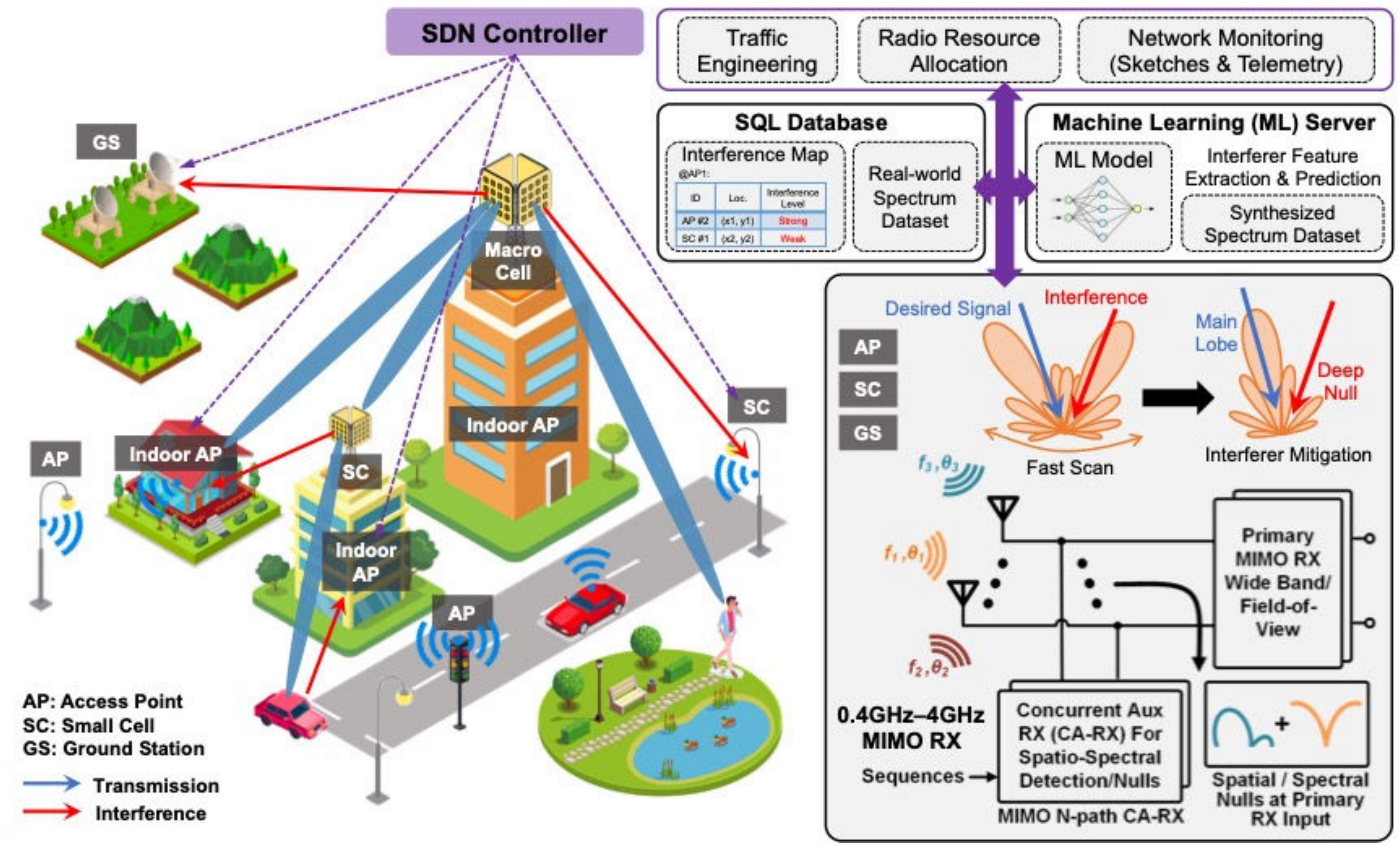
SWIFT: SHIELD: Software-Hardware Approach for Spectrum Coexistence with Rapid IntErferer Learning, Detection, and Mitigation

