Collaborative Research: NewSpectrum: Enabling Dense and In-Situ Spectrum Monitoring via Analog Correlators and Circuits-System Co-Design

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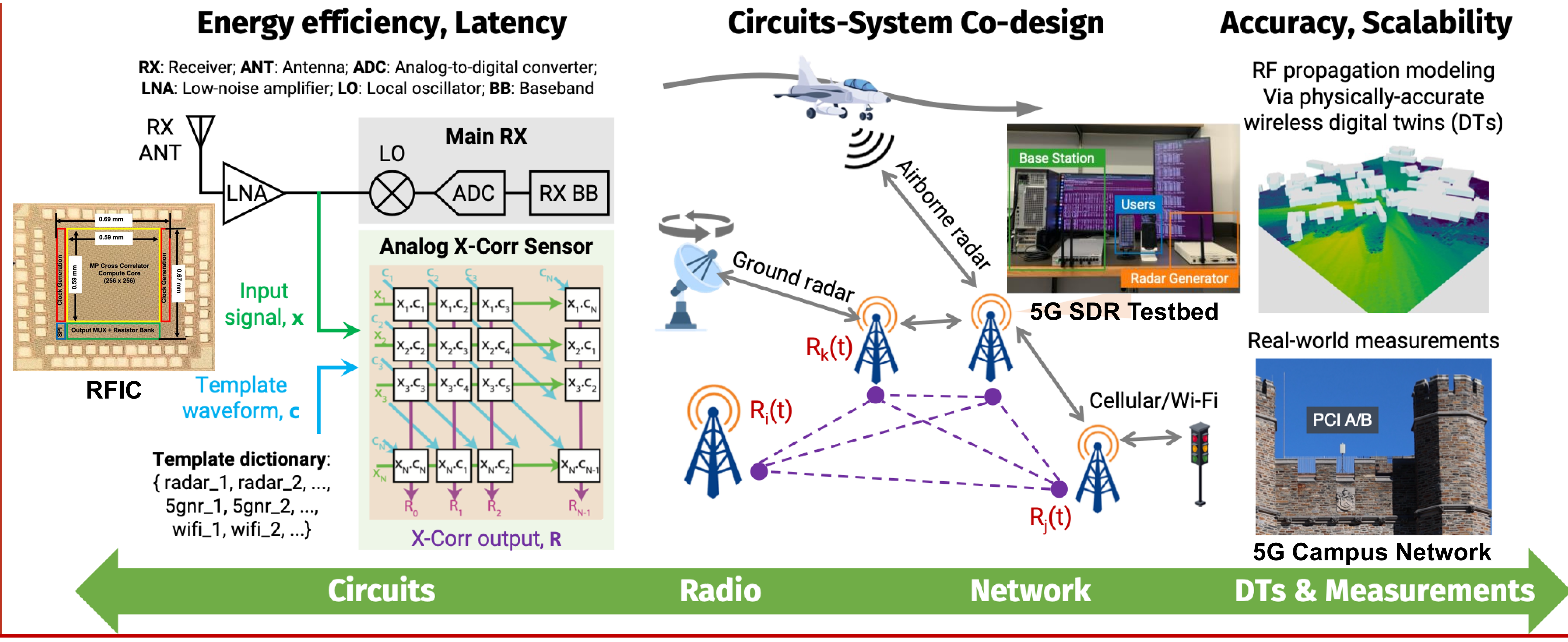
Motivation and Project Goals

