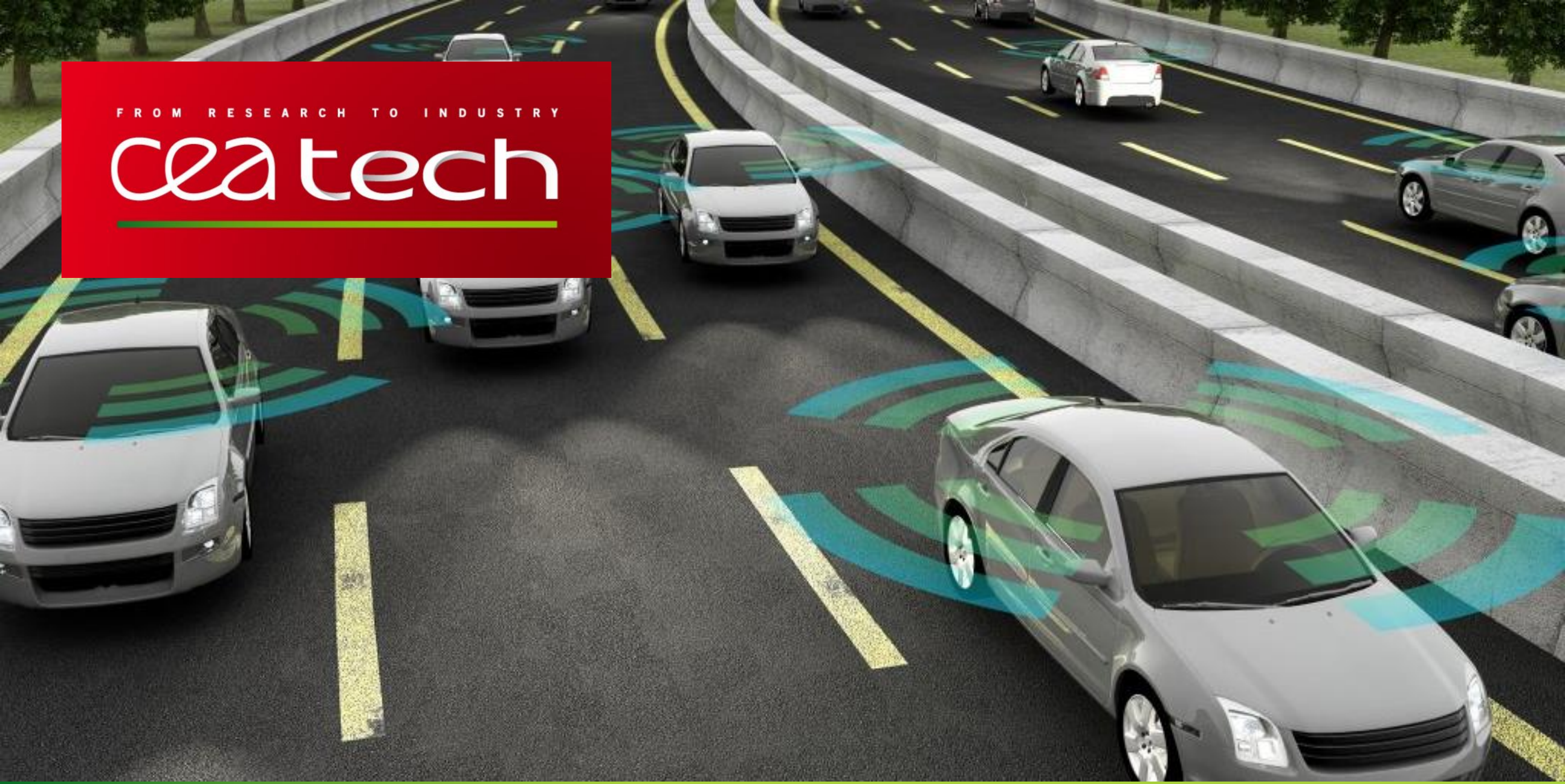
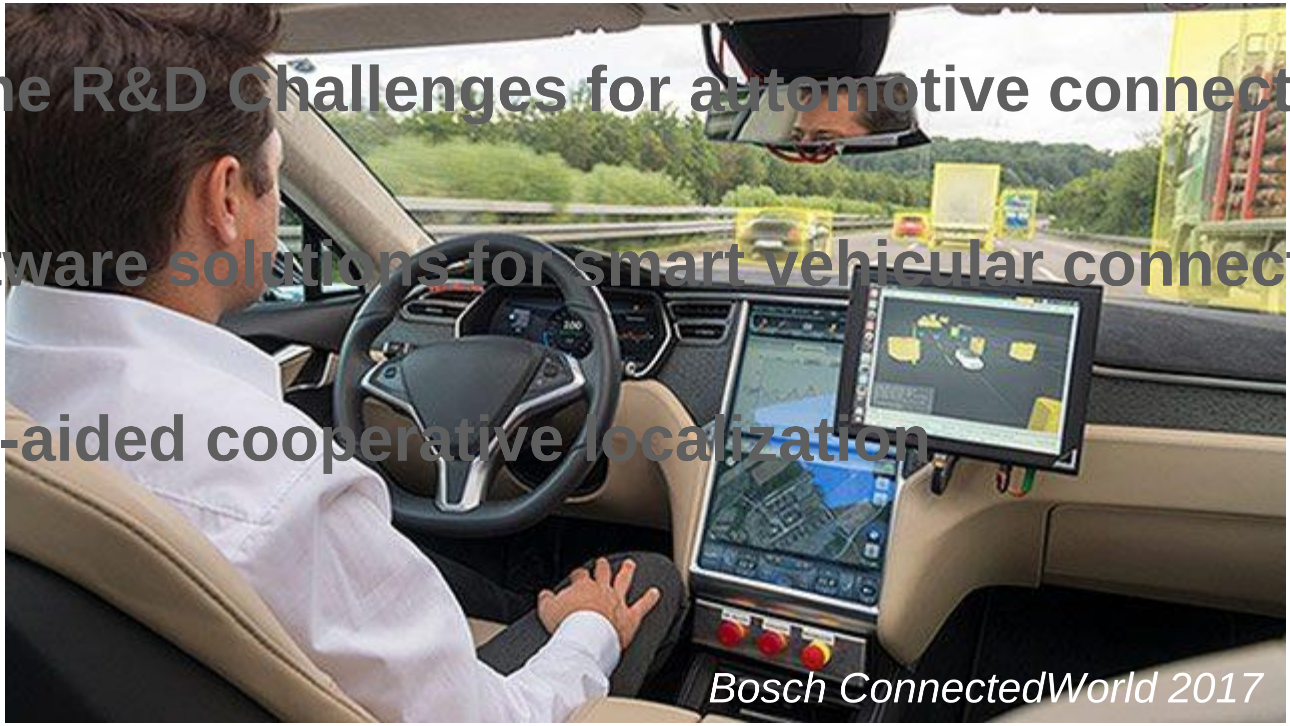


SMART MOBILITY NOW! 5G-LIKE TECHNOLOGY

5G Electronics Workshop – July 3rd 2018

Christophe JANNETEAU, Head of Communicating Systems Lab, CEA List
Dimitri KTENAS, Head Of Wireless Technologies Department, CEA Leti

What type of connectivity for the vehicle of the future ?



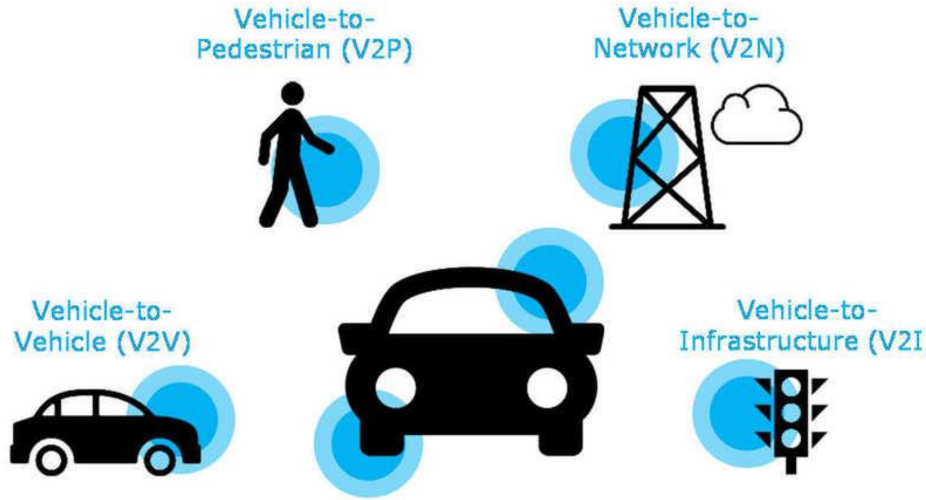
1. Some R&D Challenges for automotive connectivity
2. Software solutions for smart vehicular connectivity
3. V2X-aided cooperative localization

