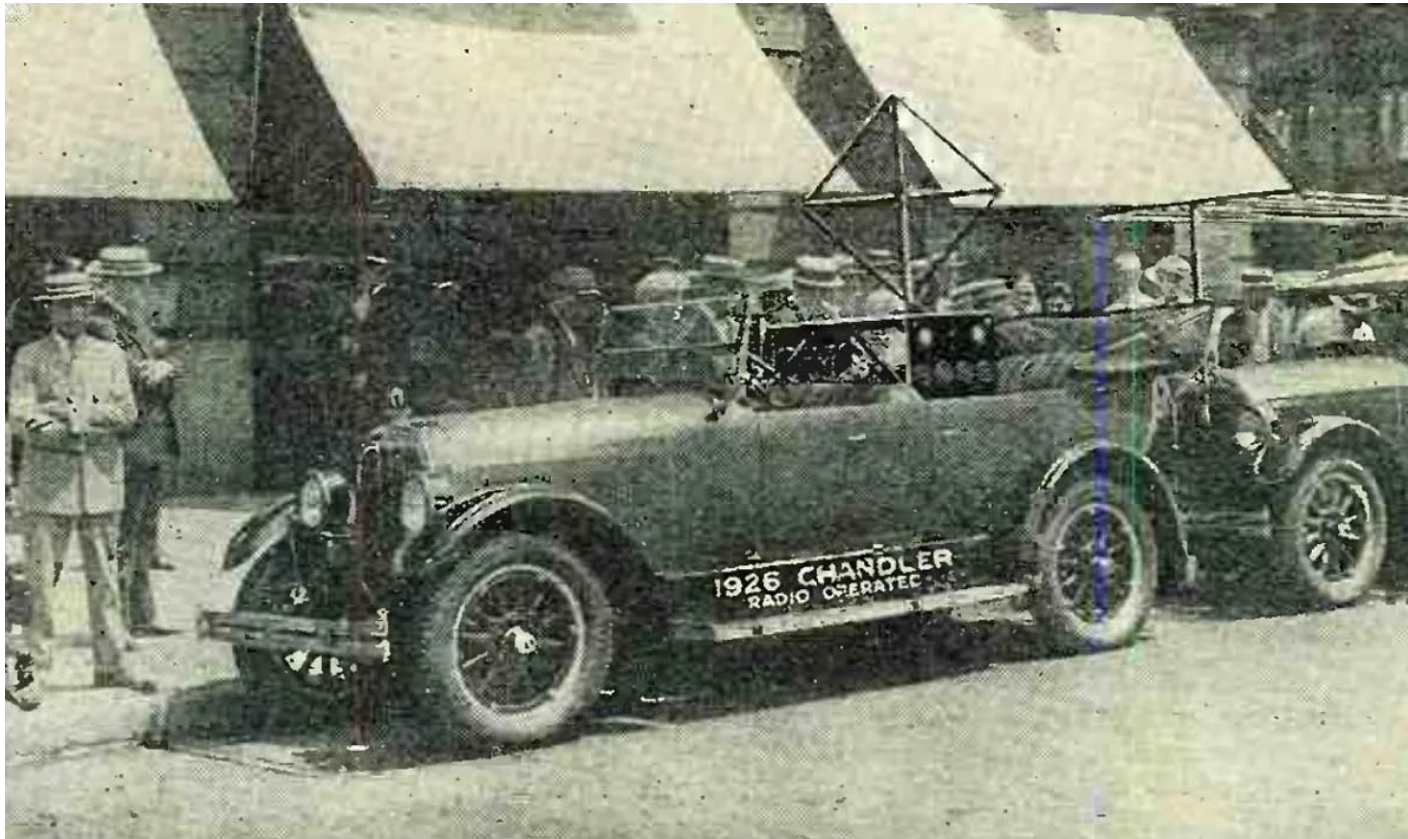


6G-V2X FOR SAFE AND COOPERATIVE AUTONOMY

Barbara Masini, Director of research at CNR-IEIIT and CNIT/Wilab co-funder
barbara.masini@cnr.it

1925

1925: THE FIRST AUTOMATED VEHICLE...