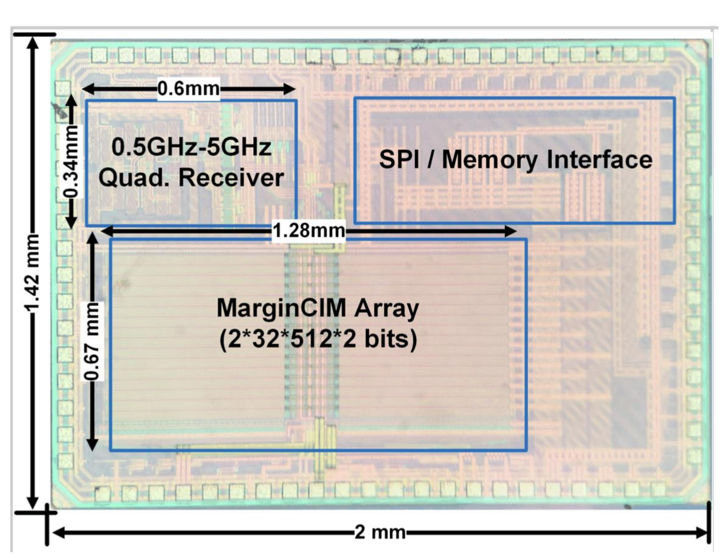


- **Circuits**: Development of ultra-efficient (>1,000 TOPS/W), single-shot, analog cross-correlators (X-Corr) using the margin computing paradigm, capable of computing cross-correlations between input signals and template waveforms across varying lags, enabling spectrum sensing with ultra-low latency
- **Algorithms**: Design of protocol-aware configuration and adaption for X-Corr sensor to enable fine-grained, in-band spectrum sensing of spectrum occupancy and detection of interference signals at the symbol/slot level (a few to 10s of usec) with both known and unknown features (e.g., for airborne and ground radars)
- **Systems**: Optimized deployment and configuration of a network of densely deployed X-Corr sensors to facilitate cooperative, in-situ spectrum sensing that is aware of the communication standards. Integration of the developed X-Corr sensor with 5G testbeds based on OAI/srsRAN and software-defined radios (SDRs)

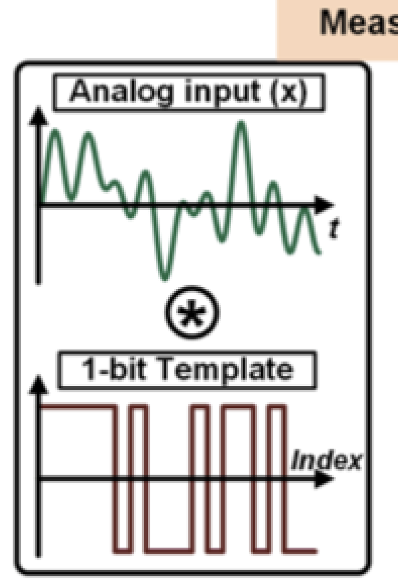
High-Speed Analog Correlator

RF/Analog-to-Feature Conversion using Margin Propagation Based Compute-in-Memory (MarginCiM)

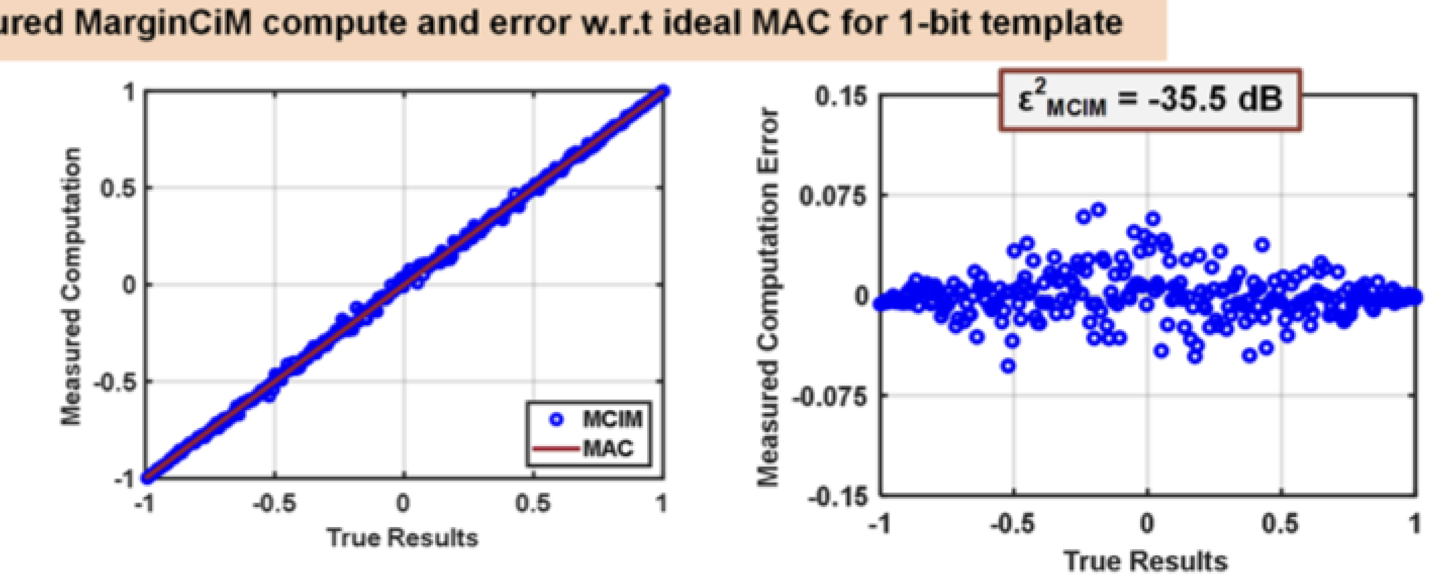
- Developed an approximate analog compute array (MarginCiM) that enables correlation of analog I/Q signals *before* ADC (with >1 GHz bandwidth) with 1-bit, 2-bit, and 4-bit template stored in SRAM memory
- Perform 512 length correlation for 2-bit templates with ~2.5pJ/Corr. → State-of-the-art energy efficiency >1 PetaOPS/W
- Transform RF/analog receiver from signal conduit to a block capable of translating RF signals to information
- Applications: (1) Spectrum sensing by correlation with sinusoidal templates; (2) Pilot tone detection of Zadoff-Chu sequences