Bosch ConnectedWorld 2017

1. Some R&D Challenges for automotive connectivity…

Some R&D challenges…

- **Vehicle-to-Everything…**



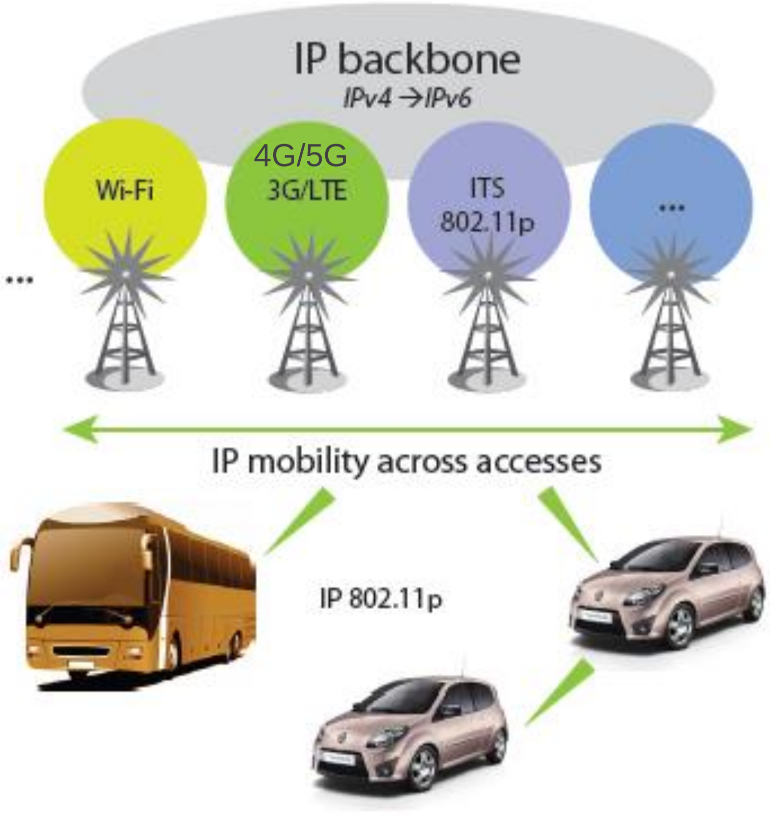
- **Ubiquitous V2N connectivity**
  - Maintain vehicle's connectivity anywhere, anytime…
- **Performance**
  - **Broadband** ➔ infotainment, vehicle maintenance (SW update...), etc.
  - **Deterministic** (low latency, low PER) ➔ new stringent applications

- **Autonomous re-configurability**
  - Platooning & Spontaneous collaboration between vehicles
- **Security**
  - Be connected….but keep vehicle secured…and safe

2. Software solutions for smart vehicular connectivity

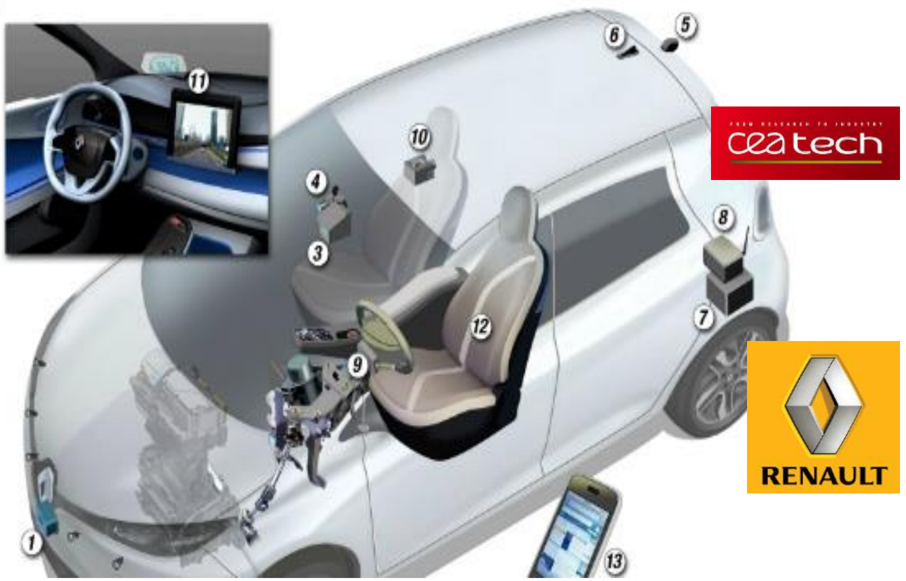
Smart multi-network V2N connectivity

Software enabling reliable connectivity management for vehicles

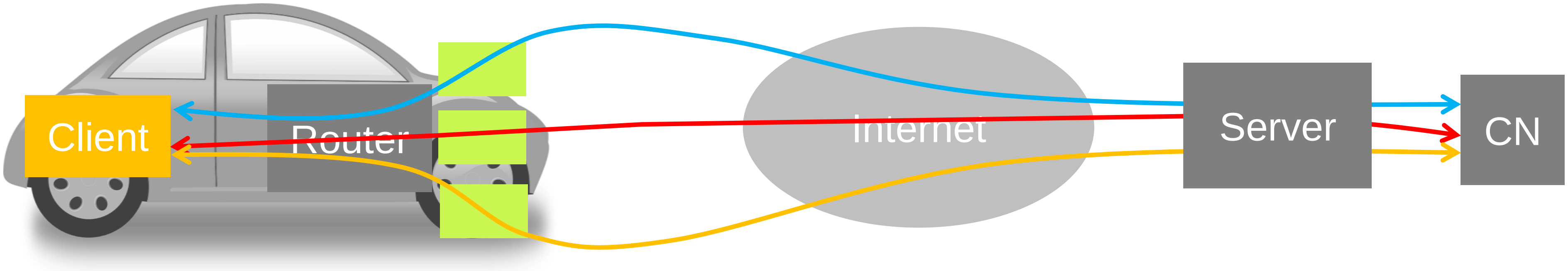


- **Multi-radio** IP-based connectivity
- **Seamless handovers** across networks
- **Easy integration** of new radio links
- Direct routing: Mobile IP bypass mode

NEXT TWO: AUTONOMOUS AND CONNECTED PROTOTYPE



V2N Bandwidth Aggregation



High-throughput connectivity with aggregation of multiple interfaces (e.g. 4G)

- **Plug & Play discovery** of network interfaces
- **Smart dispatching of data flows**
  - Per-flow interface selection based on QoS / security
- **Automatic switching** to an alternate network interface in case of connection loss
  - Seamless continuity of communications
- Ensure **vehicle reachability** from CN
  - Bonding support for CN-initiated flows
- **Per-flow or per-packet dispatching**

Generic IP V2X data link

ipwave: IP over 802.11p/OCB

Complementing ETSI ITS-G5 with a new IP transmission scheme bypassing Geonet protocol

IP Wireless Access in Vehicular Environments (ipwave)

IETF

CEA Liaison manager IETF - ISO/TC204 (ITS)

ETSI ITS-G5

CAM / DENM	TCP UDP
BTP	IPv6
Geonetworking	
802.11p MAC/PHY	

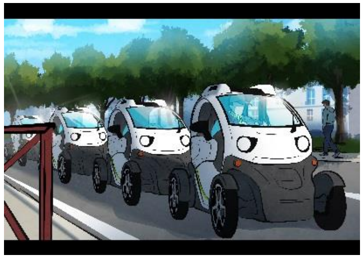
ipwave

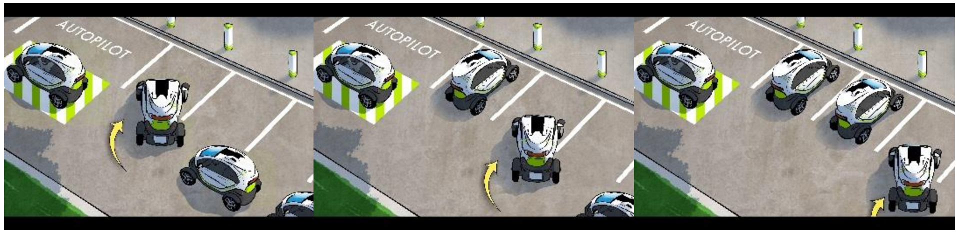
TCP / UDP
IPv6
802.11p MAC/PHY

- Standardized app messages
- V2N : **Instable IPv6 coverage around RSU** (vehicles' density…)

- Simplified stack (IP-over-foo)
- **Allows any type of V2X data flows**
- V2N : **Stable IPv6 coverage**, eases IP mobility across IP-RSU

Vehicular Wireless Connectivity for « platooning » scenario





Software enabling automatic configuration of the IP network in charge of interconnecting the vehicles (cars) within the convoy

