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National Research Council of Italy

Toward 5G vehicular networks
when vehicles will talk to each other

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Part 1: applications and technologies for connected and autonomous vehicles

Institute of Electronics Computer and Telecommunication Engineering

Toward 5G vehicular networks

Toward 5G vehicular networks

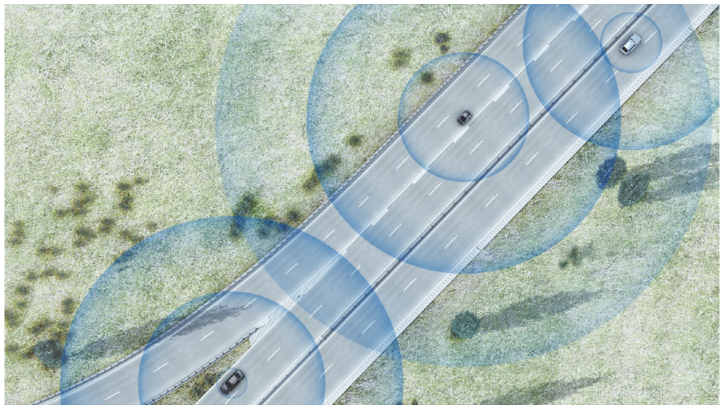
The automotive industry is undergoing key technological transformations, more and more vehicles are connected to the Internet and to each other, and advance toward higher automation levels.

Future automated vehicles will have to rely not only on their own sensors, but also on those of other vehicles, and will need to cooperate with each other.

These trends pose significant challenges to the underlying communication system

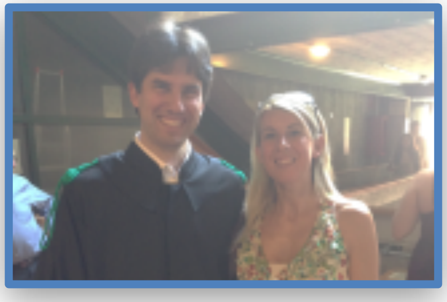
Objective of the tutorial

- To provide a general view of connected vehicles and the relation with autonomous vehicles
- To illustrate wireless enabling technologies for connected vehicles
- To provide a vision on the road to future 5G vehicular networks
- To show some recent research results on connected vehicles
- To provide useful references for future personal researches



Who we are

Researchers at CNR-IEIIT



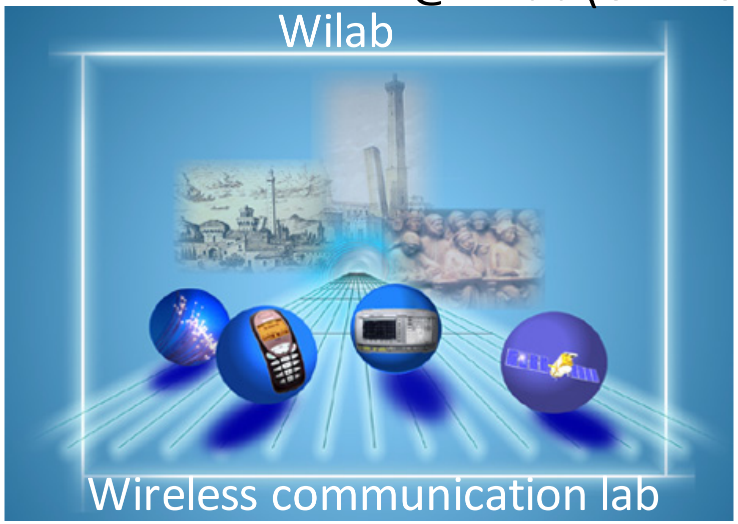
National Research Council of Italy

Institute of Electronics, Computer and Telecommunication Engineering

Research Groups

- Applied Electromagnetics & Electronic Devices
- Computer Engineering & Networks
- Decision Support Methods and Models
- Engineering for Health and Wellbeing
- Network Security
- Systems and Control Technologies
- Wireless Communication Systems

@Wilab (Univ. of Bologna, CNR-IEIIT, Unife)



Outline

Part I: Introduction and applications

- Toward autonomous vehicles
- Present, future and visionary applications for the vehicular networks
- Standardization bodies and main technologies for the connected vehicles

Part II: IEEE 802.11p/ITS-G5

- Large scale experiments
- Standards overview
- Performance

Pat III: LTE-V2V

- Why LTE-V2V
- LTE-V2V standard overview
- LTE-V2V vs. IEEE 802.11p

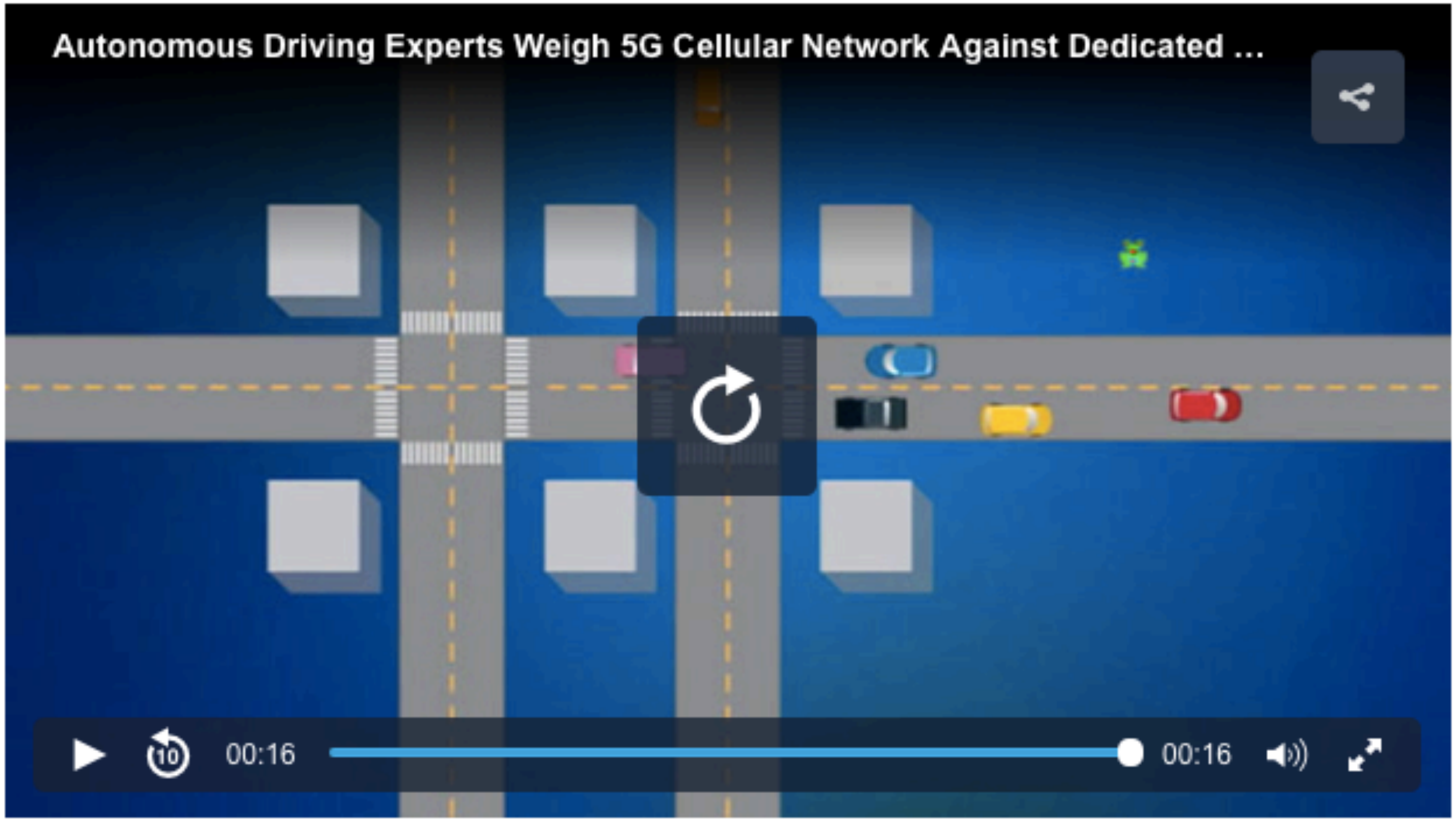
Part IV: Towards 5G

- Introduction to 5G
- Full duplex radios and the possible impact on vehicular communications
- Complementary technologies for the Internet of vehicles: visible light communication

Autonomous vehicles and (or vs.?) connected vehicles

When vehicles will talk to each other

- http://spectrum.ieee.org/cars-that-think/transportation/self-driving/autonomous-driving-experts-weigh-5g-cellular-network-against-shortrange-communications-to-connect-cars

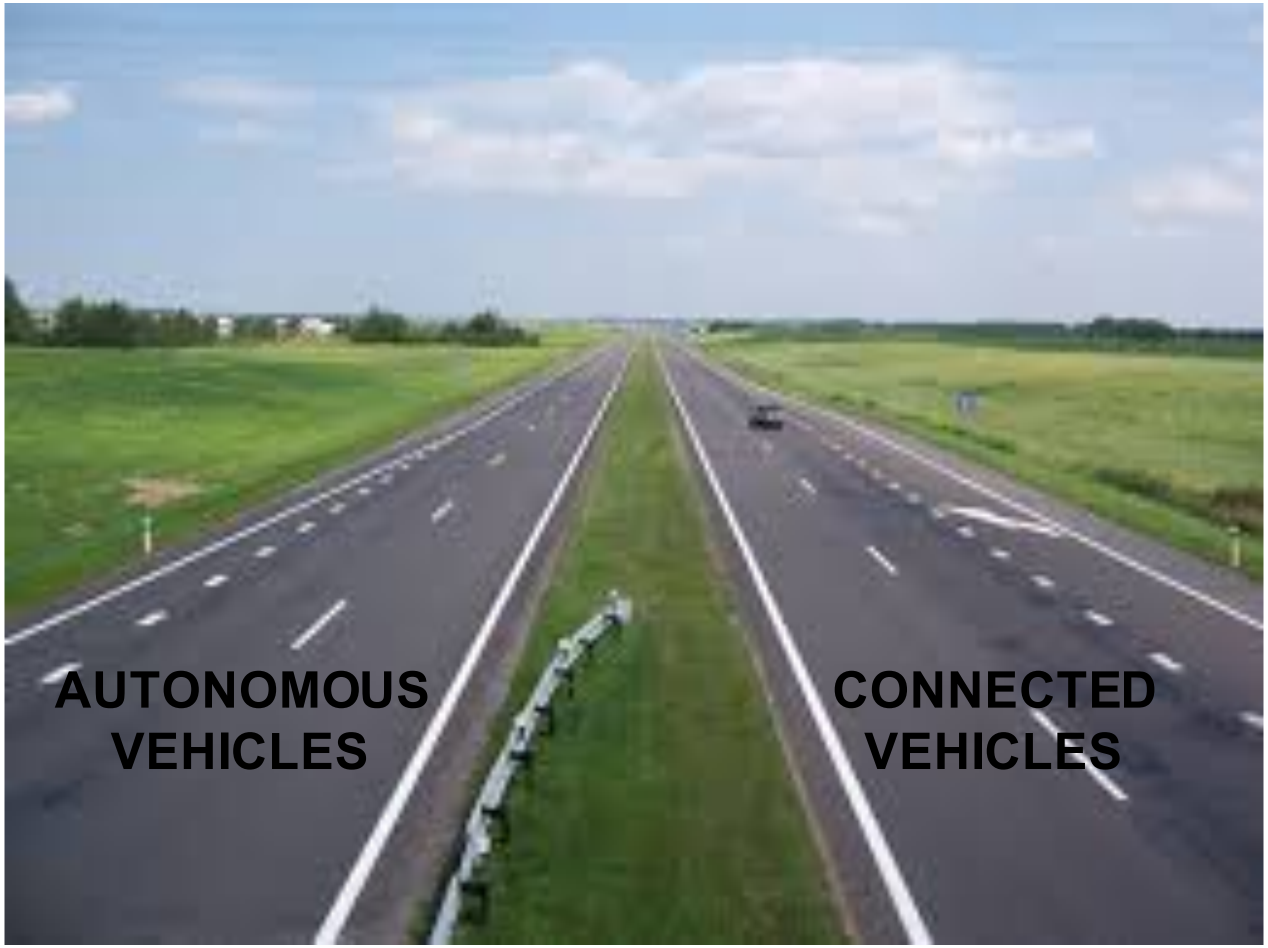


Toward 5G vehicular networks

- We have a great talking about robo-cars
- We think about travelling on an autonomous vehicle
- But we still no have connected vehicles

Can a vehicle be fully autonomous without connectivity?

Autonomous and (or vs?) connected vehicles

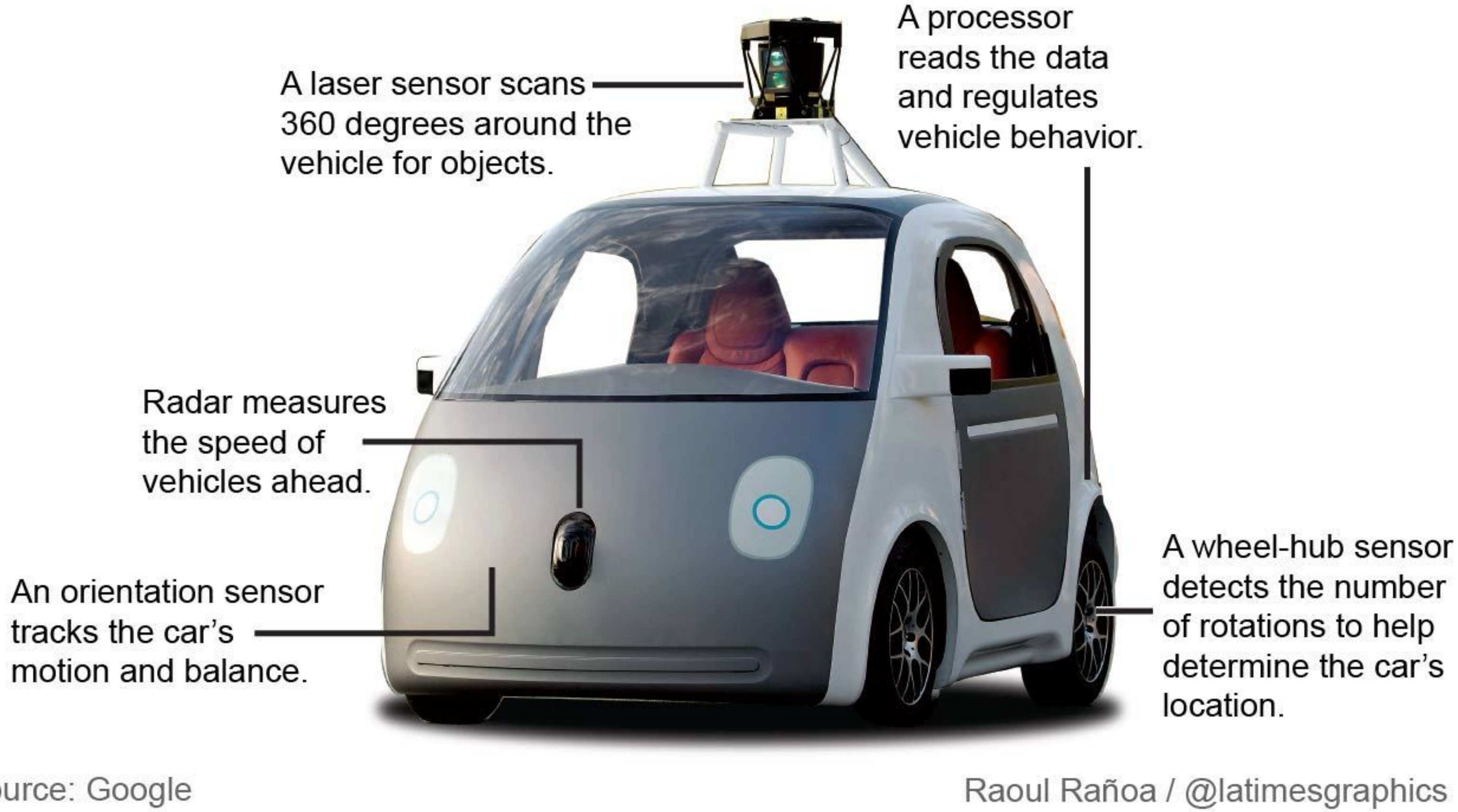


Autonomous and connected vehicles are now running on parallel highways

Autonomous vehicles

Autonomous vehicles

In order for a car to drive itself,
it needs to be able to see the world around it.



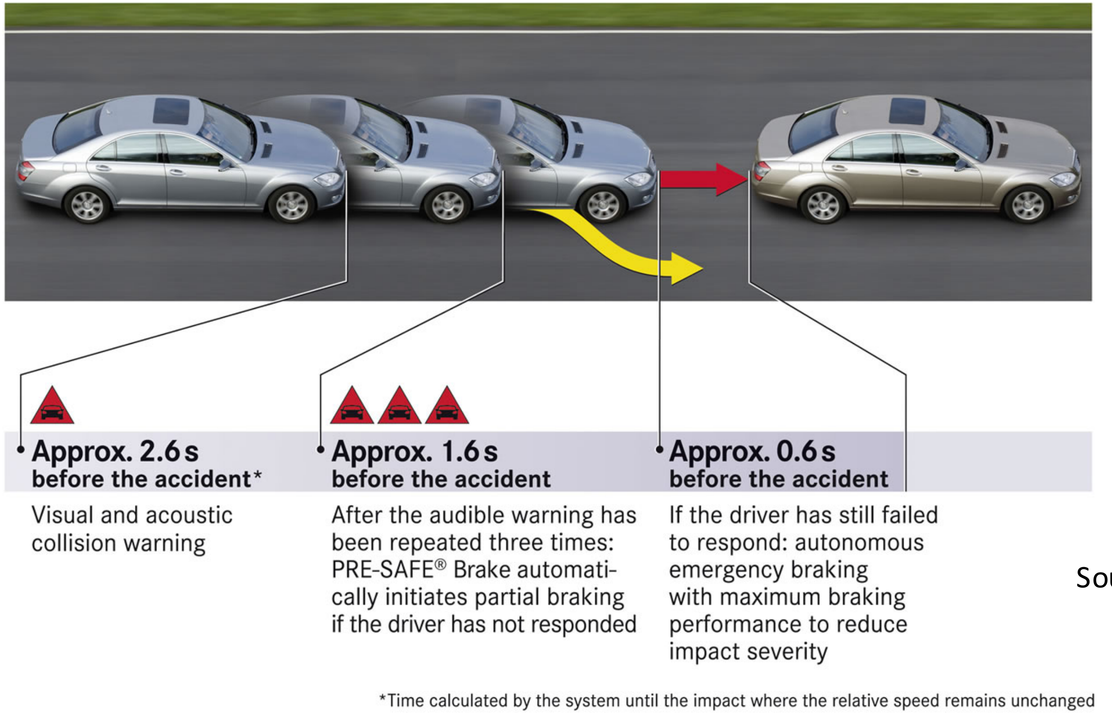
Why autonomous vehicles

The main drivers for automated driving are:

•**Safety**: Reduce accidents caused by human errors.
•**Comfort**: Enable user's freedom for other activities when automated systems are active.
•**Social inclusion**: Ensure mobility for all, including elderly and impaired users.
•**Accessibility**: Facilitate access to city centers.
•**Efficiency and environmental objectives**: Increase transport system efficiency and reduce time in congested traffic. Smoother traffic will help to decrease the energy consumption and emissions of the vehicles

http://www.ertrac.org/uploads/documentsearch/id38/ERTRAC_Automated-Driving-2015.pdf

Driver 1: Safety



Source: Mercedez-Benz

- driver error is a factor in 94 percent of crashes [FutureStructure2017]
- "as few as 5 percent of vehicles being automated and carefully controlled, we can eliminate stop-and-go waves caused by human driving behavior" [University of Illinois College of Engineering]

Driver 2: Comfort

Source: Adient

Driver 3: Social inclusion

Source: google

Driver 4: Accessibility

B. Friedrich, Verkehrliche Wirkung Autonomer Fahrzeuge, in: M. Maurer, J. C. Gerdes, B. Lenz, H. Winner (Eds.), Autonomes Fahren, Springer-Verlag, Berlin, 2015, Ch. 16, pp. 331–350.

suggests capacity gains of up to 80% on highways and of up to 40% on urban roads compared to today if all vehicles on the road were fully autonomous.

Driver 5: Efficiency

Optimize the transport system and reduce pollution

According to Daniel Work - University of Illinois, with as few as 5 percent of vehicles being automated, we can eliminate stop-and-go waves caused by human driving behavior."

