Tutorial 2:
5G Cellular-V2X communications
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Introduction to 5GCAR, and the Role of 5G in Automotive Industry

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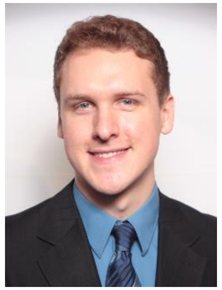


Bastian Cellarius (Ericsson)

What is C-V2X ?

C-V2X is a comprehensive road safety and traffic efficiency solution that allows **vehicles** to communicate

- **Other vehicles (V2V),**
- **Pedestrians and Cyclists via smartphones (V2P),**
- **Road Infrastructure (V2I),**

supported by the

- **Mobile network (V2N)**

guarantee full coverage and continuity of services

5GCAR Consortium

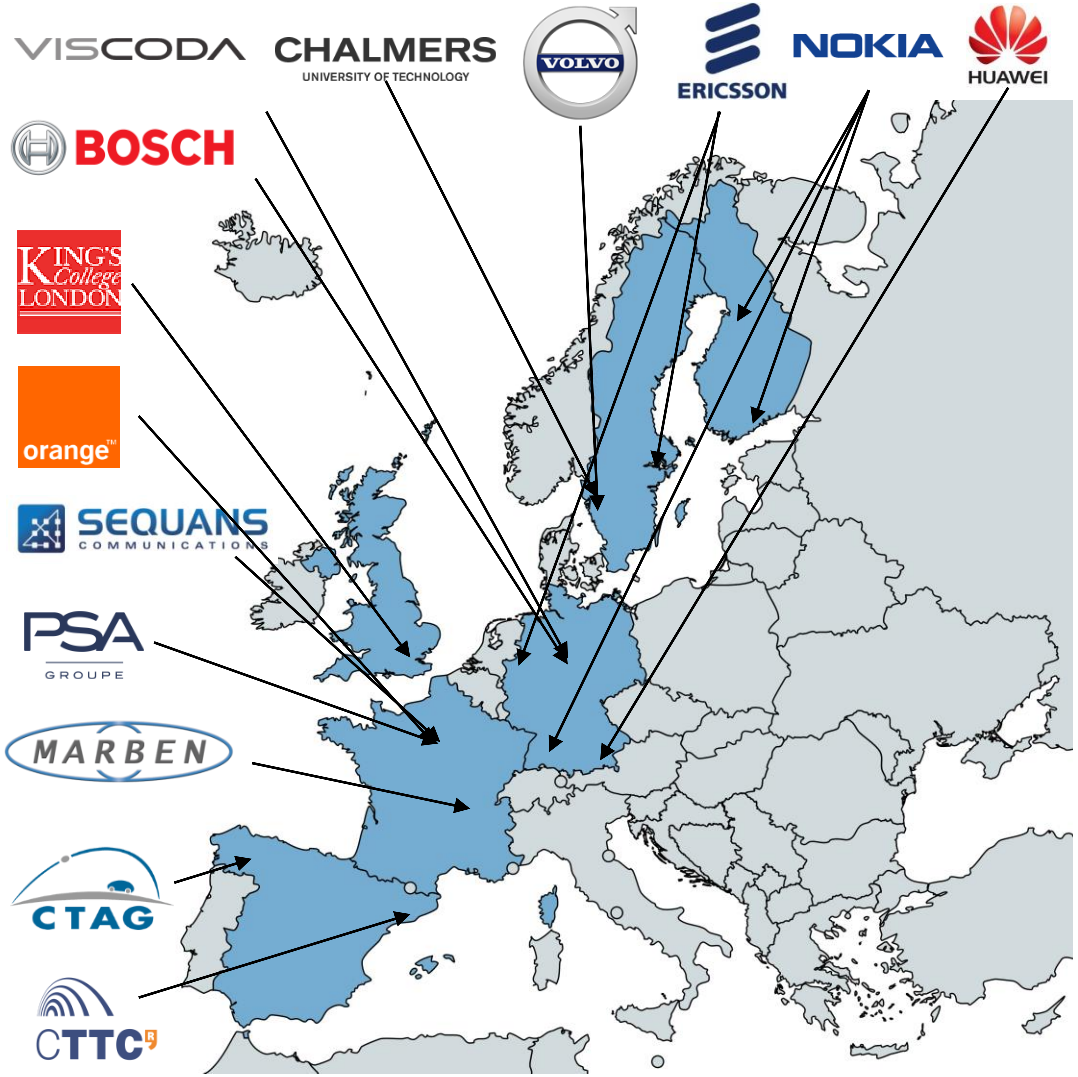
5GCAR

- From June 2017 to July 2019
- 28 full-time equivalents

https://5gcar.eu/

5G PPP Phase 2 Projects

https://5g-ppp.eu/5g-ppp-phase-2-projects/



Objectives

Develop an overall 5G V2X system architecture	Interworking of multiple Radio Access Technologies	Develop an efficient, secure and scalable sidelink interface	5G radio-assisted positioning techniques
Identify innovative business models	Demonstrate and validate the developed V2X concepts	Contribute to 5G Standardization and regulation	Integrate of the 5GCAR concepts in the 5G PPP

Methodology

A. Definition of V2X scenarios, requirements and KPIs

B. Design and validation of innovative technical solutions

C. Proof-of-concept and demonstration

Demonstrate three advanced V2X use cases

- ✓ Lane merge
- ✓ Cooperative perception for manoeuvres of connected vehicles
- ✓ Vulnerable road user protection

R&I Activities

- Business models for 5G V2X
- Spectrum for 5G V2X
- Infrastructure-based communication for 5G V2X
- Sidelink-based communications for 5G V2X
- Positioning for 5G V2X
- 5G Architecture for V2X
- Demonstrations for 5G V2X

Ambitions

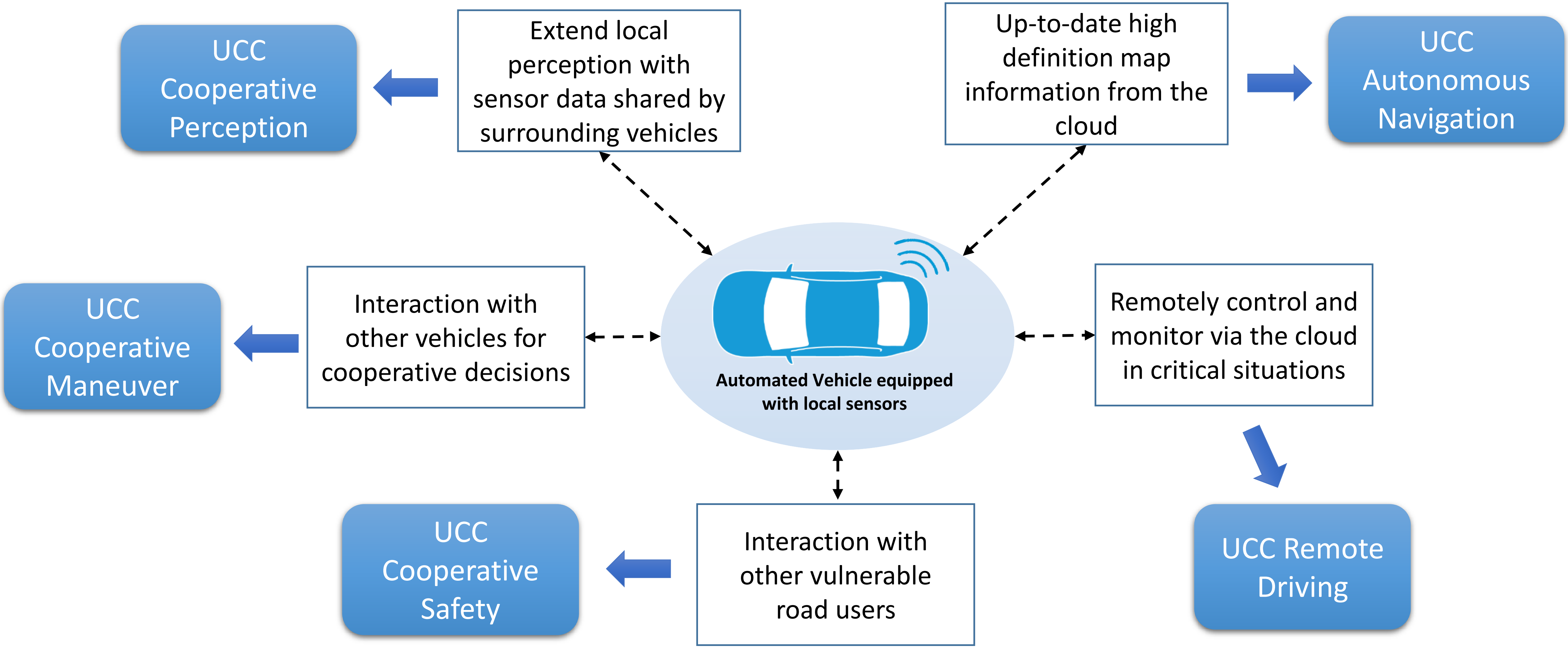
1. End-to-end latencies, below 5 ms
2. Ultra-high reliability, close to 10^{-5}
3. Very large density of connected vehicles
4. Positioning accuracy (VRUs: 10 cm, Vehicles: 30 cm)

5GCAR Results (https://5gcar.eu/deliverables/)

- 5GCAR Use Cases (D2.1 and D2.3)
- V2X Business Models and Spectrum (D2.2 and D2.3)
  - 5G Automotive Working Group white papers (v1.0 and v2.0)
    - https://5g-ppp.eu/white-papers/
- 5G V2X Radio (D3.1 and D3.3)
- Channel Modelling and Positioning (D3.2)
- 5G V2X System Level Architecture and Security Framework (D4.1 and D4.2)
- Demonstration Guidelines (D5.1)

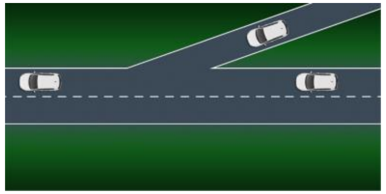
5GCAR Use Cases

5GCAR Use Case Classes (D2.1)

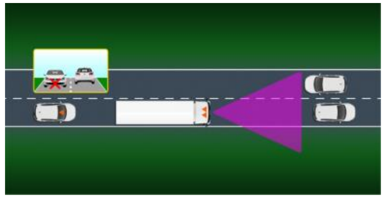


On the 5GCAR Use Cases (D2.1)

- **Cooperative maneuver**: sharing local awareness and driving intentions and negotiating the planned trajectories
  - Lane merge



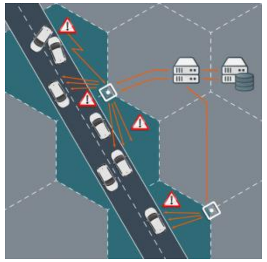
- **Cooperative perception**: perception extension is built on the basis of exchanging data from different sources, e.g., radars, laser sensors, stereo-vision sensors from on-board cameras
  - See-through



- **Cooperative safety**: achieved by exchanging the information about detection of the presence of road users
  - Network assisted vulnerable pedestrian protection

On the 5GCAR Use Cases (D2.1)

- **Autonomous navigation**: construction and distribution of real-time intelligent HD map
  - High definition local map acquisition



- **Remote driving**: control the different actuators of the car (steering wheel, brake and throttle) from outside the vehicle through wireless communication
  - Remote driving for automated parking

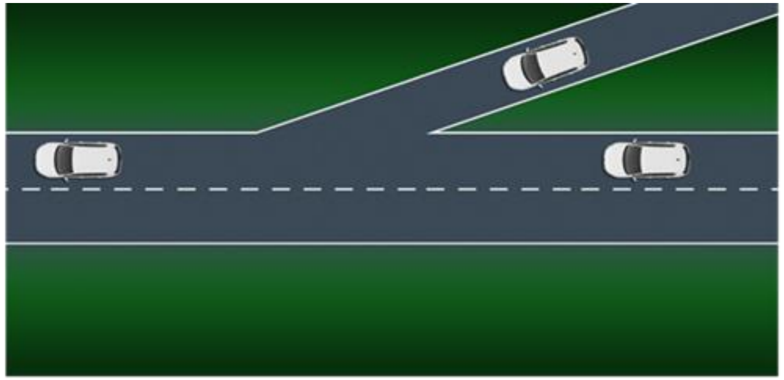
On 5GCAR Requirements (D2.1)

- **Automotive requirements**
  - Localization, minimum car distance, mobility, relevance area, etc.

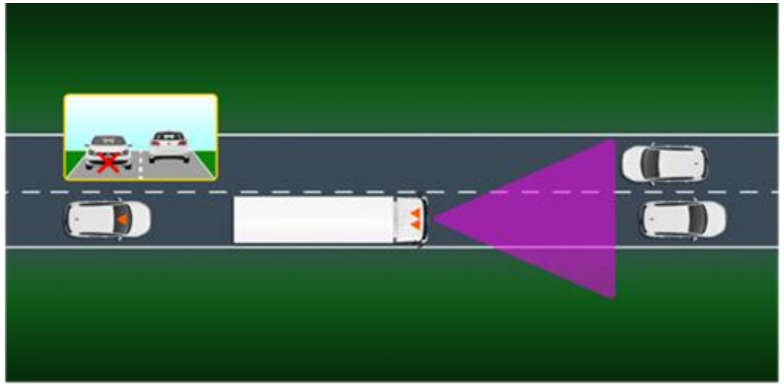
- **Network requirements**
  - Availability, communication range, data rate, latency, reliability, service data unit size
  - Latency may be considered from different perspectives (for different use cases)
    - (Layer-based) latency: similar with user plane latency in 3GPP
    - End-to-end latency: the time it takes to transmit an application message from the application layer of the source node to the application layer of the destination node

- **Qualitative requirements**
  - Cost, power consumption, security

The 5GCAR Use Cases (D2.1)

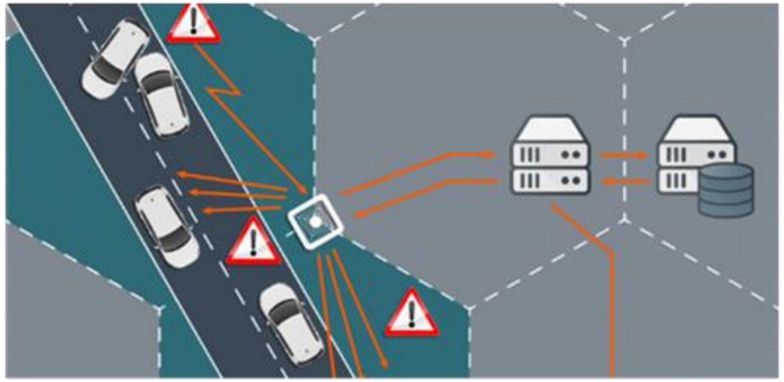


Lane merge

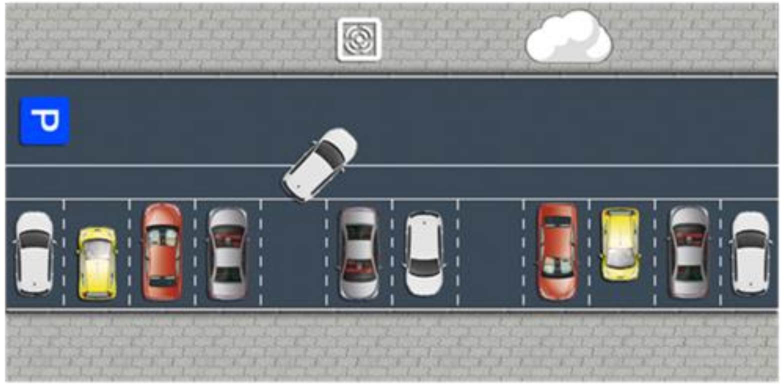


See-through

Network assisted vulnerable pedestrian protection



High definition local map acquisition



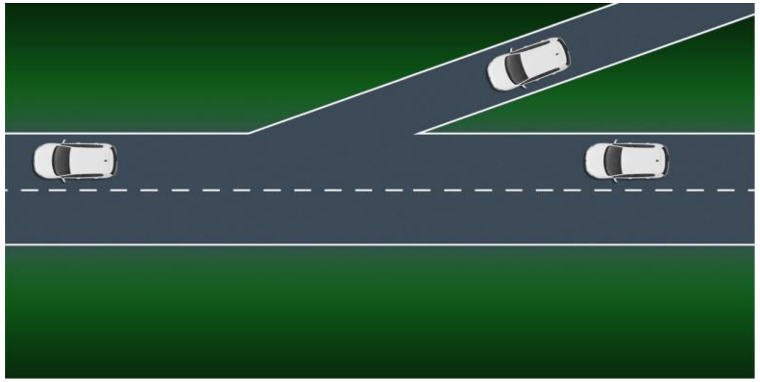
Remote driving for automated parking

On 5GCAR Requirements (D2.1)

Requirement label	Automotive	Network	Qualitative
	Intersection crossing time	Avilability	Cost
	Localization	Communication range	Power consumption
	Maneuver completion time	Date rate	Security
	Minimum car distance	Latency	
	Mobility	Reliability	
	Relevance area	Data unit size	
	Sw updates		
	Takeover time		

- Lane merge: **Localization, Latency**
- See-through: **Data rate**
- Network assisted vulnerable pedestrian protection: **Reliability, Localization**
- High definition local map acquisition: **Localization, Density, Security**
- Remote driving for automated parking: **Availability, Reliability, Latency**

On the 5GCAR Requirements (D2.1)

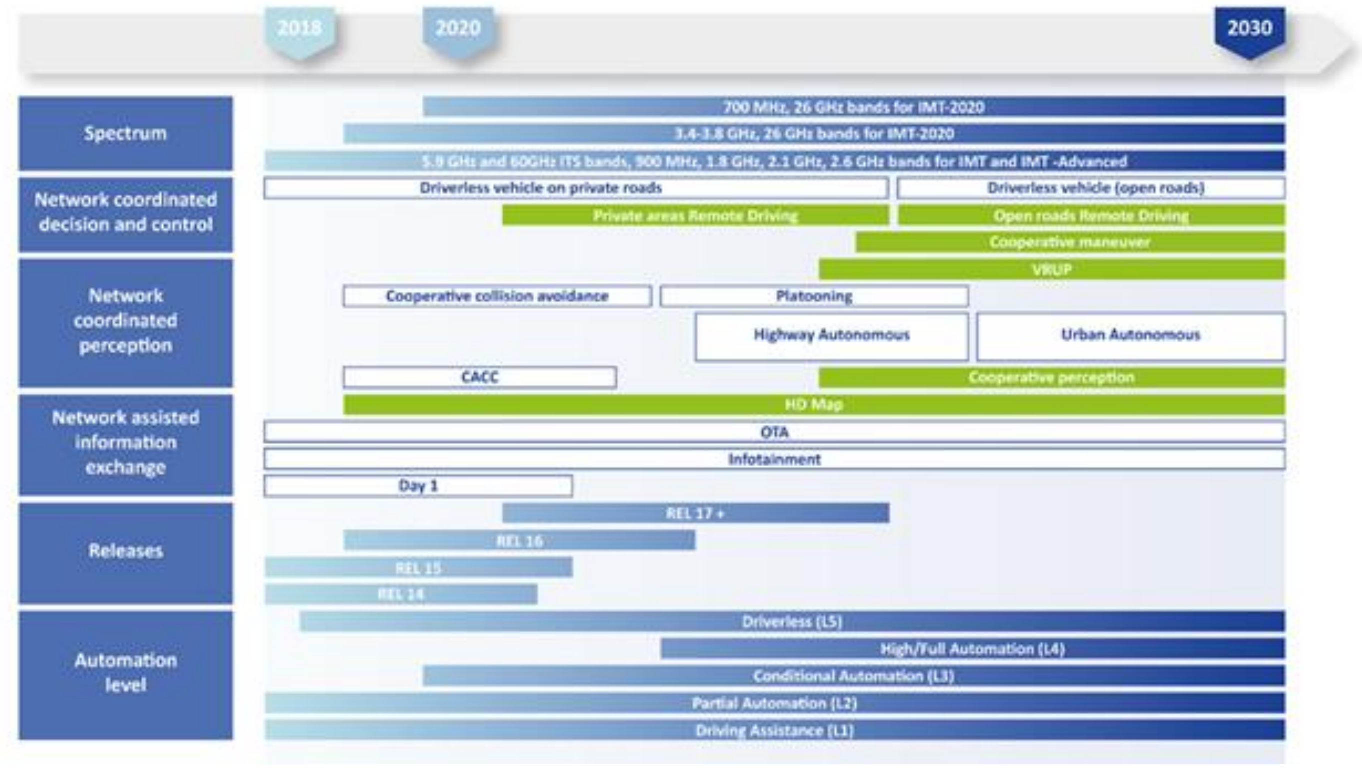


Lane merge

Use Case 1: Lane merge	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	Not applicable
Localization	1 to 4 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 150 km/h
Relevance area	250 to 350 meters
Take over time	10 seconds
Network requirements	
Availability	V2I/V2N 99% and for V2V 99.9%
Communication range	> 350 meters
Data rate	1.28 Mbps
Latency	< 30 ms
Reliability	99.9%
Service data unit size	800 bytes/message without trajectories 16000 bytes/message with trajectories
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High

