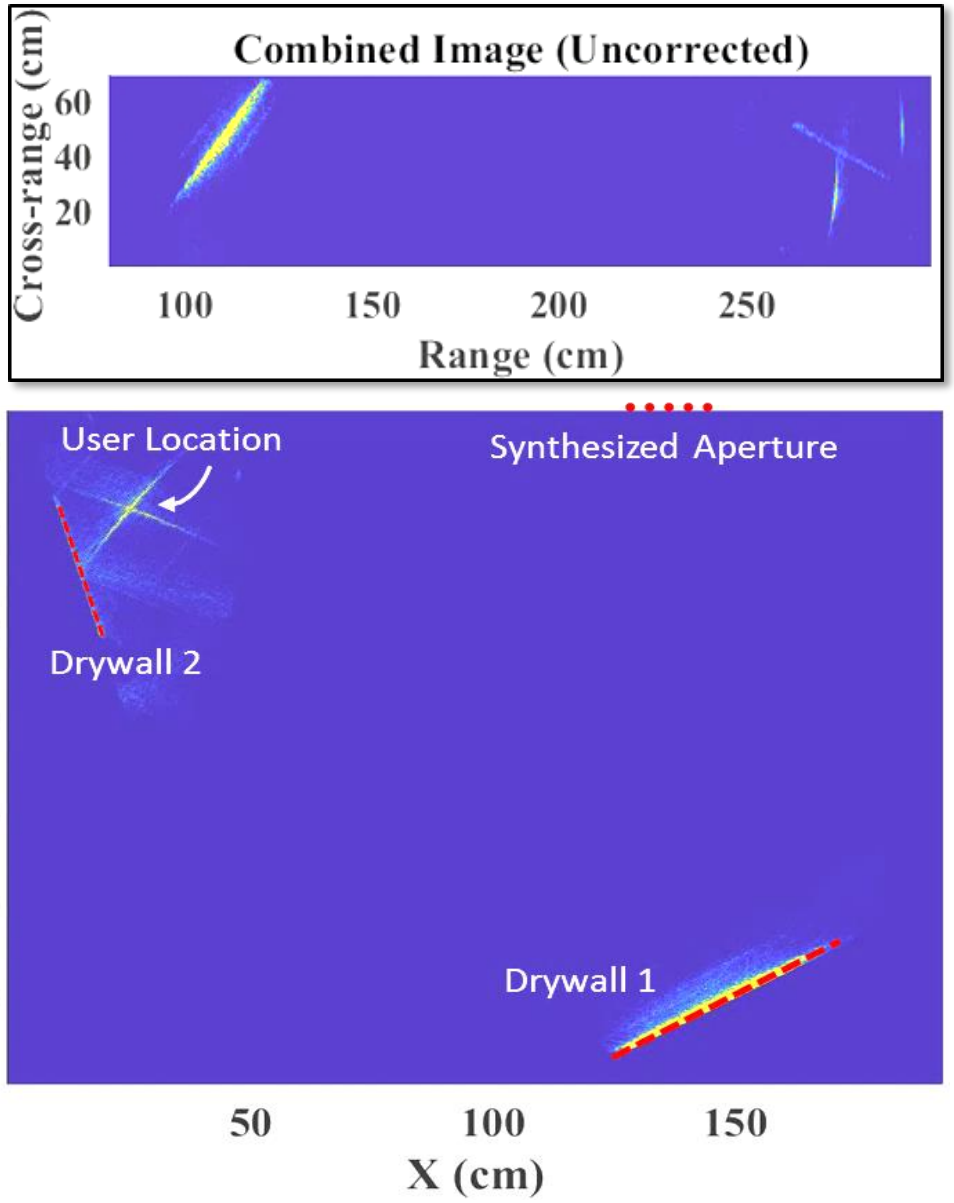
Cui, Yiran, and Georgios C Trichopoulos. "Seeing Around Obstacles with Terahertz Waves," https://arxiv.org/abs/2205.05066v1

