

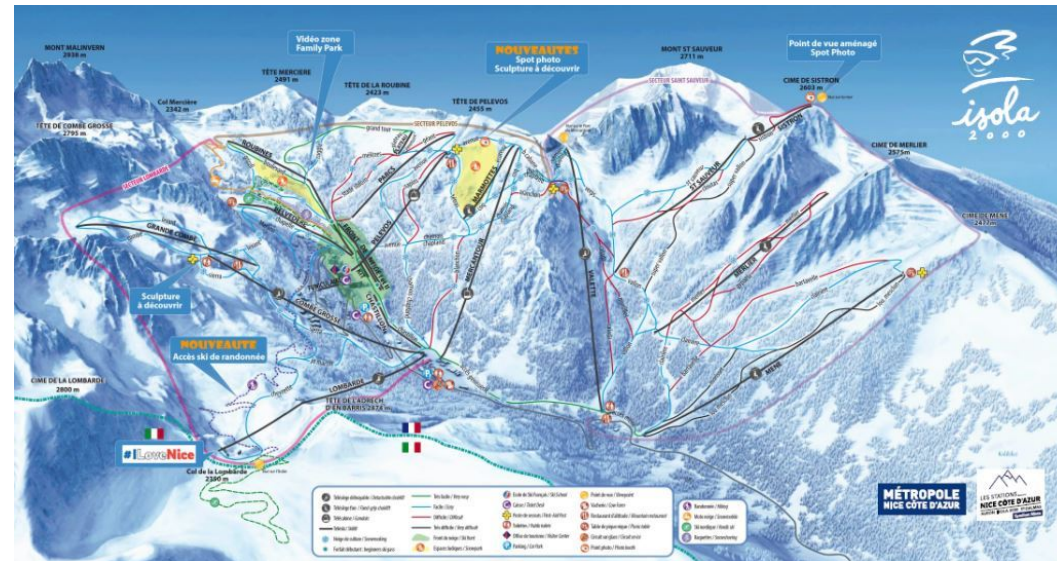


5G Challenges for Connected, Cooperative and Automated Systems

Jérôme Härri

15th Italian Networking Workshop

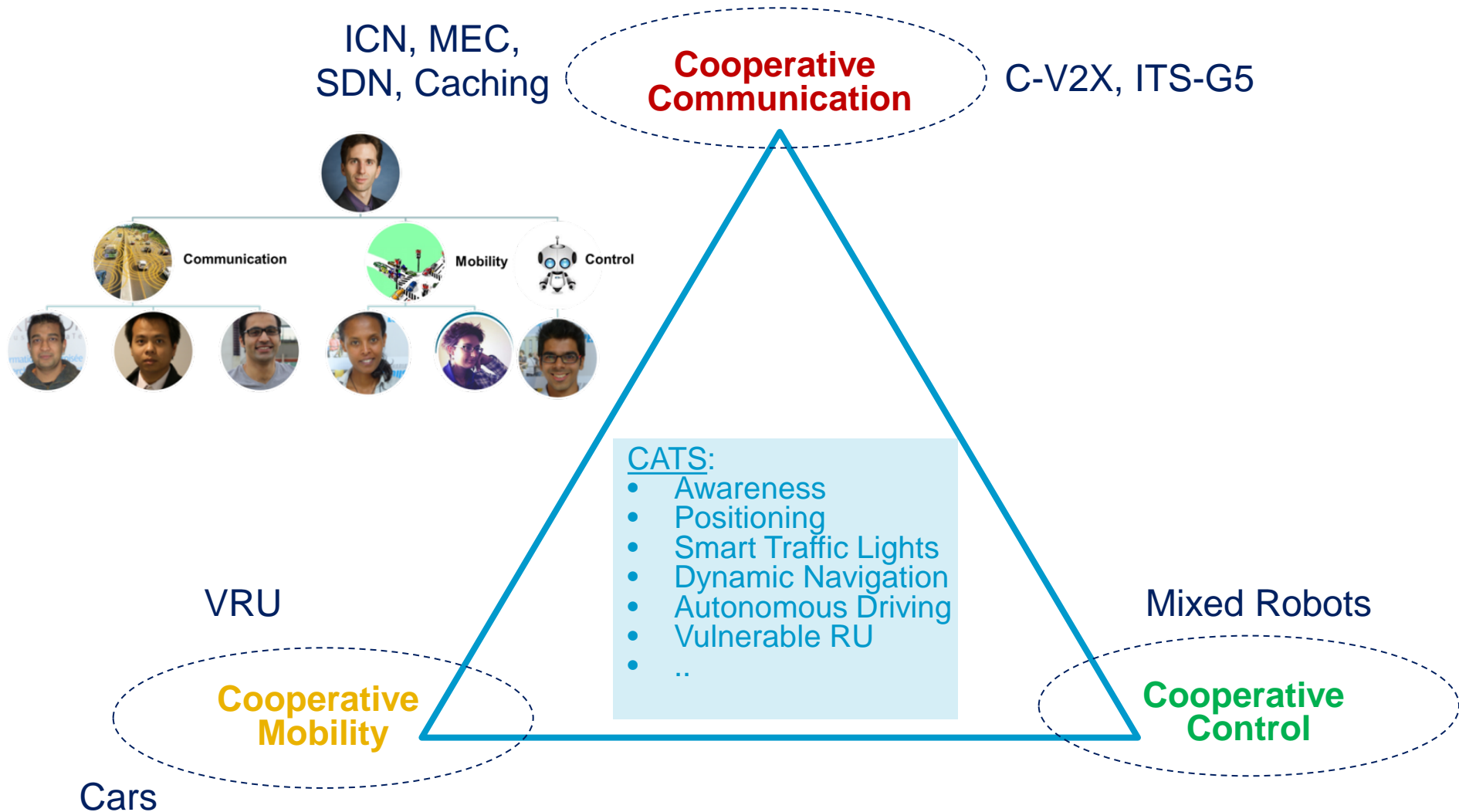
January 15th 2018



■ Call for Participation

➤ <http://2018.wons-conference.org/>

Cooperative Connected Automated Transport Systems (CATS) - Team



Cooperative Connected Automated Transport Systems (CATS)

■ Vehicular Traffic Modeling (cars, scooters, pedestrians)

- Vehicular Mobility Modeling
 - mixed cars/scooters modeling
- Vehicular Control Modeling
 - mixed autonomous/legacy control modeling

■ Vehicular Communications (ITS-G5, 5G)

- Dependable Vehicular Communication (ITS-G5, C2X)
 - ITS-G5 1-hop broadcast & congestion control
- High Precision Positioning and Mapping
 - Cooperative positioning (ITS-G5, IR-UWB...)
- 5G extensions to automotive domain
 - LTE D2D/V2X for safety communication

■ Vehicular Networking (Edge, SDN & NFV, IoX)

- SDN-based and Information-Centric Networking
- Edge Caching & Computing
- Data-as-a-service architecture for vehicular & crowd sensing

■ Automated Vehicles

- Platooning & cooperative adaptive cruise control (CACC)
- Cooperative maneuvering and navigation

■ Vehicular Standardization Bodies

- 3 STF ETSI ITS, C2C CC WG COM co-chair and subWG DCC chair
- OneM2M / W3C WoT standards
- IETF IPWAVE
- 3GPP

Cooperative vs. Automated vs. Autonomous

■ Confusing Concepts...