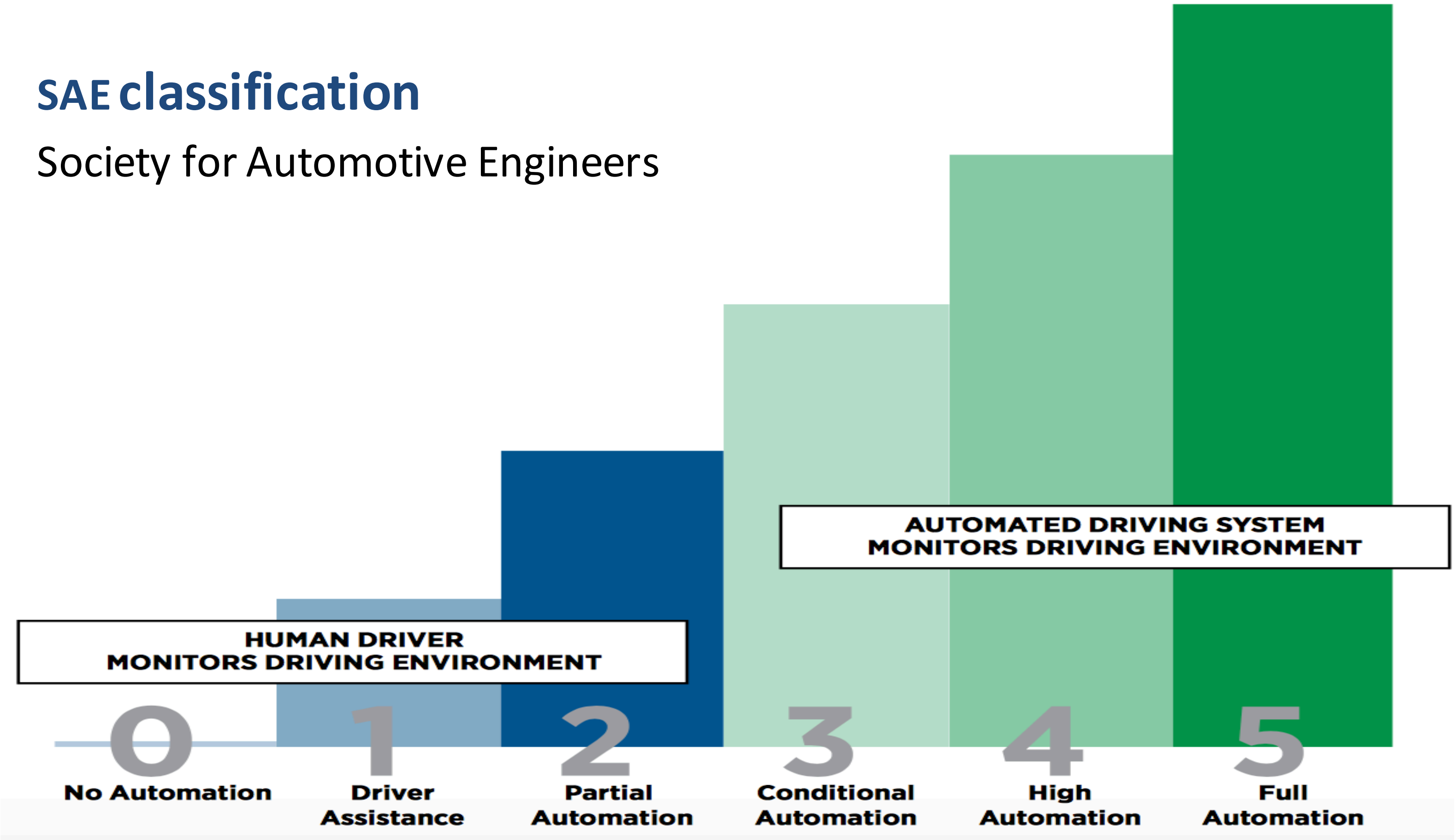
But before coming to full capacity, autonomous vehicles could mean more traffic: If nondrivers, seniors, and people with medical conditions could access automated mobility, Samaras' research shows, U.S. vehicle miles traveled could increase 14 percent.

http://spectrum.ieee.org/transportation/self-driving/the-big-problem-with-selfdriving-cars-is-people

Classification of "Automation" in vehicles

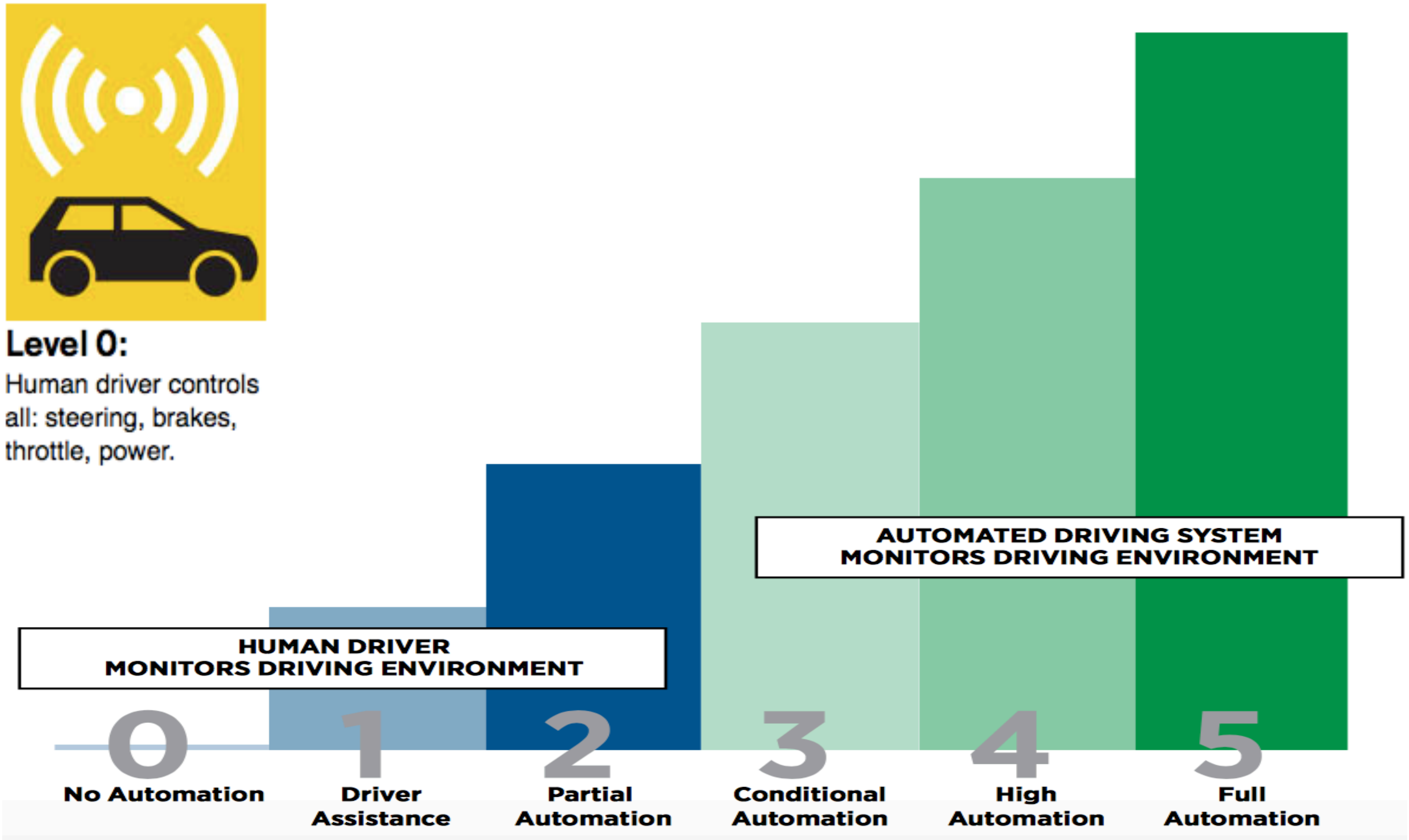
SAE classification

Society for Automotive Engineers



http://www.sae.org/misc/pdfs/automated_driving.pdf

Classification of "Automation" in vehicles



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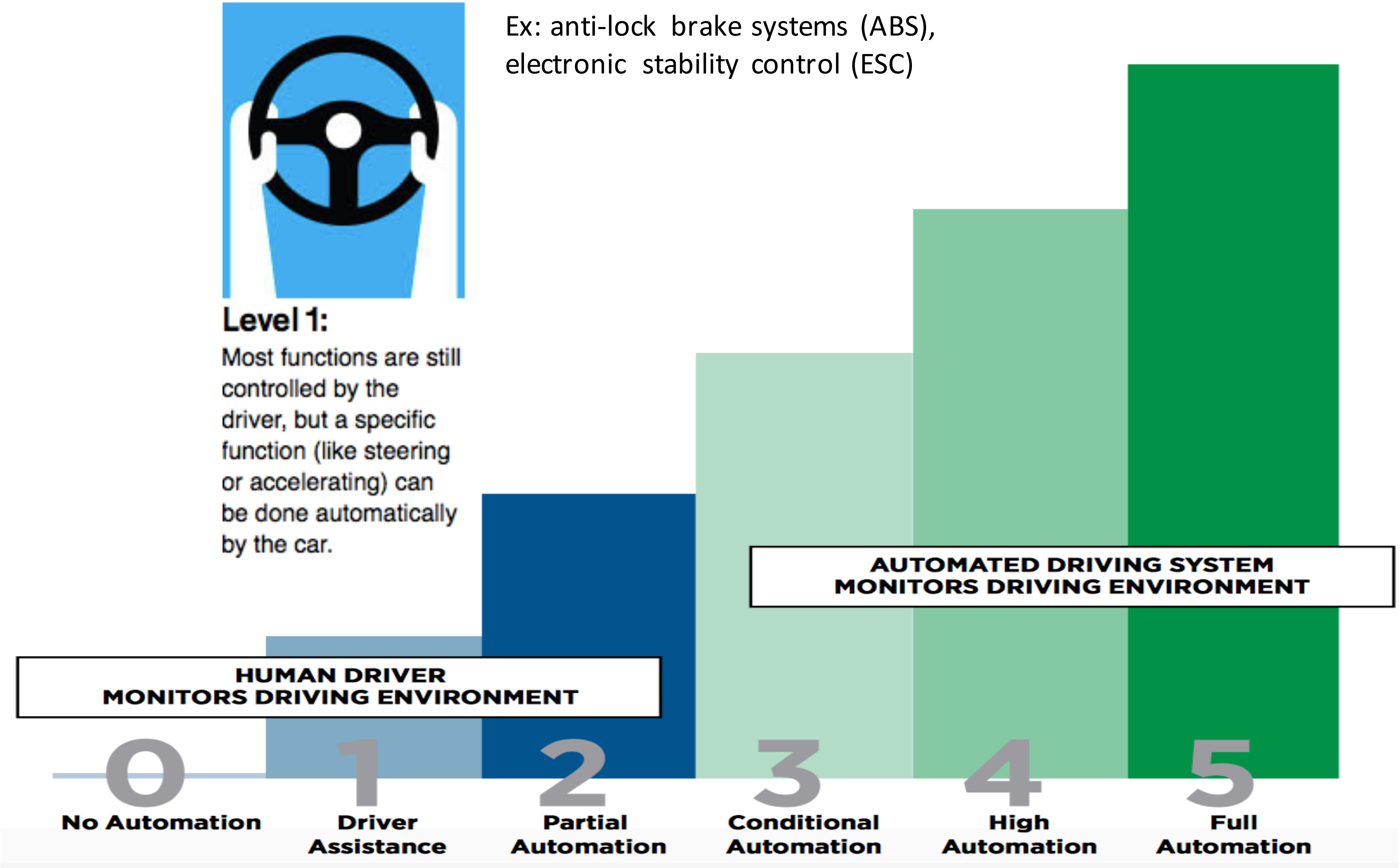
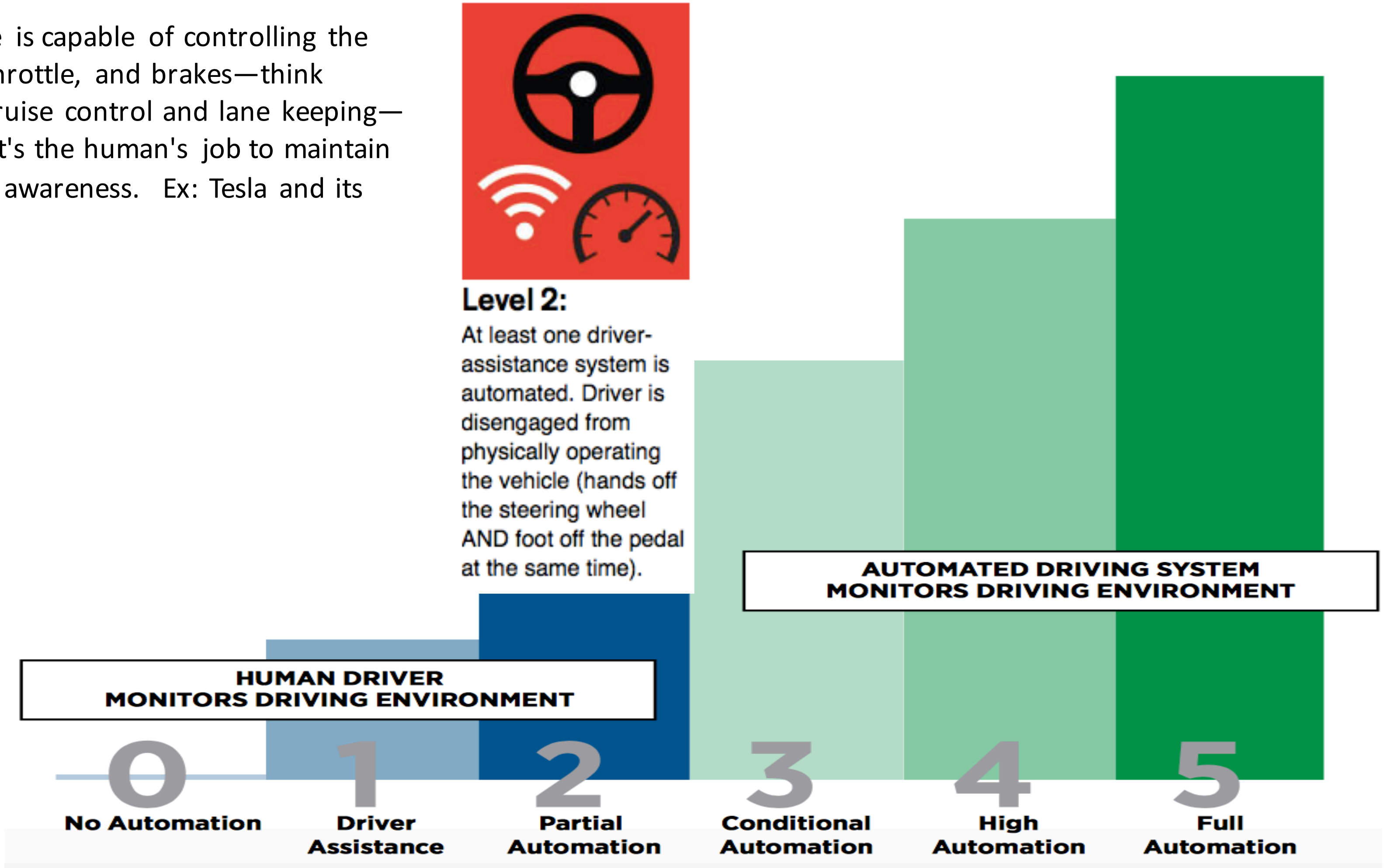
Classification of "Automation" in vehicles



http://www.sae.org/misc/pdfs/automated_driving.pdf

Classification of “Automation” in vehicles

The vehicle is capable of controlling the steering, throttle, and brakes—think adaptive cruise control and lane keeping—but again it's the human's job to maintain situational awareness. Ex: Tesla and its Autopilot

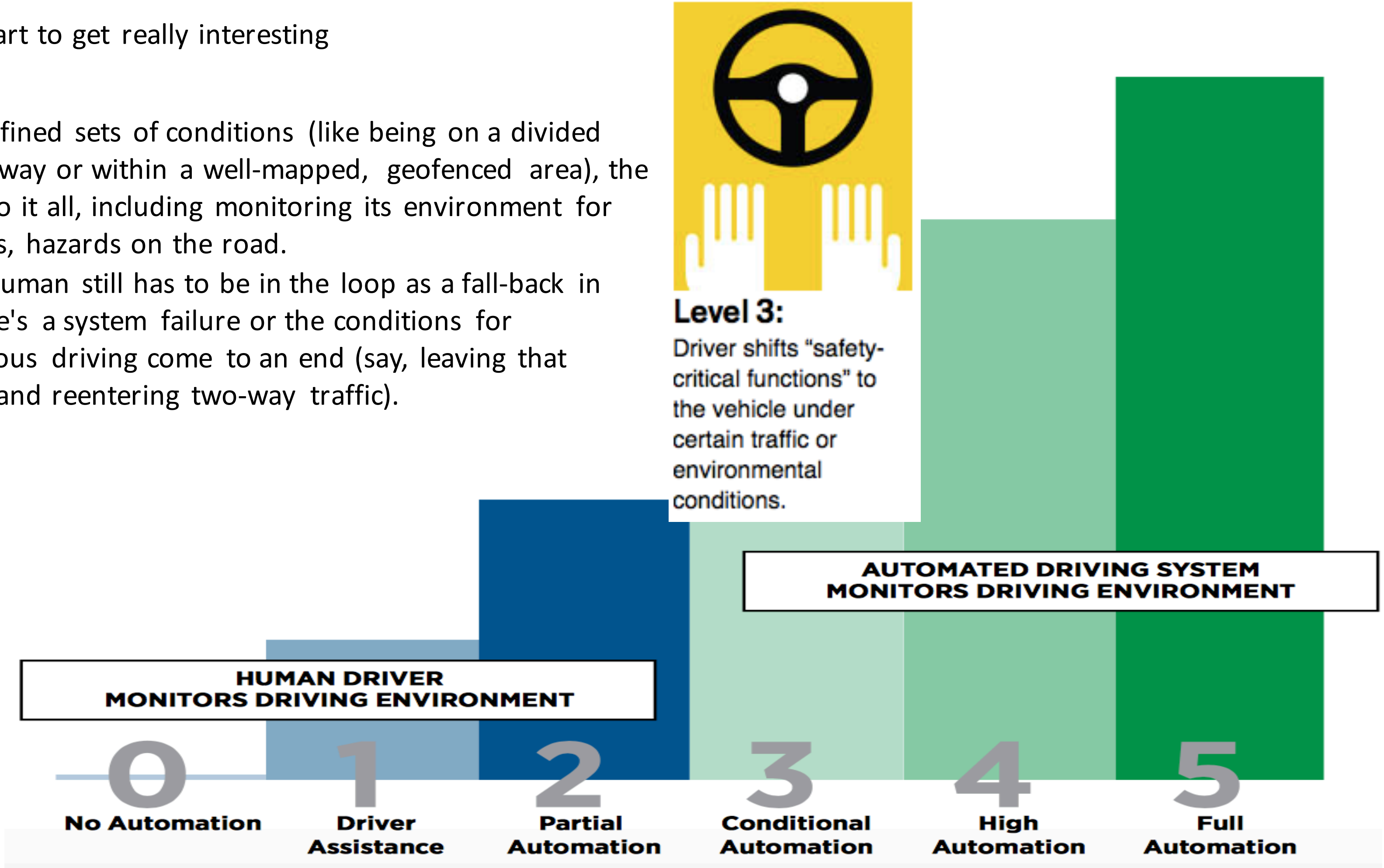


http://www.sae.org/misc/pdfs/automated_driving.pdf

Classification of “Automation” in vehicles

Things start to get really interesting

Under defined sets of conditions (like being on a divided lane highway or within a well-mapped, geofenced area), the car can do it all, including monitoring its environment for other cars, hazards on the road.
But the human still has to be in the loop as a fall-back in case there's a system failure or the conditions for autonomous driving come to an end (say, leaving that highway and reentering two-way traffic).



http://www.sae.org/misc/pdfs/automated_driving.pdf

Audi Level 3

Things start to get really interesting

Under defined sets of conditions (like being on a divided lane highway or within a well-mapped, geofenced area), the car can do it all, including monitoring its environment for other cars, hazards on the road.
But the human still has to be in the loop as a fall-back in case there's a system failure or the conditions for autonomous driving come to an end (say, leaving that highway and reentering two-way traffic).

Level 3:
Driver shifts "safety-critical functions" to the vehicle under certain traffic or environmental conditions.

https://arstechnica.com/cars/2017/07/bosch-took-us-for-a-ride-in-its-level-3-autonomous-car/

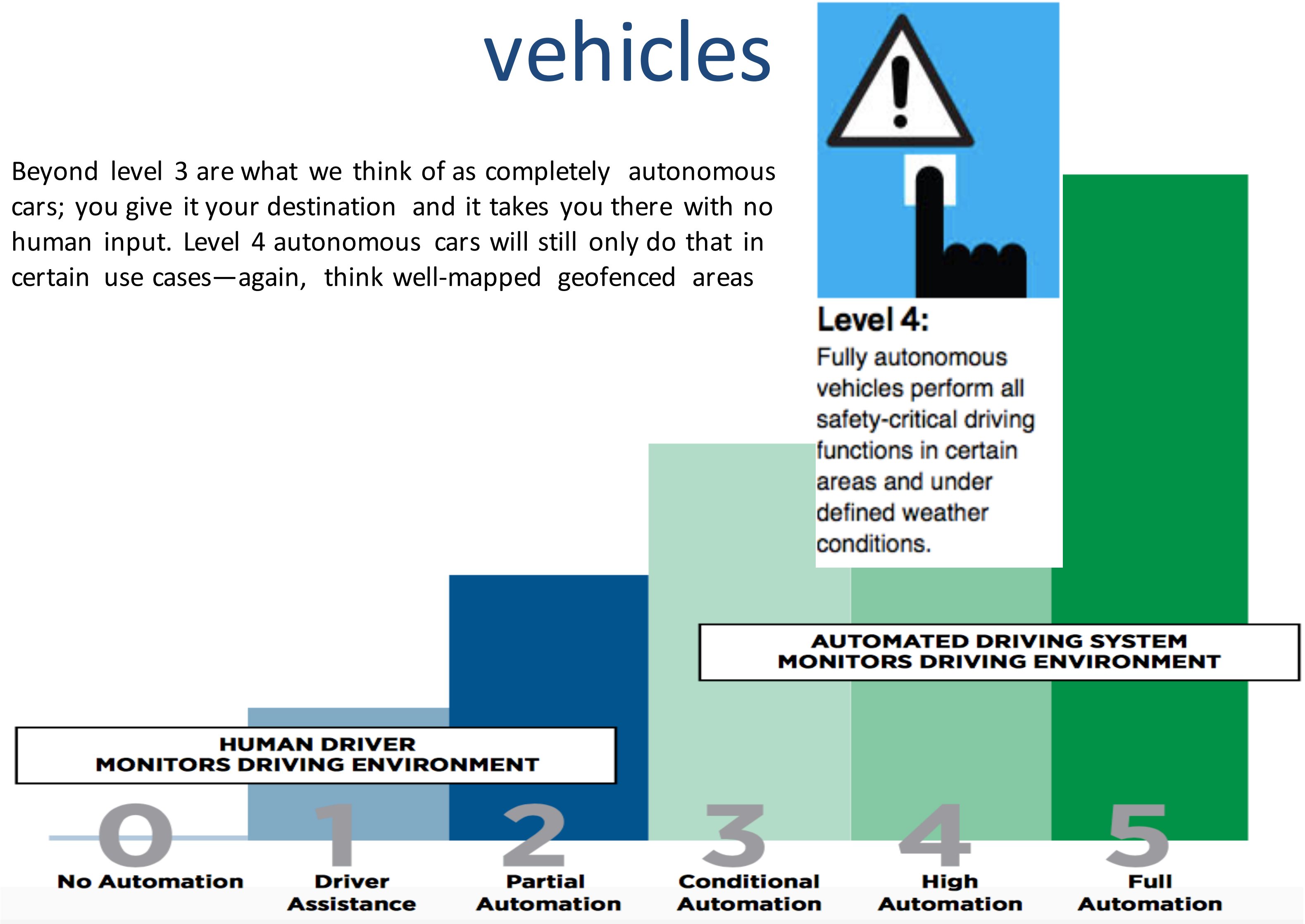
Audi A8 Sedan Level 3

The new A8 will be the world's first production level 3 autonomous car in 2018

All-wheel steering. Adaptive air suspension that uses **optical cameras** to read the road ahead. A **lidar**, **radar**, and camera-enabled level 3 autonomous driving mode **for highway** traffic jams. An all-new "black panel" cockpit with a new version of the multimedia interface (MMI) infotainment system. The rear seats can even give you a foot massage!

