AI/ML in 802.11: Use Cases and Next Steps

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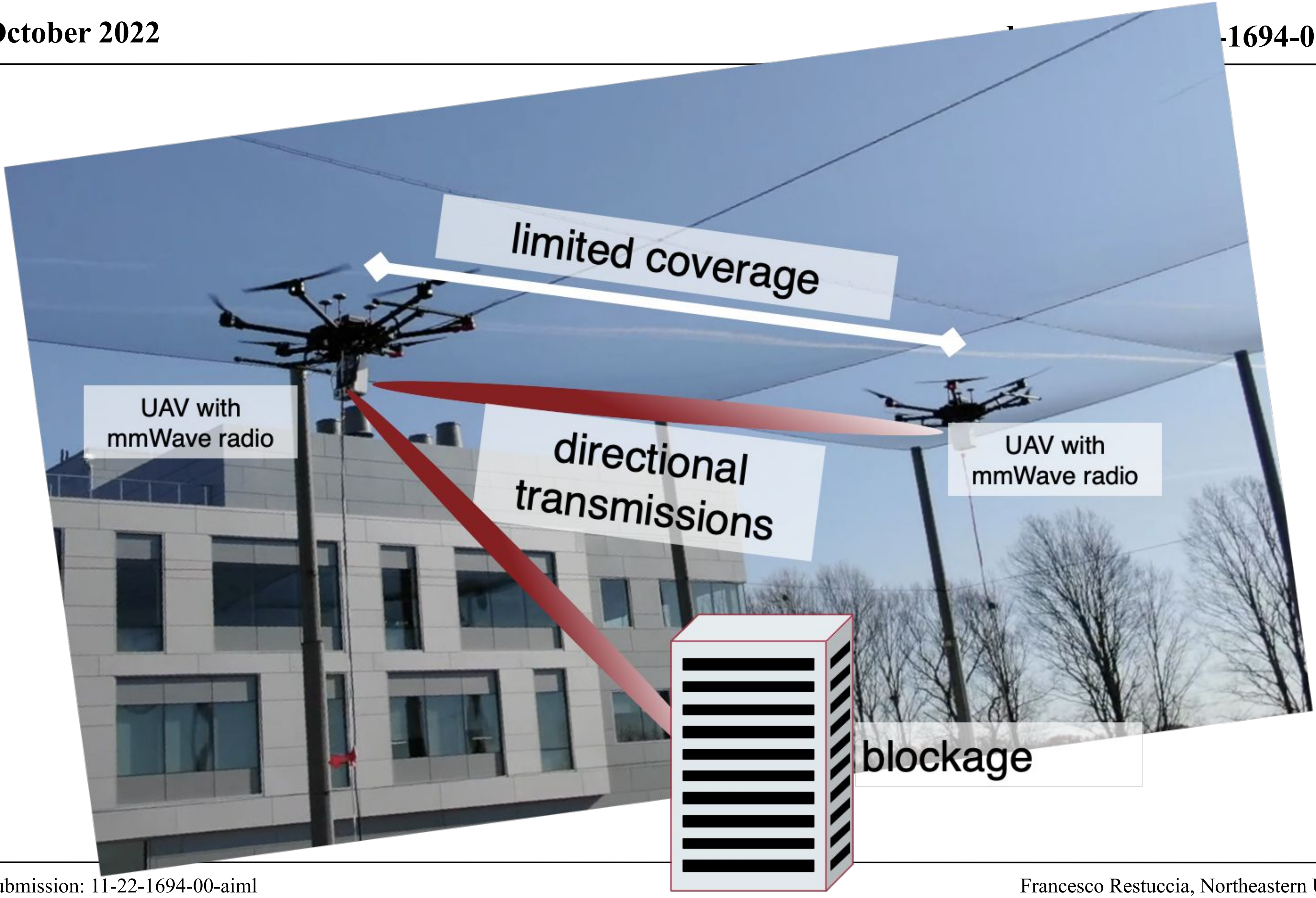
Outline

- Past work on AIML in wireless
- Current work and future directions
- What do we need to do to facilitate AI/ML in 802.11

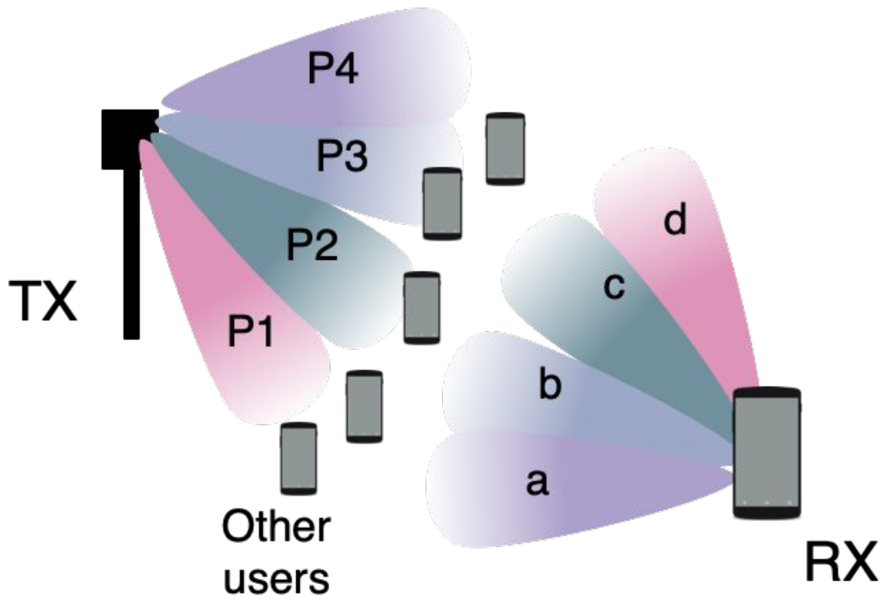
M. Polese, F. Restuccia, and T. Melodia,

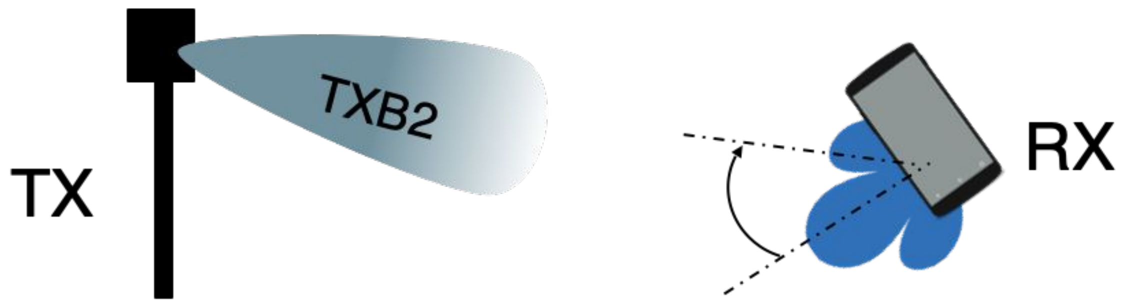
"DeepBeam: Deep Waveform Learning for Coordination-Free Beam Management in mmWave Networks"