Non-Line-of-Sight User Localization

User Localization with double bounce (2 obstacles)



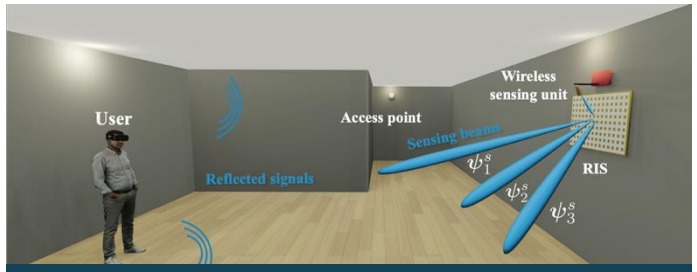
Raw mmWave Image + User location based on ToA (220 - 300 GHz)



M. Aladsani, A. Alkhateeb, and G. C. Trichopoulos, "Leveraging mmWave Imaging and Communications for Simultaneous Localization and Mapping," arXiv:1811.07097, submitted to IEEE ICASSP 2019.

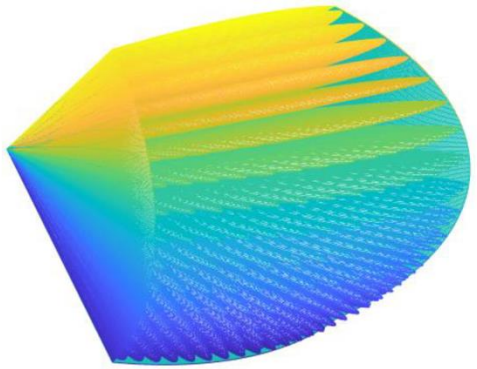
Integrated Imaging and Communications with RISs

- Problem and proposed solution:
  - RIS beam tracking is challenging (large # of antennas and narrow beams)
  - But… the large # of antennas enables high-spatial resolution imaging
  - Proposed solution: RIS imaging assisted communications