... was connected

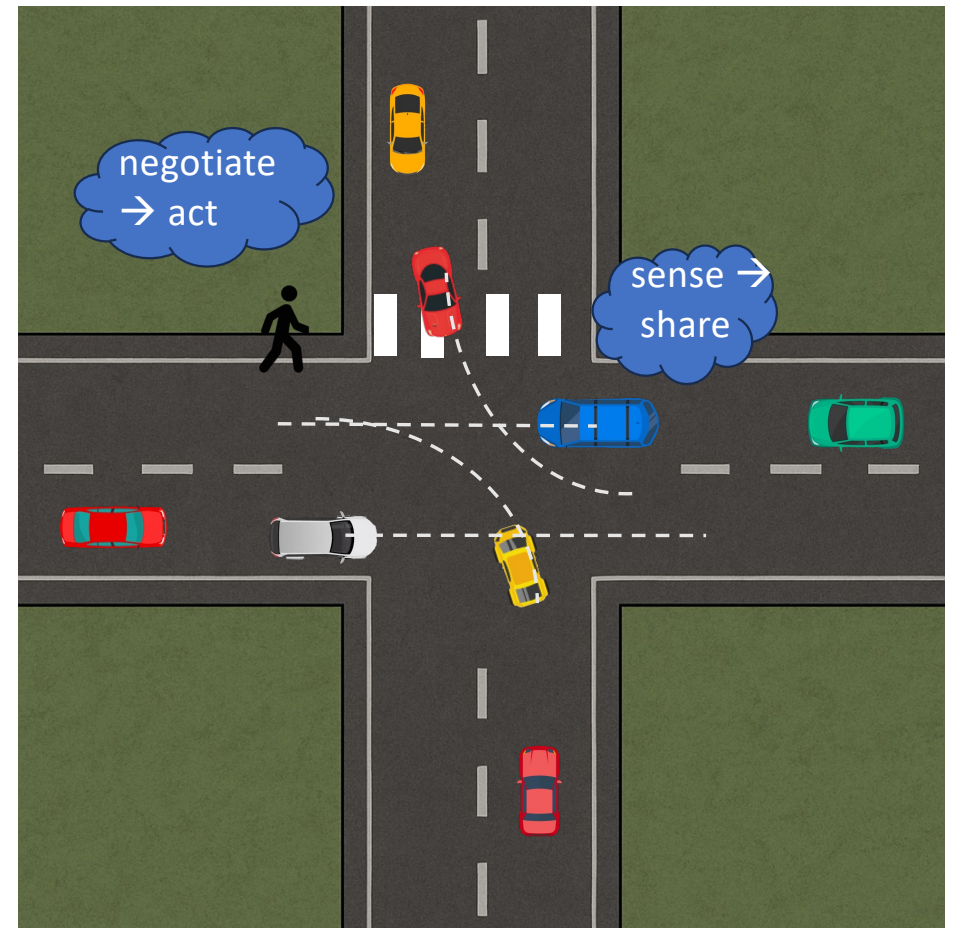
2025



Autonomy is not only about replacing drivers. It's about creating vehicles (and environments) that coordinate safely, efficiently, in real time

BEYOND SENSORS: WHY 6G CHANGES THE GAME

- Automation without context is inefficient
 - Local sensing has limits (range, field of view, NLOS)
- Cooperation becomes fundamental
 - Extend the field of view (FoV)
 - Share sensed obstacles
 - Share intentions
- Communication and sensing should become one
 - High position accuracy
 - Strong reliability/availability (coverage)
 - Low latency of position information
 - High update rate of position data
 - Scalability to manage dense node deployments



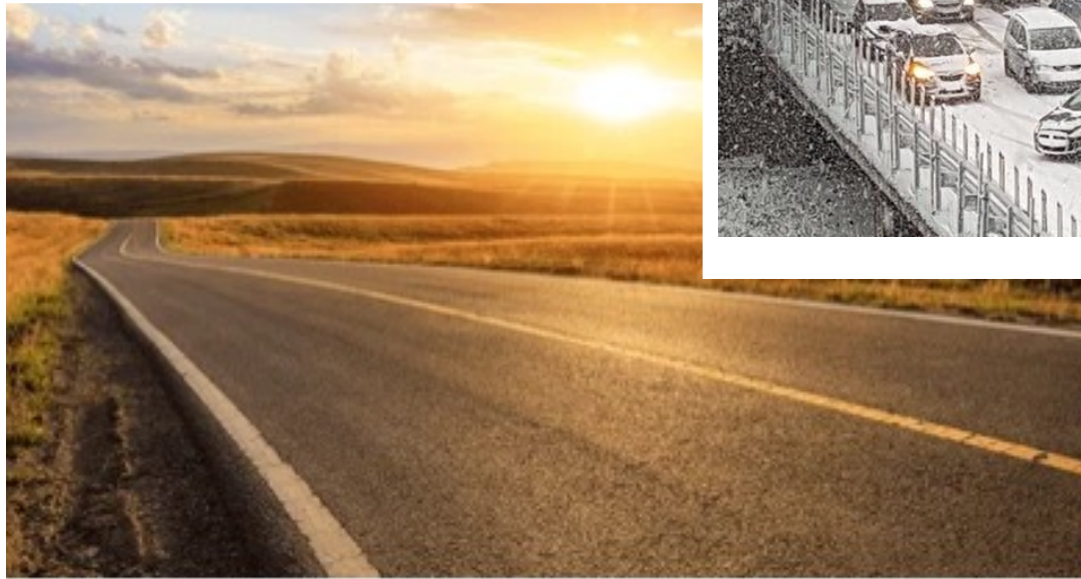
CRITICAL SCENARIOS



DIFFERENT ROAD ACTORS



CRITICAL WEATHER CONDITIONS



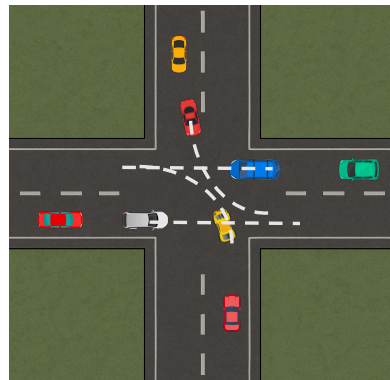
CONNECTED COOPERATIVE AUTOMATED MOBILITY (CCAM)