Use Case Roadmap (D2.3)

- Level 5 is already now available in private road or campus (shuttles).
- Level 4 should arrive to the market in the first half of the next decade.
- Automotive industry considers level 4 as the first one where connectivity may become a must
- The real level 5, i.e. on open roads is expected in the second half of the decade.
- In 2025, 5G mobile phone subscription will be around 30% in Europe



- The European regulation (Delegated ACT and CAFÉ) will modulate this roadmap

5G V2X Business Aspects

Business models

Services

- Emergency call
- Remote diagnostics
- Car sharing
- OTA software updates
- Predictive maintenance
- Environment perception through Wireless connectivity and sensor sharing
- Dynamic map
- Video streaming/gaming
- Parking reservation/payment

Technological components

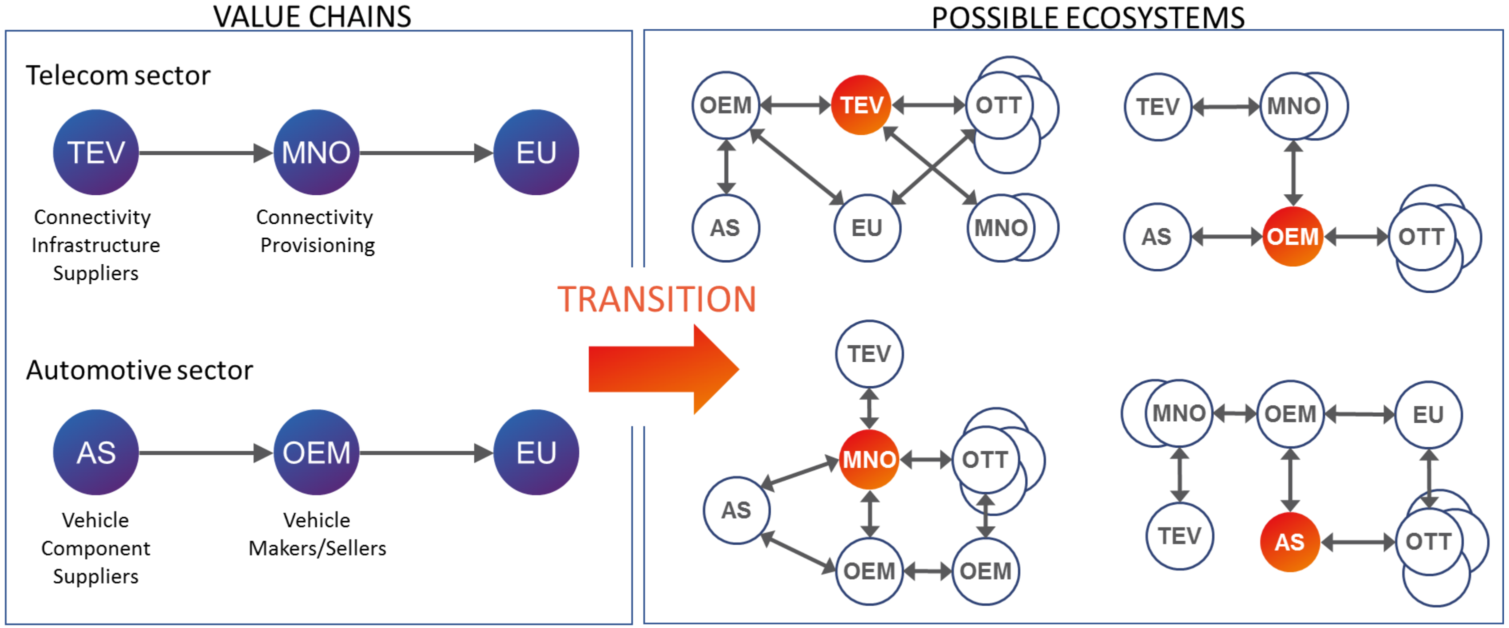
- Network densification
- Network slicing
- Mobile Edge Computing
- Sidelink communication
- Cellular radio based positioning and tracking
- Integrated moving networks

Practicalities

- Profile/SIM card provisioning
- Routing strategy
- Roaming and inter-operator coordination
- Network technologies and OEMs status

Business models (D2.2)

- There are technical features in 5G that can enable new business models for various stakeholders in the value chain.
- Existing services as well as autonomous driving features may be enhanced by 5G technologies, thereby building added value
- The value chain, may be disrupted by 5G changing eco-systems around the connected car
- The 5G Automotive working group white paper published by 5G PPP as a first outcome concerning analysis of the 5G V2X deployment cost, triggering a discussion on revenue and benefits

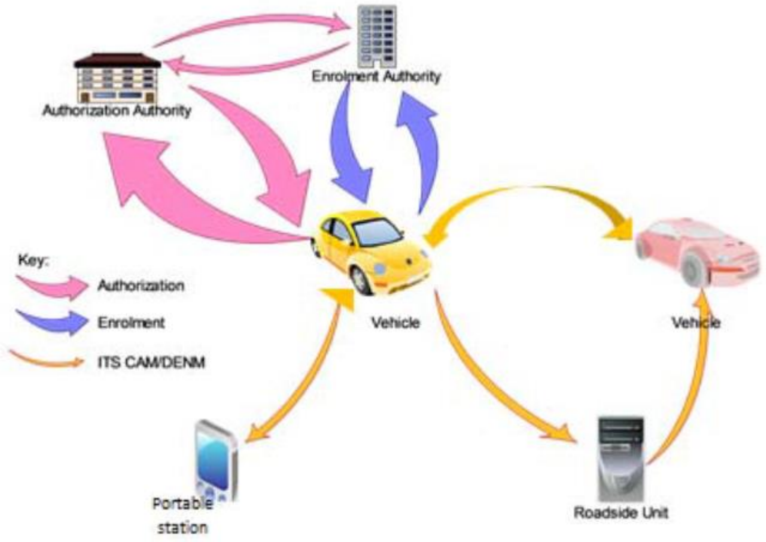


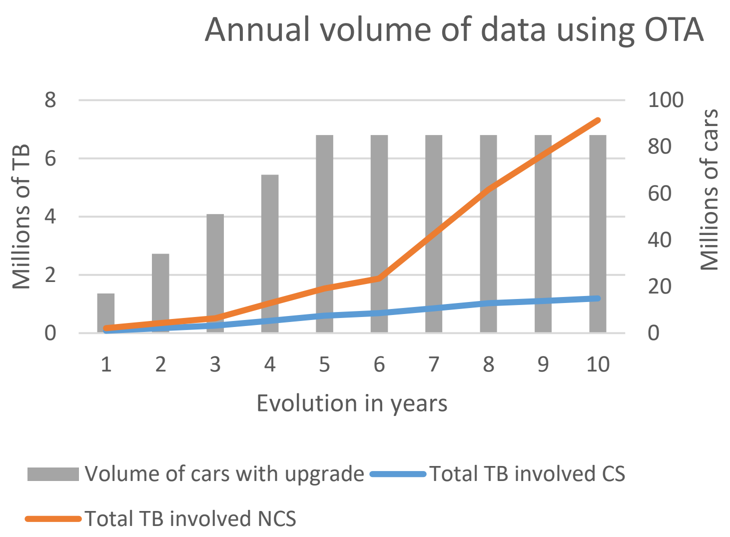
AS: Automotive Supplier
OEM: Original Equipment Manufacturer
TEV: Telecom Equipment Vendor
MNO: Mobile Network Operator
OTT: Over-The-Top Service Providers
EU: End User

Business models (D2.3)

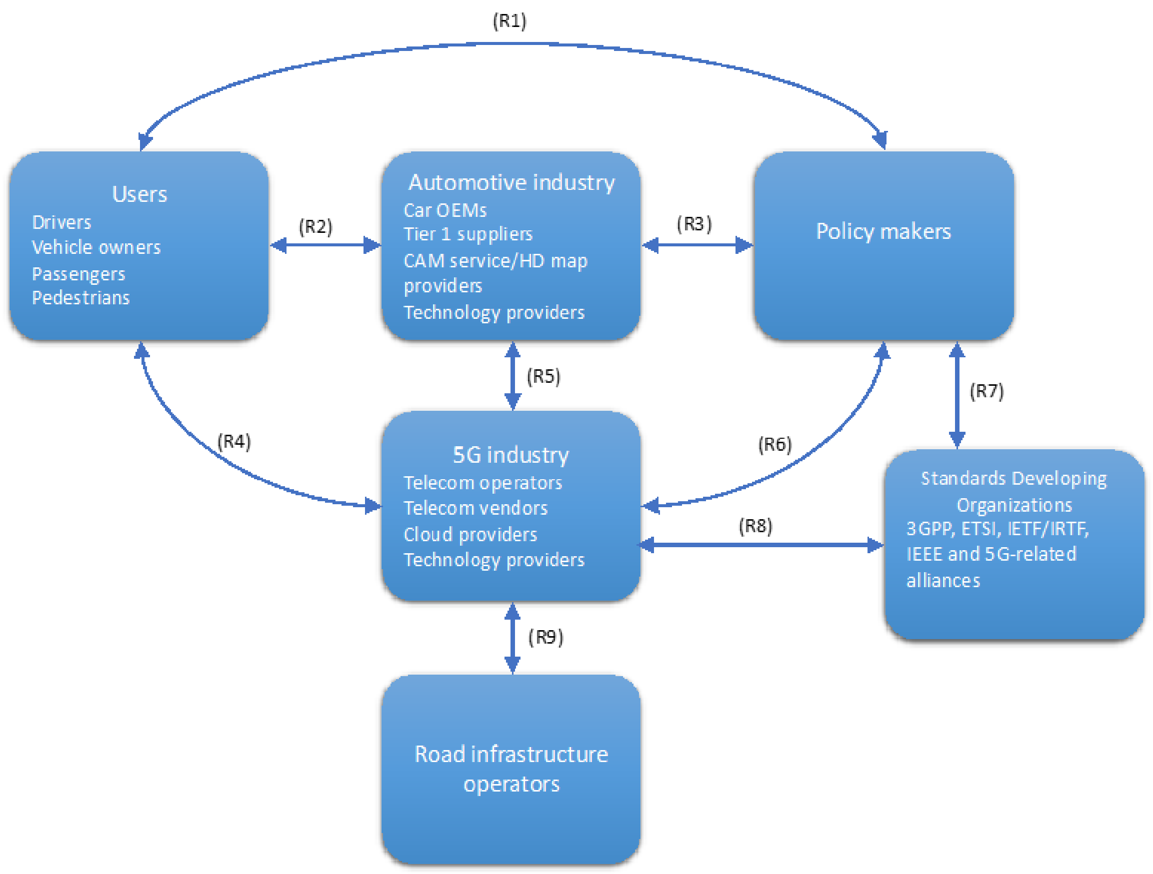
- New market opportunities are available such us Connected and Automated Mobility Services, Security psuedonymisation strategy or Over The Air (OTA) updates

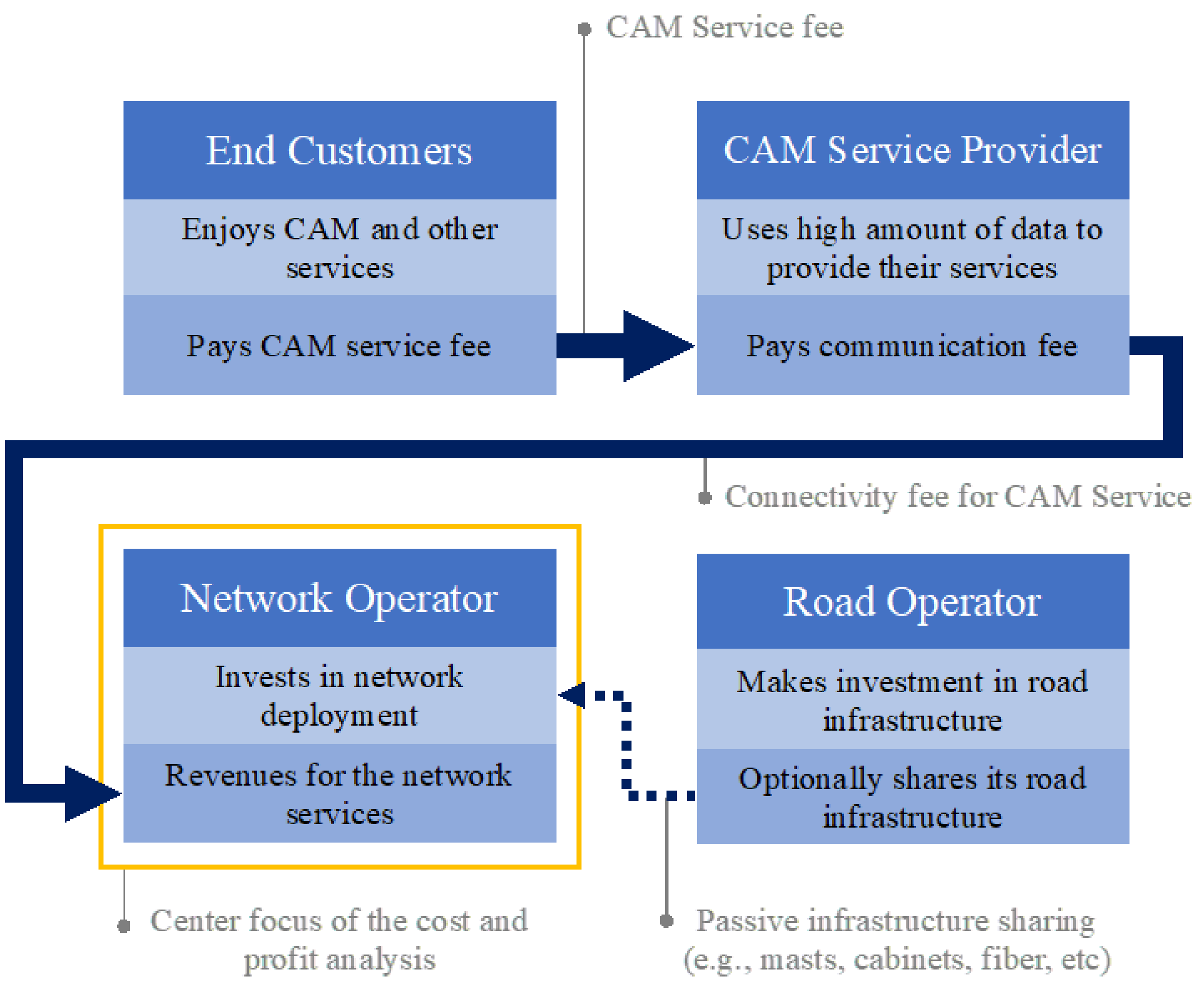
- In these market opportunities cost reduction will be a key factor for all parties: in network deployment, thanks to different network sharing mechanisms; in security cost adoption, by new technical solutions or by market competition and in OTA updates, thanks to new business model for the connected vehicle





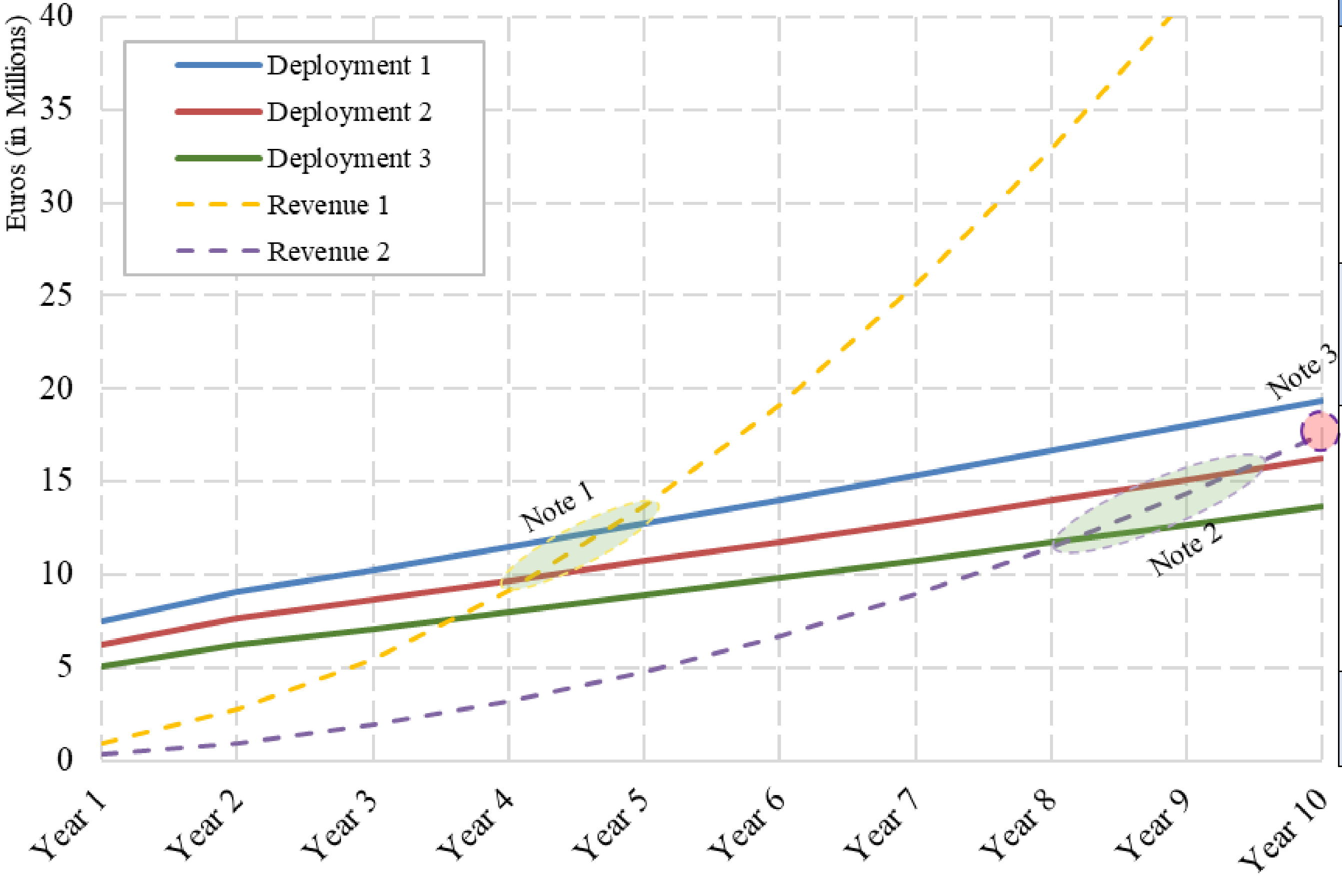
5G Automotive WG white papers (v2.0)





5G Automotive Working Group, white papers (v1.0 and v2.0)
https://5g-ppp.eu/white-papers/