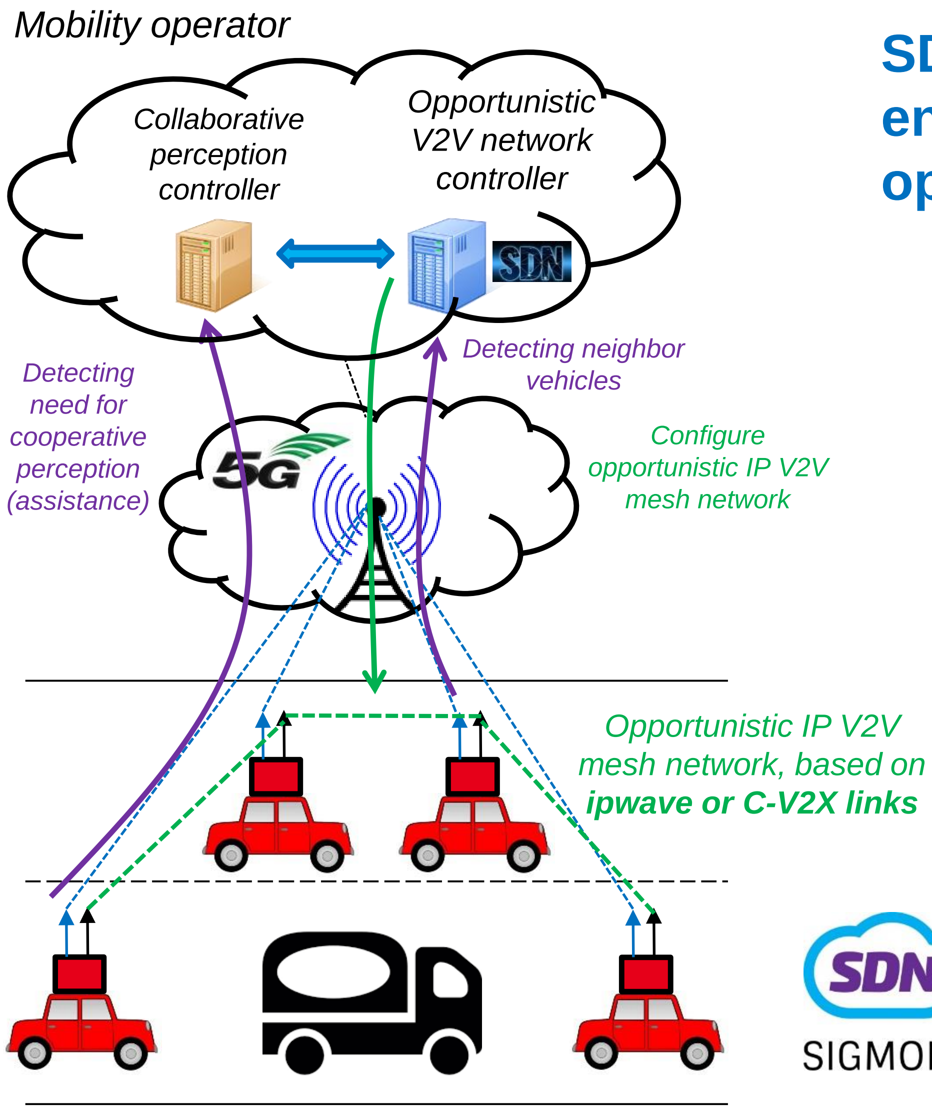
- Multiple 802.11p/OCB interfaces
- IPWAVE ; 3G/4G
- **SDN-based** dynamic configuration of
  - Radio links parameters
  - Network topology (e.g. mesh)
  - Inter-vehicle routing
  - Reliability of the connectivity
  - Network cybersecurity

Enable (IP-based) data exchange between head vehicle and other vehicles in the convoy, to support

- Assembling of the convoy,
- Mobility of the convoy,
- Disassembling of the convoy

Vehicular Wireless Connectivity for « Cooperative Perception »

Autonomous Reconfigurability



SDN-based management for V2V enabling fast configuration of opportunistic IP V2V mesh networks

Setup network configuration matching application needs

- Deterministic wireless link (e.g. URLLC)
- End-to-end QoS & routing (IETF DetNet)
- Reliability & security

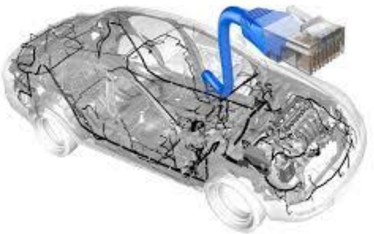
Leveraging 5G deterministic infrastructure for signaling

- URLLC, Network Slicing

SDN SIGMONA

M. Labraoui, M. Boc, and A. Fladenmuller, "Opportunistic ***SDN-Controlled wireless mesh network for mobile traffic offloading****," in 2017 International Workshop on the Practical M2M Communications Issues and Solutions on* ***5G+ Networks*** *(M2M-5G'17), May 2017.*

Intra-vehicle deterministic network



802.1 Time Sensitive Networking (TSN)

- **Coexistence of heterogeneous flows in a single network**
- Time synchronization for networked devices
- **Deterministic communication**: low PER, bounded latencies
- **Large set of QoS protocols and QoS parameters….**

How to set up the right network configuration ?

Simulation tool to select the best initial configuration (offline, AI-assisted)

Instantiate Initial configuration

Network Configuration (Qcc)

Yang model

TSN switches & nodes

Re-configuration (e.g. upon link failure, new flow….)

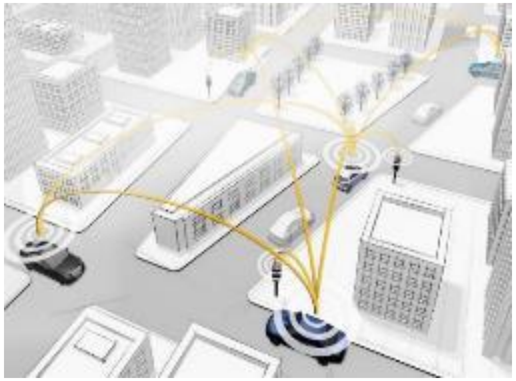
⇨ End-to-end deterministic V2X (TSN + URLLC…)

3. V2X-aided cooperative localization

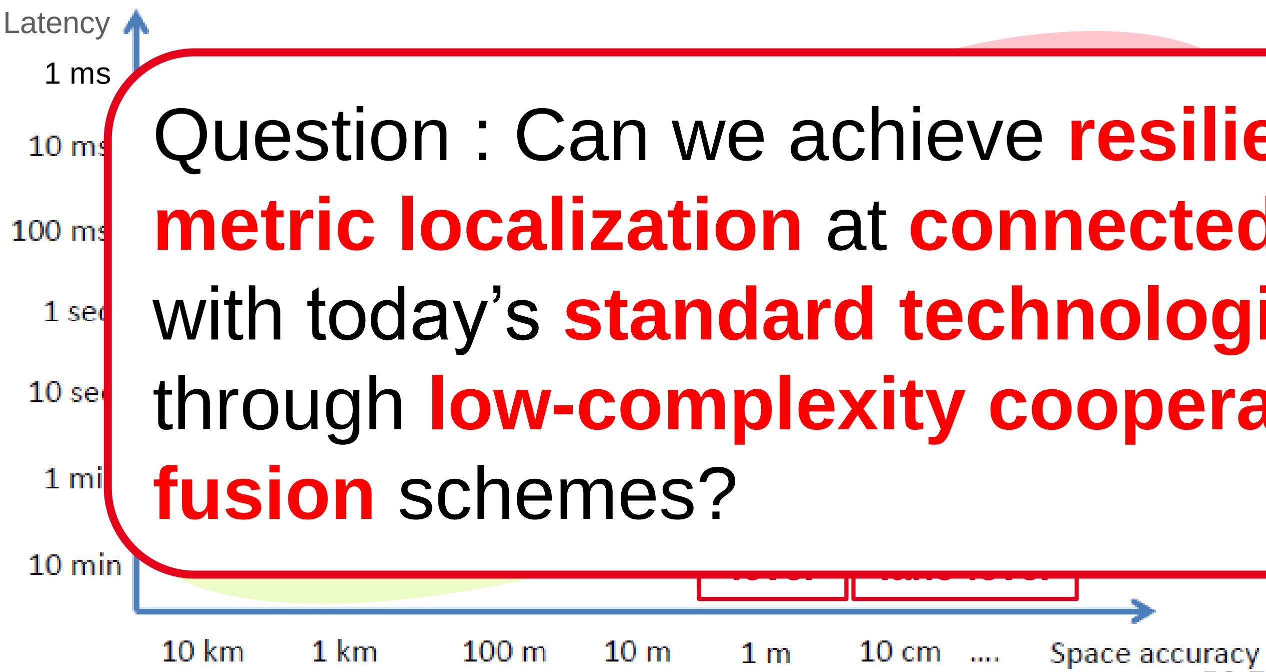
C-ITS VS. LOCALIZATION NEEDS

- **Wireless communication between vehicles (V2V) and roadside infrastructure (V2I) → V2X**
  - Road traffic safety
  - Road traffic efficiency

