Integrated Sensing and Communication and its Impact on Mobile Network Architectures

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Developing the Science of Networks

Joint Communication and Sensing (JCAS) Status

- Practical research on localization and sensing with communication hardware for the past two decades
- … but only *now* the hardware capabilities are becoming sufficient for true joint communication and sensing in more general settings

Smart factories, digital twins

Augmented/virtual reality

Autonomous vehicles

Healthcare

…

- Increased interest from industry and standardization bodies
  - Mobile network localization efforts intensified in 3GPP Rel. 18
  - 6G is expected to put a strong focus on JCAS
  - Significant work for JCAS in WLANs within IEEE 802.11bf

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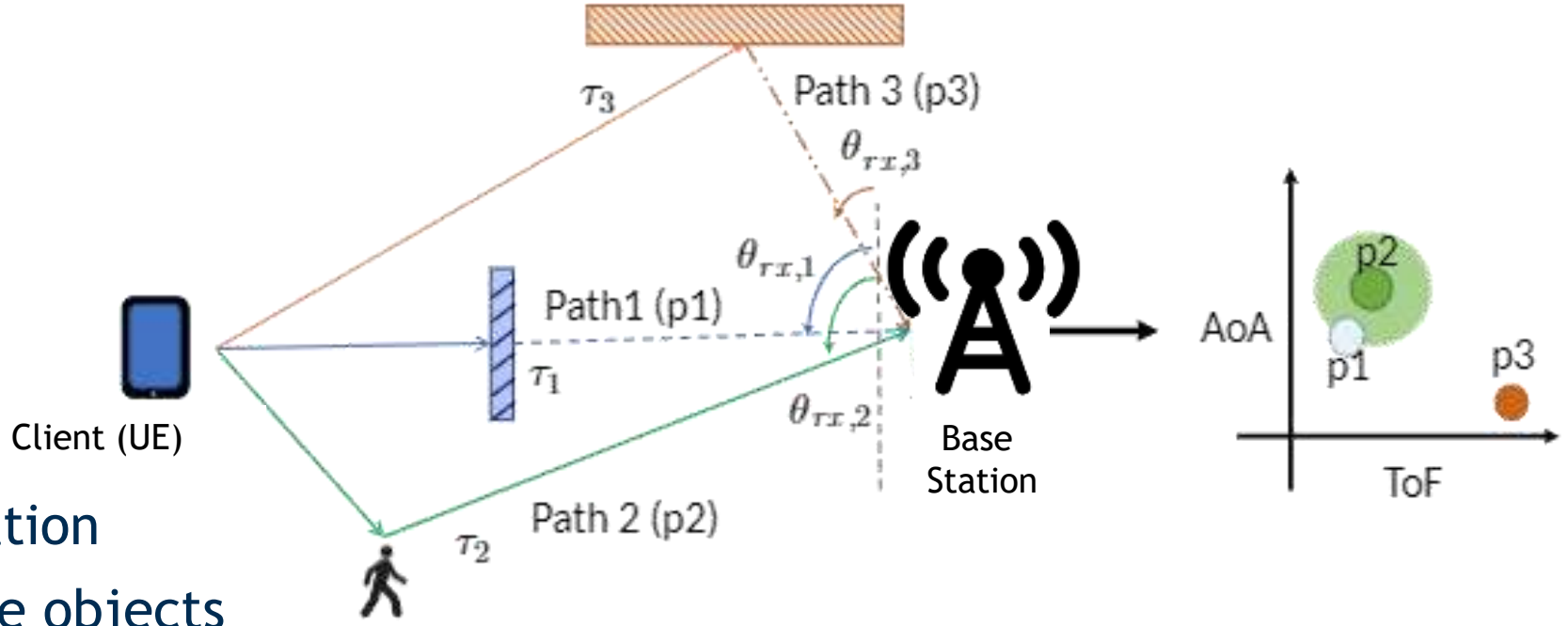
Active Localization and Beyond

Signals propagate along multiple paths → multi-path decomposition is critical

- Requires sufficiently good time and angle information to distinguish paths (→ bandwidth and number of antennas)
- Extracting multiple paths provides much better accuracy and allows for sensing



- Active Localization
- Localize passive objects
- Extract Doppler and other information

