Cooperative V2X communication

Dr. Miguel Sepulcre
Universidad Miguel Hernandez, Spain

www.transaid.eu
@transaid_h2020
www.linkedin.com/groups/13562830/
www.facebook.com/transaidh2020/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723390

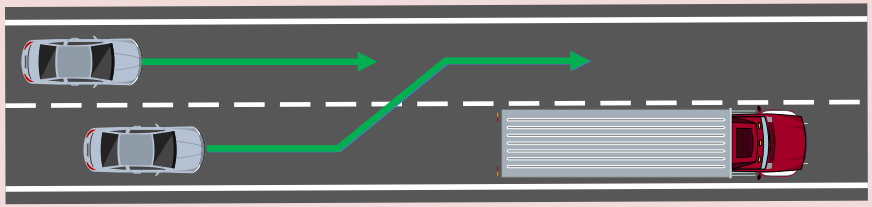
Overall goals

V2X message set definition

V2X for cooperative manoeuvring

Coordination of driving manoeuvres

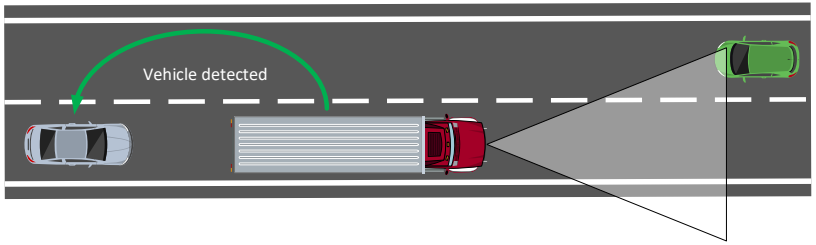
Enhanced safety and traffic efficiency



V2X for cooperative perception

Info exchange about perceived environment

Expand on-board sensors capabilities

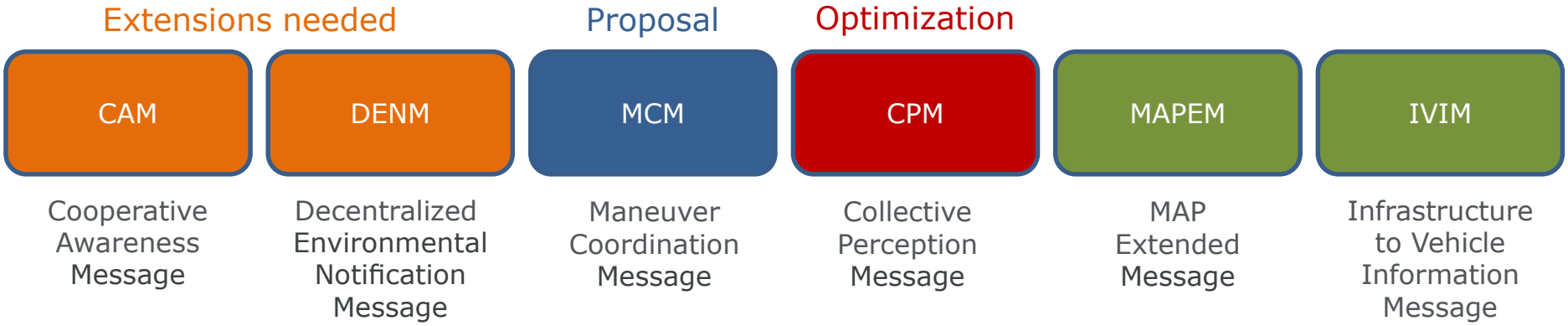


V2X message compression

Reduction of channel load and improvement of V2X reliability

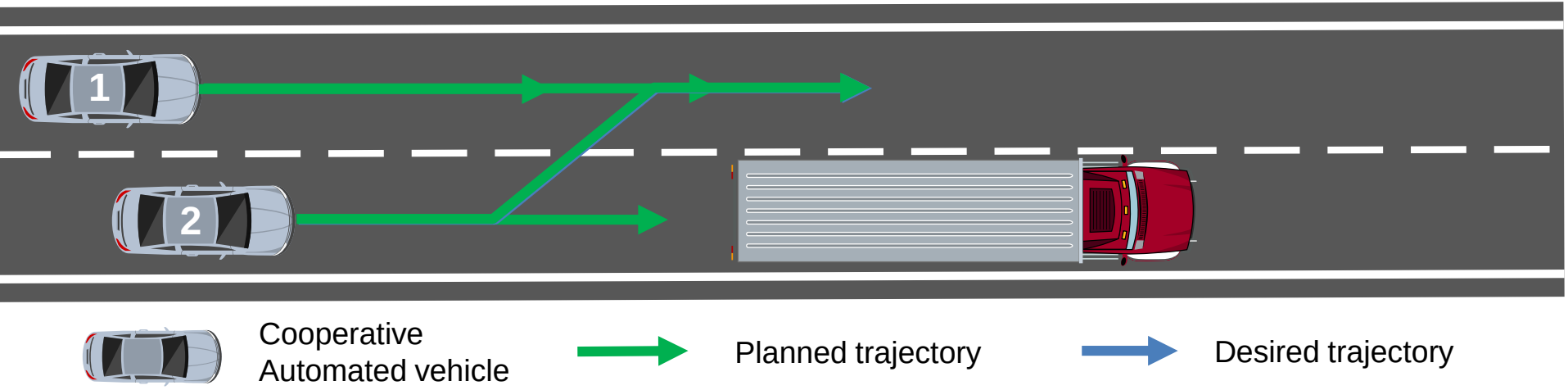
V2X message set definition

- Definition of V2X messages:
  - Support of TransAID Traffic Management Measures.
  - Cooperative perception and Cooperative manoeuvring.
- Standard-compliant, backward compatibility and interoperability.



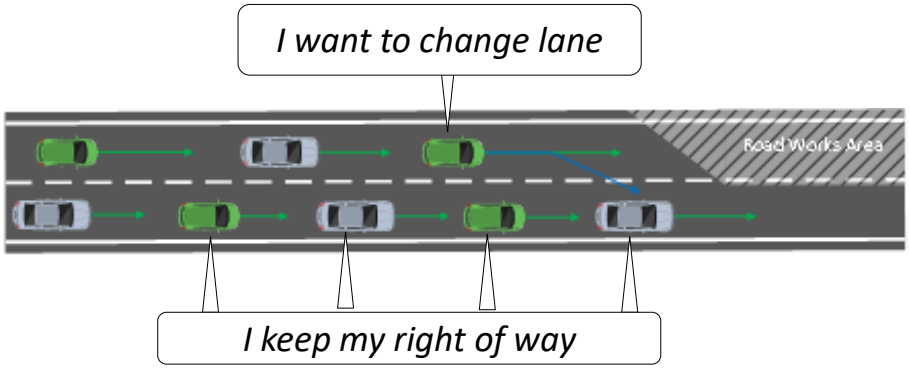
V2X for cooperative maneuvring

- V2V decentralized maneuver coordination concept (under discussion at ETSI):
  - Vehicles periodically broadcast MCM (Maneuver Coordination Message).
  - Planned trajectory: current planned trajectory for the next 5-10 seconds.
  - Desired trajectory: trajectory vehicles want to do but cannot due to right of way.
  - Implicit coordination via exchange of trajectories.