ACM MobiHoc 2021


limited coverage
UAV with
mmWave radio
directional
transmissions
UAV with
mmWave radio
blockage

Directional Transmissions for mmWave Nets

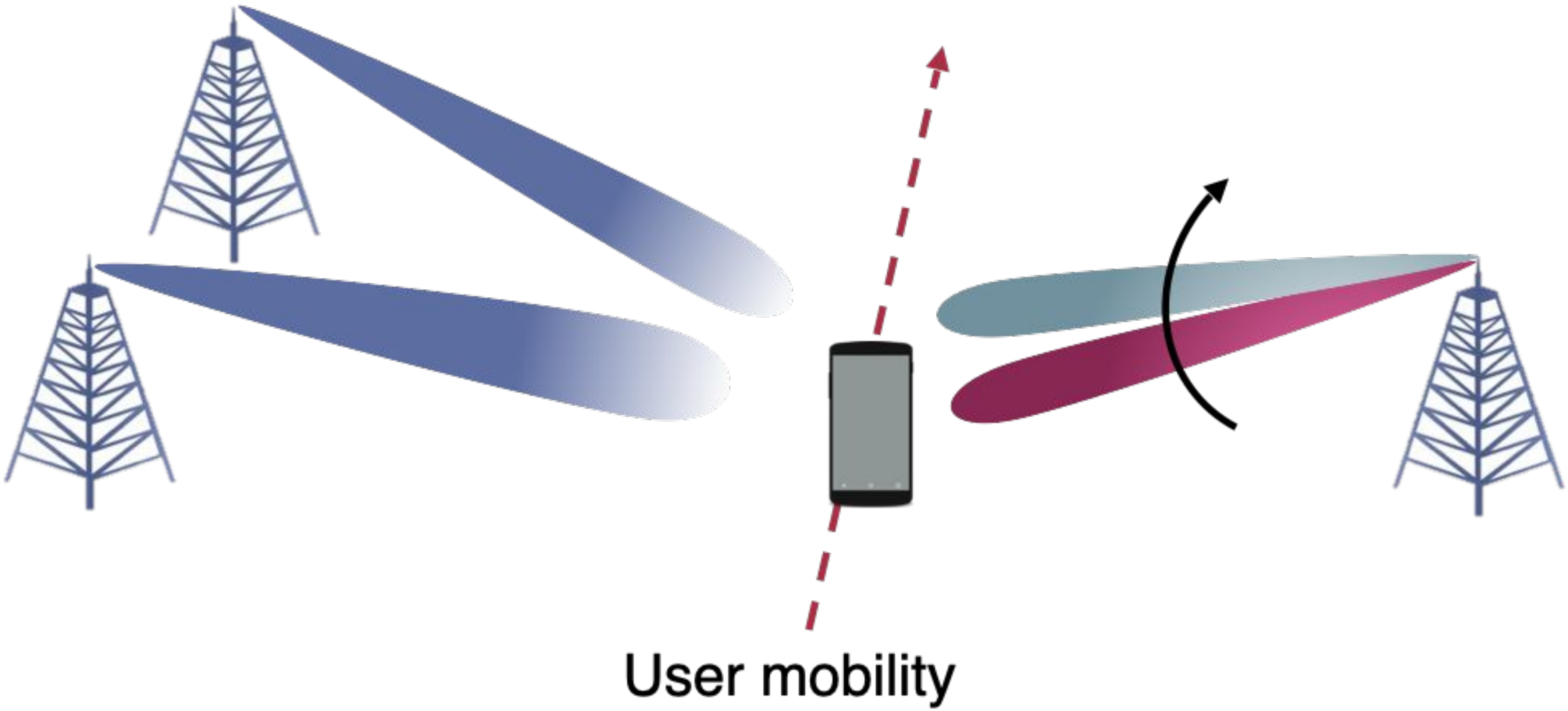




TX and RX focus their energy in narrow beams

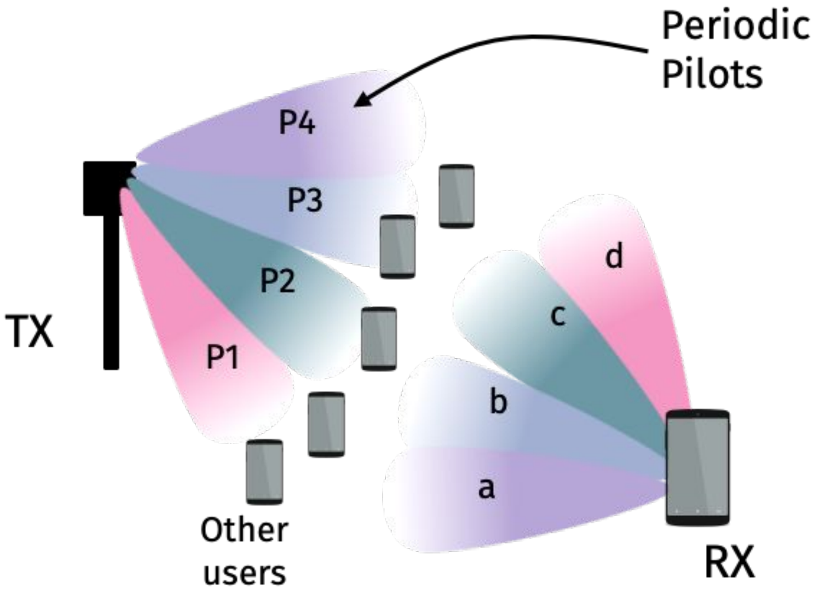
- They need to point the beams toward each other
- Otherwise, the **gain** introduced by using beamforming could disappear

