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

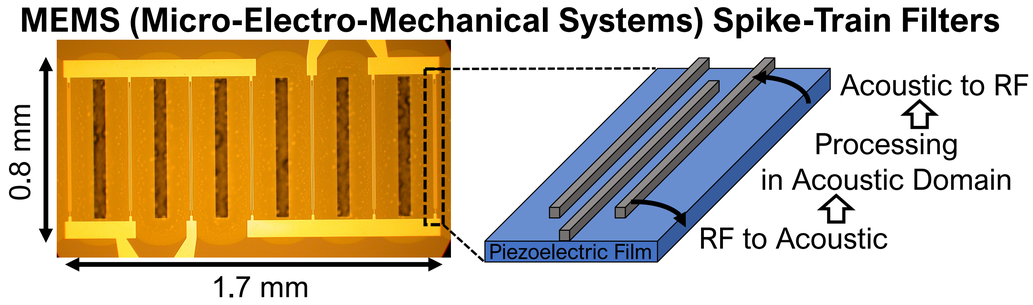
- Small cell size leads to dense deployment of base stations, providing anchor points for accurate localization.
- Wide bandwidth (up to 400 MHz in mmWave bands) results in high Time of Flight resolution.

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.

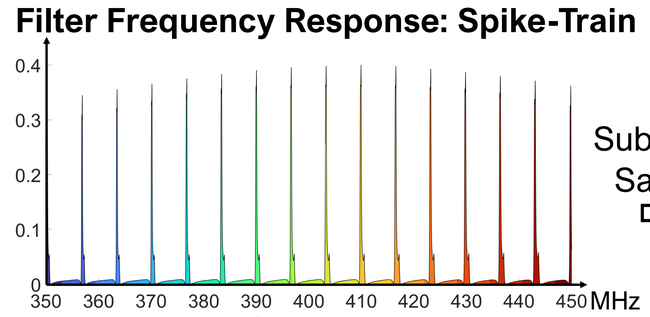
Capturing Wideband 5G Waveform on Narrowband IoT Devices

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



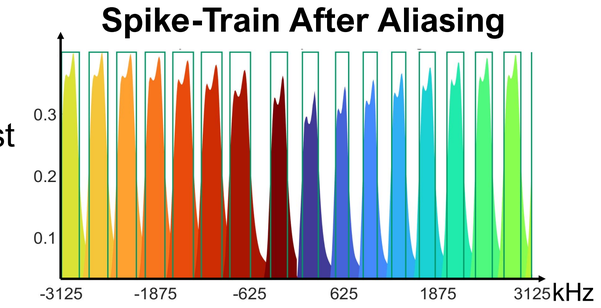
- First of its kind Spike-Train filter leveraging harmonic resonance frequencies of MEMS acoustic resonators [1].

Filter Frequency Response: Spike-Train



Sub-Nyquist Sampling

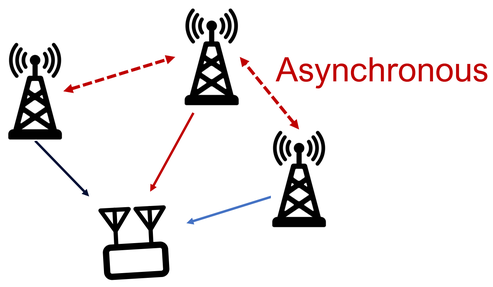
Spike-Train After Aliasing



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

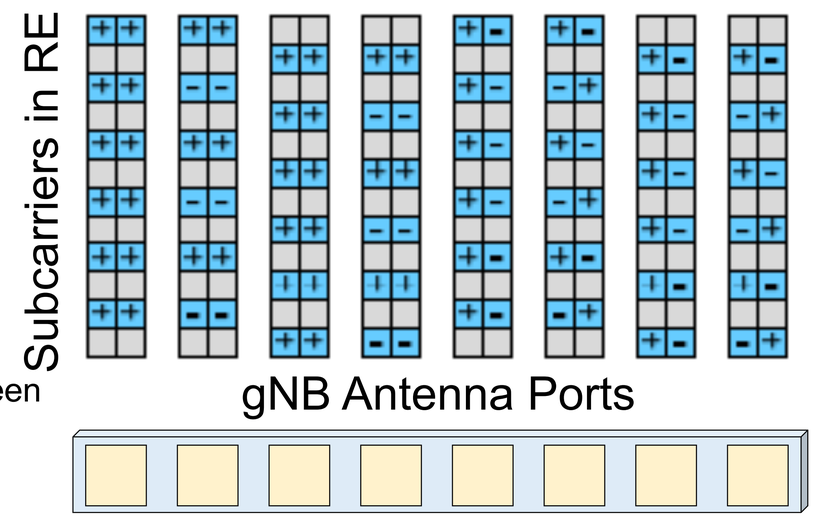
Coordination-Free Localization – Leveraging MIMO Antenna Array in 5G gNB