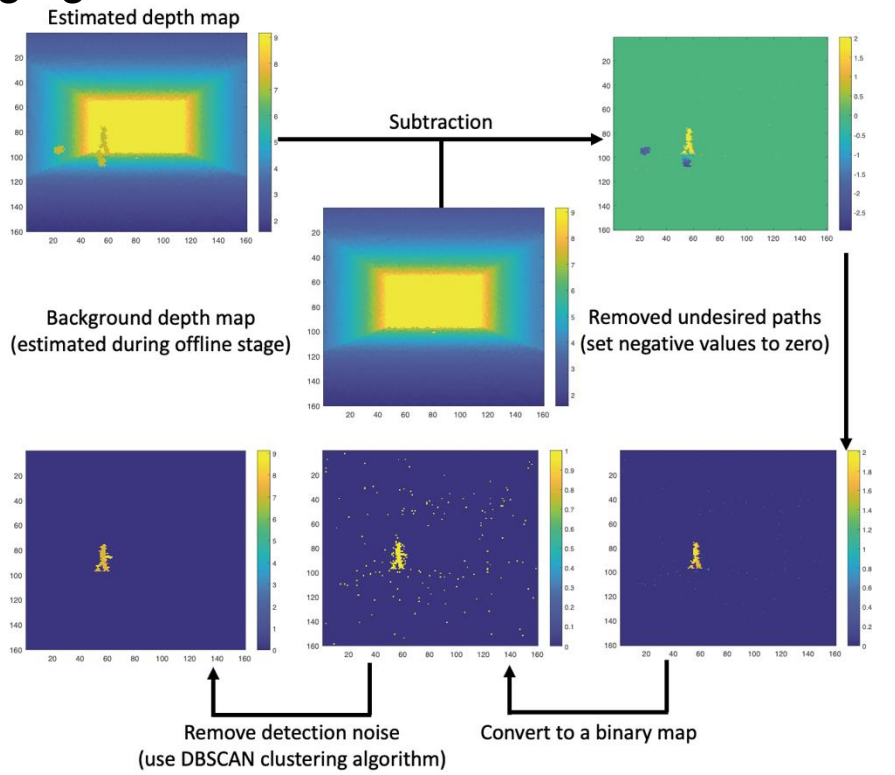
Imaging Stage - optimized codebook

Communication beam selection



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

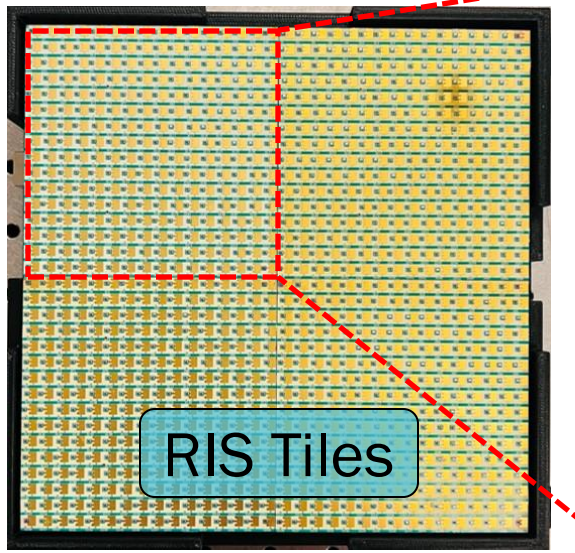
Designed a codebook optimized for the RIS depth map estimation problem