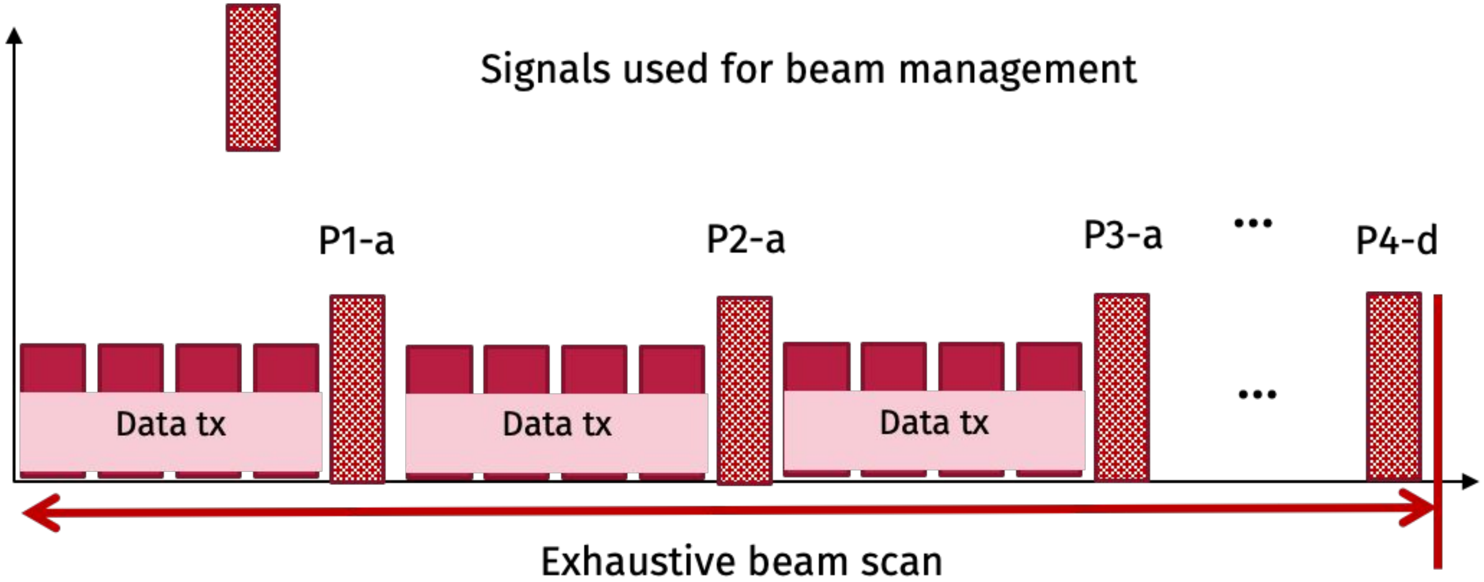
Directionality Challenges



Need to track user mobility

Traditional Beam Management



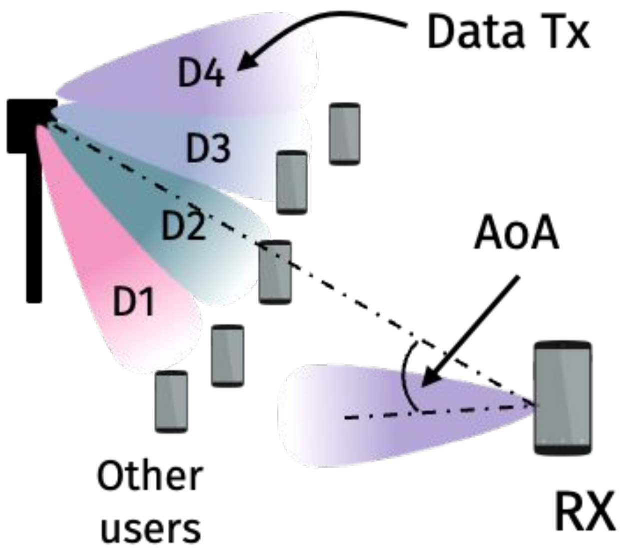


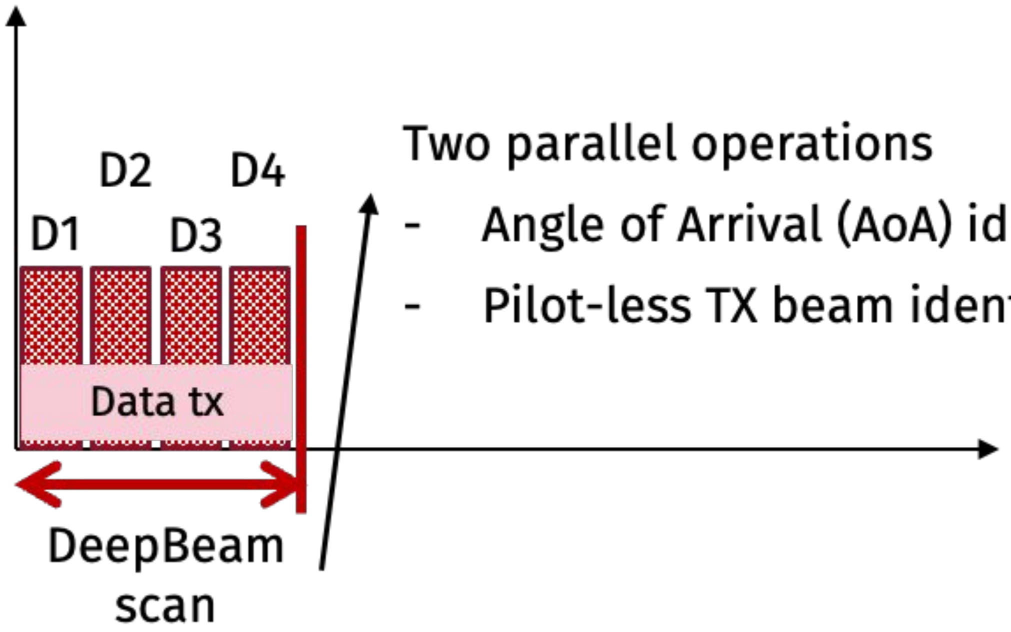
High Latency and Overhead!

Directionality | High data rates | Blockage

- Complex control procedures (e.g., beam management)
- Need for coordination among network nodes
- Need for quick reactions

AI can play a crucial role to optimize mmWave operations, with predictive and/or autonomous control policies