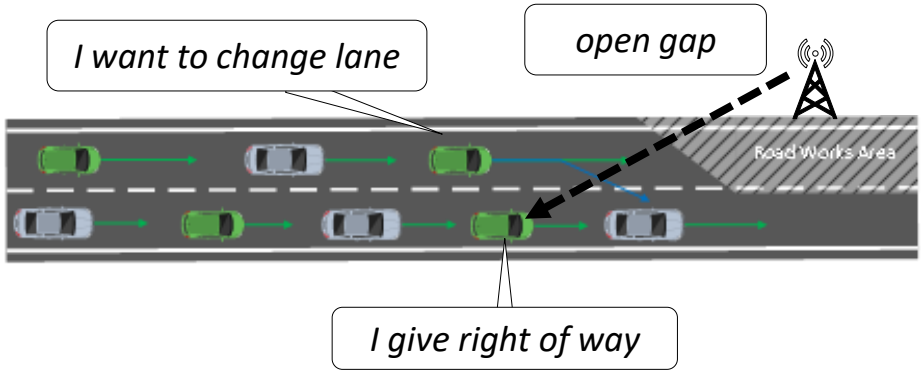


V2X for cooperative maneuvring

- Proposal of a novel V2I-aided maneuver coordination approach:
  - Enables the road infrastructure to support maneuver coordination.
  - Allows the execution of Traffic Management measures at transition areas.
  - Presented to ETSI and currently under discussion (ETSI TR 103 578).



Vehicles on left lane never get right of way and are stuck at the roadworks



Infra suggests individualized measures (e.g. gap advices) to prevent bottlenecks

V2X for cooperative maneuvring

- MCM generation rules (V2I-aided approach):
  - TransAID has defined an exter[illegible]ge flows.
  - MCMs sent in specific location[illegible]ditions.
  - No significant contribution to

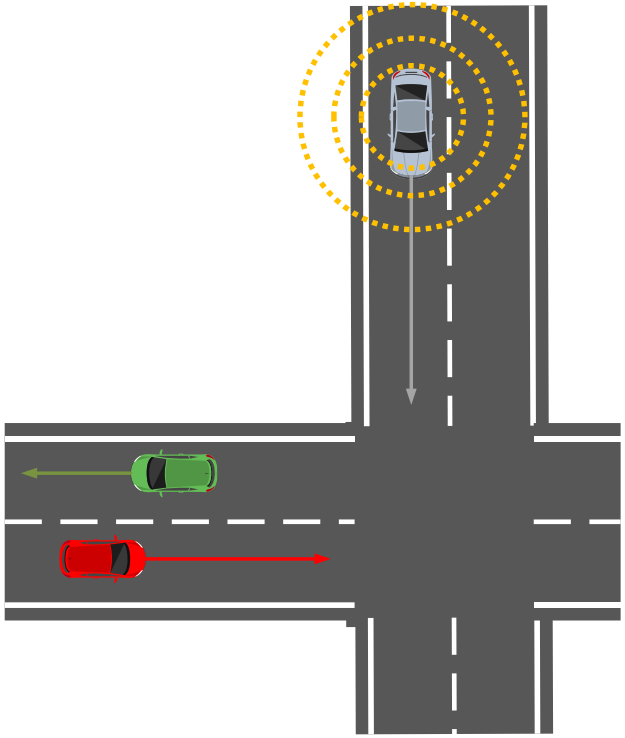
MCM generation rules have not been yet discussed at ETSI

- MCM generation rules (V2V approach):
  - MCMs need to be sent to inform other vehicles about planned/desired trajectories.
  - Should enable the coordination of cooperative automated vehicles.
  - But should efficiently use the communications channel.

V2X for cooperative maneuvring

- Proposed V2V MCM generation rules based on *risk*:
  - Vehicles periodically check if a potential risk is detected.
  - Transmission of MCMs when potential risk is detected.
  - Risk depends on time to a potential collision.

Example: grey vehicle transmits MCMs if time to collision with red vehicle is lower than a threshold.

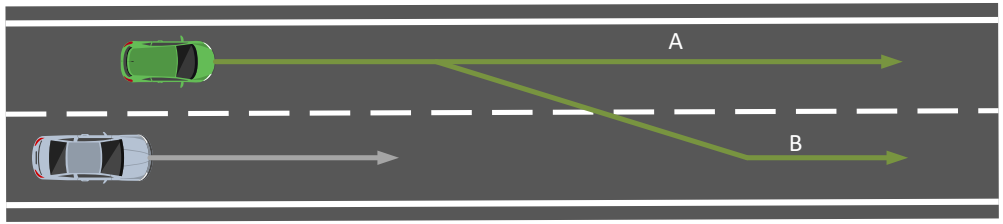


  - This approach generates MCM at high frequency to maintain updated info of all vehicles in risk.

V2X for cooperative maneuvring

- Proposed MCM generation rules based on *tracking trajectories*:
  - Transmission of MCM when the planned trajectory of ego vehicle has significantly changed compared with its previously transmitted trajectory.

Example: green vehicle immediately transmits an MCM when it plans to change lane but transmits MCMs less frequently if it just drives straight.



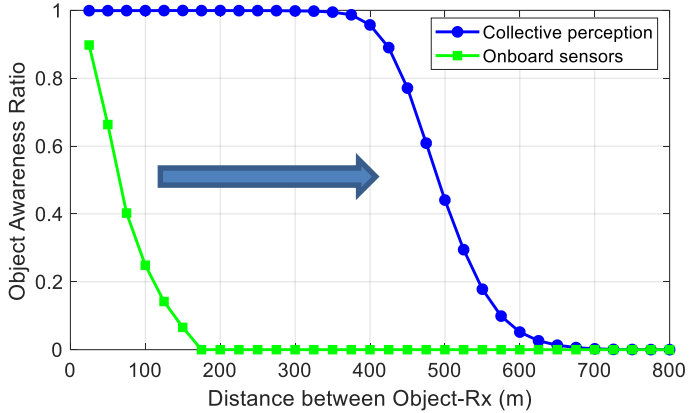
  - This approach transmits small updates assuming that vehicles follow the trajectories transmitted and are reliable.

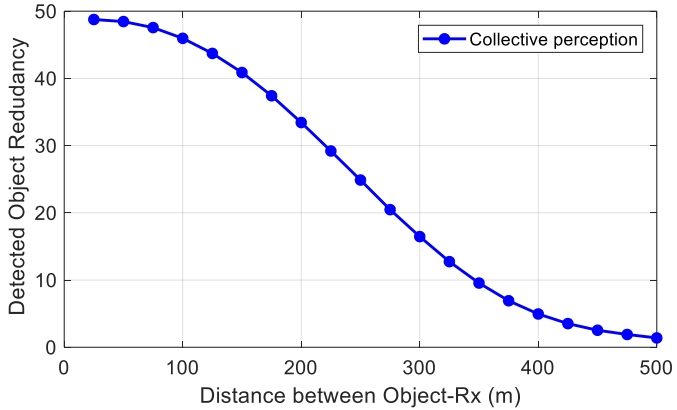
V2X for cooperative perception

- ETSI is defining the Collective Perception Service (CPS).
  - Tx/Rx CPM messages: position, speed and other info about detected objects.
  - CPM generation rules mainly depend on the mobility of the object.

- We have conducted an in-depth evaluation of ETSI CPS.
  - Different traffic densities, sensors and penetration rates.
  - Improved perception capabilities with CPM, but high level of redundancy.