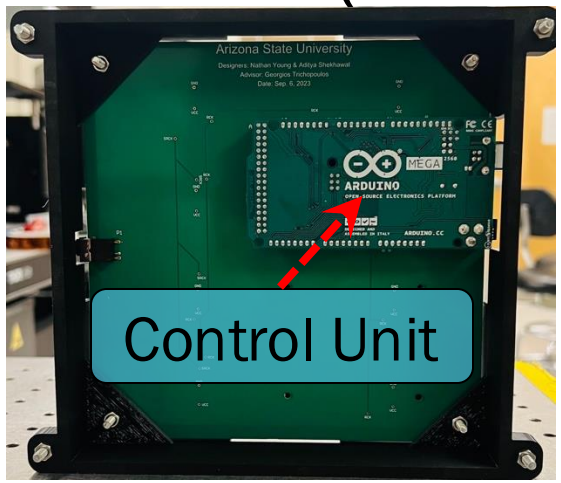
Mobile User Detection in RIS Depth Map

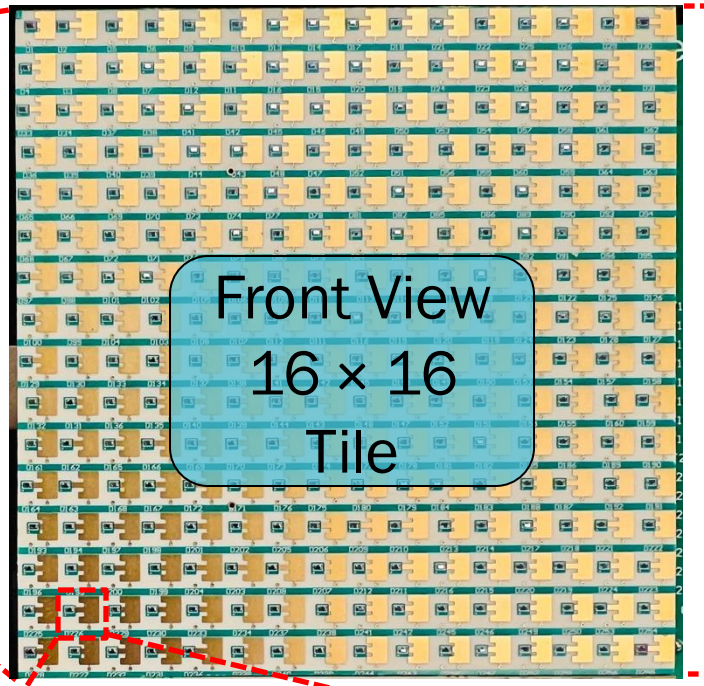
mmWave (28 GHz) RIS Prototype

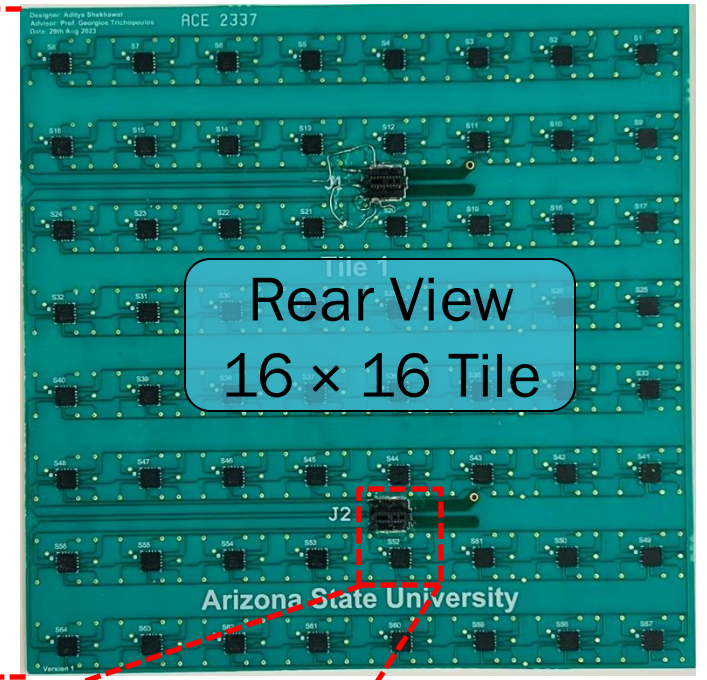
RIS Tiles (Front View)

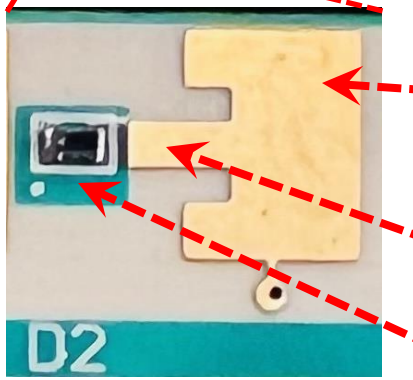


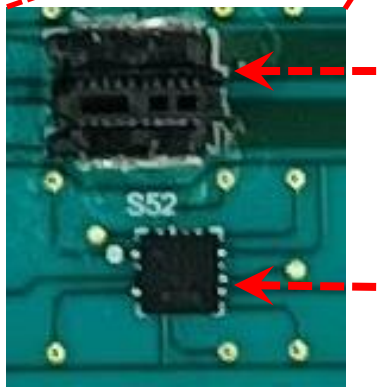
Control Board (Rear View)