Tingjun Chen (PI)[1], **Arun Natarajan**[2], **Leandros Tassiulas**[3]

[1] Duke University, [2] Oregon State University, [3] Yale University

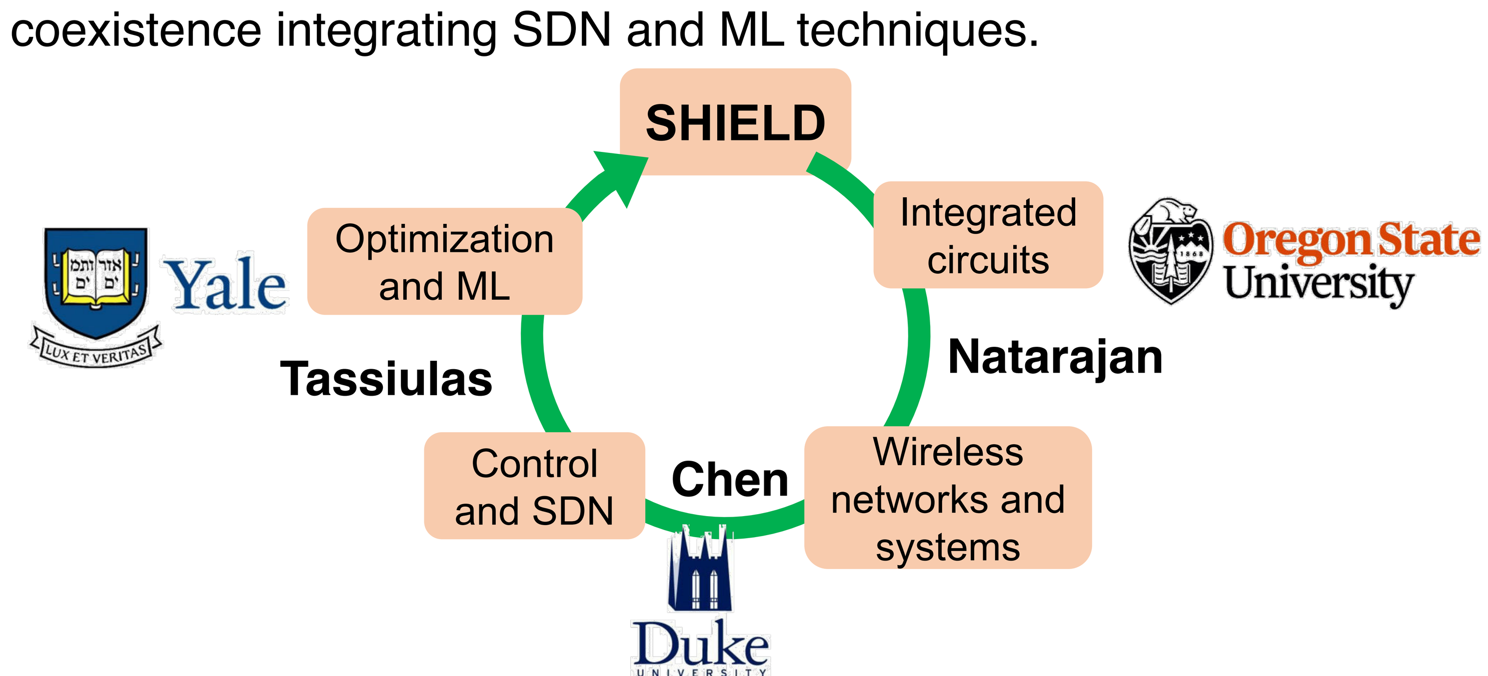
2024 NSF Spectrum Week MAY 13-17

Motivation and Project Goals



We collaboratively explore novel RF front-end architectures, control and software-defined networking (SDN), optimization and resource allocation, and ML, in three thrusts and in a top-down manner:

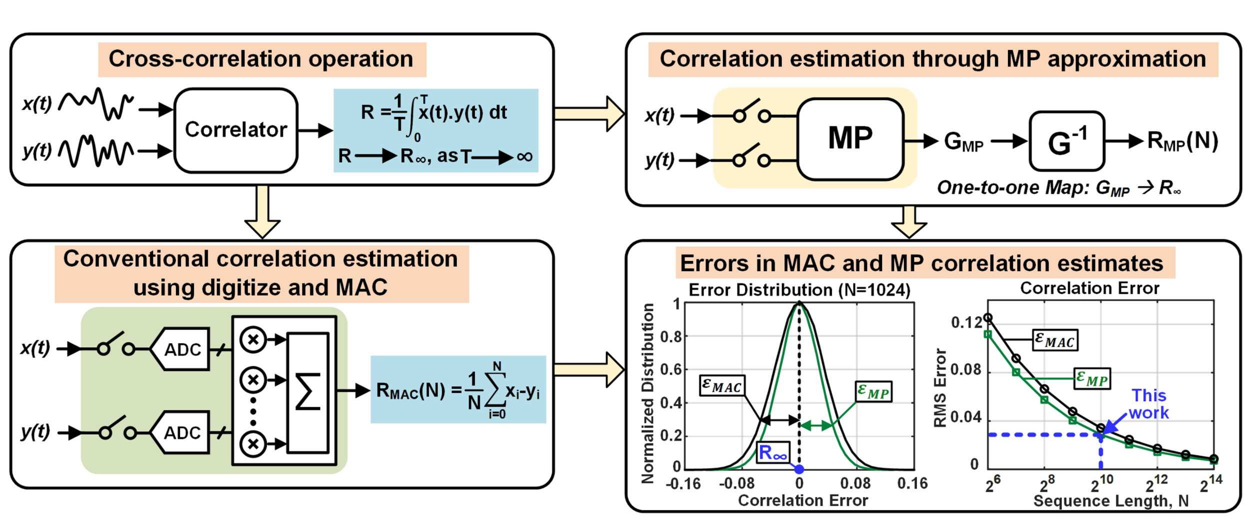
- **Thrust I**: Spectrum measurements and software-hardware integration for interferer mitigation, and spectrum coexistence demonstrations using the developed hardware/software;
- **Thrust II**: Novel 0.4–4 GHz MIMO RX architectures for rapid interference detection and N-path sequence-mixing for nulling specific interferers while preserving FoV/bandwidth for the main RX;
- **Thrust III**: Control plane design for spectrum monitoring and coexistence integrating SDN and ML techniques.