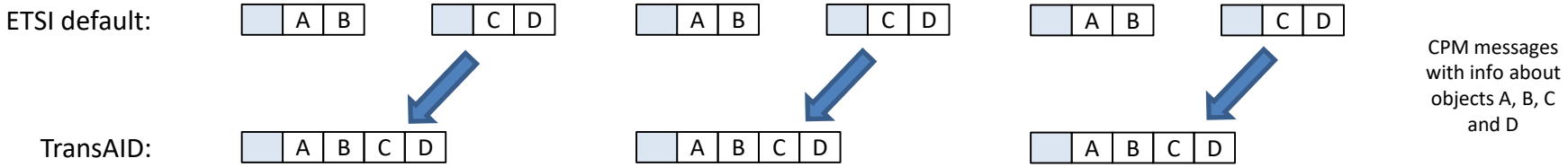
Obtained results are part of ETSI TR 103 562.





V2X for cooperative perception

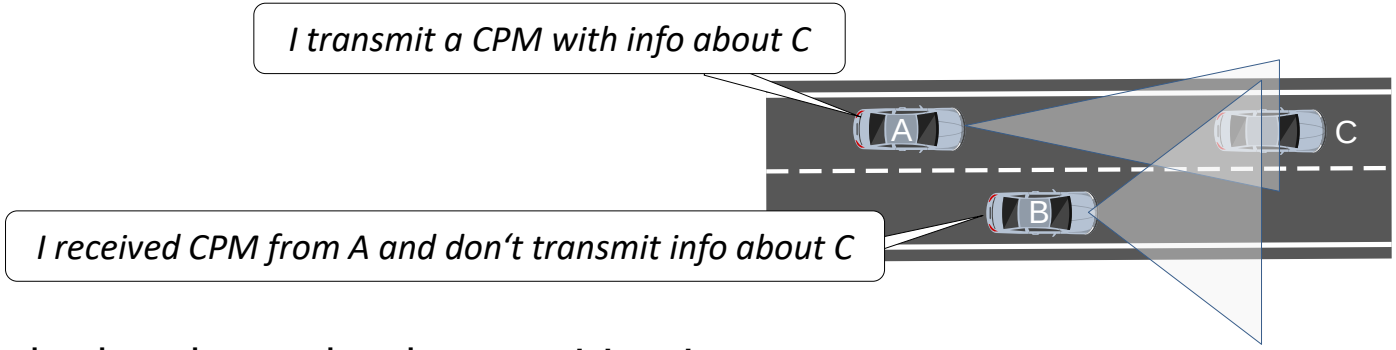
- Evolution of CPM generation rules: *look-ahead* mechanism (ETSI TR 103 562):
  - Group detected objects to avoid transmission of high number of small CPMs.
  - Transmit in current CPM objects that will need to be transmitted in the near future.



  - Reduce number of messages: reduce headers and info about ego vehicle (≈200 bytes).
  - Proposal reduces the channel load 10%-15% and improves the object perception 6%-7%.

V2X for cooperative perception

- Evolution of CPM generation rules: redundancy mitigation (ETSI TR 103 562):
  - Avoid transmission of unnecessary info (e.g. too frequent updates about each object).
  - If info about an object has been recently received ⇒ don't transmit it.
  - Proposal reduces the load 30%-40% info while maintaining perception up to 200 m.



- Look-ahead + redundancy mitigation:
  - Combination of standalone algorithms increases performance.
  - Lower load (40%-50%) and improved object perception (up to 7%).

V2X for cooperative perception

- ETSI Decentralized Congestion Control (DCC):
  - DCC Access: maintain the channel load under control based on message flow control.
  - DCC Facilities: share the available resources among different applications (or messages).

- DCC Access can maintain the load under control:
  - Improvement of object perception capabilities up to 14%.
  - But packet transmissions can be delayed due to queuing with DCC Access.
  - Increase of information age up to 400 ms can be critical for cooperative perception.

- DCC Facilities can control the CPM generation rate and reduce queuing:
  - Reduction of the information age below 15 ms.
  - Improvement of object perception capabilities up to 30%.

V2X message compression

- Conventional congestion control mechanisms adapt tx parameters:
  - Reduce message rate, transmission power, etc.
  - Reduce channel load but decrease the amount of information exchanged.

- V2X message compression as an alternative:
  - Potential to reduce the load without reducing the amount of information exchanged.
  - Evaluation with standard-compliant messages extracted from real-world experiments.
  - CAM, CPM and MCM can be compressed up to 40%-50%.
  - Channel load can be reduced between -18% and -26%.
  - Significant increase of awareness range (up to 200% increase of distance for PDR=0.7).

Summary

- V2X for cooperative manoeuvring:
  - Definition of V2I-aided approach and MCM generation rules.
- V2X for cooperative sensing:
  - Evolution of CPM generation rules and DCC analysis.
- V2X message set definition:
  - Extensions of existing messages and proposal of MCM format.
- V2X message compression.

Contributed to ETSI standards on cooperative maneuvering and sensing

Related publications

- G. Thandavarayan, M. Sepulcre, J. Gozalvez, "Redundancy Mitigation in Cooperative Perception for Connected and Automated Vehicles", Proc. IEEE Vehicular Technology Conference (VTC2020-Spring), Antwerp, Belgium, 25-28 May 2020.
- M. Sepulcre, J. Mira, G. Thandavarayan, J. Gozalvez, "Is Packet Dropping a Suitable Congestion Control Mechanism for Vehicular Networks?", Proc. IEEE Vehicular Technology Conference (VTC2020-Spring), Antwerp, Belgium, 25-28 May 2020.
  - Source code of DCC Access for ns3: https://github.com/msepulcre/DCC-ns3
- G. Thandavarayan, M. Sepulcre and J. Gozalvez, "Analysis of Message Generation Rules for Collective Perception in Connected and Automated Driving", Proc. IEEE Intelligent Vehicle Symposium, Paris (France), June 2019.
- A. Correa, R. Alms, J. Gozalvez, M. Sepulcre, M. Rondinone, R. Blokpoel, L. Lücken, and G. Thandavarayan, "Infrastructure Support for Cooperative Maneuvers in Connected and Automated Driving", Proc. IEEE Intelligent Vehicle Symposium, Paris (France), June 2019.
- M. Sepulcre, P. Tercero, J. Gozalvez, "Can Beacons be Compressed to Reduce the Channel Load in Vehicular Networks?", Proceedings of the IEEE Vehicular Networking Conference (VNC 2018), 5-7 December, 2018, Taipei, Taiwan.
- G. Thandavarayan, M. Sepulcre, J. Gozalvez,"Cooperative Perception for Connected and Automated Vehicles: Evaluation and Impact of Congestion Control", IEEE Access (under review)
- M. Sepulcre, J. Gozalvez, G. Thandavarayan, B. Coll-Perales, J. Schindler, M. Rondinone, "On the Potential of V2X Message Compression for Vehicular Networks", IEEE Access (under review)

Questions? Let's stay in touch!