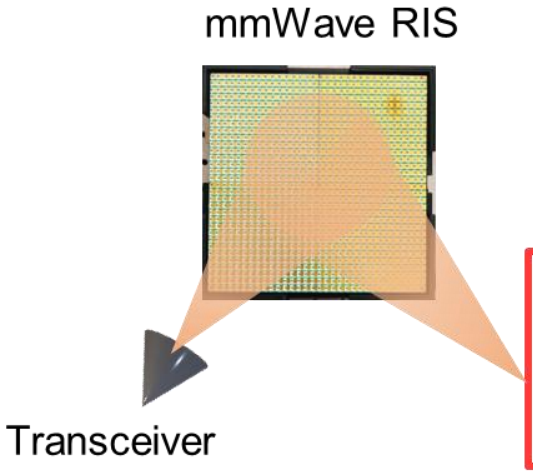


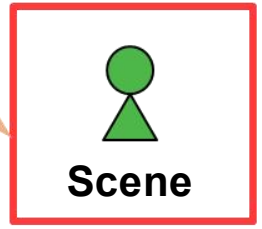






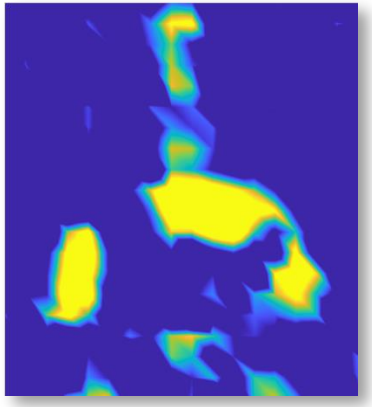
mmWave Mapping with an RIS



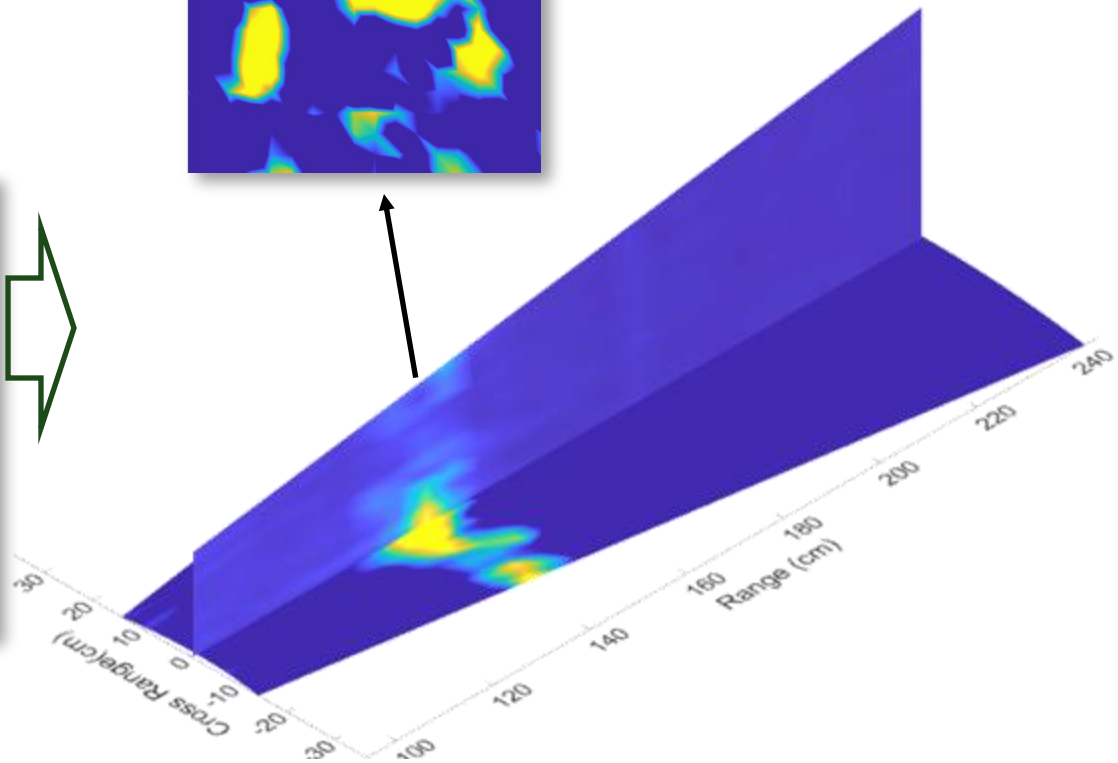


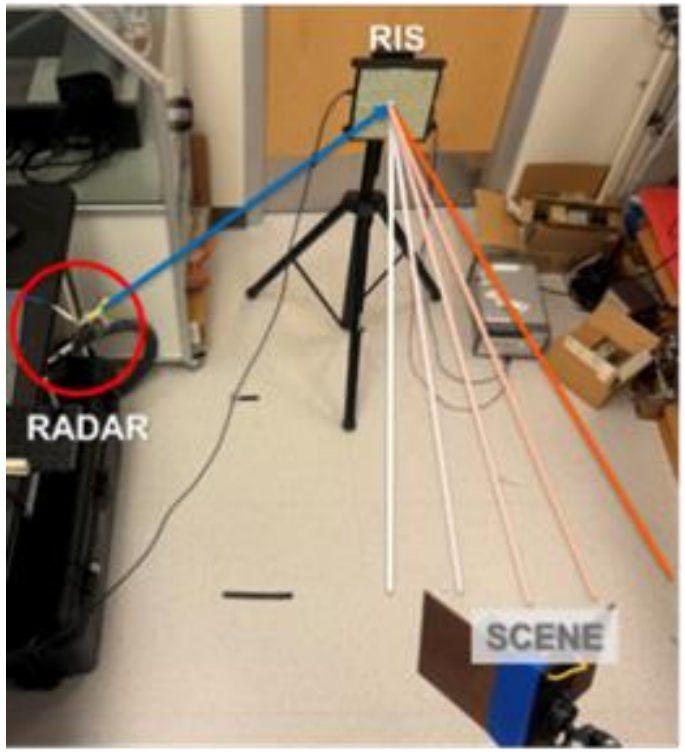