Source: Daimler



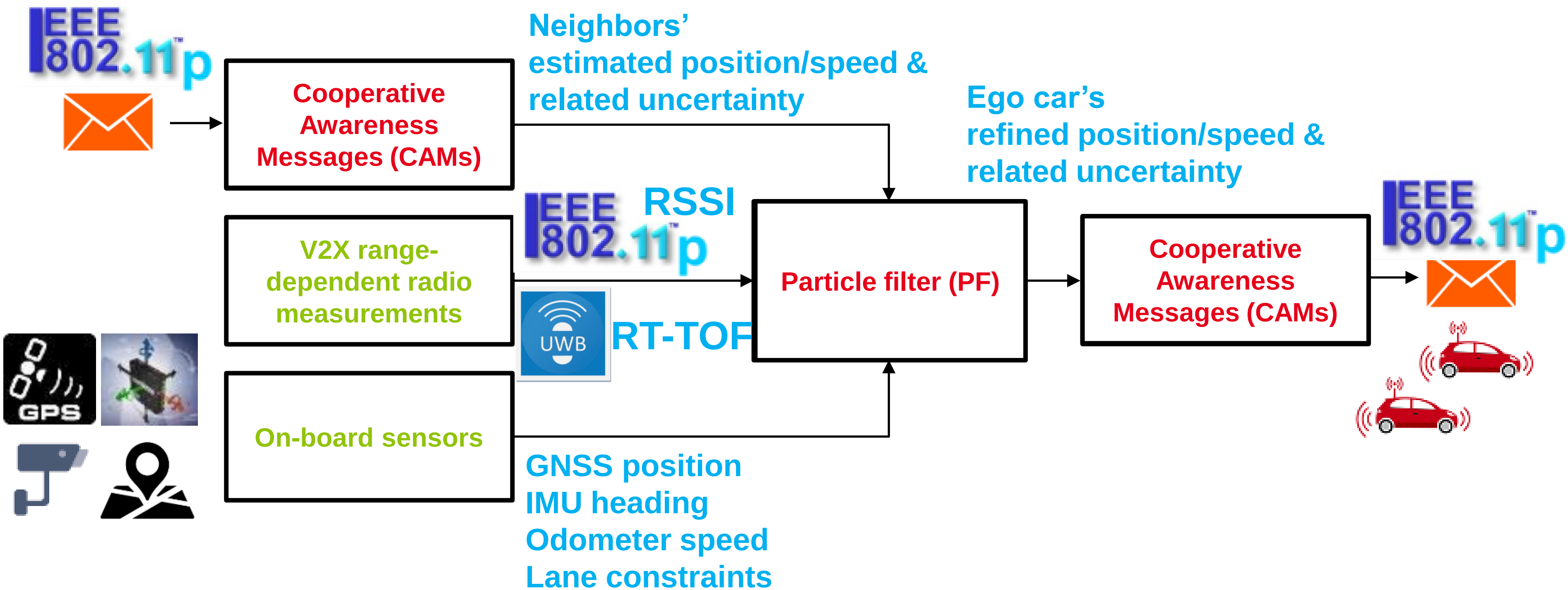
- **C-ITS applications road map (C2C-CC): Day-1 & Day-2**



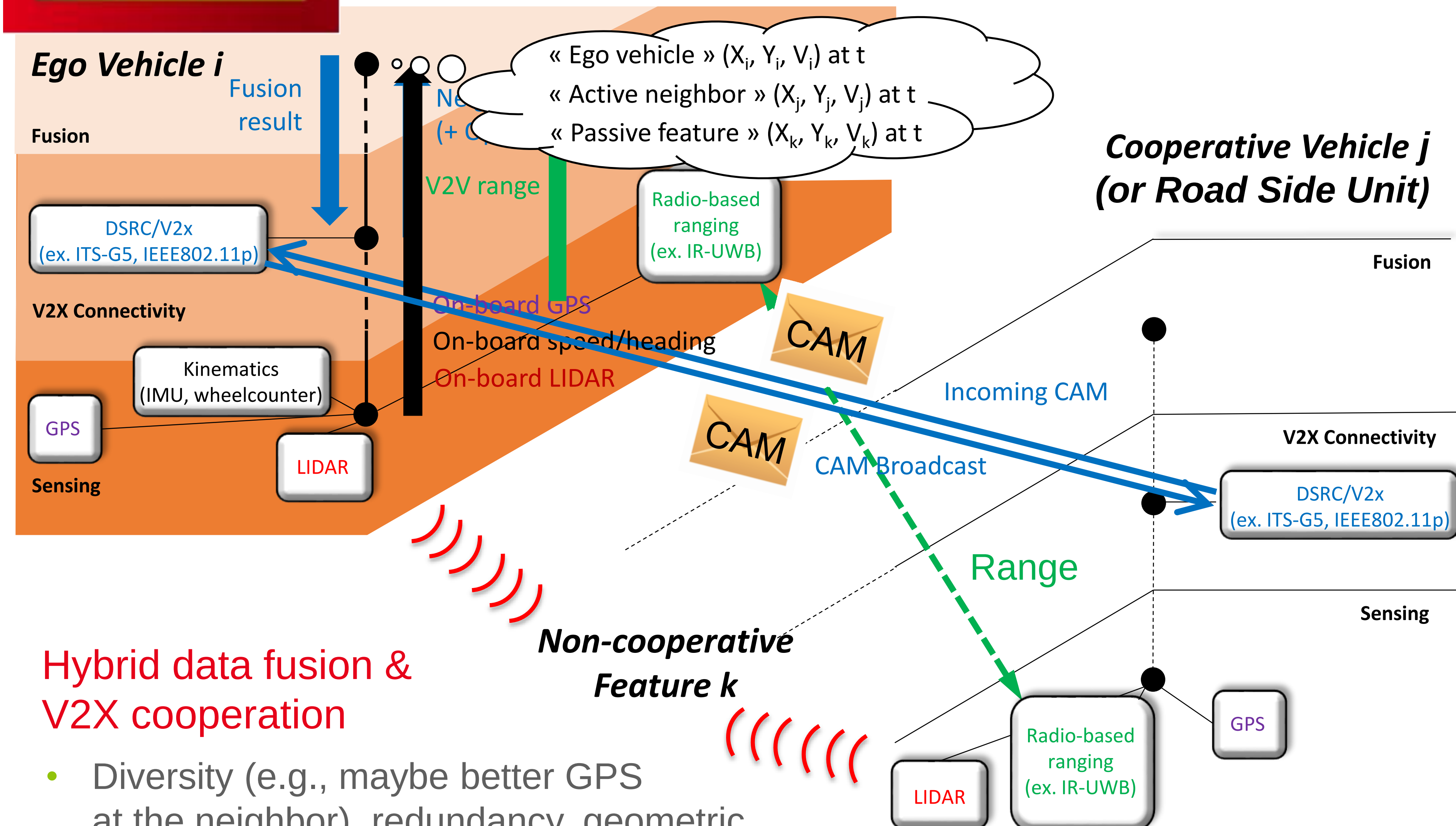
Question : Can we achieve **resilient sub-metric localization** at **connected vehicles** with today's **standard technologies** through **low-complexity cooperative fusion** schemes?

CONSIDERED TECHNOLOGIES

Maturity	Technology	Frequency	Metric
Today	**ITS-G5 / 802.11p**	**5.9 GHz**	**RSSI**
Today	**IR-UWB / 802.15.4a**	**~ 4 GHz**	**TOA / RT-TOF**
Prospective	4G LTE V2X	2 GHz	Under specification
Prospective	5G mmWave V2X	30 – 100 GHz	AOA / AOD / TOA
Prospective	WiFi extension	2.4 GHz	Not standardized



EG. V2X-AIDED COOPERATIVE LOCALIZATION AND MAPPING

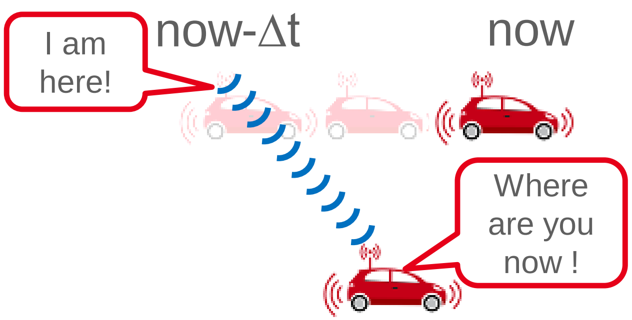


Hybrid data fusion & V2X cooperation

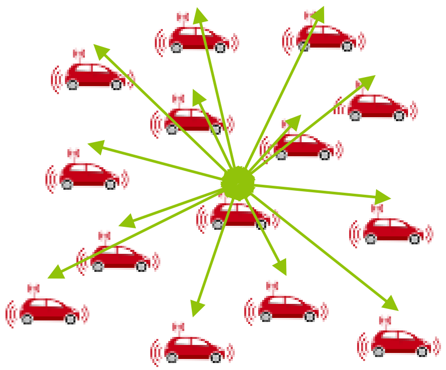
- Diversity (e.g., maybe better GPS at the neighbor), redundancy, geometric ambiguity solving → Better accuracy & resilience