- **Autonomous Car** – a car, which driving dynamics are based on its own sensor and intelligence, without the assistance of any external information
- **Automated Car** – a car, which driving dynamics are based on its own sensors and intelligence, potentially enhanced with external support (data, human)
- **Connected Car** – a car capable of obtaining external information or exchange information with other cars or infrastructure
- **Cooperative Car** – a car, which telematics system collaborate with other systems to reach a common global goal.

■ What are we 'really' aiming at ?

- **(maybe) Cooperative Connected Automated Vehicles**
 - Vehicles will require external information to self-drive
 - Full autonomous driving is highly unlikely (under global context)

Automated Vehicles

■ Expected to radically change the automotive Industry

- Autonomous Cars & Platooning expected to appear next decade
- Automated vehicles are yet not limited to cars and trucks



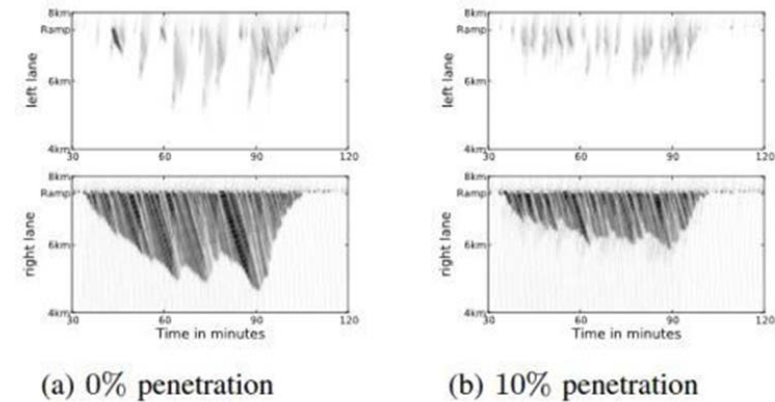
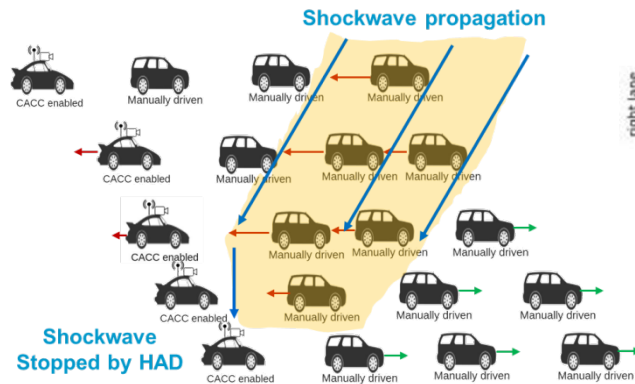
■ Benefits of Automated Vehicles

- Estimated 585,000 lives between 2035-2045
- Massive economic opportunity (> 7 trillion \$ - Intel)
- 250 million hours of consumers' commuting time per year
- Price of Safety - Priceless

Cooperative Connected Automated Vehicles – Benefits and Challenges

■ Intercept Shockwave

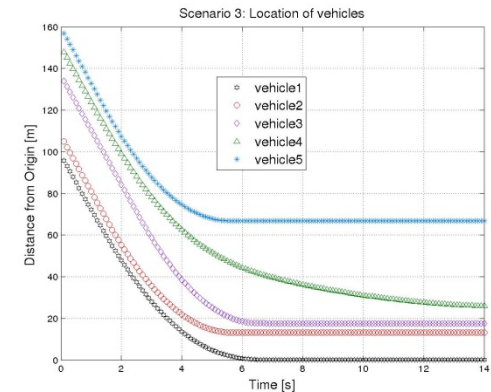
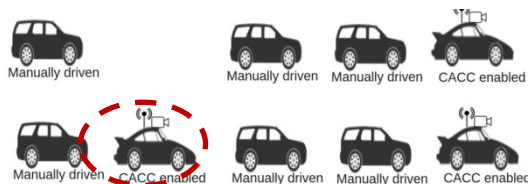
- CATS anticipate speed reduction
- CATS stops shockwaves already at low penetration



Source: Markus Forster et al., IEEEInfocom, 2014

■ Increase Capacity

- CATS require less inter-distance
- CATS may use the inter-distance of other cars
 - at no impact on safety

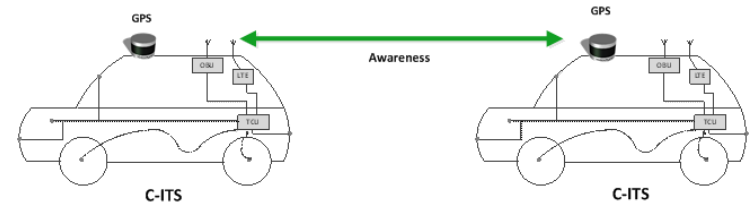


Percentage penetration of APs	0	20	40	60	80	100
Collisions Avoided	0	1	11	35	57	61

Cooperative Connected Automated Vehicles – Benefits and Challenges

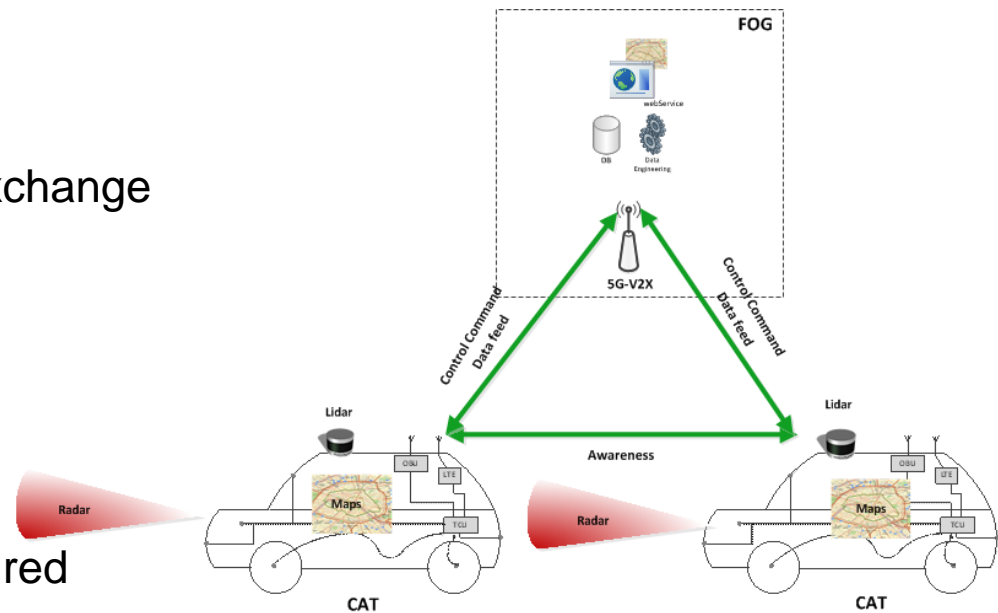
■ Connected Cars

- Mostly focused on Awareness
- V2V



■ Connected 'Automated' Cars

- Require large amount of data exchange
 - Map synchronization
 - Environmental information
 - Control Command
 - ...
- V2V must be cranked up
- V2I becomes critical
 - Robust Core Network Required