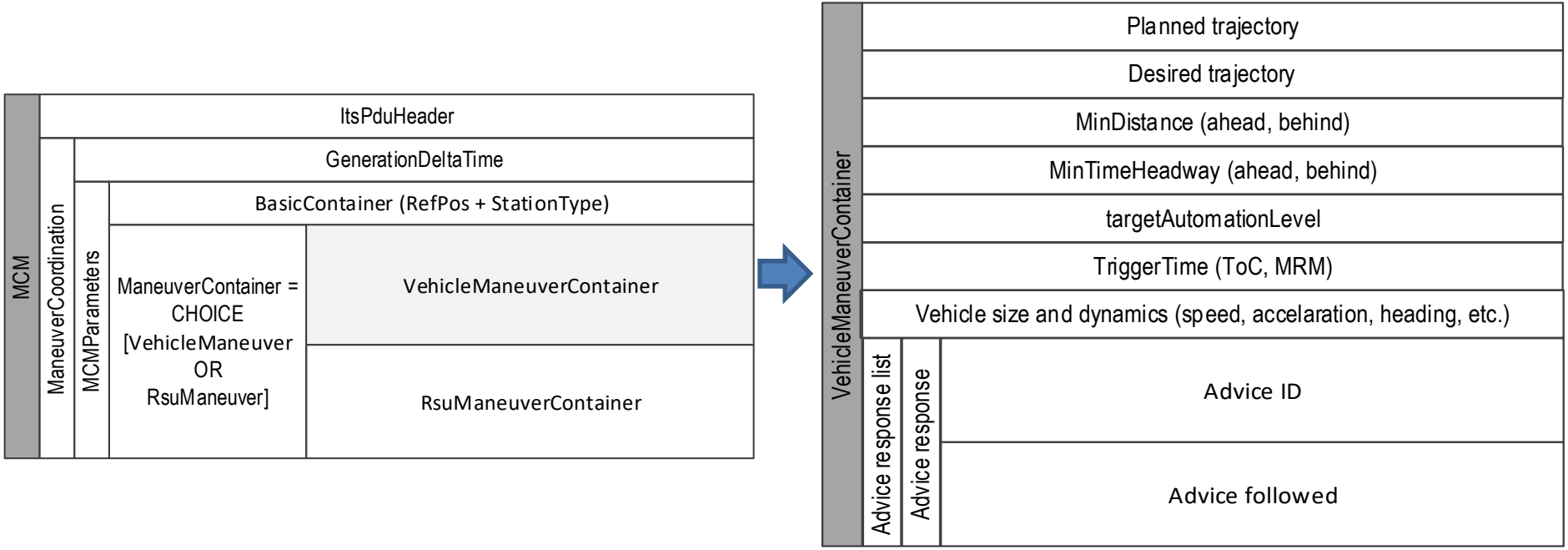
Contact:
Miguel Sepulcre, msepulcre@umh.es
Julian Schindler, julian.schindler@dlr.de (Project Coordinator)

www.transaid.eu
@transaid_h2020
www.linkedin.com/groups/13562830/
www.facebook.com/transaidh2020/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723390

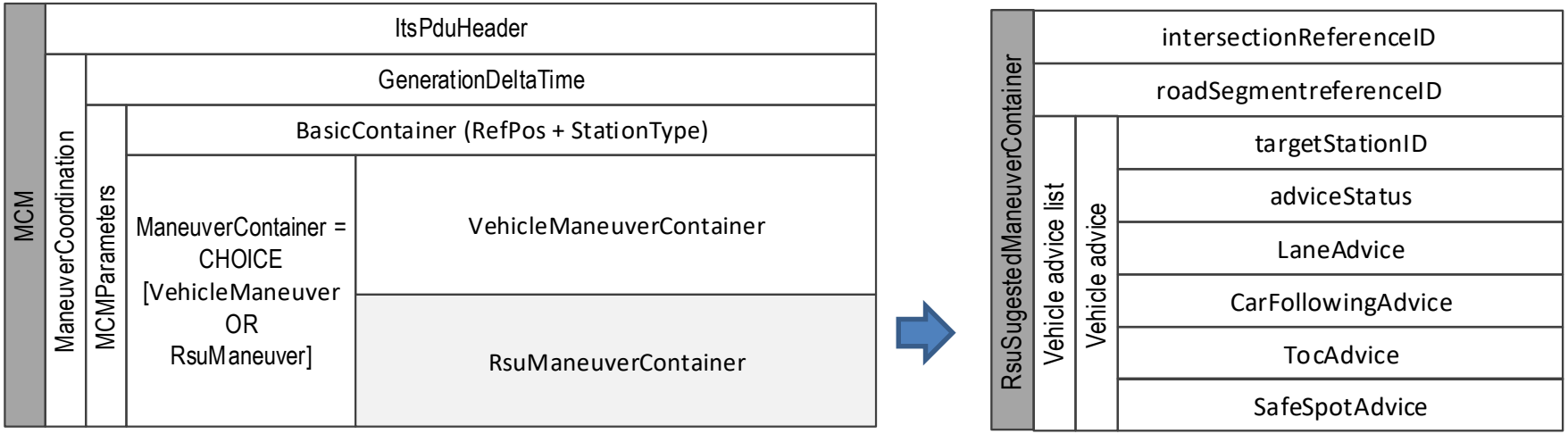
V2X for cooperative maneuvring

- Proposal for MCM message format:



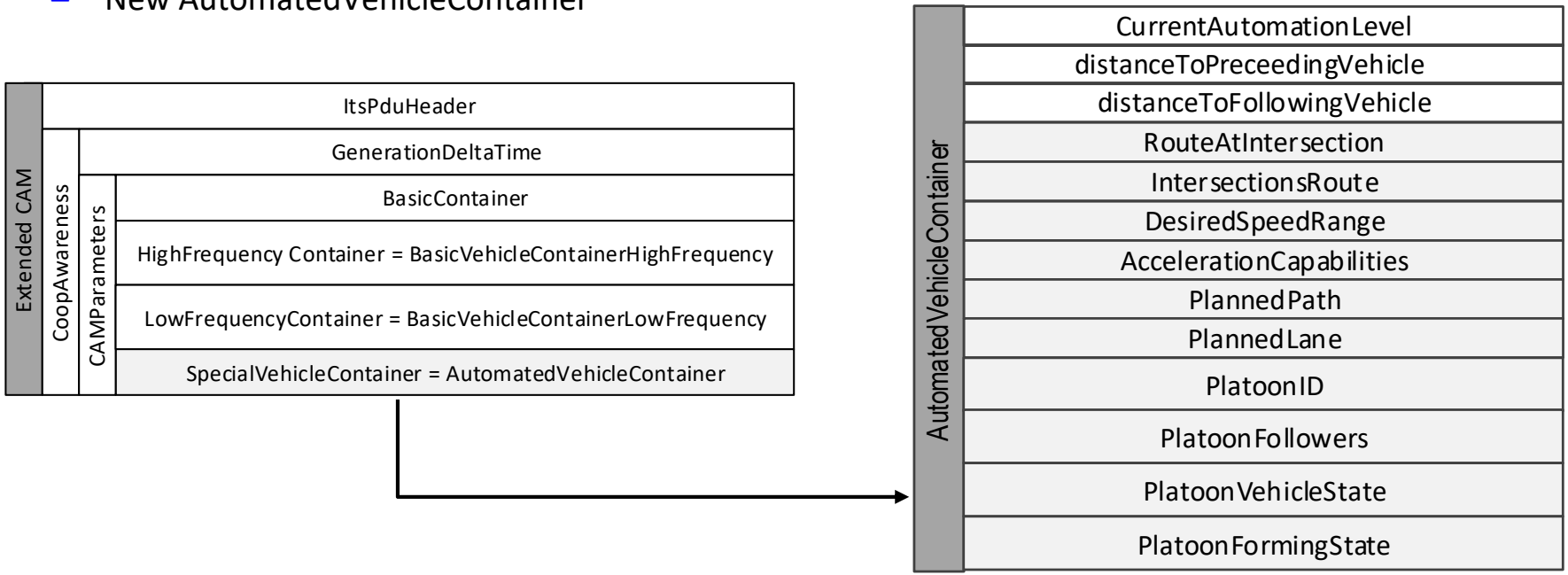
V2X for cooperative maneuvring

- Proposal for MCM message format:



