Integrated Sensing and Communication

Some System and Access Issues

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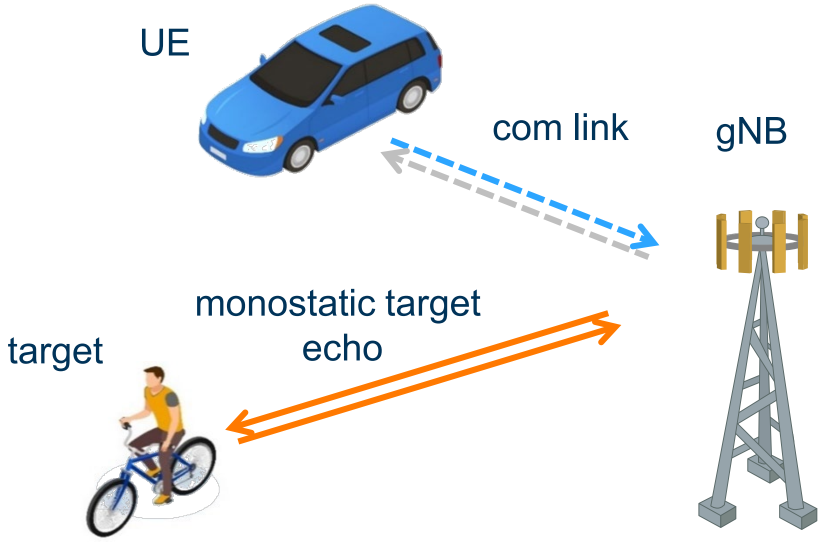
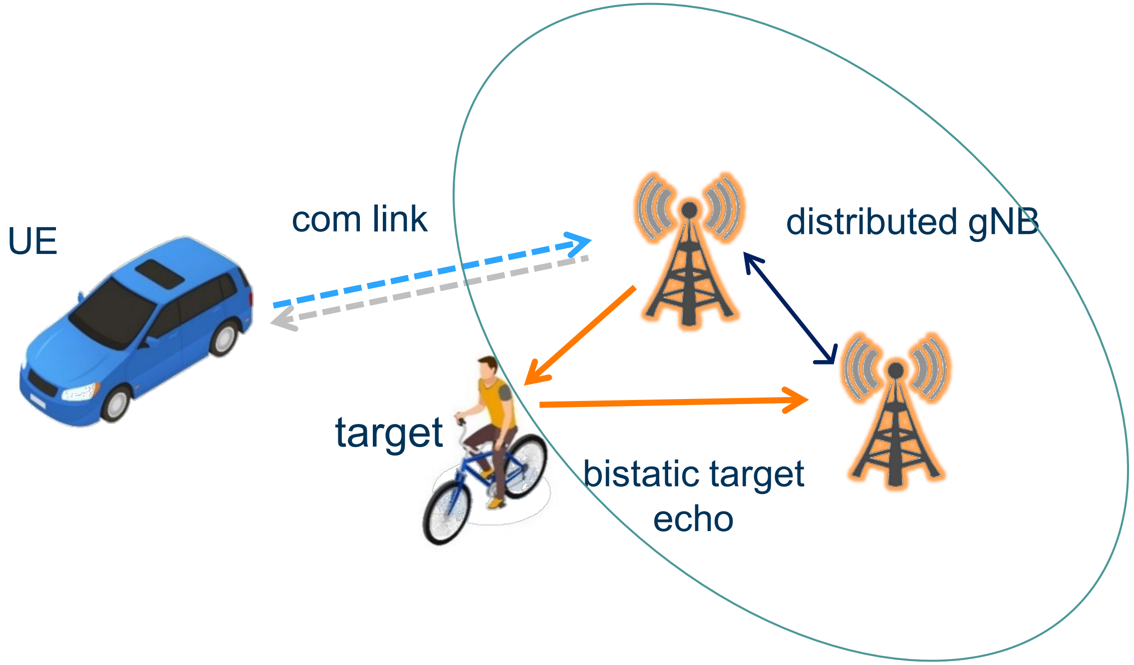
ISAC System Issues: Infrastructure Based Sensing