High-Speed Analog Correlator

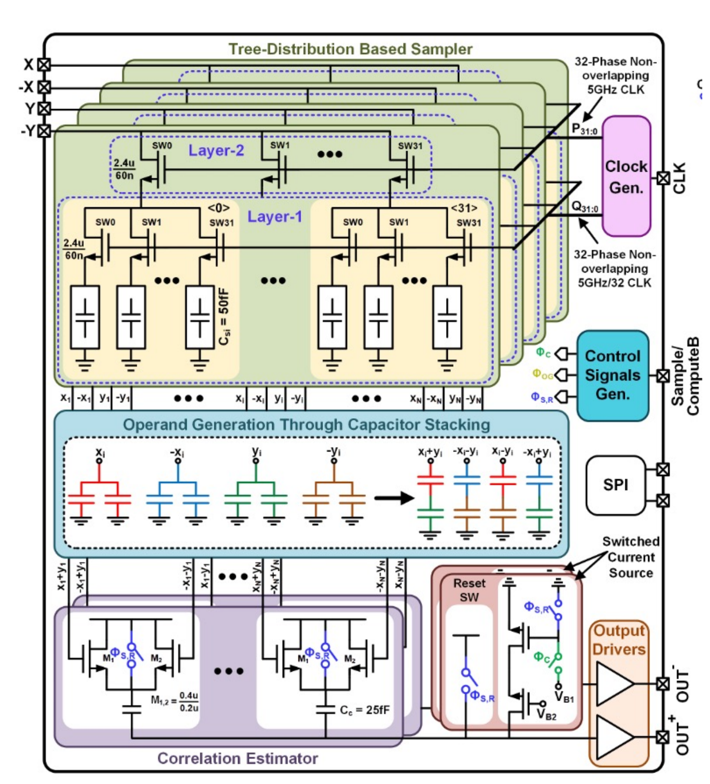
Ultra-Low-Power Analog Approximation

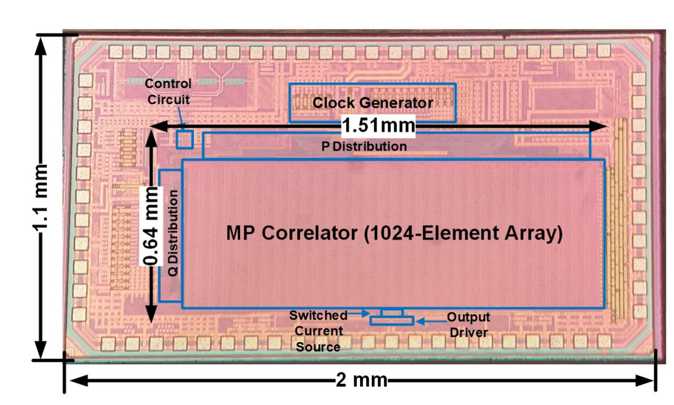
- Spectrum sensing can be modeled as correlations of spectrum signals with template waveforms (DFT, Fourier, wavelet, etc.)
- Develop analog approximation functions that are ultra low-power and can provide error performance comparable to digital multiply-accumulate (MAC) for random sequences



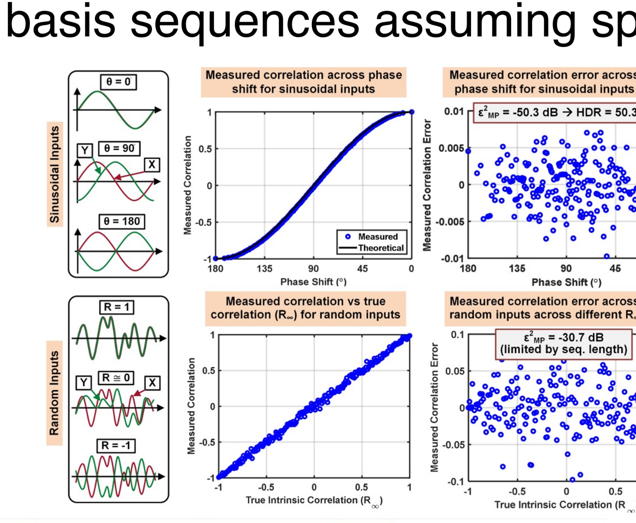
Integrated Implementation of Analog CMOS Correlator as a High-Speed Spectrum Sensor

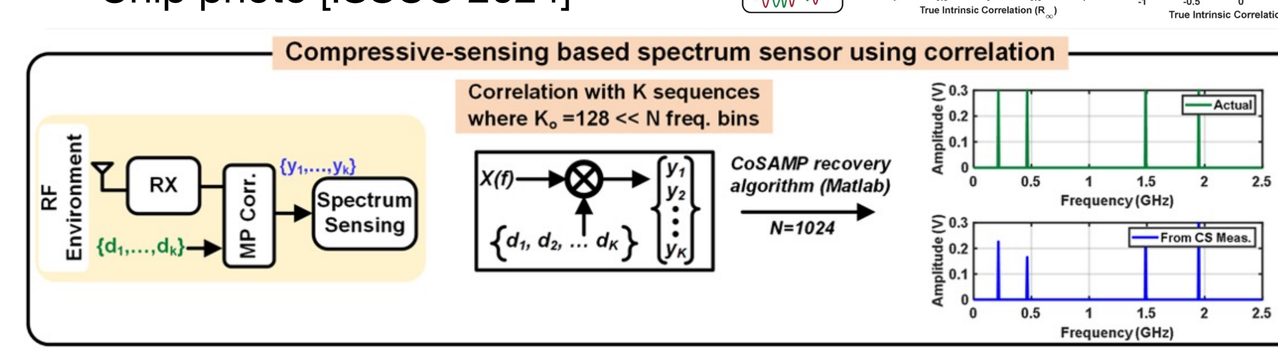
- Gen-1 implementation in 65nm CMOS: Capable of correlating two 5 GSa/s sequences with 1,024 samples
- Demonstration of compressive spectrum sensing by correlating with basis sequences assuming sparsity