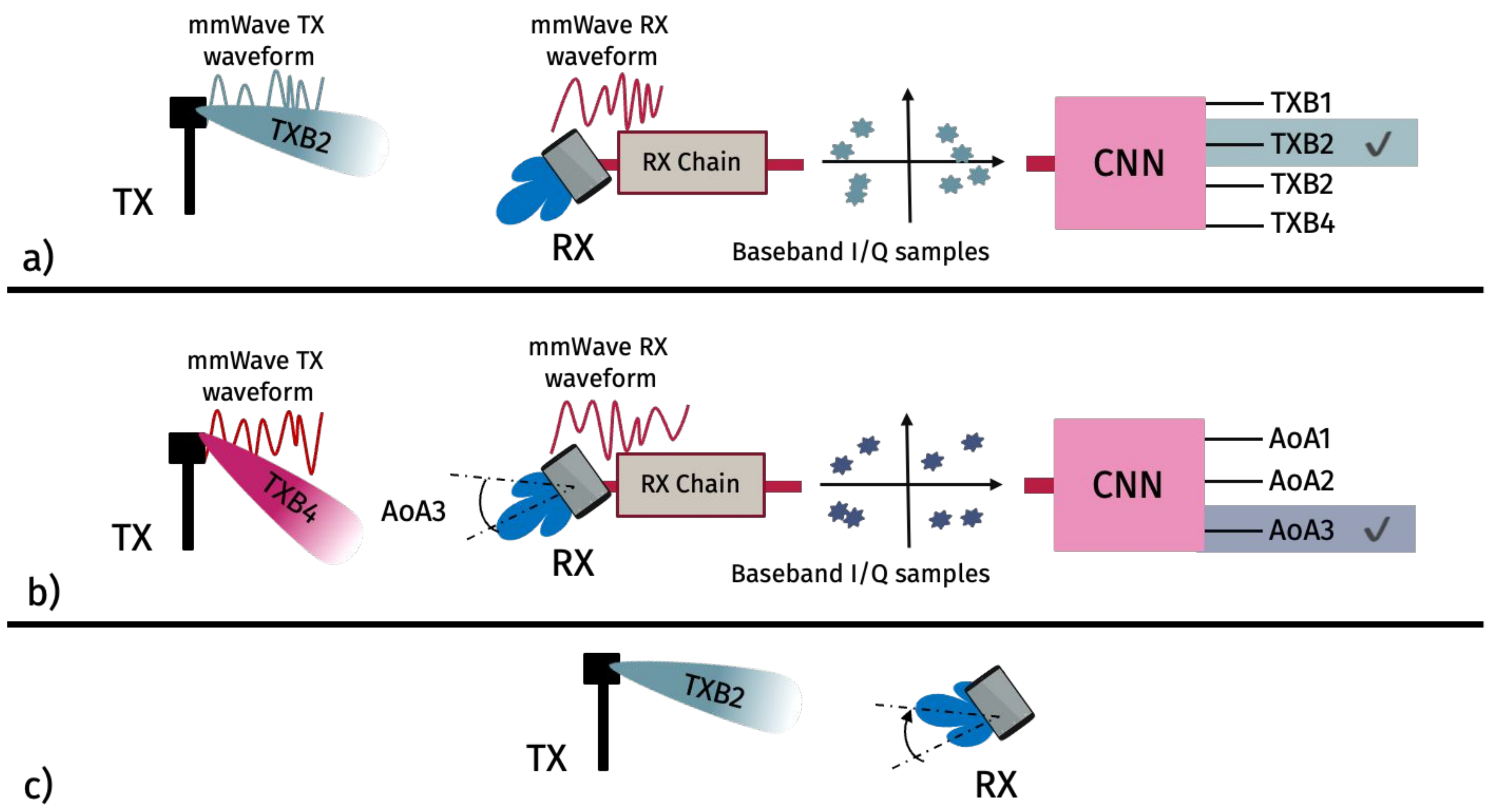
Two parallel operations

- Angle of Arrival (AoA) identification
- Pilot-less TX beam identification

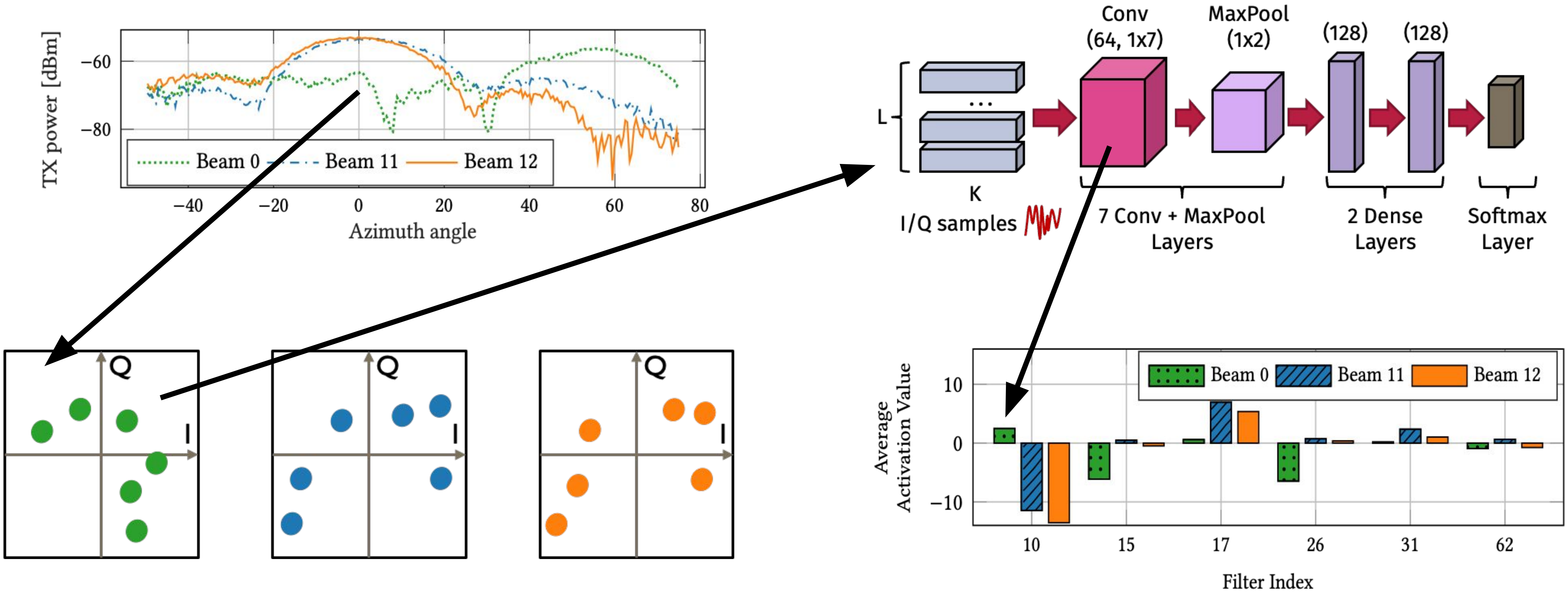
Traditional AoA detection methods either require

- Multiple antennas and RF chains (*Oumar et al, ICFGCT, 2012*)
- The sampling of the signal in multiple spatial location (*Wei et al, NSDI, 2016*)

