The Role of Car Connectivity in Future Mobility

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A short Resume of the Presenter

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Outline I

Future mobility and transportation services - Goals

Goals - in general

- road safety - making vehicles safer,
- traffic efficiency
  (e.g. less congestion, dynamic and more efficient traffic routing
  $\Rightarrow$ reduced and predictable travel time),
- automation of driving,
- to make transportation enjoyable
  (e.g. smoother driving experience - by optimizing the trip to be faster and cheaper using predictive maintenance, convenience services, infotainment services),
- to make transportation greener
  (e.g. reduced carbon emission).

Levels of driving automation

Levels	Characterization	Diver responsibility / Level of automatization
Level 0	No driving automation	Full manual control
Level 1	Driver assistance "hands on"	Manual control up to single automated control / e.g. Adaptive Cruise Control (ACC)
Level 2	Partial automation "hands off"	Monitoring and take control any time Full automatic but erroneous control
Level 3	Conditional Automation "eyes off"	Eventual pre-warned intervention in limited time Level 2 + errorfree immediate automatic safety reactions (due to environmental detection capabilities)
Level 4	High Automation "mind off"	Manual control only other than specific conditions Full automation under specified conditions
Level 5	Full Automation	Providing destination - no manual intervention required Full and safety automation

Defined by Society for Automotive Engineers (SAE) [1]

Critical requirements

Goals $\Rightarrow$ New, critical requirements

- To achieve higher automation levels - connectivity seems critical $\Rightarrow$ Vehicular communications to share sensing data and enhance sensing capability.
- To improve road safety - advanced sensing, communication and computing technologies should be integrated into vehicles.

$\Rightarrow$ Requires new levels of **connectivity** and **intelligence** - to make vehicles smarter.

Technology streams of future mobility and transportation

New ways of future mobility and transportation services

1. **Connected vehicles** - vehicle-to-everything communication.
2. **Automated vehicles** - some safety-critical control functions without direct driver input.
   $\Rightarrow$ MAY OR NOT MAY BE CONNECTED.
   $\Rightarrow$ MAY OR MAY NOT BE SELF DRIVING.
3. **Autonomous vehicles** - self driving capabilities without connectivity.
   $\Rightarrow$ MAY OR NOT MAY BE CONNECTED.

Realization ways of critical requirements

Realization of critical requirements

- Connectivity - with outside world
  - Heterogenous connectivity - WiFi, Cellular.
    $\Rightarrow$ Real-time navigation, Wireless EV charging, Connected infotainment.
- Intelligence - inside, on-device.
  - Always-on sensing.
  - Internal computer networks - FlexRay/CAN/LIN/Ethernet.
  - Functional safety.
  - Automotive security.
  - Machine learning.
  - Augmented reality.
  - Multimedia.

On board intelligence

Providing higher level of predictability and autonomy

Source: Qualcomm [2]

Lidar (also called 3-D laser scanning) = ”light detection and ranging” or ”laser imaging, detection, and ranging”.

V2X - Vehicle-to-Everything communication

The vehicle of tomorrow will communicate with its entire environment

- Vehicle-To-Everything (V2X) Communication [3] - the key element for the new generation Inteligent Transportation Systems (ITS) [4] [5] [6]
- V2X communication partners
  - V2V - Vehicle to Vehicle - e.g. collision avoidance safety systems,
  - V2I - Vehicle to Infrastructure - e.g. traffic signal timing/priority,
  - V2N - Vehicle to Network - e.g. real-time traffic / routing, cloud services,
  - V2P - Vehicle to Pedestrian - e.g. safety alerts to pedestrians, bicyclists.

V2X is a key enabler I. - ADAS

ADAS - Advanced Driver Assistance Systems [7]

- Improved active safety - Provides 360non-line-of-sight awareness.
- Better traffic efficiency - Allows vehicles to safely drive closer to each other and enables optimization of overall traffic flow.
- Increased situational awareness.
- Provides ability to gather data from further ahead to deliver a more predictable driving experience.

V2X is a key enabler II.

Groups of V2X use cases - applications

1. Road safety
2. Traffic management & efficiency
3. Infotainment

V2X use cases defined by

- global standard organization 3GPP and
- regional standard developing organizations ETSI, C2C-CC in Europe, US-SAE, CCSA, China ITS Industry Alliance and SAE-china in China.

V2X is a key enabler III. - Indirect use cases

Use cases for other areas

- Tele-operating AV - remotely driven vehicle - based on perceived environment. $\Rightarrow$ Cost reduction.
- Utilizing best quality sensors in
  - determining what happened during an accident and
  - preventing crashes and avoiding repair costs as impact.

  $\Rightarrow$ Use case for insurance business.
- Health monitoring - trauma prevention, managing chronic diseases and safely bringing the car to a stop when needed. $\Rightarrow$ Healthcare use case.

V2X use cases - I.