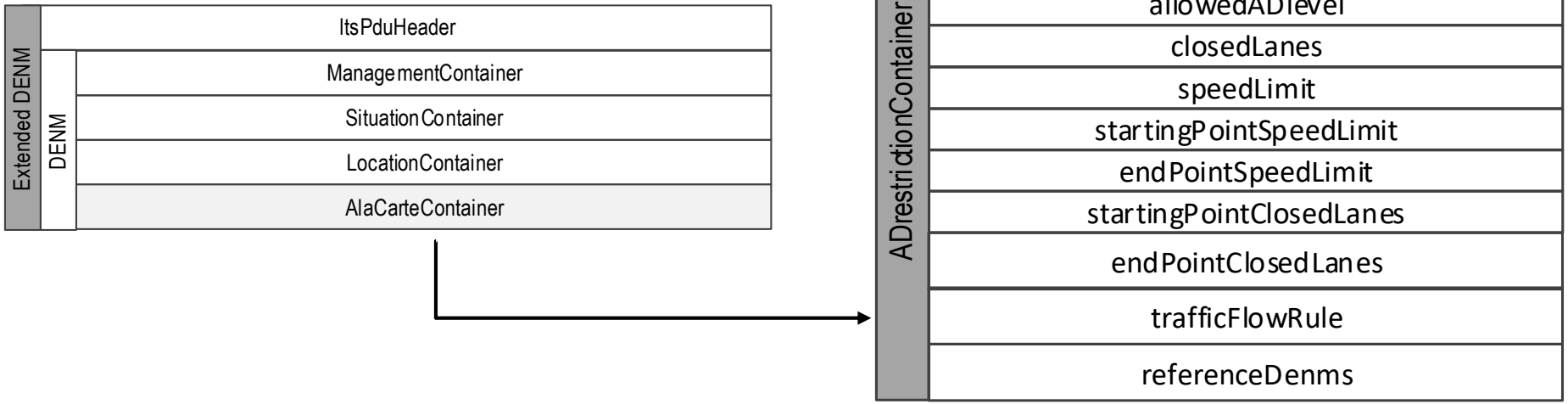
V2X message set

- Extensions of CAM:
  - New AutomatedVehicleContainer



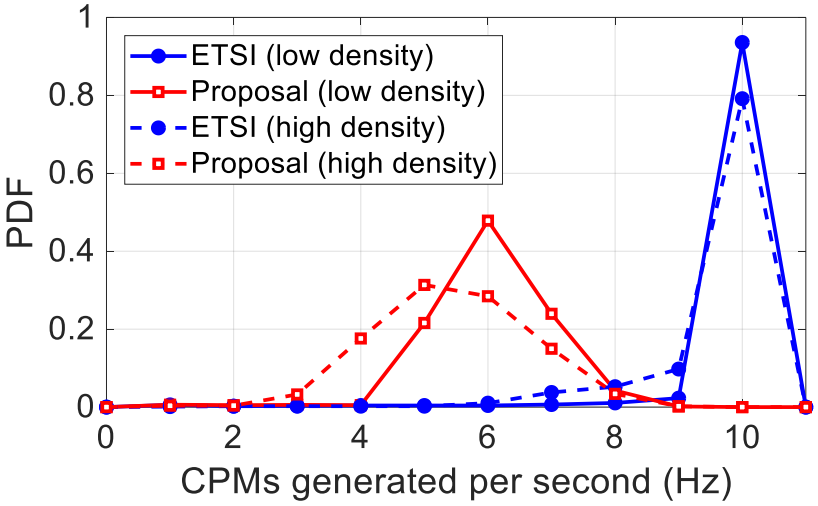
V2X message set

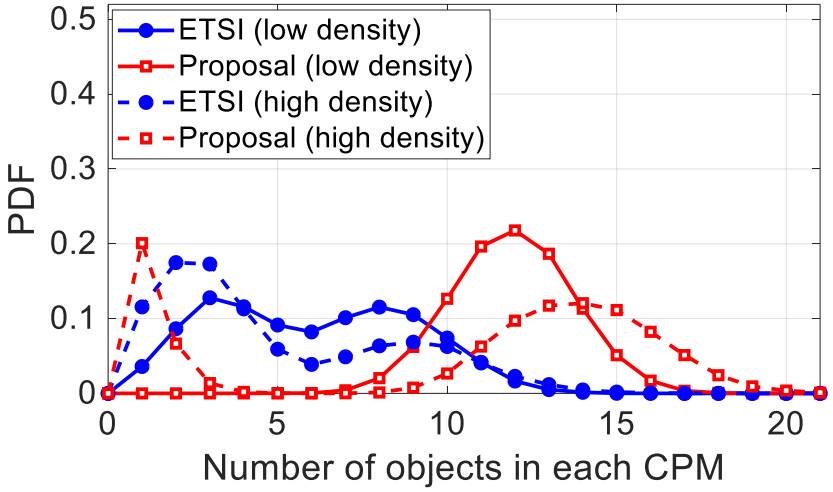
- Extensions of DENM:
  - New ADrestrictionContainer



V2X for cooperative perception

- Evolution of CPM generation rules: look-ahead mechanism

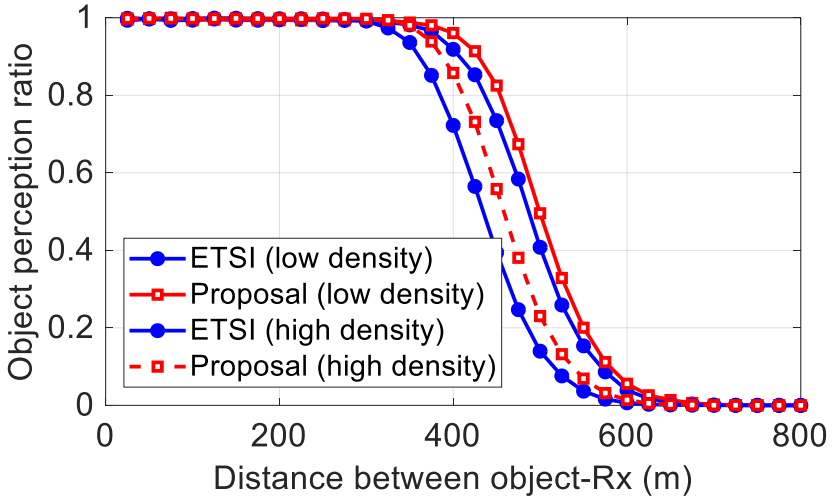




V2X for cooperative perception

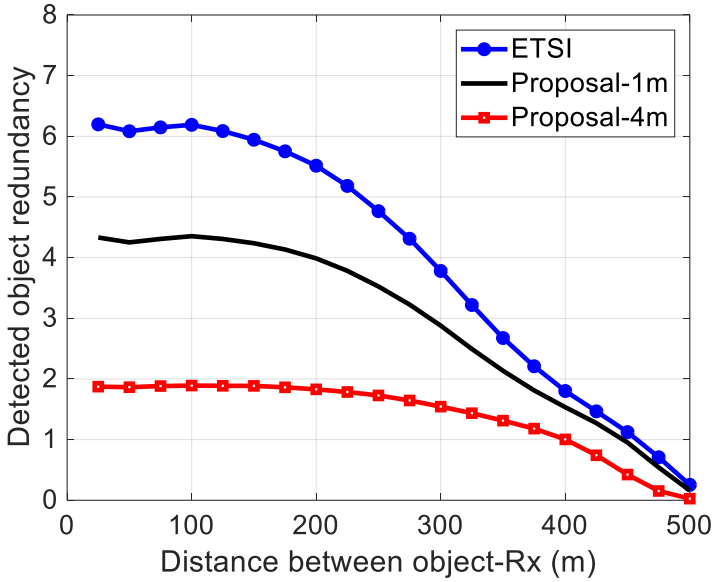
- Evolution of CPM generation rules: look-ahead mechanism