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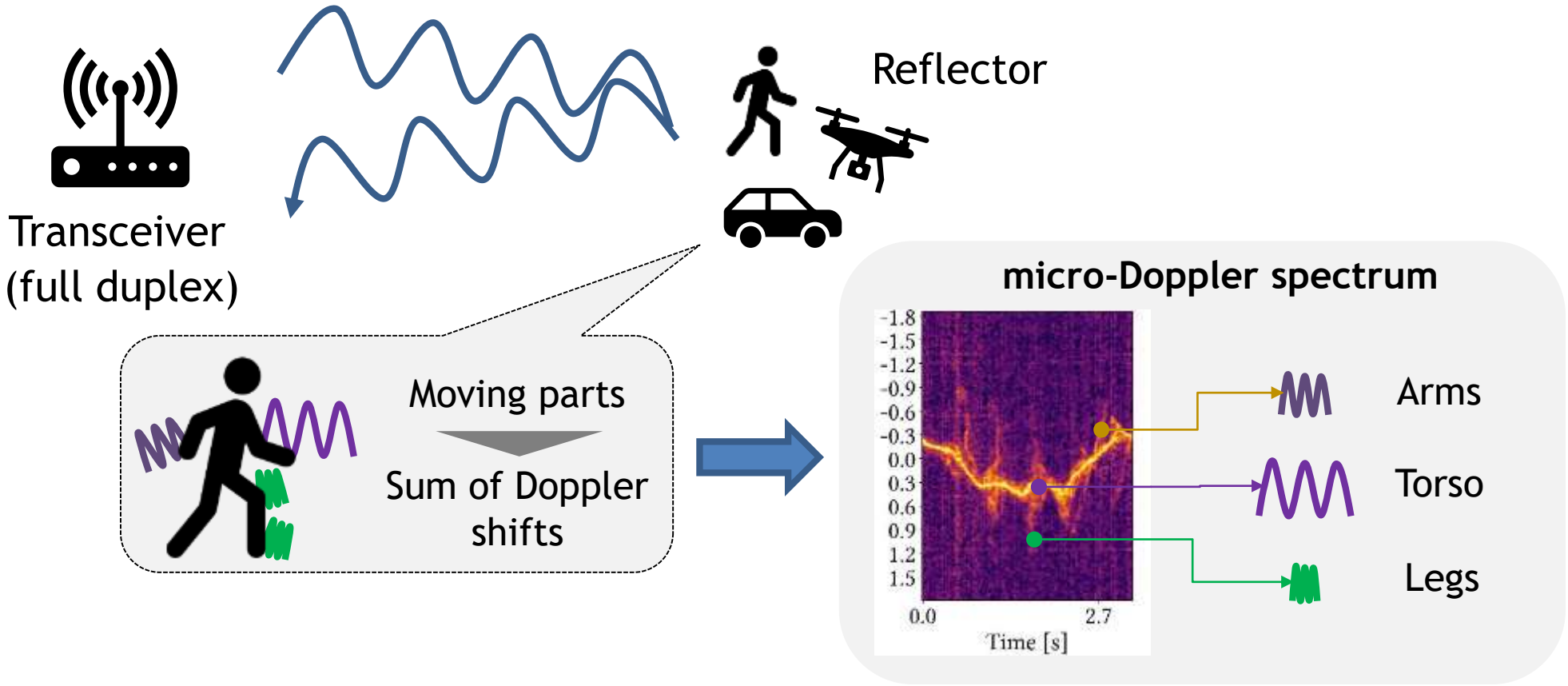
Example:

- Integrated Sensing and Communication using 5G/6G
- Fine-grained localization and sensing with micro-Doppler
- Decimeter-level accuracy with mmWave (FR2)