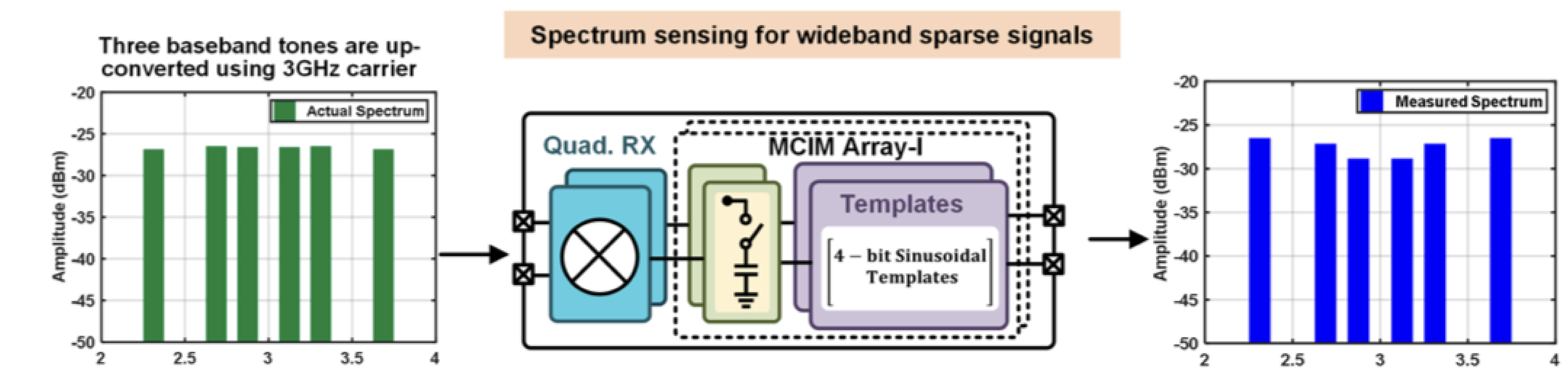


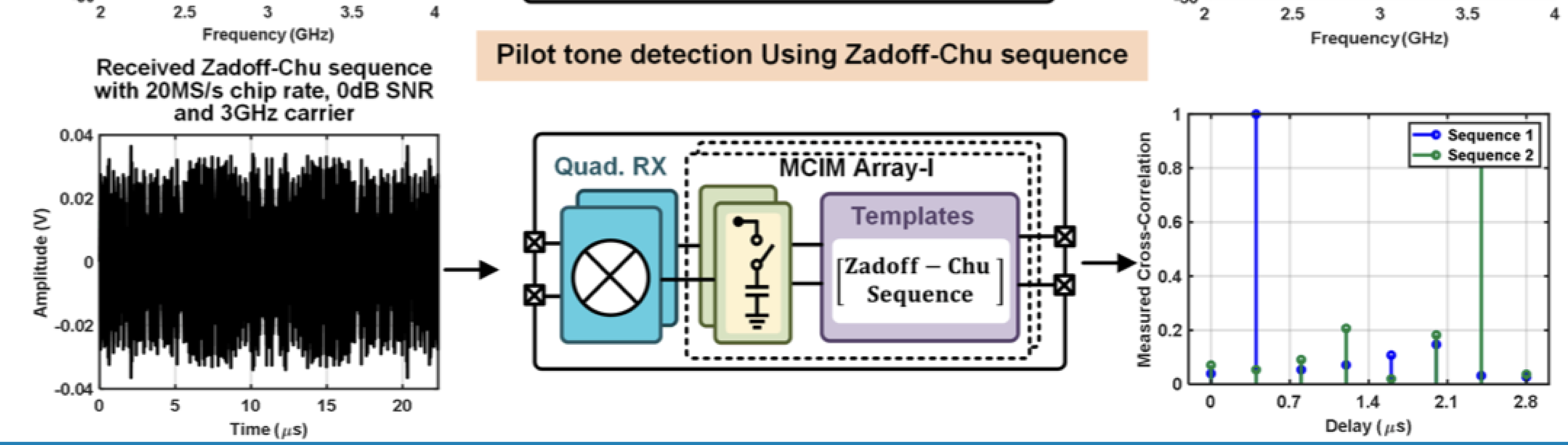
Chip photo [*under submission*]



Measured MarginCiM compute and error w.r.t ideal MAC for 1-bit template