5G Automotive WG white papers (v2.0)



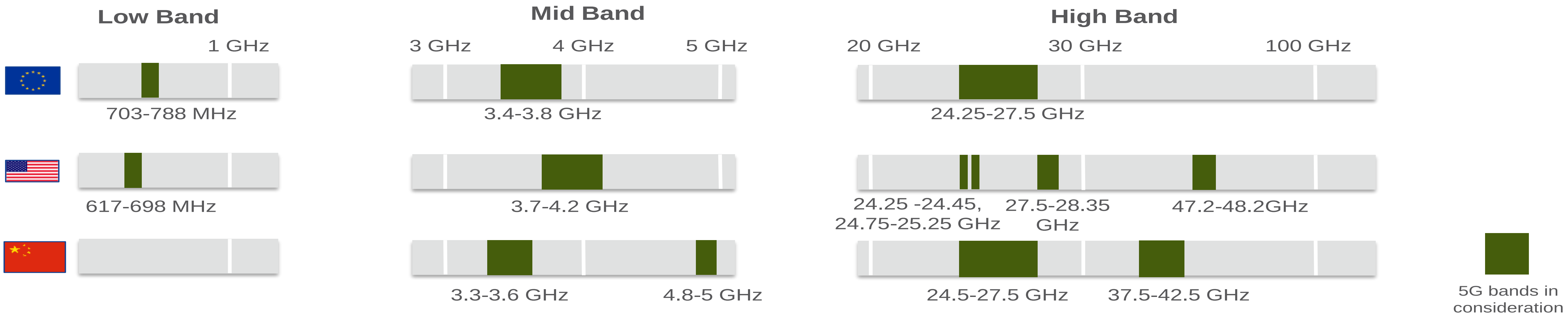
	Parameter	Value	Unit
Deployment costs	5G site (CAPEX)	64 000	Euro per site
	Civil works (CAPEX)	20 500	Euro per site
	Fibre backhaul (CAPEX)	23 000	Euro per km
	Network operation (OPEX)	10	% of total CAPEX
	Site lease (OPEX)	5 700	Euro per site
Area and capacity demand	Inter-site-distance (ISD)	1	km
	Deployment length	100	km
	Number of vehicles	50 000	Vehicles/100 km/day
Deployment rate	Connectivity cost for CAM	0.5	Euro per 100 km per vehicle
	Network deployment rate	55 5	% for year 1 for coverage % from year 2 to 10 for capacity
	Fiber deployment rate	80 20	% year 1 % year 2
	Yearly penetration rate	10	% from year 1 to 10
Costs evolution	CAPEX Yearly price evolution	-3	% from year 1 to 10
	OPEX Yearly price evolution	3	% from year 1 to 10

Deployment 1: Single network operator (NO)
Deployment 2: 3 NOs passive sharing
Deployment 3: 3 NOs active sharing

Note 1: single NO break-even in 5 years
Note 2: multiple NO & network sharing
Note 3: multiple NO, no network sharing

Spectrum

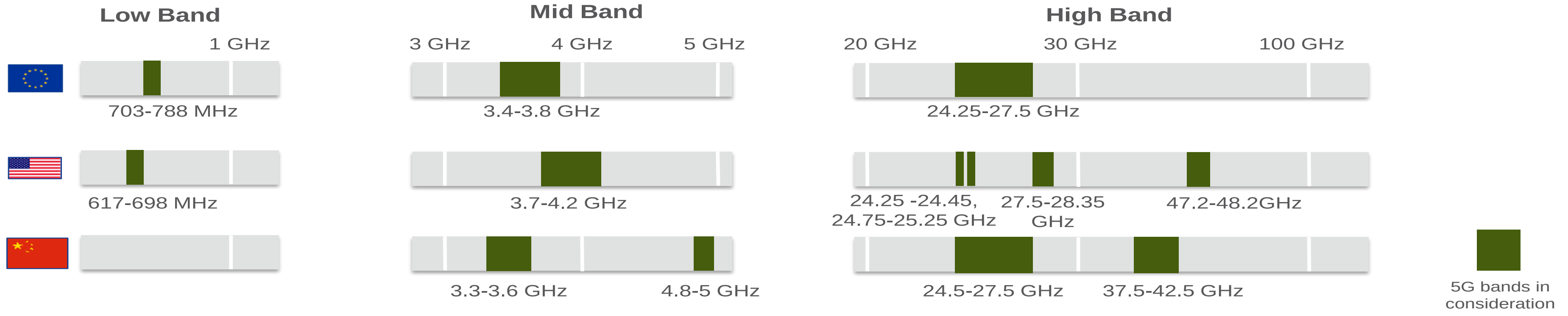
Spectrum (D2.2)



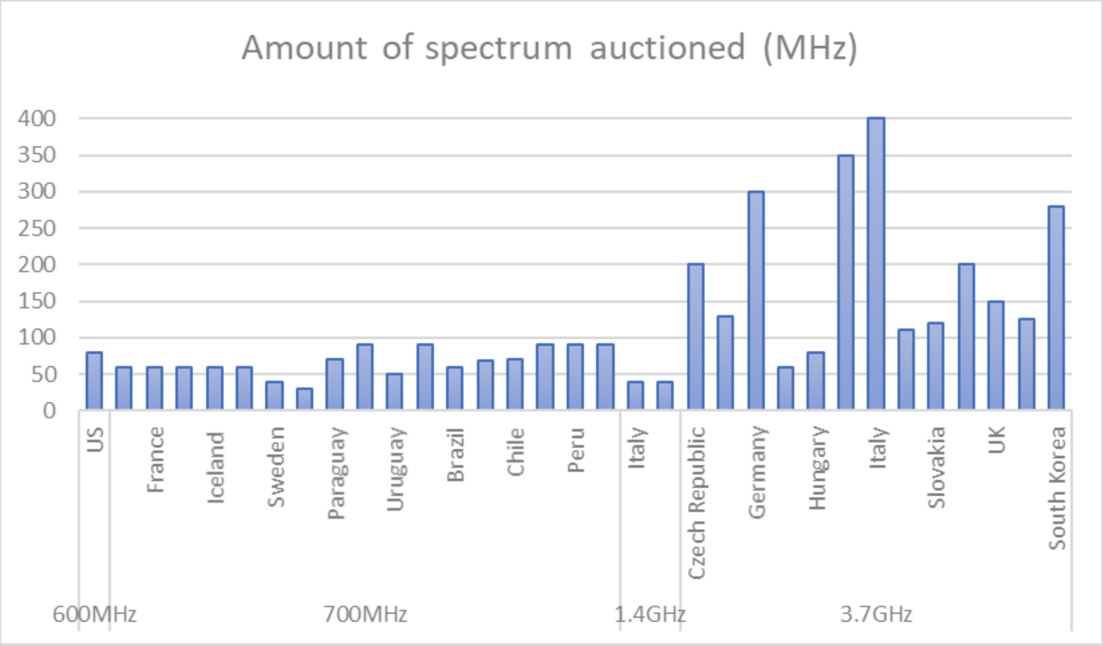
- 5GCAR use cases analyzed:
  - Better spectrum bands are medium or low frequencies with lower propagation loss and better range
  - Coverage has precedence over bandwidth for V2X use cases so far

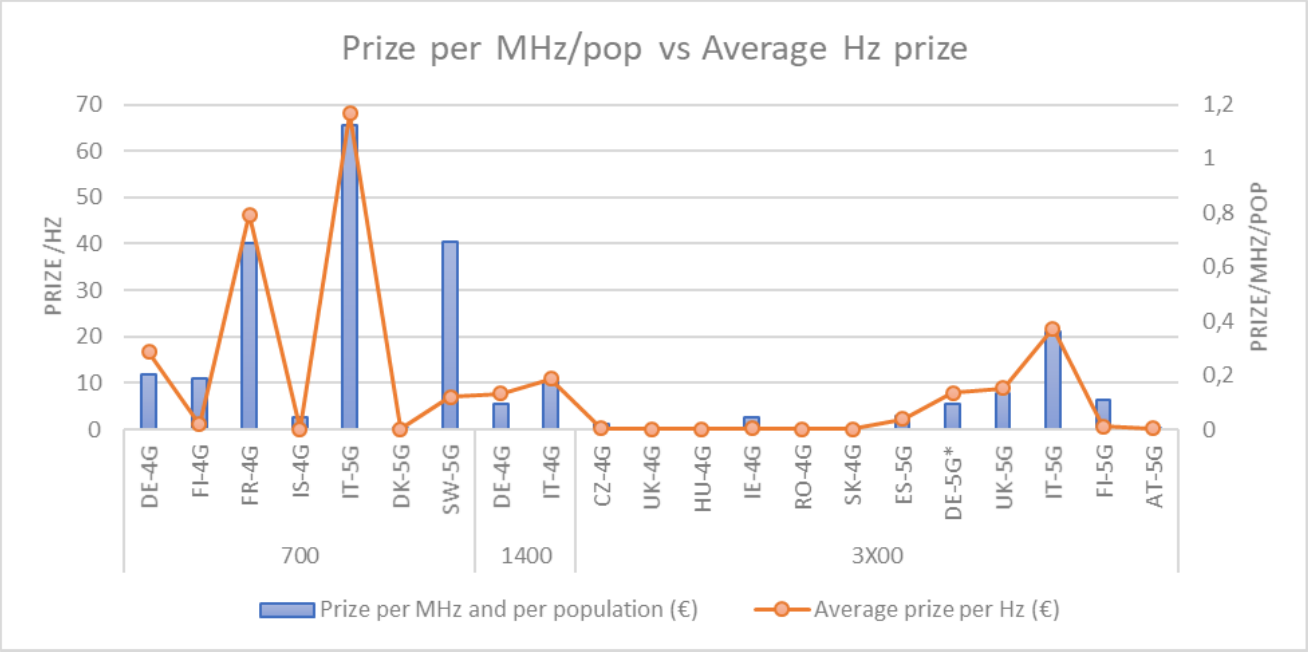
Spectrum (D2.2)

- The European Union is leading 5G band auctions, USA and South Korea are also having a pioneer role. In Europe, Italy has leaded the spectrum auction in all the 5G bands, with a higher price compared to other markets. Germany has defined important technical requirements in the auction.
- The spectrum usage for V2X remains under discussion, this may slow down the market roll-out of V2X technologies. Spectrum allocation should be technology neutral.
- According to the 5GCAR use cases, the most suitable spectrum bands are the medium and low frequencies. Coverage has priority over bandwidth for the defined V2X use cases so far.



Spectrum (D2.3)





- The uncertainty in spectrum usage remains. This uncertainty in spectrum usage has also impacts that may slow down the market roll-out and business development of V2X technologies
- From a regulatory point of view, spectrum allocation should be technology neutral

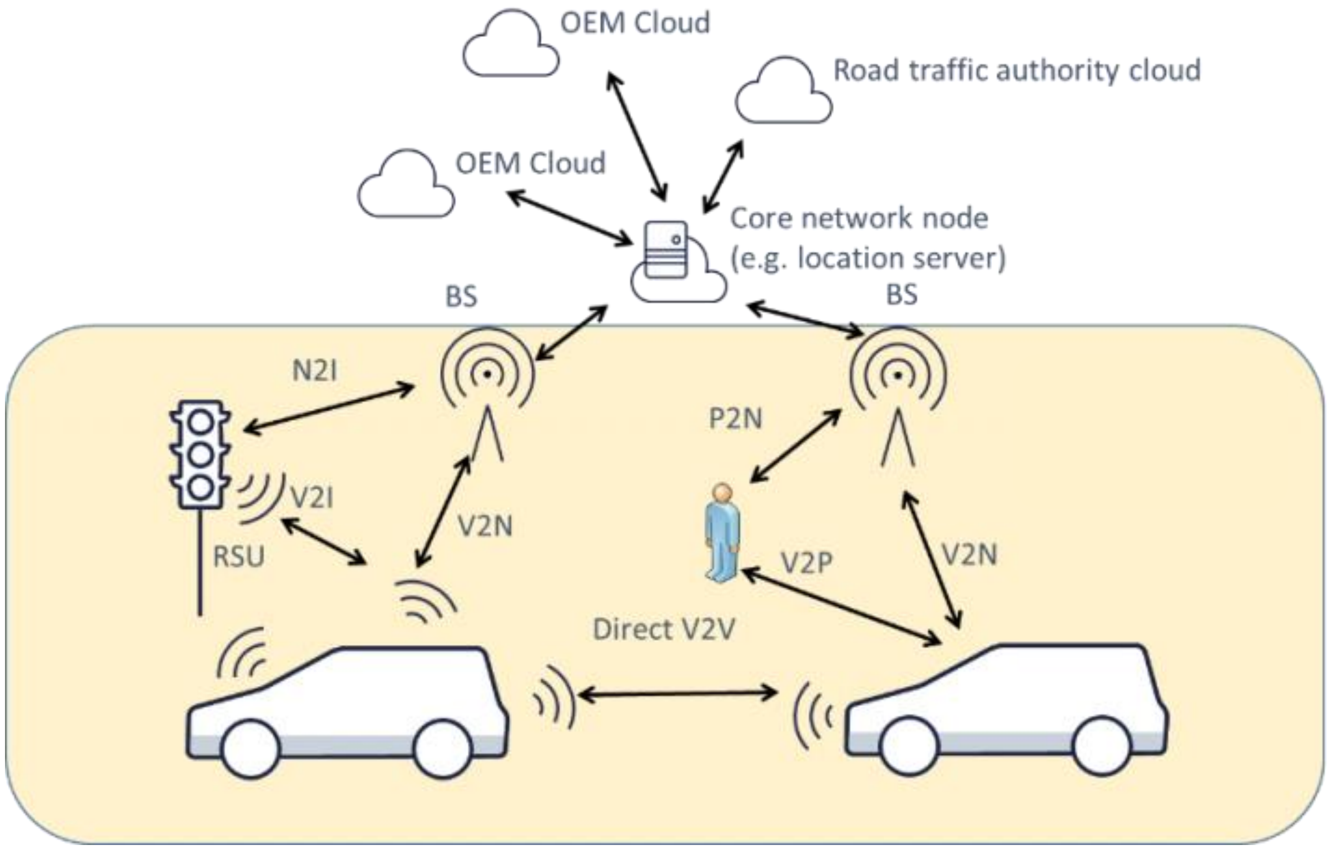
5G V2X Radio Interface

On Selected Technology Components

5G V2X Radio Interface (D3.1 and D3.3)

Scope

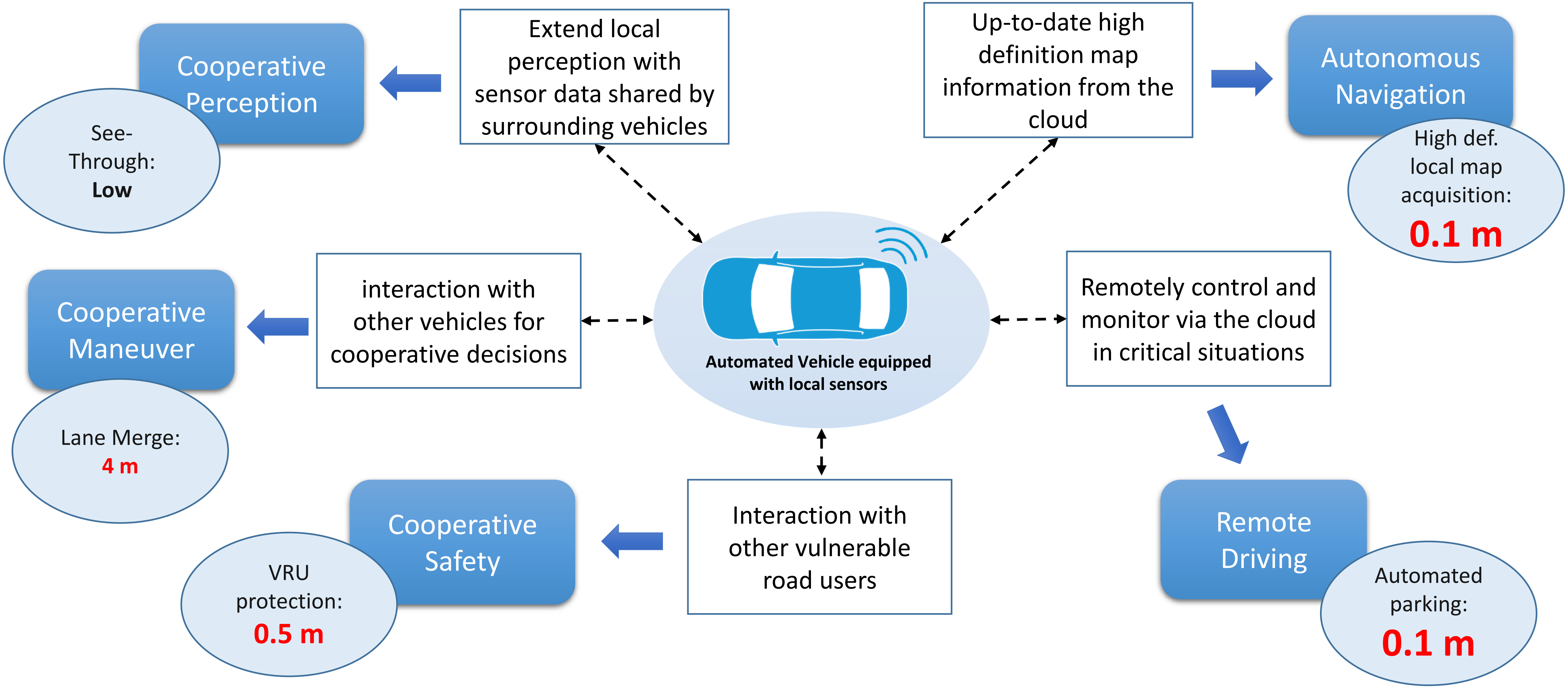
- **Efficient** and scalable 5G air interface to enable **low-latency**, **high-reliability** V2X communications
- **Infrastructure-based** communication (between vehicles and network)
- **Sidelink** communication (direct data exchange among vehicles without routing data traffic through the network infrastructure)
- **Evaluate** the individual enabling technologies with theoretical analysis, simulations and overall system performance evaluation.
- Propose 5G radio-assisted **positioning** techniques for both VRU and vehicles.