MAIN CHALLENGES RELATED TO V2V COOPERATION

High mobility vs.
outdated info



Large amount of vehicles

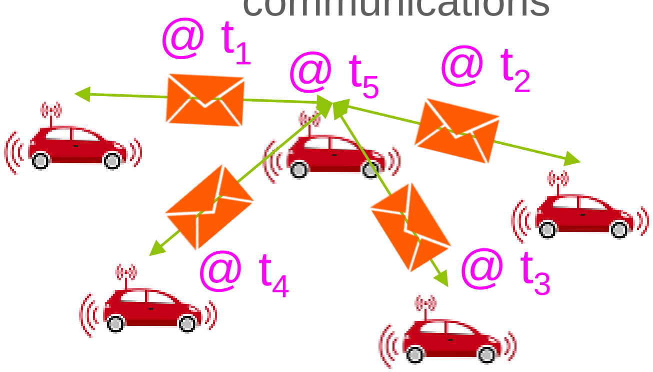


Limited V2X communication channel

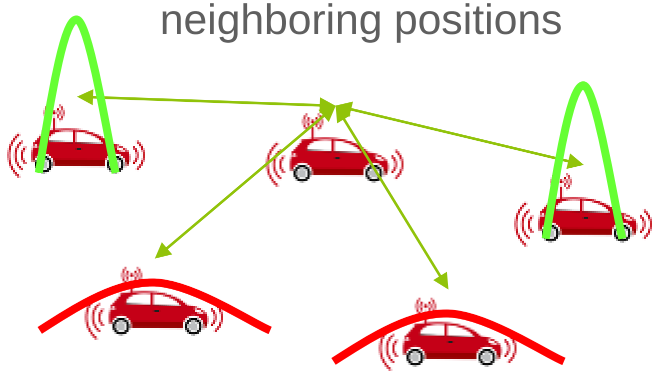
300 – 800 bytes

6 Mbps

Unscheduled V2X communications



Imperfect/unfavorable neighboring positions

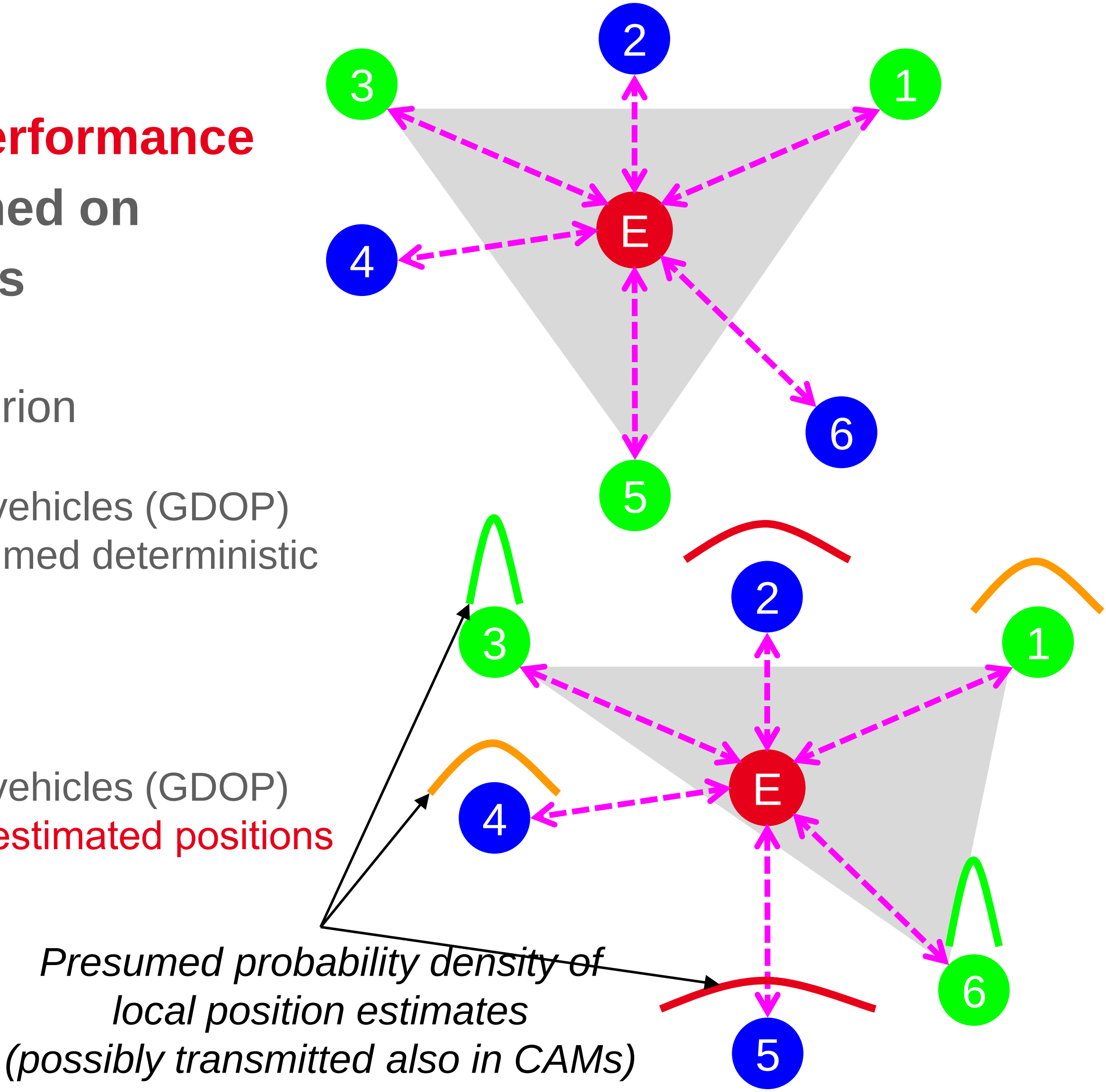


SELECTION OF COOPERATIVE LINKS (1)

- **Link selection** based on **theoretical positioning performance bounds (CRLB)** conditioned on **a priori sub-constellations**

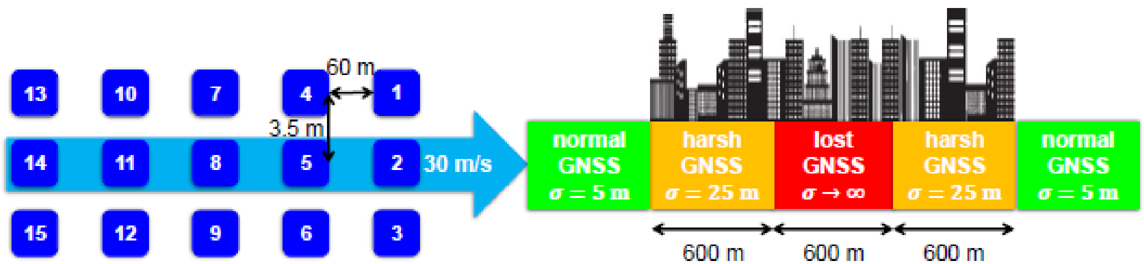
  - Non-Bayesian CRLB criterion
    - Radio link quality
    - Geometry of neighboring vehicles (GDOP)
    - All involved positions assumed deterministic (& perfect)

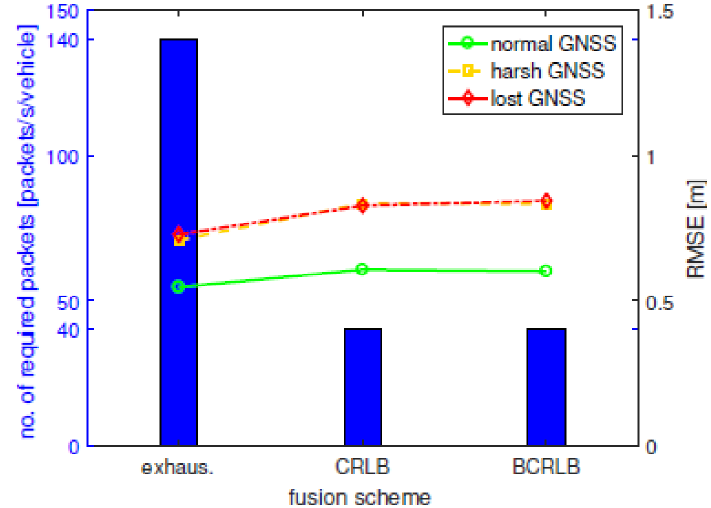
  - Bayesian CRLB criterion
    - Radio link quality
    - Geometry of neighboring vehicles (GDOP)
    - Uncertainty of neighbors' estimated positions



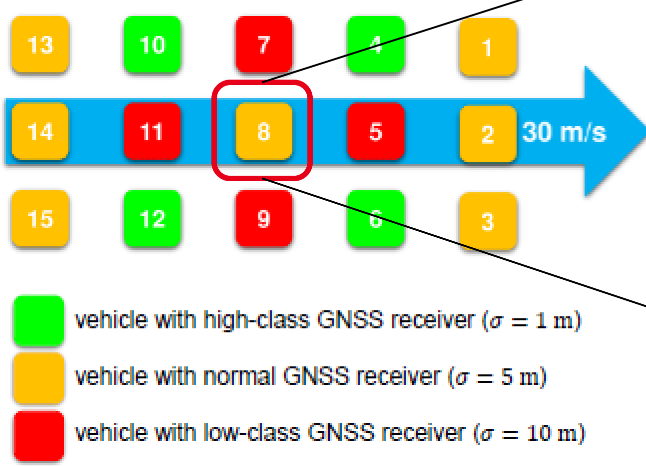
SELECTION OF COOPERATIVE LINKS (2)

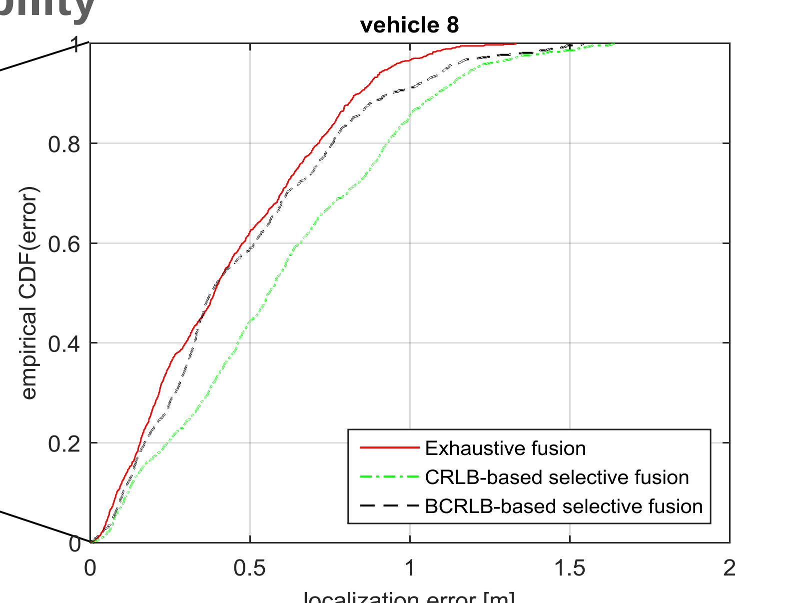
- **Large-scale GNSS error (urban canyon)**
  - Saved complexity at (almost) no accuracy degradation (vs. exhaustive cooperation)