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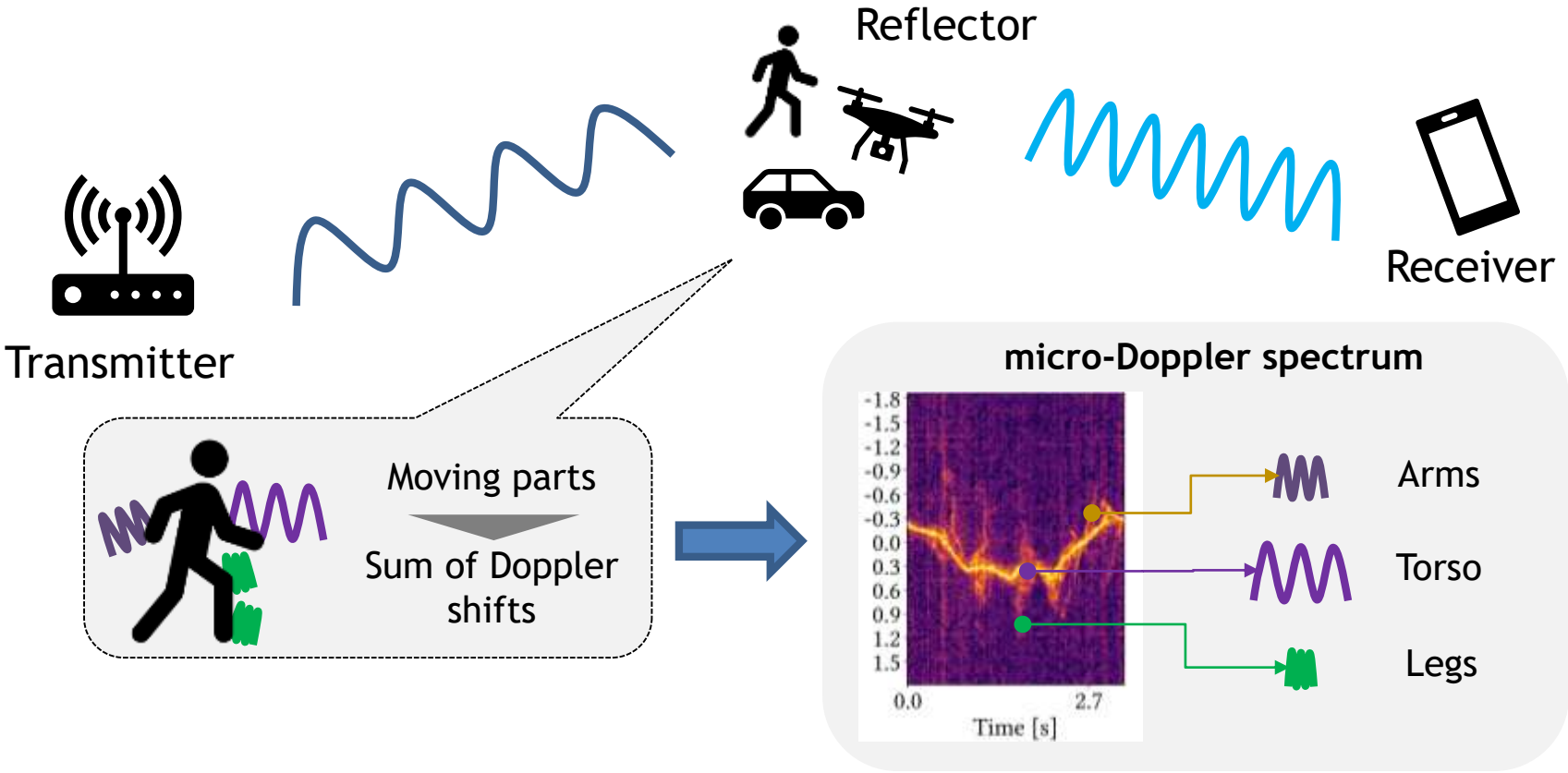
Multi-Static Sensing

- Full-duplex operation typically not supported in mobile network
- Sensing should ideally make use of the many different available links in a wireless network to learn more about the environment