Monostatic case

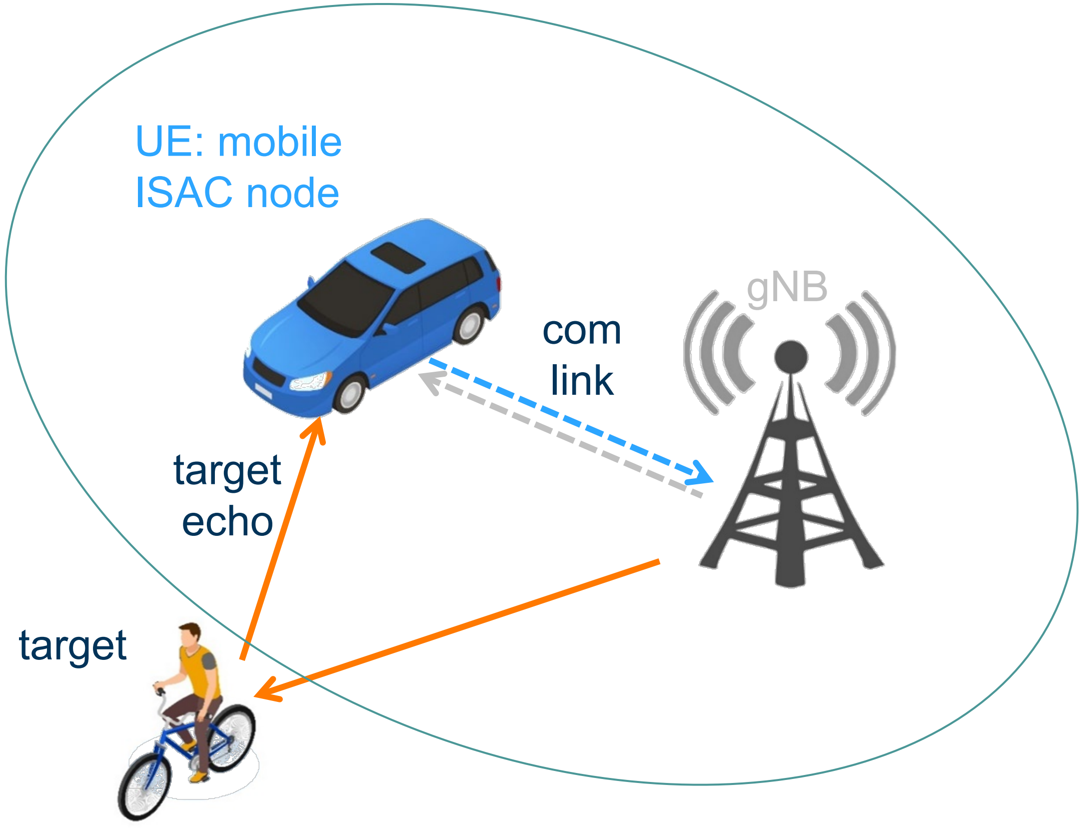
- gNB with antenna array as stand-alone radar (single station)
- DoA/ToF estimation
- Requires full duplex air interface

Bi/multistatic case

- gNB with **R**emote **R**adio **U**nits and BB processing pool (multiple RRUs required)
- Multilateration estimation (ellipses)
- Full duplex air interface **not** required
- Antenna arrays may be useful, but not required

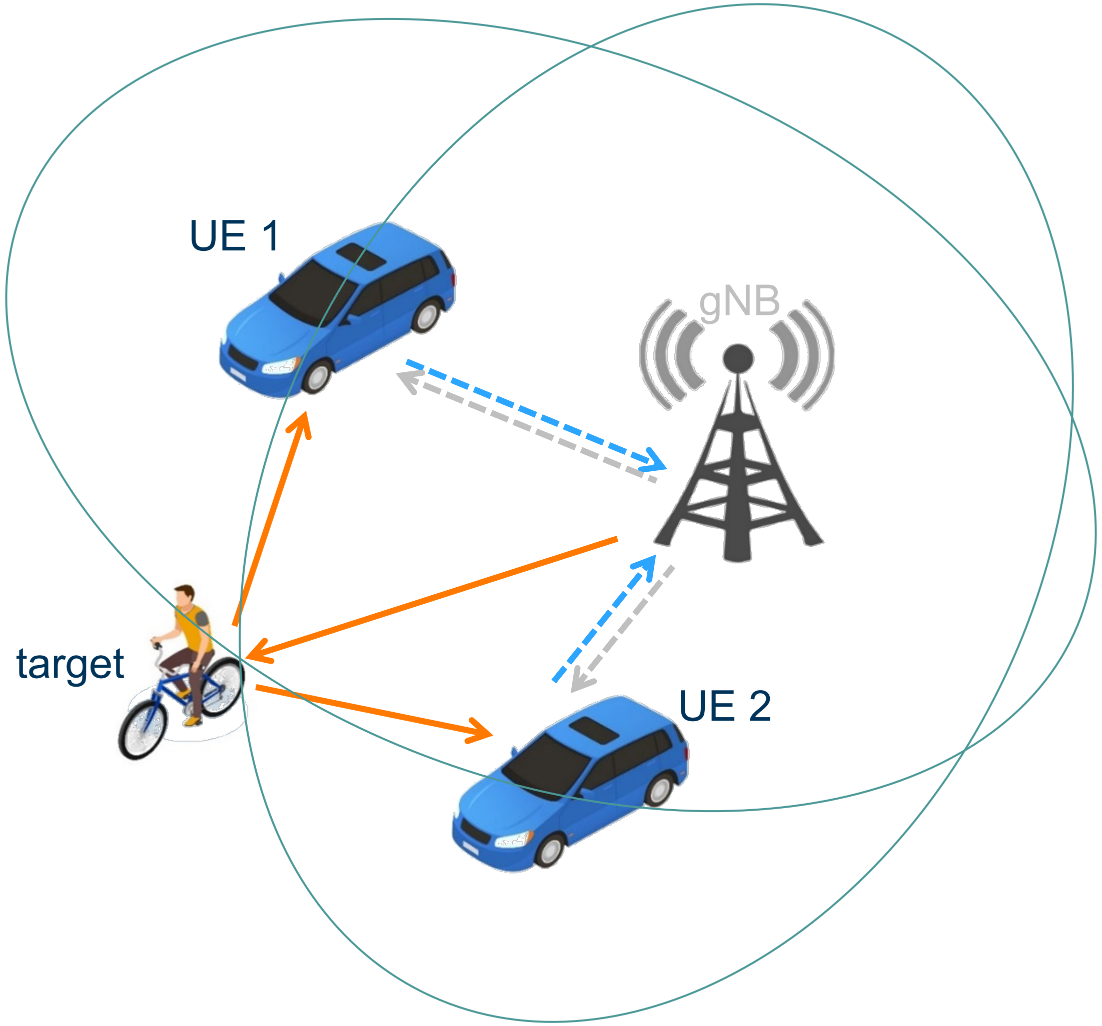
ISAC System Issues: Reuse of Communication Waveform DL/UL Sensing (Inclusion of UE)