Chip photo [ISSCC 2024]



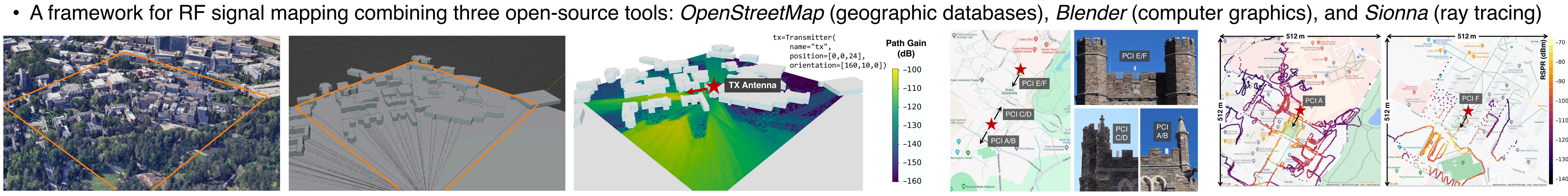


RF Signal Propagation Mapping

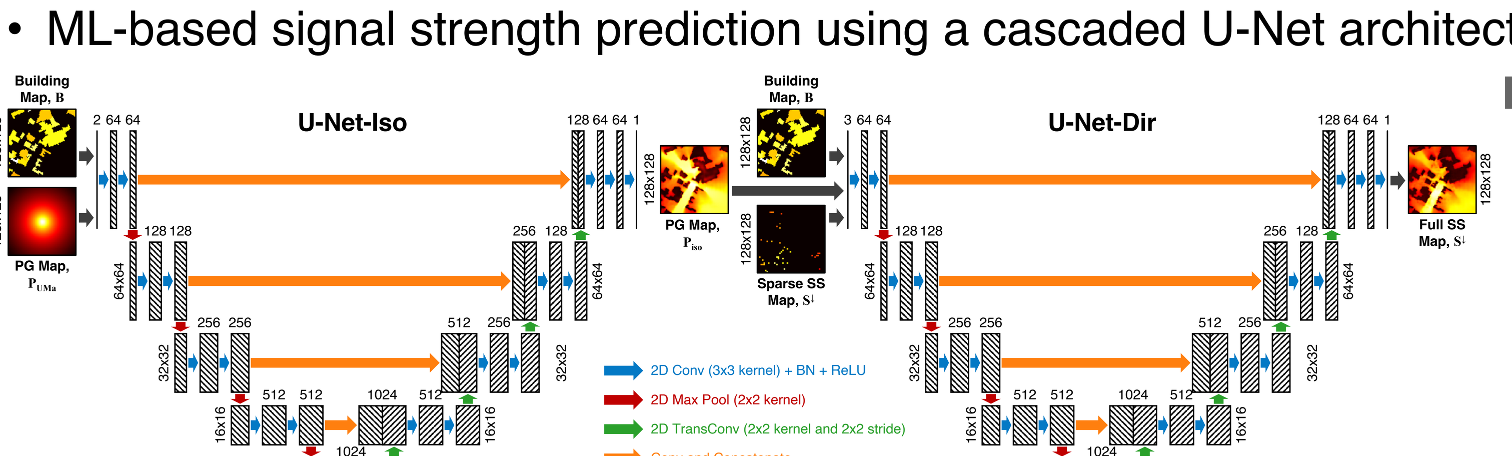
Geo2SigMap: High-Fidelity RF Signal Mapping Using Geographic Databases