1. Road safety applications
   - Collision Avoidance System (CAS) - also called forward collision warning.
   - Lane Departure Warning System (LDWS) - also called Lane change warning/ Do Not Pass Warning (DNPW).
   - Intersection collision warning.
   - Pedestrian crossing warning.
   - Roadworks warning.
   - Emergency vehicle approaching.
   - Cooperative driving (based on on-vehicle sensor data including break usage, accelerating, etc.).
   - Emergency braking warning.

V2X use cases - II.

2. Traffic management & efficiency
    - Parking slot discovery.
    - Navigation provisioning:
        - optimal speed advisory, sending alerts to prevent accidents and
        - providing fastest routes $\Rightarrow$ also reduce traffic congestions.

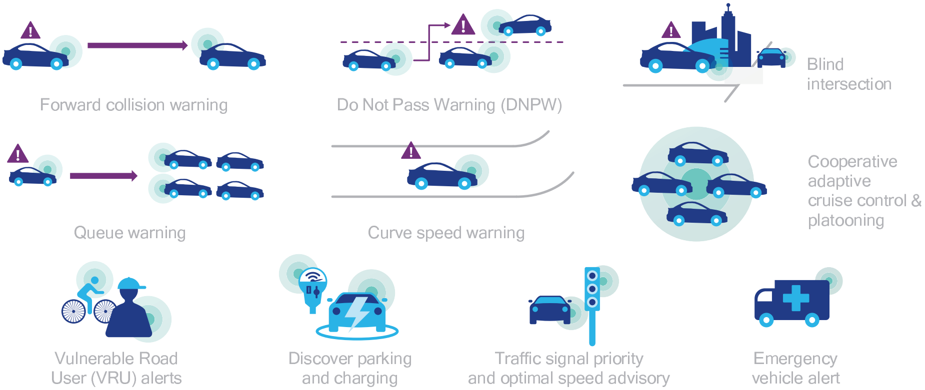
3. Infotainment
    - Vehicle connected (through mobile devices) to application server.

For a comprehensive list and explanation of the V2X use cases see [8].

Overview of use cases

V2X enables a broad and growing set of use cases

Much more than collision avoidance



Source: Qualcomm [9]

SDOs - I.

SDO = Standards Developing Organization

Relevant SDOs - International

1. ISO = International Organization for Standardization,
2. IEEE = Institute of Electrical and Electronics Engineers (standardisation of 802.11a, 1609.x, etc.),
3. ITU = International Telecommunication Union,
4. ITU-R = International Telecommunication Union, Radiocommunication Sector,
5. 3GPP = 3rd Generation Partnership Project,

SDOs - II.

SDOs - USA and Asia

6. FCC - American Federal Communication Commission,
7. NHSTA = National Highway Traffic Safety Administration (USA institute),
8. CCSA - China Communications Standards Association,
9. ARIB - Japanese Association of Radio Industries and Businesses,
10. TTA - Telecommunication Technology Association (Republic of Korea),

SDOs - III.

SDOs - Europe

11. ETSI = European Telecommunications Standards Institute,
12. ETSI technical committee for ITS (standardization, technical report related to ITS),
13. C-ITS Deployment Platform - European Commission's industry stakeholder supporting the deployment of C-ITS in Europe, including also working on a regulatory framework for V2X,
14. C2C-CC - Car 2 Car Communication Consortium (mainly, but not only European companies, vision zero - reach accident free traffic, developing and specifying technology for cooperative V2X communications - C-ITS).

European standards related transportation solutions

- ITS = Intelligent Transport Systems - a future transportation solution defined by EU in 2010.
- C-ITS - Cooperative Intelligent Transport Systems - developed in Europe [10].

VANETs - Vehicular Ad Hoc Networks

Evolution V2X technologies started from VANETs

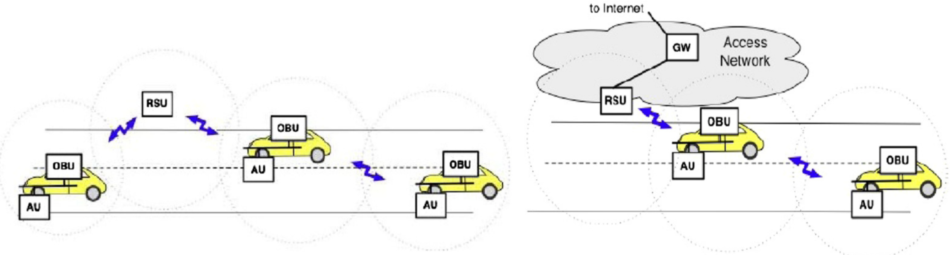
- a mobile ad hoc networks (MANETs) in the context of vehicles and
- a communication technology for the Intelligent Transportation Systems.

