UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

# Enabling IoT Self-Localization Using Ambient 5G mmWave Signals

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## Number of Deployed IoT Devices is Surging

- Widely used in various applications, e.g., Smart City Monitoring, Data Drive Agriculture, Industry Automation, etc.
- Localization and Tracking IoT devices are essential primitives for many applications.

## Can IoT device accurately localize itself by simply listening to ambient 5G signals?

### mmWave 5G networks provide great opportunities for IoT localization

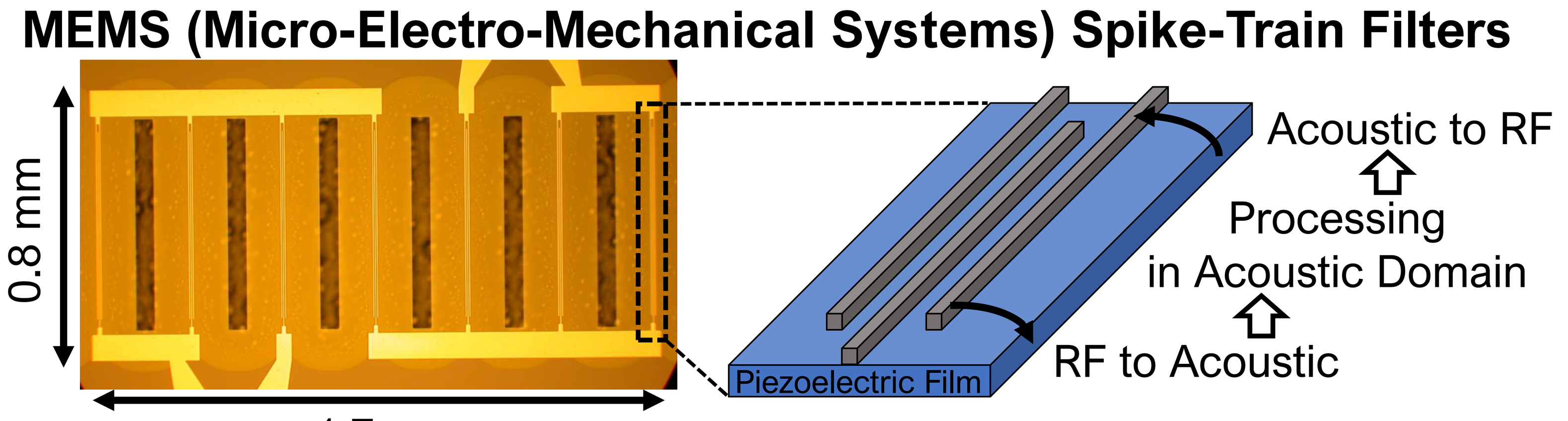
- Small cell size leads to dense deployment of base stations, providing anchor points for accurate localization.
- Wide bandwidth (up to 400 MHz in mmWave bands) results in high Time of Flight resolution.

### Challenges:

- Low-cost IoT devices, equipped with low-power low-speed ADCs are incapable of capturing wideband 5G signals.
- Scalable IoT self-localization techniques should not require any dedicated resources or active participation of the gNBs for coordination or synchronization.

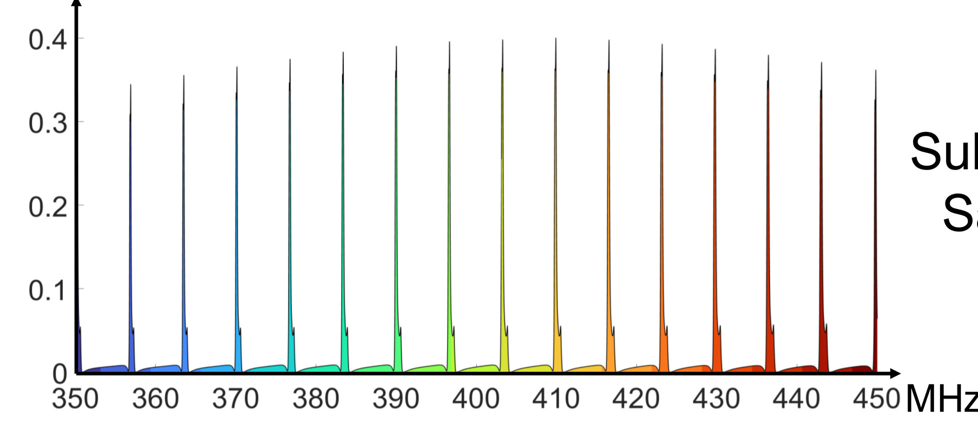
## Capturing Wideband 5G Waveform on Narrowband IoT Devices