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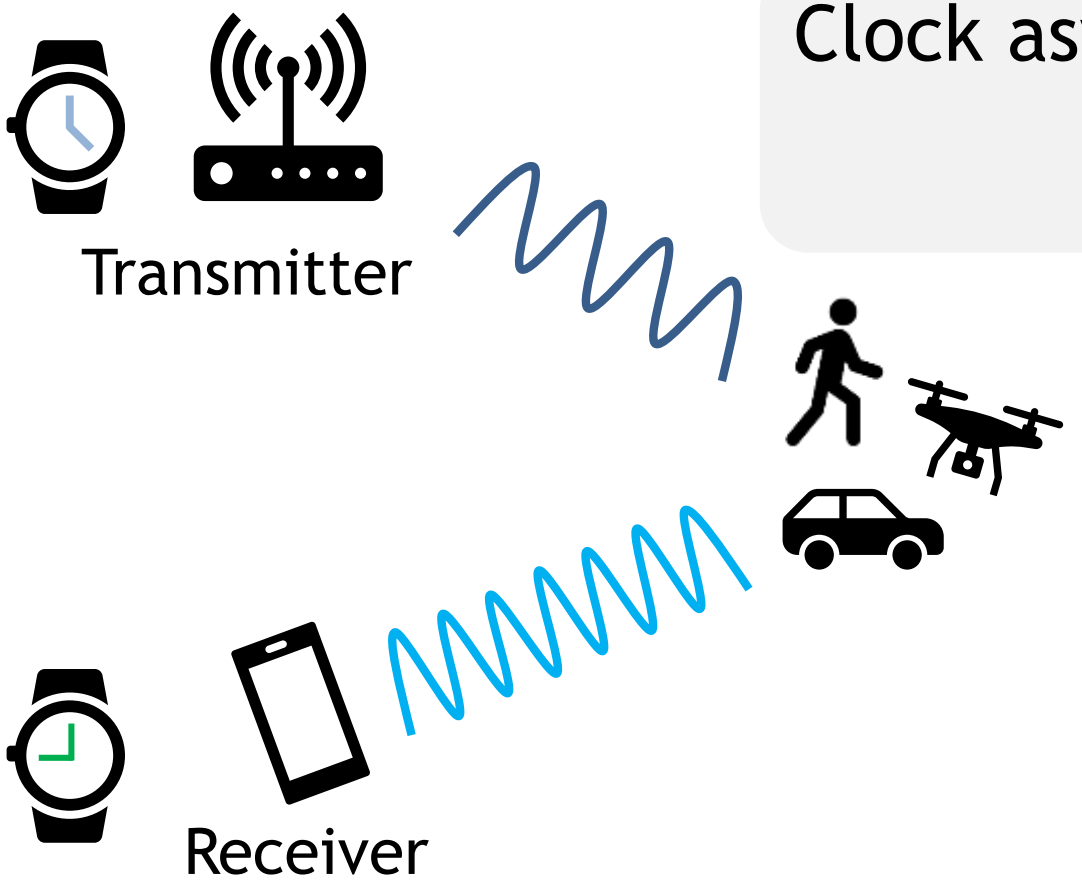
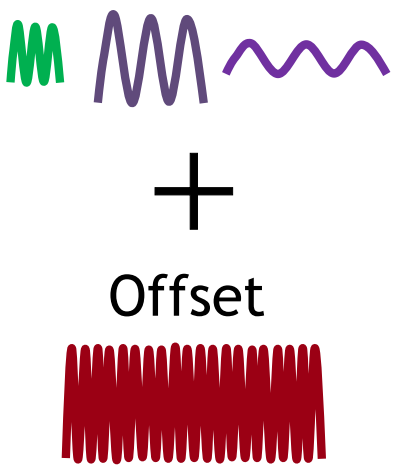
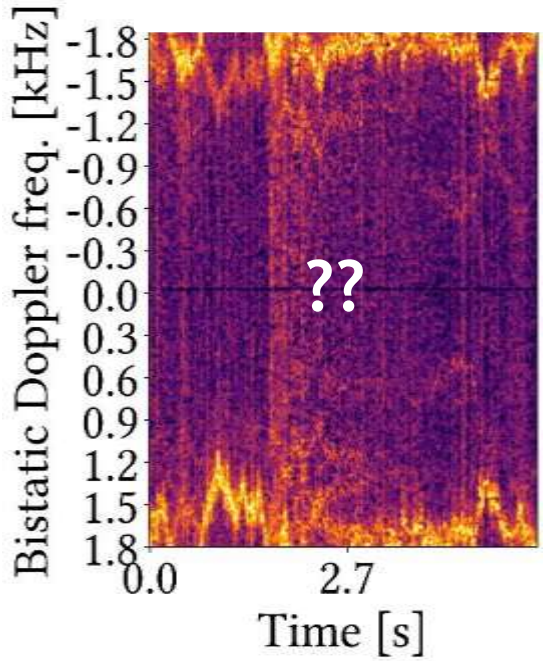
Challenge: unsynchronized nodes

Clock asynchrony ⇒ Frequency offset, Timing offset







Note: Communication systems use algorithms to compensate for TO and FO, but they treat the sensing parameters (delay and Doppler shift) as part of the undesired offsets and *remove* them

J. Pegoraro et al. "JUMP: Joint communication and sensing with unsynchronized transceivers made practical", arXiv preprint arXiv:2304.07766, 2023