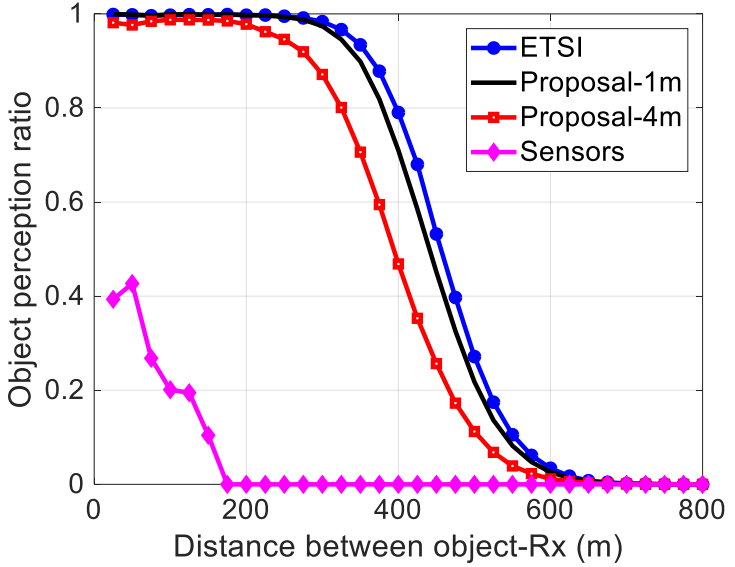
Traffic Density	Policy	Highway	Urban
Low	ETSI	27.56 %	13.96 %
	Proposal	24.89 %	11.20 %
	Difference	-9.6 %	-19.77 %
High	ETSI	45.10 %	19.0 %
	Proposal	38.33 %	16.55 %
	Difference	-15.0 %	-12.89 %



V2X for cooperative perception

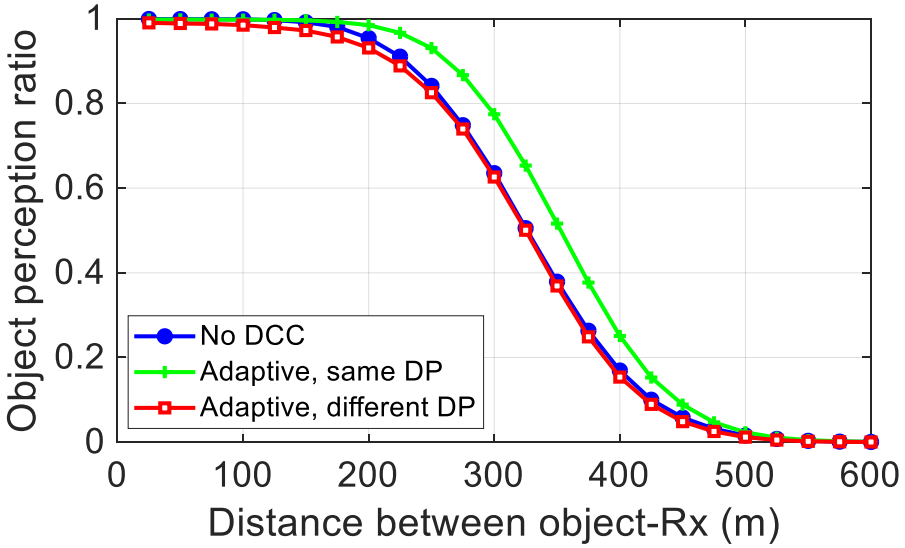
- Redundancy mitigation mechanism:

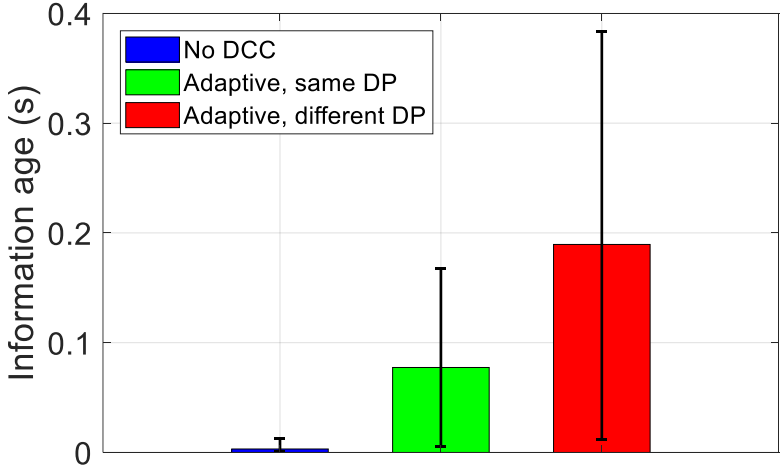




V2X for cooperative perception

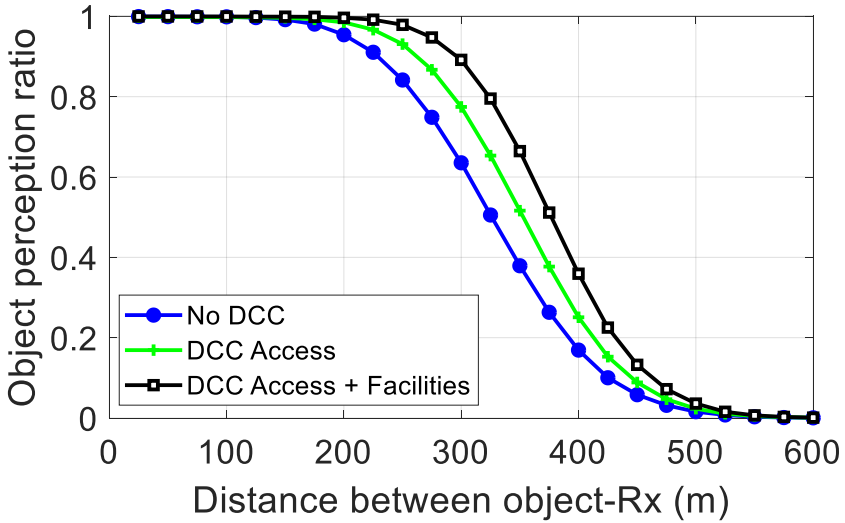
- DCC Access:

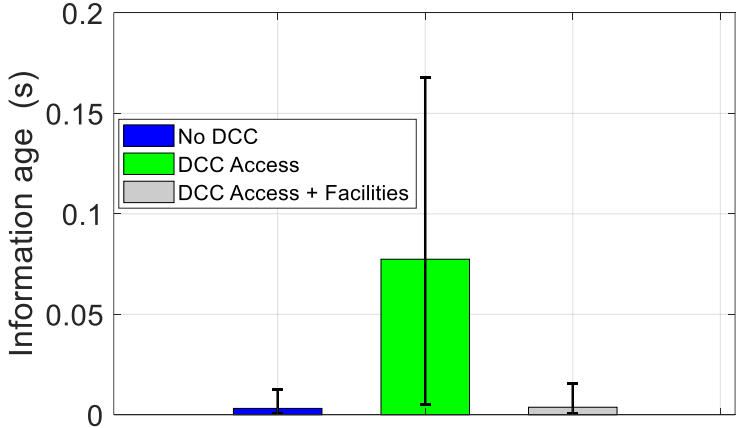




V2X for cooperative perception

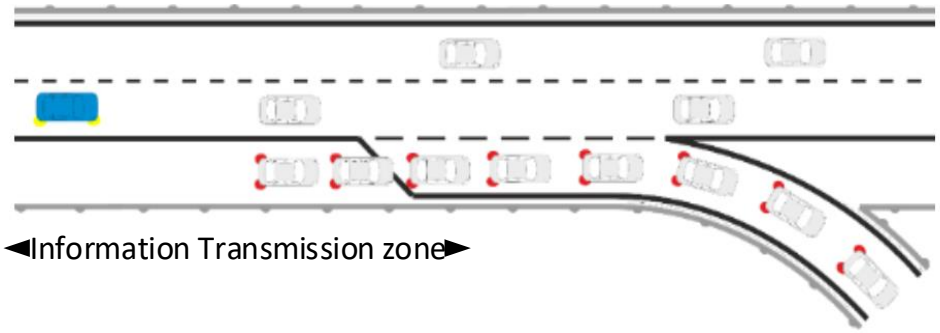
- DCC Access + DCC Facilities:

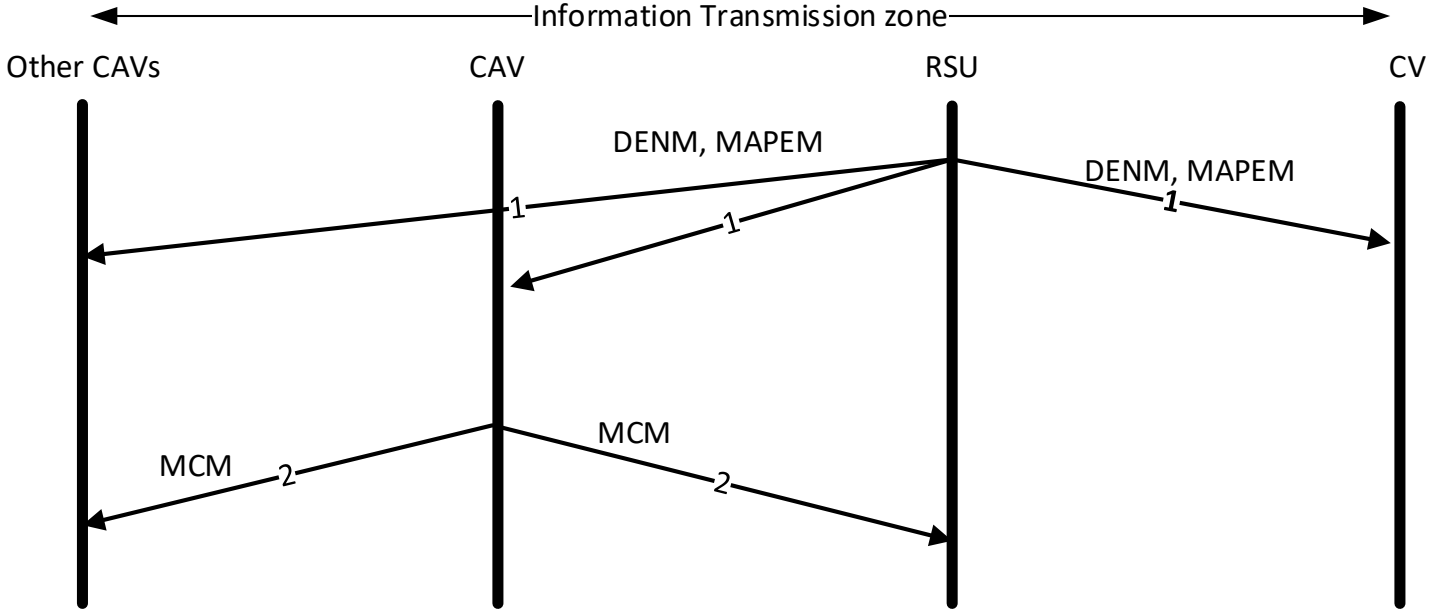




Maneuver coordination

- Example Service 1.3:Queue spillback at exit ramp





1) RSU sends a DENM with the alert information about the queue and the end of the queue position. The RSU also sends a MAPEM message including the section of the emergency lane opened for queueing and the new speed limits applicables at each segment and lane of the scenario.

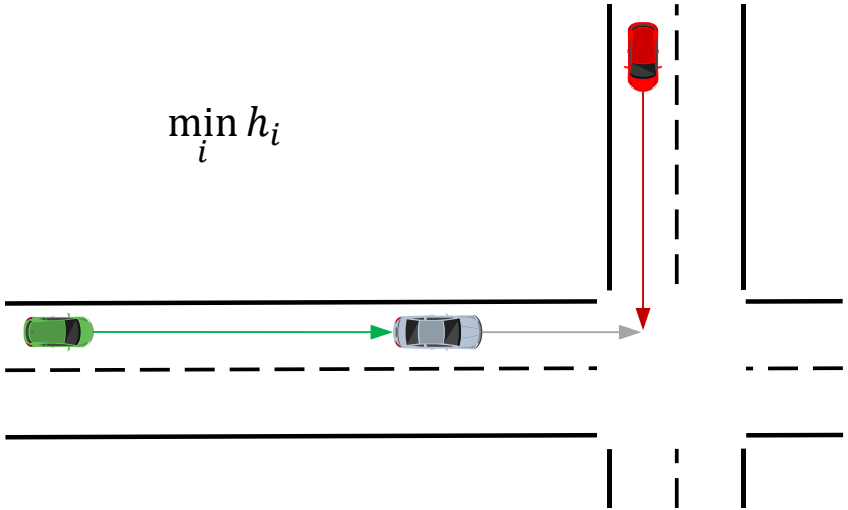
2) Upon reception of the information about the section of the emergency lane opened, CAVs that want to exit the road will plan the lane change to the emergency lane and they will send a new MCM with the new planned trajectory.