**MEMS (Micro-Electro-Mechanical Systems) Spike-Train Filters**



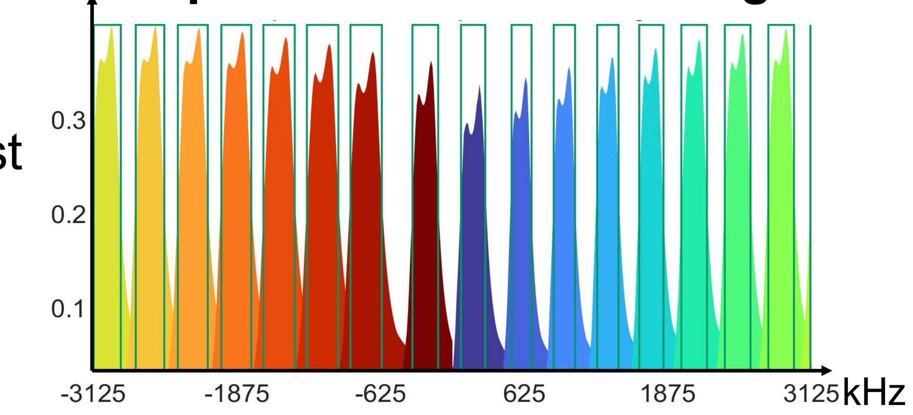

- First of its kind Spike-Train filter leveraging harmonic resonance frequencies of MEMS acoustic resonators [1].

**Filter Frequency Response: Spike-Train**




Sub-Nyquist Sampling

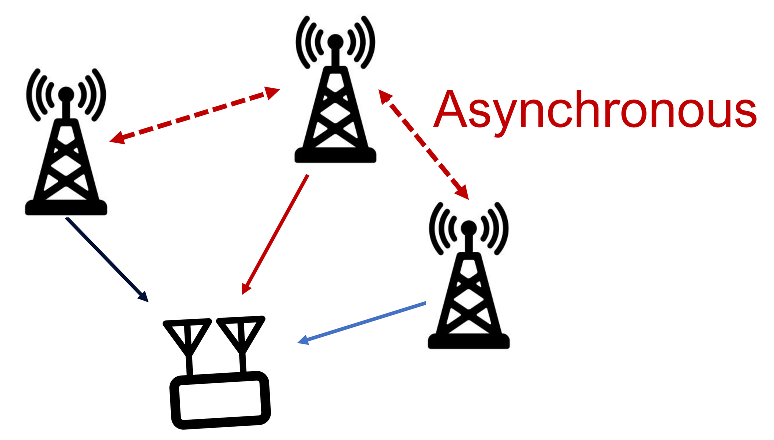
**Spike-Train After Aliasing**




- Structured sparsity in the filtered wideband spectrum allows for recovery after sub-Nyquist Sampling.
- Co-designing filter hardware and sparse recovery algorithm.