Automated Vehicles vs. Remote Control Vehicles

- **Joint EURECOM, BUPT, CHINA Mobile Demo**
 - Actually: 4G only 😊



V2X Technologies

CURRENT TECHNOLOGIES

WiFi-V2X - ITS-G5

- **Specification completed in 2010 (IEEE 802.11p-2010)**

- Later integrated in IEEE 802.11-2012

- **Key characteristics**

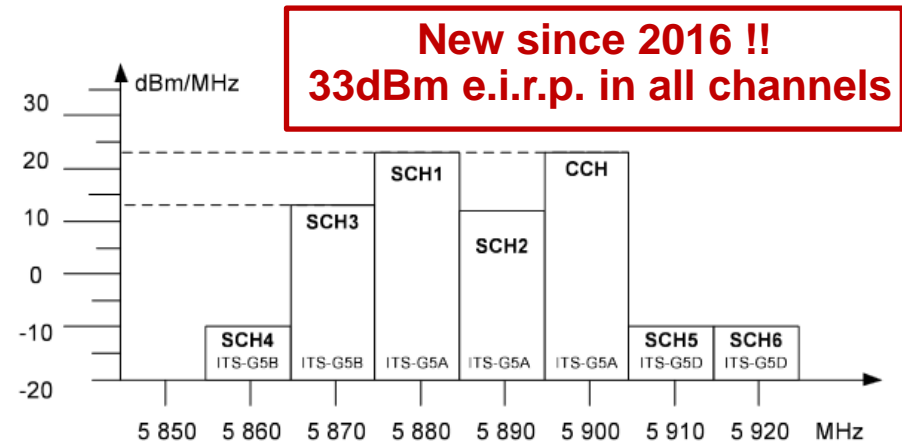
- 5.9 GHz frequency domain
- Based on IEEE 802.11a (OFDM PHY)
- 10 MHz channel bandwidth
- Rates: 3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
- Operates without a BSS

CAR 2 CAR
COMMUNICATION CONSORTIUM



- **ITS/ATS Frequency Band**

Name	Center Frequency	Type
SCH6	5920	ITS-G5D - Future ITS
SCH5	5910	
SCH4	5860	ITS-G5B - Non-Safety related
SCH3	5870	
SCH2	5880	
SCH1	5890	ITS-G5A - Safety-Related
CCH	5900	



ITS-G5 Release 2 – Design Directions

- In November 2016, the CAR 2 CAR initiated a WI on ITS-G5 Rel. 2

- CAR 2 CAR white paper – “Enhanced 11p Investigations and Proposal”

- Design directions:

- Enhanced channel usage (modulation, congestion control)
- Enhanced information exchange (Tx what is ‘required’)
- Enhanced PHY & MAC
- Enhanced Capacity
 - mmWAVE bands

- Input currently under discussions at the CAR 2 CAR

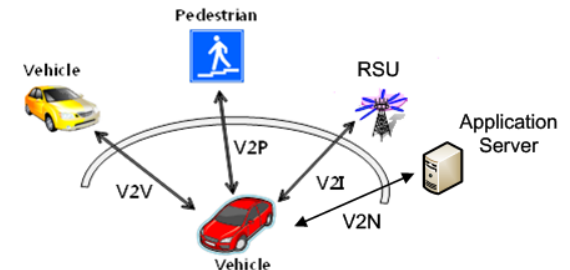
- Objectives:
 - > 5dB gain at 5GHz
 - 10x capacity at 60Hz



Cellular LTE-V2X

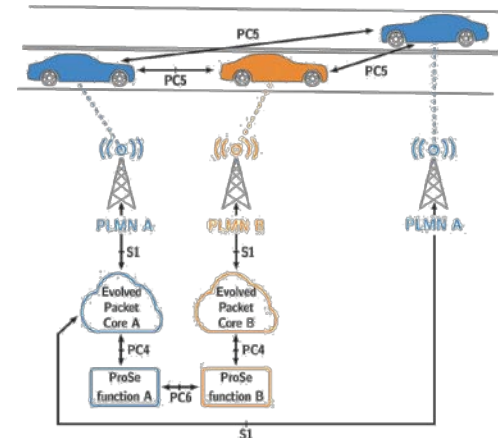
■ Since 3GPP LTE Rel. 14

- LTE-V2X operation
 - Sub-group of Proximity Service (ProSe)
- Provides Dedicated communication services:
 - V2V – **Vehicle-to-Vehicle**
 - V2I – **Vehicle-to-RSU**
 - V2P – **Vehicle-to-Pedestrian**
 - V2N – **Vehicle-to-Network**



■ Architecture Extension:

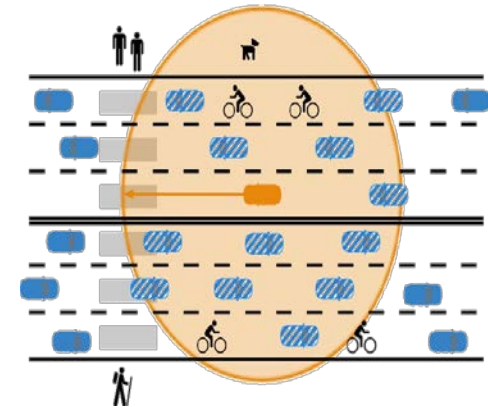
- PC5 interface
- V2X/ProSe Function/Applications
- Two modes of Operations:
 - **Managed (Mode 3)** – eNB allocate resources
 - **Ad-Hoc (Mode 4)** – UEs self-allocate resources
 - ☞ GPS-based Synchronization
 - ☞ USIM-less operation



Cellular LTE-V2X - Mode 4

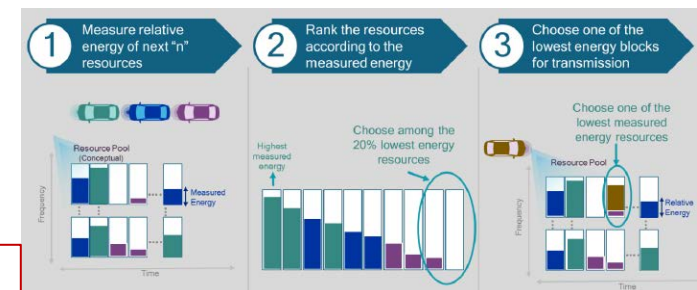
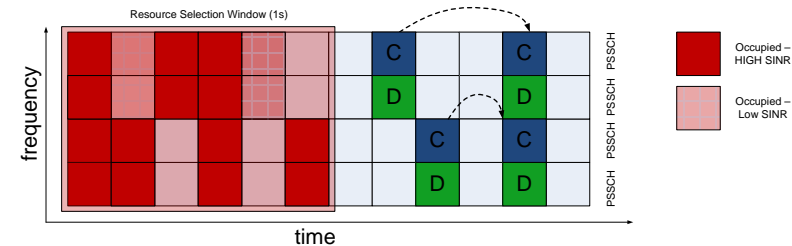
- **LTE-V2X mode 4 is a full ad-hoc**