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

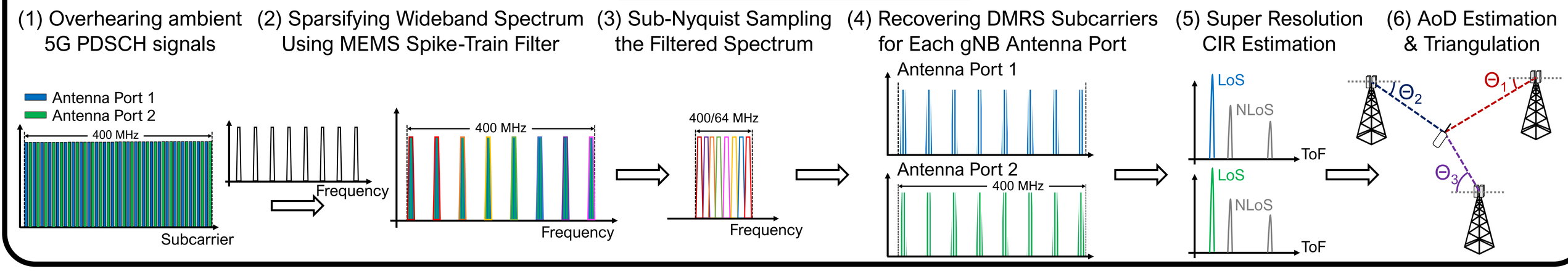
Leverages Unique Opportunities in 5G-NR

- 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.

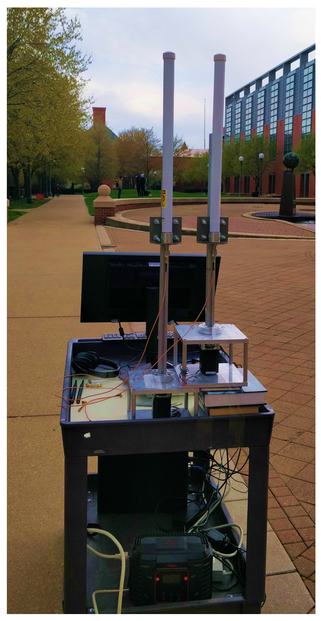
mm-ISLA System Pipeline



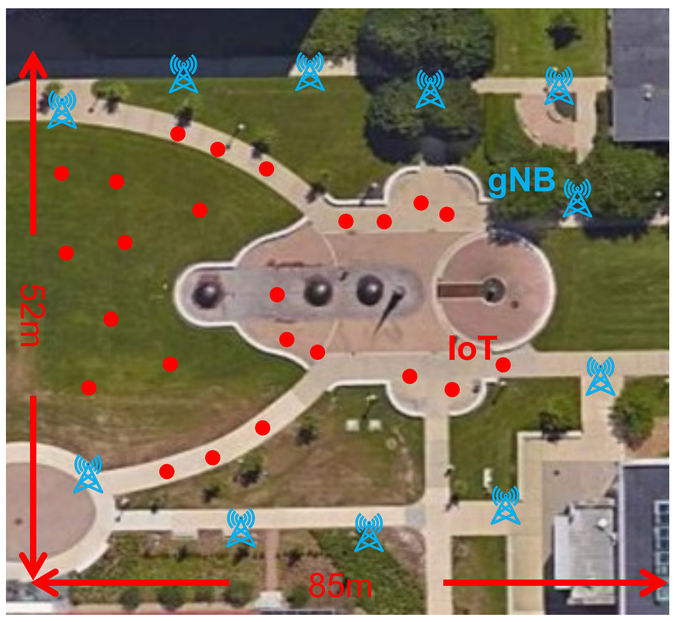
Preliminary Results

Experiment Setup

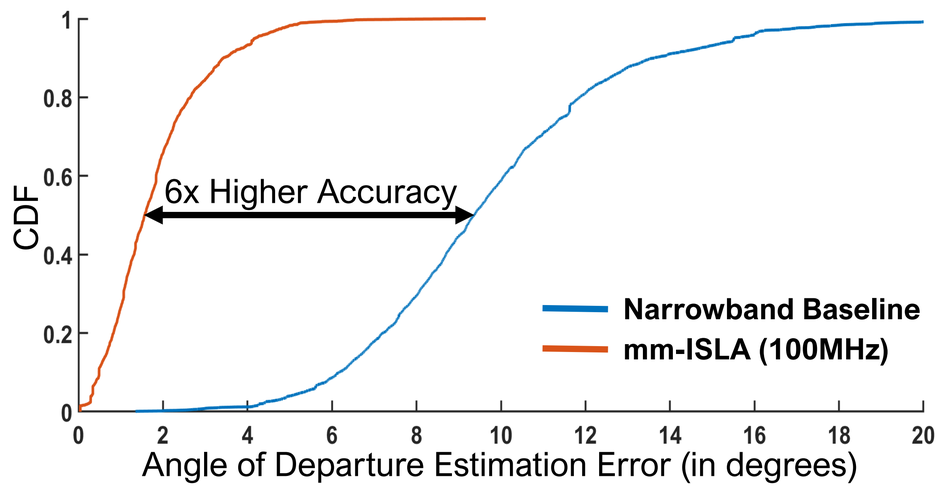
- Due to the lack of MIMO-enabled mmWave frond-ends, we evaluate mm-ISLA at 1 GHz.
- 5G gNB and mm-ISLA IoT node are emulated using X310 USRPs.
- Dual-antenna gNB transmitting 100 MHz OFDM waveform.
- mm-ISLA node samples at 6.25 MHz (16x lower than the Nyquist sampling rate).
- AoD estimation accuracy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