Channel modeling (D3.2)

- Discussion of prior art channel models used for V2X
  - Most important components are: LOS blockage analysis, path loss, shadow fading, fast fading
- Based on gap analysis, key contributions from 5GCAR are
  - V2V Measurements in cmWave and mmWave
  - mmWave V2V (Sidelink) Channel Modelling
  - Multi-Link Shadowing Extensions
  - New Channel Measurements for Predictor Antenna for M-MIMO Adaptive Beamforming
- Key achievement reflected in D3.2 (channel modeling part)
  - 5GCAR contributions led to agreements in 3GPP and results achieved in 5GCAR are reflected in 3GPP V2X channel models
  - Channel modeling on path loss (ABG parameters) and blockage loss accepted in 3GPP TR 37.885

Positioning (D3.2)



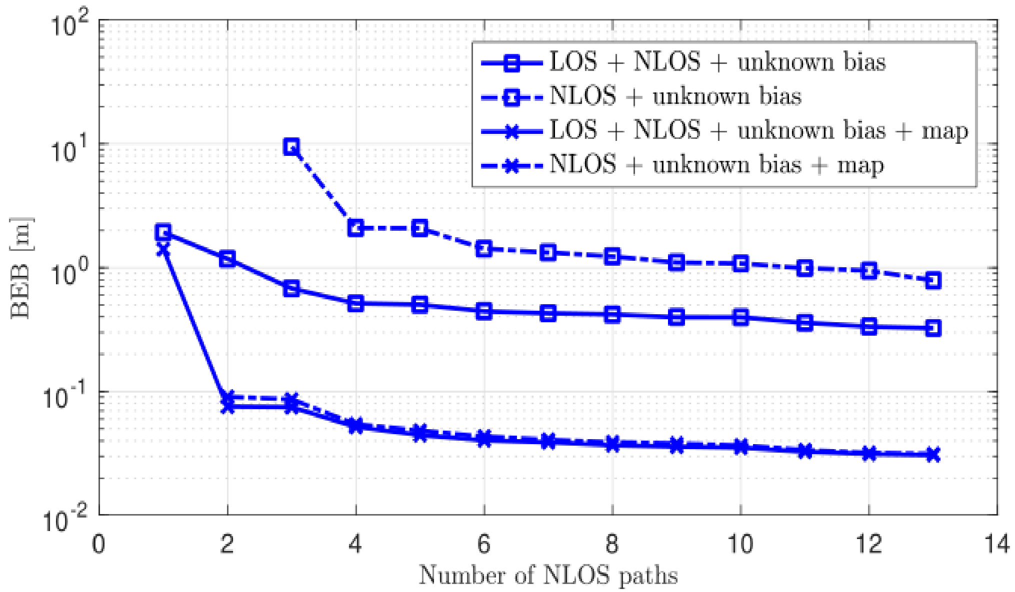
Positioning (D3.2): Technology Components

Technology component	Main concepts	5GCAR key application
Trajectory prediction with channel bias compensation and tracking	- User tracking with sensor fusion - Collision predicition	VRU protection
Tracking of a vehicle’s position and orientation with a single base station in the downlink	- Determine channel parameters for each multipath component - Single base station	High definition local map acquisition
Beam-based V2X positioning	- Network-assisted UE-centric approach - Angle estimation using 3D-beamforming	Automated parking
Data-aided beam-based positioning	- Data-aided positioning	Lane merge
Enhanced assistance messaging scheme for GNSS and OTDOA positioning	- Broadcast LPP assistance information	VRU protection
Multi-array 5G V2V relative positioning	- Using sidelink for time and angle measurements	Lane merge

Positioning (D3.2): Exemplary Result

Tracking of a vehicle's position and orientation with a single base station in the downlink

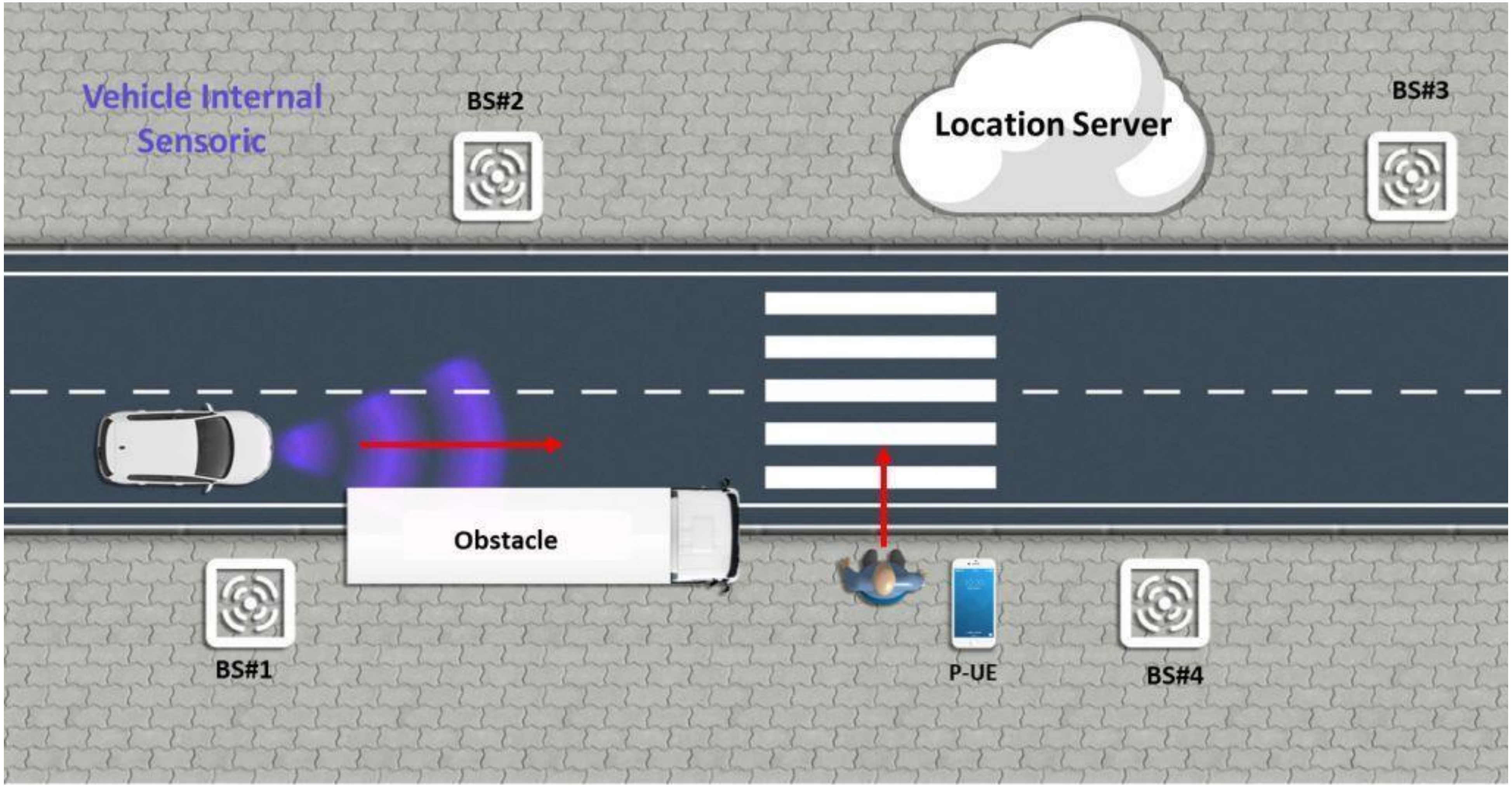
Fisher information analysis



Lessons Learned

- Position bias error bound (BEB) below 0.1 m is possible
- Multipath propagation and NLOS don't necessarily disturb the positioning performance, but even increase the accuracy if the right concept is applied
- Knowledge of the environment ('map') improves the performance
- Knowledge of clock offset between base station and UE is not required ('unknown bias')
- LOS path helps if map is not available

Positioning: Proof-of-Concept Vulnerable Road User Protection

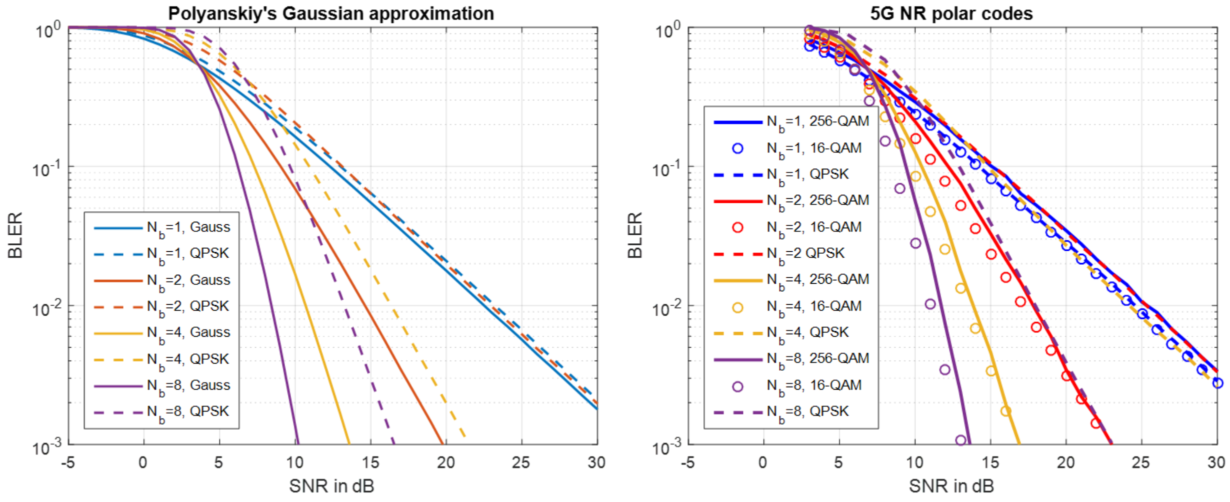


Positioning: PoC integration at test track

HMI Alert
Display

5GCAR V2X Radio Interface

- Fundamental tradeoff between latency and reliability
  - It is known that there is a trade-off between latency and reliability. The idea is to to obtain general design guidelines for coded modulation schemes according to the channel fading characteristics, ensuring high reliability with a limited latency.
  - Example result



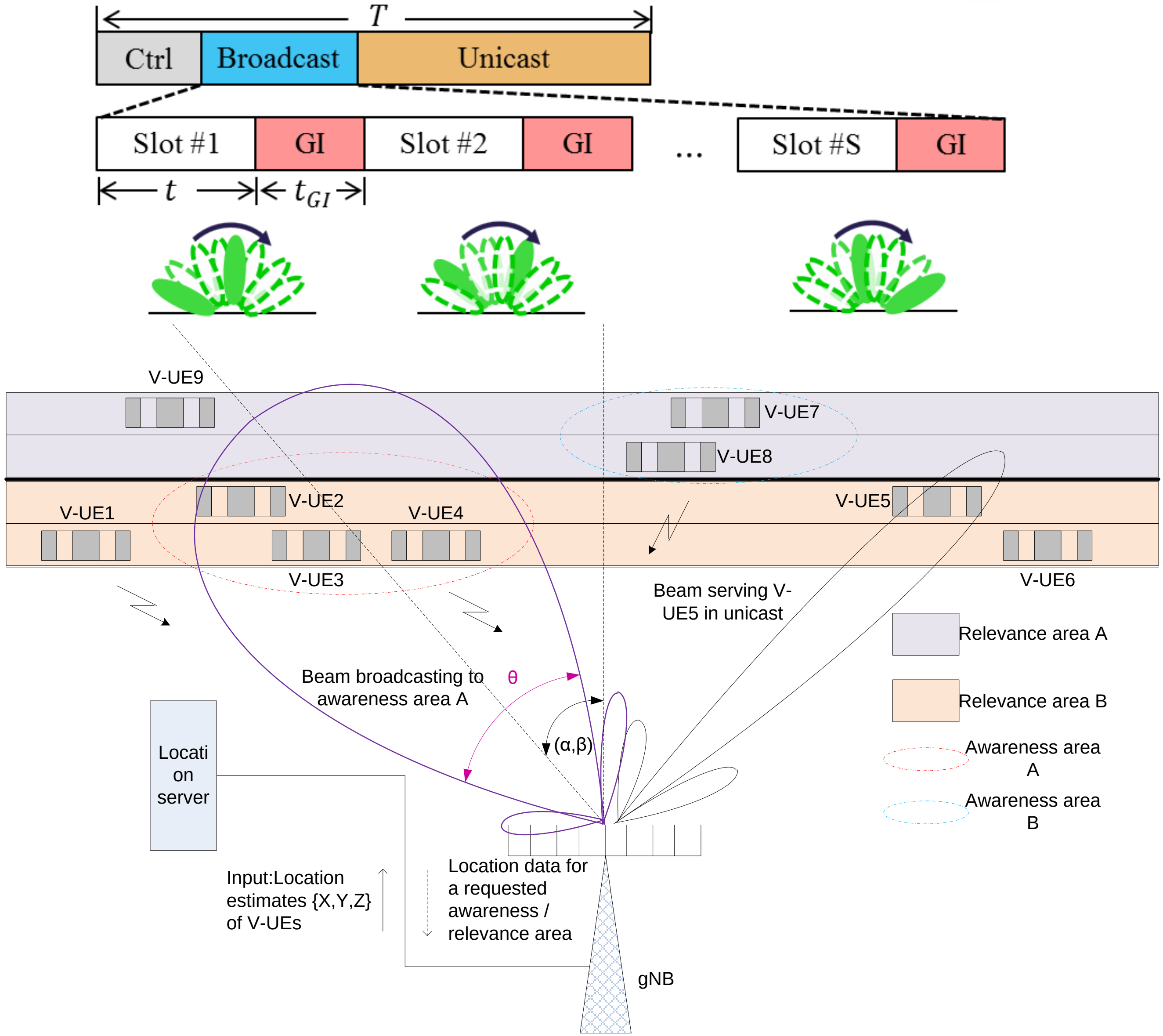
Block error rates for transmission of 192 info bits in 128 resource elements (R = 1.5 bit/use) over N_b Rayleigh fading blocks. Theoretical results (left) and 5G polar codes (right).

- A proper choice of the coding and modulation scheme is essential to meet the high reliability requirements of URLLC services in fast time-varying V2X scenarios.

5GCAR V2X Radio Interface

Example: Beam based V2X broadcast

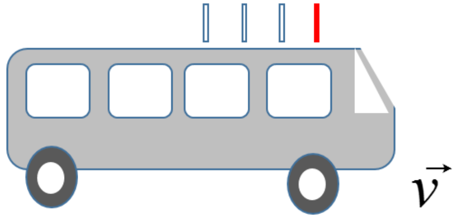
- Utilization of multicast / broadcast transmission especially at mmWave band could enable high data rate V2N/I communication links with resource efficient transmission of common content to multiple V-UEs.
- Reliance on highly directional transmission and reception considerably complicates the beam-based broadcast for V2X communications, which is expected to be designed properly considering different beam patterns, beam configuration, and multiplexing schemes, etc.
- Location based beamforming and the frame structure design.

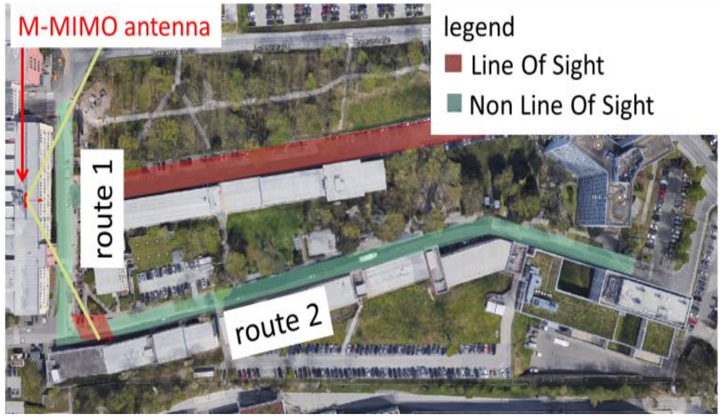


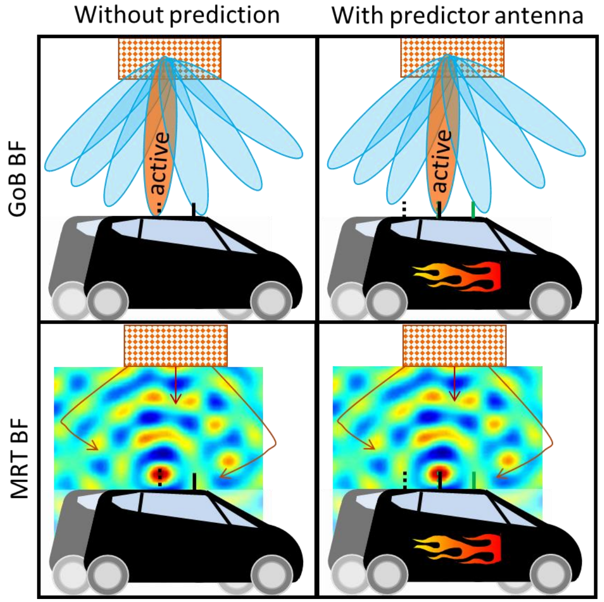
5GCAR V2X Radio Interface

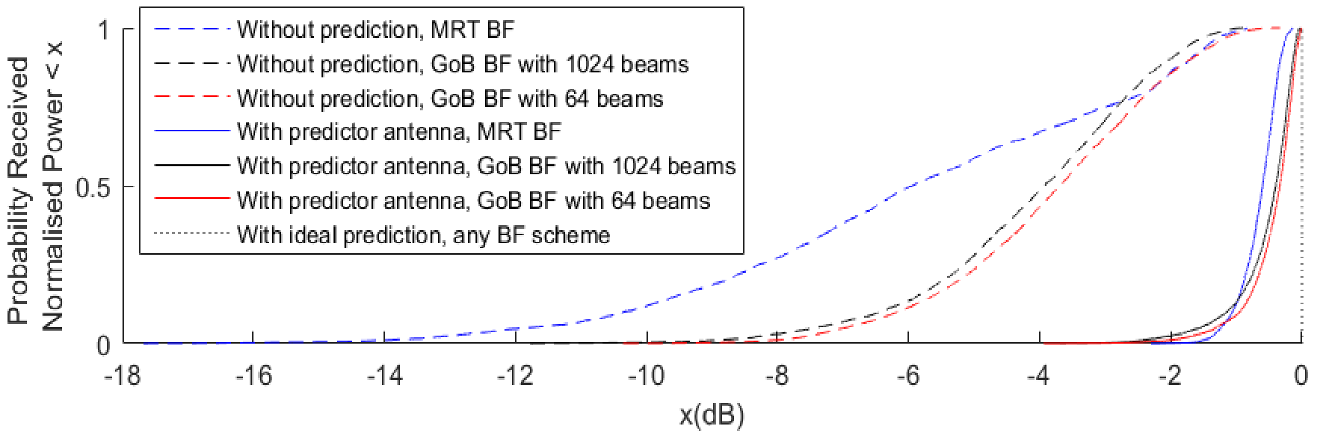
Example: Predictor antenna

- From concept to real measurement
- Results shows the channel estimates provided by the predictor antenna are accurate enough to support adaptive M-MIMO with high speed UEs.
- Sensitivity analysis e.g. antenna coupling, velocities etc.