- Selected mode for Safety-related V2X communication



- **3GPP rel.14 mode 4 proposal:**

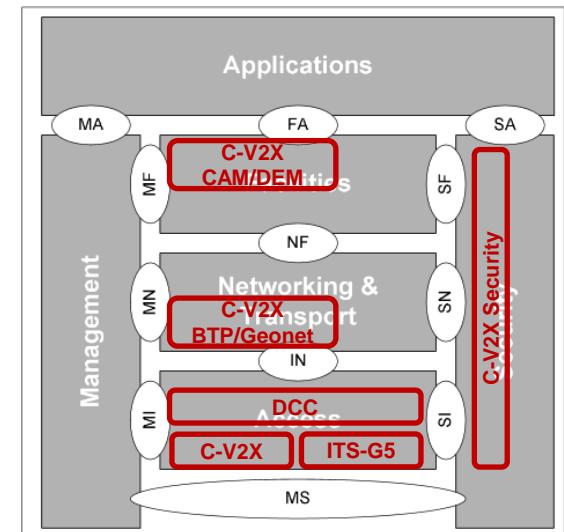
- **Semi-Persistent Scheduling**
 - UE reserves RB over consecutive Sub-frames
- **Listen-before-Talk access**
 - RSSI-based resource selection



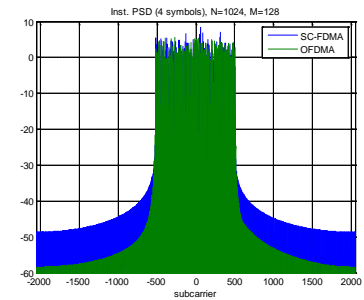
Source: Qualcomm

Cellular LTE-V2X – Standardization Status

- 3GPP specification freeze in July 2017
- In January 2017, the CAR 2 CAR initiated a WI on LTE-V2X
 - CAR 2 CAR White Paper – “Technical Evaluation and Open Issues”
- Objectives:
 - Introduce **new concepts** behind LTE-V2X
 - Define **common scenarios** and parameters
 - Identify **required architecture extension**
 - Gather **open challenges**
- In October 2017, Cellular Stakeholders proposed multiple WI to ETSI ITS for LTE-V2X
 - C-V2X is expected to be integrated in ETSI ITS in 2018
 - **Access Technology** -
 - LTE-V2X mode 3-4 rel.14 on PC5 for V2V
 - LTE-V2X on Uu for V2I/V2N communication



Coexistence ITS-G5 – LTE-V2X



source:

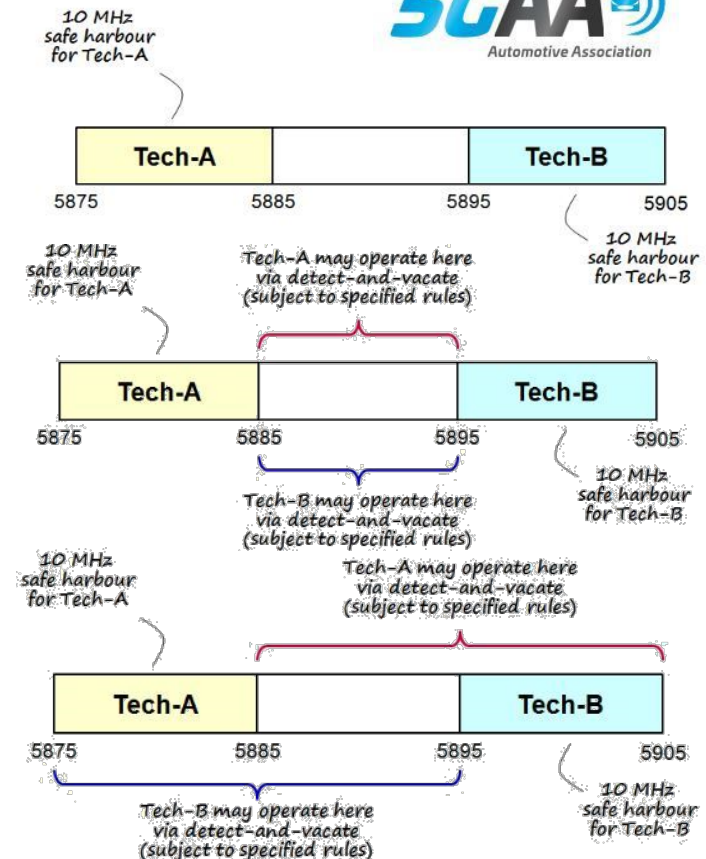


■ Based on the technology neutrality of the ITS-G5 band

- Both ITS-G5 and LTE-V2X can be granted access

■ Three phases coexistence:

- Phase 1 – LTE-V2X and ITS-G5 on different 10Mhz isolated bands
- Phase 2 – LTE-V2X and ITS-G5 may coexist on additional shared band based on 'detect and avoid'
- Phase 3 – LTE-V2X and ITS-G5 coexist on the full ITS-G5 band based on the detect and avoid mechanism