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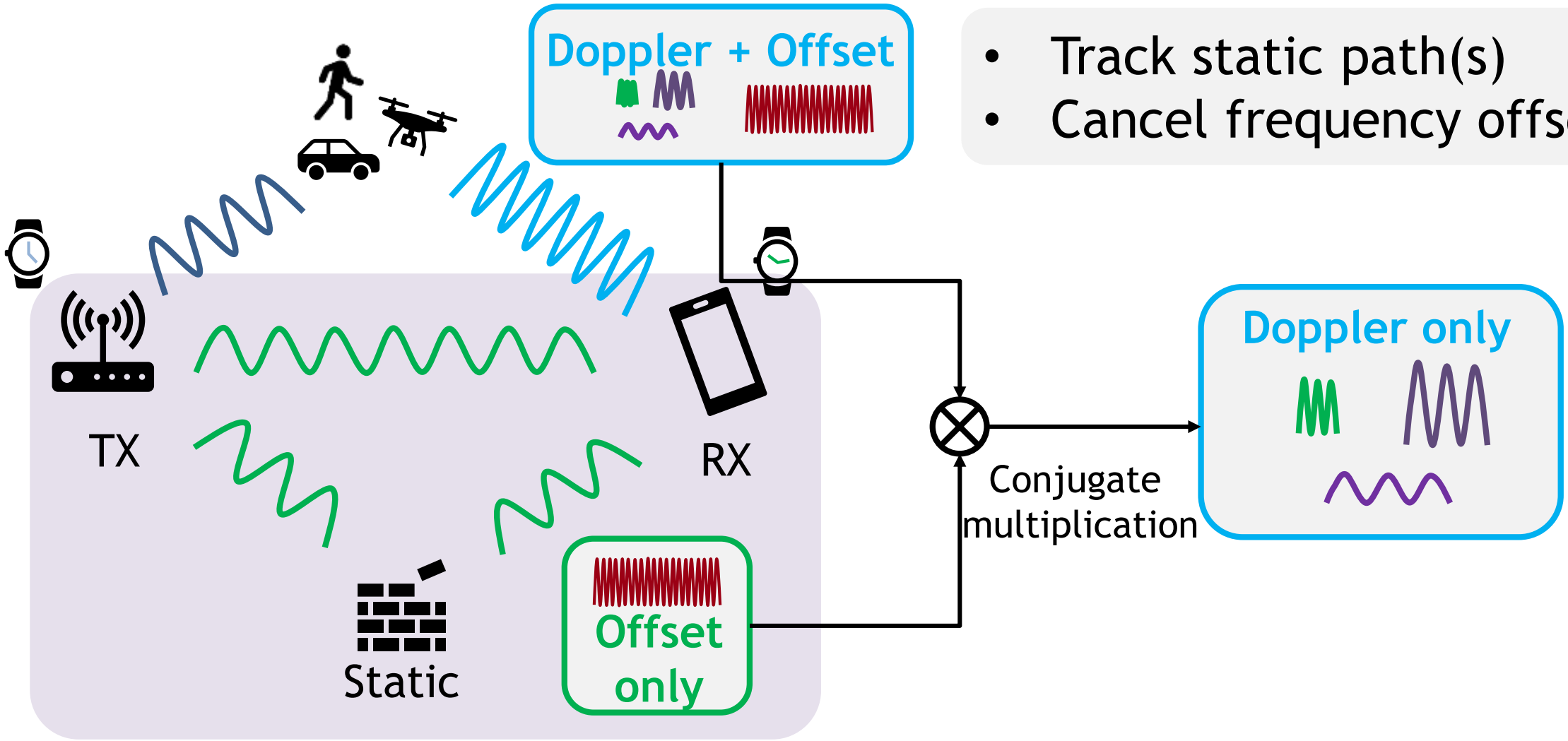
Our solution



- Track static path(s)
- Cancel frequency offset

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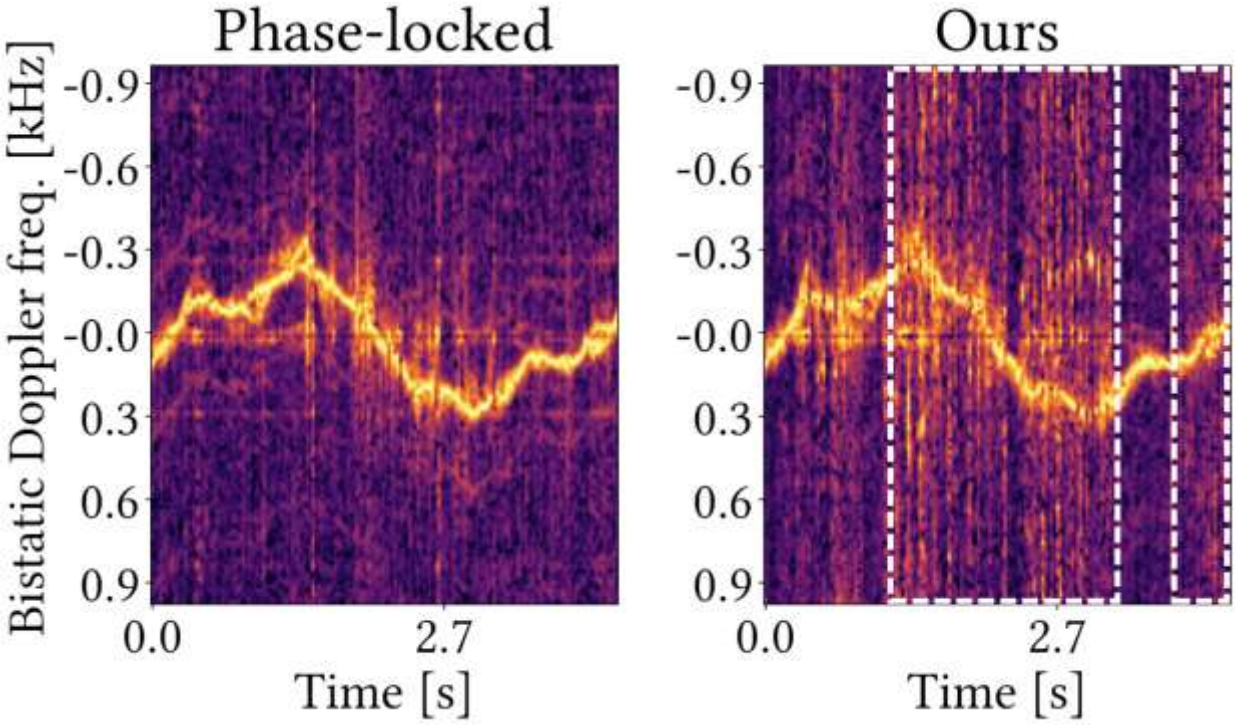
Micro-Doppler Reconstruction