DeepBeam can operate directly on I/Q samples from a single RF chain

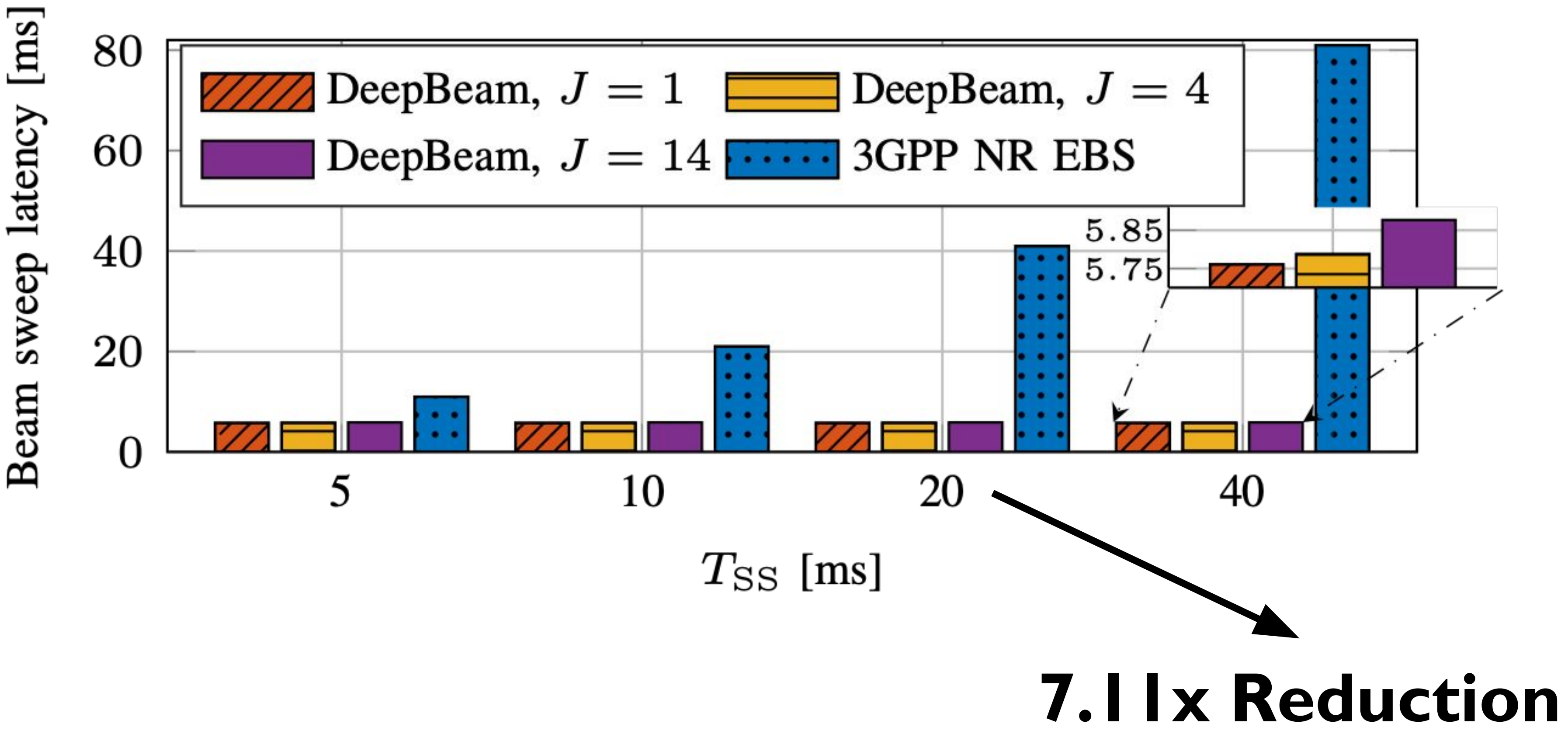


- Which beam is the transmitter using?
- What is the angle of arrival wrt to the transmitter?
- Adaptation step

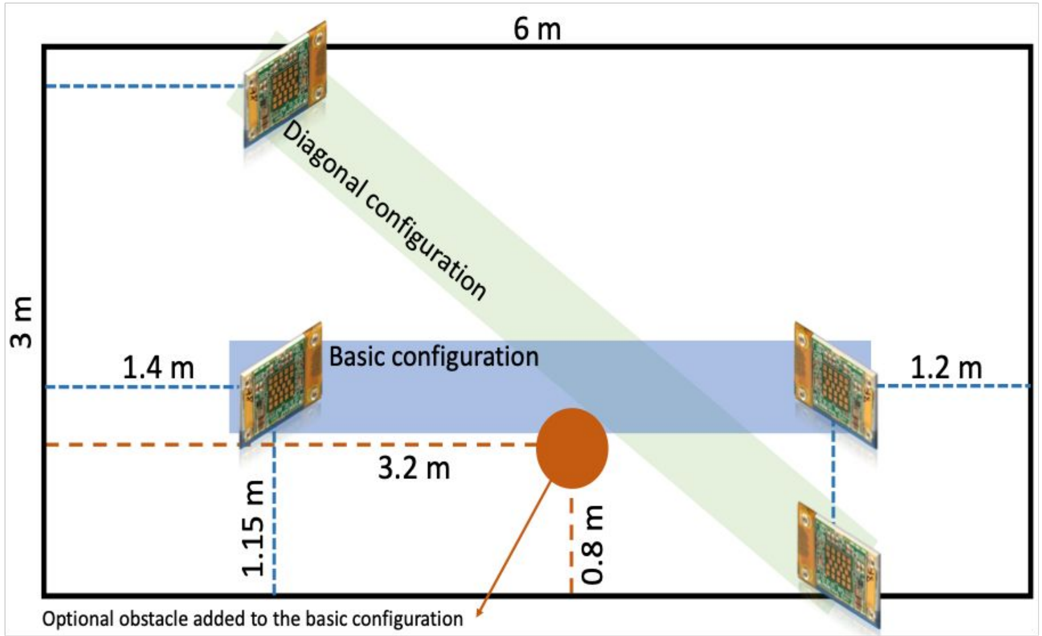


Conv filters learn the unique beam characteristics

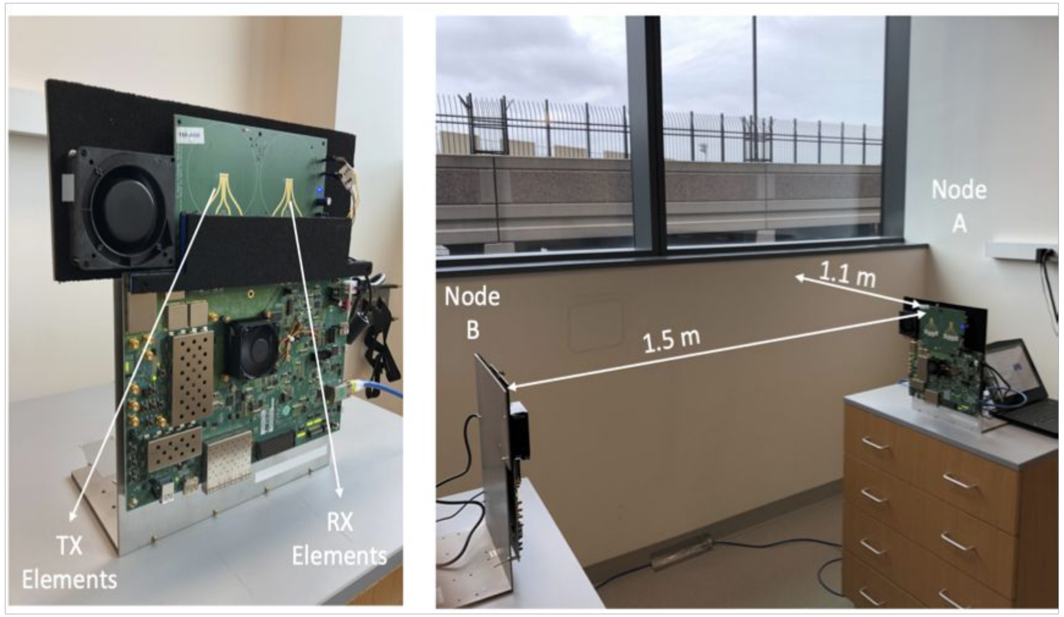
- FPGA implementation of CNN (0.492 ms for e2e delay, 0.34 ms for slowest layer)
- Comparison with 12 beams at TX and RX, 3300 subcarriers (400 MHz BW), 3GPP numerology 3