Cooperative manoeuvring

- Time to risk of collision:

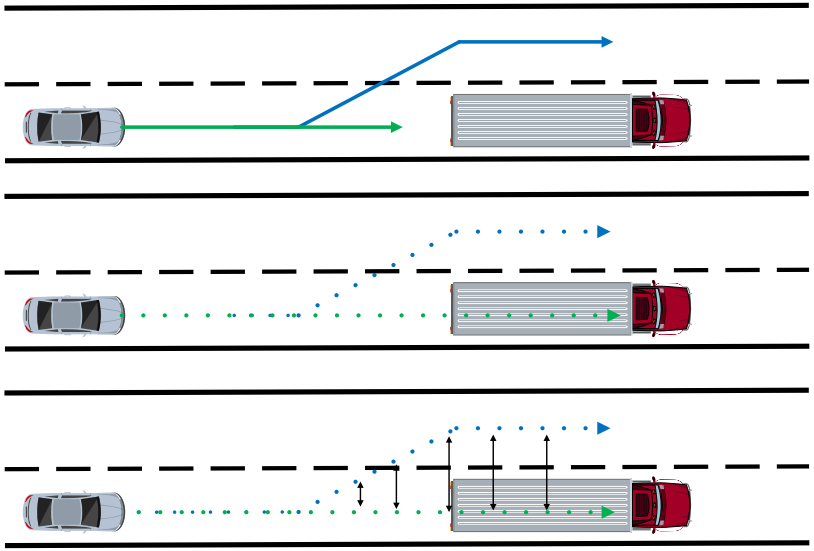
$$h_i = {}^{d_i}/_{v_i} + t_i$$

$$\min_i h_i$$



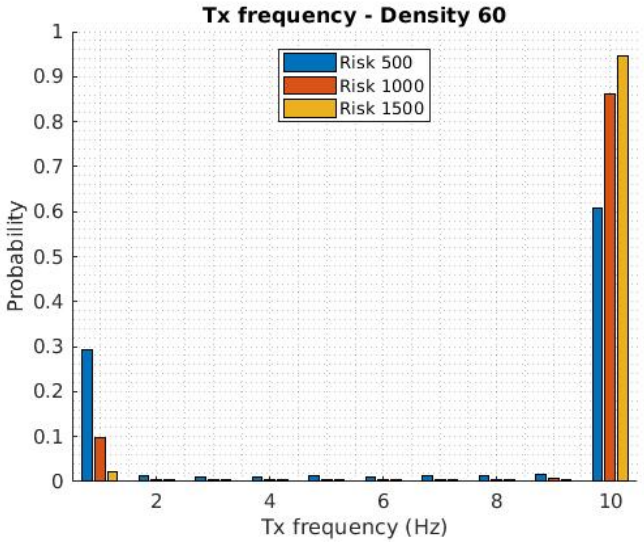
- Distance between trajectories:

$$\max_i d_i$$

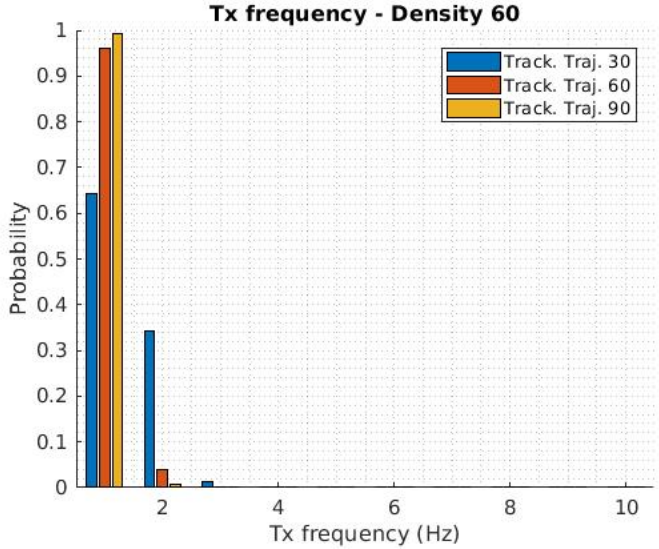


Cooperative maneuvring

- MCM generation rules:



Threshold: 500ms, 1000ms or 1500ms

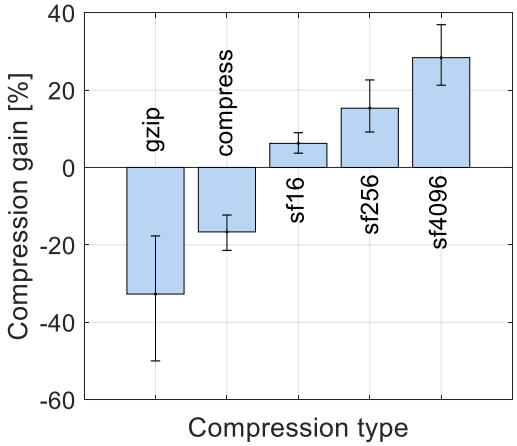


Threshold: 30, 60, 90 cm

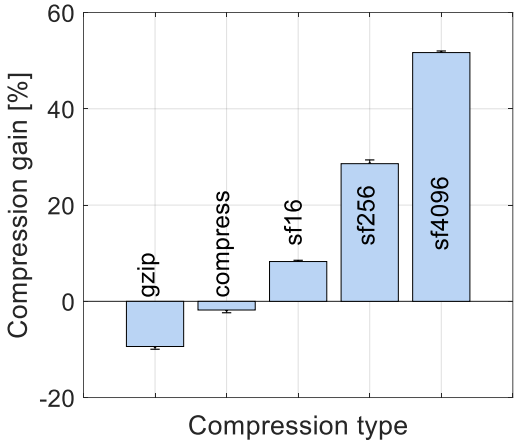
V2X message compression

- Compression gain

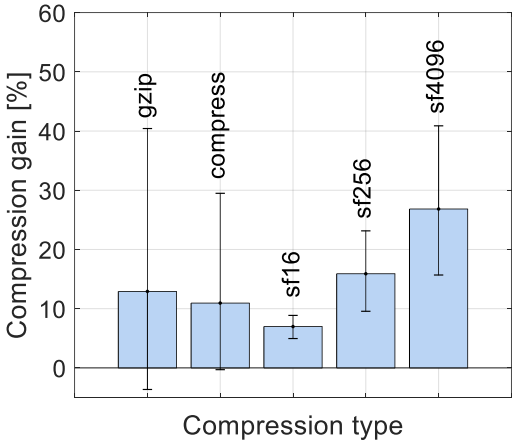
CAM



CPM



MCM



V2X message compression

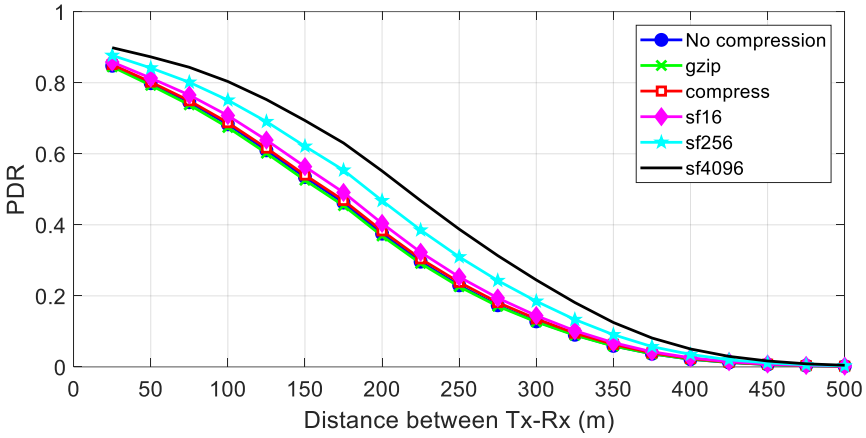
- Average CBR (Channel Busy Ratio)

Compression	Traffic density		
	Low	Medium	High
None	41.80%	61.80%	73.31%
Gzip	42.54% (+1.8%)	62.08% (+0.5%)	73.43% (+0.2%)
Compress	41.45% (-0.8%)	60.98% (-1.3%)	72.46% (-1.2%)
sf16	39.80% (-4.8%)	59.51% (-3.7%)	71.18% (-2.9%)
sf256	35.70% (-14.6%)	54.64% (-11.6%)	66.61% (-9.1%)
sf4096	30.61% (-26.8%)	48.31% (-21.8%)	60.36% (-17.7%)

V2X message compression

- PDR (Packet Delivery Ratio) with and without compression.

120 veh/km



180 veh/km