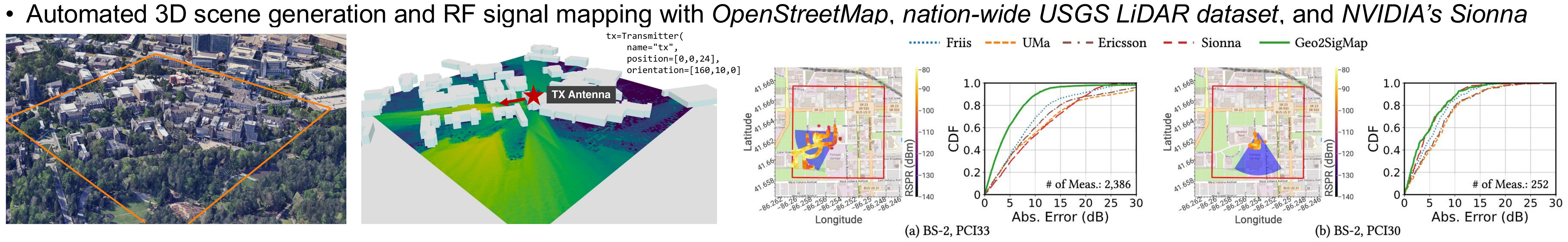


RF Signal Propagation Mapping

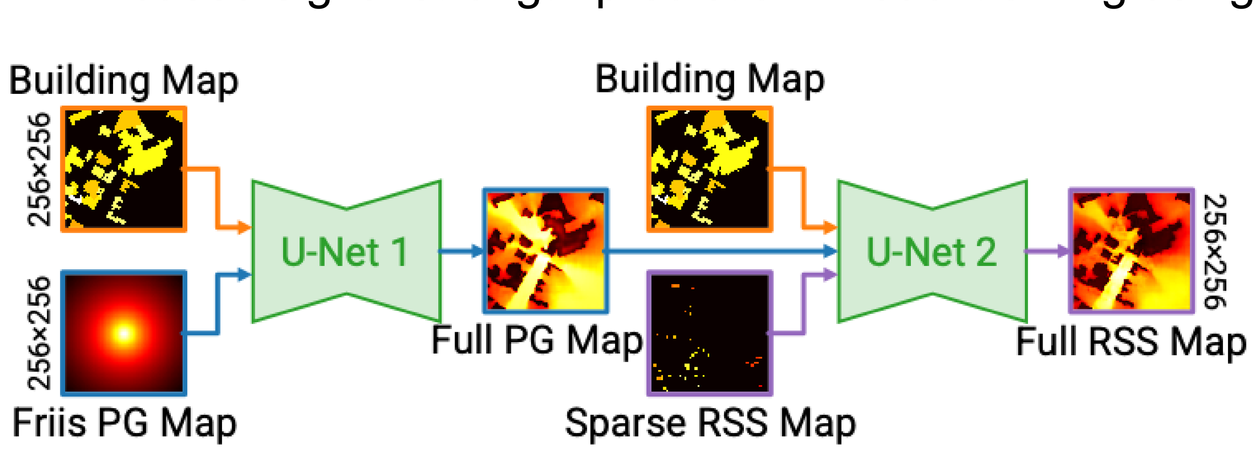
Geo2SigMap: High-Fidelity RF Signal Mapping Using Geographic Databases