Frequency: 27.2-27.7 GHz
Field of view: +/- 40°
 # beams: 400

2D mmWave Image



3D mmWave Image

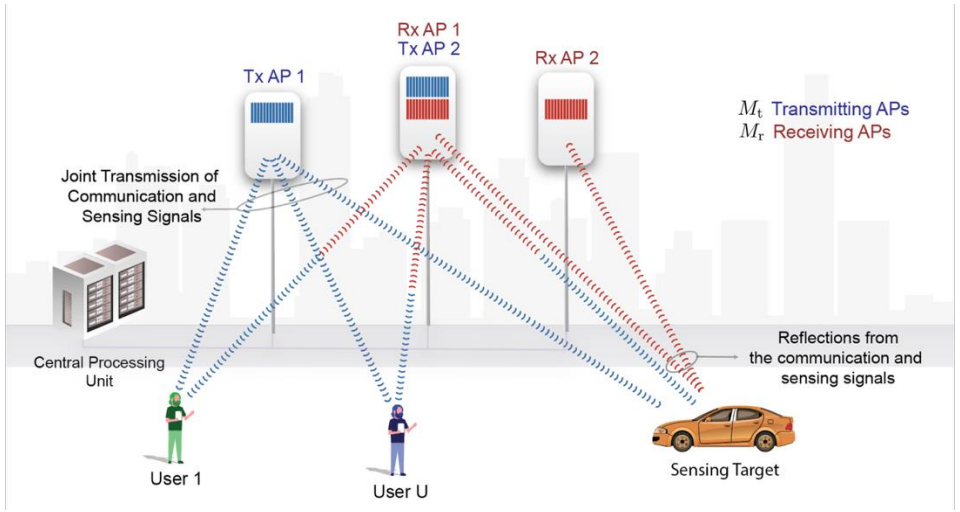




Scene

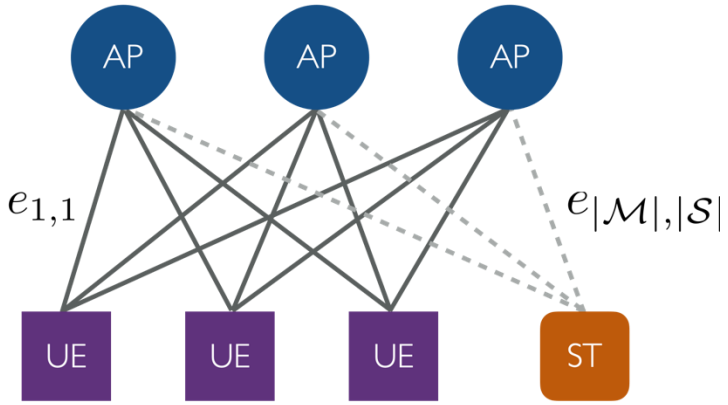
Learning Beamforming in Cell-Free ISAC MIMO Systems