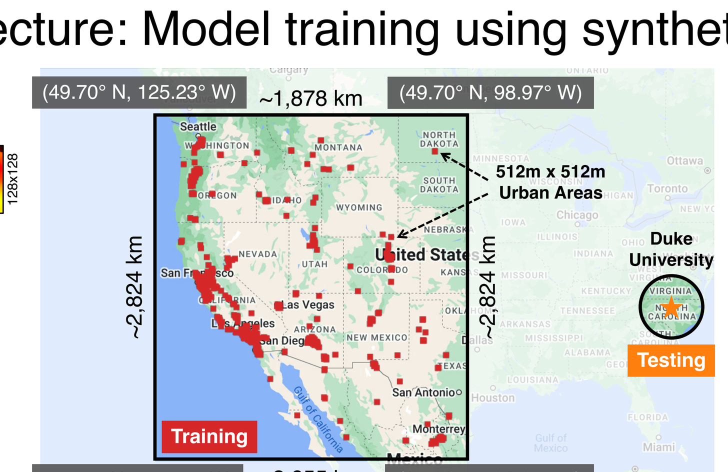
Code and measurement data available on GitHub! https://github.com/functions-lab/geo2sigmap

- A framework for RF signal mapping combining three open-source tools: *OpenStreetMap* (geographic databases), *Blender* (computer graphics), and *Sionna* (ray tracing)

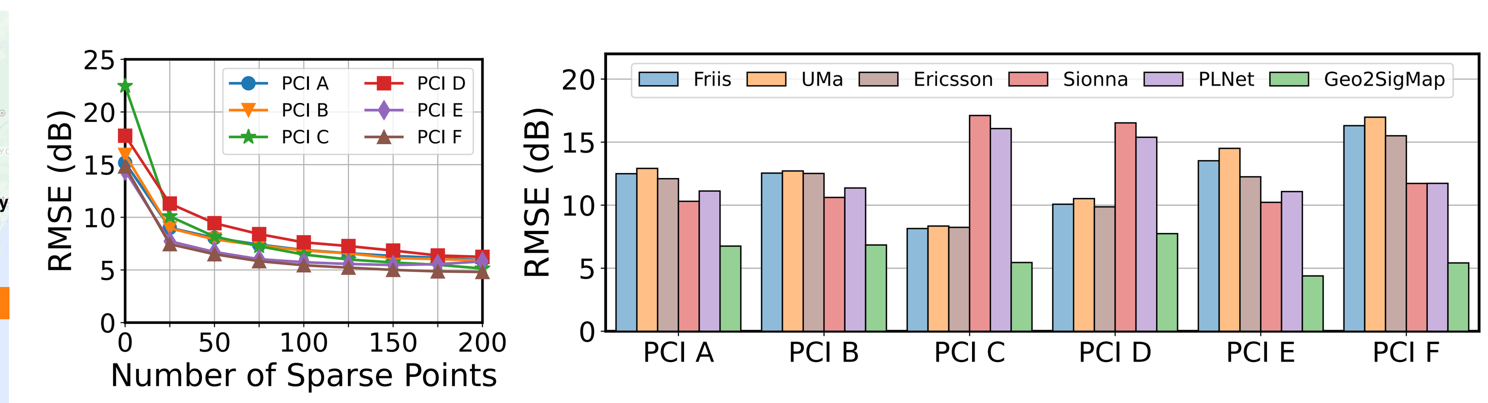


- ML-based signal strength prediction using a cascaded U-Net architecture: Model training using synthetic dataset and inference using sparse real-world measurement points





Proposed cascaded U-Net architecture (*left*) and the datasets used for model training and testing (*right*)

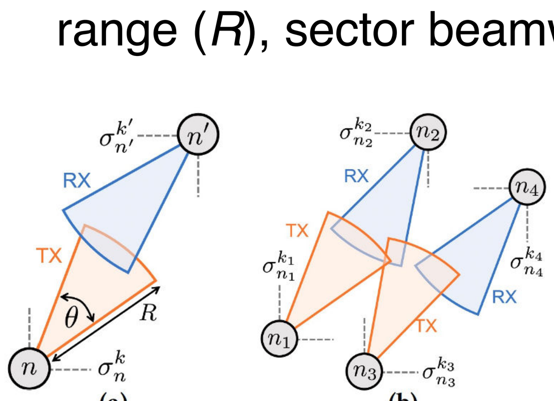


RMSE of the predicted RSRP map: (*left*) with varying number of sparse measurement points, and (*right*) compared to existing baselines