Code and measurements data available online at: https://github.com/functions-lab/geo2sigmap

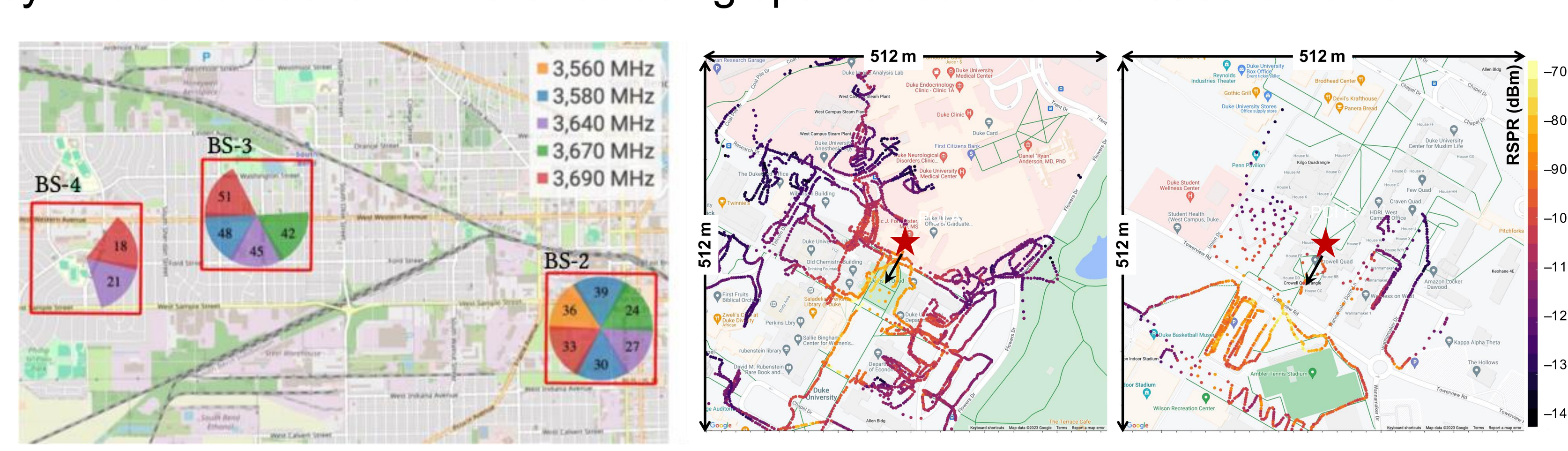
- Automated 3D scene generation and RF signal mapping with *OpenStreetMap*, *nation-wide USGS LiDAR dataset*, and *NVIDIA's Sionna*



- ML-based signal strength prediction: Model training using synthetic dataset and inference using sparse real-world measurements



Cascaded U-Net model architecture



CBRS measurements in South Bend, IN (*left*) and Durham, NC (*right*)

Ongoing Work

- BatStation: In-situ radar sensing at 5G base stations using zero-shot template generation, evaluated using srsRAN and CBRS radar signals
- Optimization and integration of the zero-shot template generation framework with the MarginCiM IC for spectrum and radar sensing tasks
- Continue our spectrum measurement campaigns and investigate cooperative spectrum sensing across multiple base stations and MarginCiM-based sensors

References

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[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.

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[5] Z. Gao, Z. Liu, and T. Chen, "BatStation: Toward in-situ radar sensing on 5G base stations with zero-shot template generation," *arXiv:2509.06898 [cs.NI]*, Sept. 2025.

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