- ISAC precoding design in cell-free MIMO is challenging
  - Computational complexity scales fast with the network size
  - Performance is very sensitive to channel estimation errors



Considered cell-free ISAC MIMO system with flexible access point-user connections

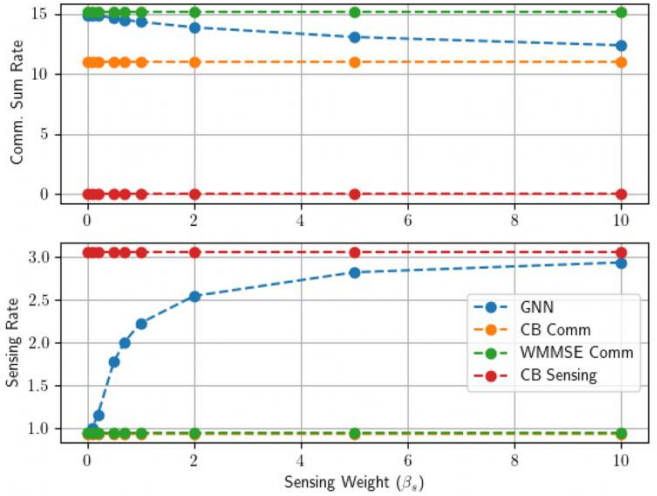
Graph neural network-based design



Node order invariance

Single neural network for all UEs

Single neural network for all sensing targets



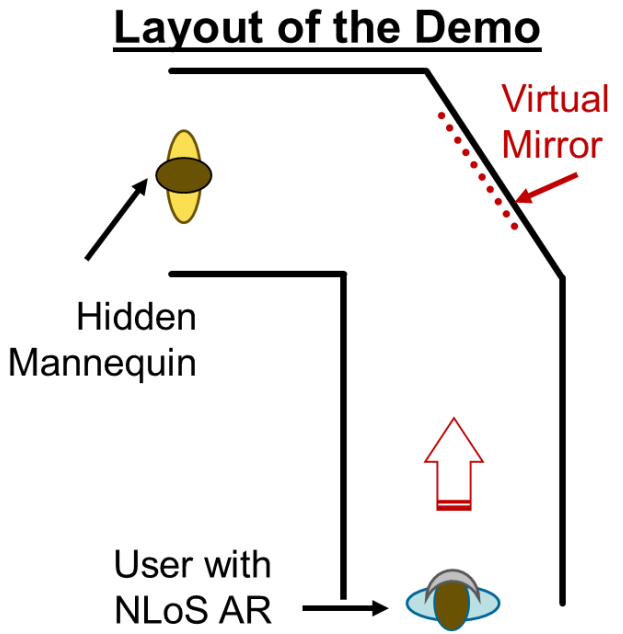
Near optimal communication/ sensing performance

Scalable - no need for retraining when new nodes are added

U. Demirhan and A. Alkhateeb, "Learning Beamforming in Cell-free Massive MIMO ISAC Systems," *in Proc. of IEEE 25th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Lucca, Italy, pp. 326-330, 2024

Broader Impacts

- The developed signal processing and optimization tools/techniques (such as the ones designed for joint sensing and communication beamforming in cell-free MIMO systems) can find applications in areas beyond wireless communications such as cognitive radar, adaptive sensing, and medical imaging
- The code produced by this research for cell-free ISAC, graph neural networks, joint communication and RFID localization, and joint imaging and comm was made publicly available.
- Cell-free ISAC was added as one of lectures in Advanced Topics on MIMO Communications course
- Multi-modal sensing and communication RIS dataset collected and planned to be published soon as part of the DeepSense 6G dataset



Acknowledgements

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