Cellular LTE-V2X on OpenAirInterface

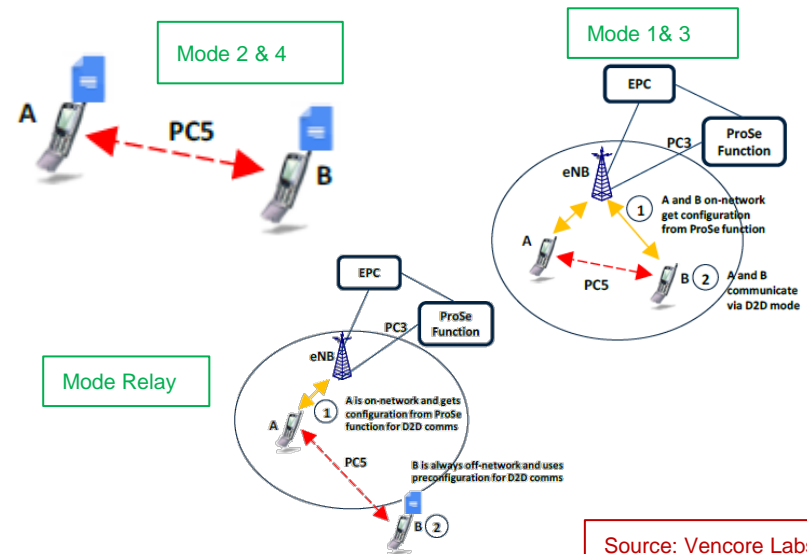
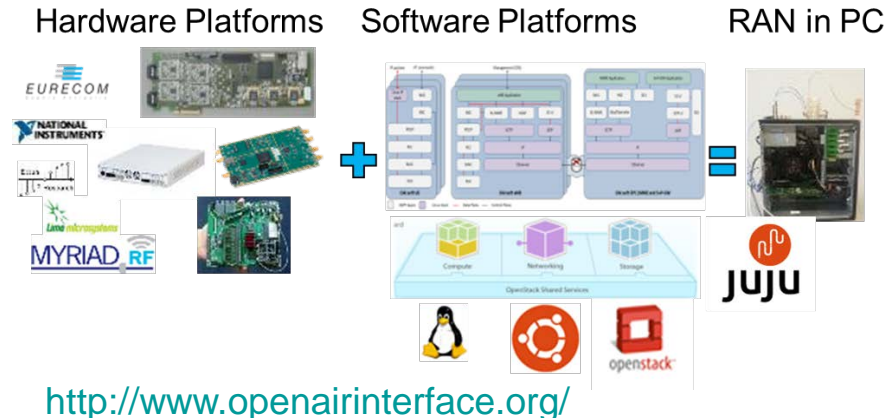
■ Extension of OAI for Sidelink communication

- LTE Rel.14 compliant
- Supporters:
 - Orange Labs
 - Vencore Labs (US)
- Objective: 1st Open V2X/D2D Platform

■ Architecture Extension:

- New emulation architecture
 - Toward dense UE networks
- New procedures:
 - New Sidelink PHY
 - MAC/RRC Distributed Scheduling
- Operation Mode:
 - **LTE ProSe Public Safety**
 - ☞ Mode 1 & 2
 - ☞ LTE Relay mode
 - **LTE-V2X**
 - ☞ Mode 3 & 4

■ First prototype to be ready early 2018

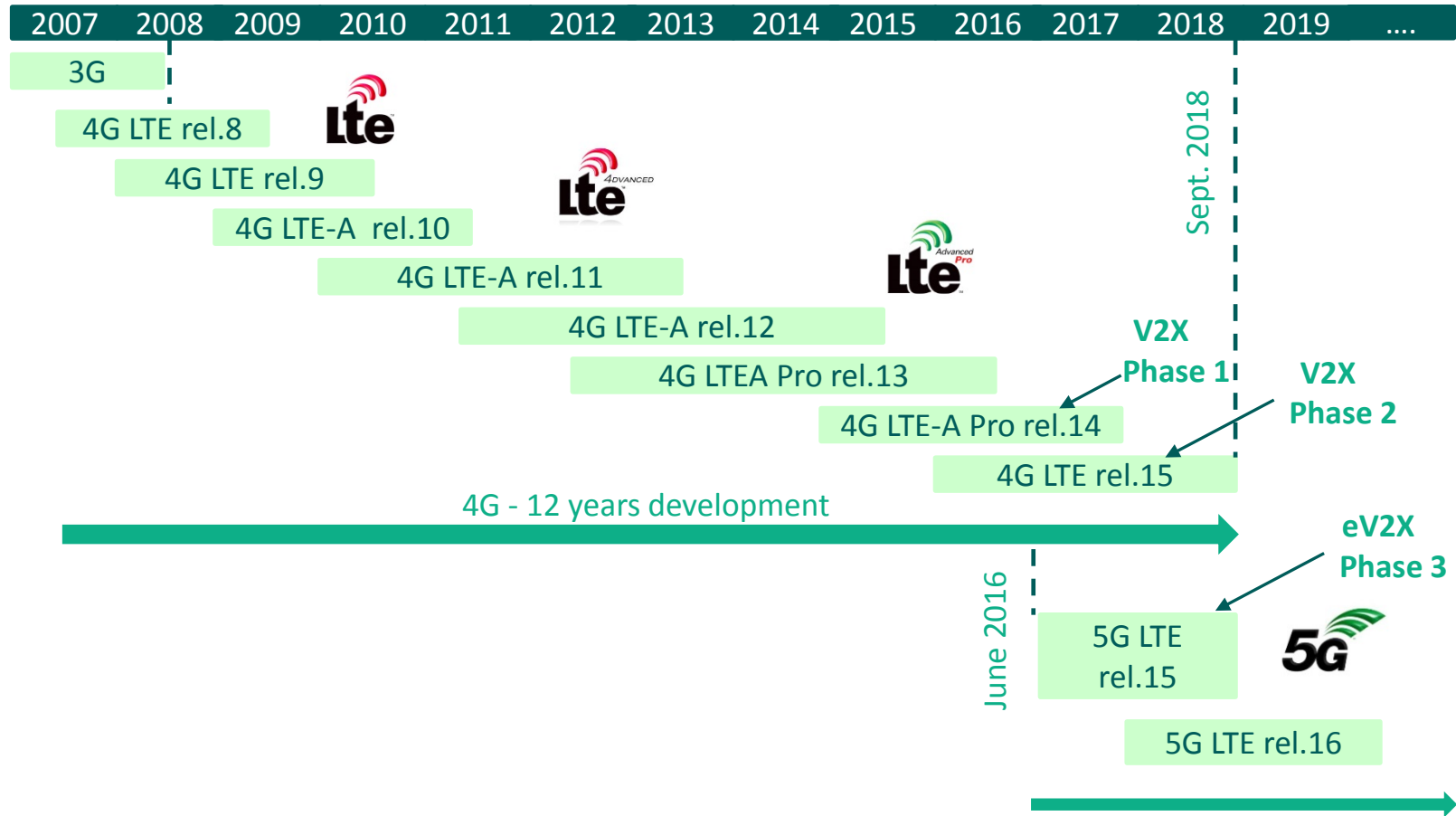


Source: Vencore Labs

V2X Technologies

MOVING TOWARD 5G

Cellular V2X – 3GPP Roadmap



LTE-V2X toward Automated Driving

D2D communications

R12/13



Enhanced safety

C-V2X R14 (Ph. I) C-V2X R15 (Ph. II)



Autonomous driving

C-V2X R16 5G NR support (Ph. III)
(Advanced safety applications)



Established foundation for basic D2D comm.