- Phase coherent measurement across (long) packet trains
- Even works with intermittent LOS/NLOS (static paths change)
  - NLOS regions are enclosed in white dashed rectangles



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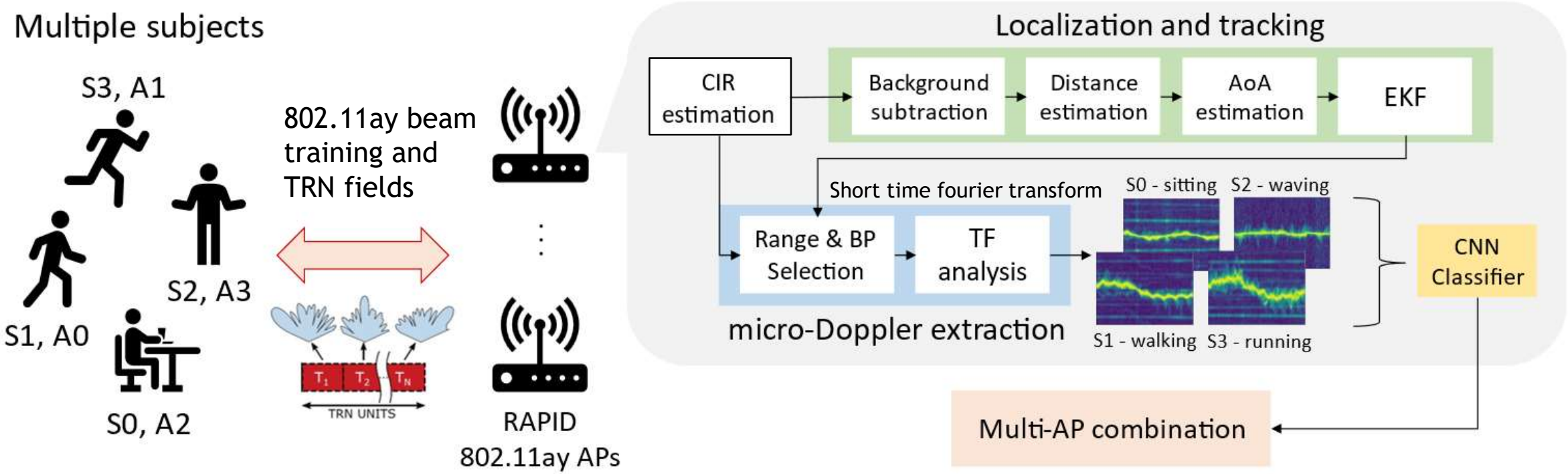
Sensing Workflow



- Phase estimation from Channel Impulse Response (CIR) changes
- Inter-arrival time determines maximum velocity, length of packet sequence determines velocity resolution
- Sparse estimation to deal with random packet inter-arrival times

Joint work with University of Padova

Jacopo Pegoraro et al. “SPARCS: A sparse recovery approach for integrated communication and human sensing in mmWave systems”, ACM IPSN, May 2022