Two VANETs blocks - arising also in V2X technologies:

- Road Side Unit (RSU) - handling V2I communication (within the communication range of RSU) and infotainement services and
- Onboard Unit (OBU) - handling V2V communication by broadcasting - even if no communication with Infrastructure.

For details on VANET we refer to [11].

V2V and V2I communications



V2V communication | V2I communication

Source: S. Al-Sultan et al., ”A comprehensive survey on vehicular ad hoc network”, 2014. [11]

ITS - Intelligent Transportation Systems

Intelligent Transportation Systems (ITS)

- in the narrow sense - a technology solution defined by a directive of the European Union 2010/40/EU and
- in the broader sense - technology for smarter use of transport, a term used world-wide.

ITS services

- Emergency vehicle notification systems - e.g. immediate notification of emergency services about accident.
- Automatic road enforcement - to enforce traffic laws with the help of cameras and vehicle-monitoring device.
- Variable speed limits.
- Collision avoidance systems (sensors on highway to notify motorists about blocked cars ahead, installed e.g. in Japan).
- Emergency Electric Brake Light Warning.

DSRC - Standards, protocols

DSRC = Dedicated Short-Range Communications

Communication technology - standards, protocols

- DSRC - set of protocols and standards for V2X communication developed in the USA [12] and based on IEEE 802.11p (=standard for wireless physical and mac link layers).
- European counterpart: ETSI ITS G5 technology and standard [13] [14].
- Similar standards were developed in Japan by ARIB and in Republic of Korea by TTA around 2012-2015.

DSRC - Application to V2X communication

Application to V2X communication

- WAVE = Wireless Access in Vehicular Environments is IEEE 1609 Family of Standards for network, transport layers and end-to-end security (presentation layer) in V2X communications, enabling the application of radio technology (like DSRC) to V2X communication [15].
  $\Rightarrow$ WAVE applied in VANET.
- European counterpart: C-ITS = Cooperative Intelligent Transport Systems [10] - applies mature ad-hoc radio technology (like ETSI ITS G5) to V2X communication.

DSRC - Goal & Technology

Goal: support vehicular communication with safety and non-safety applications $\Rightarrow$ support ad hoc mode and both V2I and V2V.

Technology elements

- Two VANET blocks:
  - RSU for handling V2I communication and
  - OBU for handling V2V communication.
- IEEE 802.11p = IEEE 802.11a (Wi-Fi) extended by ad hoc mode
  - multi-path reflections and Doppler shifts handling and
  - congestion handling by Distributed Congestion Control (DCC) and Multiple Access with Collision Avoidance (CSMA-CA).
- Transmission technique: multiple access with Orthogonal Frequency Division Multiplexing (OFDM) - like in WiFi.
- Spectrum: 5.9 GHz range - defined for VANETs in 1999 by American FCC [16].

DSRC - Technology limitations

Technology limitations

- Single communication medium for all vehicles $\Rightarrow$ fair and efficient resouce allocation is required.
- 802.11p not applicable in high connection density.
- 802.11p has significant overhead which causes high latency due to retransmissions.
- Reliability limitation due to the limited available radio spectrum.

C-V2X

Cellular V2X (C-V2X) is candidate to support vehicular communication, due to its

- wide coverage,
- high capacity,
- mobile services and
- security services.

Service requirements of basic V2X safety use cases - ETSI, 3GPP [17]

- frequency of message transfer: 10 Hz,
- response time $\leq$ 100 ms,
- mobility up to 250 km/h and
- communication both in and out of network coverage ranges.

C-V2X - Rel-14/15

C-V2X Rel-14/15 - Overview

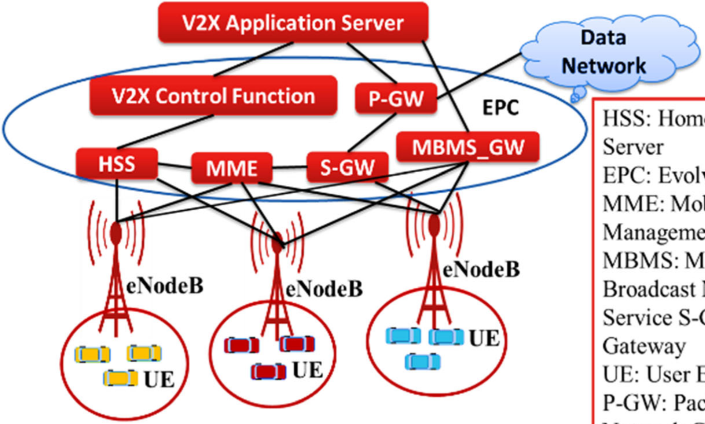
- Supports V2X services - V2V, V2I, V2P, V2N.
- Based on Long Term Evolution (LTE) - and introduces 5G from Rel. 15.