- UE included in DL or UL
- Most efficient: reuse communication waveforms for radar
- Related to passive radar – but sensor and illuminator belong to the same network
- **Cooperative** passive coherent location (CPCL)
  - Measures excess ToF and bistatic Doppler
  - needs LOS reference for cross correlation
- Communication centric (RAN)



R.S. Thomä, et.al.,
"Cooperative Passive Coherent Location: A Promising 5G Service to Support Road Safety"
IEEE Communications Magazine, Vol.: 57, no. 9, September 2019, pp. 86-92

ISAC System Issues: Multilateration Needs Multiple Distributed Sensors



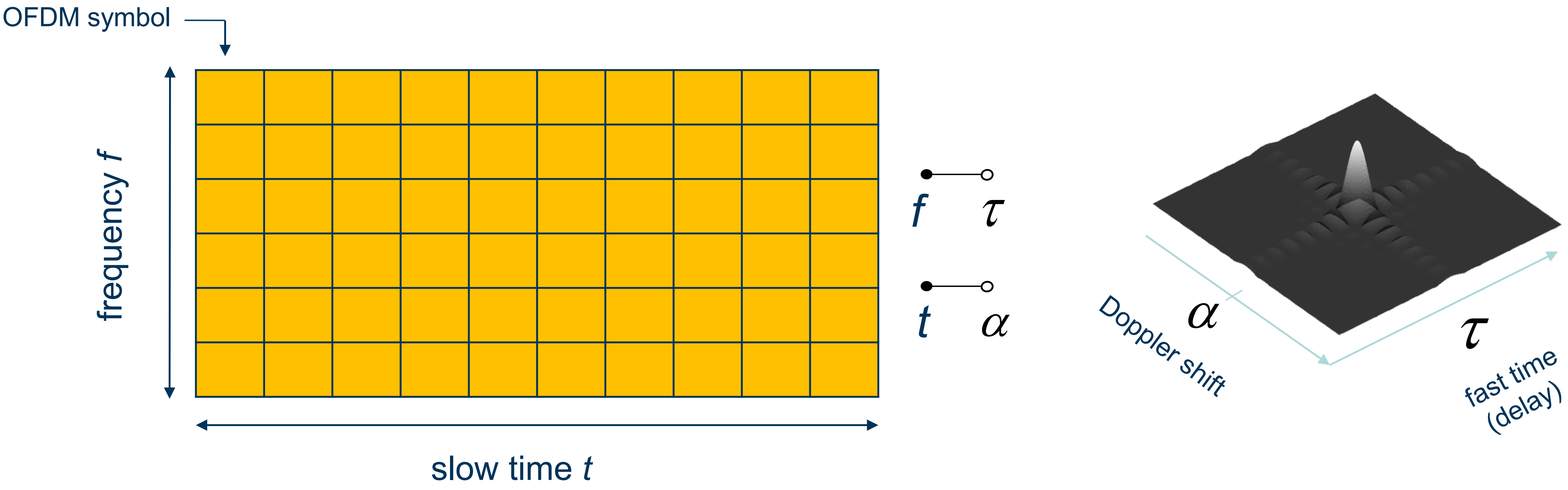
- Multilateration allows unique localization
- Multisensor access in DL/UL
- Requires multisensor access coordination

ISAC Radio Issues: Reuse or Sharing of Radio Resources?

- Sharing of resources between radar and comms
  - Share radio interface, time slots, and frequency bands
  - Flexible partitioning in frequency and time (resource competition)
  - Waveform for radar and comms can be different