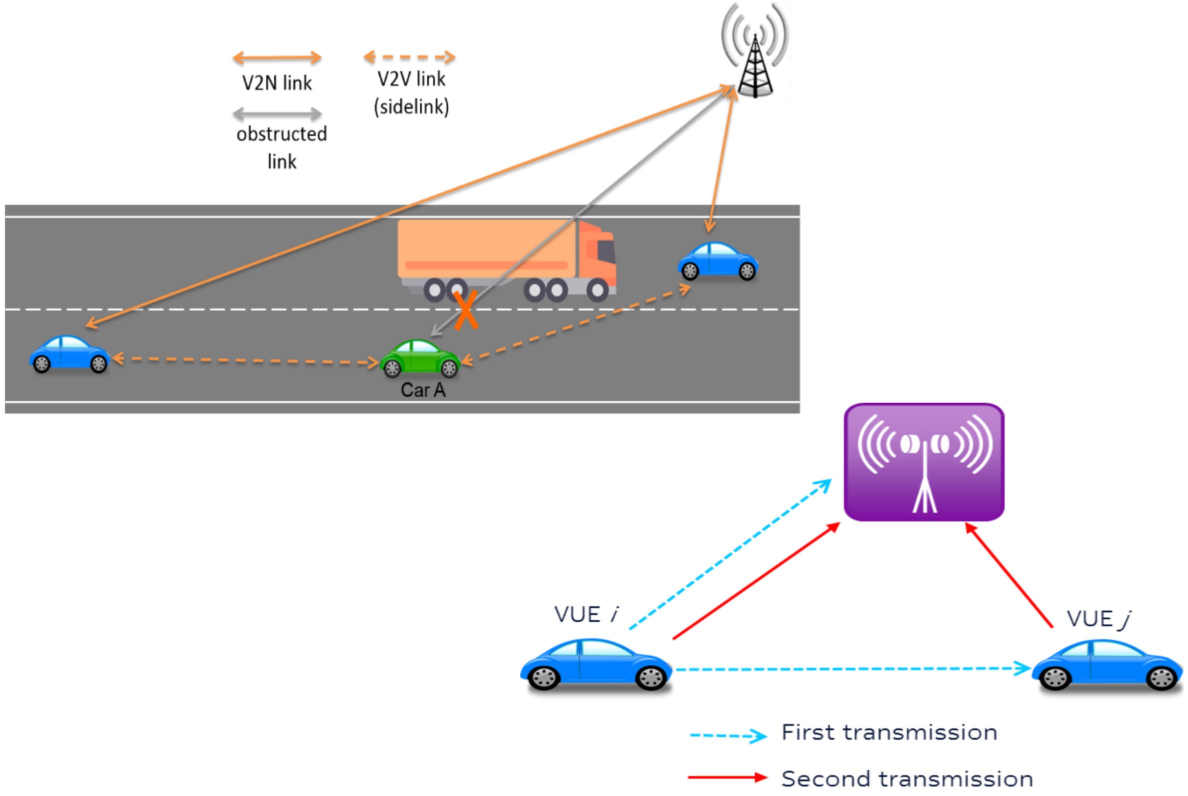


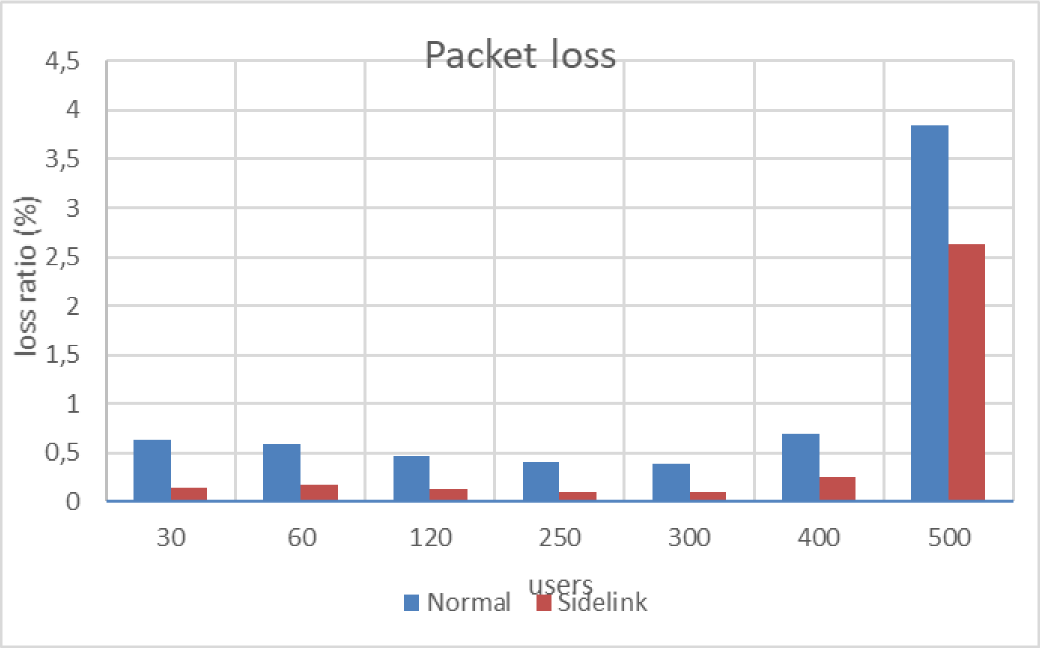
CCDF of the normalized received power metric based on practical experiments

5G V2X radio interface

Example: Sidelink assisted cellular communication (“Uu+PC5”)

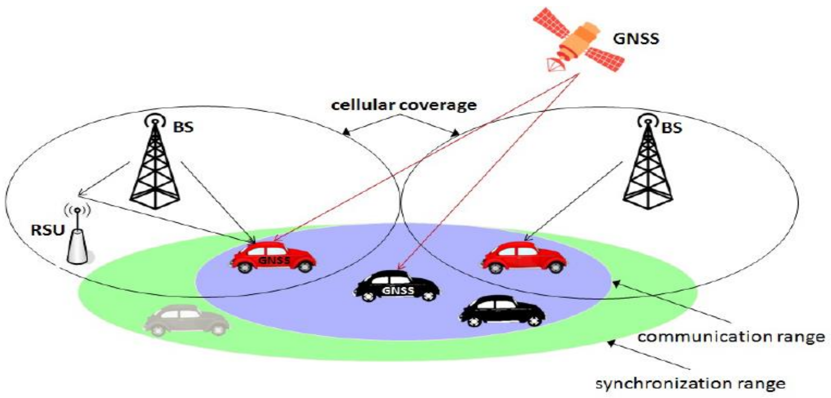
- All vehicles maintain a V2N connection to the 5G gNB and at the same time V2V links to other vehicle(s) in the vicinity (after D2D discovery).
- V2V link can be used to enhance the reliability of the regular V2I link both DL and UL.

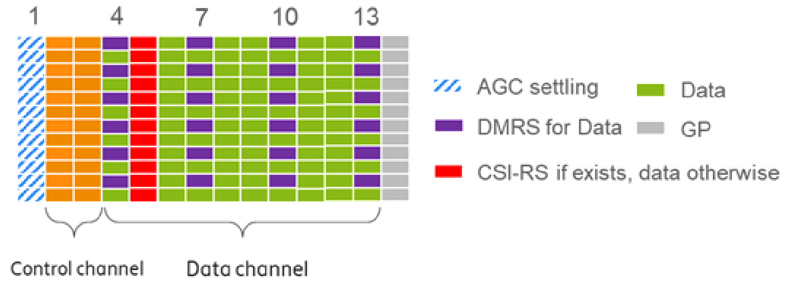


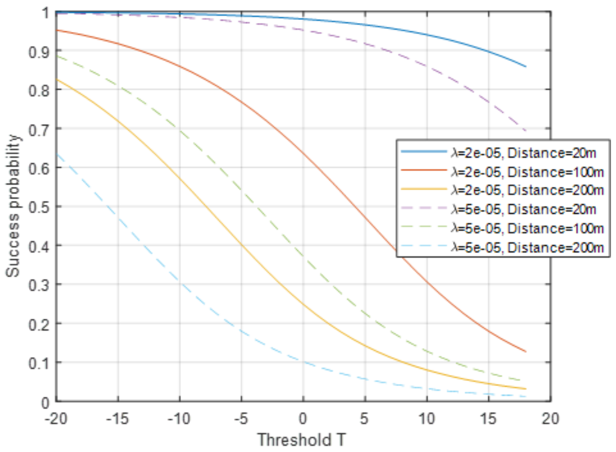


5G V2X radio interface
Sidelink design

- Sidelink concepts:
  - Synchronization signal design
    - Allowing more efficient usage of the time/frequency resources allocated for synchronization and carrying additional information in the synchronization signals, e.g., coverage status or type of synchronization source.
  - Reference signals design
    - Balancing the robustness and the induced overhead.
  - V2V sidelink discovery
    - The discovery scheme follows the principles of random-access procedure and consists of three sequential phases of message exchange among a transmitting (Tx) vehicle/user, each receiving (Rx) vehicle/user within a discovery distance, and the discovery entity.



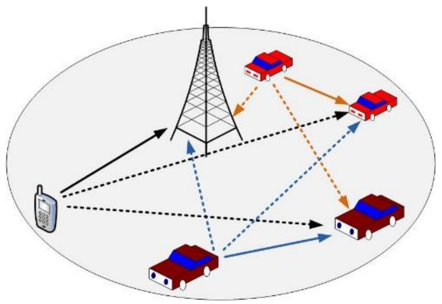




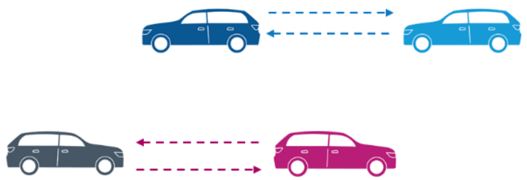
5G V2X radio interface

Sidelink resource allocation

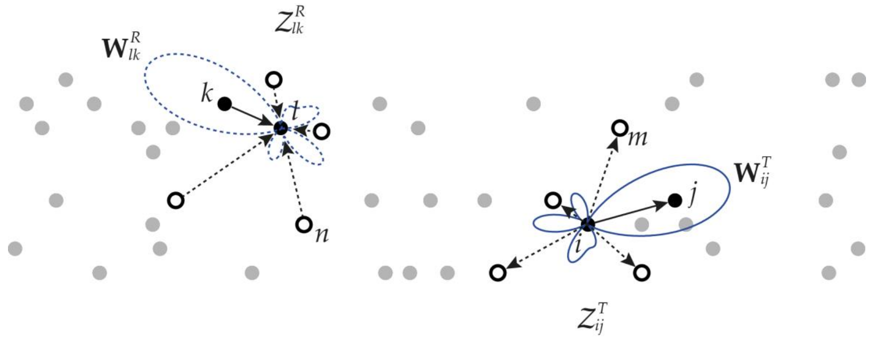
- Diverse concepts:
  - Centralized resource allocation
    - Two-stage RRM framework: the BS first allocates RBs and power to V-UEs, i.e., the UEs with more strict requirements, on a semi-persistent basis, and then in the second stage conducts C-UE scheduling on a dynamic basis as in e.g. LTE/NR.
    - Integration of beamforming/MIMO for sidelink resource allocation: UEs report their ability to use multi-antenna transmission/reception to cancel interference to/from nearby UEs.
    - Geographical zones based resource allocation with flexible slot/half-slot operation.
  - Distributed resource allocation
    - The TC is based on cooperation between the pair of users forming the unicast link where the sender and the receiver share the results of their local sensing mechanism and adjust the parameters of the semi-persisting scheduling accordingly.



Centralized mode: UL radio resources are shared by C-UE and V-UEs



Distributed mode: Mode 4 or OOC



Integration of beamforming/MIMO techniques in the sidelink with BS-assisted resource allocation

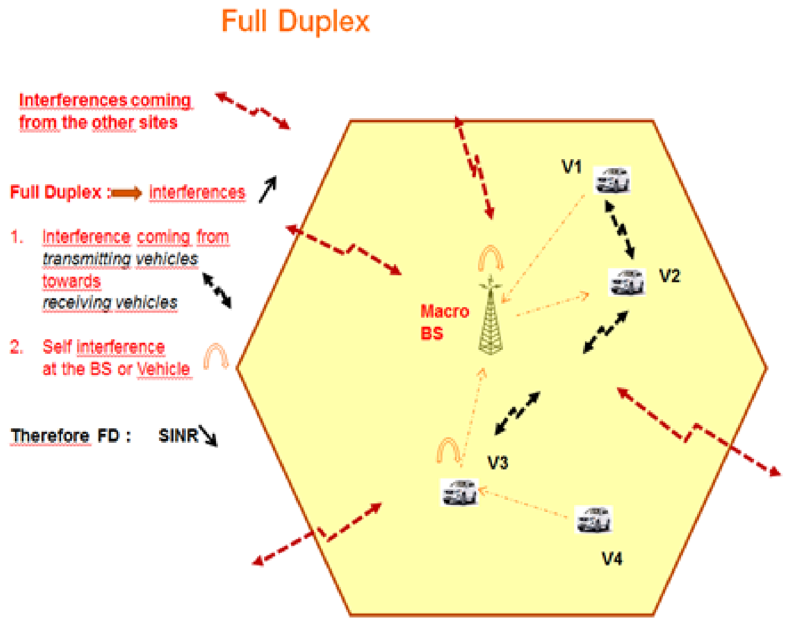
5G V2X radio interface

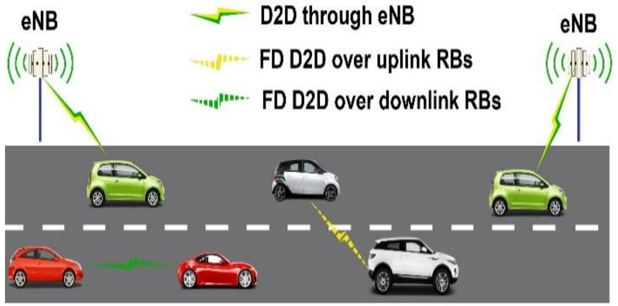
Full duplex

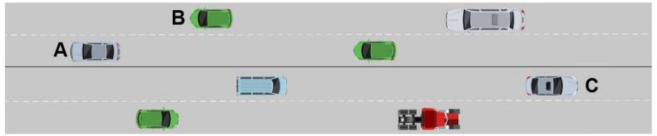
- Full Duplex Impact on V2X Performance
  - Interference situation analysis

- Cognitive Full Duplex Communications
  - Cognitive scheme for full duplex V2V communication of two secondary users (cars) over downlink or uplink channels

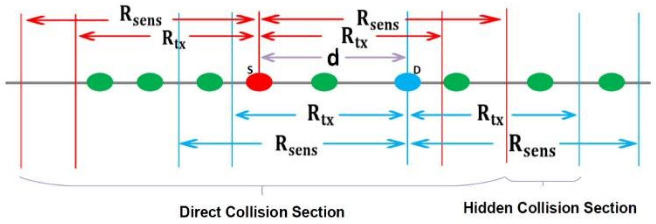
- Full Duplex Collision Detection in V2X Networks
  - FD capability has been exploited for detection of any collision of broadcast messages of vehicles, and a cross layer MAC protocol has been proposed to avoid such collisions and guarantee the delivery of important messages with higher priorities.







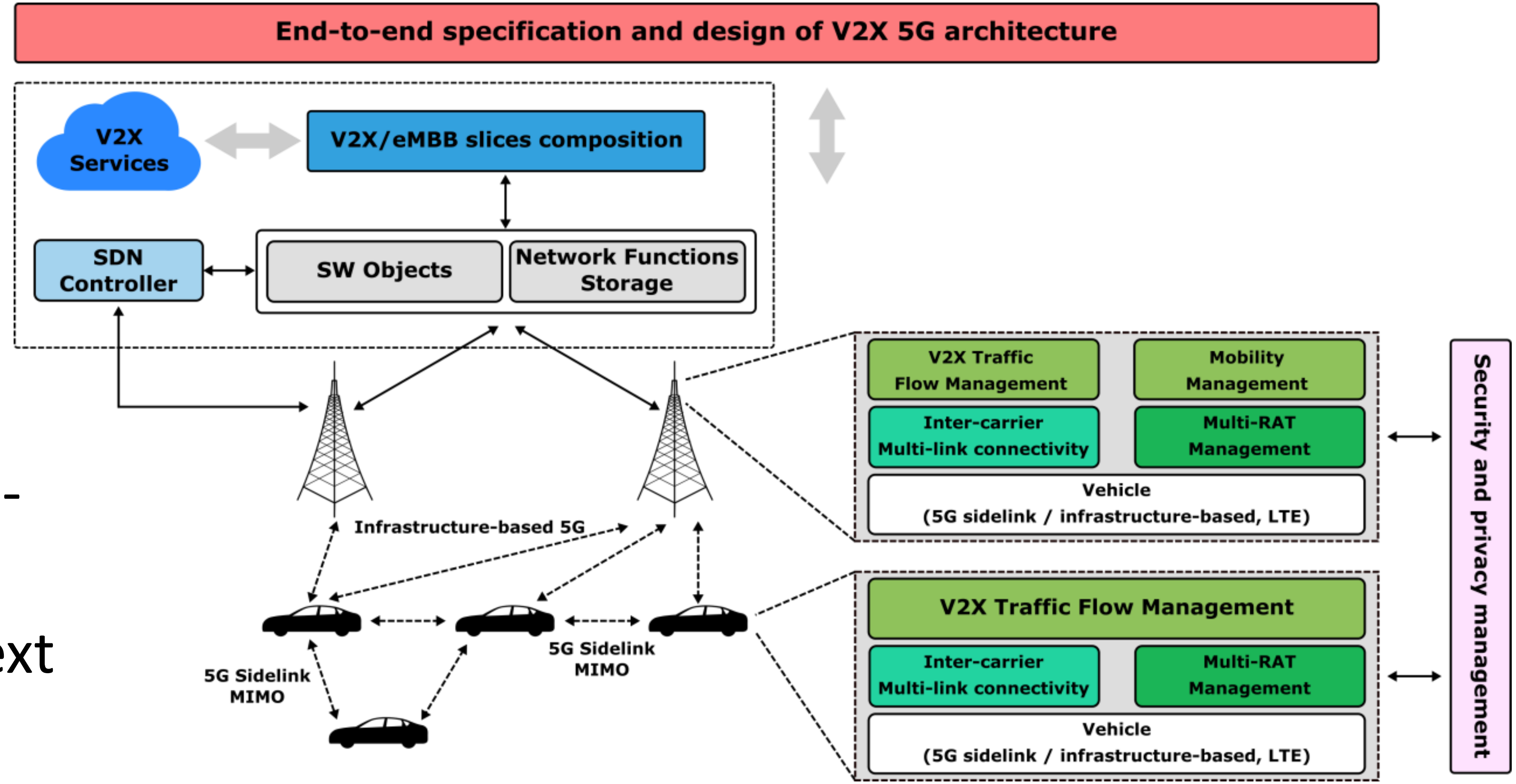
(a) VANET model



V2X System Level Architecture

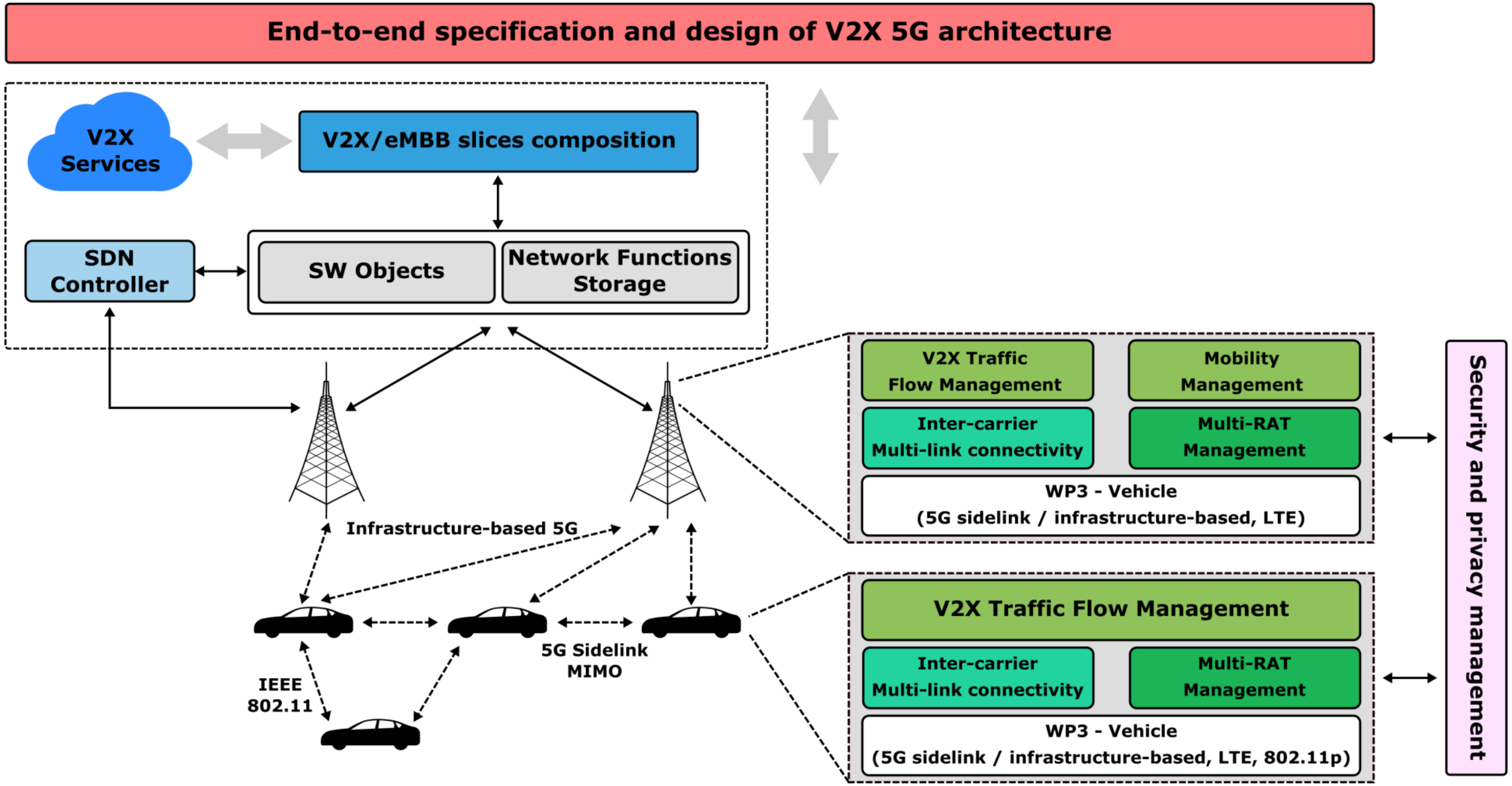
V2X System Level Architecture (D4.1)

- Support of multi-operator
- Security and privacy
- Smart Zoning
- Dynamic use of Multi-RAT and Multi-Links
- Use of advance context information



Objectives

- Develop an **overall 5G system architecture** providing a dedicated **V2X network slice** with network and application functions for highly reliable and low-latency V2X services.
- **Multi-Radio Access Technology** (RAT) interworking to embed existing communication solutions (including short range technologies, IEEE 802.11p) comprising **multi-RAT mode selection** working in **side link and/or infrastructure-based** mode.
- Enable **optimized Quality-of-Service** (QoS) handling and traffic flow management in a **multi-RAT and multi-link** V2X communication system.
- Develop an **overall security and privacy solution** for 5G V2X communications based on multi-RAT and multi-link connectivity.