C-V2X Rel-14/15 - Content

- 3GPP Release 14 - since 2015, completed in March 2017 [18] [19] [20]
  - Based on LTE.
  - V2V safety use cases.
- 3GPP Release 15 - enhancement to Rel. 14, completed in June 2018 [21] [22] [23]
  - Enhancement for other V2X use cases: Navigation & Infotainment.
  - Both LTE (for V2X) and 5G (for V2N).

⇒ *LTE-V2X - C-V2X based on LTE as part of 3GPP Rel-14 & 15.*

LTE-V2X architecture



HSS: Home Subscriber Server
EPC: Evolved Packet Core
MME: Mobile Management Entity
MBMS: Multimedia Broadcast Multicast Service S-GW: Serving Gateway
UE: User Equipment
P-GW: Packet Data Network Gateway

Source: Abdel Hakeem et al., "5G-V2X: standardization, architecture, use cases, network-slicing, and edge-computing", 2020. [24]

UE = User-Equipment (end user), eNodeB = Evolved Node B - base station

C-V2X technology - Communication modes I.

Communication modes

- Network communication mode
- Direct communication mode

Network communication mode = V2X communication over the cellular network in network coverage ranges - V2N

- LTE Uu interface - the cellular interface using LTE Broadcast optimized for V2X to offer additional applications/services.
- Wide area networks communications.
- More latency tolerant use cases, e.g. V2N situational awareness.
- Scheduled communication $\Rightarrow$ interference and collision can be controlled.

C-V2X technology - Communication modes II.

Direct communication mode - V2V, V2I, V2P (e.g. location, speed), also called Device-to-Device mode, in 3GPP Radio Access Network (RAN) refered as sidelink

- Via LTE-PC5 interface - ennhancement of LTE Direct for V2X direct communications, introduced in Rel. 12.
- Proximal direct communications (100s of meters).
- Latency-sensitive use cases, e.g. V2V safety.
- Discovery of devices in 500m.
- Multi-hop - from Rel. 14.
- Support for high mobility (500 km/h).

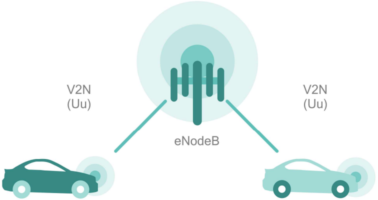
C-V2X technology - Communication modes III.

Network communications

V2N on "Uu" interface operates in traditional mobile broadband licensed spectrum

Uu interface

e.g. accident 2 kilometer ahead

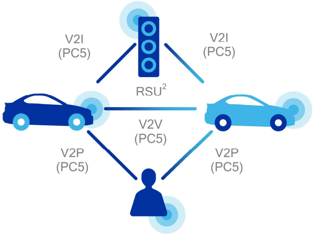


Direct communications

V2V, V2I, and V2P on "PC5" interface[1], operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network

PC5 interface

e.g. location, speed



Source: Qualcomm [2]

C-V2X technology - Communication modes IV.

C-V2X designed for both in-coverage and out-of-coverage.

- Out-of-coverage $\Rightarrow$ Only direct communications.
- In-coverage $\Rightarrow$ Both network communications and direct communications.

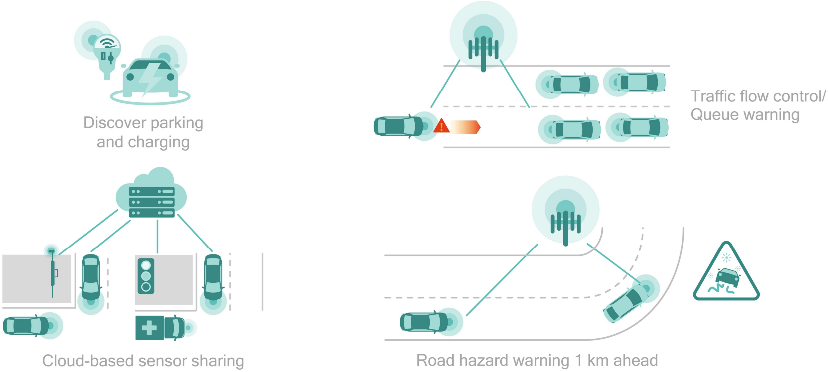
Benefits of direct communication mode - resulting in

- reduced cost (no licensed spectrum), higher reliability (does not rely on network coverage),
- reduced complexity (no need for coordination between operator, resource assignment and subscription),
- lower delay, better spectrum utilization (the same spectrum can be used elsewhere) and
- lower energy consumption.