CCAM work item in WG2 of One6G: identification and investigation of technologies to enable the new CCAM use cases

- Vulnerable road user (VRU) (one6G) protection
- Platooning
- Intersection management
- Multimodal transportation
- Teleoperated driving



6G-V2X



TECHNOLOGIES ROADMAP FOR CCAM

Wi-Fi- based

2010 – IEEE 802.11p

- 10 MHz channels @ 5.9 GHz ITS band
- Low-latency broadcast; basic safety; communication without authentication

2020 – IEEE 802.11bd (backward compatible)

- 10 or 20 MHz channels
- Higher throughput & range;
- Considers mmWave; fast ranging procedures

2024 – IEEE 802.11-2024

- Baseline consolidation of V2X PHY/MAC improvements

Cellular based

2017 – Rel-14 LTE-V2X

- Basic safety apps; broadcast sidelink
- 10 or 20 MHz channels @ 5.9 GHz ITS band

2020 – Rel-16 5G NR-V2X (not backward compatible)

- Unicast / groupcast / broadcast
- FR1 + FR2 operation

2022 – Rel-17

- Higher KPIs; UE relaying
- Sidelink positioning & sensing
- Beamforming; FR1 / FR2 / mmWave

2025 – Rel-18

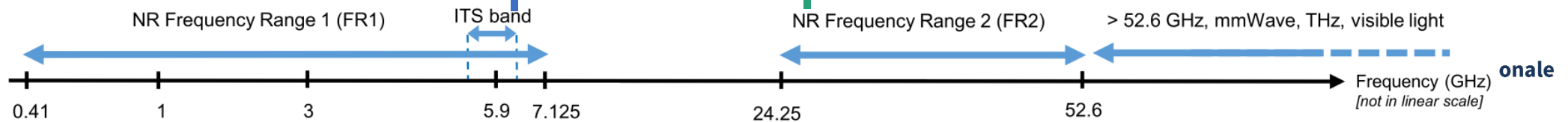
- AI-based resource allocation
- Mesh networking

2027 – Rel-19

- Context-aware sidelink protocols
- NTN inter-operation

2030+ (tbd) – Rel-20

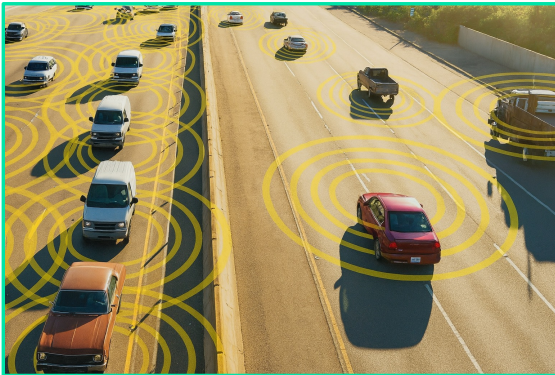
- RIS-assisted; THz bands; VLC integration



TECHNOLOGIES ROADMAP FOR CCAM

DAY 1:

I share where I am

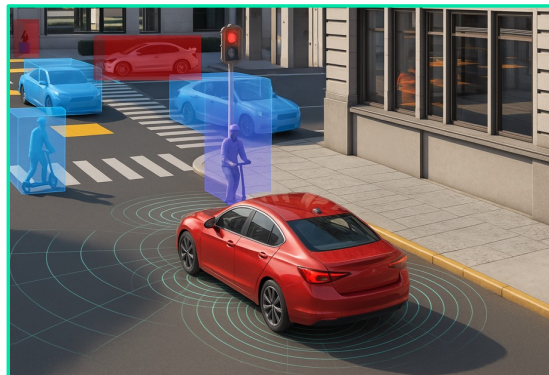


Awareness Driving

- Cooperative Awareness Message (CAM): Periodic messages with a frequency varying between 1 Hz and 10 Hz, carrying kinematic data and path history
- Decentralized Environmental Notification Message (DENM): Event-triggered messages to notify about events as hazards

DAY 2:

I share what I see

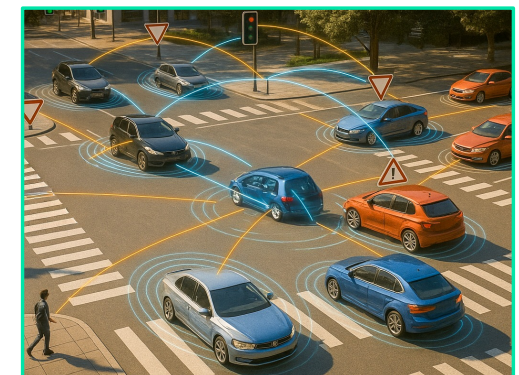


Sensing Driving

- Collective Perception Message (CPM): to inform other vehicles and the infrastructure about perceived objects and sensor capabilities
- ...