Areas of action

1. **Network orchestration and management**
   - Infrastructure as a service for V2X
2. **End-to-end security**
   - Enable secured and anonymous communication between a group of vehicles
   - Avoid requiring all messages to be signed with costly cryptographic signature
   - Privacy constraints
3. **Multi connectivity cooperation**
   - Multi link / multi-Radio Access Technology connectivity (sub-6 Ghz / mmWave)
   - Dynamic link selection (sidelink / Uu)
4. **Edge computing enhancements**
   - Advanced job migration in edge computing
5. **Network procedures**
   - Road side unit-based Smart Zoning
   - Localized scheduling / low level-routing

Technical enabler: network slicing

1 – Network orchestration and management

Infrastructure as a Service for vehicular domain

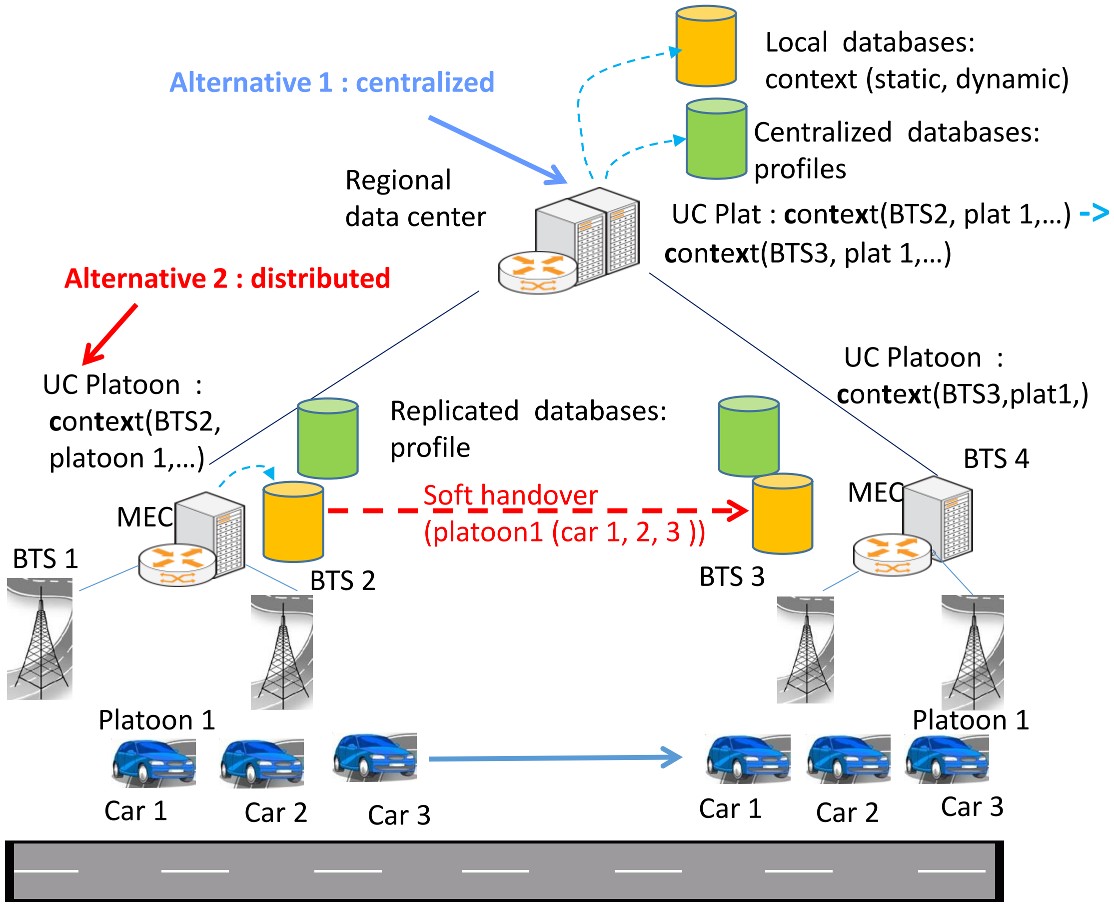
Problem: critical application (software) deployment / orchestration by 1st /3rd party entities for ITS domain

- Integrating redundancy, reliability, QoS constraints
- Dynamic deployment: distributed/centralized

- Service adaptation to network conditions
- Application(distributed) logic dependent to network context at UE side (location, QoS requirements)

Solution: knowledge plan (NWDAF+) -> NEF opened to Application, Operation Support System (service orchestration)

Result: architecture separating service plan from network control plan, opened to 1st /3rd party developers, road operators, and authorities



KPIs	Data rate	Latency	Reliability

2 – End-to-end security

Security

Problem:

- Security impacts bandwidth and latency
- Certificates need to be attached to messages:
  - Introduce significant **header**
  - They are **costly** to generate

Proposition:

- Rely on central entity for Authentication and Authorization checks;
- Provide session key for a group of communicating UEs;
- Use the key to sign / encrypt exchanges in the group

Privacy

Context:

- GDPR does not apply to anonymous data
- V2X applications use pseudonyms
- Pseudonyms ≠ anonymization
  - For instance for misbehaviour detection, which requires link to true identity
- For how long can driving data be stored

Recommendations:

- GDPR shall better address V2X devices
- CAMs and CPMs: critical for Day-2 applications: not clear how they can be compliant with GDPR – for discussion

KPIs | **Security and privacy**

3 – Multi connectivity cooperation

Problem:

- V2X include different classes of use cases, with different impact on radio interface

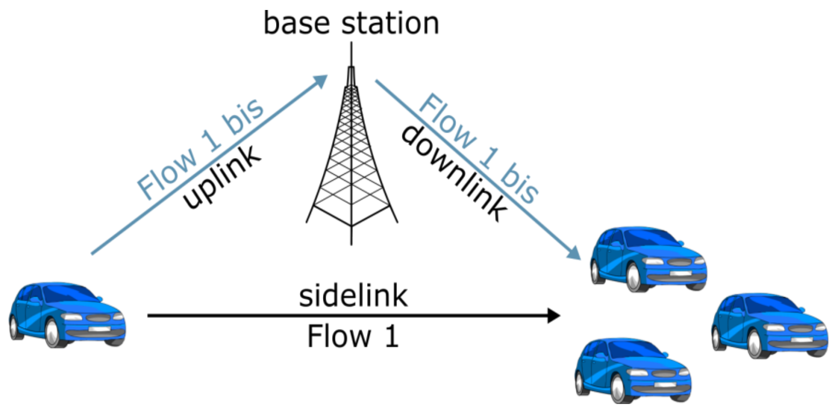
Solutions (different perspectives):

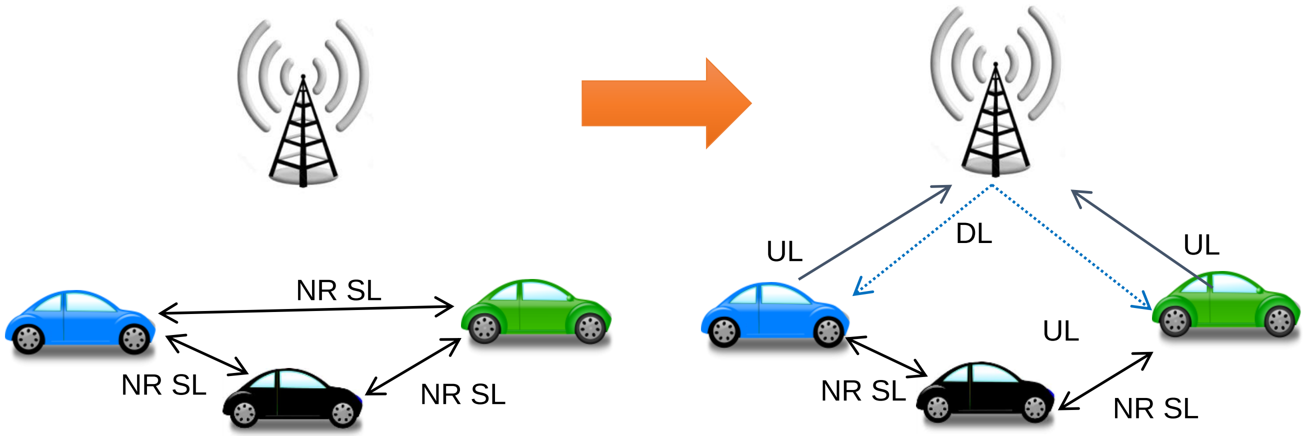
Sidelink might not be sufficient for some type of communications

Redundancy over air interface (higher reliability), dual link for higher data rate

Dynamic sidelink or Uu selection based on QoS requirements

Best solution may be achieved by combining multiple links over multiple RATs, based on use case





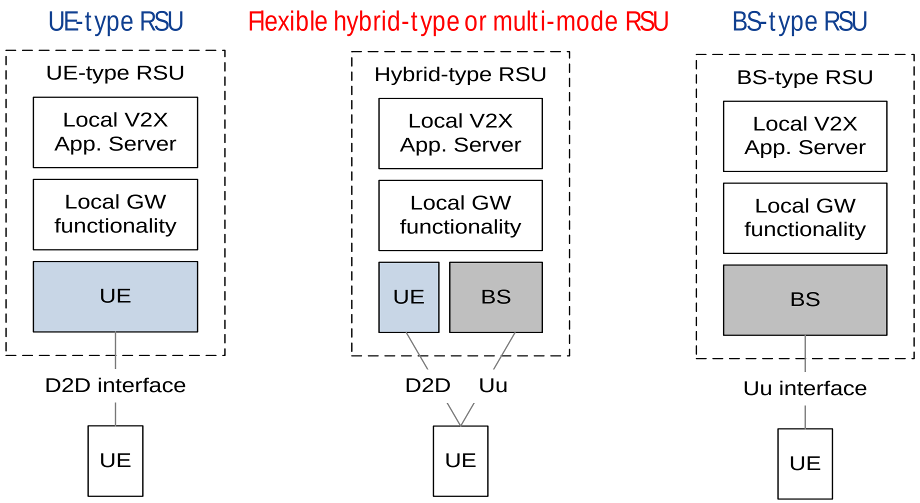
KPIs	Data rate	Latency	Reliability

4 – Edge computing enhancements

- **SON-based multi mode RSU**

  Problem: Uu connections for V2X may face capacity and/or efficiency issues depending on road-traffic conditions and service demands, therefore need to be scalable and adaptable.

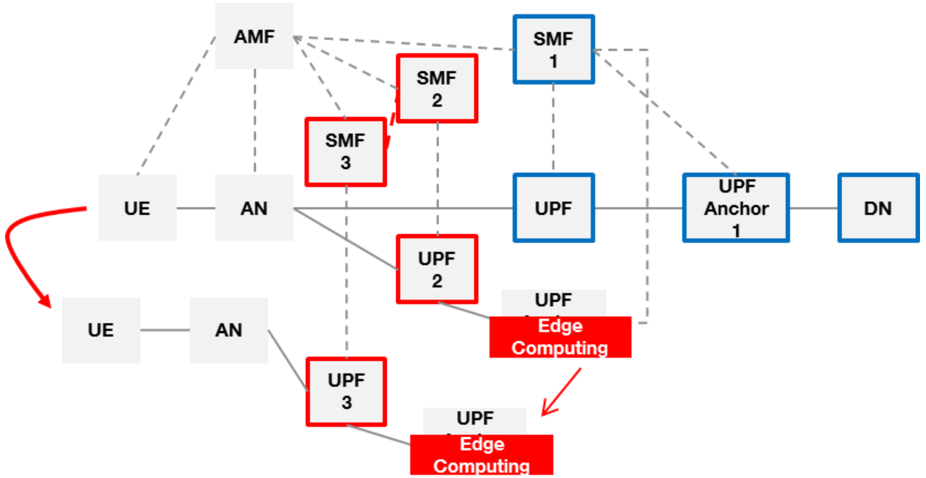
  Solution: control of adaptive RSU operation and UE behavior on-the-fly, depending on dynamics of road-traffic characteristics and service demands



- **Enhanced 5G edge-computing-based mobility**

  Problem: maintain jobs running on edge computing servers synchronized and improve availability when UEs hand over

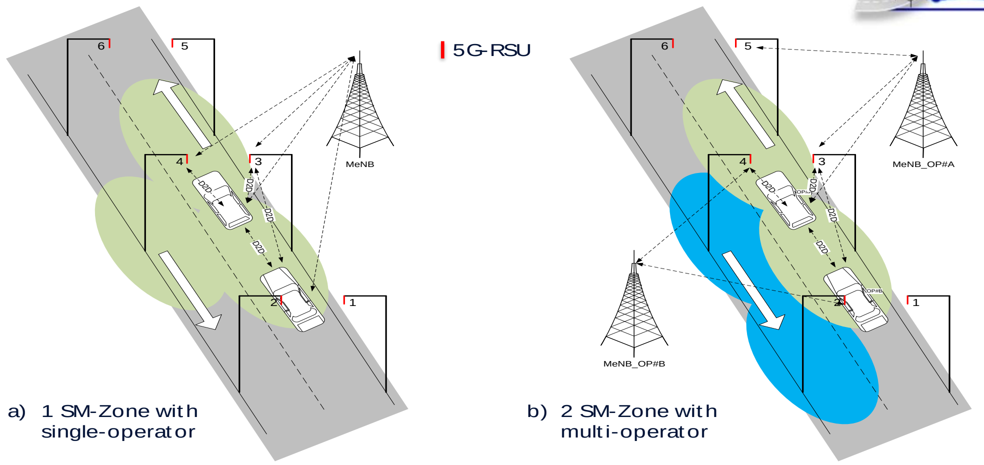
  Solution: network analytics to anticipate the hand over procedure, and pre-emptively migrate jobs

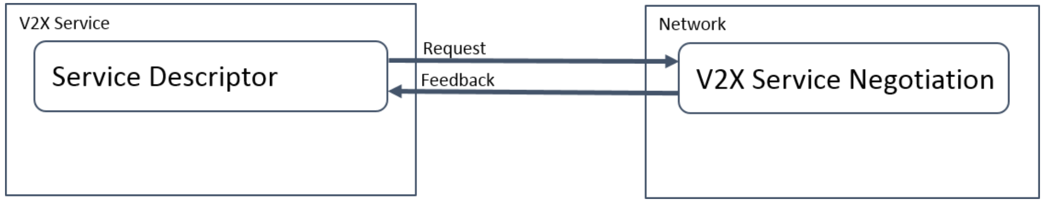


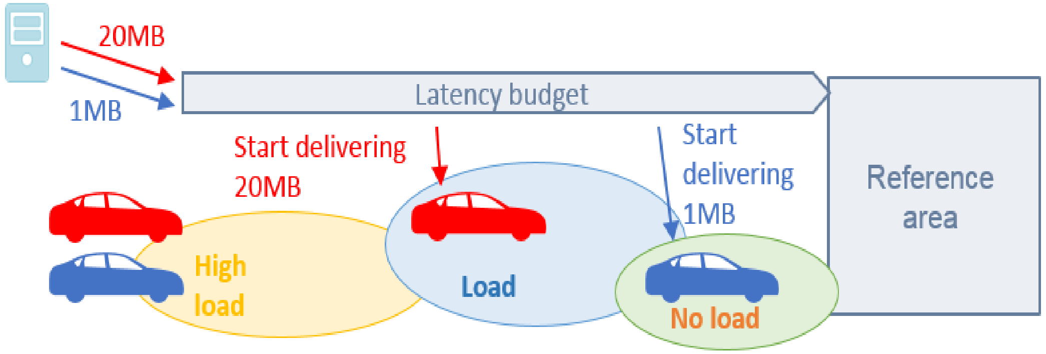
KPIs	Data rate	Latency

5 – Network procedures

- **RSU-based smart zones**
  - smart local on-road radio coverage, SM-Zone with multi-operator support
- **V2X service negotiation**
  - delivery of V2X services depending on network capabilities in space and time.
- **Multi operator solutions for V2X**
  - geographical splitting of coverage areas
  - network improvements: procedures to force attach to a different operator