C-V2X technology - Use of network communication mode

Network communications for latency tolerant use cases

Suitable for telematics, infotainment and informational safety use case

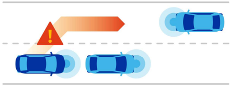


Source: Qualcomm [2]

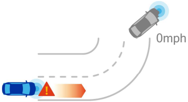
C-V2X technology - Use of direct communication mode

Direct communications for active safety use cases

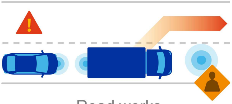
Low latency communication with enhanced range, reliability, and NLOS performance



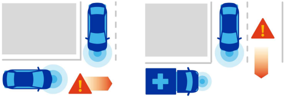
Do not pass warning (DNPW)



Blind curve/ Local hazard warning

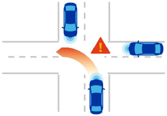


Road works warning



Intersection movement assist (IMA) at a blind intersection

Vulnerable road user (VRU) alerts at a blind intersection



Left turn assist (LTA)

Source: Qualcomm [2]

LTE-V2X technology - Features

Transmission modes

- Mode 3 - Network assisted communication.
- Mode 4 - Out-of-coverage/SIM-less operation (also called UE Autonomous Mode):
  - default mode,
  - distributed (semi-persistent sensing based) resource allocation scheme.

Further technology features

- Transmission technique: Single-Carrier Frequency Division Multiplexing (SC-FDM) with semi-persistent sensing.
- Spectrum: 450 MHz4.99 GHz (cellular frequency range) and 5.9 GHz range
- Data rate: 100 Mbit/s to 1 Gb/s (LTE data rates)

DSRC versus LTE-V2X - Features

Features	802.11p	LTE-V2X
Communication mode	only direct	direct and network
Channel width	10/20 MHz	10/20MHz
Frequency Band	5.865.92 GHz	450 MHz4.99 GHz & 5.9 GHz
Bit Rate	327 Mb/s	100 Mbit/s to 1 Gb/s
Range	Up to 1 km	$>$ 1 km (network mode)
Capacity	Medium	Very high
Mobility support	up to 500 km/h	up to 500 km/h

DSRC vs. LTE-V2X - Performance I.

Performance metrics

- for DSRC - mainly Packet Delivery Ratio (PDR).

Way of perormance evaluations

- DSRC: analytical, simulation and real application.
- LTE-V2X: mainly only simulation - as it is newer technology.

Both performs acceptable in safety applications, if connection density is not too high.

$\Rightarrow$ Performance degradation with increasing connection density

- in DSRC: due to packet collisions and
- in LTE-V2X mode-4: because of increasing interference due to smaller frequency reuse distance.

DSRC vs. LTE-V2X - Performance II.

LTE-V2X exceeds DSRC

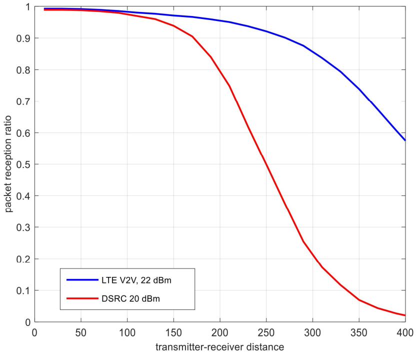
- Due to having network communication mode providing
  - higher resistency again interference due to scheduled communication and
  - Non-Line-Of-Sight (NLOS) due to another frequency band (cellular).
- In direct communication mode due to
  - increased sidelink speed ,
  - better PDR, communication range and reliability as well as
  - lower signal-to-noise-ratio (SNR) to achieve the same performance.

Source: 5GAA [25]

DSRC vs. LTE-V2X - Performance III.

Enhanced range and reliability: Free way 70 km/hr speed

~60% gain in distance at 0.9 PRR; @400m PRR changed from 0.02 to 0.58



Source: Qualcomm [2]

Packet reception ratio in dependency of transmitter-receiver distance

V2X upper layer standards

Upper layer standards - V2X will apply

- ETSI-ITS, ISO, SAE and IEEE standards and
- tests refined by the automotive industry and others in the ITS community for over a decade.

Innovative V2X uses cases

3GPP identified innovative V2X use cases - having very strict Quality of Service (QoS) constraints on V2X [26].

- Extended sensors: enhance the environment perception by the perception of sensors of other vehicles, RSUs, etc. ⇒ provides a more holistic view of the situation.
- Advanced driving: semi- or fully-autonomous driving.
- Remote driving: enables to operate a vehicle remotely, e.g.
    - for persons who can not drive or
    - when a vehicle travels in dangerous environments.
- Platooning - (dynamically) forming a group travelling together
    - small distance between vehicles,
    - autonomously driven following vehicles are allowed.

Also other organisations investigated such innovative V2X use cases, like 5G-PPP [27] and NGMN [28].

QoS requirements of innovative use cases

QoS requirements of innovative V2X use cases

Use case	Maximum latency (ms)	Reliability (%)	Data rate (Mbps)	Packet size (Bytes)	Minimum range (m)
extended sensors	3-100	90 - 99.999	10-1000	1600	50-1000
advanced driving	3-100	90 - 99.999	10-50	300-12000	360-700
remote driving	5	99.999	UL: 25 DL: 1	-	-
platooning	10 - 500	90 - 99.99	50-65	50 - 6000	80 - 350

Source: 3GPP Release 15 [26]

Neither DSRC nor LTE-V2X can fulfill such strict QoS requirements.