DAY 3+:

I coordinate with the others

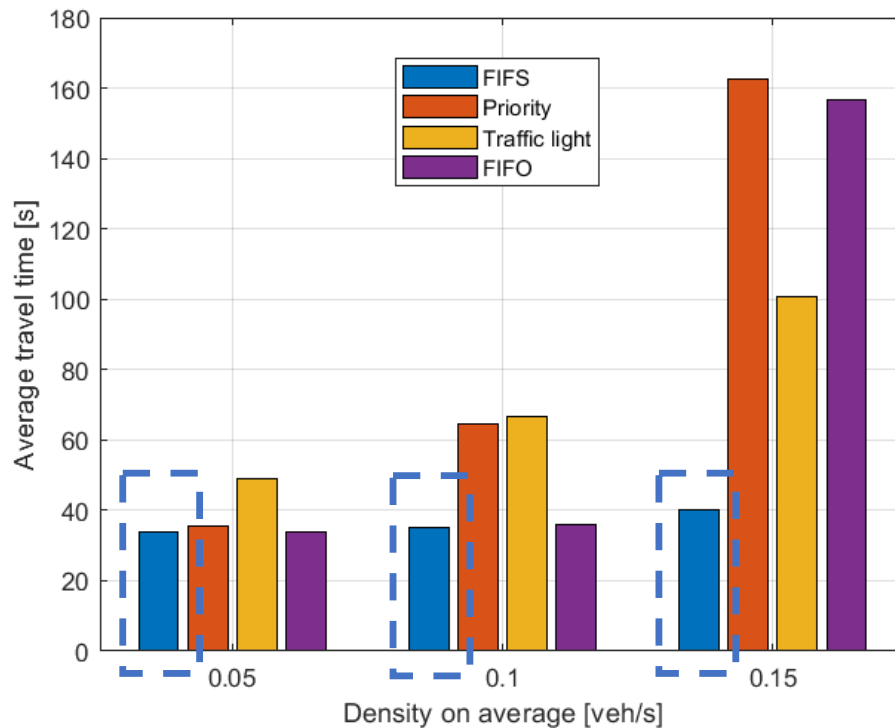


Cooperative Driving

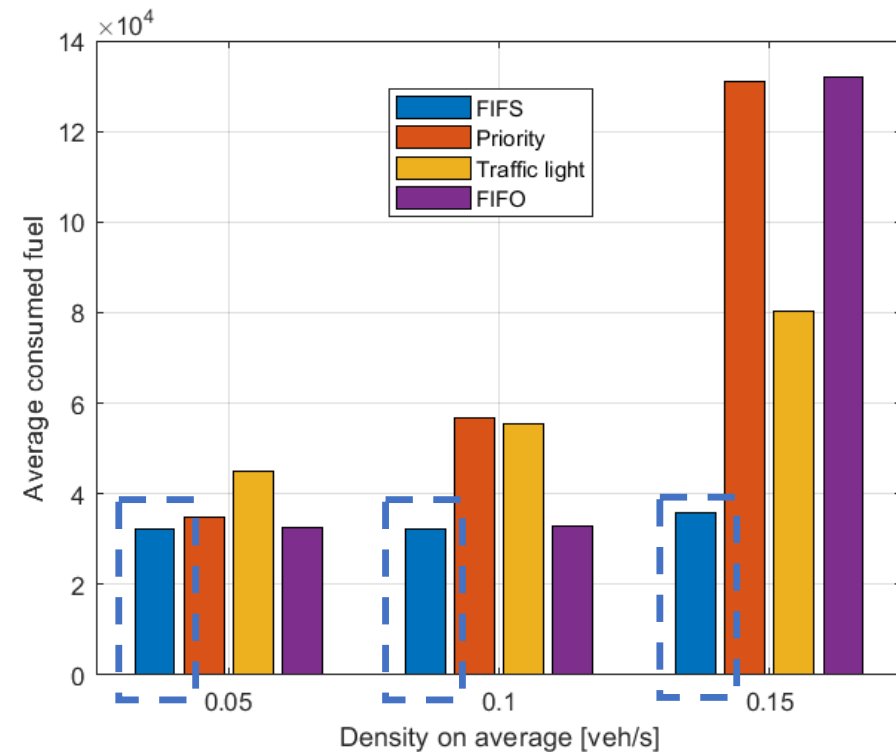
- Vulnerable Road Users Awareness Message (VAM): Periodic messages with a frequency varying between 0.2 Hz and 10 Hz, carrying kinematic and status data of Vulnerable Road Users
- Manoeuvre Coordination Message (MCM)
- ...

COORDINATION AT INTERSECTIONS

Travel time



Consumed fuel



L. Farina, M. Rapelli, B. M. Masini, C. Casetti and A. Bazzi, "Maneuver Coordination Using V2I to Improve Traffic Efficiency at Intersections," VNC 2024

CONNECTED VEHICLES PENETRATION

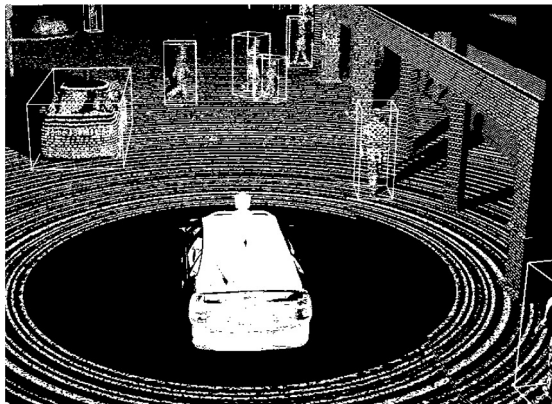
Region	Legacy connected vehicles	Vehicles with sidelink V2X
Europe	~70%	<1% (802.11p)
USA	~91%	<1% (802.11p, transition toward C-V2X)
China	~84%	China: ~2% (C-V2X)

Source: market trackers + public institutions (Statista, EU eCall, FCC docket, China C-V2X volumes).