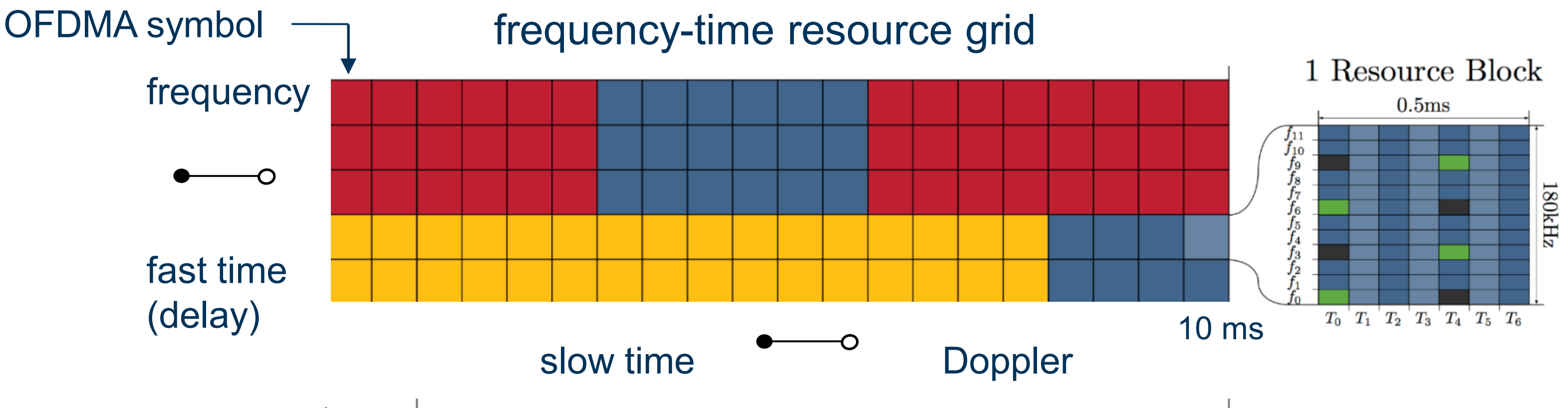
- Reuse communication waveforms
  - Sensing makes full use of data payload (Tx power fully used)
  - Double use of coms data (for comms and radar) - most resource efficient
  - Data payload needs to be known at sensor
  - Communication centric RAN design
  - Subjected to comms numerology (scalability) and MAC
  - Pilot and synchronization blocks used for target acquisition and link adaption
  - “Waveform design” reduces to resource allocation, scheduling and predistortion
  - Compound optimization of resources (jointly for radar and comms)

OFDM Frequency-Time Frame and Ambiguity Function



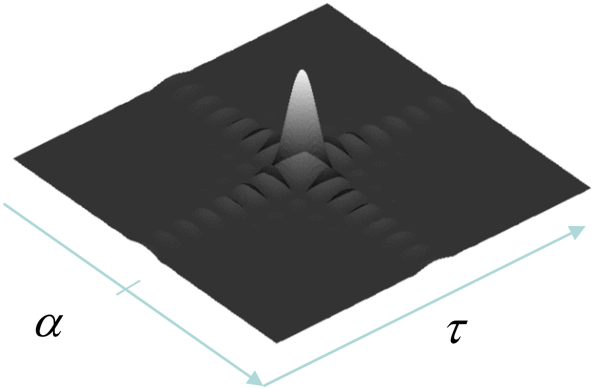
- Frequency transforms to delay, delay resolution = 1/bandwidth
- Slow time transforms to Doppler, Doppler resolution = 1/observation time window
- Ambiguity function with sinc-sidelobes
- CPX removal and coherent FFT processing avoids carrier leakage variance
- Observation time window (radar integration time) limited by range cell migration

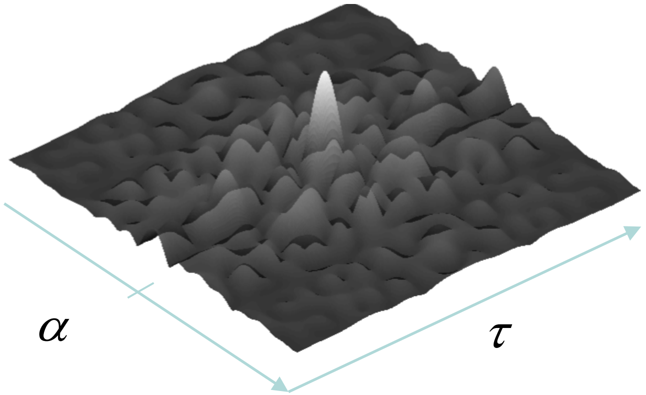
ISAC Signal Processing: OFDMA Resource Grid and Ambiguity Function



- OFDMA multisensor access allows interleaved sensor access (MAC sensor channel)
- Effects delay resolution and sensor latency (resp. update rate)
- Sparse occupancy of the frequency-time resource grid causes stronger, irregular side-lobes
- Doppler resolution and radar integration time limited by available observation time (slow time window)