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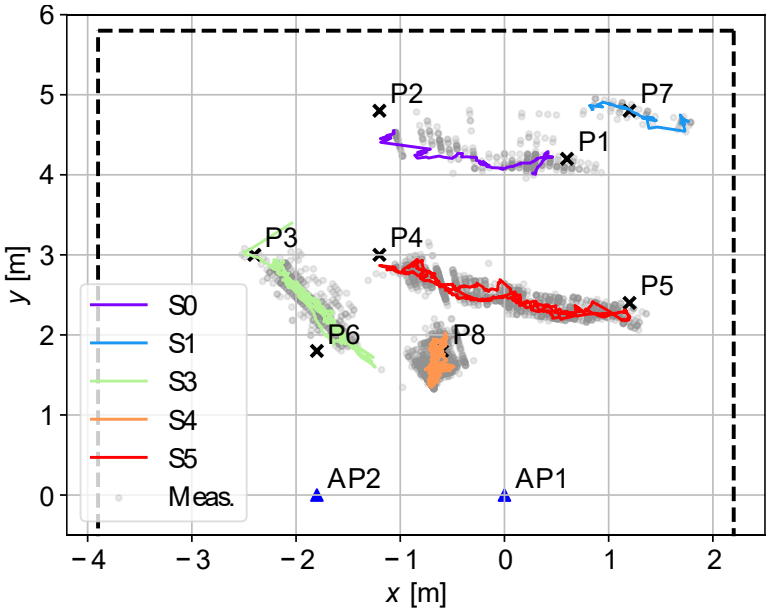
Activity recognition and person identification

- Tracking of 1 to 5 subjects carrying out different activities
- Accurate activity recognition

	Predicted [%]			
True [%]	Walking	Running	Sitting	Waving
Walking	**92.9**	0.8	6.2	0
Running	16.2	**71.6**	12.2	0
Sitting	0.2	0	**99.8**	0
Waving	3.3	0	6.8	**89.9**



- Person identification with up to 7 subjects with 90-97 % accuracy

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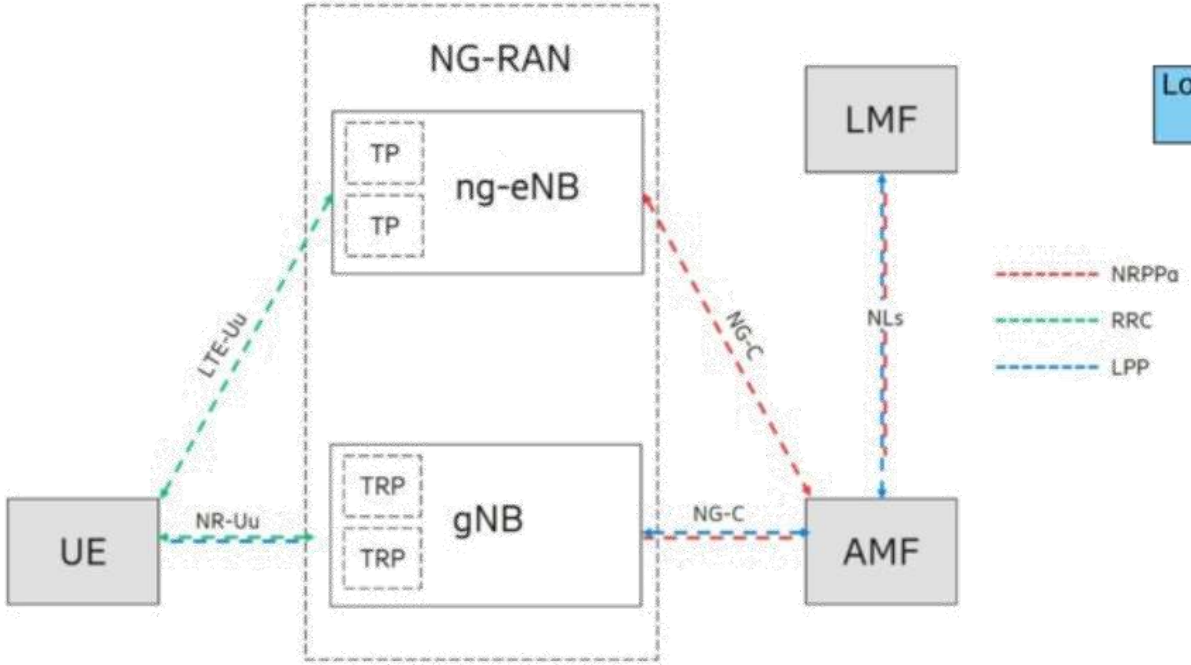
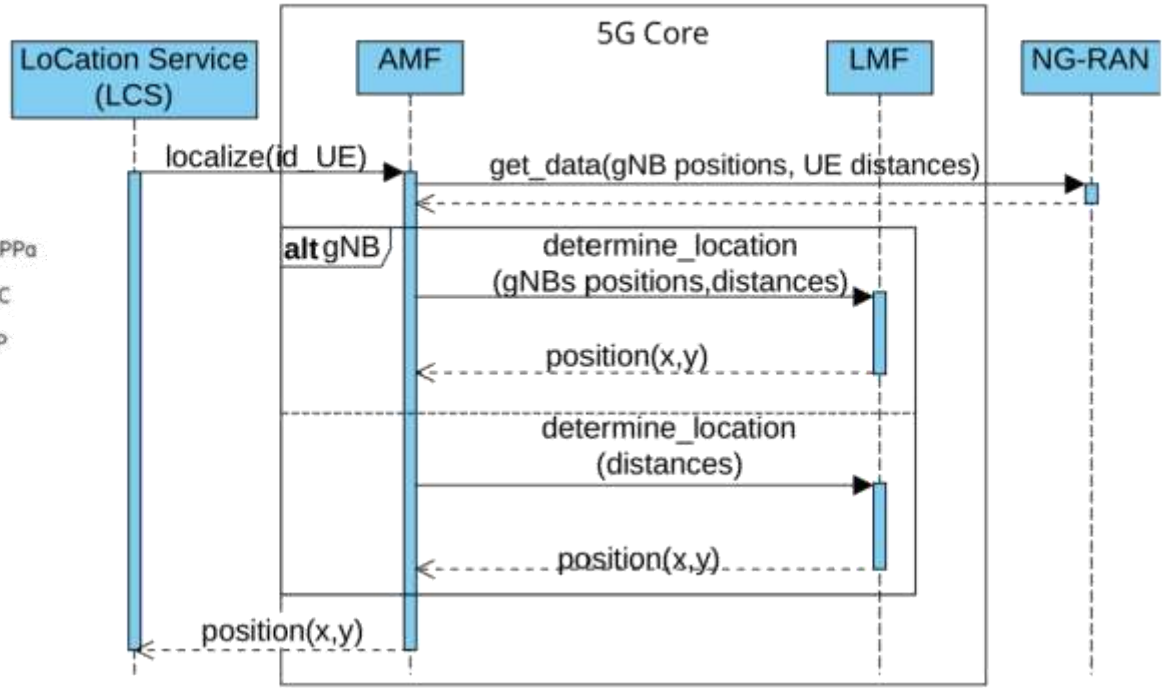
5G Location Management