LIDARS AND CAMERAS STILL WIN

Onboard “Single-Anchor” Systems (Self-Contained)

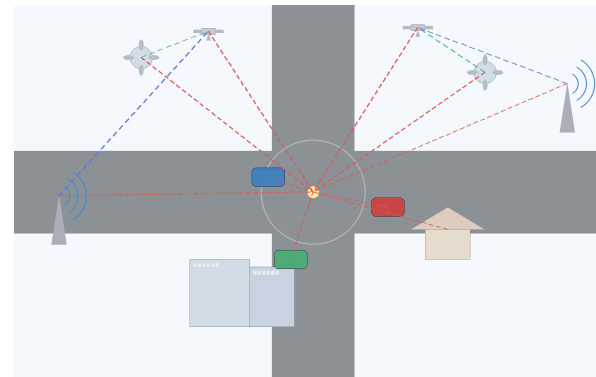
- Decision-making relies entirely on onboard perception
- No dependency on external coverage (5G...)
- No need to interact with roadside infrastructure
- No need to cooperate with other vehicles
- Low latency: processing remains on the vehicle



6G-V2X

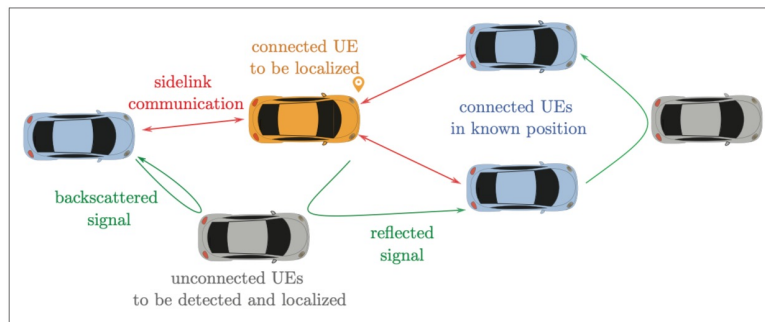
Limits of Infrastructure / Cooperative Approaches

- If comms or localization infrastructure is unavailable, capability degrades
- Moving anchors have positions estimated with uncertainty
- Latency often worsens due to multi-node information exchange
- Cooperative perception can explode latency and bandwidth needs (raw sensor sharing)
- AI-based fusion of many heterogeneous data streams can add significant processing delay

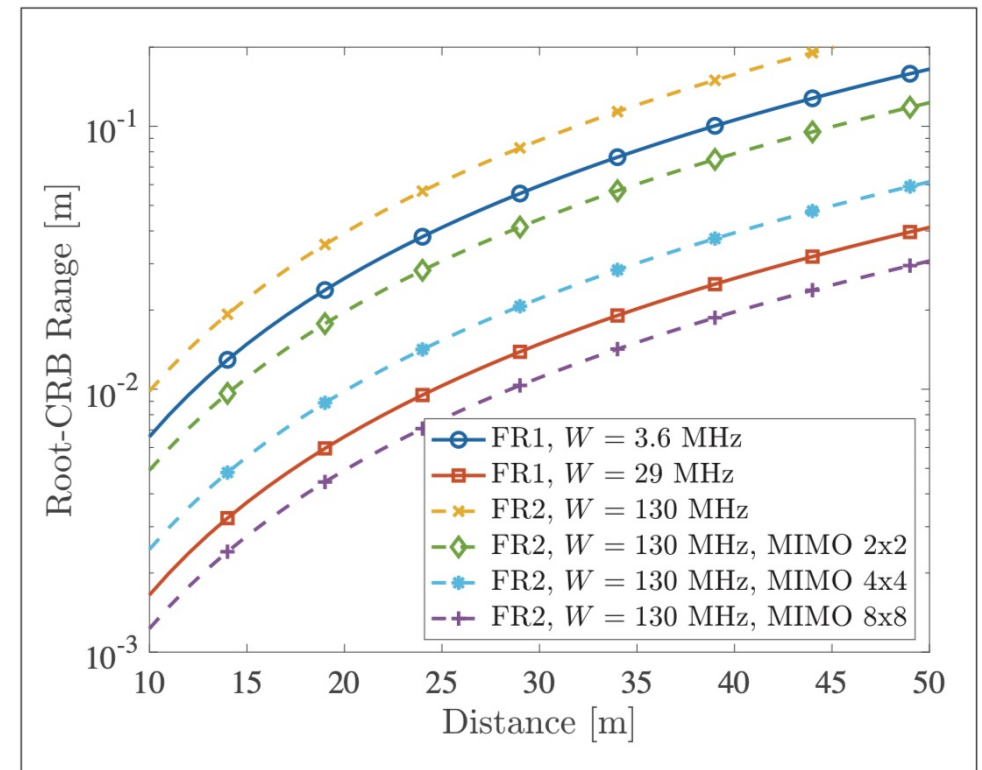


WE NEED TO RETHINK HOW WE SENSE

- Monostatic sensing
 - Integration of HW
 - Waveform optimization
 - Self interference rejection
 - Expanded bandwidth
 - New carrier frequencies
 - Channel estimation
 - Balance between communication and sensing
 - New standardization efforts