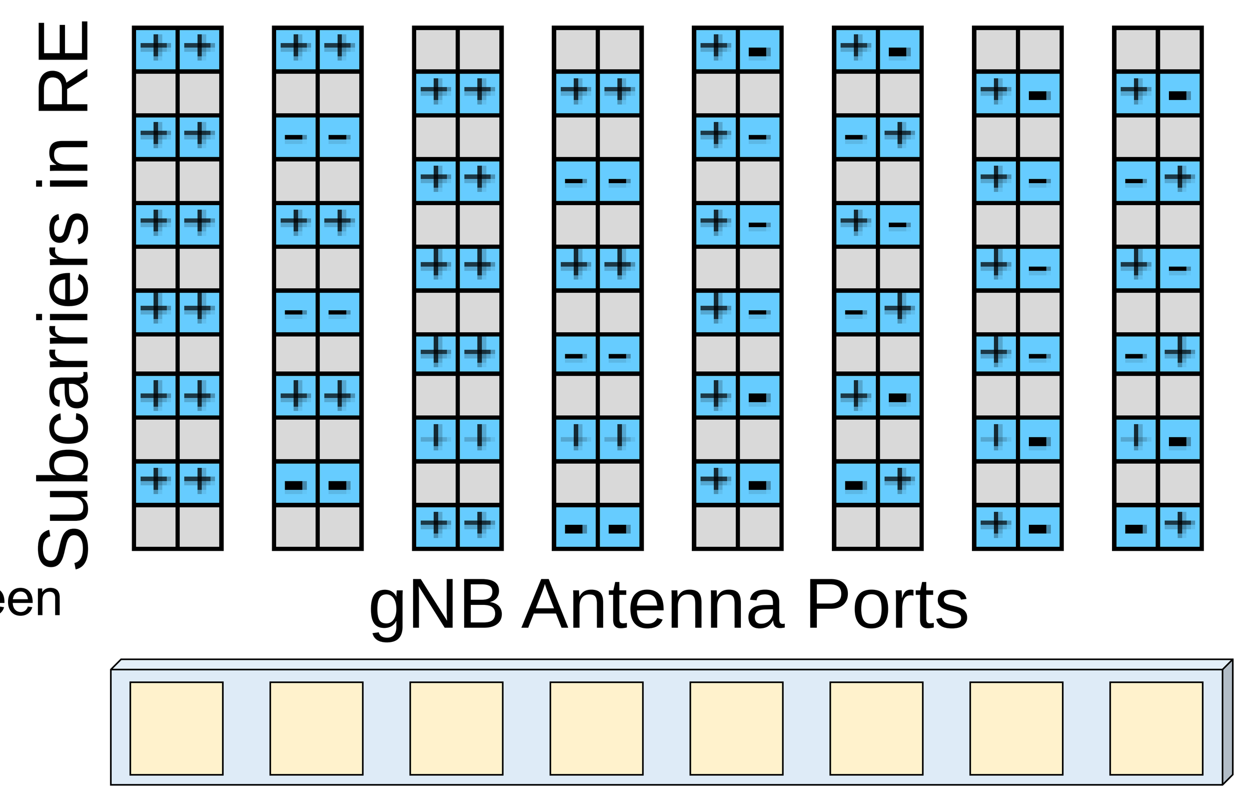
## Coordination-Free Localization – Leveraging MIMO Antenna Array in 5G gNB

Synchronization offsets between gNBs and IoT nodes corrupts ToF estimation.




Prior work [2] measures differential ToF between two antennas to localize the IoT node.

Limitation: Additional front-end and RF chain doubles power consumption and cost.




**PDSCH DMRS Resource Allocation**

### Leverages Unique Opportunities in 5G-NR

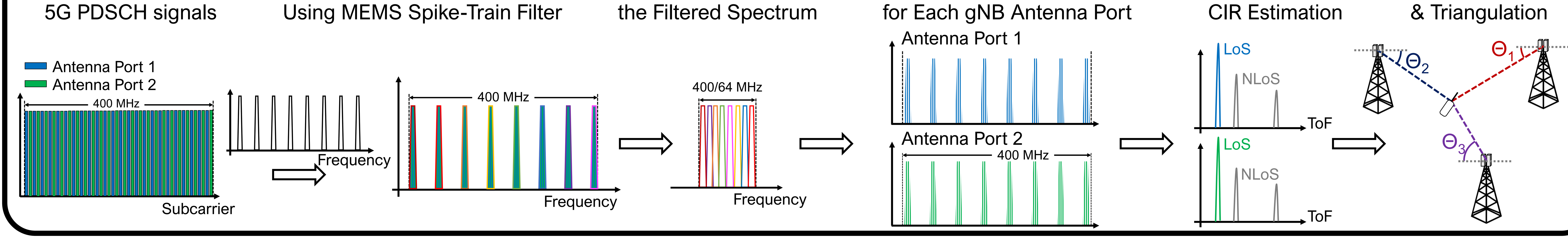
- Spatial diversity of MIMO antenna arrays in 5G gNBs, which allows for AoD estimation and triangulation-based localization.
- Particular resource allocation in the PDSCH DMRS waveform, which allows for resolving different gNB antenna ports.