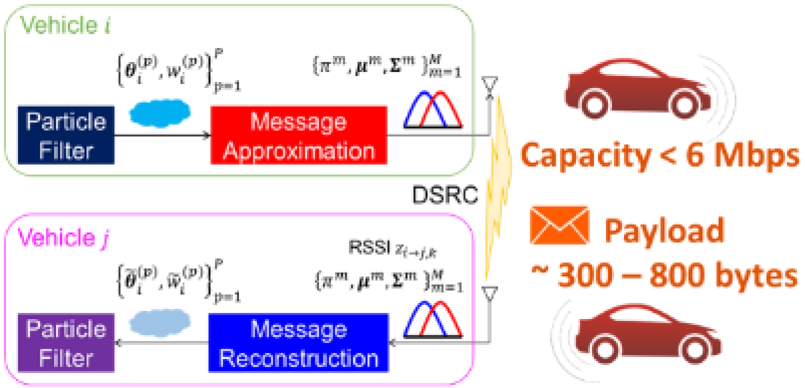
- **Small-scale locally degraded GNSS capability**
  - Local accuracy gains with Bayesian-CRLB criterion (vs. non-Bayesian)





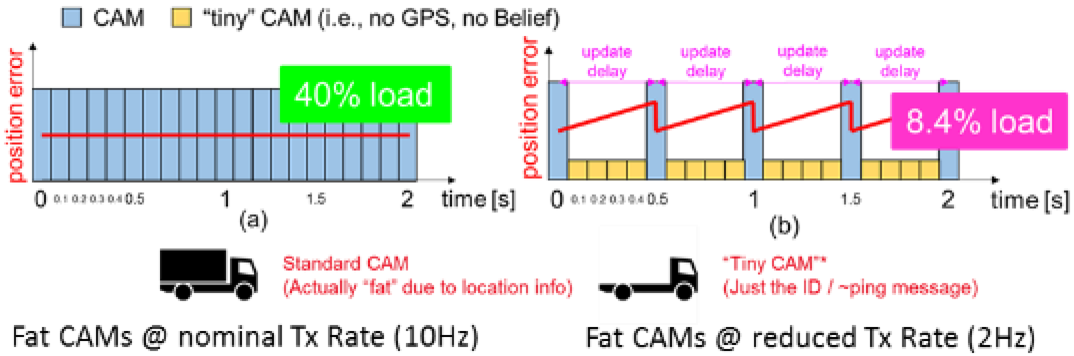
FOOTPRINT OF COOPERATIVE FUSION WRT. COMMUNICATION CONGESTION (1)

- Minimizing footprint on V2V communications (traffic & channel load)
  - Limited CAM size (300−800 bytes)



→ V2x messages approximation

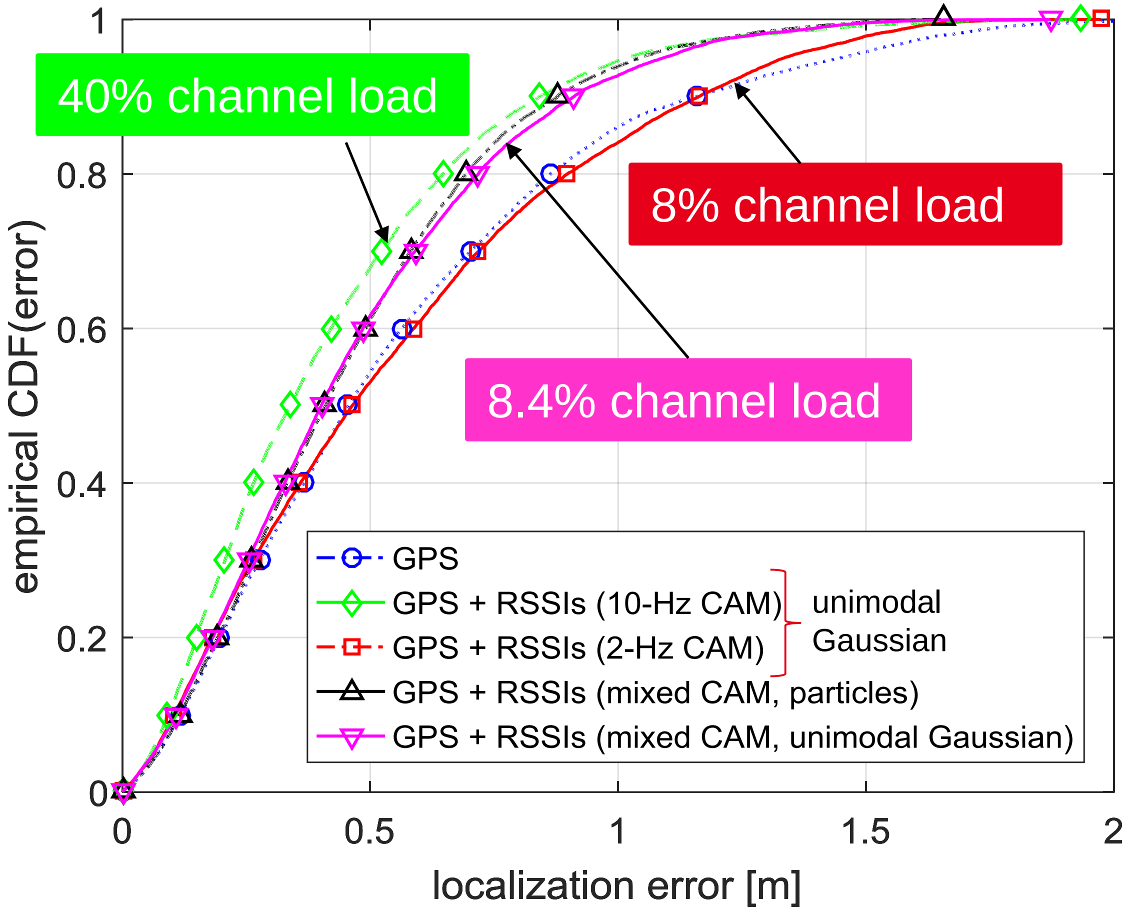
  - Limited channel capacity (6 Mbps, incl. 60−70% for CAMs)
    - Ex. 1,000 particles for filtering → > 430% channel load (10 neighbors, 10 Hz, binary64)
  - ETSI Decentralized Congestion Control (DCC)
    - Reduced CAM rate (e.g., 2 Hz) → Expected loc degradation (fewer beliefs & meas.)



→ V2x transmission control (e.g., Jointly adaptive transmission payload, rate, and power)

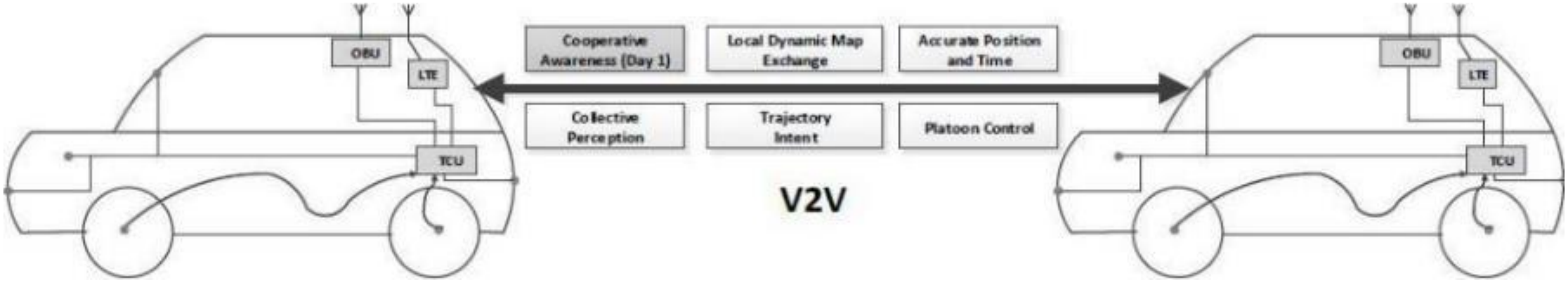
FOOTPRINT OF COOPERATIVE FUSION WRT. COMMUNICATION CONGESTION (2)

- Ex. of cooperative fusion-based localization performance for different message approximation and transmission control strategies (1000 particles)



G.M. Hoang, B. Denis, J. Härri, D. Slock, "On Communication Aspects of Particle-Based Cooperative Localization in GPS-aided VANETs", IEEE Intelligent Vehicles Symposium (IEEE IV'16), Gothenburg, June 2016

APPLICATION-DEPENDENT MESSAGES TAILORING (1)