Enhanced communication's range and reliability for V2X safety

Ultra-reliable, low latency, high throughput communication for autonomous driving

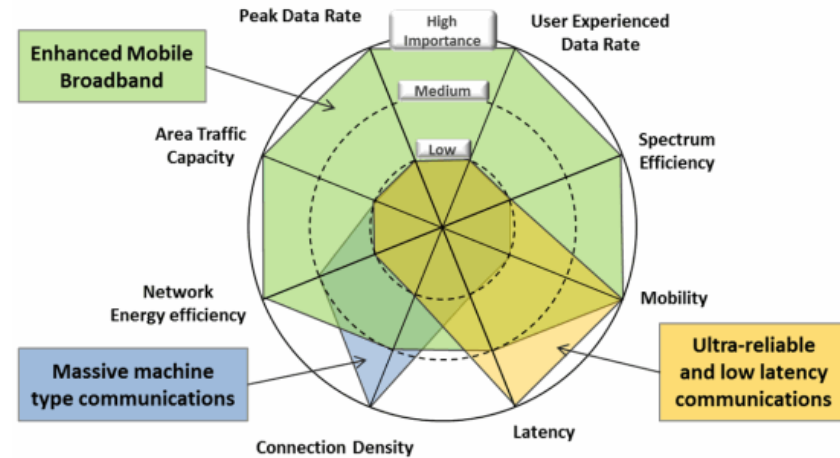
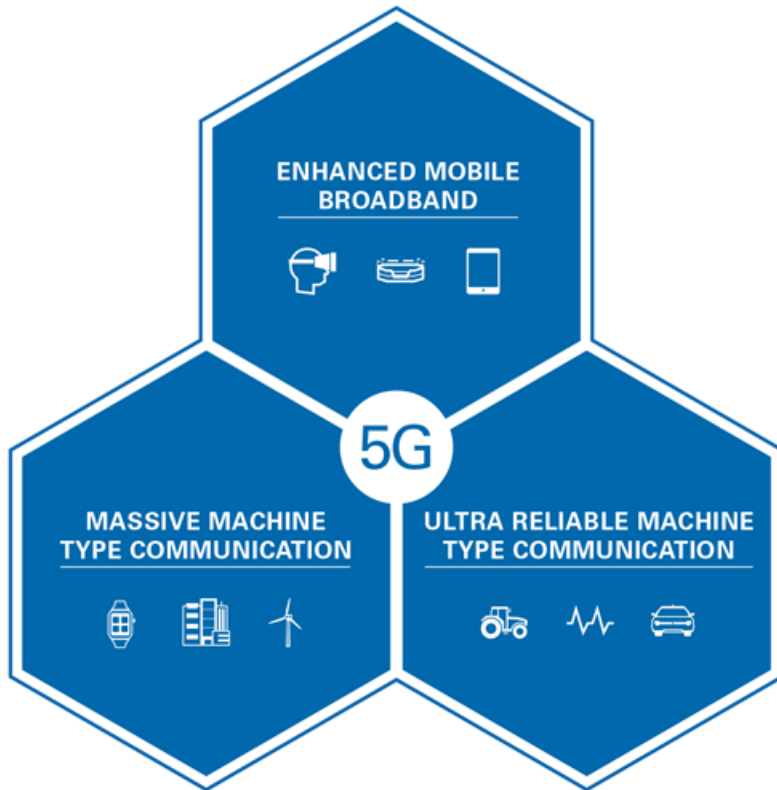
Network independent	No	Yes	Yes
Communications ¹	Broadcast only	Broadcast only	Broadcast + Unicast/Multicast
High speed support	No	Yes	Yes
High density support	No	Yes	Yes
Throughput		High throughput for enhanced safety	Ultra-high throughput
Latency		Low latency for enhanced safety applications	Ultra-low latency
Reliability		Reliability for enhanced safety application	Ultra-high reliability
Positioning	No	Share positioning information	Wideband ranging and positioning

1. PHY/MAC communications; R16 is still under development

Source: Qualcomm

6

IMT Definition and Requirements for 5G



Attribute	IMT-Advanced 4G	IMT-Future 5G
Achievable Rate	1 Gbps	10-50 Gbps
Connection Density		10^6 - 10^7 /km ²
Mobility & Coverage	350km/h	500km/h
Energy Efficiency	1x	50x – 100x
Spectral Efficiency	1x	5x-15x
Latency	10ms	1ms

Source: ITU

5G Challenges for Cooperative Connected Automated Vehicles

■ Key 5G Innovations

- URLLC Communication
- eMBB Communications

■ 3GPP roadmap mostly on V2I (5G phase 1)

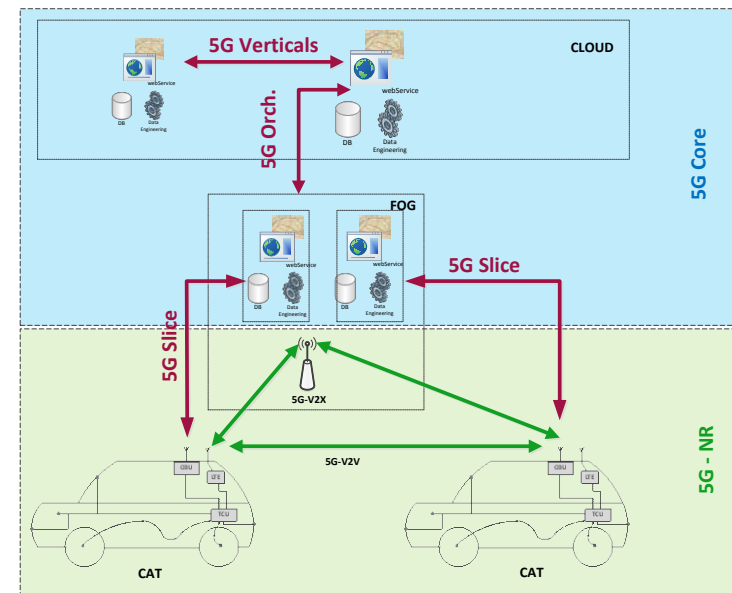
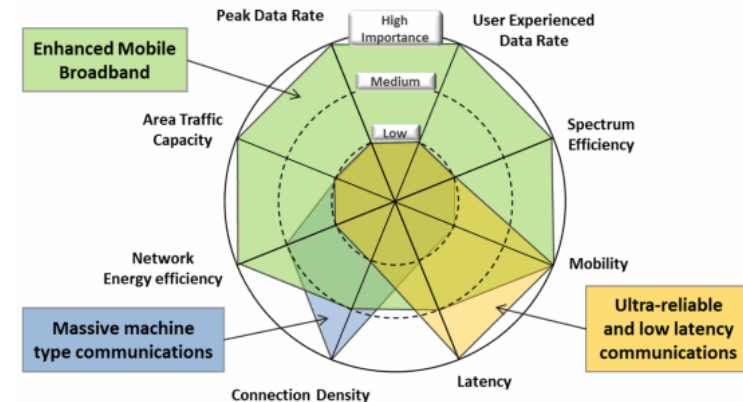
- 5G V2V will not evolve much

■ Critical role of 5G Core

- Mobile Edge Services
- Network Slices
- Cooperative 'Infrastructure'

■ Key Message:

- 4G was mostly V2V
- 5G will be V2I



5G Challenges – Make Communication or Control more Robust ?