Classification of “Automation” in vehicles

Beyond level 3 are what we think of as completely autonomous cars; you give it your destination and it takes you there with no human input. Level 4 autonomous cars will still only do that in certain use cases—again, think well-mapped geofenced areas



http://www.sae.org/misc/pdfs/automated_driving.pdf

Bosh AI for level 4 autonomous vehicles

Artificial Intelligence (AI) provides:

•Detection: understanding the world around the vehicle

•Localization: using what’s perceived to create a detailed local map

•Occupancy grid: building a real-time 3D environment around the vehicle

•Path planning: determining how to proceed along the mapped route

•Vehicle dynamics: calculating how to drive smoothly

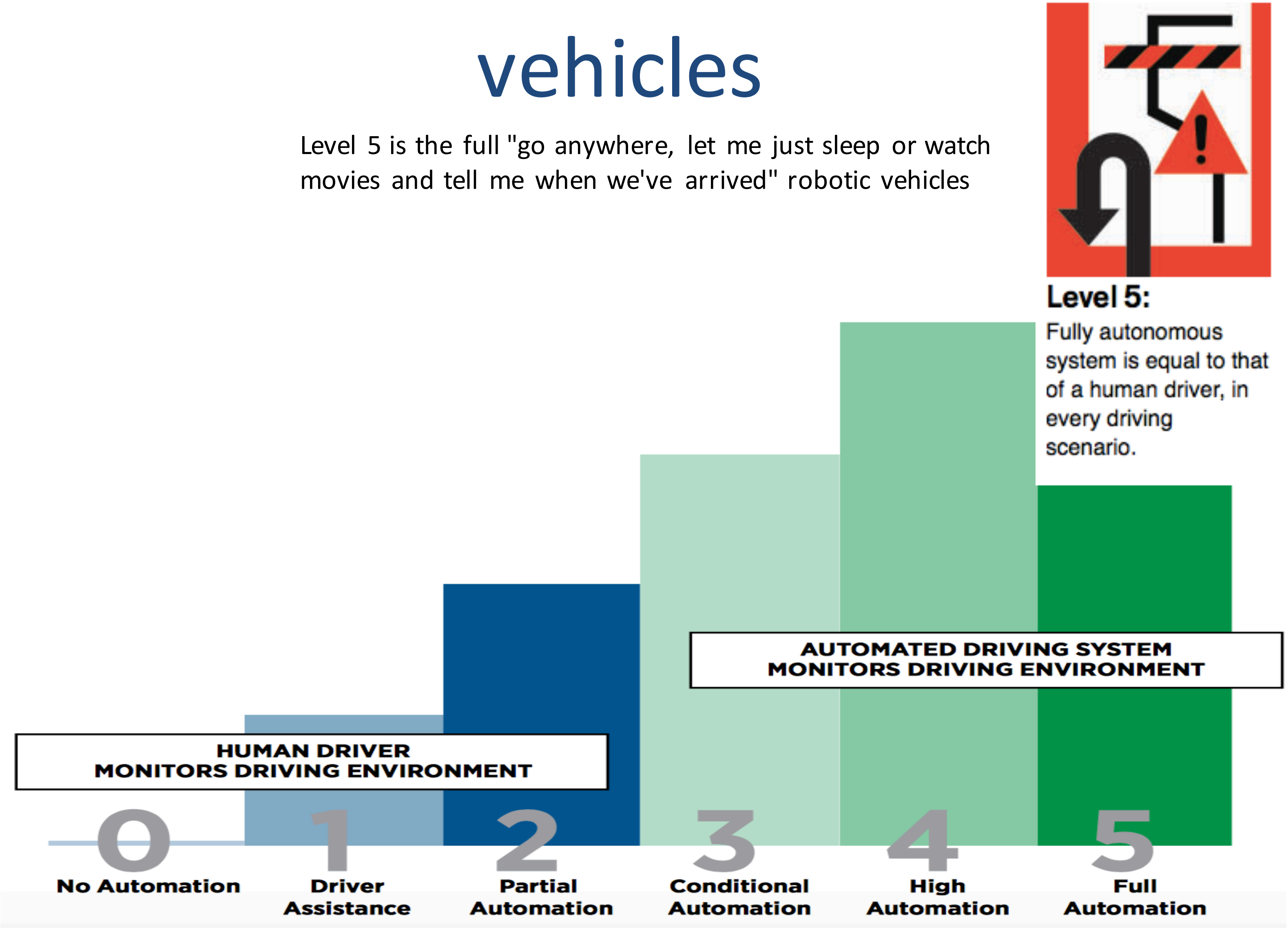
Level 4 capabilities promised by the end of 2018

Level 4:
Fully autonomous vehicles perform all safety-critical driving functions in certain areas and under defined weather conditions.

https://blogs.nvidia.com/blog/2017/03/16/bosch/

Classification of “Automation” in vehicles

Level 5 is the full "go anywhere, let me just sleep or watch movies and tell me when we've arrived" robotic vehicles



http://www.sae.org/misc/pdfs/automated_driving.pdf

Levels of Automation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*	
***Human driver* monitors the driving environment**							
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	
1	**Driver Assistance** "hands on"	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	*example: cruise control*
2	**Partial Automation** "hands off"	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	*example: adaptive cruise control, automatic emergency braking*
***Automated driving system* ("system") monitors the driving environment**							
3	**Conditional Automation** "eyes off"	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	*human ready for intervention*
4	**High Automation** "mind off"	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	*not all cases... for example: max speed, good weather*
5	**Full Automation** "wheel optional"	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	

http://www.sae.org/misc/pdfs/automated_driving.pdf

Deals, investments, partnerships, and new entrants

Technologies				Enabling services	
Adaptive driver assistance systems	***Infotainment***	***Human–machine interface***	***Communications, computing, and cloud***	***Connected vehicle services***	***Connected device services***
OEMs (major automakers)					
Acquisition Audi/Daimler/BMW: Here (2015) GM: Cruise Automation (2016) ***Investment*** Volvo: Peloton (2015) ***Partnership*** Audi & Nvidia (since 2005) Bosch & TomTom (2015) GM & Mobileye (2015) VW & Mobileye (2015) BMW & Intel & Mobileye (2016) Hyundai & Cisco (2016)	***Investment*** Ford: Livio (2013) ***Partnership*** Audi & Nvidia (since 2005)		***Partnership*** Daimler & Qualcomm (2015) Hyundai & Cisco (2016) Toyota & KDDI (2016)	***Partnership*** Ford & State Farm (2012) BMW & Pivotal (2015) Ford & Microsoft Azure (2015) Volvo & Microsoft (2015) Nissan & Microsoft Azure (2016)	***Acquisition*** Daimler: Mytaxi (2014) GM: Sidecar (2016) ***Investment*** BMW: RideCell (2014) BMW: Zendrive (2014) GM: Telogis (2014) BAIC: Didi Chuxing (2015) Ford: Pivotal (2016) GM: Lyft (2016) Toyota: Uber (2016) VW: Gett (2016) ***Partnership*** BMW & Baidu (2015) BMW & Microsoft Azure (2016) Seat & Samsung & SAP (2016) Toyota & Microsoft Azure (2016)

Convergence of the automotive world and information systems

August 2017: FCA agreement with BMW-Intel-Mobyeye

Source: Connected-car-report-2016.pdf

Deals, investments, partnerships, and new entrants

Technologies				Enabling services	
Adaptive driver assistance systems	***Infotainment***	***Human–machine interface***	***Communications, computing, and cloud***	***Connected vehicle services***	***Connected device services***

New entrants from outside automotive

Adaptive driver assistance systems	Infotainment	Human–machine interface	Communications, computing, and cloud	Connected vehicle services	Connected device services
Acquisition Panasonic: Ficosa (2014) Google: FCA (2016) Nvidia: AdasWorks (2016) ***New entrants*** AdasWorks, Baselabs, Vector, Velodyne, Wind River	***New entrants:*** Apple, Baidu, Google	***Investment*** Intel: Omek (2013) ***New entrants*** Atmel, Fujitsu, Kyocera, LG, Toshiba	***Acquisition*** Cisco/NXP: Cohda Wireless (2013) ***New entrants*** Cohda Wireless, Kymeta, Veniam	***Investment*** Verizon: Hughes (2012) ***Partnership*** Airbiquity & Arynga (2016) ***New entrants*** Airbiquity, Allstate, Fleetmatics, Pivotal, Progressive, SiriusXM, Trimble, Verisk	***Partnership*** Daimler Moovel & IBM (2014) Airbiquity & Arynga (2016) ***New entrants*** Airbiquity, Apple, Contigo, Dash, Google, iTrack, Lyft, MyCarTracks, Uber

Source: Connected-car-report-2016.pdf

Autonomous car forecasts

The number of cars with various levels of autonomy will grow to a total of 150 million vehicles by 2025 https://blogs.nvidia.com/blog/2017/03/16/bosch/

http://www.driverless-future.com/?page_id=384

NVIDIA to introduce level-4 enabling system by 2018

At the Bosch Connected World 2017 in Berlin NVIDIA's CEO Jen-Hsun Huang announced that NVIDIA will provide technology enabling Level-4 autonomous driving capabilities by the end of 2018.

(Source: NVIDIA, 2017-03-16)

Audi to introduce a self-driving car by 2020

Scott Keogh, Head of Audi America announced at the CES 2017 that an Audio that really would drive itself would be available by 2020.

(Source: IEEE Spectrum, 2017-01-05)

First autonomous Toyota to be available in 2020

Toyota is starting to overcome its long-standing reluctance with respect to autonomous driving: It plans to bring the first models capable of autonomous highway driving to the market by 2020.

(Source: Wired.com, 2015-10-08)

Elon Musk now expects first fully autonomous Tesla by 2018, approved by 2021

In an interview by Danish newspaper Borsen, Tesla's founder Elon Musk accelerates his timeline for the introduction of fully autonomous Teslas by 2 years (!) compared to his estimate less than a year ago (October 2014). He now expects fully autonomous Teslas to be ready by 2018 but notes that regulatory approval may take 1 to 3 more years thereafter.

(Source: Borsen Interview on youtube, timeline: 8:06-8:29, recorded on 2015-9-23)

Autonomous cars forecasts

A recent study by Bosch suggests that autonomous driving is going to be a big selling point for customers in the future—54 percent of the 6,000 people the company surveyed said it would increase their interest in buying a new vehicle

http://www.driverless-future.com/?page_id=384

Ford CEO announces fully autonomous vehicles for mobility services by 2021

Mark Fields, Ford's CEO announced that the company plans to offer fully self-driving vehicles by 2021. The vehicles, which will come without steering wheel and pedals, will be targeted to fleets which provide autonomous mobility services. Fields expects that it will take several years longer until Ford will sell autonomous vehicles to the public.

Source: Reuters, 2016-08-16

Volkswagen expects first self driving cars on the market by 2019

Johann Jungwirth, Volkswagen's appointed head of Digitalization Strategy, expects the first self-driving cars to appear on the market by 2019. He did not claim that these would be Volkswagen models.

Source: Focus, 2016-04-23

GM: Autononomous cars could be deployed by 2020 or sooner

General Motor's head of foresight and trends Richard Holman said at a confererence in Detroit that most industry participants now think that self-driving cars will be on the road by 2020 or sooner.

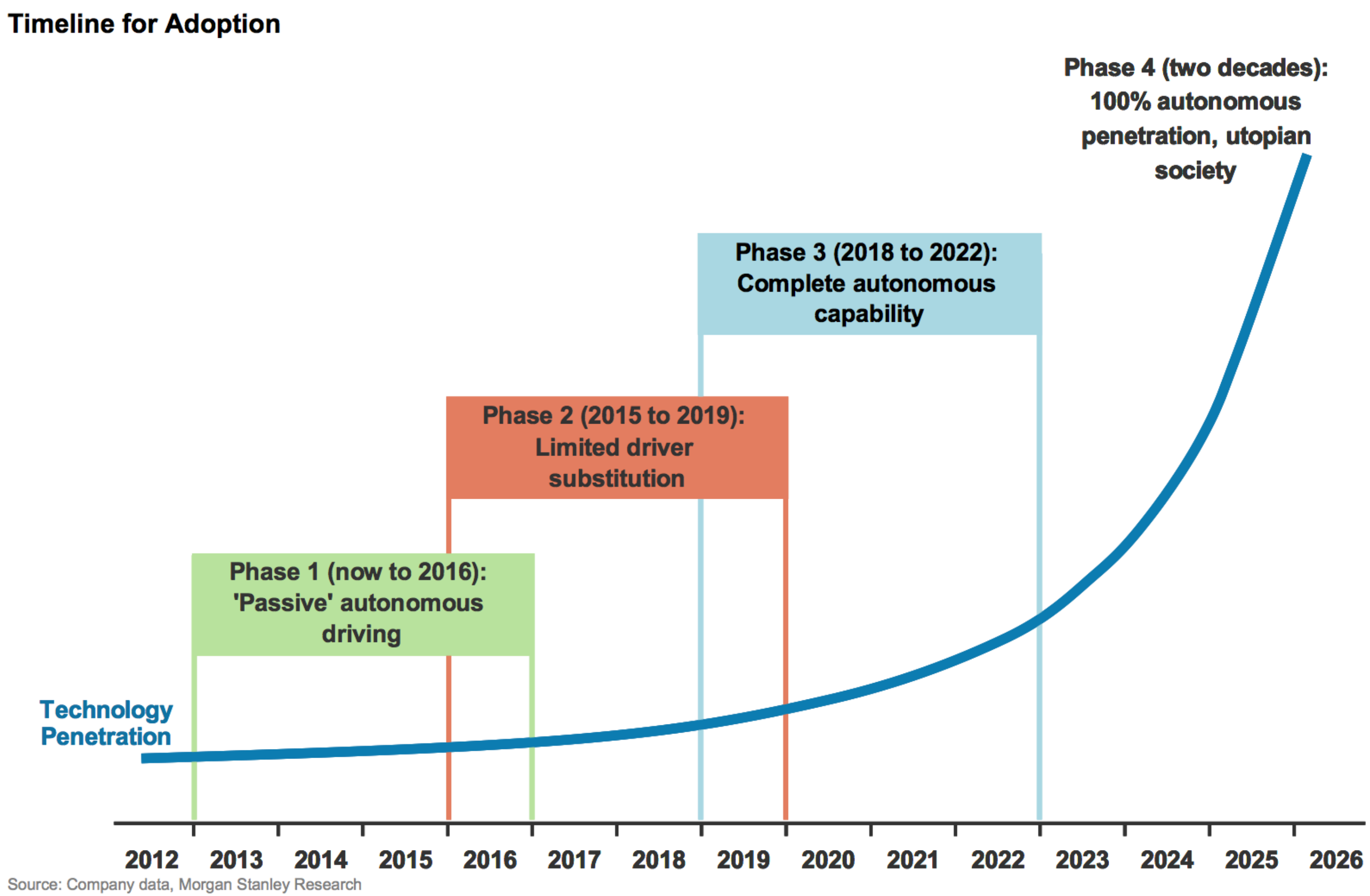
Source: Wall Street Journal, 2016-05-10

BMW to launch autonomous iNext in 2021

At their annual shareholder meeting, BMW CEO Harald Krueger said that BMW will launch a self-driving electric vehicle, the BMW iNext, in 2021.

Source: Elektrek, 2016-05-12

Autonomous cars forecasts



Where we are

Google gets first self-driven car license in Nevada

By Mary Slosson

(Reuters) - Google's self-driven cars will soon be appearing on Nevada roads after the state's Department of Motor Vehicles approved on Monday the nation's first autonomous vehicle license.

The move came after officials rode along on drives on highways, in Carson City neighborhoods and along the famous Las Vegas Strip, the Nevada DMV said in a statement.

The Nevada legislature last year authorized self-driven cars for the state's roads, the first such law in the United States. That law went into effect on March 1, 2012.

Related News

Oracle confronts Google's Schmidt about Java

Oracle trial against Google turns into CEO day

Oracle says Google's own emails show its guilt

Analysis & Opinion

A London divided against itself

http://www.reuters.com

Ethical questions:
Should your driverless car kill you if it means saving five pedestrians?
Legal questions: which is the guilty part in case of accident?

Other interesting readings:

http://thinkinghighways.com/a-driverless-future/

https://www.driverless.id/news/definitive-guide-levels-automation-for-driverless-cars-0176009

Summarizing Autonomy

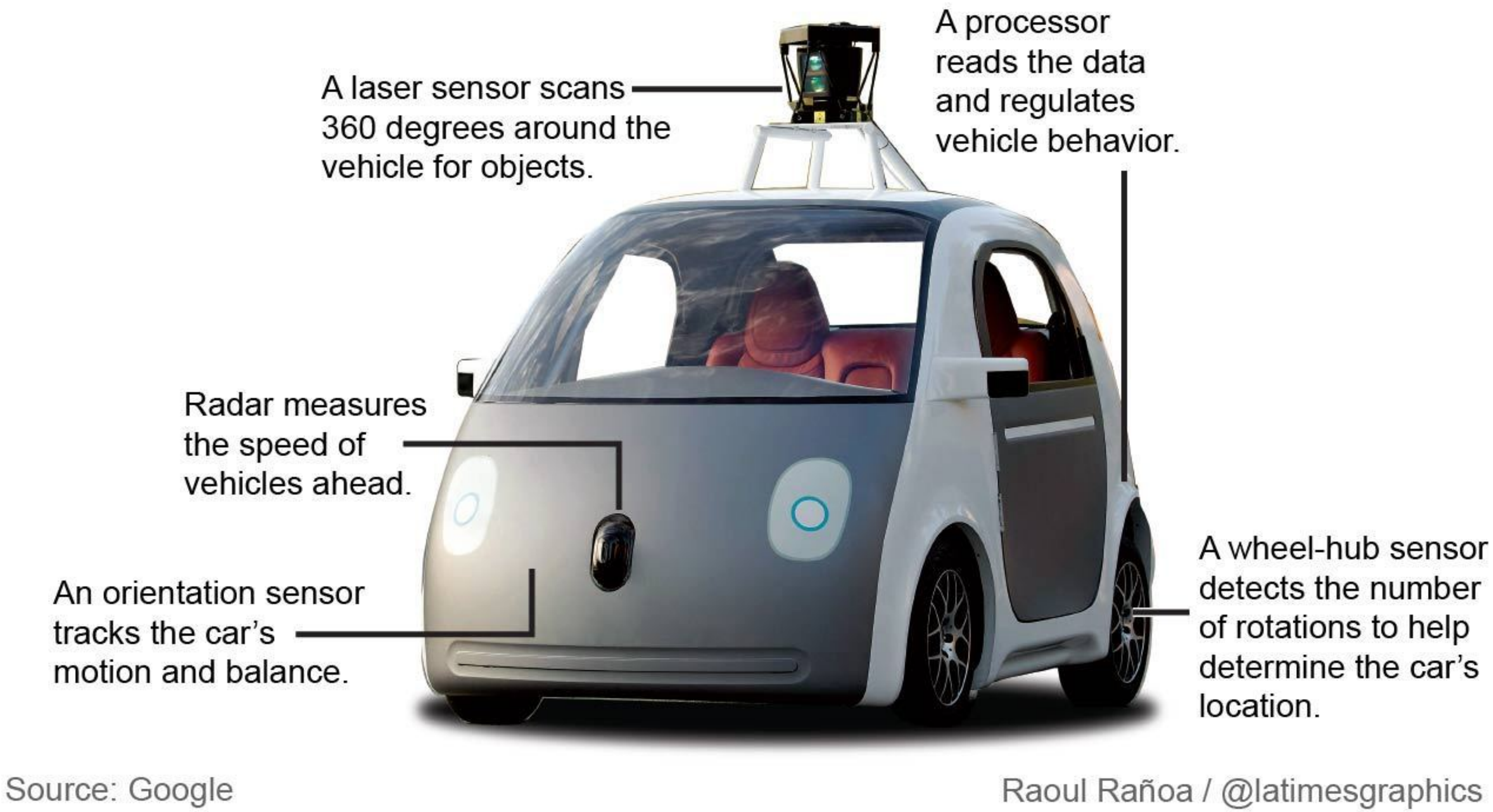
- It is all about on board sensors and Artificial Intelligence (AI)
- They are not autonomous, they are automated vehicles

BUT

- They do not see around the corner
- They cannot receive or transmit updated info

Remember…

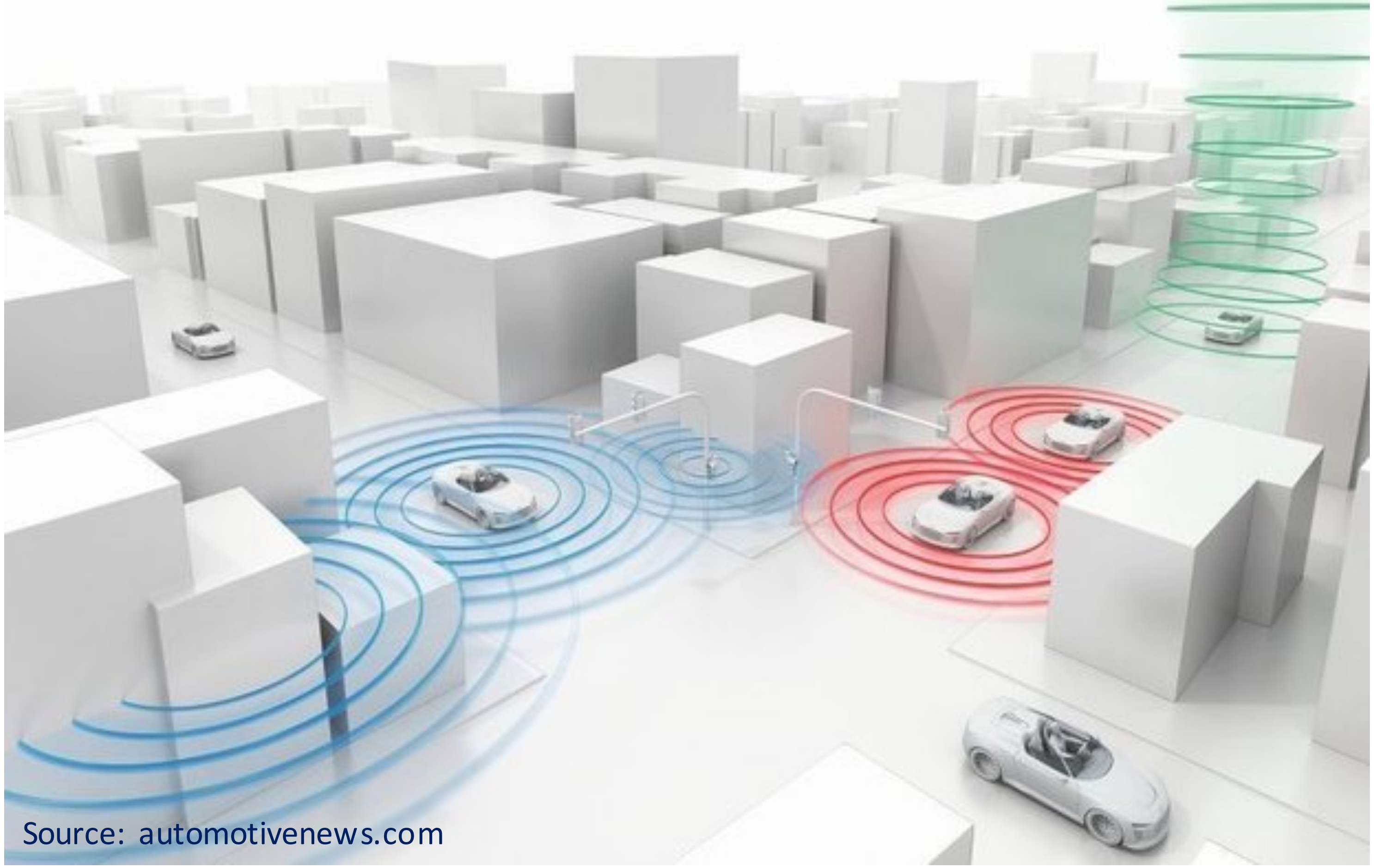
In order for a car to drive itself,
it needs to be able to see the world around it.