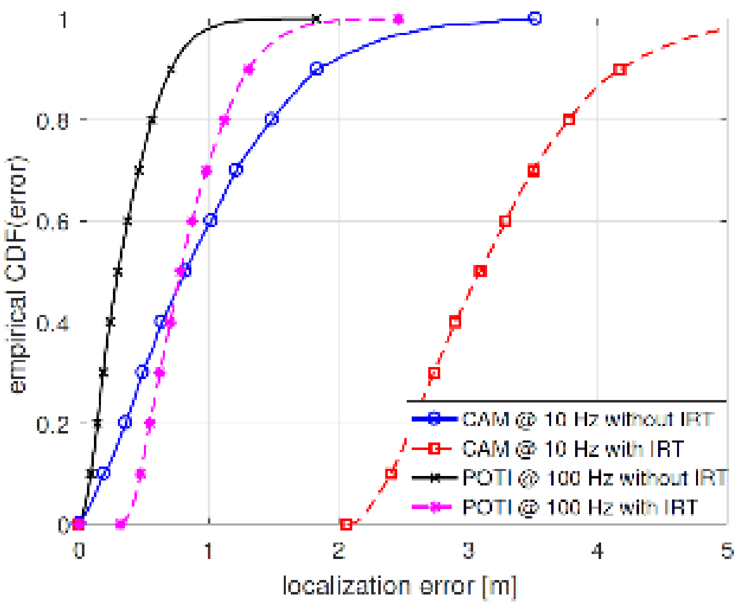
- **Day 1 messages (Current ETSI Standardization):**
  - CAM (different sizes, different rates) – Periodic/routine messages that broadcast status (e.g., GPS position, speed, trajectory…) to improve neighbors' awareness / 1-10Hz
  - DEMN – Short event-driven safety messages (events breaking physical regularity) / 2-5 Hz

- **Day 2 messages (under discussion)**
  - CAM (different sizes, different rates) / 1-10Hz
  - CPM – Sensor information / 2-5 Hz
  - POTI – Position and time / 10Hz
  - LDM – Local Dynamic Map content exchange / 1Hz
  - PAM – Precise Positioning Message / 100Hz
  - ….

cea tech
FROM RESEARCH TO INDUSTRY

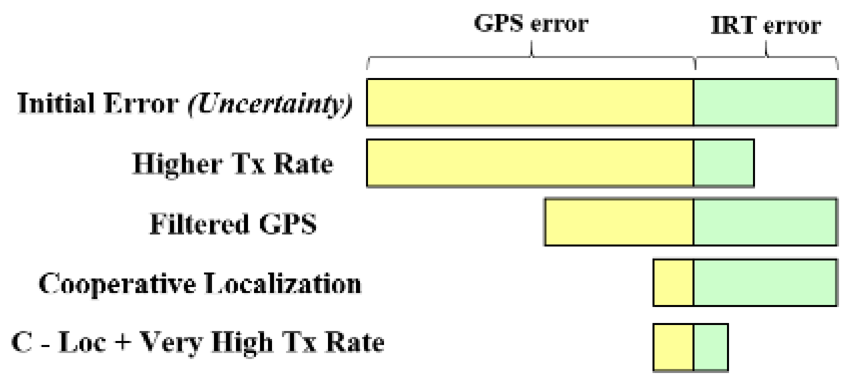
APPLICATION-DEPENDENT MESSAGES TAILORING (2)

- ## Ex. of devoted Precise Awareness Message (PAM)
  - Providing sub-meter awareness ‘precision’



Inter Reception Time (IRT) → Uncertainty of neighbor’s position between two receptions.

- Ex: 2 meter for 10 Hz CAM, 20m/s speed (72km/h)



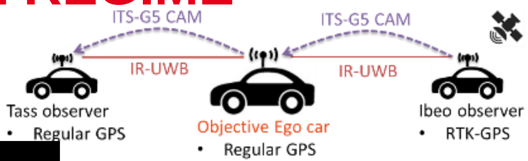
- ## Ex. of new message structure:
  - No GPS transmission, rather fusion data
  - Smaller (70 bytes) than standard CAM
  - Can reach 100Hz at 60% channel load

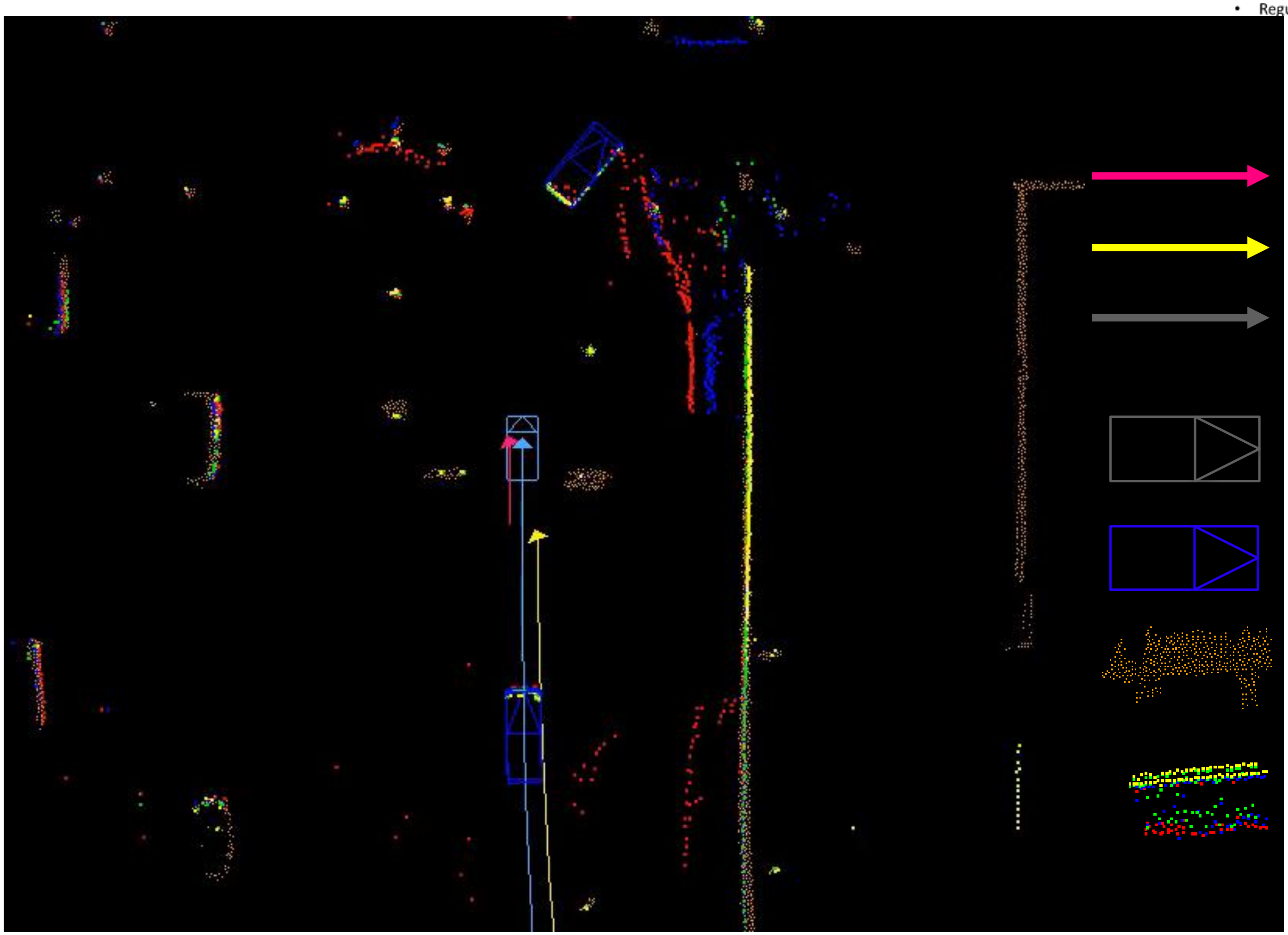
Position 2 x 4 byte scalar
Covariance Matrix 3 x 4 byte scalar
Timestamp 1 x 8 byte
Headers, MAC & PHY 42 byte
Total Packet Size = 70 bytes

EXPERIMENTAL SET-UP & SCENARIO

- Several kms of highway test tracks
- Platoon of 3 vehicles
  - Connected by ITS-G5 CAMs (Cohda MK5)
  - BeSpoon IR-UWB devices for V2V ranging
  - Standard GPS (Cohda MK5)
- Reference: Graph SLAM fusion of RTK-GPS, LiDAR scans, odometry (Ibeo)

EX. OF EXPERIMENTAL RESULTS (1A) – STEADY-STATE V2V COOPERATION REGIME





V2V-aided localization

GPS position (Cohda)

Reference position

Test vehicle

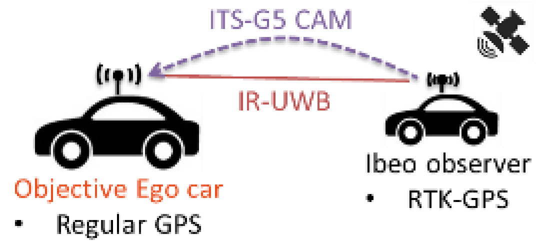
Other vehicles (dynamic LiDAR objects)

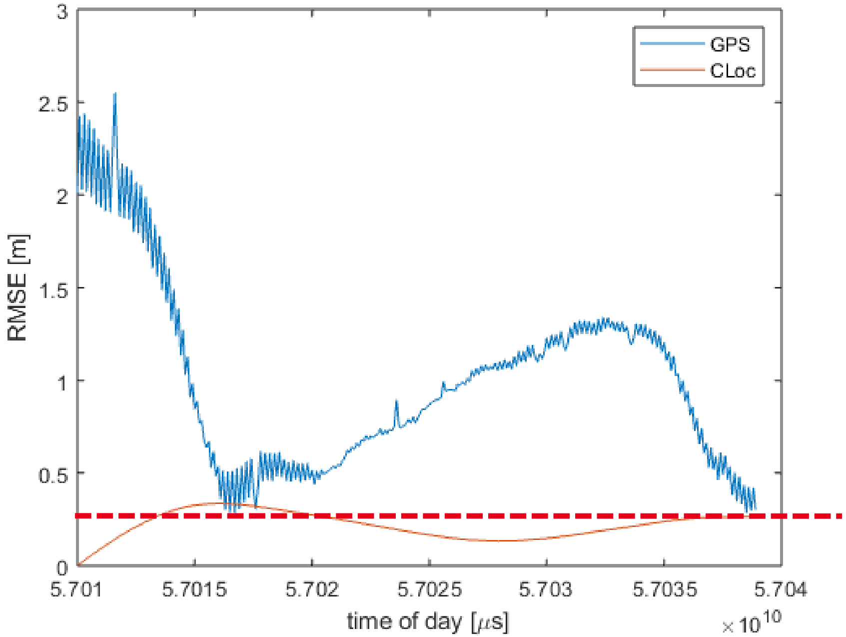
Point Cloud Map (LiDAR)