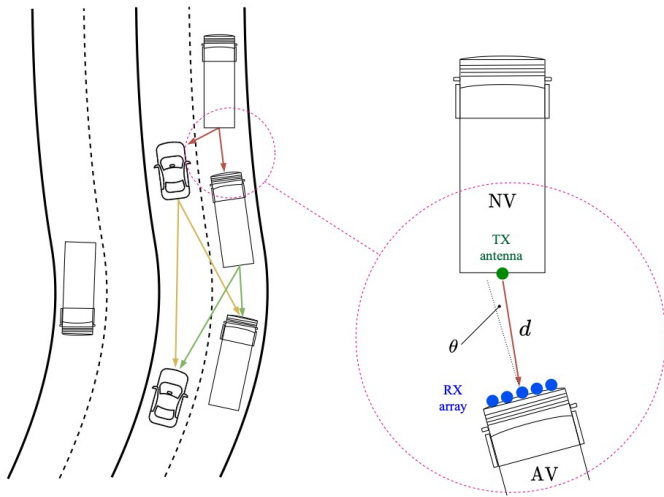


Best distance estimation in FR1 and FR2



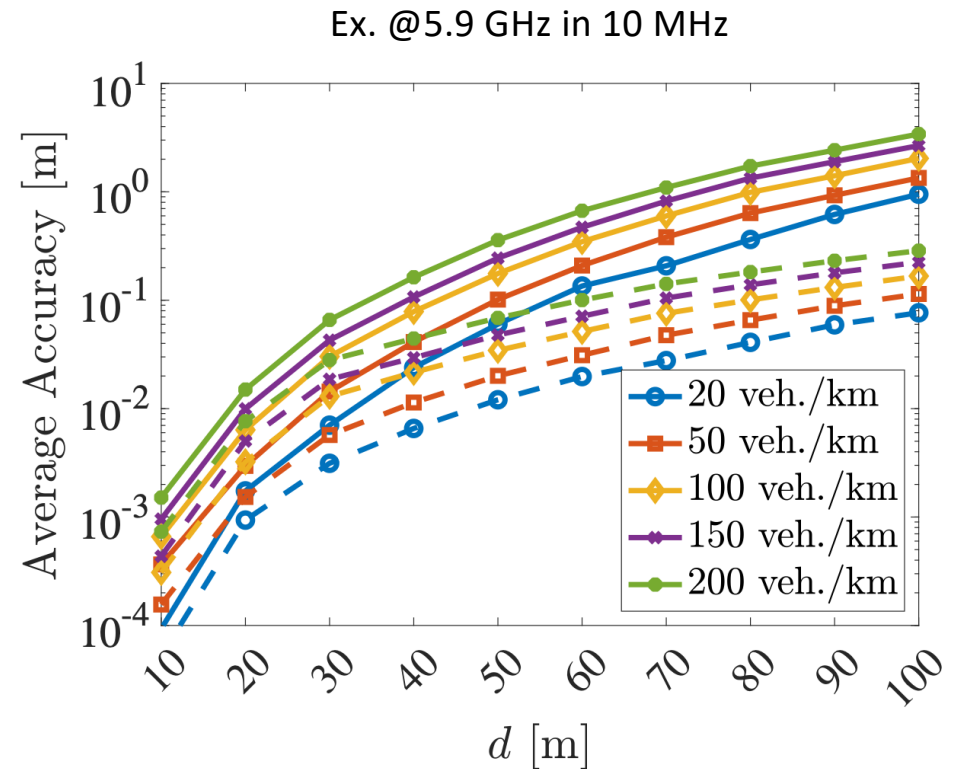
WE NEED TO RETHINK HOW WE SENSE

- Near field localization
 - absolute position of vehicles is often unnecessary
 - Near vehicles as large antenna array



N. Decarli et al, "V2X Sidelink Localization of Connected Automated Vehicles," in *IEEE Journal on Selected Areas in Communications*, 2023