SiBeam/NI with analog phased arrays

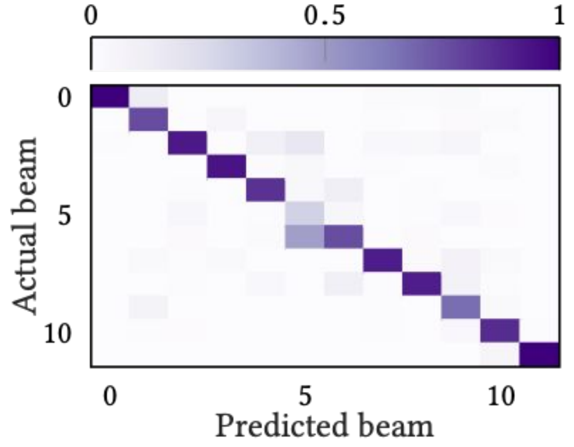


Pi-radio SDR with digital beamforming

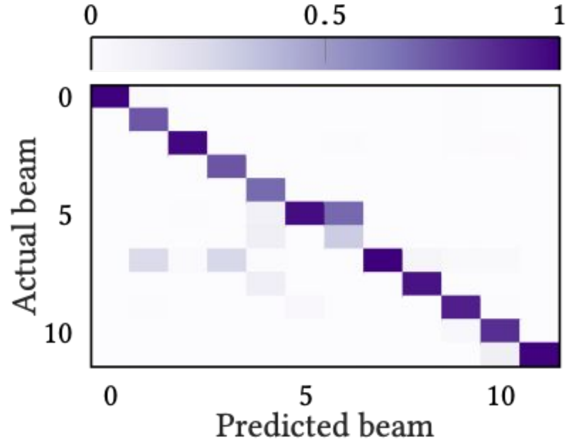


Classification target	TX Codebook	Testbed	Configuration	(TX, RX) antenna combinations
TXB	24-beams codebook	Single-RF-chain	Basic, with obstacle, diagonal	SiBeam (0, 1), (1, 0), (2, 1), (3, 1)
TXB	12-beams codebook	Single-RF-chain	Basic, with obstacle, diagonal	SiBeam (0, 1), (1, 0), (2, 1), (3, 1)
AoA	24-beams codebook	Single-RF-chain	Basic, with obstacle, diagonal	SiBeam (0, 1), (1, 0), (0, 2), (0, 3)
TXB	5-beams codebook	Multi-RF-chain	Multi-RF-chain basic	Node A, Node B