Driving forces to novel communication solution for C-V2X

Driving forces to new communication solution for C-V2X

1. Next generation (innovative) use cases: extended sensors, fully autonomous driving or high-density vehicle platooning.
   $\Rightarrow$ New levels of latency, reliability required.
2. Advanced driving and remote driving - massive amount of sensor data per vehicle (self-driving: up 1 TB per hour), real-time information flow.
   $\Rightarrow$ Enhanced mobile broadband with variable-sized packets is required.
3. Account for faster moving vehicles and denser traffic.
   $\Rightarrow$ Advanced mobility capability and high connection density required.

$\Rightarrow$ *New communication solution is needed for V2X !*

New V2X requirements against cellular technology

Automotive requirements against cellular technology - [26], [27] and [28]

1. Low end-to-end latency down to the range of 1 and 10 ms.
2. High data rate, ranging between 10 and 1000 Mbps, with lower requirements for downlink traffic.
3. Very high connection density, namely 2000-4000 $vehicles/km^2$.
   $\Rightarrow$ Massive machine-type communications (M-MTC).
4. Ultra-high availability, namely, 99.999%.
   $\Rightarrow$ Services should be supported also in out-of-coverage conditions.
5. Ultra-high reliability, namely, 99.999%.
6. Security - without user registration. $\Rightarrow$ Providing authentication, authorization without user registration.

Next step - New Radio (NR) V2X

Enhance the facilities of DSRC and C-V2X with

- more modes of operations and
- higher throughput.

Enhancement work from two directions

- IEEE 802.11 Next Generation V2X (began March 2018) $\Rightarrow$ formed IEEE Task Group 802.11bd (TGbd) in 2019.
- 3GPP develops NR V2X for Rel. 16. - on the top of 5G NR standardized in 3GPP Rel. 15.
  $\Rightarrow$ Enhancing 5G with the requirements of V2X.

5G - in general

Fundamental terms

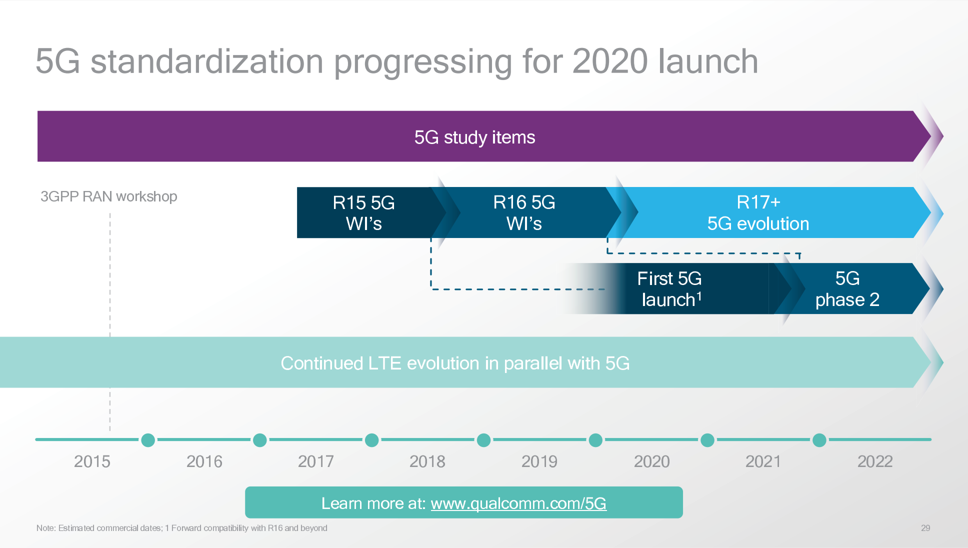
- 5G - 5th generation cellular networks.
- 5G New Radio (5G NR) - radio access technology (RAT) of 5G.

Standardization - by 3GPP

- Phase 1 standardization - Release 15, ready in 2018 [23].
- 5G Phase 2 standardization - Release 16, ready in June 2020 [29].
- Release 17 - rescheduled from September 2021 to June 2022.

Spectrum for 5G services

- Frequency Range 1 (FR1): sub-6 GHz frequency bands.
- Frequency Range 2 (FR2): mmWave - frequency range 24 GHz - 100 GHz.



Source: Qualcomm [30]

5G Selected Elements - relevant to V2X

1. Integrated and Flexible Framework
2. New wireless technologies
   - mmWave technology
   - Multiple-Input Multiple-Output (MIMO) antenna techniques
3. Further innovative concepts
4. Main services

5G - Integrated and Flexible Framework

- Deployment modes
  - Non-standalone mode: LTE - 5G NR dual connectivity
    Dynamic Spectrum Sharing (DSS) between 4G LTE and 5G NR.
  - Standalone mode: only 5G.