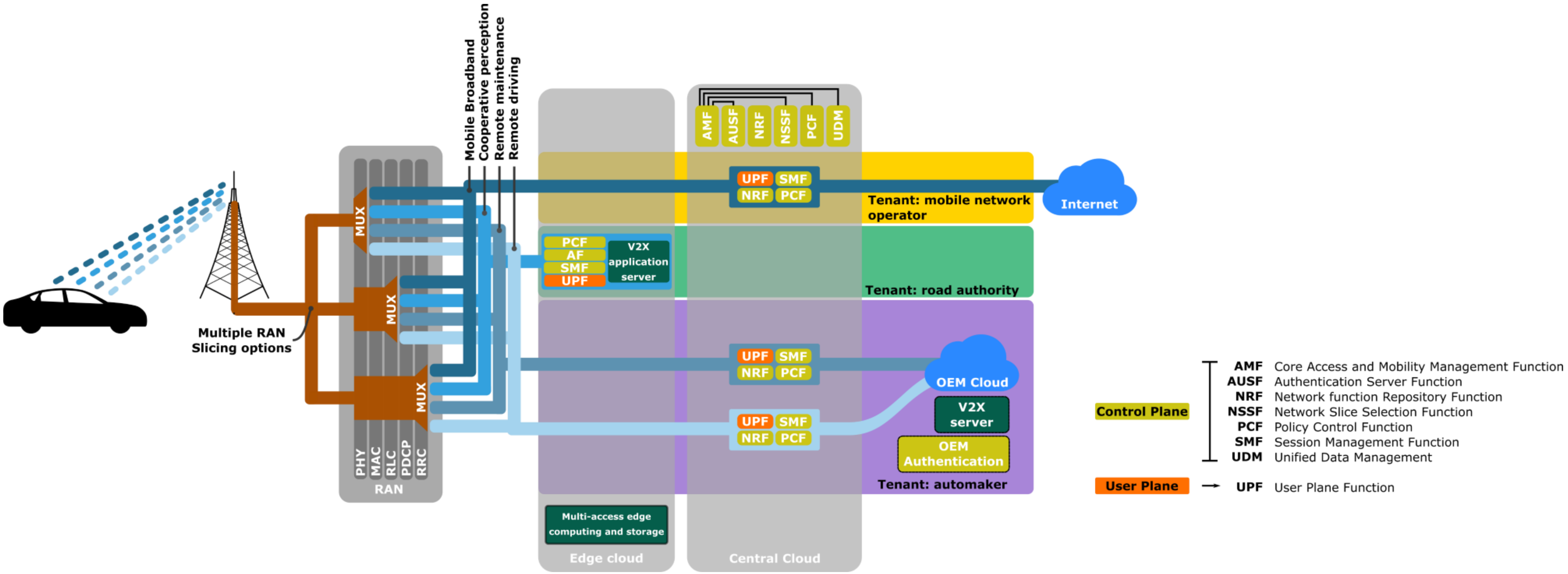






KPIs	Data rate	Latency	Reliability

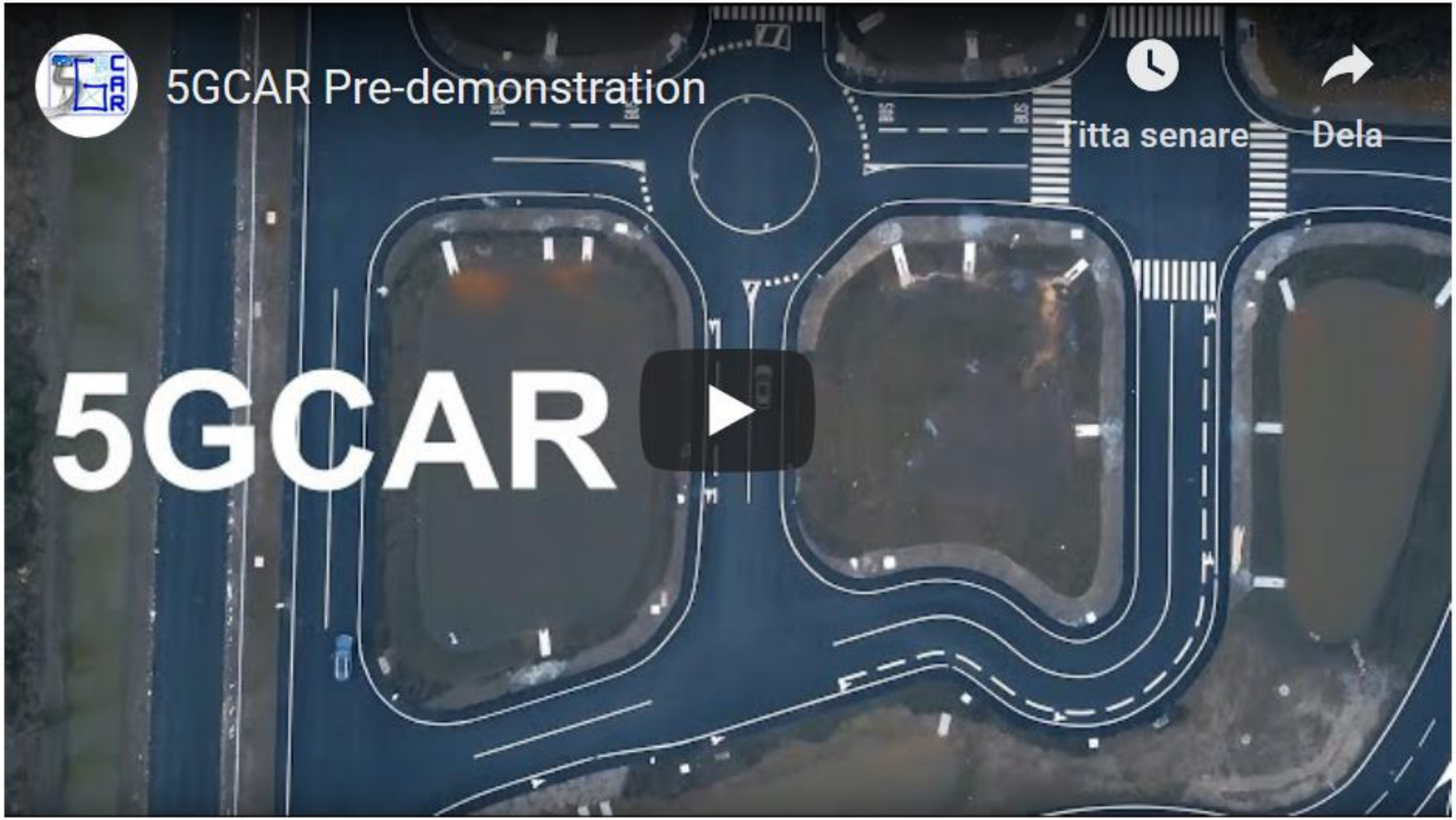
Network slicing for V2X



V2X: different classes of services, offered by different tenants

5GCAR Demonstrations

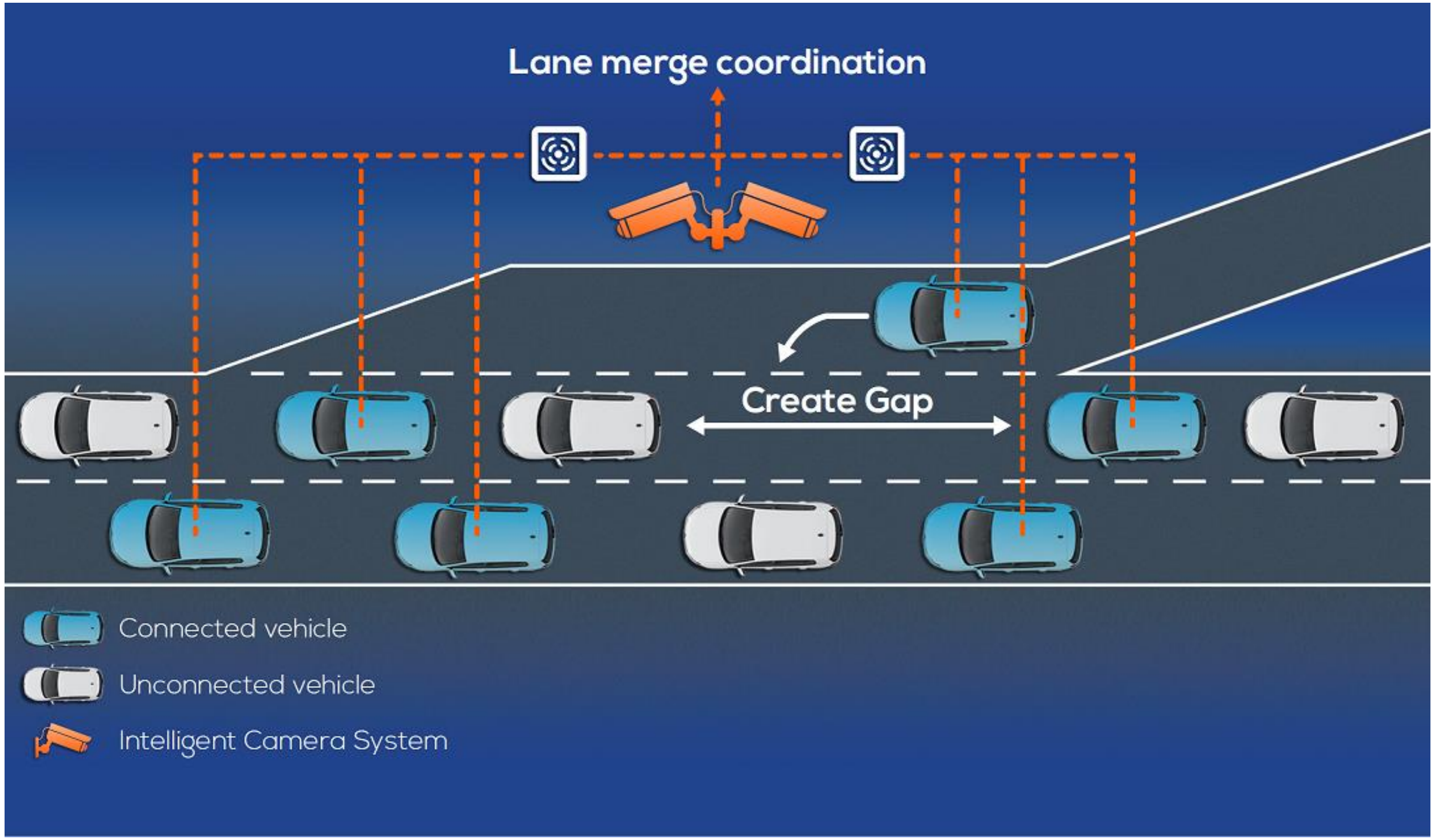
5GCAR Pre-Demonstration



Video on https://5gcar.eu/

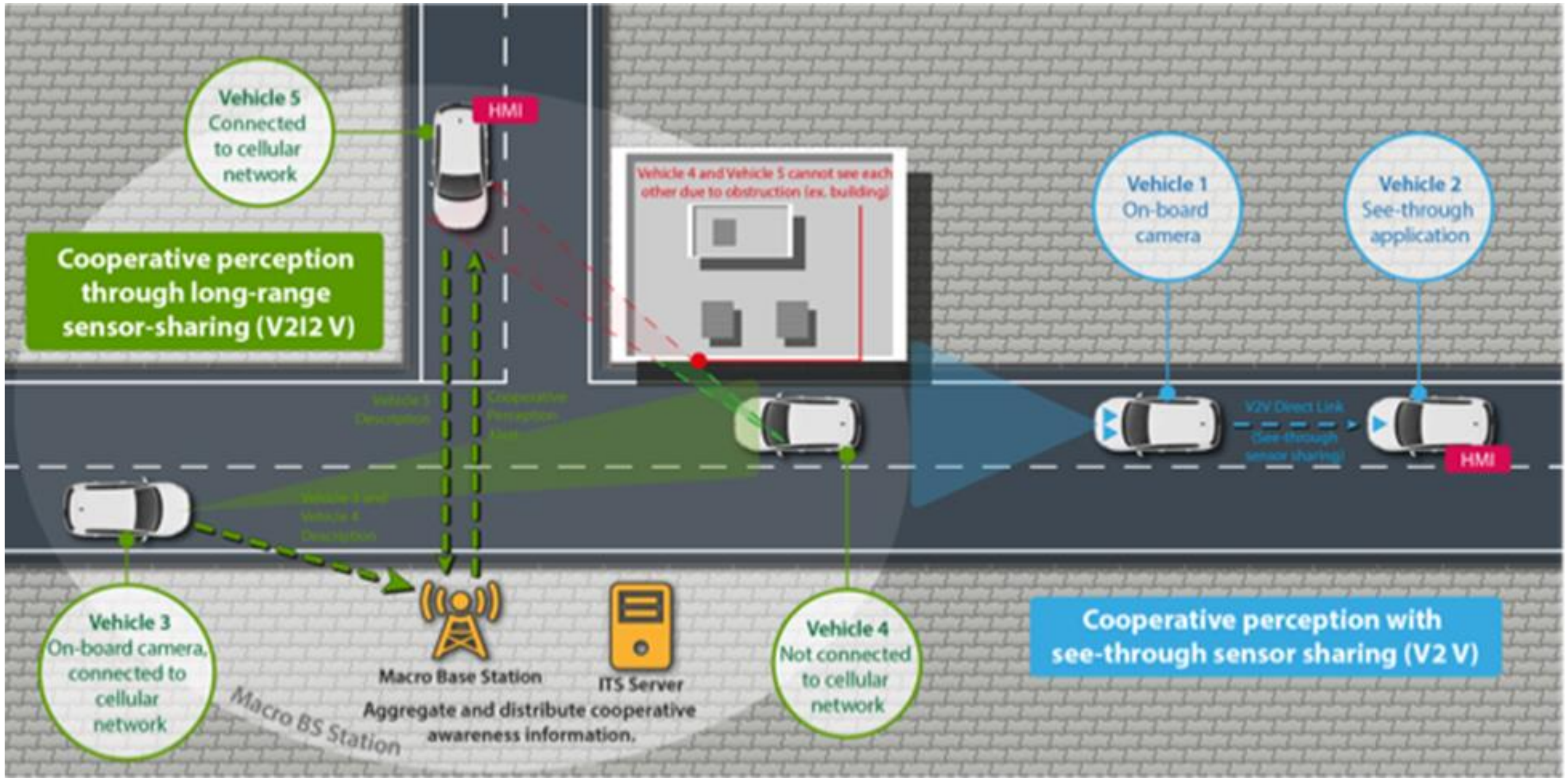
Lane Merge Coordination

- Connected vehicles make room for an entering vehicle
  - Coordinated by a central entity
  - Camera system for detection of unconnected vehicles



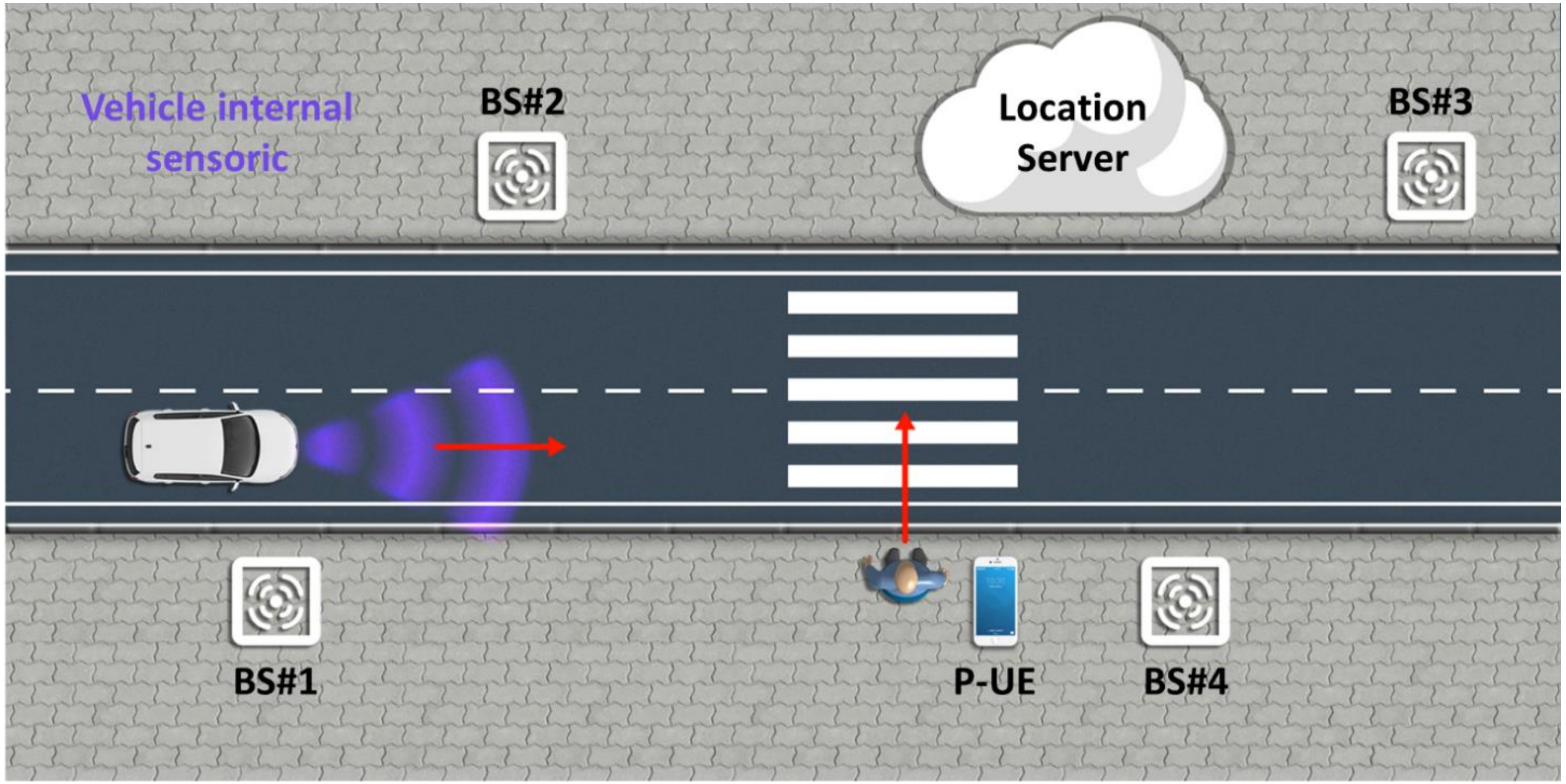
Cooperative Perception for Maneuvers of Connected Vehicles

- Camera-equipped vehicle streams region of interest from video (and other sensor data) to a rear vehicle
- The rear vehicle displays the received information as overlay over the occluded area



Vulnerable Road User Protection

- Pedestrian-UEs and CAR V-UE send out specific waveforms to infrastructure
- Base stations receive it, and the location server triangulates the positions
- Positions are sent via Infrastructure to Car (optional to Pedestrians, app required)
- Potentially triggering warnings via Alert message to Car (optional to pedestrian)



Role of 5G in Automotive Industry

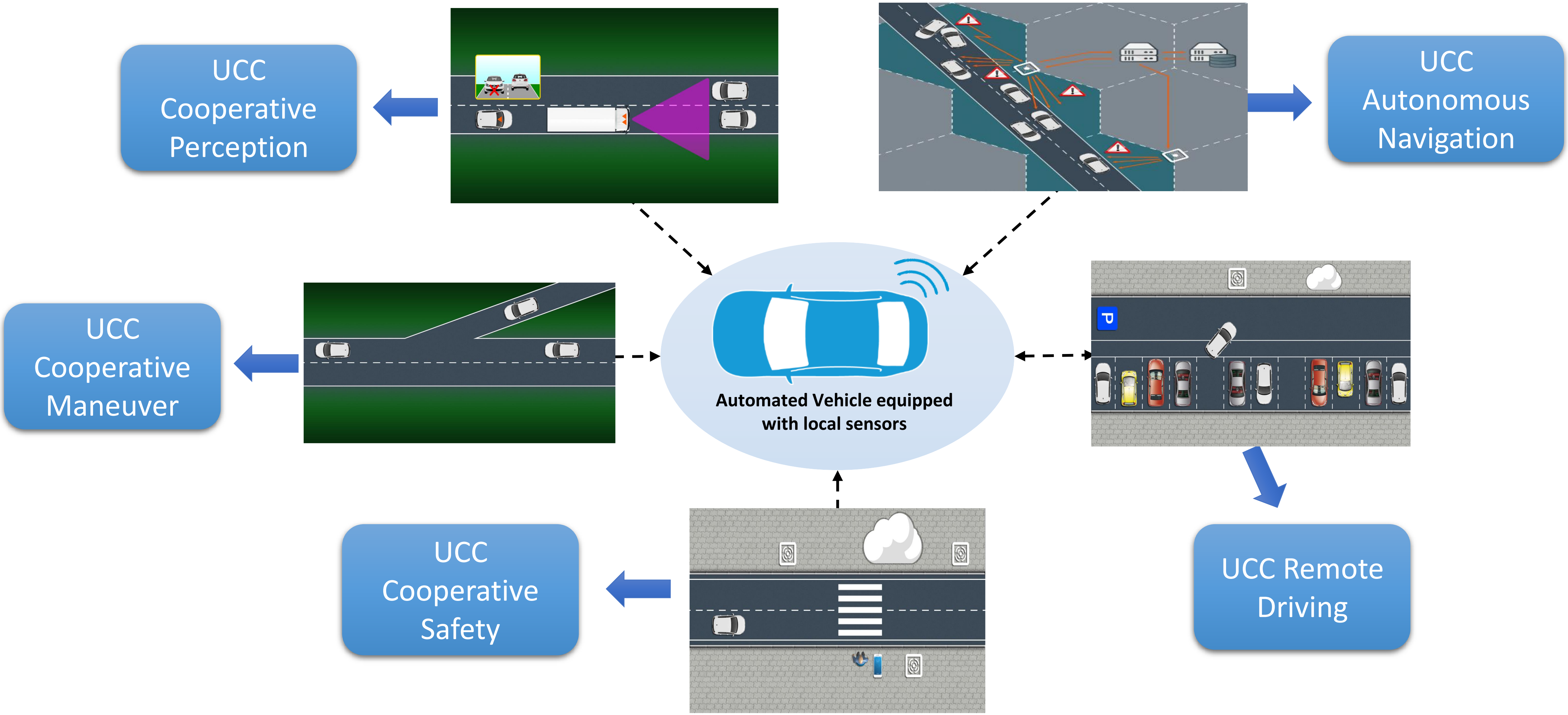
- **New 5G radio technology for more advanced automotive services of** infotainment and a continuously safer system, while leverage on existing infrastructure and device support
- **Cost-effective** coverage, e.g. in rural areas
- **Coverage** is key for Automated Driving (AD) since if e.g. an (Original Equipment Manufacturer) OEM or transport company are liable than one would need to control if in AD or not
- **Cellular** can accommodate both long range and short range communication, e.g. on licensed spectrum
- **Reliability and low latency** connectivity in high mobility
- **QoS** can be used to e.g. prioritise OEM traffic over MBB
- To be **secure**d from potential attacks and ensure privacy (e.g. how much personal location information is stored and possible to access for others)