…Hence

Connectivity becomes essential

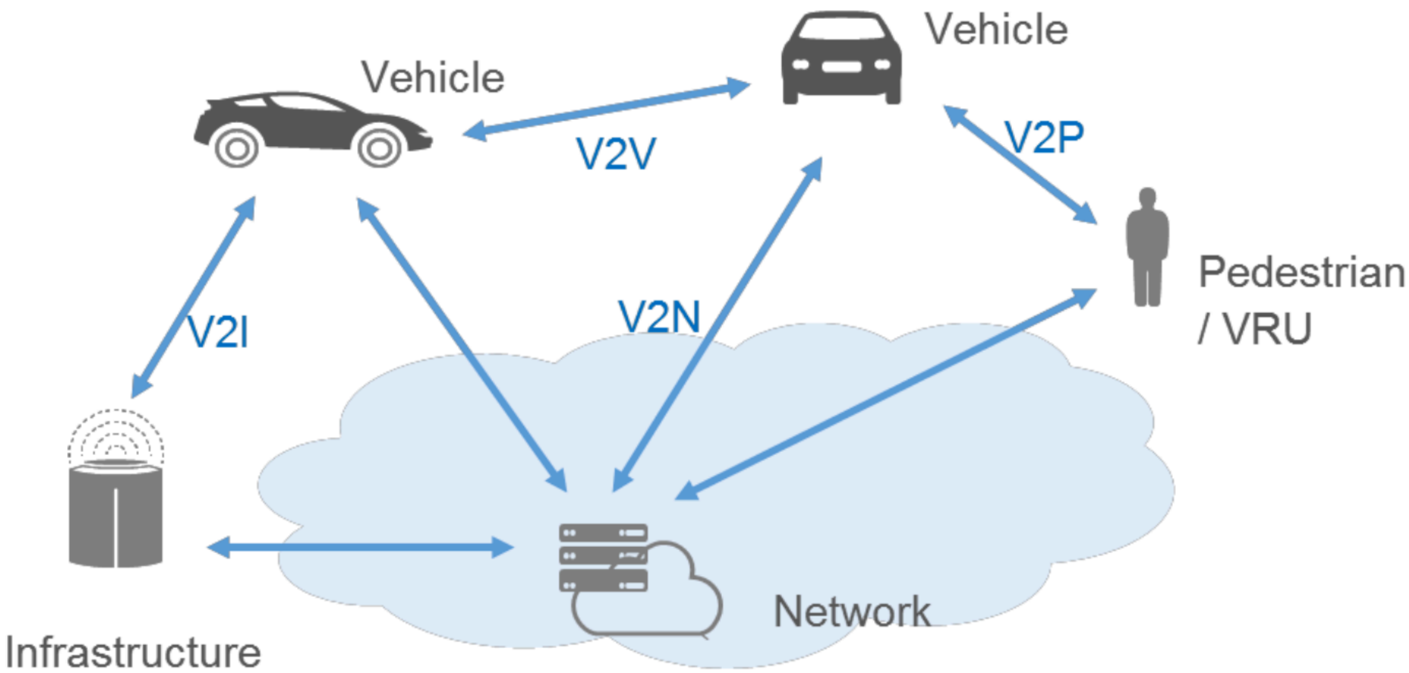
Connectivity can improve safety and efficiency of autonomous vehicles



Source: automotivenews.com

Connected vehicles

V2X communications



http://www.5gamericas.org/files/2914/7769/1296/5GA_V2X_Report_FINAL_for_upload.pdf

Why V2X communications

- Improve safety
- Improve traffic efficiency
- Introduce entertainment

Why V2X communications

- Improve safety
- Improve traffic efficiency

Table 1: Fatalities and Fatality Rate by Quarter, First Half, and the Percentage Change From the Corresponding Quarter or First Half in the Previous Year

Quarter	1st Quarter (Jan–Mar)	2nd Quarter (Apr–Jun)	3rd Quarter (Jul–Sep)	4th Quarter (Oct–Dec)	Total (Full Year)	1st Half (Jan–Jun)
Fatalities and Percentage Change in Fatalities for the Corresponding Quarter/Half From the Prior Year						
2005	9,239	11,005	11,897	11,369	43,510	20,244
2006	9,558 [+3.5%]	10,942 [-0.6%]	11,395 [-4.2%]	10,813 [-4.9%]	42,708 [-1.8%]	20,500 [+1.3%]
2007	9,354 [-2.1%]	10,611 [-3.0%]	11,056 [-3.0%]	10,238 [-5.3%]	41,259 [-3.4%]	19,965 [-2.6%]
2008	8,459 [-9.6%]	9,435 [-11.1%]	9,947 [-10.0%]	9,582 [-6.4%]	37,423 [-9.3%]	17,894 [-10.4%]
2009	7,552 [-10.7%]	8,975 [-4.9%]	9,104 [-8.5%]	8,252 [-13.9%]	33,883 [-9.5%]	16,527 [-7.6%]
2010	6,755 [-10.6%]	8,522 [-5.0%]	9,226 [+1.3%]	8,496 [+3.0%]	32,999 [-2.6%]	15,277 [-7.6%]
2011	6,726 [-0.4%]	8,227 [-3.5%]	8,984 [-2.6%]	8,542 [+0.5%]	32,479 [-1.6%]	14,953 [-2.1%]
2012	7,521 [+11.8%]	8,612 [+4.7%]	9,171 [+2.1%]	8,478 [-0.7%]	33,782 [+4.0%]	16,133 [+7.9%]
2013	7,166 [-4.7%]	8,207 [-4.7%]	9,024 [-1.6%]	8,496 [+0.2%]	32,893 [-2.6%]	15,373 [-4.7%]
2014	6,856 [-4.3%]	8,179 [-0.3%]	8,799 [-2.5%]	8,910 [+4.9%]	32,744 [-0.5%]	15,035 [-2.2%]
2015	7,335 [+7.0%]	8,765 [+7.2%]	9,708 [+10.3%]	9,284 [+4.2%]	35,092 [+7.2%]	16,100 [+7.1%]
2016†	8,175 [+11.5%]	9,600 [+9.5%]	—	—	—	17,775 [+10.4%]

More than 30000 deaths a year in the USA

https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812332

Why V2X communications

- Improve safety
- Improve traffic efficiency
- Introduce entertainment

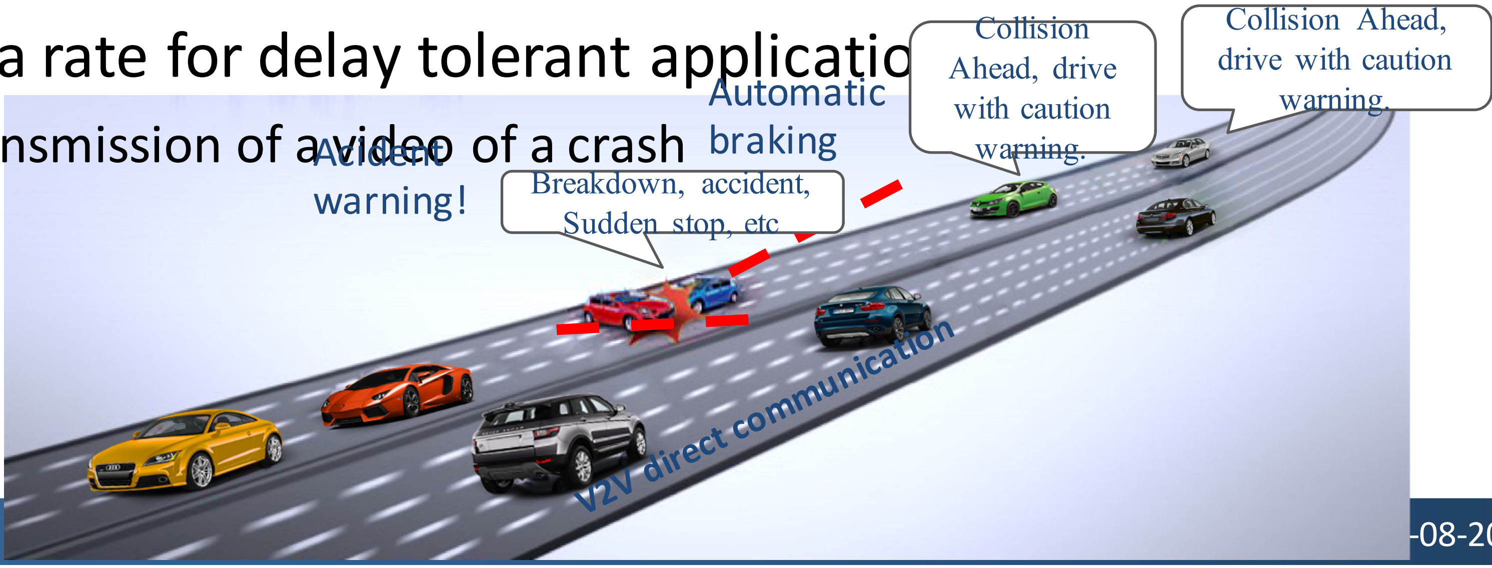
- About **1.25 million people die** each year worldwide as a result of road crashes.
- Road traffic injuries are the **leading cause of death among people aged between 15 and 29** years.
- Road traffic crashes cost most countries 3% of their gross domestic product.

Source: http://www.who.int/mediacentre/factsheets/fs358/en/ (updated May 2017)

Safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of (non-impaired) crashes, including crashes at intersections or while changing lanes. [Source: NHTSA]

V2X for safety: requirements

- Low latency, real time information
  - Direct V2V communications
  - Dedicated channels
  - Reliable wireless systems
  - Interaction with on board sensors
- Also low data rate
  - Small but frequent amount of data
- High data rate for delay tolerant applicatio
  - Ex: transmission of a video of a crash



Why V2X communications

- Improve safety
- Improve traffic efficiency
- Introduce entertainment

- Updated information in traffic and optimal routes can reduce the travel time
  - Annual delay per peak period: 47 hours
  - Economic cost: $63.1 billion a year
- Road transport is responsible for the bulk of transport emissions, in terms of greenhouse gases and air pollutants
- Over 70% of transport greenhouse gas emissions, 39% of NOx and 13% of particulate matter

congestions

Source: A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility, 30-11-2016

V2X for efficiency: requirements

- Updated information (not real time)
  - Optimal route
- Data rate and bandwidth depending on the application

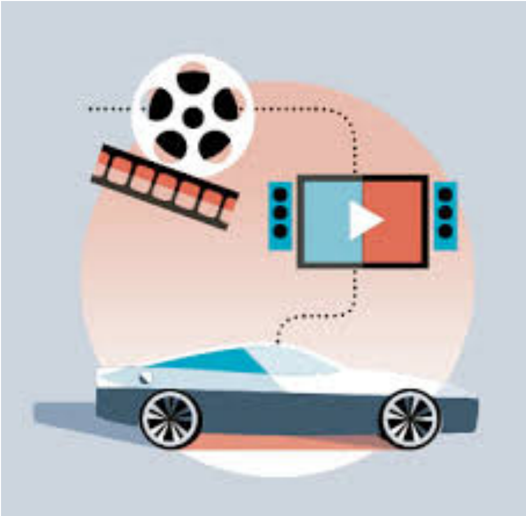
Why V2X communications

- Improve safety
- Improve traffic efficiency
- Introduce entertainment

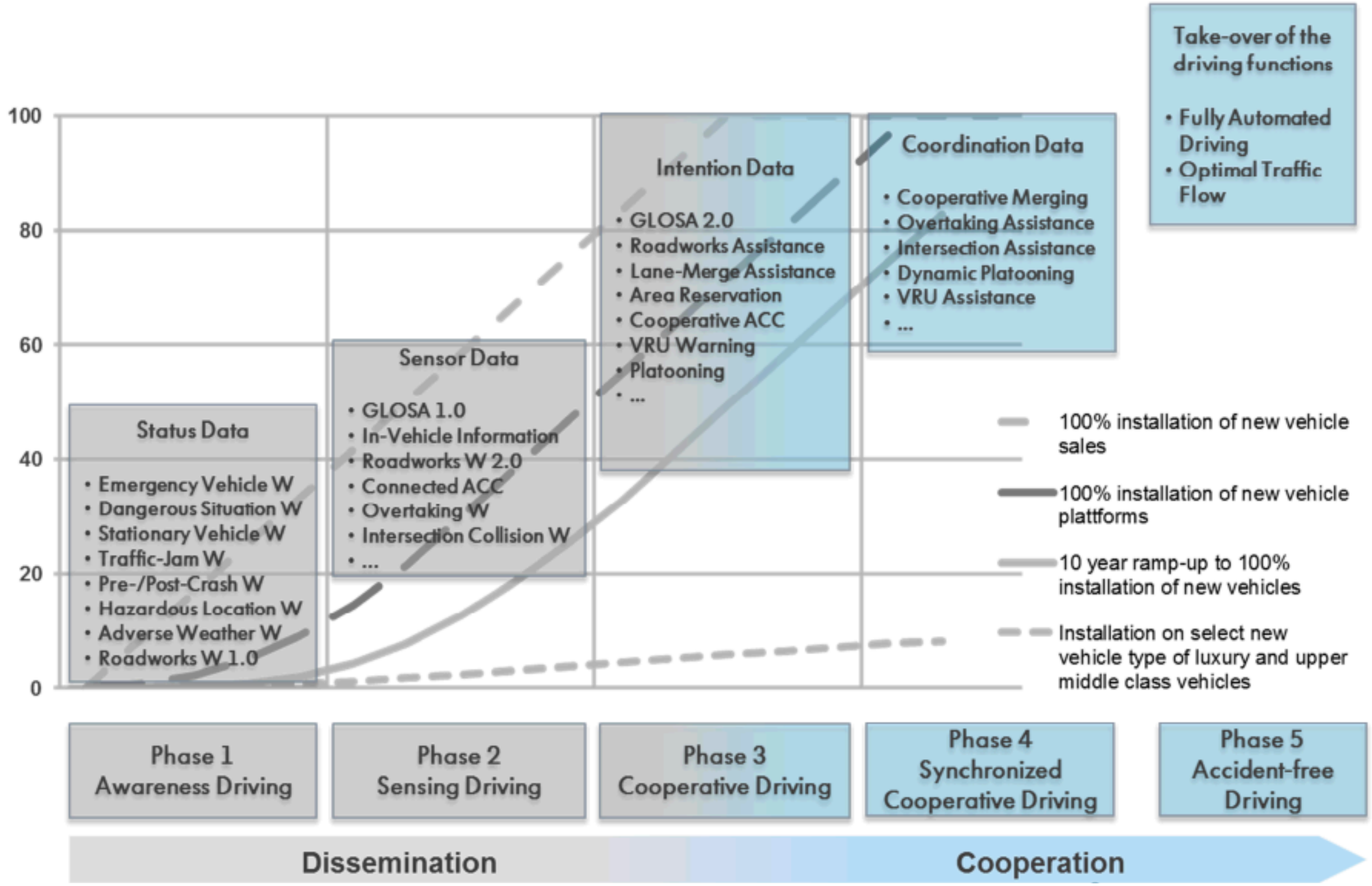
Internet access
Internet backbone
Social networking
Video streaming

V2X for entertainment: requirements

- High data rate
  - Video streaming
  - Social gaming
  - Internet access
- Latency not high
  - V2V communications (social gaming)
  - Not priority apps