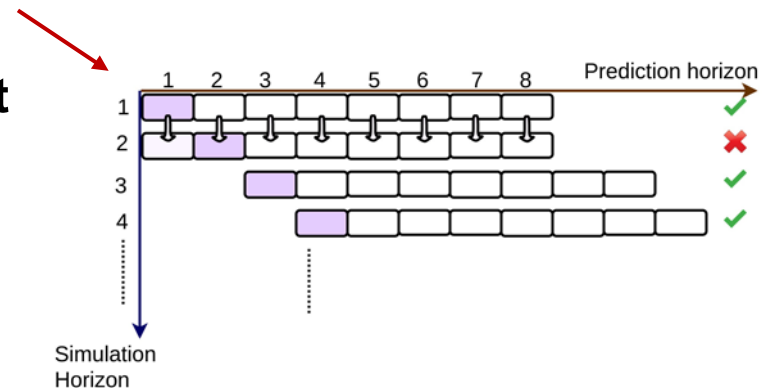
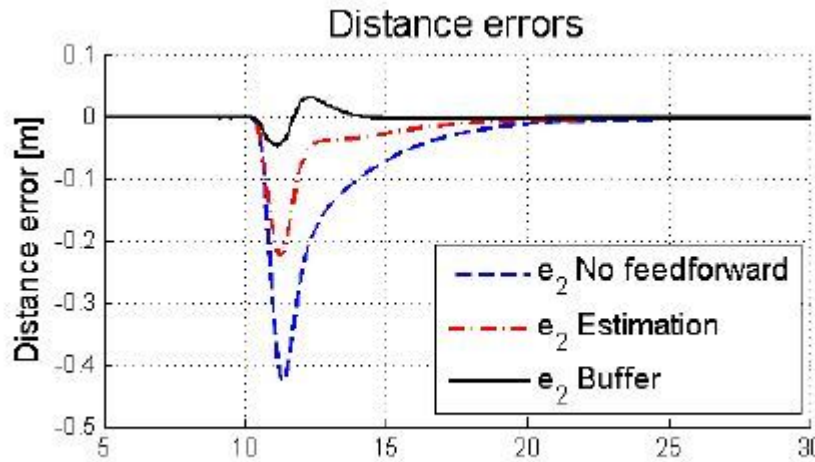
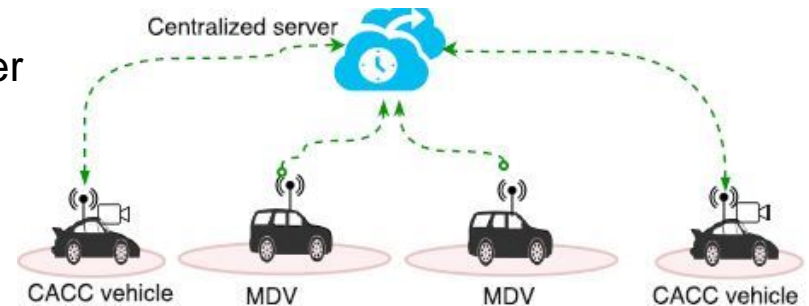
■ CACC subject to V2X Impairments

- Assumptions: 25Hz CAM / 100Hz controller
- Block loss of CAMs

■ Impact on CACC

- Any CAM loss leads to dangerous situation...
- But a more robust control strategy allows to mitigate it

■ Designing 5G V2X requires to match it with control mechanisms !!

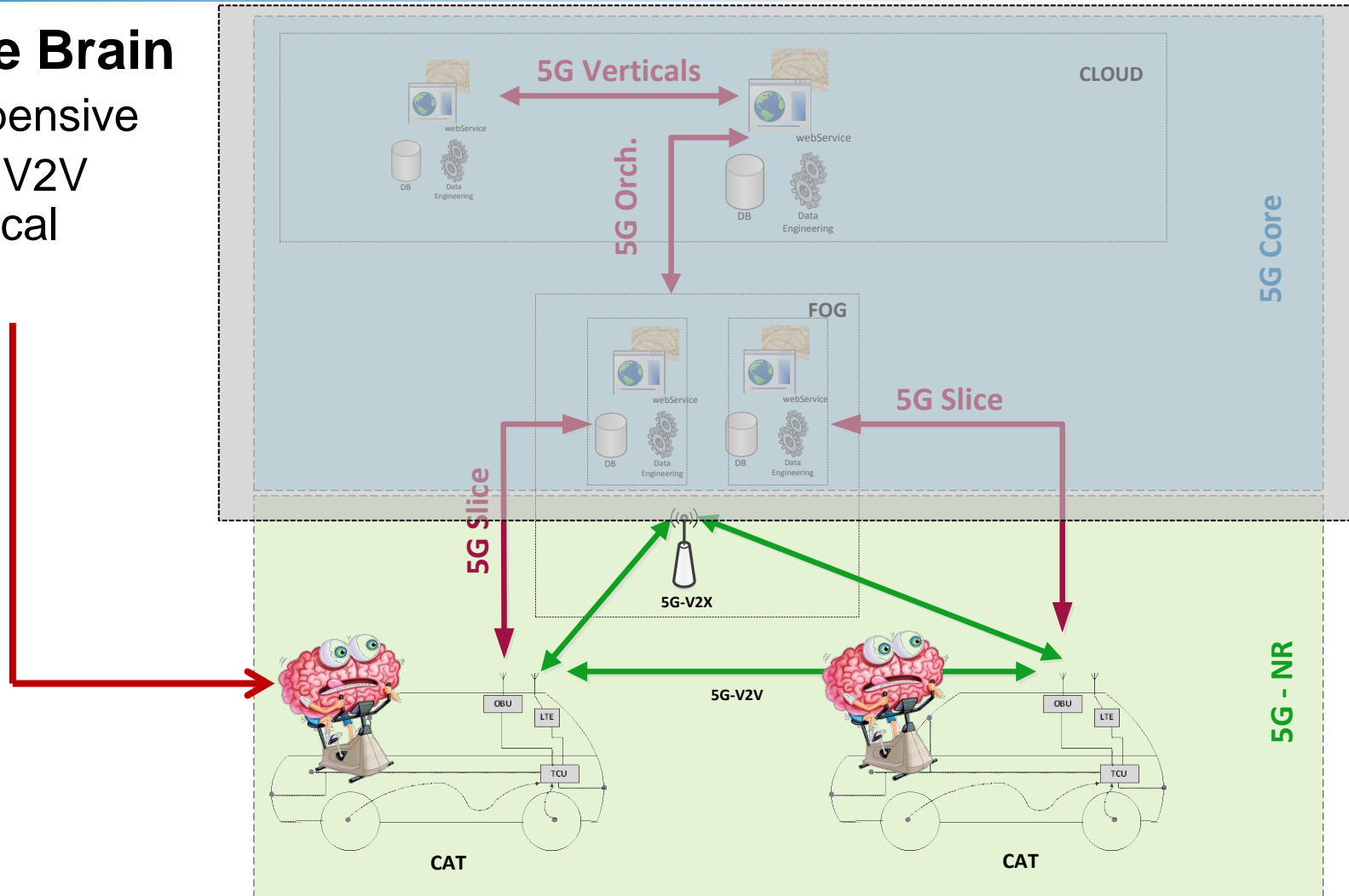


Source: Ellen van Nunen et al. , **Robust Model Predictive Cooperative Adaptive Cruise Control Subject to V2V Impairments**, IEEE ITSC 2017

5G Challenge – where to put the ‘Brain’ ?