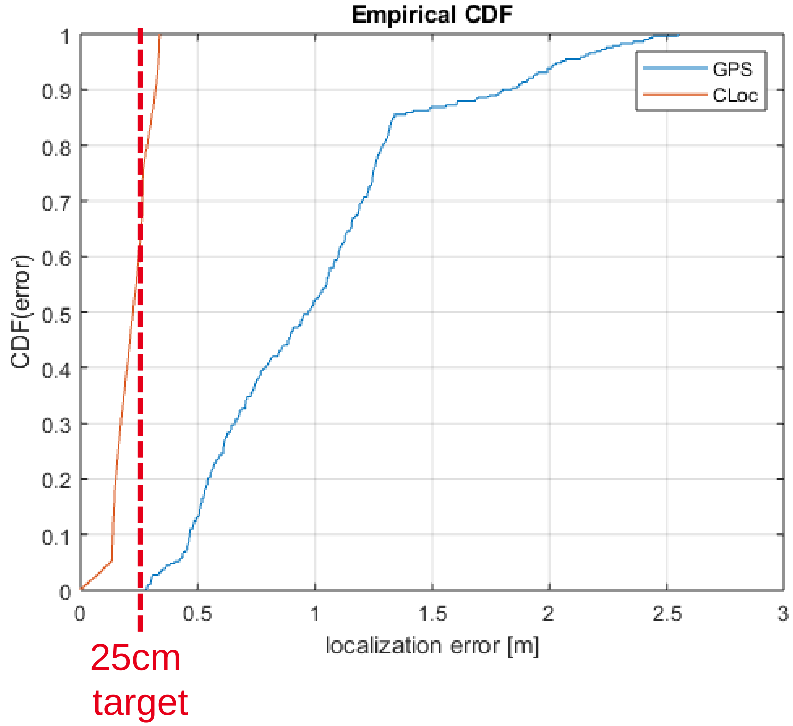
LiDAR scan points (live)

EX. OF EXPERIMENTAL RESULTS (1B) – STEADY-STATE V2V COOPERATION REGIME

- Off-line validation based on real data from Helmond (2 involved cars)



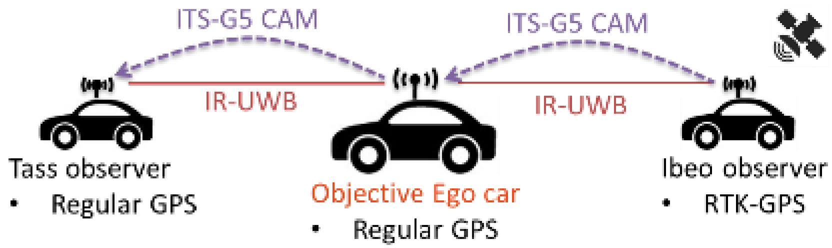


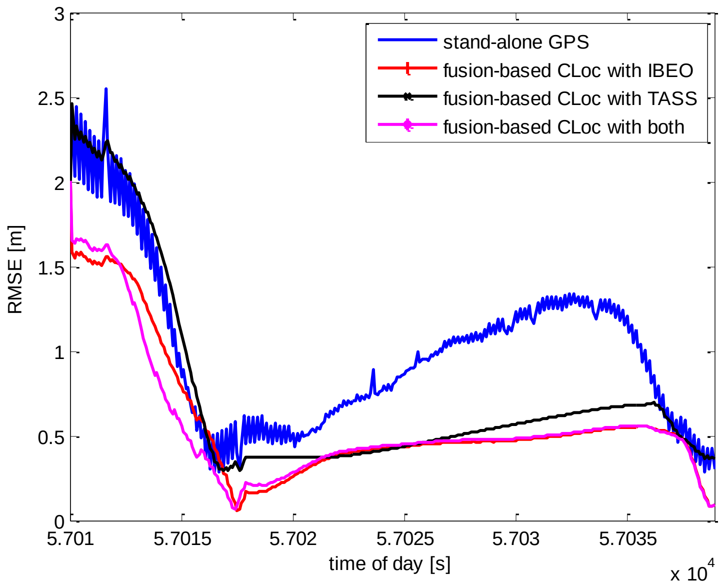


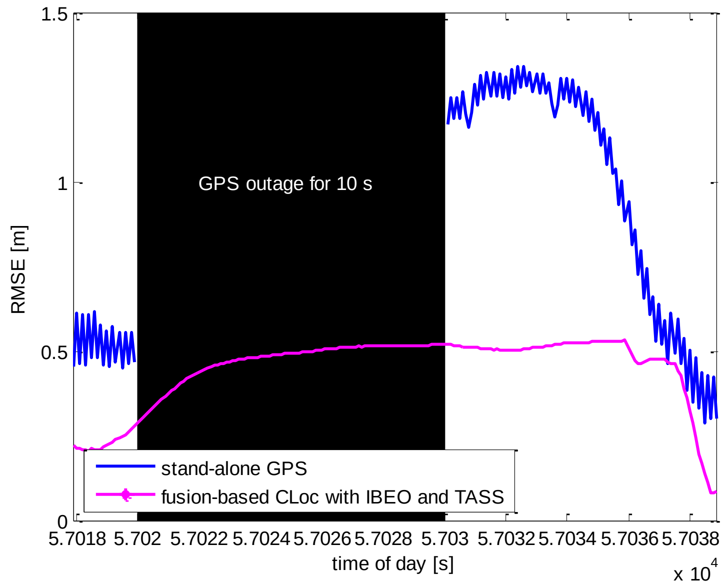
- Testing steady-state fusion regime: 2D localization error at Objective's Ego vehicle assuming reliable info received from Ibeo's neighboring vehicle (RTK) & reliable initial guess at the Ego

EX. OF EXPERIMENTAL RESULTS (2) - GNSS DENIAL & COLD START

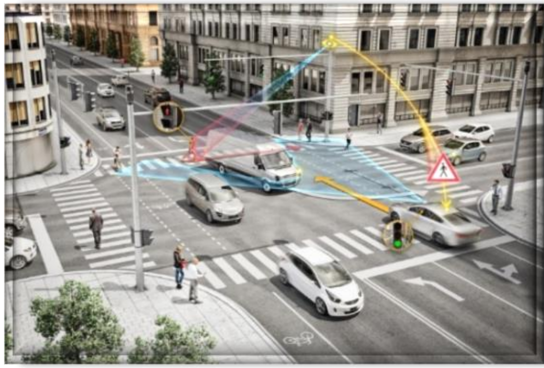
- Off-line validation based on real data from Helmond (3 involved cars)







- Testing cold start, variable neighbors reliability & partial GPS denial: 2D localization error at Objective's Ego vehicle, assuming 1 additional -less reliable- neighbor (i.e., Tass' Standard GPS), standard GPS-based initial guess and partial GPS loss for 10 sec at the Ego vehicle



THANKS !

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THE HIGHTS PROJECT AT A GLANCE

HIGHTS for "HIGH PRECISION POSITIONING FOR COOPERATIVE-ITS"

EC PROGRAMME: H2020-MG-3.5a-2014_2Stages: MOBILITY FOR GROWTH

website: **www.hights.eu**

Leti's contributions

- Characterization of vehicular radio channels (V2x)
- Design of cooperative data fusion algorithms for high-precision car navigation
- HW/SW developments enabling cooperative vehicle-to-vehicle ranging based on Impulse Radio - Ultra Wideband ICs
- Evaluation of vehicular communications security against jamming

Coordinator: JACOBS UNIVERSITY BREMEN (DE)

Partners: CEA–LETI (FR), EURECOM (FR), DLR (DE), CHALMERS UNIVERSITY (SE), FB CONSULTING (LU), BOSCH (DE), TASS (NL), BESPOON (FR), ZIGPOS (DE), PAULS CONSULTANCY (NL), OBJECTIVE SOFTWARE (DE), IBEO AUTOMOTIVE (DE), IT21 (DE).

Budget: 6M€

Period: June 15 – May 18

Main objectives

- High-precision & resilient car localization (within ~ 25 cm) and dynamic mapping of road users, obstacles, neighboring cars...
- Combining various radio or non-radio localization technologies (IR-UWB, laser-scanners, GNSS…) with Vehicle-to-X communications (ex. DSRC IEEE 802.11p…) and crowd-sourcing.
- ETSI standardization.
- Field validations.

Main outcomes

- Extended V2X channel models (e.g., w.r.t. pedestrians)
- Co-simulation tools (traffic/channel/protocol/algorithms)
- **Cooperative fusion-based loc. algorithms**
- GPS-aided IR-UWB localization system **demonstrator**
- Scientific dissemination: **2 journal articles, >10 international conference papers**