- Location Management Function (LMF) determines location
  - Communication via the Access and Mobility Function (AMF)
  - Limited scalability
  - Suitable for localization but not for fine-grained sensing





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Architecture Challenges

- Mobile network as a large scale distributed sensing system
- BS deployment inherently provides a multi-static sensory mesh with very good area coverage
- What architectures changes and principles are needed to support the resulting (massive volumes of) sensing and location data in mobile networks, besides the data traffic?
  - Some signal processing functionality needs to be on eNB (or the BBU in case of C-RAN)
  - May require interfaces to very low layer functionality
  - High sensing data volume may require architecture adaptations and a mix of local pre-processing and edge/cloud ML training and inference
- Where to collect the raw data, where to process it, where and what processed data to store, where to run ML inference on that data, how to make it available… all depends on
- What applications are realistic and will be deployed first?

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Privacy Challenge: Mobile Operators as Data Custodians

- Exciting new localization and sensing opportunities, in particular for mobile operators
  - "Sensing Slice"; provide (real-time) sensing data to 3rd party service providers
- Privacy and security are extremely important; highly sensitive personal data
- Tradeoff: rich applications vs. privacy of the mobile users
- Often very hard to understand what is sensitive data and what isn't
- Aggregation for anonymization not straightforward
  - Closely connected to federated/distributed machine learning
- Experience of mobile operators to deal with sensitive data might be a plus
- How can you protect users/objects from sensing
  - CSI obfuscation (works to a limited degree)
  - Adversarial ML? Metasurfaces?

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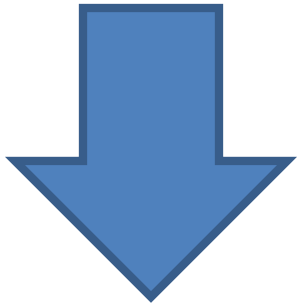
Connections

- Integrated Sensing and Communication and Mobile Network Architectures

Connections to other topics



- Privacy, security, IoT
- Growing G's forever is not sustainable - 7G should be software! How can we make that happen?
- Network Digital Twins, O-RAN, Modeling of cloud environments
- Distributed Deep Learning, Edge AI
- Testbeds for Reproducible Research

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THANK YOU !

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