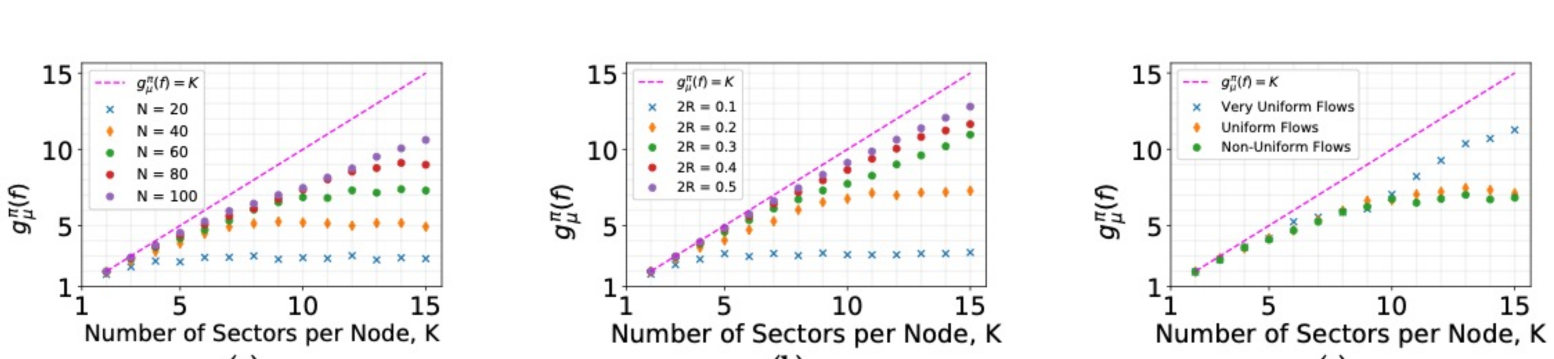
Scheduling in Sectorized Networks

Capacity-Achieving Scheduling Algorithms in Directional Networks

- We evaluate the capacity of sectorized networks that employ directional antennas at each infrastructure node to achieve improved capacity and reduced interference in communication
- We design (i) a general sectorized multi-hop wireless network model and characterize its capacity region using matching polytopes, and (ii) a distributed approximation algorithm that optimizes the sectorization of each node under a network flow with performance guarantee
- Considered network parameters: Number of nodes (N), sectors per node (K), communicate range (R), sector beamwidth width (θ), and uniformity of network flow (ϕ)



Sectorized node model and the interference model



The approximate sectorization gain as a function of the different network parameters, which increases sub-linearly with the number of sectors per node

Ongoing Work

- Full transceiver IC design and integration with an SDR platform for experimental evaluation of spectrum sensing using tunable MIMO phased array front ends
- Leveraging ML techniques (e.g., CNN and U-Net) for detecting and identifying interference from different (*angle, freq*) pairs
- Continue our spectrum measurement campaigns and incorporate of RAN-side information and telemetry frameworks (e.g., srsRAN and NG-Scope) to improve spectrum awareness

References

[1] K. Rashed, A. Undavalli, S. Chakrabartty, A. Nagulu, and A. Natarajan, "A scalable and instantaneously wideband 5GS/s RF correlator based on charge thresholding achieving 8-bit ENOB and 152 TOPS/W compute efficiency", in *Proc. IEEE ISSCC'24*, 2024.

[2] Y. Li, Z. Li, Z. Gao, and T. Chen, "Geo2SigMap: High-fidelity RF signal mapping using geographic databases," in *Proc. IEEE DySPAN'24*, 2024.

[3] P. Promponas, T. Chen, and L. Tassiulas, "Optimizing Sectorized Wireless Networks: Model, Analysis, and Algorithm," in *Proc. ACM MobiHoc'23*, 2023.

This project is supported by the NSF SWIFT program under awards CNS-2128638, CNS-2128530, and CNS-2128535.