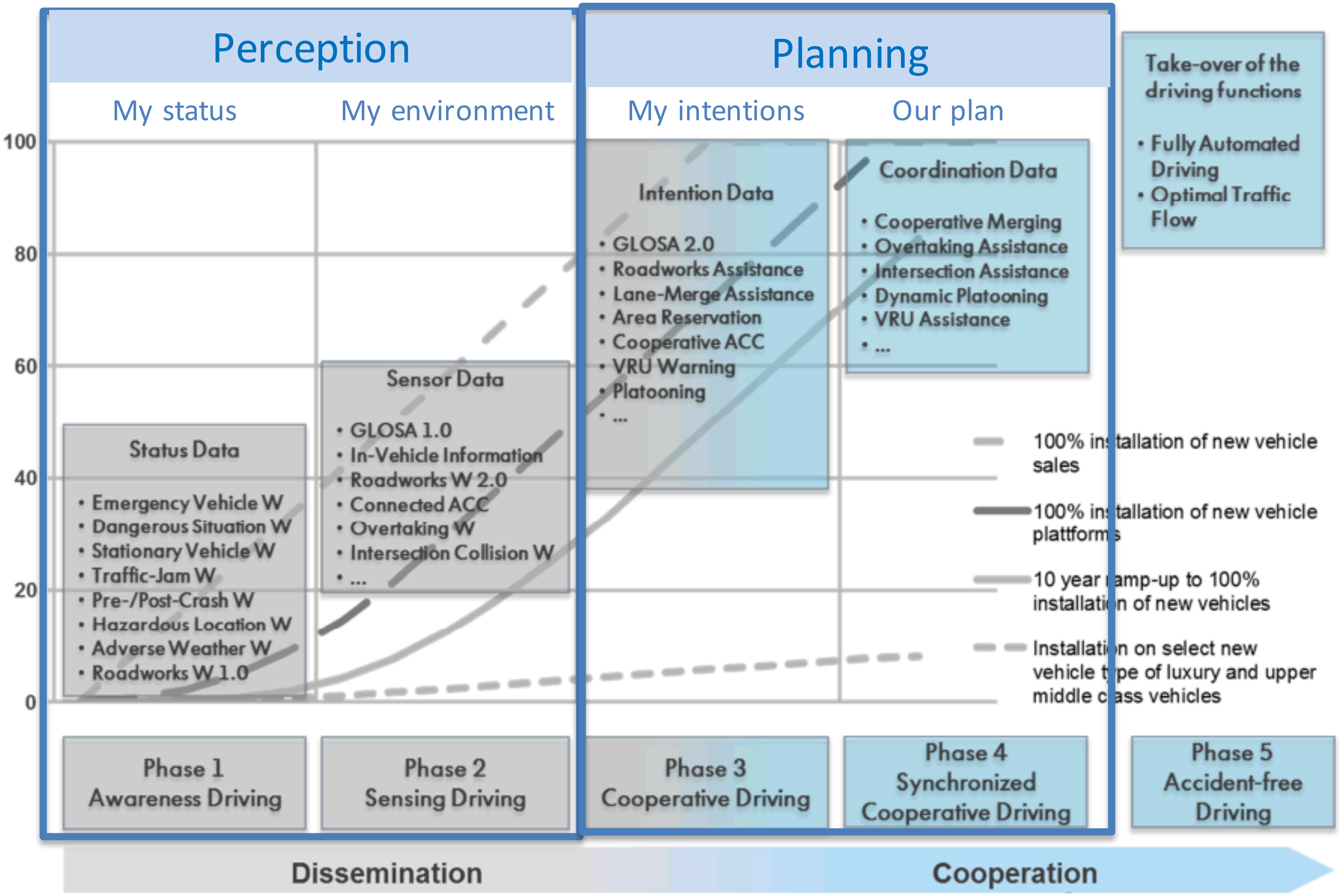


The roadmap of applications



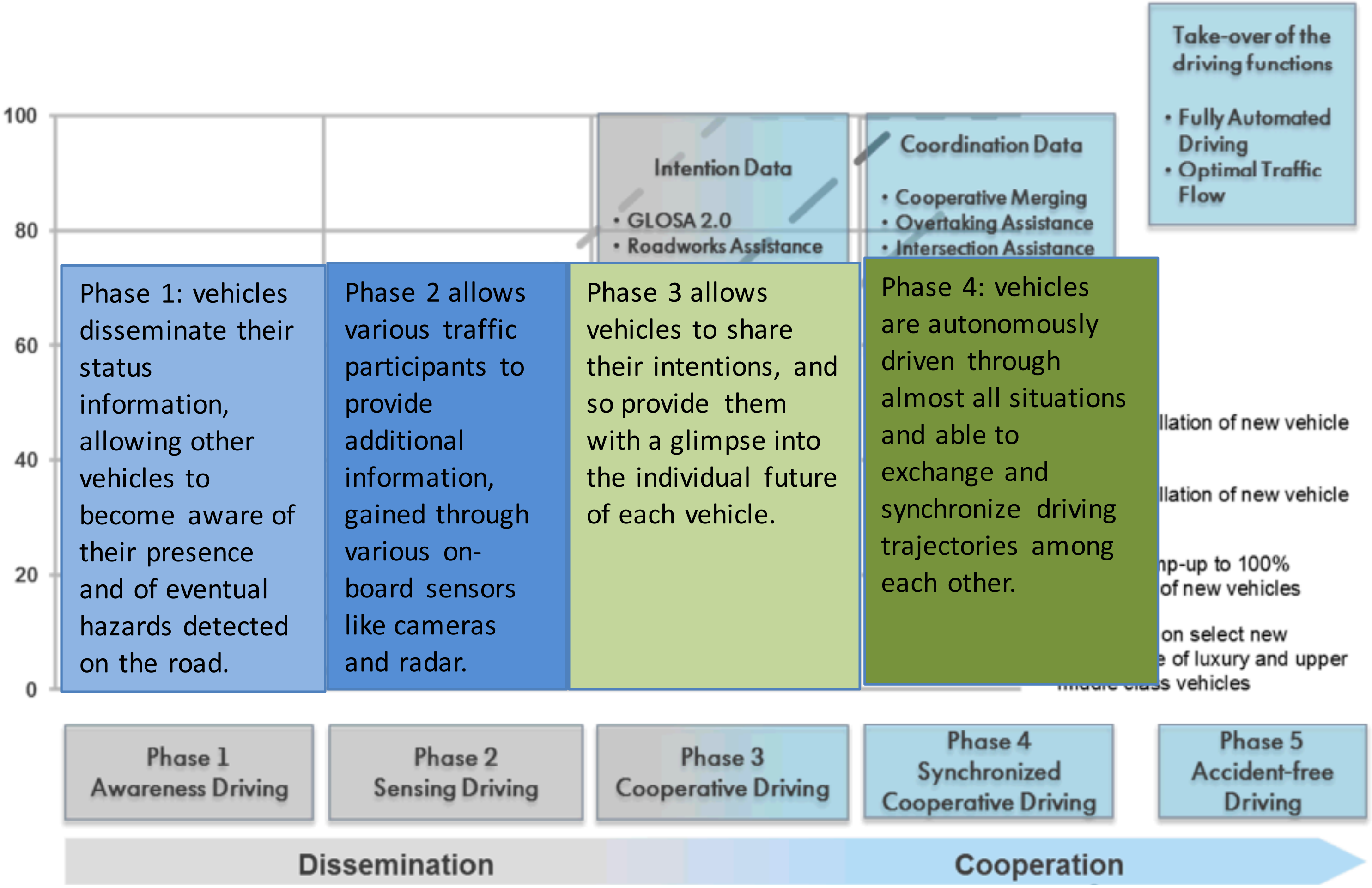
Source: 5gpp white paper

The roadmap of applications



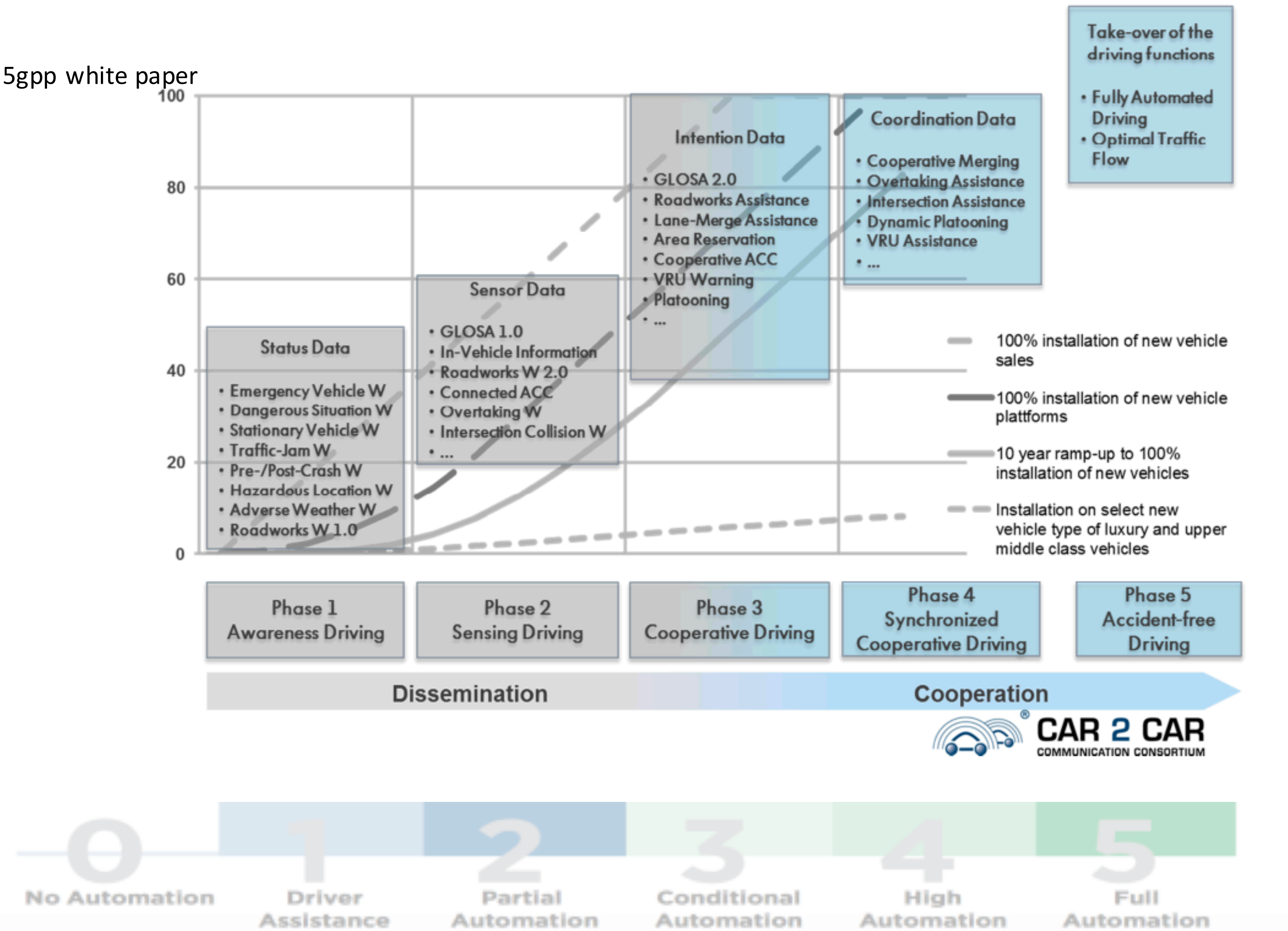
Source: 5gpp white paper

The roadmap of applications



Mapping connected on autonomous vehicles

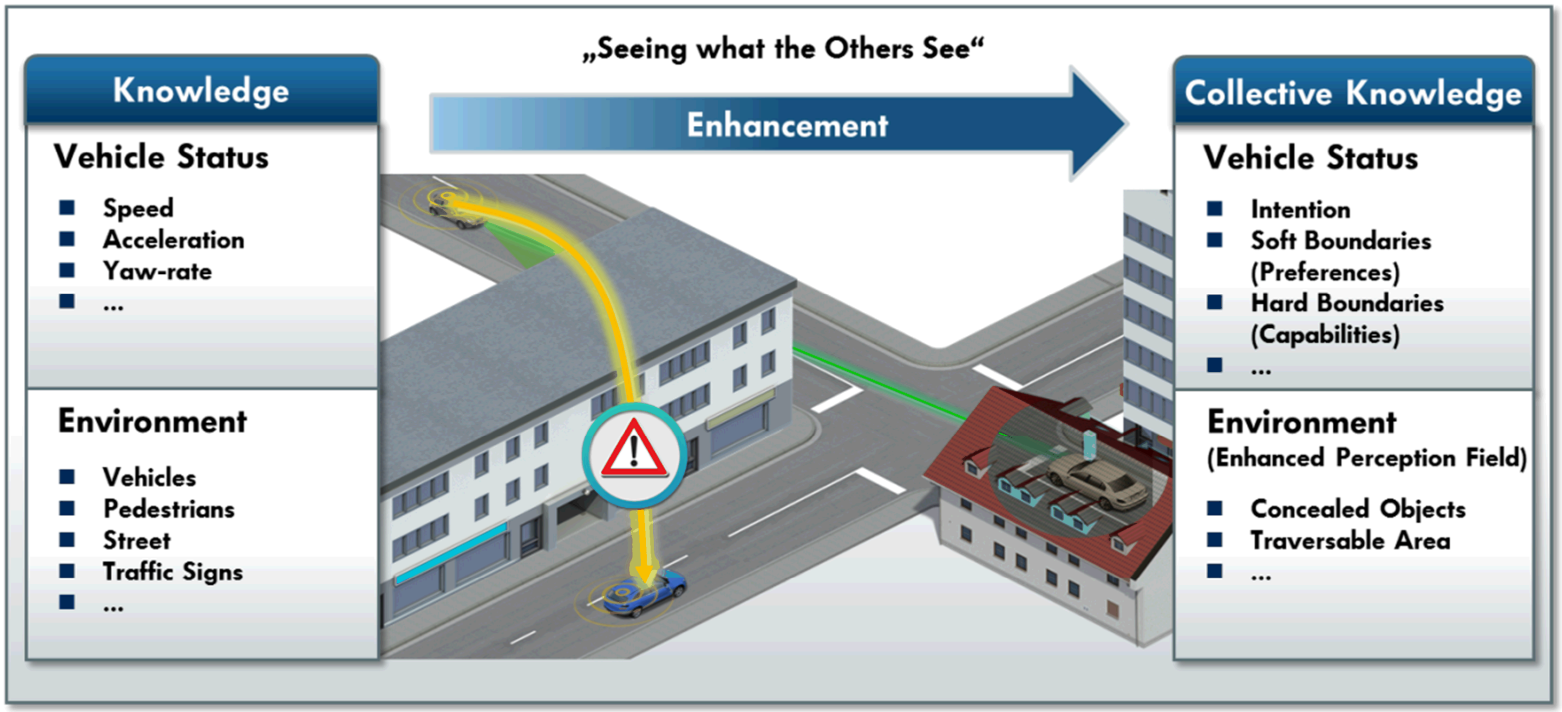
Source: 5gpp white paper



In summary…

Future (especially safety) applications are based on the awareness of the environment

Collective Knowledge through Collective Perception



Source: 5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf

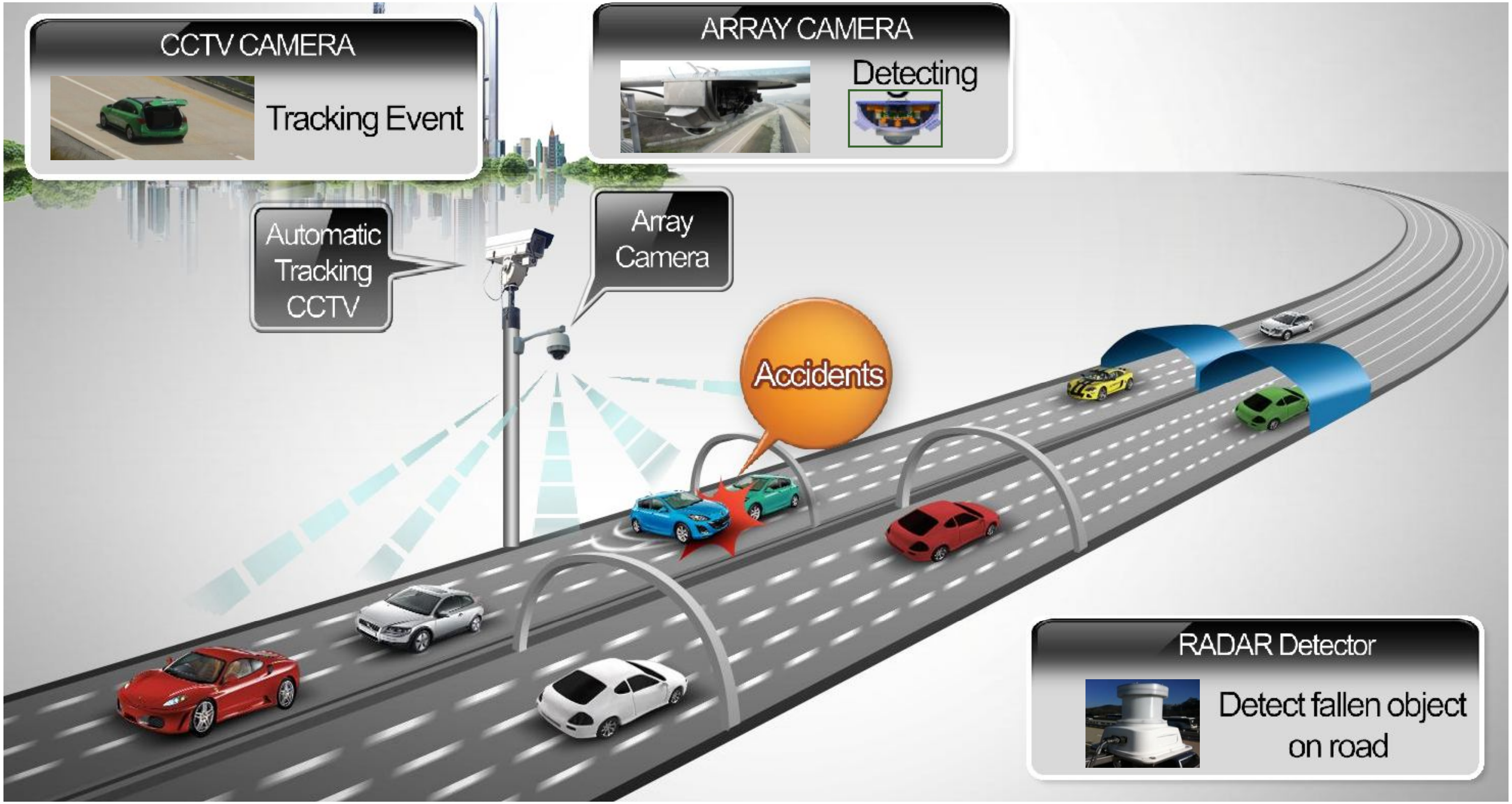
What we need to have connected (and autonomous cars)

- Awareness
  - Local awareness (in vehicles)
- Environment awareness
  - Out-of-vehicle (obstacles, nearby cars, …)
- Collective awareness

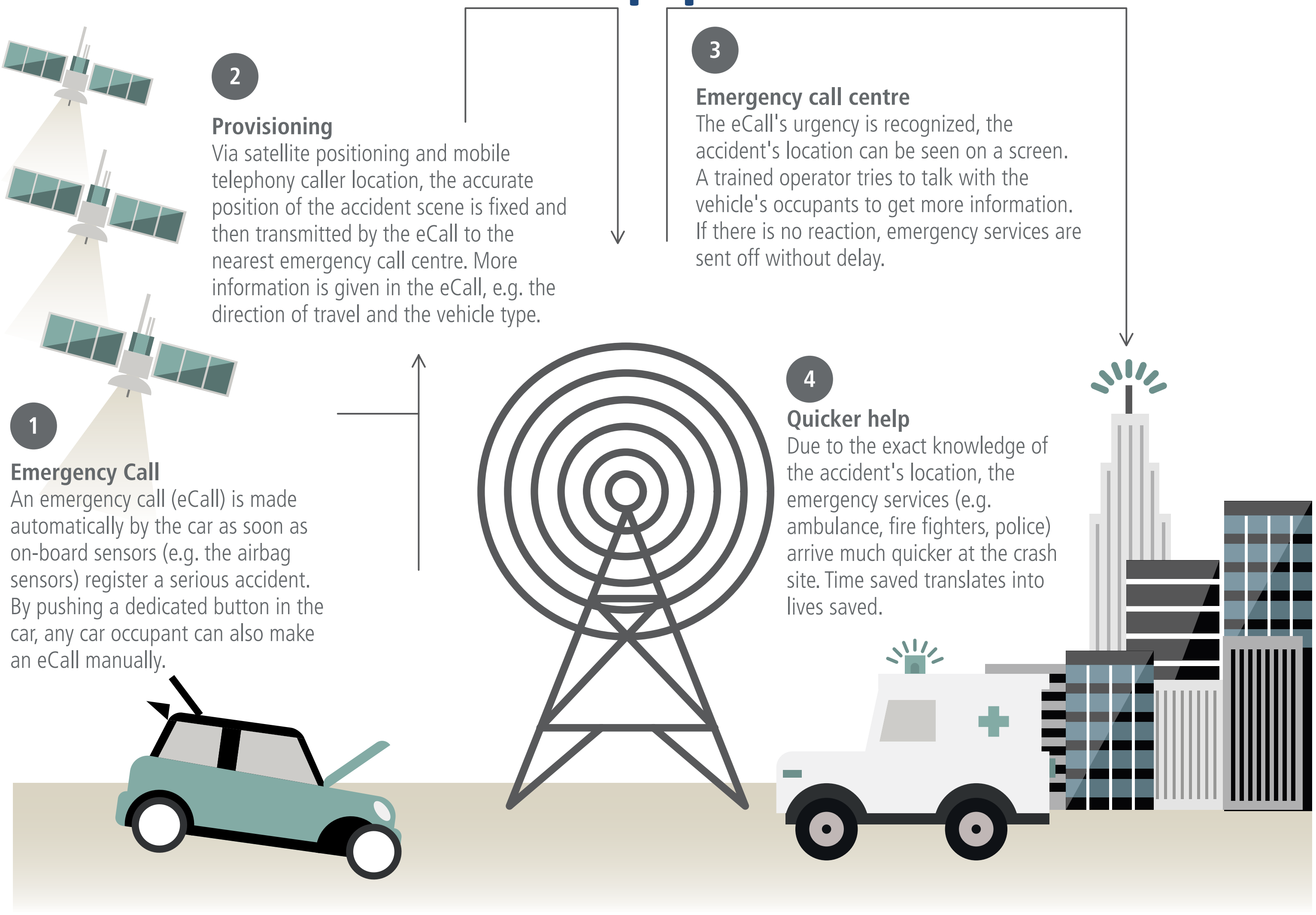
To achieve awareness, vehicles have to exchange short and frequent messages (**beacons**) about their status (ID, position, speed, acceleration, etc.)
This way, each vehicle can build a cooperative vision of the environment
More frequent the beacons, better the knowledge of the environment
More frequent the beacons, higher channel load and performance degradation
→ tradeoff

Present, future and visionary applications

Present apps: on board sensors



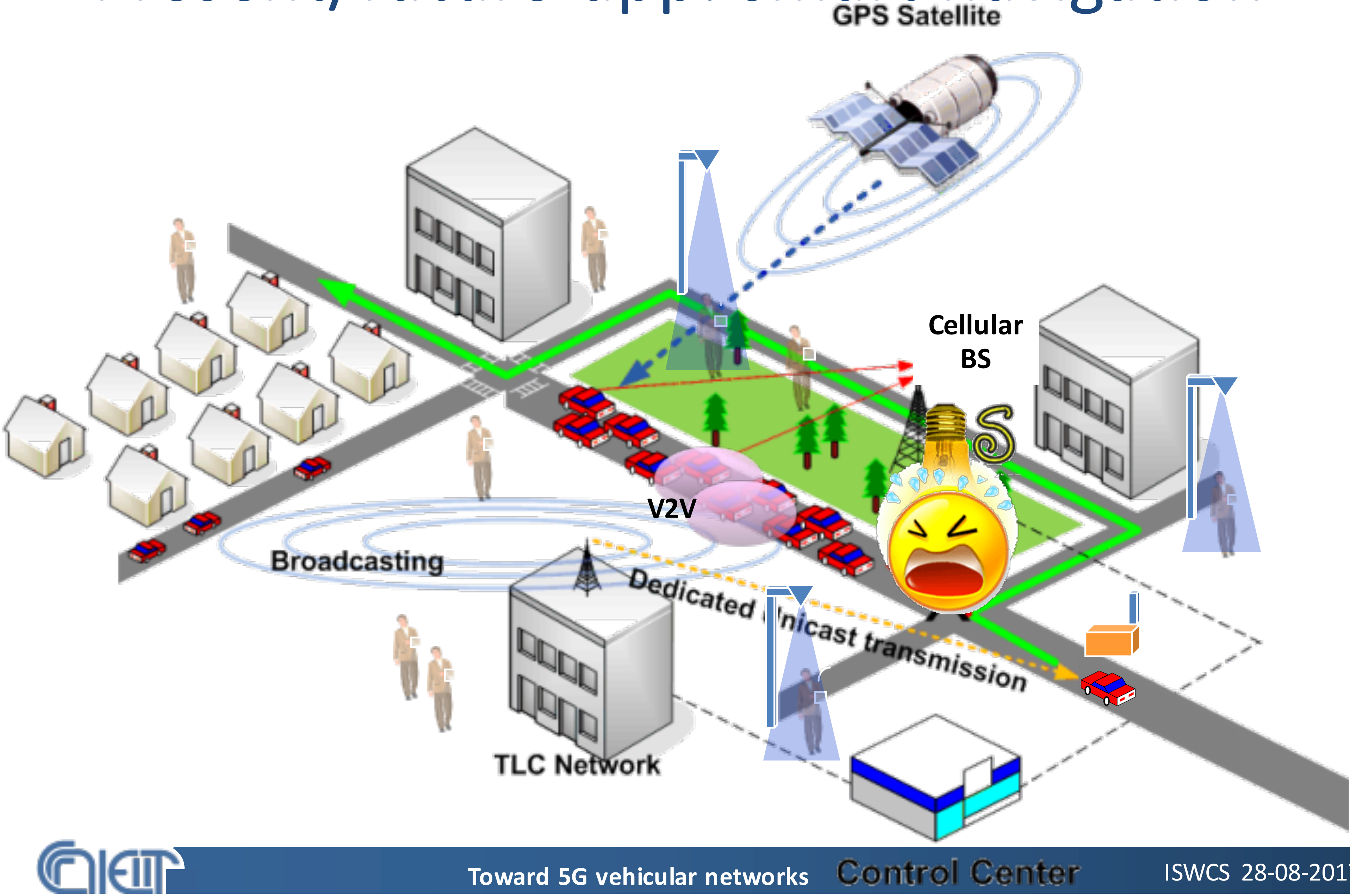
Present apps: eCall



V2I cellular communication

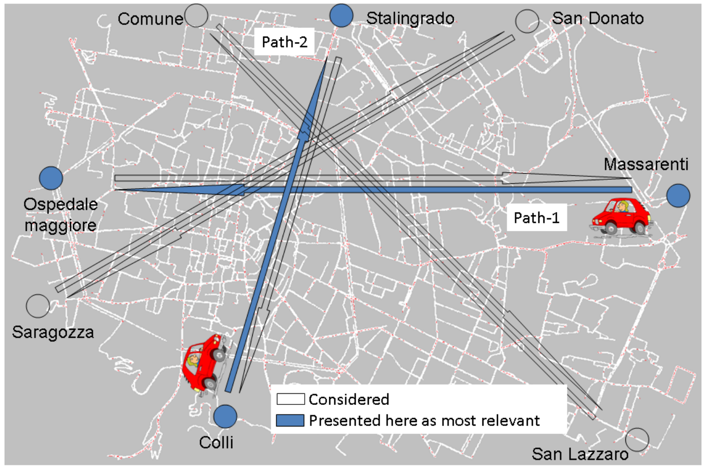
Source: European Commission

Present/future app: smart navigation



Impact of smart navigation

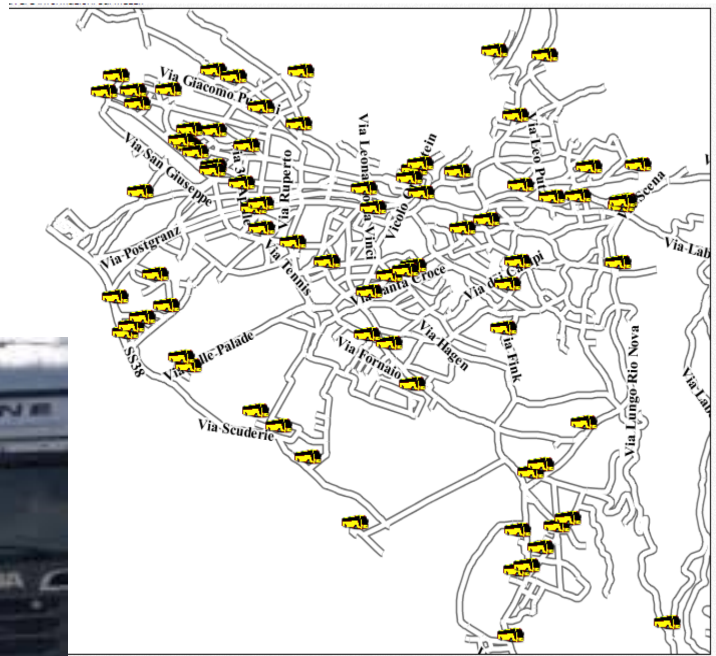
- 10% of connected vehicles
- Information transmitted from vehicles to control center (uplink) every 10 s
- Information transmitted from the control center back to vehicles (downlink) every 20s or 60s
- Up to 50% of saved time (if an alternative route exsists)