- Providing network to users
  - Coexistence of mmWave, 5G deployment in sub-6 GHz bands and 4G LTE - in tight integration.
  - Coordination by using Software-Defined Networking (SDN) and Network Functions Virtualization (NFV).
    - SDN - network management enbling dynamic and efficient network configuration.
    - NFV - network architecture concept enabling decoupling functionalities from physical network (virtualization).

New 5G wireless technologies - mmWave technology I.

- mmWave - up to 300 GHz,
  but range used for 5G: 24 GHz - 100 GHz.
- Transmission techniques:
  - duplex (time-division) and
  - robust OFDM - like in Wi-Fi and LTE networks.

New 5G wireless technologies - mmWave technology II.

- Primary benefits
  - new frequency bands $\Rightarrow$ high capacity,
  - high bandwidth (up to 2 GHz),
  - high data rates (up to 10 Gbps peak throughput).
- Disadvantages
  - high propagation loss,
  - mm wave signals are blocked by buildings or humans - Line-Of-Sight (LOS).

New 5G wireless technologies - mmWave technology III.

- Properties:
  - smaller cell size (due to high propagation loss),
  - higher connection density (enabled by high bandwidth),
  - outdoor cells (100m to 200m) or indoor cells (10m),
    but no outdoor to indoor connectivity (due to LOS),
  - efficient use of spectrum (frequencies can be reused due to small cell size).
- Challenges:
  - overcome path losses,
  - overcome Non-Line-Of-Sight (NLOS).

New 5G wireless technologies - mmWave technology IV.

mmWave vs. sub-6 GHz communication

- mmWave:
  - smaller cells with high connection density,
  - low latency and high data rates.
- sub-6 GHz:
  - larger cells with low connection density,
  - higher latency and smaller data rates.

New 5G wireless technologies-MIMO antenna techniques I.

- Goals/Properties - in general
  - Highly directional beams
    $\Rightarrow$ Property: spatial reuse of frequencies
  - Focus transmitted energy
    $\Rightarrow$ Properties:
    - overcome path losses and
    - operating also under NLOS conditions.
- Goal/Property - mobile device specific
  - Compensate channel changing due to mobility
    $\Rightarrow$ Property: enable high mobility.

New 5G wireless technologies-MIMO antenna techniques II.

- Solution - in general
  - High number (128, 256) of phased arrays implementing beam-forming, beam-steering, and beam-tracking.
  - Small elements enabled by the short wavelengths in mm range.
    - $\Rightarrow$ Resulting in compact and effective MIMO antennas and hence they can be easily integrated into user equipments.
    - $\Rightarrow$ MIMO fulfil the challenges of mmWave technology.
- Solution - mobile device specific
  - Prediction of quality of the radio channel in future time.

5G - Further innovative concepts

Further 5G innovations

- Network slicing
  = re-architecting of the network in order to deliver customized, dedicated and logically isolated network services based on the differentiated requirements.

- Multi-access edge computing (MEC)
  = offers computing capabilities and an IT service environment at the edge of the network.

5G - Main services

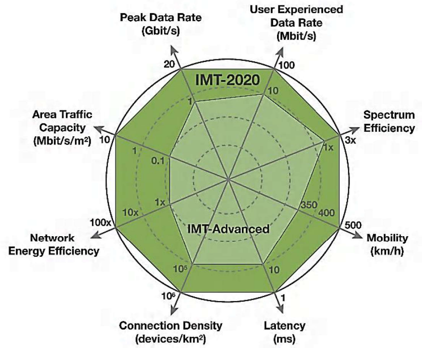
1. Enhanced Mobile Broadband (eMBB)
   - For greater mobile capacity, e.g. for multimedia applications.
2. Ultra-reliable Low-latency Communications (uRLLC)
   - For mission-critical services requiring low latency, high availibility (e.g. using redundant links), high reliability and security.
   - Application examples:
     - real-time applications,
     - autonomous driving, C-V2X and
     - drone communications.
3. Massive Machine Type Communications (mMTC)
   - For applications with vast numbers of low-cost, low-energy devices and small data packets.
   - Application examples:
     - Internet of Things (IoT),
     - smart cities,
     - smart homes.