### Physical Downlink Shared Channel (PDSCH) DeModulation Reference Signal (DMRS) in 5G-NR

- Preamble-like waveform used for channel estimation in PDSCH data decoding.
- Different antenna ports are allocated with different sets of interleaved subcarriers, allowing for resolving different antennas.

## mm-ISLA System Pipeline

(1) Overhearing ambient 5G PDSCH signals (2) Sparsifying Wideband Spectrum Using MEMS Spike-Train Filter (3) Sub-Nyquist Sampling the Filtered Spectrum (4) Recovering DMRS Subcarriers for Each gNB Antenna Port (5) Super Resolution CIR Estimation (6) AoD Estimation & Triangulation

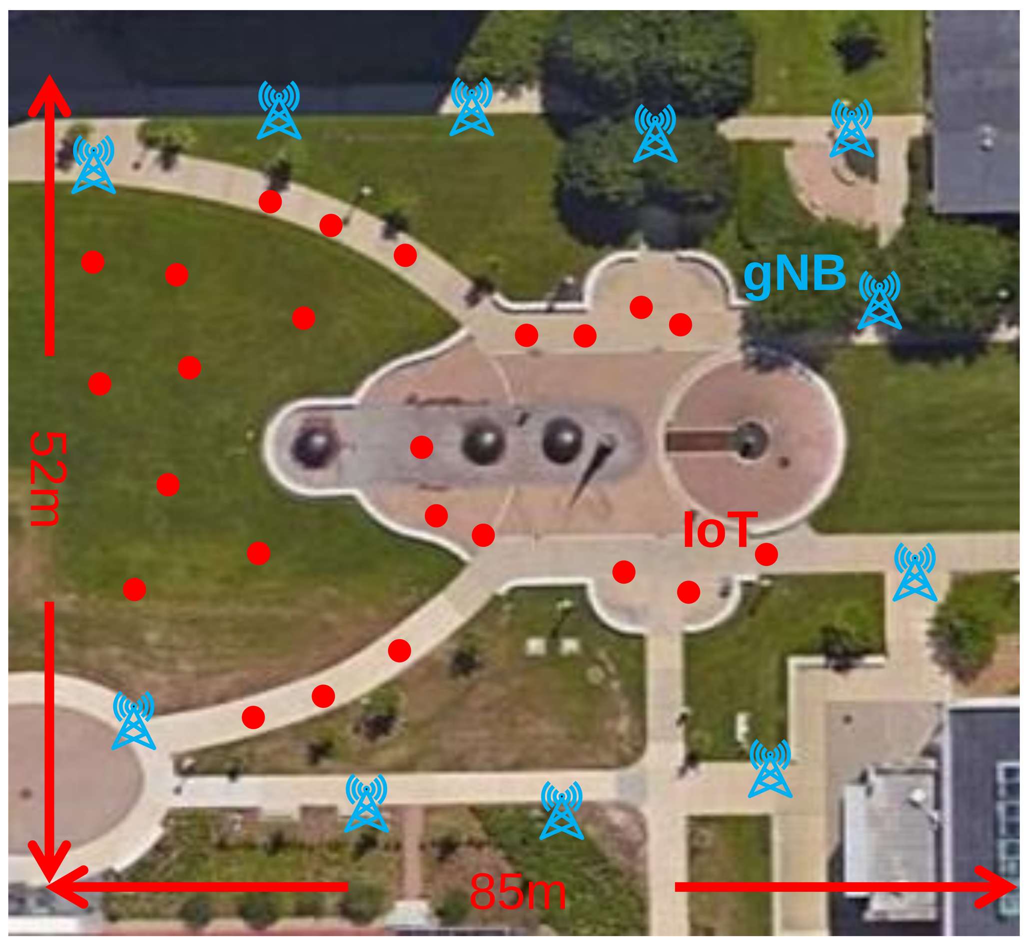



## Preliminary Results

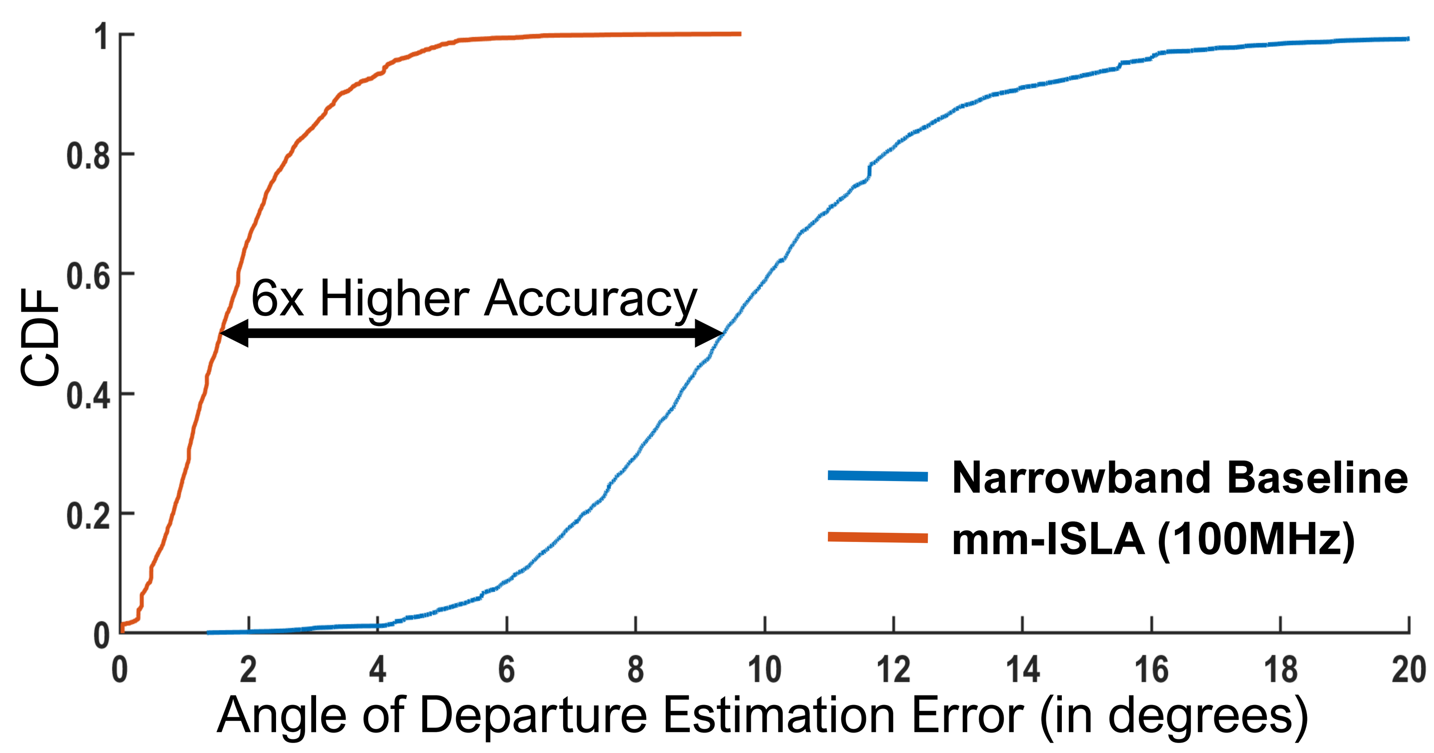
### Experiment Setup

- Due to the lack of MIMO-enabled mmWave frond-ends, we evaluate mm-ISLA at 1 GHz.
- 5G gNB and mm-ISLA IoT node are emulated using X310 USRPs.
- Dual-antenna gNB transmitting 100 MHz OFDM waveform.
- mm-ISLA node samples at 6.25 MHz (16x lower than the Nyquist sampling rate).
- AoD estimation accuracy of mm-ISLA compared against that of narrowband receiver.

Prototype Base Station




Campus Testbed




**References**

[1] R. Lu et al. 2018. RF Filters with periodic Passbands for Sparse Fourier Transform-Based Spectrum Sensing. Journal of Microelectromechanical Systems.

[2] S. Jog et al. 2022. Enabling IoT Self-Localization Using Ambient 5G Signals, USENIX Symposium on Networked Systems Design and Implementation (NSDI).

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