E->W:	40.3%	saved time
W->E:	44.5%	saved time
NW->SE:	12.9%	saved time
SE->NW:	29.2%	saved time
NE->SW:	4.0%	saved time
SW->NE:	0.0%	saved time
N->S:	13.1%	saved time
S->N:	49.0%	saved time

Present/future app: Fleet management

V2V with extremely low latency



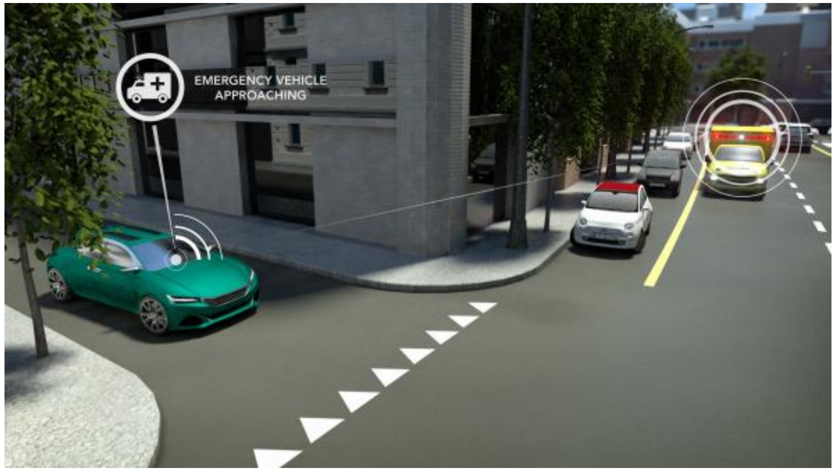
Increasingly

vehicles within a platoon will constantly exchange their kinematic state information in real time

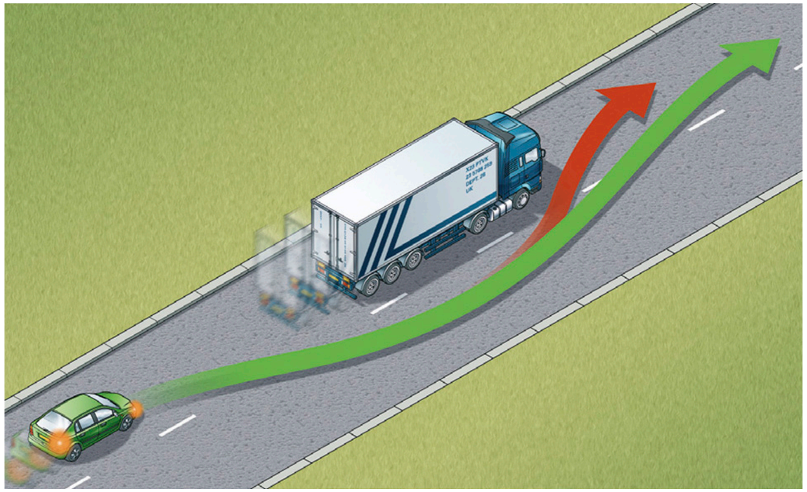
Future apps: alert messages and safe overtaking

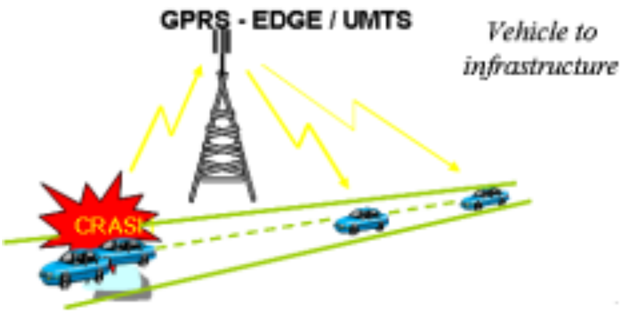
V2V and V2I communications

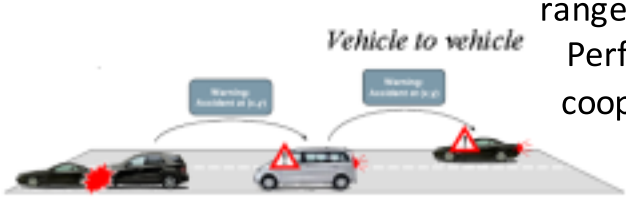
See around the corner



Safe overtaking

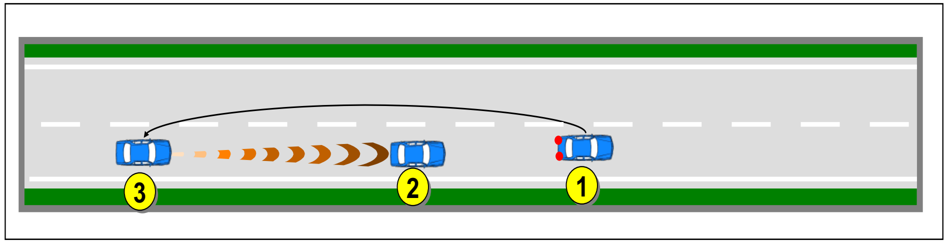


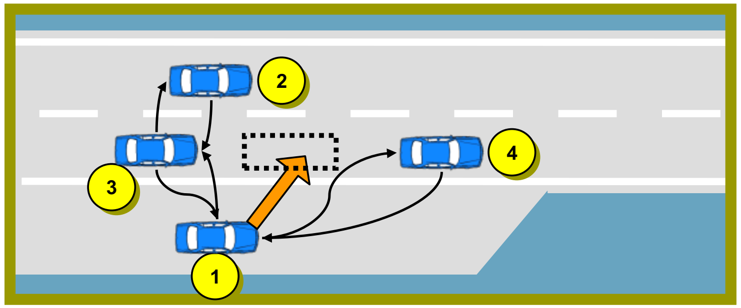




A fully autonomous self-driving car will need to perform overtake maneuvers not only on highways (unidirectional travel) but also on two-way roads, where oncoming vehicles may be well beyond the range of its sensors and approaching very quickly. Performing such maneuvers safely will require cooperation among vehicles on multiple lanes.

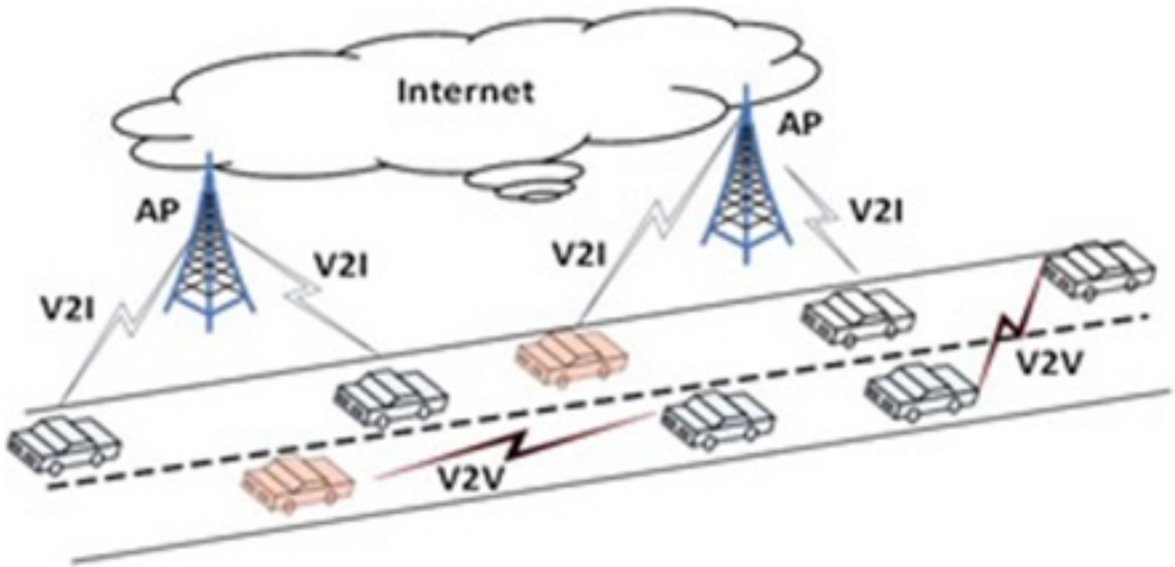
Future apps: Driving assistance and cooperative driving





Started with Radar
Soon with V2V

Future app: Internet access



Internet backbone on
the move

Future app: See through

Source: Samsung

This use case requires a very high reliability and availability (it should work even out of coverage and even if the network is loaded with other services), a low latency (a few tens of ms) and a high data rate to share all relevant data with vehicles and pedestrians in the neighborhood.

Future/visionary app: Virtual Traffic Light

Source: Carnegie Mellon University

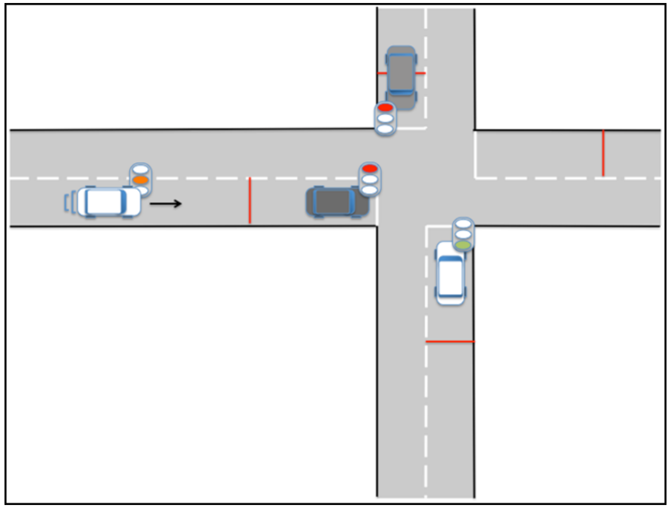
Source: Slash Gear

- Only 0.5% of over 50 millions of crossing points in USA are equipped with traffic lights
- Operative costs (per year) for traffic lights : 780 milions of dollars
- It is impossibile to have all crossing points equipped by traffic lights

All vehicles must be equipped with V2V communication interface
Better with backup on V2I

Future/visionary app: Virtual Traffic Light

At intersections without a physical traffic light, V2V communications to exchange the priorities at the crossing with a distributed control



Why is VTL important?

- Only 0.5% of over 50 millions of crossing points in USA are equipped with traffic lights
- Operative costs (per year) for traffic lights : 780 milions of dollars
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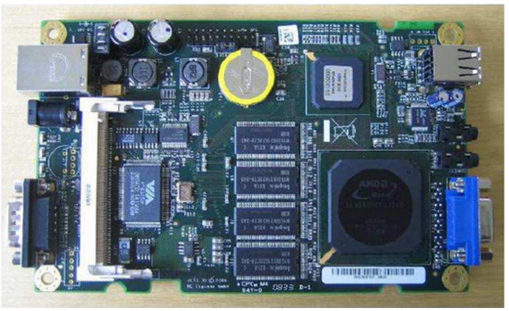


Key-characteristics:
wireless, efficient, low cost

Basic rule:
ony one car at a time can pass the crossing point

Future/visionary app: Virtual Traffic Light

Four vehicles approaching the junction

Standardization bodies and main technologies

Where we are

Despite much effort in the last 10+ years, not much more on field ...

- Auxiliary services and emergency help (eCall in Europe) through cellular
- Several projects with hundreds to thousands of vehicles

... but things might change soon ...

- Mandate expected for V2V in USA (for new vehicles, by late 2019/early 2020?)
- In Europe: Strategy adopted by EC in November 2016 to make connected vehicles possible in 2019.

EUROPEAN
COMMISSION

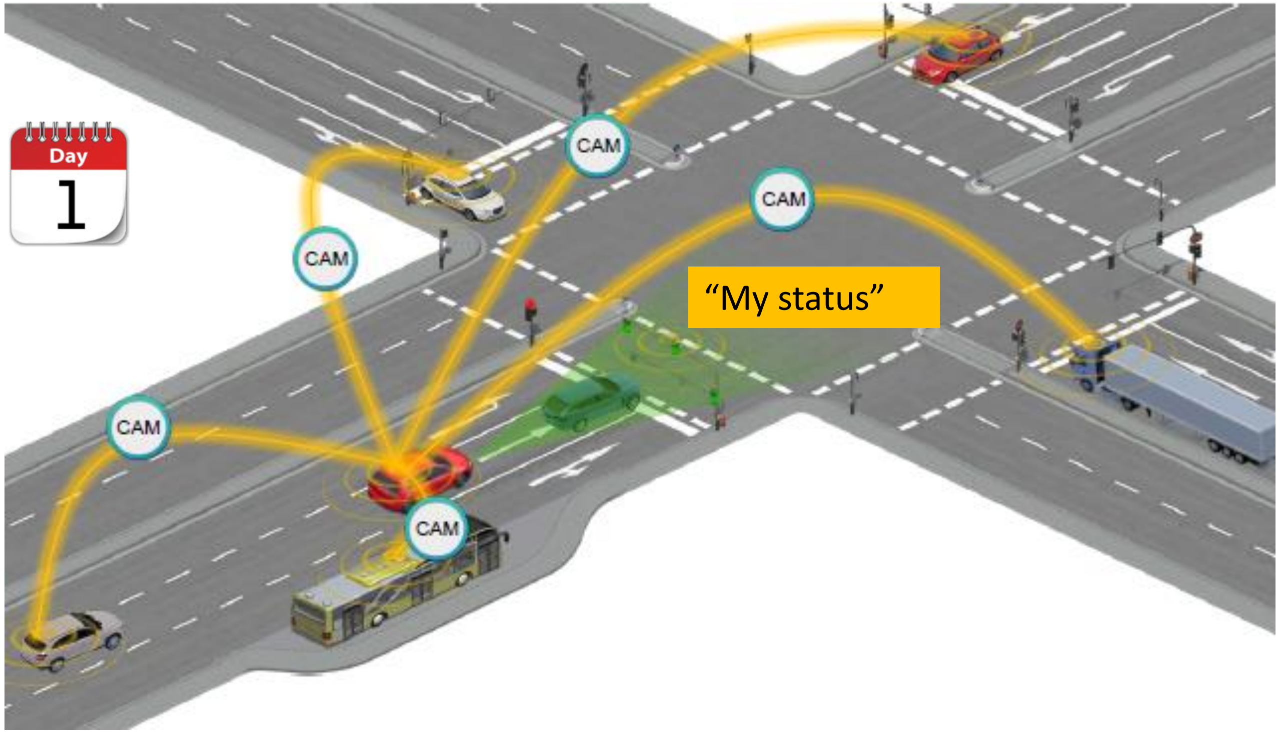
Brussels, 30.11.2016
COM(2016) 766 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility

EU intentions and priorities

Day 1: V2X communication



Source: Wolkswagen

Local Perception Sensors

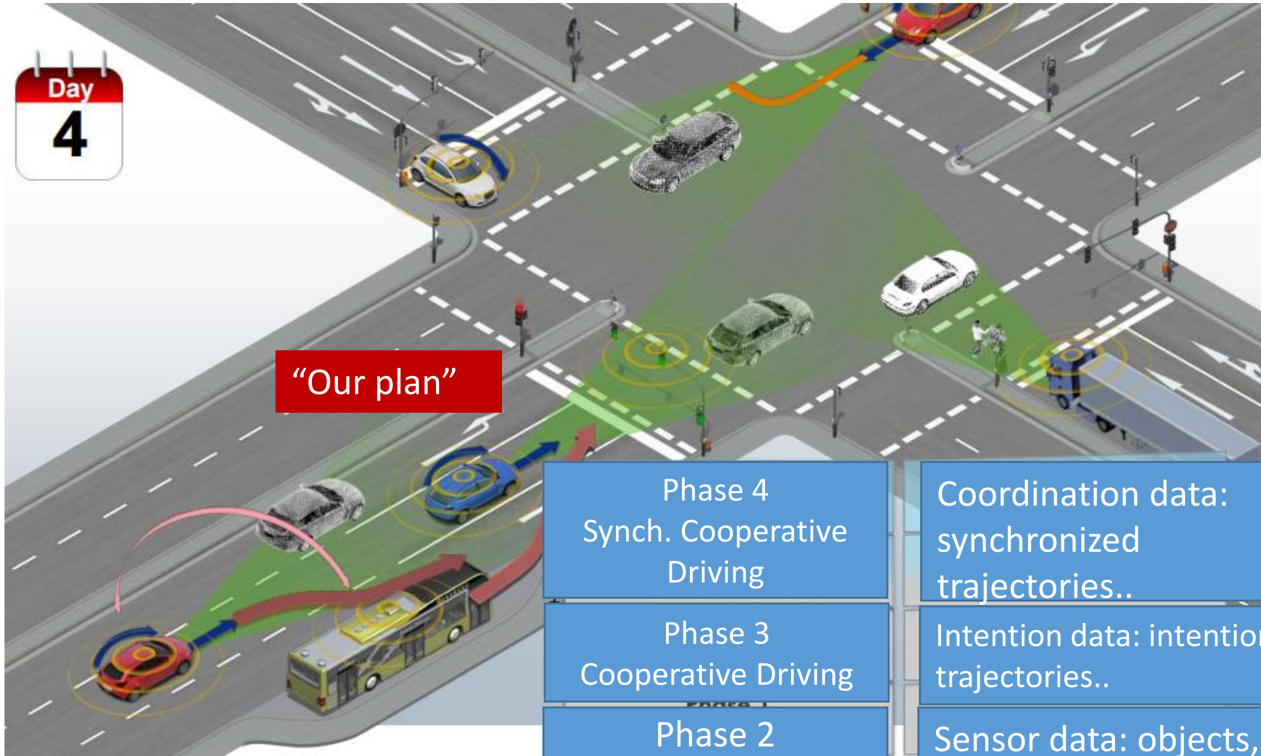
V2X Communication
Red ego-vehicle additionally knows about V2X vehicles within the communication range
Vehicles broadcast **Cooperative Awareness Messages (CAMs)**

Phase 1
Awareness Driving

Status data: position, speed, events…

EU intentions and priorities

Day 4: Coordinating intentions



Source: Wolkswagen

Phase 4 Synch. Cooperative Driving	Coordination data: synchronized trajectories..
Phase 3 Cooperative Driving	Intention data: intentions, trajectories..
Phase 2 Sensing Driving	Sensor data: objects, field-of-view…
Phase 1 Awareness Driving	Status data: position, speed, events…

V2X Communication

Collective Perception

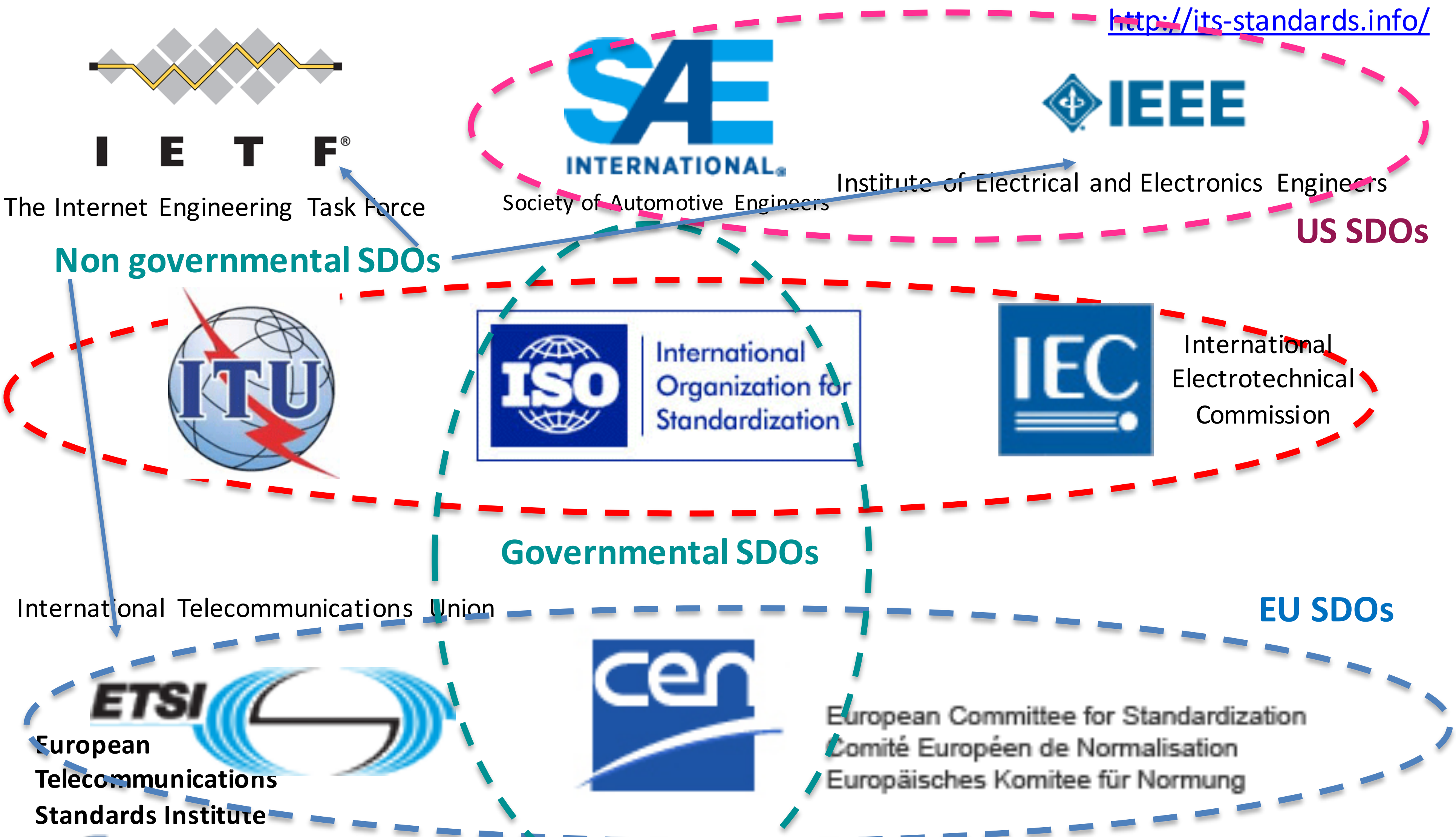
Intention planning

Coordinating Intentions

Vehicles are autonomously driven through almost all situations (levels 4 and 5) and are able to exchange and synchronize driving trajectories among each other.