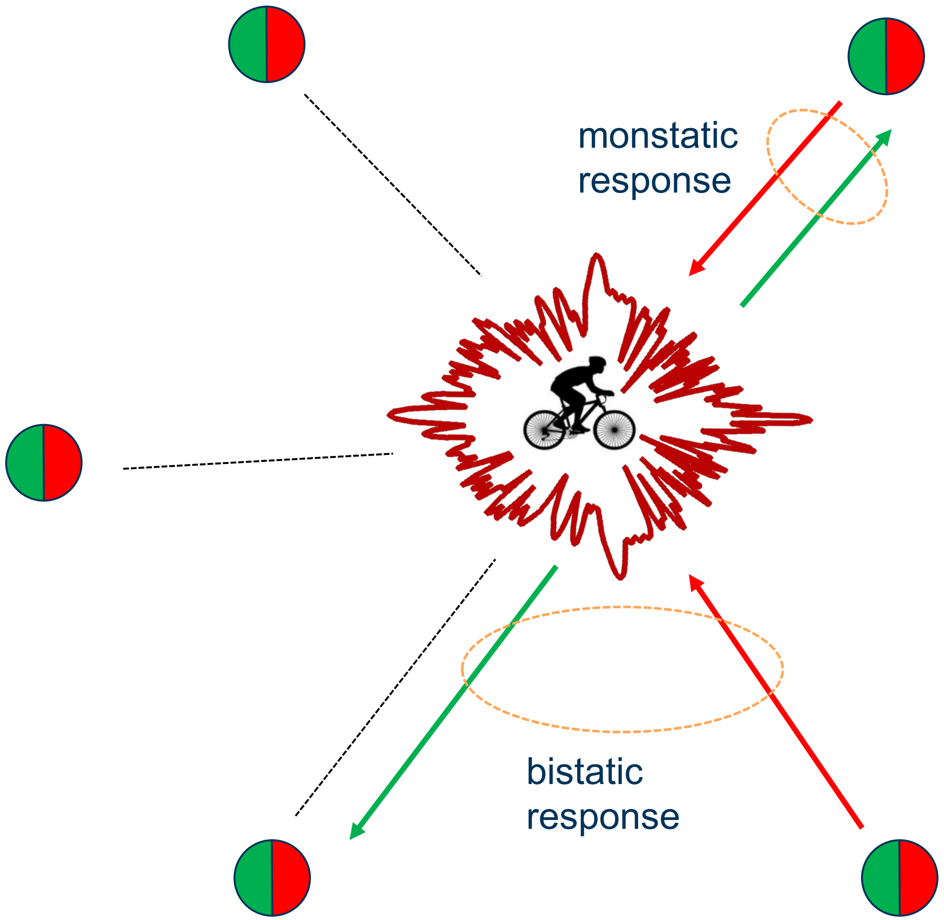
Fully occupied resource grid





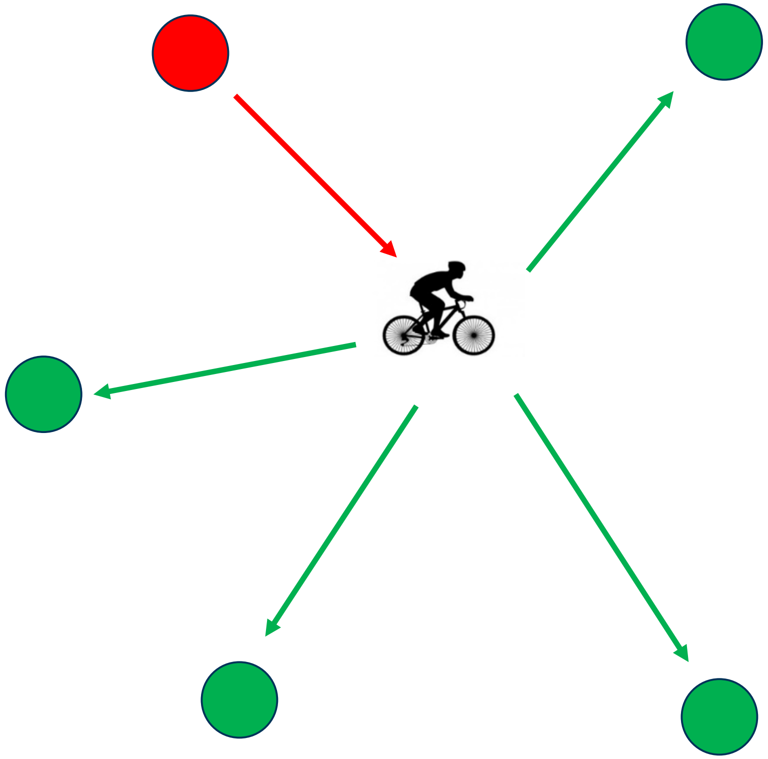
Sparse resource grid

Distributed MIMO ISAC



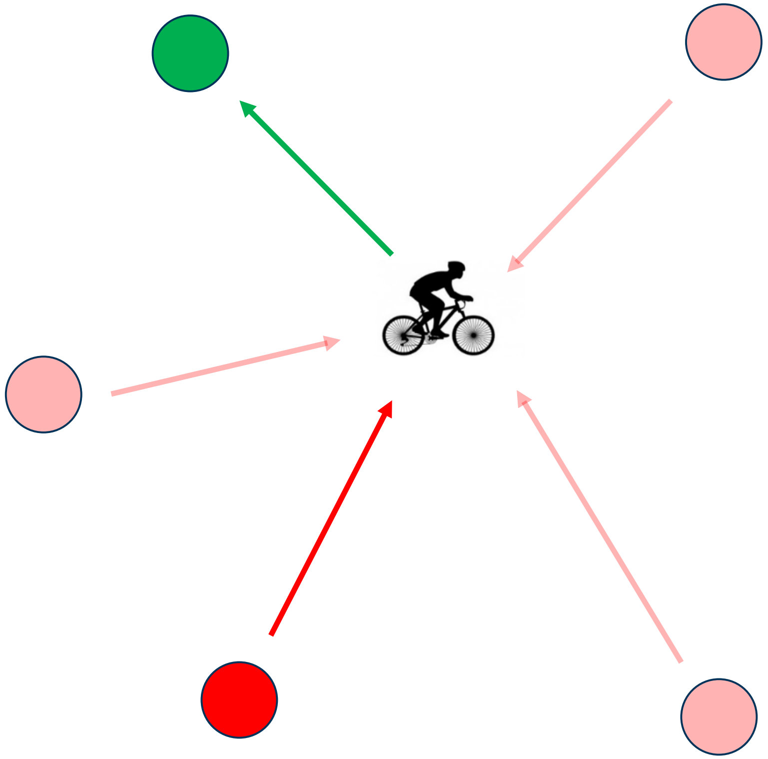
- Close to distributed MIMO radar
- Full MIMO matrix only with monostatic and multistatic response
- Monostatic observation needs full duplex radio access
- Bi-/multistatic links increase target diversity
- Mitigates Doppler blindness
- Supports object/shape recognition
- Different levels of radio node synchronization
  - From coherent to non-coherent node cooperation
- Tx/Rx links reciprocal in terms of propagation but perhaps not in terms of DL/UL access
- Radio nodes could be even heterogonous