Thank You

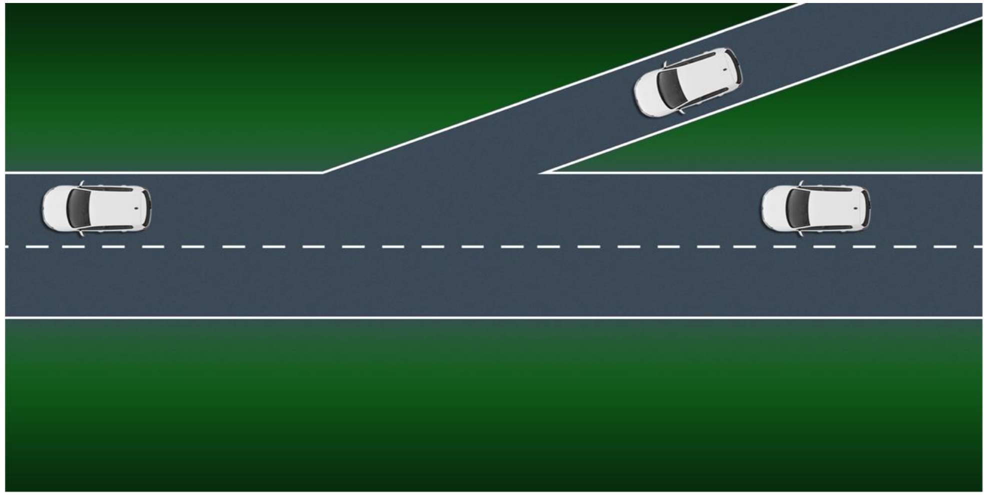
https://5gcar.eu/

Annex

Scenario definitions and requirement specifications
Use Case Classes and Use Cases



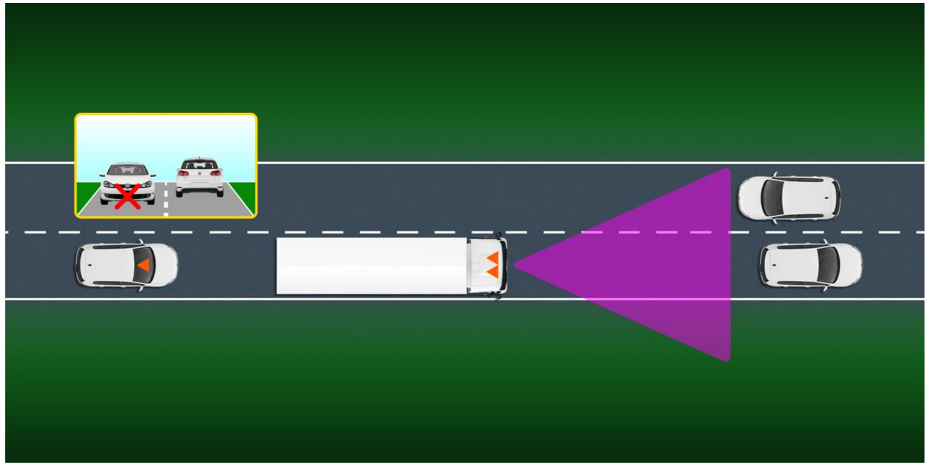
UC1 : Lane merge



- **Goal:** Provide trajectories for the vehicles that are on the main lane to merge smoothly into the main lane without collisions and with minimal impact on the traffic flow.
- **Target environment:** Anywhere including highways, urban roads, and intersections
- **Pre-conditions:** A remote vehicle is a connected and equipped vehicle, where connected implies wireless connectivity capabilities and equipped implies on-board sensors and autonomous driving capabilities. Involved vehicles are authenticated.
- **Triggering event:** A vehicle wants to merge the insertion to the main lane.
- **Operational requirements:** The connected vehicle needs a wireless communication capability and a Global Navigation Satellite System (GNSS)
- **Post-conditions:** The safety distance between vehicles is to be respected, i.e. no collision due to the vehicle maneuvers.

Use Case 1: Lane merge	
Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	Not applicable
Localization	1 to 4 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 150 km/h
Relevance area	250 to 350 meters
Take over time	10 seconds
Network requirements	
Availability	V2I/V2N 99% and for V2V 99.9%
Communication range	> 350 meters
Data rate	1.28 Mbps
Latency	< 30 ms
Reliability	99.9%
Service data unit size	800 bytes/message without trajectories 16000 bytes/message with trajectories
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High

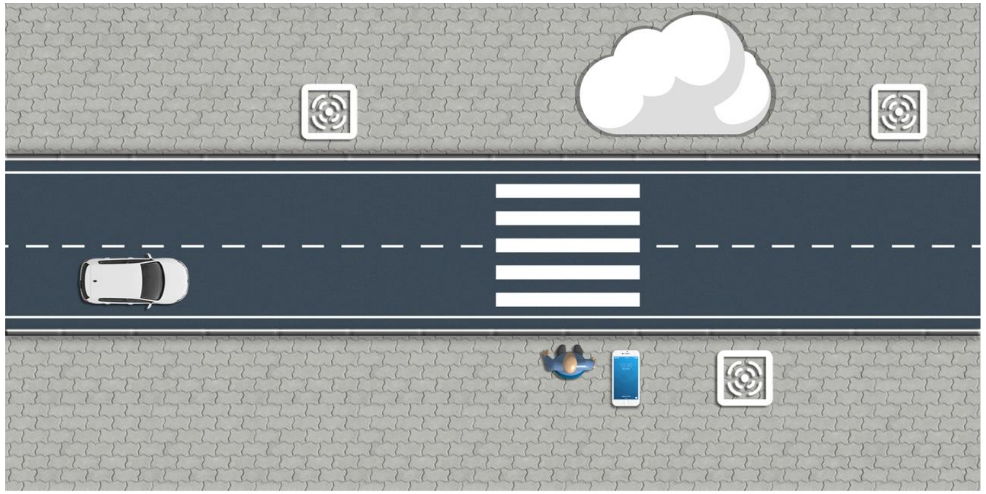
UC2: See-through



- **Goal:** To overcome the visibility limitation of a subject vehicle due to the occultation caused by the vehicle driving ahead by providing the driver of the subject vehicle with a direct overview of the scene in front of the vehicle driving ahead.
- **Target Environment:** All national roads, highways, urban roads, road crossings.
- **Pre-conditions:** Video data sharing is enabled and the involved vehicles are mutually authenticated.
- **Triggering Event:** The Rear Vehicle (with obstructed view) wants to start certain maneuvers (e.g., overtaking, lane changing) or is driving in certain locations (e.g. close to a road crossing, high risk area (identified based accident statistics) where a see-through assistance is needed to cross the area safely.
- **Operational requirements:** Both vehicles need a vision-based sensor (e.g. stereo camera) and a computational server
- **Post-condition:** Drivers have a good awareness about the traffic situations and scenes ahead

Use Case 2: See-through	
Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	Not applicable
Localization	10 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 seconds
Mobility	0 to 30 km/h
Relevance area	300 to 500 meters
Take over time	4 seconds
Network requirements	
Availability	99%
Communication range	50 to 100 meters
Data rate	14 to 29 Mbps
Latency	50 ms
Reliability	99%
Service data unit size	41700 bytes per frame
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: Medium Confidentiality: Low Integrity: High Authentication: High

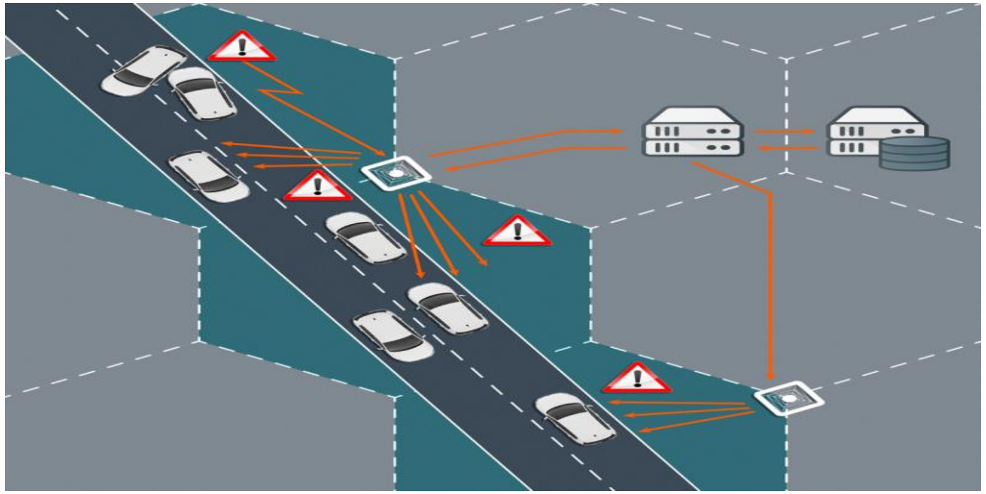
UC3: Network assisted vulnerable pedestrian protection



- **Goal:** To detect the presence of vulnerable pedestrian users in proximity of a vehicle and deliver such information to the vehicle to avoid the potential collision with the help of accurate positioning technology.
- **Target environment:** Crossroad or roads without pavement where pedestrians shall be in the trajectory of a vehicle.
- **Pre-conditions:** A pedestrian is crossing a road in bad visibility conditions. The equipped pedestrian user is carrying a P-UE device and registered in infrastructure network and a location server with enhanced positioning algorithm and data fusion.
- **Triggering Event:** A risk for the pedestrian safety is detected
- **Operational requirements:** Components for synchronous infrastructure and base stations. 5G User Equipment V-UE and P-UE.Location
- **Post-conditions:** Potential collision is avoided and pedestrian users safely cross street.

Use Case 3: Network assisted vulnerable pedestrian protection	
Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	7 seconds
Localization	25 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	Not applicable
Mobility	0 to 100 km/h
Relevance area	40 to 70 meters
Take over time	10 seconds
Network requirements	
Availability	99.99%
Communication range	>70 meters
Data rate	128 kbps
Latency	< 60 ms
Reliability	99.9%
Service data unit size	1600 bytes per message
Qualitative requirements	
Cost	Medium to High
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High

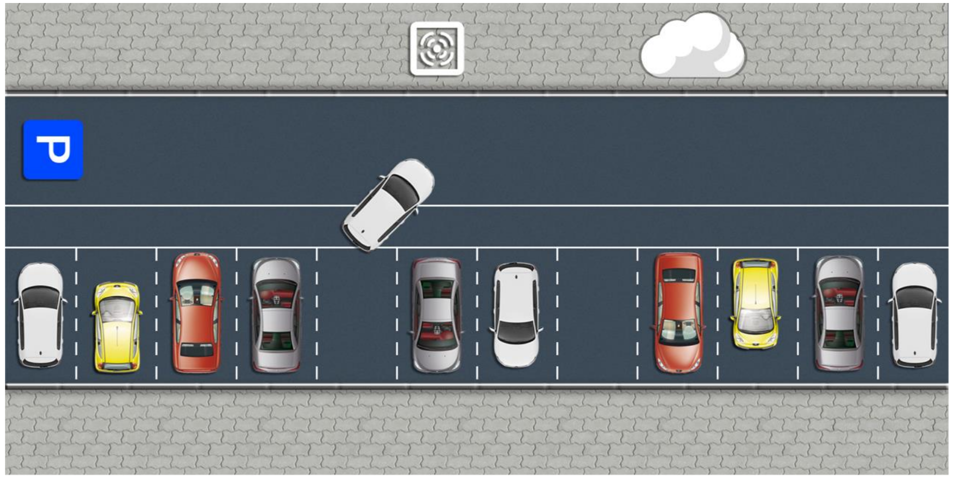
UC4: High definition local map acquisition



- **Goal:** To update the local dynamic map of vehicles on the move.
- **Target environment:** Any driving environment (urban, road or highway) to be enabled for semi and full autonomous driving.
- **Pre-conditions:** The vehicle receiving the map must be in a cellular coverage zone to receive the map updates.
- **Triggering Event:** Two different events may trigger the map update: the periodically refreshed information polled by the vehicle with a frequency determined by the vehicle driving conditions or a push made by the server
- **Operational requirements:** The application server must have communication, computation, and storage capabilities. Infrastructure (optional), a system of sensors to collect information and wireless communication capability to transmit the collected information to the application server
- **Post-conditions:** The host vehicle will make optimal driving decision based on an up-to-date, precise, and reliable vision of the environment.

Use Case 4: High definition local map acquisition	
Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	Not applicable
Localization	5 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 250 km/h
Relevance area	>250 meters
Take over time	10 seconds
Network requirements	
Availability	99%
Communication range	>1 km
Data rate	960 kbps for objects farther than 100m 1920 kbps for objects closer than 100m
Latency	<30 ms
Reliability	99.99%
Service data unit size	60 bytes per object
Qualitative requirements	
Cost	Medium to High
Power consumption	Medium to High
Security	Privacy: High Confidentiality: High Integrity: High Authentication: High

UC5: Remote driving for automated parking



- **Goal:** To drive remotely, by an application server, a vehicle from the “last mile” near a parking to the parking entrance to the parking spot without a human driver inside the car.
- **Target Environment:** Public or private parking (indoor or outdoor) and “one-mile” distance area around it.
- **Pre-conditions:** The vehicle and the remote cloud server are mutually authenticated for sharing video and sensor data. The vehicle has enough perception capabilities and allows access to its actuators. The parking area has installed sensors and/or cameras that could facilitate the remote cloud server decision of trajectories.
- **Triggering Event:** The driver leaves the vehicle in the “Pick up/Drop off” zone and request an automated remote parking
- **Operational requirements:** Vehicles some panoramic vision sensors. Parking facilities equipped with cameras or other type of sensors.
- **Post-condition:** The vehicle is successfully parked in one of the parking spots.

Use Case 5: Remote driving for automated parking	
Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	1 to 6 seconds
Localization	5 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	2 seconds
Mobility	30 to 50 km/h
Relevance area	1000 meters
Take over time	10 seconds
Network requirements	
Availability	99.999%
Communication range	Several kms
Data rate	14 to 29 Mbps video uplink 1,28 Mbps trajectories downlink
Latency	5 to 30 ms
Reliability	99.999%
Service data unit size	16000 bytes per message for trajectories 41700 bytes per frame for video
Qualitative requirements	
Cost	High
Power consumption	Low
Security	Privacy: Medium Confidentiality: Low Integrity: High Authentication: High

Technical components

Multi-antenna techniques	
Sensitivity Analysis of the Predictor Antenna System	[5GC19-D33, Sec. 3.1.1]
Predictor Antenna for Massive MIMO Adaptive Beamforming	[5GC19-D33, Sec. 3.1.2]
Genetic-Algorithm Based Beam Refinement for Initial Access in Millimeter-Wave Mobile Networks	[5GC19-D33, Sec. 3.1.3]
Rate Adaptation in Predictor Antenna Systems	[5GC19-D33, Sec. 3.1.4]
Beam-Domain Broadcasting for V2N/V2I links	[5GC19-D33, Sec. 3.1.5]
Beam-based Broadcast Schemes for V2X Applications	[5GC19-D33, Sec. 3.1.6]
Beamformed Multi-Cast with HARQ feedback and retransmission	[5GC19-D33, Sec. 3.1.7]
LOS MIMO Design for V2V	[5GC19-D33, Sec. 3.1.8]
Resource allocation and management	
Efficient Preemption-based Multiplexing of Services	[5GC19-D33, Sec. 3.2.1]
Decentralized Pilot-to-Data Power Ratio Configuration in Multi-Cell Multi-User MIMO Systems	[5GC19-D33, Sec. 3.2.2]
Joint Optimization of Link Adaptation and HARQ Retransmissions for URLLC Services in a High-Mobility Scenario	[5GC19-D33, Sec. 3.2.3]
Power Control and Scheduling to Mitigate Adjacent Channel Interference in Vehicle-to-Vehicle Communication	[5GC19-D33, Sec. 3.2.4]
Sidelink Resource Allocation with Network Assistance using Multiple Antennas	[5GC19-D33, Sec. 3.2.5]
Distributed RRM for Direct V2X Communication	[5GC19-D33, Sec. 3.2.6]
Radio resource management in 5G-enabled vehicular networks	[5GC19-D33, Sec. 3.2.7]
V2V Resource Allocation and MAC Capacity	[5GC19-D33, Sec. 3.2.8]

Technical components

Sidelink design	
Synchronization for the V2V Sidelink: Sequences and Algorithms	[5GC19-D33, Sec. 3.3.1]
Reference Signals Design for Direct V2X Communication	[5GC19-D33, Sec. 3.3.2]
Code-expanded Random Access for Reliable V2X Discovery	[5GC19-D33, Sec. 3.3.3]
Full duplex	
Cognitive Full Duplex Communication in V2X networks	[5GC19-D33, Sec. 3.4.1]
Full Duplex Collision Detection in V2X Networks	[5GC19-D33, Sec. 3.4.2]
Full Duplex Impact on V2X Performance	[5GC19-D33, Sec. 3.4.3]
Reliability enhancement	
Fundamental Tradeoff Between Latency and Reliability	[5GC19-D33, Sec. 3.5.1]
Enhancing V2N Reliability by Sidelink Cooperation	[5GC19-D33, Sec. 3.5.2]
Sidelink Assisted Reliable Communication	[5GC19-D33, Sec. 3.5.3]
Enhancing Control Channel Reliability by Using Repetitions	[5GC19-D33, Sec. 3.5.4]
Positioning	
Trajectory Prediction with Channel Bias Compensation and Tracking	[5GC19-D33, Sec. 3.6.1]
Tracking of a Vehicle’s Position and Orientation with a Single Base Station in the Downlink	[5GC19-D33, Sec. 3.6.2]
Beam-based V2C positioning	[5GC19-D33, Sec. 3.6.3]
Data-aided Beam-based C2V Positioning	[5GC19-D33, Sec. 3.6.4]
Enhanced Assistance Messaging Scheme for GNSS and OTDOA Positioning	[5GC19-D33, Sec. 3.6.5]
Multi-Array 5G V2V Relative Positioning	[5GC19-D33, Sec. 3.6.6]

Technical components

Multi-antenna techniques	
RSU enabled Smart Zone (SM-Zone)	[5GC19-D42, Sec. 3.1]
Fast application-aware setup of unicast SL	[5GC19-D42, Sec. 3.2]
SL and Uu multi-connectivity	[5GC19-D42, Sec. 3.3]
Location aware scheduling	[5GC19-D42, Sec. 3.4]
Infrastructure as a Service (IaaS) for vehicular domain	[5GC19-D42, Sec. 3.5]
Redundant mode PC5 and Uu	[5GC19-D42, Sec. 3.6]
Evolution of infrastructure-based communication for localised V2X traffic	[5GC19-D42, Sec. 3.7]
Use case-aware multi-RAT, multi-link connectivity	[5GC19-D42, Sec. 3.8]
Multi operator solutions for V2X communications	[5GC19-D42, Sec. 3.9]
V2X service negotiation	[5GC19-D42, Sec. 3.10]
Edge computing in millimetre Wave Cellular V2X networks	[5GC19-D42, Sec. 3.11]
Dynamic selection of PC5 and Uu communication modes	[5GC19-D42, Sec. 3.12]
Security and privacy enablers	[5GC19-D42, Sec. 3.13]
5G core network evolution for edge computing-based mobility	[5GC19-D42, Sec. 3.14]

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