Standard Development Organizations (SDOs)

Joint standard development for Cooperative Intelligent Transport Systems C-ITS



Other important organizations

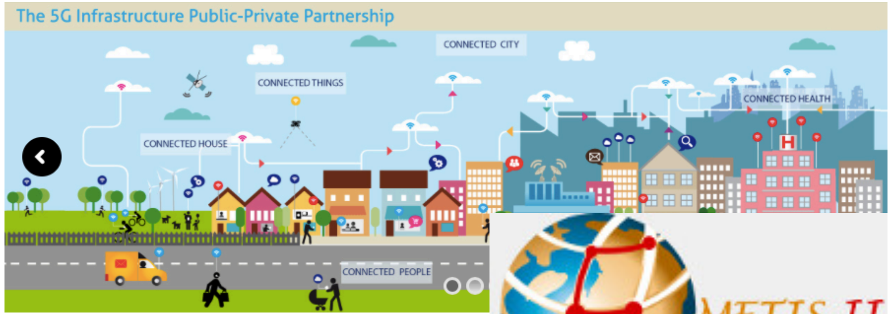
5GAA

EU

5G PPP

The 5G Infrastructure Public Private Partnership

MEMBERS



METIS II

CAR 2 CAR COMMUNICATION CONSORTIUM

25 YEARS ERTICO ITS EUROPE

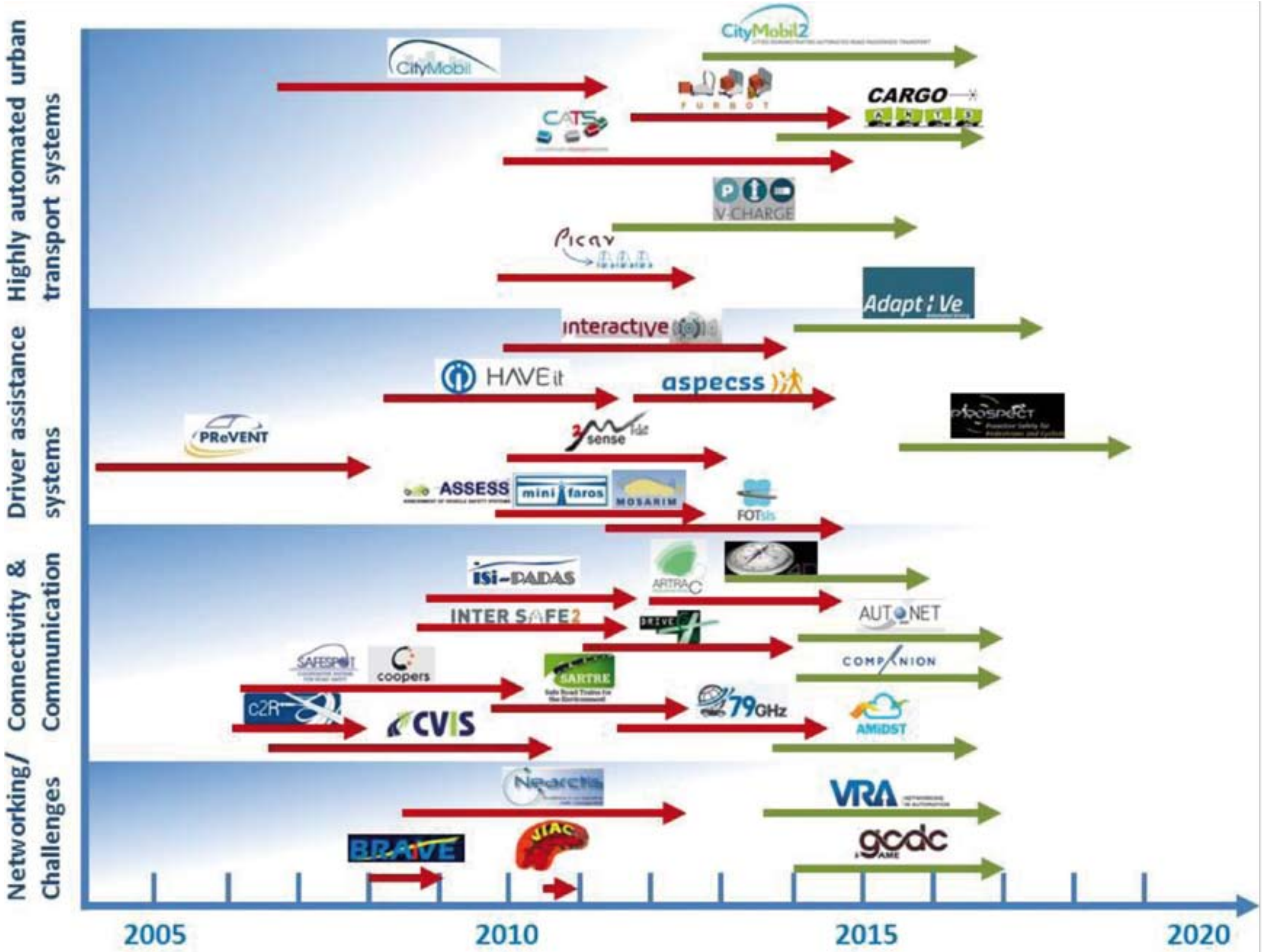
5G Americas Member Companies

5G americas

US

NHTSA NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

EU investments



Dedicated frequencies for V2X worldwide

Region	Frequency Bands (MHz)
North America	5850-5925
Europe	5795-5815, 5855/5875-5905/5925
Japan	755.5-764.5, 5770-5850
China, India, Singapore	Studying allocation or allocated in the 5.9 GHz band

Source: "5G Americas V2X Cellular Solutions"
http://www.5gamericas.org/files/2914/7769/1296/5GA_V2X_Report_FINAL_for_upload.pdf

Peculiarities of vehicular scenarios (where technologies have to work)

- **Highly dynamic topology:** Due to relative speed of cars, that in some cases can be very high, the time interval in which two cars can communicate can be extremely small.
- **Frequently disconnected network and variable device density**
- **Sufficient availability of energy and storage:** devices are installed on cars there are no power or memory constrains.
- **Geographical addressing:** unicast and broadcast, are no longer sufficient. Some applications, e.g., alert the drivers in a certain area of a possible hazard, require the ability, known as *geocasting*, to address only the nodes in a specific geographic area.
- **Different communication environments:** wireless technologies have to work in very different propagation scenarios (urban, highway, country, …)
    - High speed (doppler, quickly variable channels)
    - Heavy multi-path
- For safety purposes: latency and errors with very stringent requirements
- Particular importance of security (in particular authentication, integrity, and no ripudiation)
- Need for international agreements

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- **Frequen**

- **Sufficien** are no power or memor

Which technology can better perform in a so challenging scenario?

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- Particula … ripudiation)
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Which technology can better perform in a so challenging scenario?

To answer we also need to know the requirements

As example, those of NHTSA, ETSI, 3GPP

NHTSA requirements

NHTSA www.nhtsa.gov	Packet Type	Comm. Type	Beacon Periodicity [Hz]	End-to-End Latency [ms]	Comm. Range [m]
Traffic Signal Violation Warning *	Periodic	I2V	10	100	250
Stop Sign Violation Warning *	Periodic	I2V	10	100	250
Left Turn Assistant *	Periodic	I2V/V2I	10	100	300
Stop Sign Movement Assistance *	Periodic	I2V/V2I	10	100	300
Intersection Collision Warning *	Periodic	I2V	10	100	300
Blind Merge Warning *	Periodic	I2V	10	100	200
Pedestrian Crossing Information at Designated Intersections *	Periodic	I2V	10	100	200
Approaching Emergency Vehicle Warning *	Event-driven	V2V	1	1000	1000
Emergency Vehicle Signal Pre-emption *	Event-driven	V2I	N/A	1000	1000
SOS Services *	Event-driven	V2V/V2I	1	1000	400
Post-Crash Warning *	Event-driven	V2V/V2I	1	500	300
In-Vehicle Signage *	Periodic	I2V	1	1000	200
Curve Speed Warning *	Periodic	I2V	1	1000	200
Low Parking Structure Warning *	Periodic	I2V	1	1000	100
Wrong Way Driver Warning *	Periodic	V2V	10	100	500
Low Bridge Warning *	Periodic	I2V	1	1000	300
Work Zone Warning *	Periodic	I2V	1	1000	300
In-Vehicle Amber Alert *	Event-driven	I2V	1	1000	250
Safety Recall Notice *	Event-driven	I2V	N/A	1000	400
Just-In-Time Repair Notification *	Event-driven	I2V/V2I	N/A	N/A	400
Cooperative Forward Collision Warning *	Periodic	V2V	10	100	150
Vehicle-Based Road Condition Warning *	Event-driven	V2V	2	500	400
Emergency Electronic Brake Lights *	Event-driven	V2V	10	100	300
Lane Change Warning *	Periodic	V2V	10	100	150
Blind Spot Warning *	Periodic	V2V	10	100	150
Highway Merge Assistant *	Periodic	V2V	10	100	250
Cooperative Collision Warning *	Periodic	V2V	10	100	150
Road Condition Warning *	Event-driven	I2V	1	1000	200
Pre-Crash Sensing *	Event-driven	V2V	50	20	50

safety (*)

traffic management (**)

infotainment (***)

NHTSA requirements

NHTSA www.nhtsa.gov	Packet Type	Comm. Type	Beacon Periodicity [Hz]	End-to-End Latency [ms]	Comm. Range [m]
Highway/Rail Collision Warning *	Periodic / Event-driven	V2V/I2V	1	1000	300
Vehicle-To-Vehicle Road Feature Notification *	Event-driven	V2V	2	500	400
Cooperative Glare Reduction *	Periodic	V2V	1	1000	400
Cooperative Vehicle-Highway Automation System (Platoon) **	Periodic	V2V/V2I /I2V	50	20	100
Cooperative Adaptive Cruise Control **	Periodic	V2V/I2V	10	100	150
Intelligent On-Ramp Metering **	Event-driven	V2I	1	1000	100
Intelligent Traffic Flow Control **	Event-driven	V2I	1	1000	250
Free-Flow Tolling **	Event-driven	V2I /I2V	N/A	50	50
Adaptive Headlamp Aiming **	Periodic	I2V	1	1000	200
Adaptive Drivetrain Management **	Periodic	I2V	1	1000	200
Visibility Enhancer **	Periodic	V2V	2	100	300
Enhanced Route Guidance and Navigation **	Event-driven	I2V	N/A	1000	200
Point of Interest Notification ***	Periodic	I2V	1	1000	400
Instant Messaging ***	Event-driven	V2V	N/A	1000	50
Map Downloads and Updates ***	Periodic / Event-driven	V2I /I2V	1	1000	400
GPS Correction ***	Periodic	I2V	1	1000	400

safety (*)

traffic management (**)

infotainment (***)

ETSI requirements

ETSI World Class Standards	Packet Type	Comm. Type	Beacon Periodicity [Hz]	End-to-End Latency [ms]
Emergency electronic brake lights *	Periodic	V2X	10	100
Safety function out of normal condition warning *	Periodic	V2X	1	100
Emergency vehicle warning *	Periodic	V2X	10	100
Slow vehicle warning *	Periodic	V2X	2	100
Motorcycle warning *	Periodic	V2X	2	100
Vulnerable road user Warning *	Periodic	V2X	1	100
Wrong way driving warning *	Event-driven	V2X	10	100
Stationary vehicle warning *	Event-driven	V2X	10	100
Traffic condition warning *	Event-driven	V2X	10	N/A
Signal violation warning *	Event-driven	V2X	10	100
Roadwork warning *	Periodic	I2V	2	100
Decentralized floating car data *	Event-driven	V2X	1-10	N/A
Overtaking vehicle warning *	Periodic	V2X	10	100
Lane change assistance *	Periodic	V2X	10	100
Pre-crash sensing warning *	Event-driven	V2X	10	50
Co-operative glare reduction *	Periodic	V2X	2	100
Across traffic turn collision risk warning *	Periodic	V2X	10	100
Merging Traffic Turn Collision Risk Warning *	Periodic	V2X	10	100
Hazardous location notification *	Event-driven	V2X	10	N/A
Intersection Collision Warning *	Periodic	V2X	10	100
Co-operative forward collision warning *	Periodic / Event-driven	V2X	10	100
Collision Risk Warning from RSU *	Periodic / Event-driven	V2X / I2V	10	100

safety (*)

traffic management (**)

infotainment (***)

ETSI requirements

ETSI World Class Standards	Packet Type	Comm. Type	Beacon Periodicity [Hz]	End-to-End Latency [ms]
Regulatory/contextual speed limits **	Event-driven	I2V	1-10	N/A
Traffic light optimal speed advisory **	Periodic	I2V	2	100
Traffic information and recommended itinerary **	Periodic	I2V	1-10	500
Enhanced route guidance and navigation **	Periodic / Event-driven	I2V	1	500
Intersection management **	Periodic	I2V	1	500
Co-operative flexible lane change **	Periodic / Event-driven	I2V /V2V	1	500
Limited access warning, detour notification **	Periodic / Event-driven	I2V /V2V	1-10	500
In-vehicle signage **	Periodic	I2V	1	500
Electronic toll collect **	Periodic / Event-driven	I2V /V2I	1	200
Co-operative adaptive cruise control **	Periodic	V2X	2	100
Co-operative vehicle-highway automation system (Platoon) **	Periodic	V2X	2	100
Point of interest notification ***	Periodic / Event-driven	I2V /V2I	1	500
Automatic access control/parking access ***	Periodic / Event-driven	I2V /V2I	1	500
Local electronic commerce ***	Periodic / Event-driven	I2V /V2I	1	500
Car rental/sharing assignment/reporting ***	Periodic / Event-driven	I2V /V2I	1	500
Media downloading ***	Periodic / Event-driven	I2V /V2I	1	500
Map download and update ***	Periodic / Event-driven	I2V /V2I	1	500
Ecological/economical drive ***	Periodic / Event-driven	I2V /V2I	1	500
Instant messaging ***	Periodic / Event-driven	I2V /V2I	1	500
Personal data synchronization ***	Periodic / Event-driven	I2V /V2I	1	500
SOS service ***	Periodic / Event-driven	I2V /V2I	1	500
Stolen vehicle alert ***	Periodic / Event-driven	I2V /V2I	1	500
Remote diagnosis and just in time repair notification ***	Periodic / Event-driven	I2V /V2I	1	500
Vehicle relation management ***	Periodic / Event-driven	I2V /V2I	1	500
Vehicle data collect for product life cycle management ***	Periodic / Event-driven	I2V /V2I	1	500
Insurance and financial Services ***	Periodic / Event-driven	I2V /V2I	1	500
Fleet management ***	Periodic / Event-driven	I2V /V2I	1	500
Vehicle software/data provisioning and update ***	Periodic / Event-driven	I2V /V2I	1	500
Loading zone management ***	Periodic / Event-driven	I2V /V2I	1	500
Vehicle and RSU data calibration ***	Periodic / Event-driven	I2V /V2I	1	500

safety (*)

traffic management (**)

infotainment (***)

3GPP requirements

3GPP A GLOBAL INITIATIVE	Packet Type	Comm. Type	Beacon Periodicity [Hz]	End-to-End Latency [ms]
Forward Collision Warning *	Periodic	V2V	10	100
Control Loss Warning *	Periodic / Event-driven	V2V	10	100
V2V Use case for emergency vehicle warning *	Periodic	V2V	10	100
V2V Emergency Stop Use Case *	Periodic / Event-driven	V2V	10	100
V2I Emergency Stop Use Case *	Periodic / Event-driven	V2X	10	100
Queue Warning *	Periodic / Event-driven	V2X	N/A	100
Road safety services *	Periodic / Event-driven	V2I	10	100
Wrong way driving warning *	Periodic / Event-driven	V2V	N/A	N/A
Pre-crash Sensing Warning *	Event-driven	V2V	N/A	20
V2X in areas outside network coverage *	Event-driven	V2V	N/A	N/A
V2X Road safety service via infrastructure *	Event-driven	V2X	N/A	N/A
Curve Speed Warning *	Periodic	V2I	1	1000
Warning to Pedestrian against Pedestrian Collision *	Periodic / Event-driven	V2X	N/A	N/A
Vulnerable Road User Safety *	Periodic / Event-driven	V2X	1	100
Cooperative Adaptive Cruise Control **	Periodic / Event-driven	V2V	1	1000
V2I / V2N Traffic Flow Optimisation **	Periodic / Event-driven	V2V	0.1	1000
Automated Parking System **	Event-driven	V2X	N/A	100
V2V message transfer under operator control ***	Event-driven	V2V	N/A	N/A

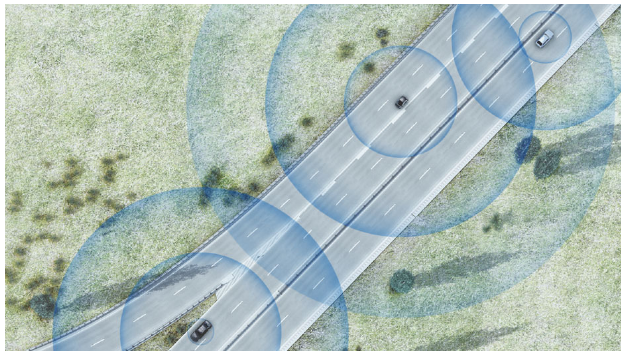
safety (*)

traffic management (**)

infotainment (***)

Summary of first "wave" requirements

- Periodic broadcast of beacon messages every 1-10 Hz
  - Beacons are typically small packets of ~200-500 bytes
- Latency lower than ~100 ms
- 90% of reception success within ~100-300m



Incoming 5G (more challenging) requirements

Source: Metis-II

- End-to-End Latency: 5ms
- Beacon Periodicity: 10Hz (adaptive?)
- Reliability: 99.999%
- Communication Range: up to 1Km
- Positioning Accuracy: less than 0.5m

Summary of first and second “wave” requirements

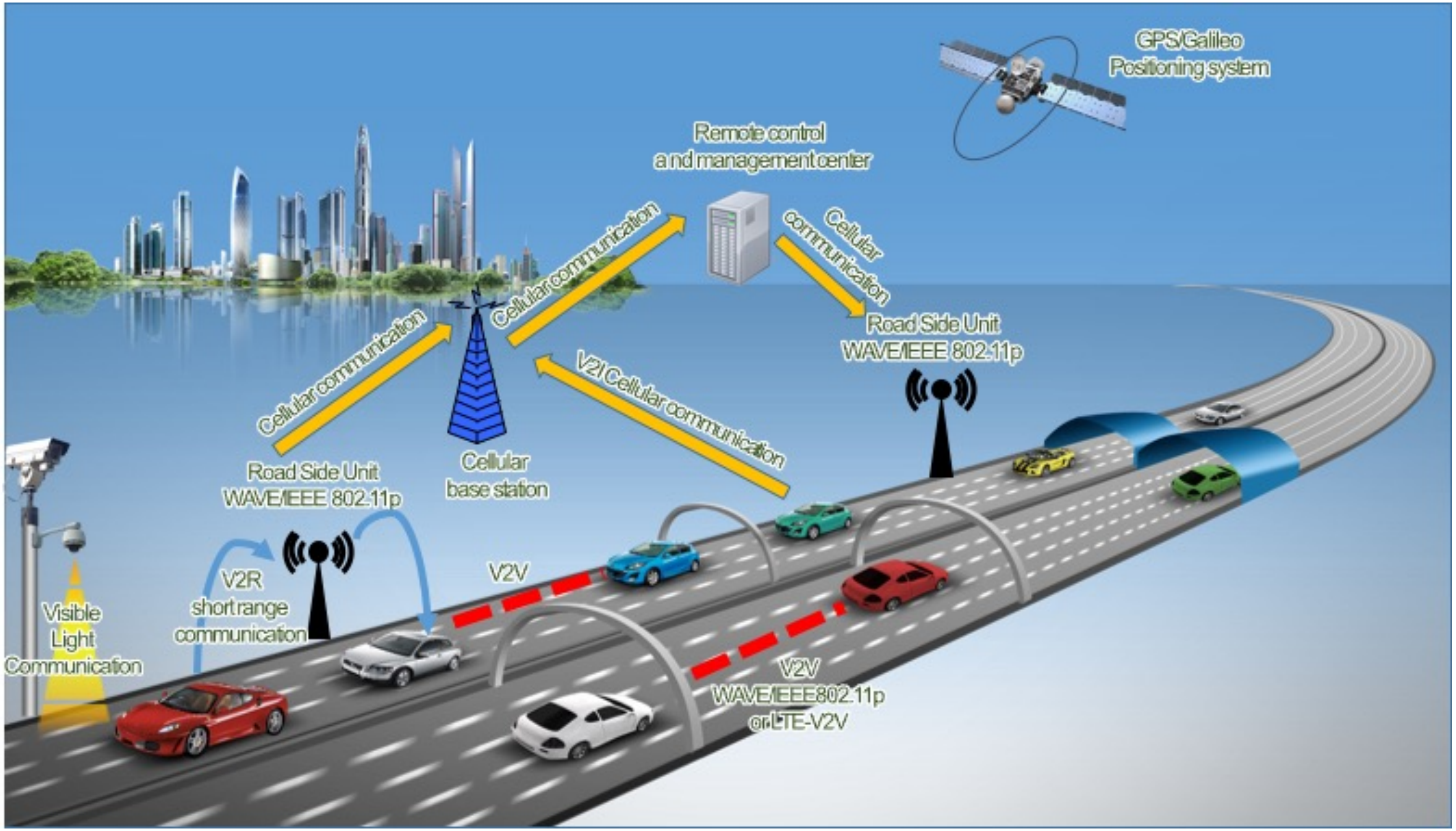
Before 5G requirements

- Periodic broadcast of beacon messages every 1-10 Hz
  - Beacons are typically small packets of ~200-500 bytes
- Latency lower than ~100 ms
- 90% of reception success within ~100-300m