■ Single Brain

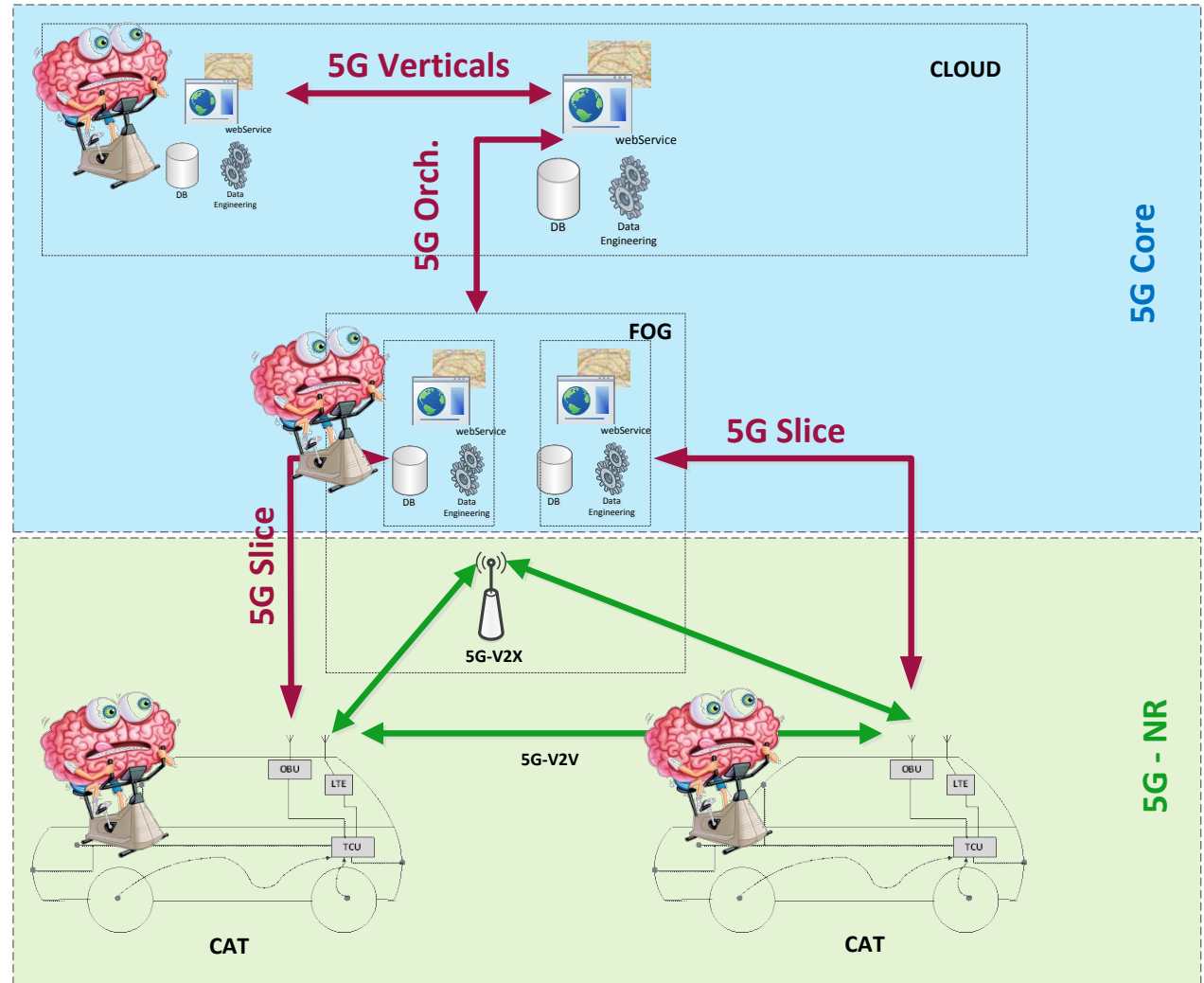
- Expensive
- 5G V2V critical



5G Challenge – where to put the ‘Brain’ ?

■ Split Brain

- Distributed efforts
- 5G Core critical



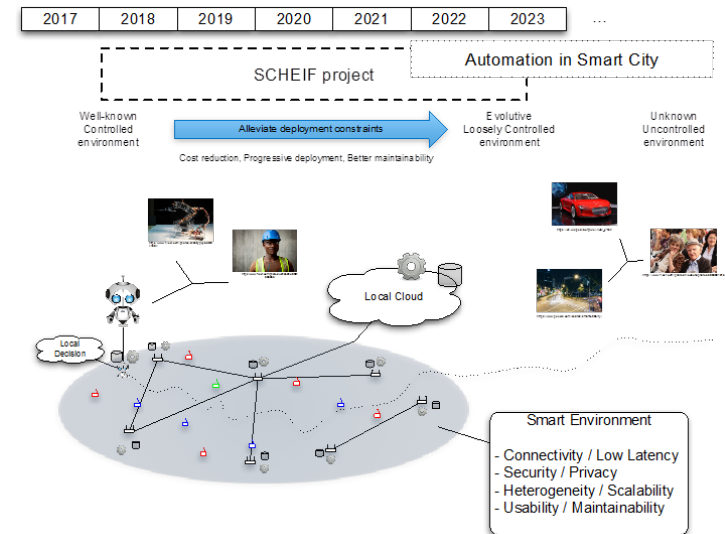
Cooperative Connected Automated Transport Systems – not only vehicles...

■ Bring 5G-V2X to Industry 4.0

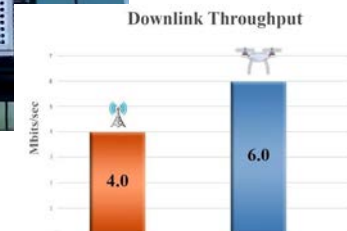
- Decentralized Production Control
- Evolving Production Environment
- Plug-and-Produce
- Hybrid-level Cooperation
- Secured and resilient

■ Drones to enhance 5G-V2X

- Drone act as 5G eNBs
 - Find optimal position to maximize capacity/reliability
- Drone follow traffic



Source: Prof. Gesbert, ERC Perfume



Conclusions

■ 5G for Cooperative Connected and Automated Vehicles

- Radically changes how 5G-V2X systems will operate
 - V2I most innovation
 - 5G MEC for near vehicle control
 - 5G Slice for multi-feeds control

■ Extensions of current Solutions

- ITS-G5 is moving toward a Release 2
- C-V2X will soon be ready as well



Jérôme Härrri, haerri@eurecom.fr

■ Challenge (among others):

- Cooperative Connected Automated Vehicles have specific behaviors on 5G
 - Need to understand it to design 5G