Multiple Sensor Link Coordination: Broadcast Mode



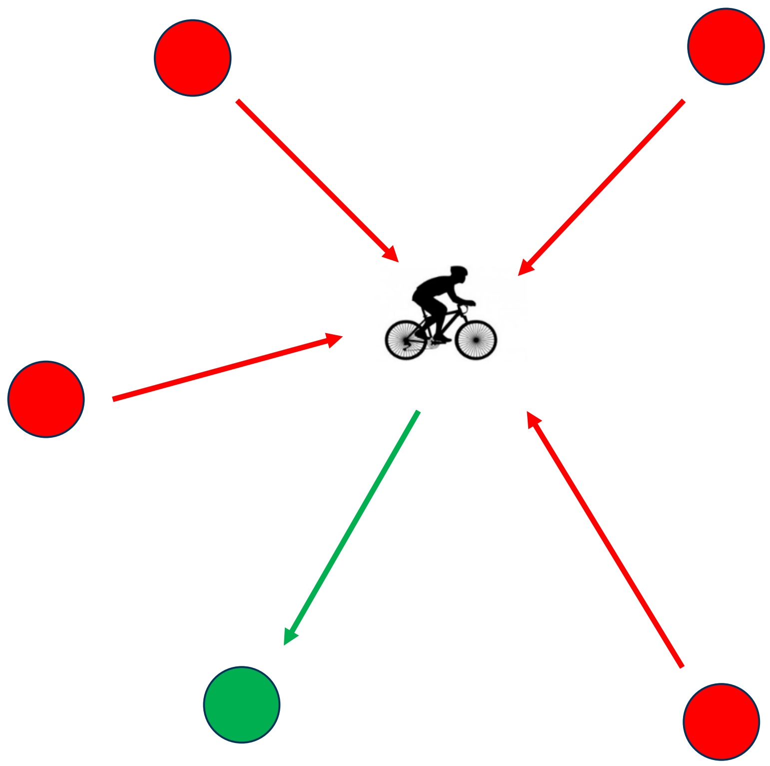
- Broadcast: Distributed SIMO Radar
- Multiple Rx in parallel (simultaneous observation)
- Rx can be other RRUs, UEs, or dedicated receivers ("sniffer")
- Radar parameter occur at distributed radio nodes (need to be retransmitted and fused)

Multiple Sensor Link Coordination: Multiple Sensor Access



- Orthogonal multiple sensor access for sensor coordination
- FDMA, TDMA, CDMA, SDMA
- OFDMA influences range resolution
- TDMA influences Doppler resolution
- Frequency-time resource grid becomes sparse
- Resource scheduling depends on estimation procedure and resolution requirements
  - multiple target and clutter resolution
  - target dynamics

Multiple Sensor Link Coordination: Joint Transmission CoMP (Cooperative Multi-Point) ICAS



- Joint transmission needs coordinated links
- Coherent or non-coherent focus at target
- Coherent or non-coherent ambiguity function
- Coherent focusing maximizes target SNR
- Non-coherent focusing maximizes diversity gain
- Focusing achieved by proper predistortion
- **Target channel** has to be estimated in advance
- MU Comms access has most mechanisms for ICAS multiple sensor CSI estimation and predistortion already built in