5G of requirements

- Adaptive beaconing?
  - Beacon frequency adapted to the reliability of the app and to the channel load
- Latency lower than 5-10 ms (1ms for platooning)
- 99% of reliability
- High data rate (e.g., exchange of video captured onboard for see thorough)

V2X Enabling technologies



V2X Enabling Technologies

- WAVE/IEEE 802.11p in USA and ETSI ITS G5 in EU
  - Widely tested and commercial devices available
  - Reliability: random access is prone to collisions
  - Unclear business model
  - Not diffused
- LTE-V2X, defined in the Release 14 of 3GPP
  - Exploitation of existing infrastructure/system
  - Standardized May 2017)
  - Sketches the road to 5G vehicular networks
- Visible light communication (VLC) – IEEE 802.15.7
  - Exploitation of existing infrastructures (LED lamps)
  - Exploitation of vehicles lights
  - Vehicles must be in visibility
- 5G
  - Still to be clearly defined
  - Very high performance

IEEE & ETSI World Class Standards

3GPP A GLOBAL INITIATIVE

IEEE

IEEE 802.11p and ETSI ITS G5

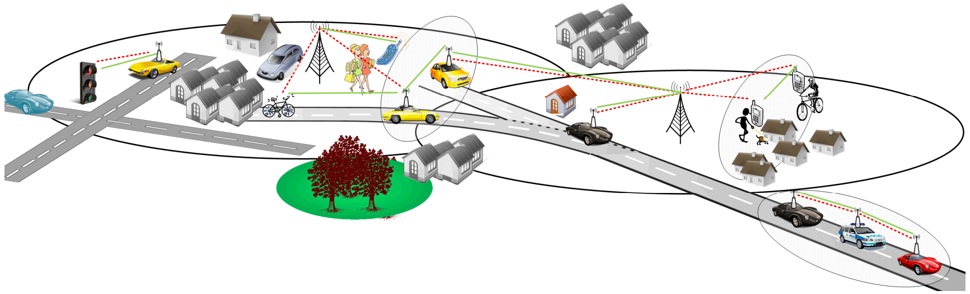
Dedicated short range communications (DSRC) in the USA

Wireless access in vehicular environments (WAVE) protocol stack

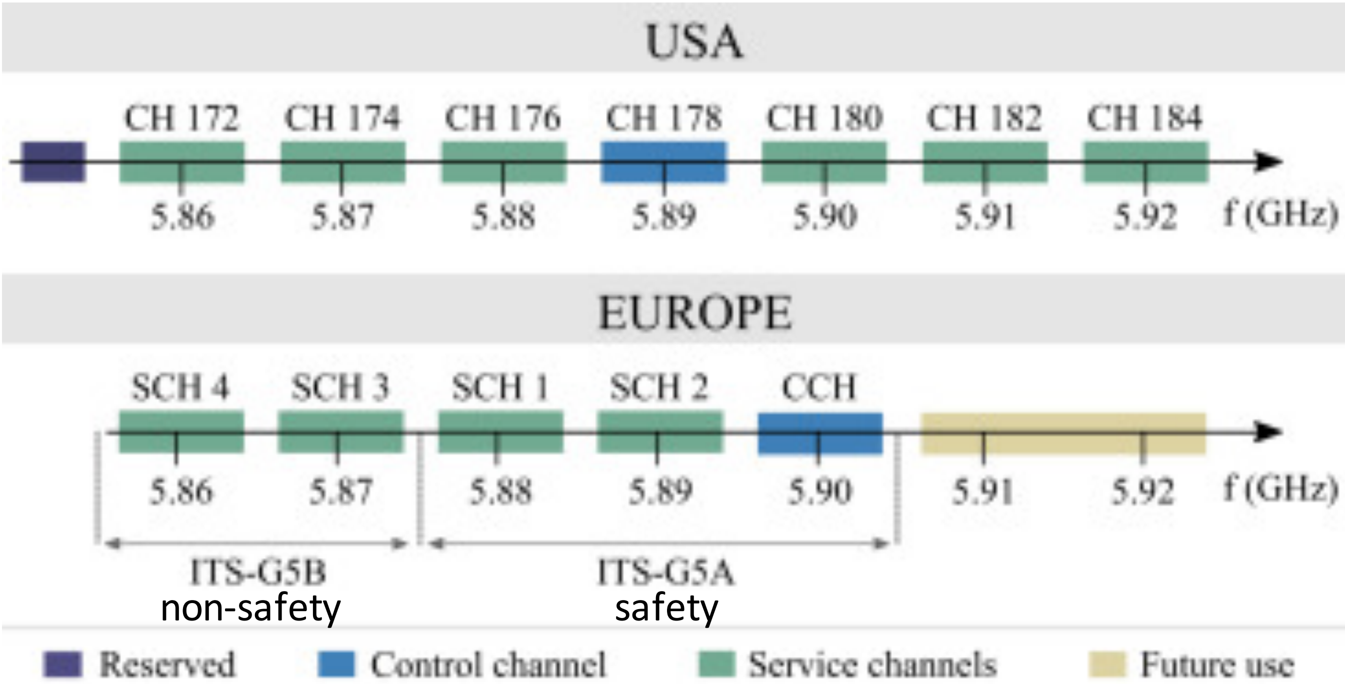
includes IEEE 802.11p and IEEE 1609.x

Cooperative-ITS (C-ITS) in Europe

includes ETSI ITS-G5 and other ETSI and ISO standards

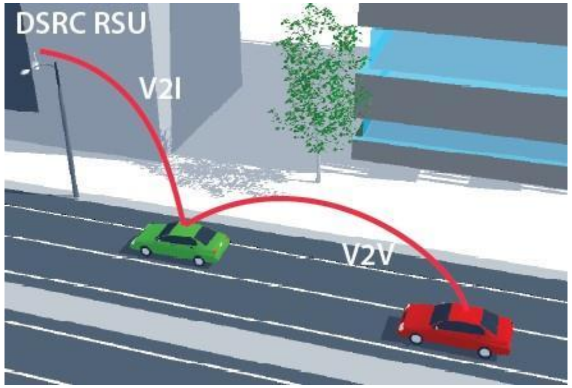


Frequency allocation in USA and EU



- U.S. FCC allocates 75 MHz in 1999 for ITS, from 5.850 GHz to 5.925 Ghz
- 7 channels: one control channel (178), 6 service channels
- Practically the same frequencies in EU
- But two channels still not used in EU
- The frequency of the control channel is different

DSRC challenges



DSRC provide:

- Event driven message, always triggered by application
- Event position, event type, event duration, event related information.
- 1-10 Hz beacon transmission (also known as CAM messages in 802.11p).

But consider that:

•The system also relies on road side units (RSUs), which are not currently deployed.

• At the physical layer, several inefficiencies arise due for example to the asynchronous nature of the system, resulting in reduced performance, such as

➢ access overhead

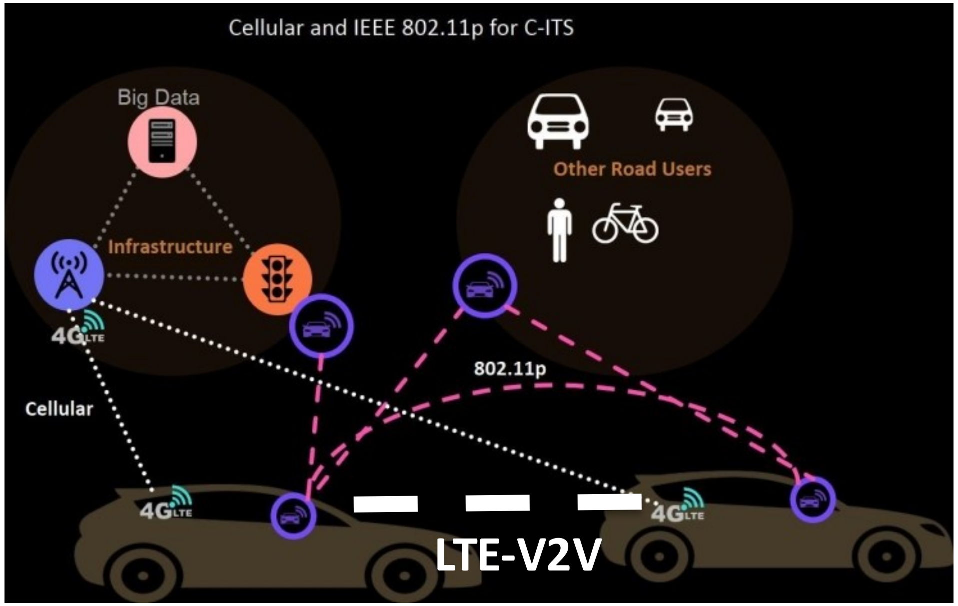
➢ high error rate in heavy congested trraffic scenarios IEEE 802.11p/DSRC/ITS G5A: long in development, still to be deployed at large scale

•In the long run, there is no evolutionary path (or IEEE 802.11 standards activities) to enable improvements in the DSRC physical/MAC layers with respect to range, robustness and reliability.

•Lack of a clear business model.

LTE-V2X

- While the ITS community has spent 15 years developing future C-ITS systems, and had still not made any significant commercial implementations, the world of mobile communications has sprinted forward.

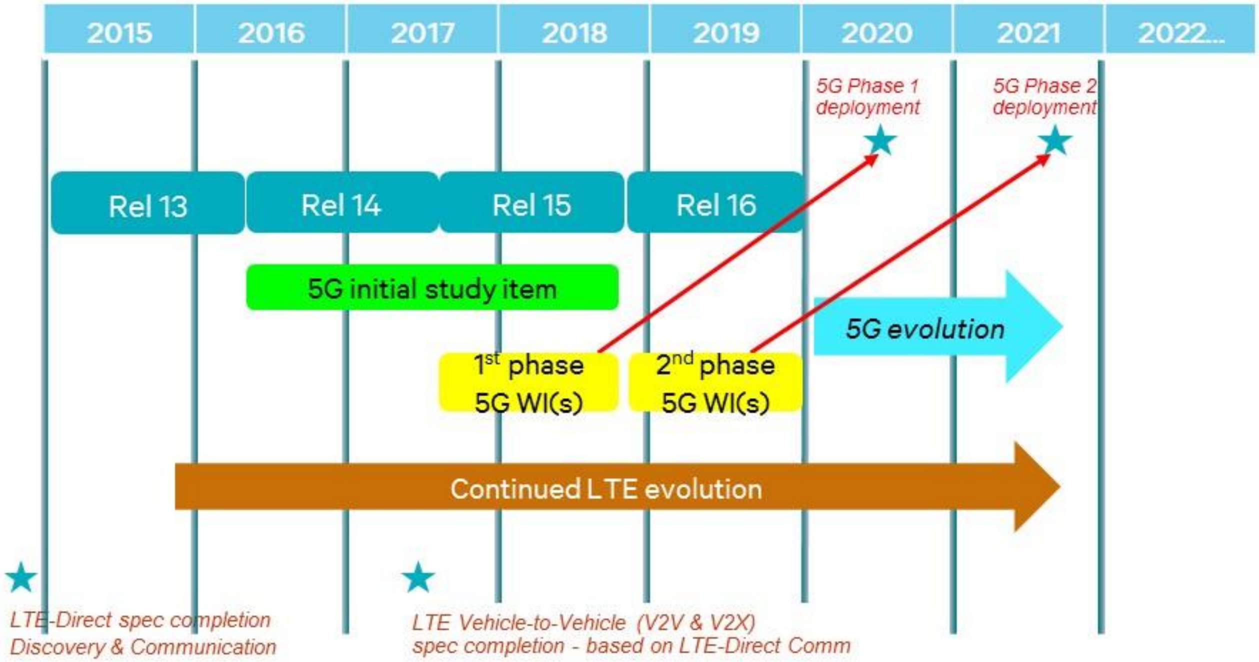


"LTE and fifth-generation (5G) cellular systems have the potential of supporting not only existing DSRC use cases, but also the more challenging and futuristic use cases that require low-latency, high reliability or high bandwidth.
Cellular V2X could also complement DSRC communications to enhance V2X communications capabilities."

http://www.5gamericas.org/files/2914/7769/1296/5GA_V2X_Report_FINAL_for_upload.pdf

LTE-V2X

- Study started end of 2014 in 3GPP
- Normative specification June 2017
- Products expecetd in ~ 2018
- Key advantage is ability to leverage the whole cellular ecosystem & capability set
    - reusing MNOs' network infrastructure
    - One chip for all (also vehicle-to-pedestrian enabled!)
- Open the road to 5G vehicular networks



DSRC or LTE-V2X (or 5G)

- Proponents of DSRC point out that it can accommodate all necessary V2V and V2I communications in modules that are already commercially available (General Motors will install them in 2017 Cadillacs)
- Regulators in Europe and the U.S. embraced DSRC until 2016
- But the anticipated arrival of 5G (opened by LTE-V2X) has led others to argue that automakers ought to wait to run cars on next-generation cellular networks.

Source: Spectrum, May 2016

Which one will win the battle?

DSRC or LTE-V2X (or 5G)

Before 5G requirements

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  - Beacons are typically small packets of ~200-500 bytes
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- 90% of reception success within ~100-300m

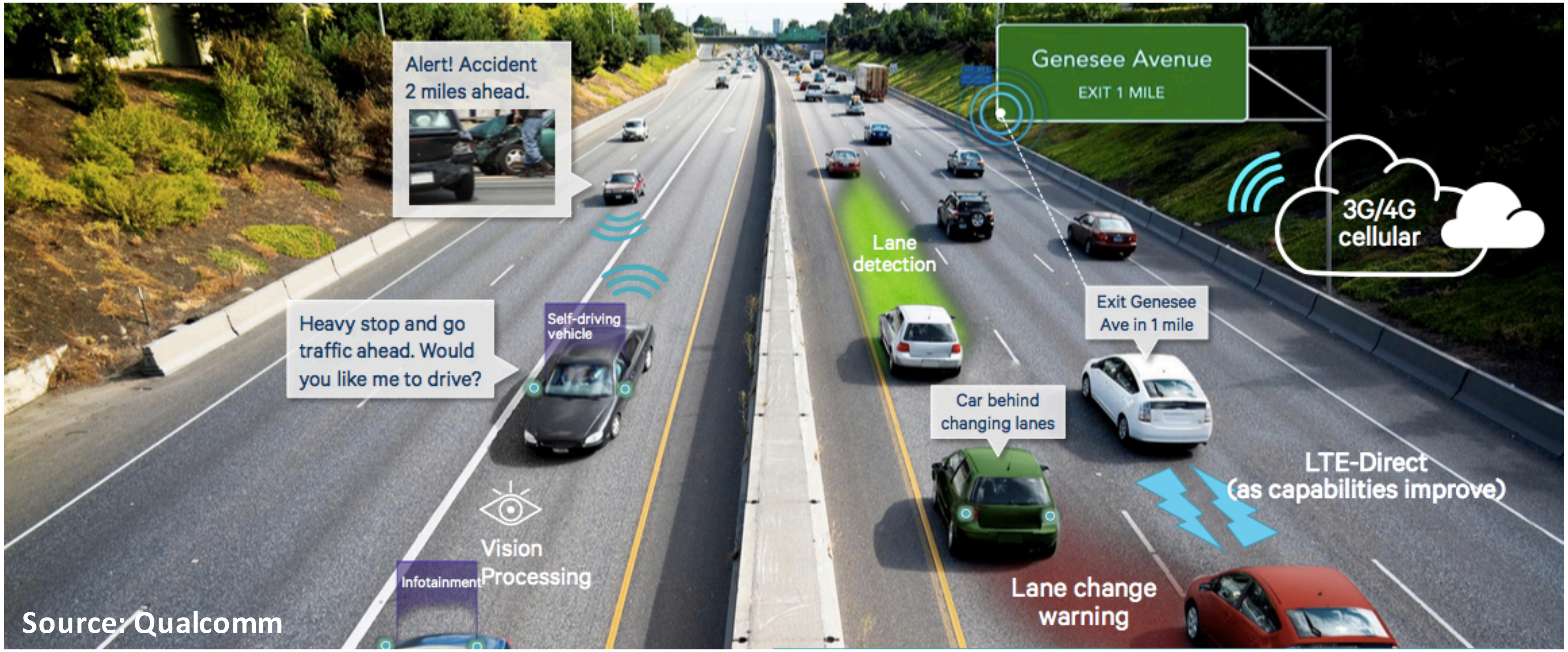
Can be targeted by both IEEE 802.11p and LTE-V2X

5G requirements

- Adaptive beaconing?
  - Beacon frequency adapted to the reliability of the app and to the
- Latency lower than 5-10 ms (1ms for platooning)
- 99% of reliability
- High data rate (e.g., exchange of video captured onboard fo thorough)

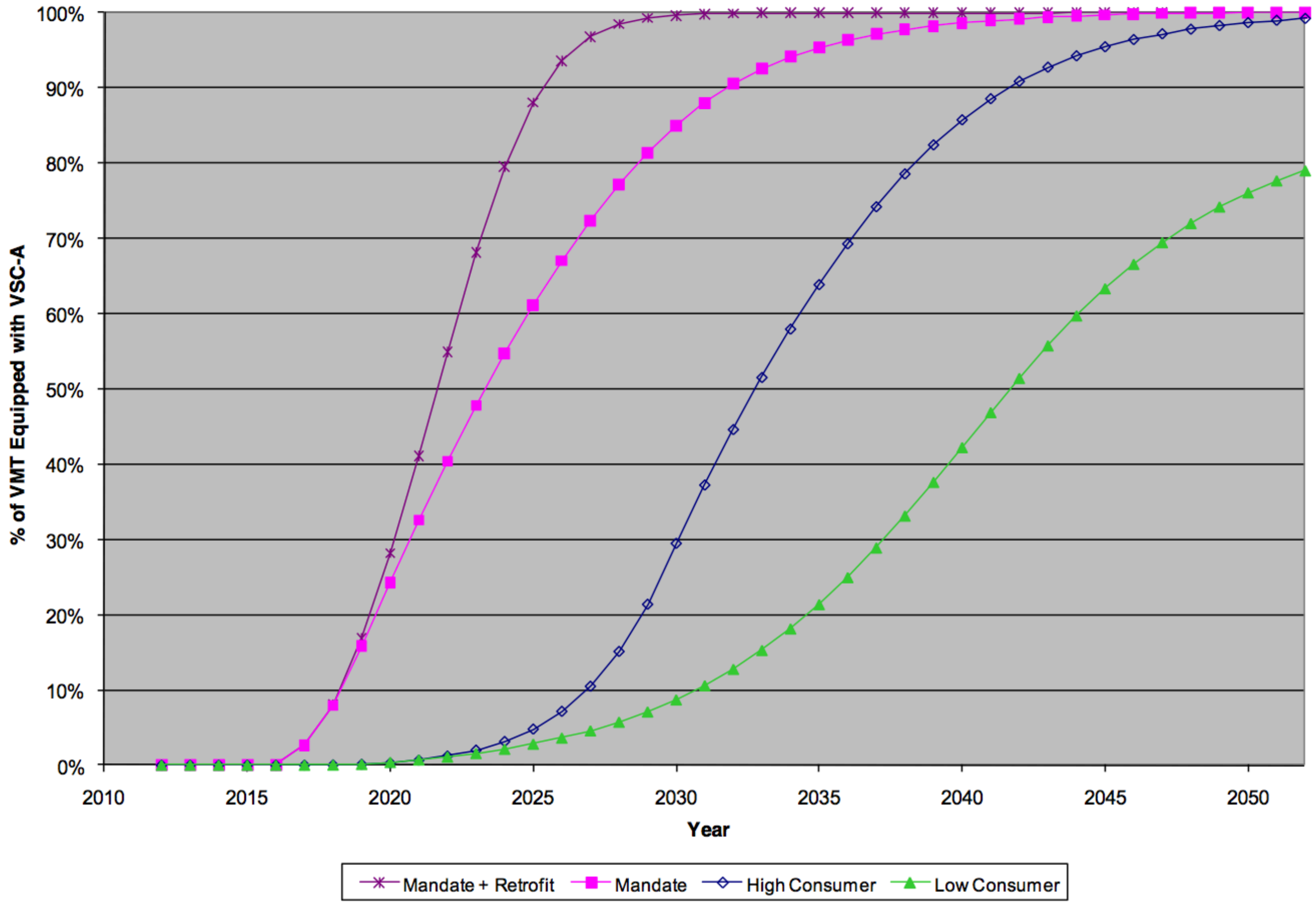
Limitations of 802.11p Targeted by LTE-V2X and 5G (specific apps by VLC)

DSRC and LTE-V2X



- They could cooperate
- DSRC could be used for channel access and LTE for data transmission
- …

The importance of a business model to make the revolution happen



Vehicle Safety Communications – Applications (VSC-A)

Source: “Market Penetration Analysis for VSC-A Safety Benefit Opportunities Estimation”, Discussion Document, James Chang, Noblis, June 8, 2010