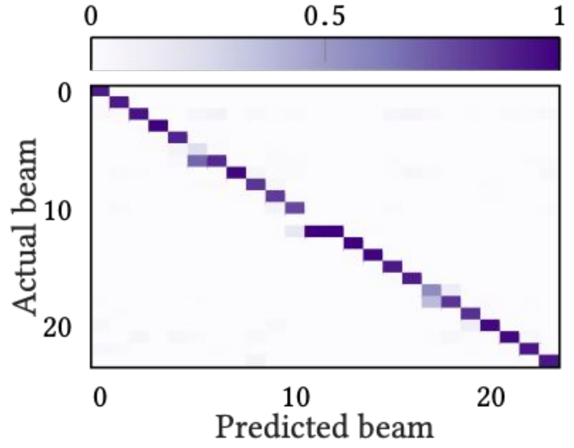
Beam Classification Accuracy



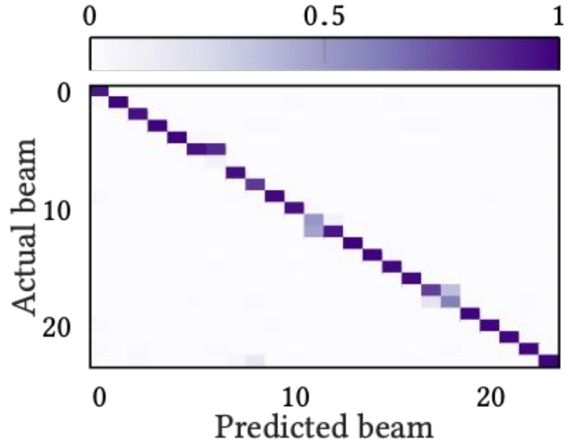
(a) 12-beam, $L = 1$, Accuracy: 81.02%



(b) 12-beam, $L = 5$, Accuracy: 84.02%

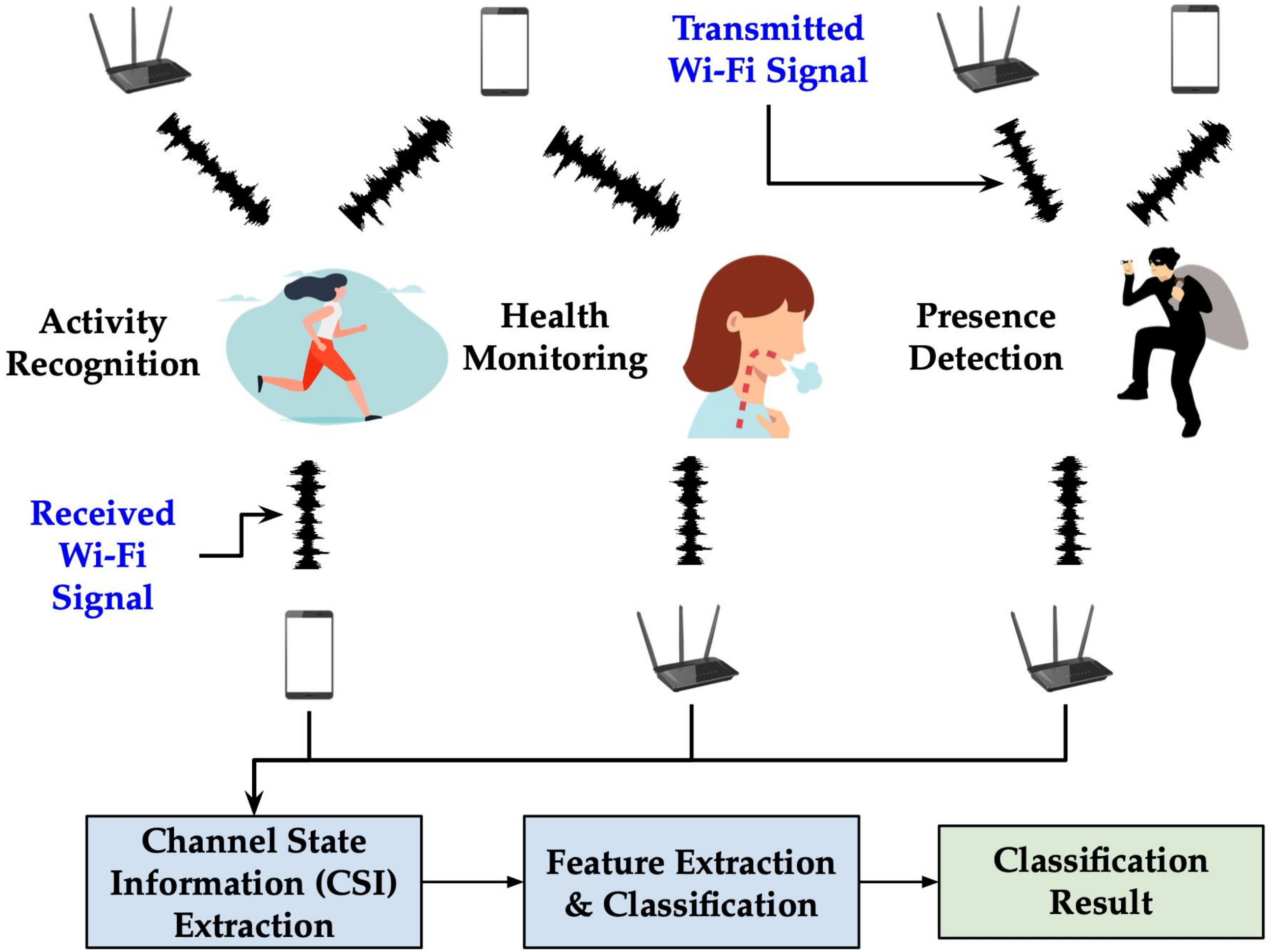


(c) 24-beam, $L = 1$, Accuracy 68.77%



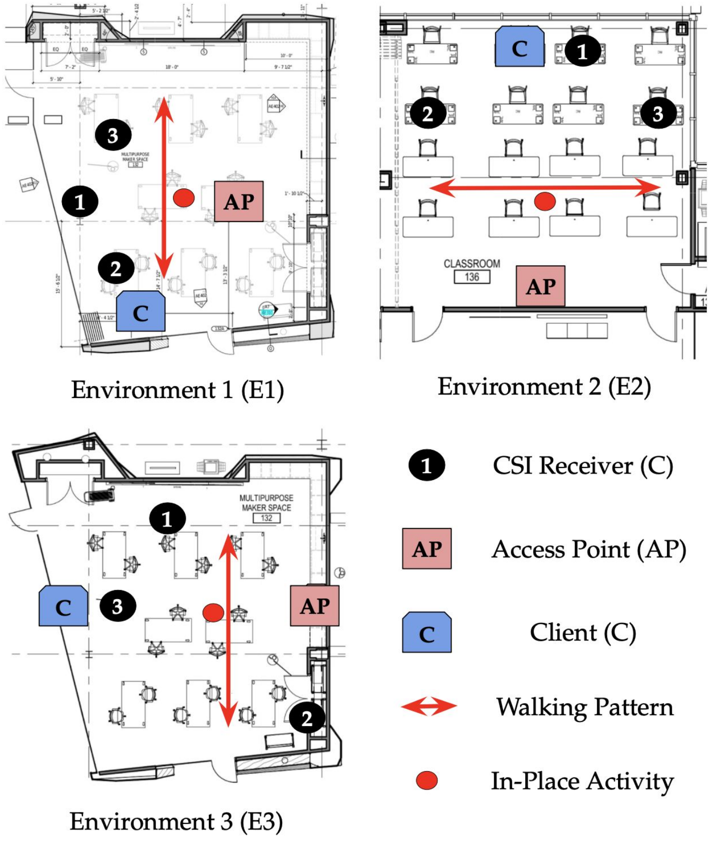
(d) 24-beam, $L = 5$, Accuracy: 77.46%

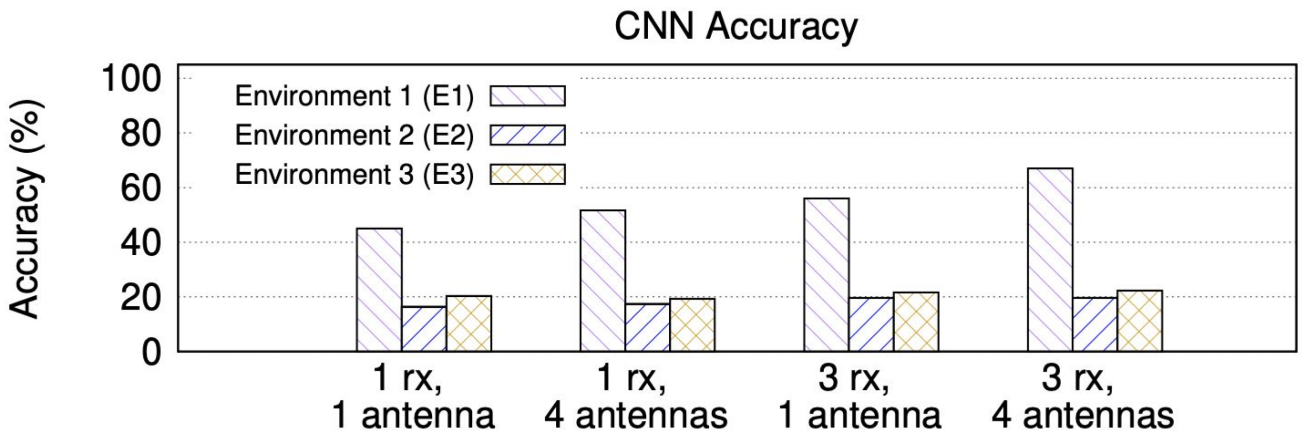
- Wi-Fi Sensing



- The research community has worked on these topics for **~10 years**
- First "See Through Walls With Wi-Fi!" paper in **2013**
- Extreme commercial potential, that's why **802.11bf** was created