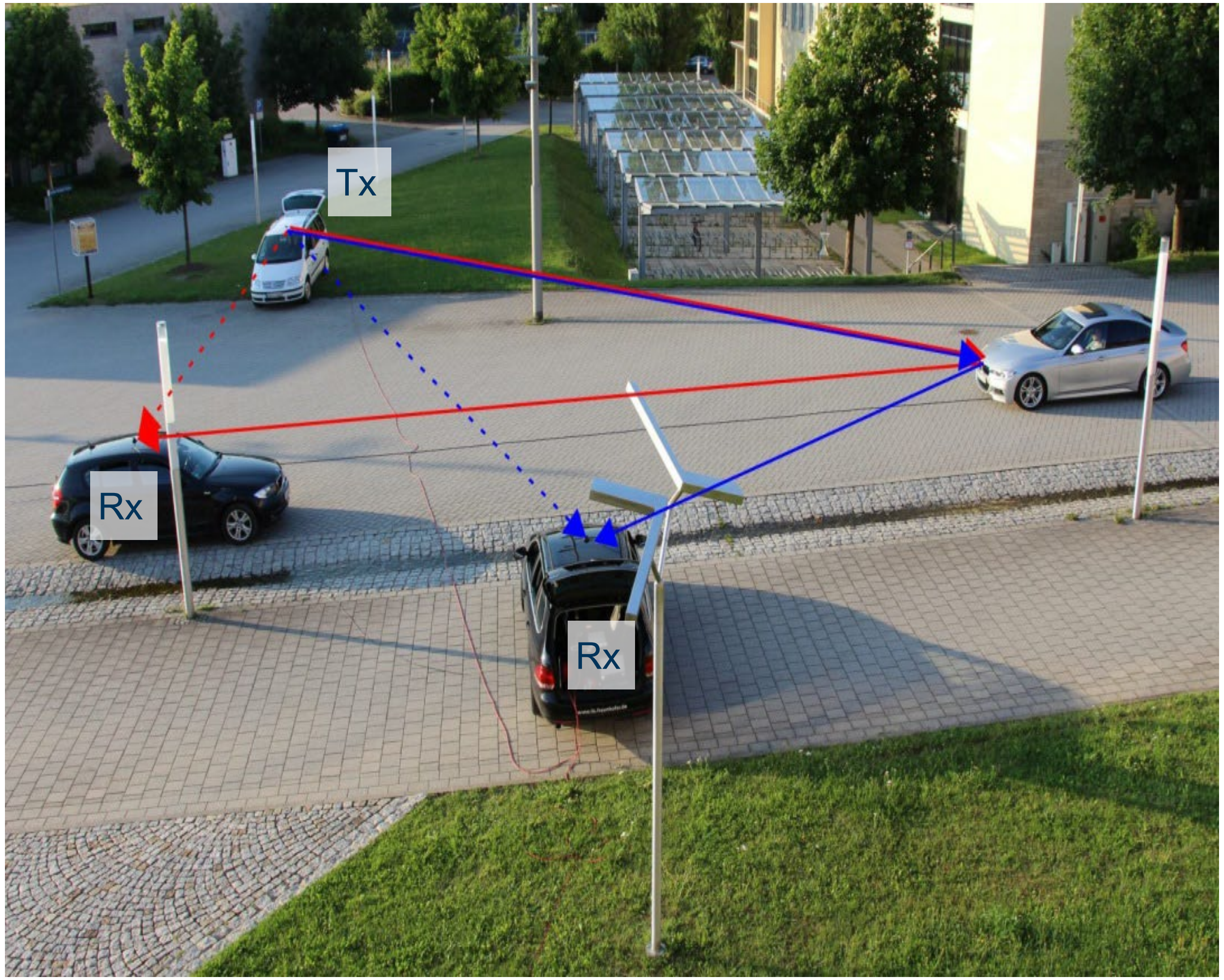
ISAC– Conclusions - and Many Open Questions

Challenging research –
Let’s do it!

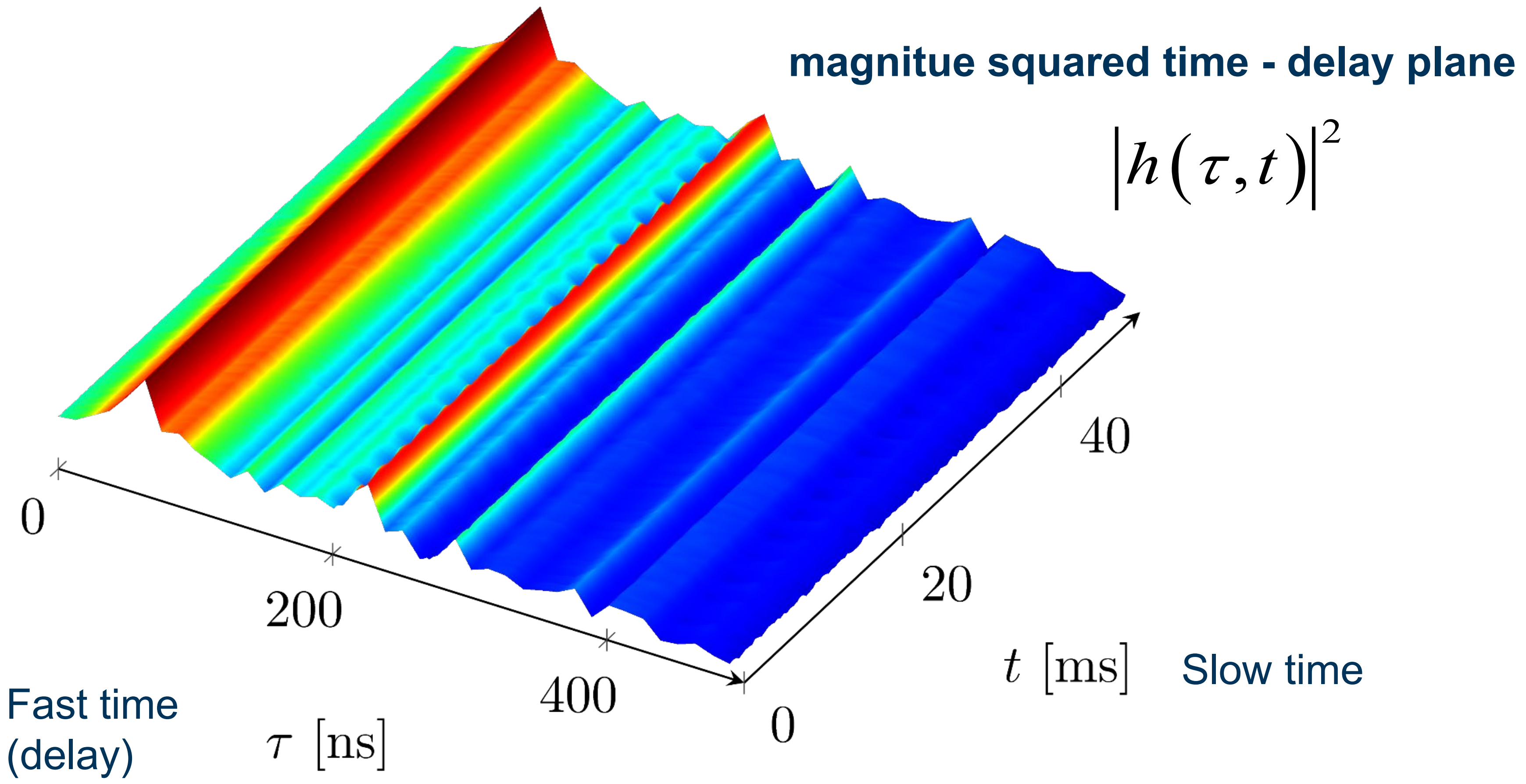
- **The 5G/6G radio network can be developed a full-fledged distributed radar network with cognitive performance**
- Reuse of communication waveforms exploits mobile radio access schemes (OFDMA, TDMA, multisensor, broadcast, and cooperative)
- “Waveform design” reduces to MU-access scheme, predistortion and link adaptation
- Holistic view of propagation, signal processing and network issues
- Can MNOs create a business model for radar as a public value-added service? Feature in campus networks? Vertical industries?
- Coms>ISAC Upgrade comes with minimum CAPEX and OPEX
- Can JCAS relax the competition for frequency bands between mobile radio and radar?
- Administrated radar service (FCAPS)?
  - Fault Management, Configuration Management, Accounting Management, Performance Management, Security Management
- “Radar Quality of Service”