6G-V2X



(a) (—) Longitudinal accuracy; (---) Lateral accuracy

WE NEED TO RETHINK HOW WE SENSE

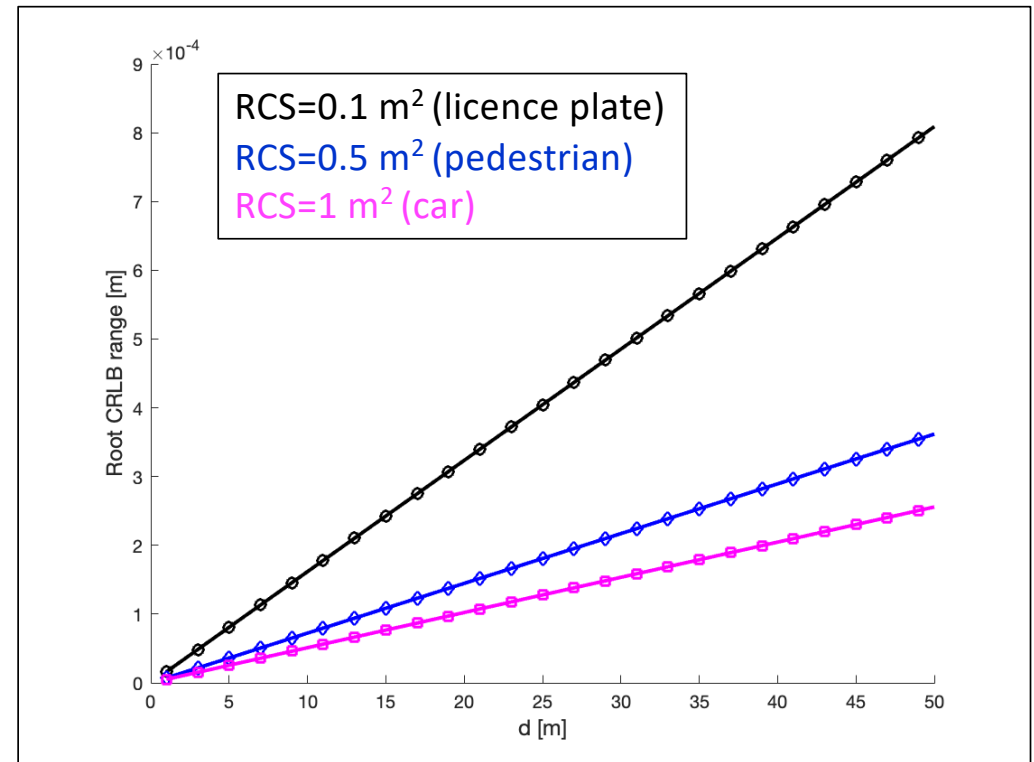
- Higher frequency bands:

- FR1
- FR2
- Mmwaves
- THz
- VLC

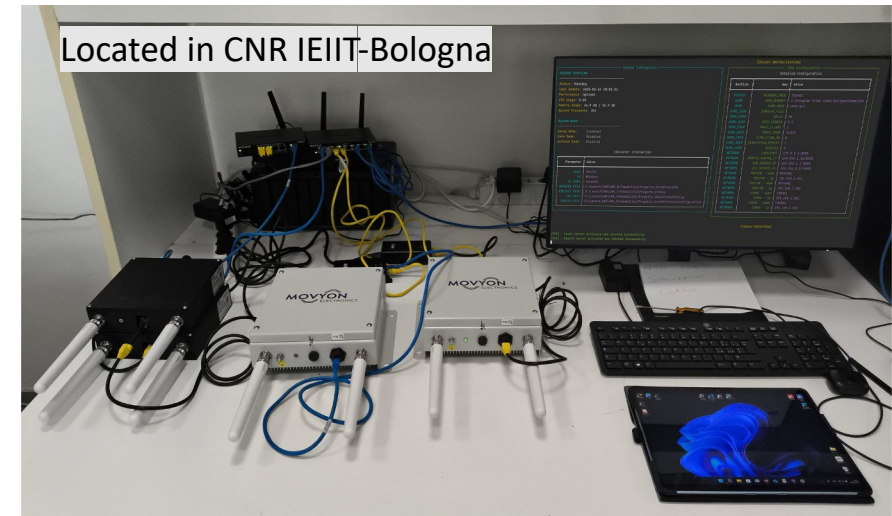
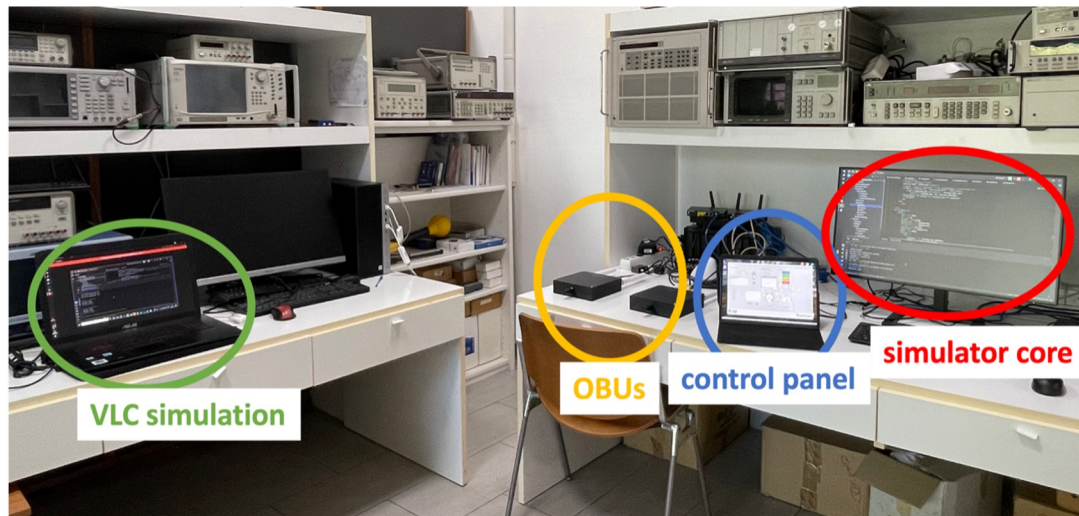