Problems: Generalization, Robustness

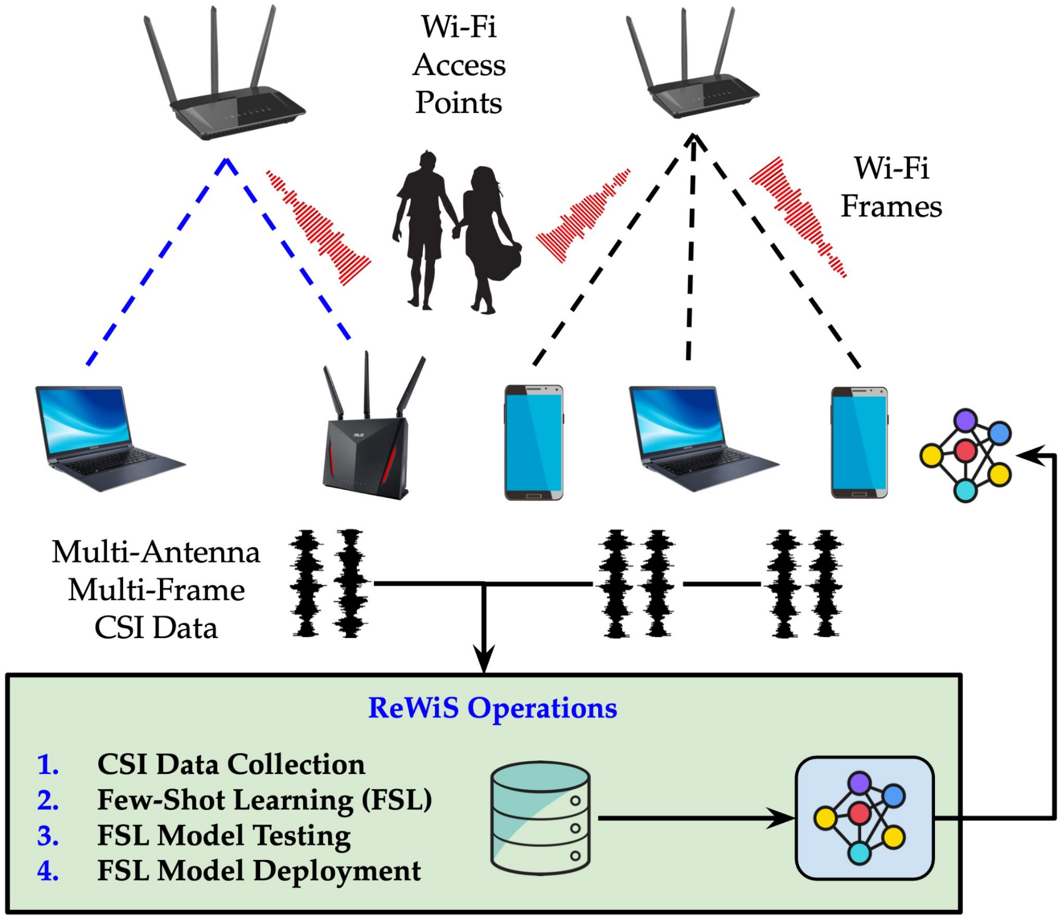


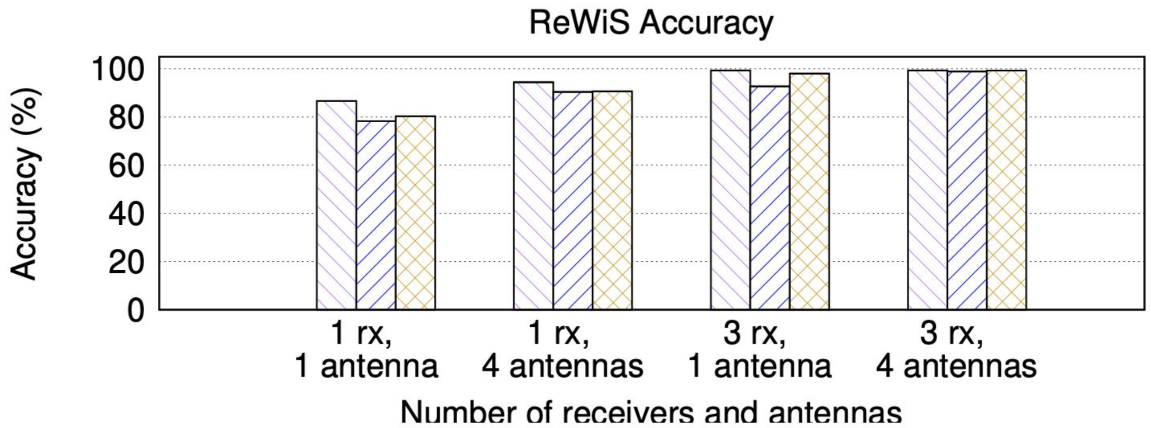


- Trained and tested in different environments
- Performance does not generalize to different environments
- Clients may not like the product
- Some Wi-Fi sensing devices have been shown to experience problems in actual deployments [1]

[1] Christopher Null (TechHive). “Aura review: This home monitoring system is more trouble than it’s worth.” https://www.techhive.com/article/583109/aura-review.html, December 27, 2017.

Better Performance Through Cooperation





- Through CSI fusion, we are able to generalize among different environments
- Ultimately, more sales because the product satisfies the customer better!

N. Bahadori, J. Ashdown, and F. Restuccia, "**ReWiS: Reliable Wi-Fi Sensing Through Few-Shot Multi-Antenna Multi-Receiver CSI Learning,**" **IEEE WOWMOM 2022 (Best Paper Award).** Preprint available at https://arxiv.org/abs/2201.00869

Other applications

- Spectrum sensing [1,2]
- Radio fingerprinting [3,4]

[1] L. Baldesi, F. Restuccia and T. Melodia, ``ChARM: NextG Spectrum Sharing Through Data-Driven Real-Time O-RAN Dynamic Control," **IEEE INFOCOM 2022 Best Paper Award.**
[2] D. Uvaydov, S. D'Oro, F. Restuccia and T. Melodia, ``DeepSense: Fast Wideband Spectrum Sensing Through Real-Time In-the-Loop Deep Learning," **IEEE INFOCOM 2021**

[3] F. Meneghello, M. Rossi and F. Restuccia, ``DeepCSI: Rethinking Wi-Fi Radio Fingerprinting Through MU-MIMO CSI Feedback Deep Learning," **IEEE ICDCS 2022.**
[4] A. Al-Shawabka et al, ``Exposing the Fingerprint: Dissecting the Impact of the Wireless Channel on Radio Fingerprinting," **IEEE INFOCOM 2020**.

How can we improve 802.11 to support these applications?

What needs to change at the protocol level?

Thanks!
Questions?