Integrated Sensing and Communication

Some System and Access Issues

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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 Remote Radio Units 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
• 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)
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 heterogenous
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

- 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)?
- "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

magnitude squared delay - Doppler plane (scattering function)

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