6G-V2X

Best distance estimation via VLC monostatic sensing



DISTRIBUTED SIMULATION PLATFORMS WITH HIL

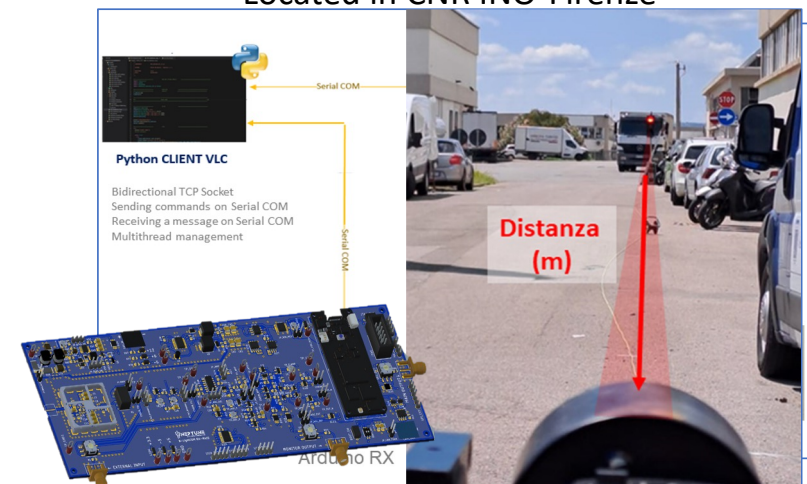


6G-V2X



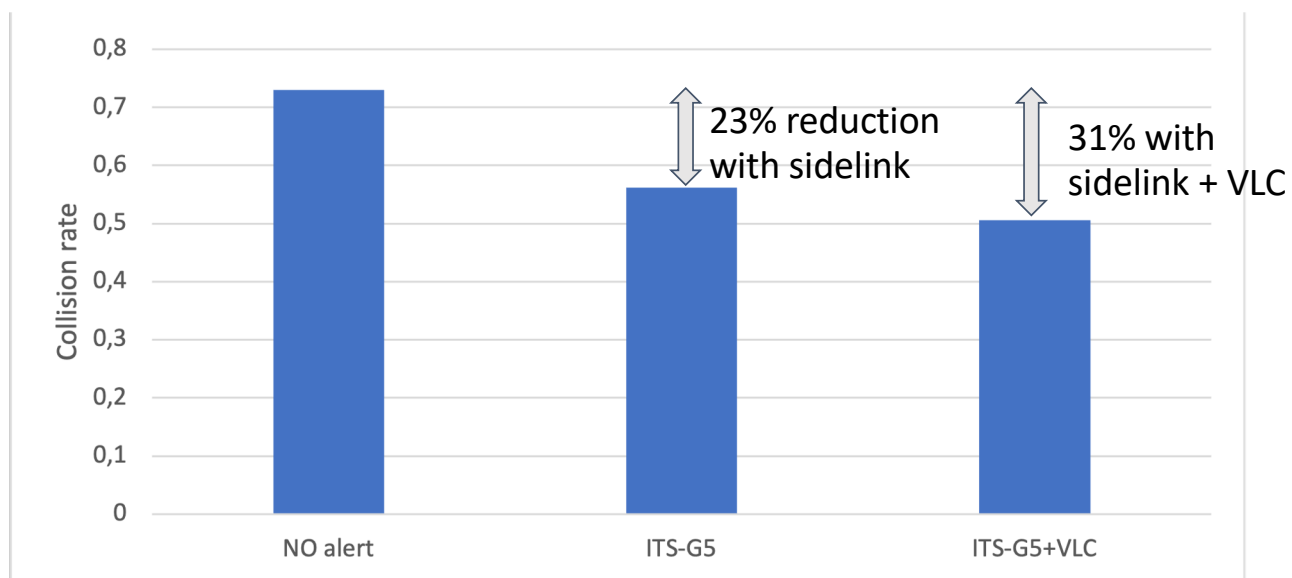
B. M. Masini *et al.*, "Sto-CAV: A Distributed Simulation Platform for Connected and Automated Vehicles Running With Heterogeneous Technologies and Devices in the Loop," 2025

Located in CNR INO-Firenze



EXAMPLE RESULTS: IMPACT of V2X IN SAFE OVERTAKING

Collision risk: impact of heterogeneous technologies



CONCLUDING REMARKS

Cooperation needed: data exchange, infrastructures and facilities availability

- 5GAA Marketplace
- European Connected and Autonomous Vehicle Alliance (announced, March 2025)
- Euro New car Assessment Program (NCAP)

New frequency bands needed...

- FCC Reduced to 30 MHz the 5.9 GHz band for ITS (by December 2026, 11p-based operations will be phased out in favour of C-V2X)
- 500-750 MHz of new spectrum needed → expected to be assigned @World Radiocommunication Conference 2027

6G-V2X is not just the backbone of connected mobility
It's the language of collective decision-making.

Thank you for the attention

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