Demonstration Example: Moving Car

- Tx: USRP X310 with additional PA
- Rx: USRP X310 (dual channel)
- Tx-Rx Synchronization with GPSDO
- Tx signal: OFDM
  - 5.2 GHz
  - 33 dBm
  - 80 MHz BW
- Ground truth: Laser



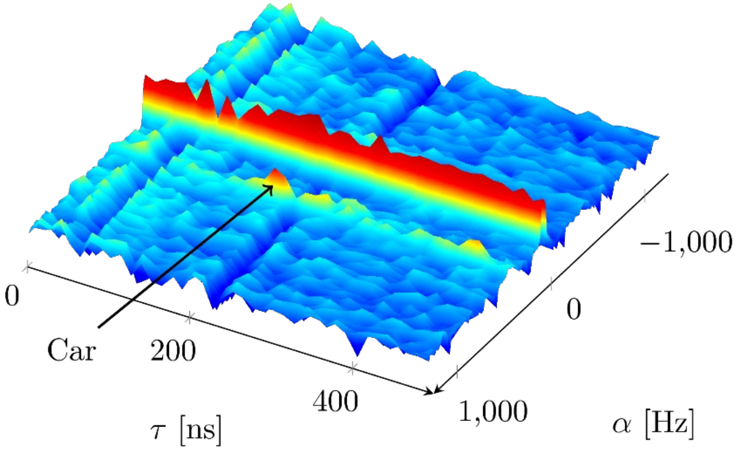
Demonstration Example: Time-variant Power-delay Profile



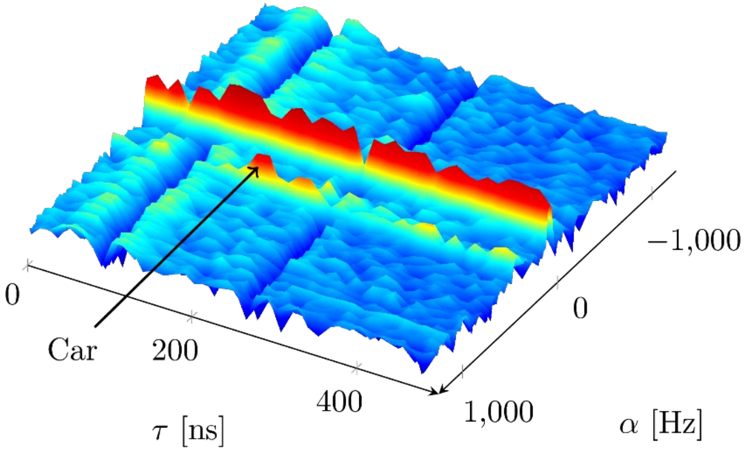
Strong static clutter masks all signals backscattered from moving objects

Demonstration Example: Delay-Doppler Estimation

magnitue squared delay - Doppler plane (scattering function)



$$\left|S(\tau,\alpha)\right|^2$$



Sensor: Car 2

target car at 201.1 ns
LOS at 58.2 ns and reflection 227.4 ns removed

Sensor: Car 3

target car at 182.2 ns
LOS at 81.9 ns and reflection at 259.7 ns ns removed

Doppler FFT

- separates static clutter and dynamic target contributions
- allows longer integration time

LOS and dominating reflections estimated and removed (HRPE)

- Center frequency: 5.2 GHz
- Bandwidth: 80 MHz
- Delay grid/resolution: 12.5 ns
- Doppler-FFT length: 10 ms
- Doppler resolution: 20 Hz
- Doppler bandwidth: 2500Hz