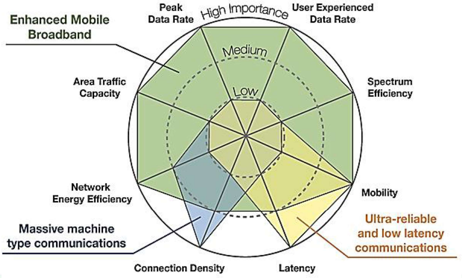
IMT2020 - 5G performances and services

Towards 5G

5th Generation (5G) – IMT2020

IMT performances: from IMT-Advanced to IMT2020





Source: ITU [31]

Institutionalization of spectrum allocation

Spectrum harmonization

- International activity.
- C-ITS is a catalyst - International organizations, such as the ITU, CITEL (Inter-American Telecommunication Comission), Europe CEPT (Europian Conference on Postal and Telecommunications) and APT (Asia Pacific Telecommunity), have also started addressing C-ITS systems

ITU Radio Regulations (RR) - International Agreement

- elaborated during World Radio Conferences(WRC),
- binding for ITU member states and
- ITU act as depositary of RR.

Candidate 5G frequency bands

Frequency Ranges Below/Above 6 GHz of by Region (WRC-15)

← Below 6GHz → ← Above 6GHz/mm-Wave →

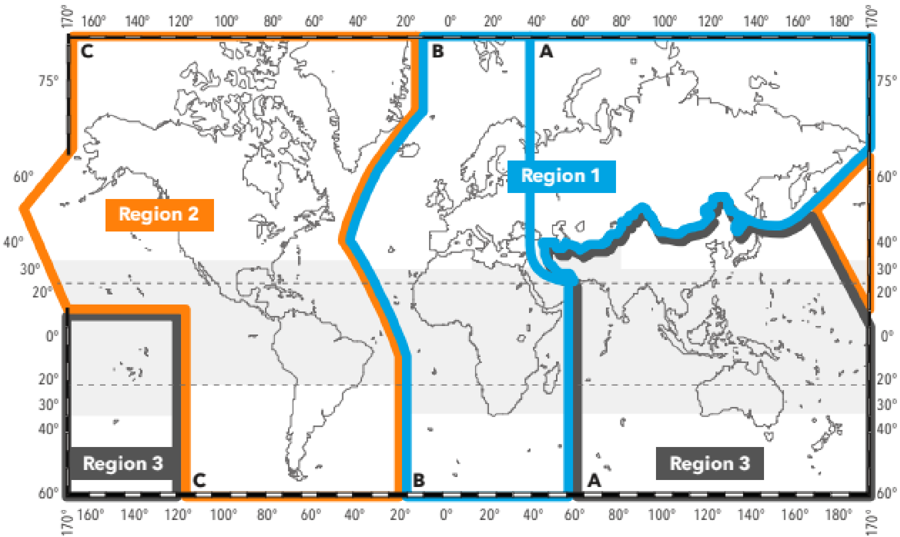
	< 6GHz (MHz)	6-20	*20-30*	30-40	40-50	50-60	60-70	70-80	80-100
APAC *(APT)*	1427 – 1452 1492 – 1518		25.25 – 25.5	31.8 – 33.4	39 – 47 47.2 – 50.2	50.4 – 52.6	66 – 76		81 – 86
Europe *(CEPT)*	1427 – 1518 3400 – 3800		24.5 – 27.5	31.8 – 33.4	40.5 – 43.5 45.5 – 48.9		66 – 71 71 – 76		81 – 86
Americas *(CITEL)*	1427 – 1515 3488 – 3600	10 – 10.45	23.15 – 23.6 24.25 – 27.5 **27.5 – 29.5**	31.8 – 33 37 – 40.5	45.5 – 47 47.2 – 50.2	50.4 – 52.4	59.3 – 76		
Russia *(RCC)*	5925 – 6425		25.5 – 27.5	31.8 - 33.4 39.5 - 40.5	40.5 – 41.5 45.5 – 47.5 48.5 – 50.2	50.4 – 52.4	66 – 71 71 - 76		81 - 86
Mid. East *(ASMG)*	1452 – 1518 3400 - 3600			31 - 100					

※ APT : Asia-Pacific Telecommunity (APT)
CITEL : Inter-American Telecommunication Commission
ASMG : Arab Spectrum Management Group
CEPT : European Conference of Postal and Telecommunications Administrations
RCC : Regional Commonwealth in the Field of Communications (Russia etc.)

Source: ITU [32]

Presented at ITU WRC-15 - Used for developing International Mobile Telecommunications (IMT) standard by ITU-R

Spectrum harmonization



Result of ITU WRC-19.

Source: ITU [33]

5G - expected other new capabilities also for connected vehicles

Performance capabilities

- Connection Density up to 1 million $devices/km^2$.
- Mobility capability up to 500 km/h.

Communication architechture

- Big data management (collecting and organizing vast amounts of vehicle data from many players).
- Achieving autonomy in processes, such as automated assembly lines.

$\Rightarrow$ *5G - A key enabling technology ofconnected vehicles.*

Key innovations of 5G for C-V2X

5G innovations representing major enabling technologies for C-V2X

1. mmWave communication.
2. New air interface design - antenna improvements (including beam forming and massive MIMO).
3. Network slicing.
4. Multi-access edge computing.
5. Enhanced V2X (eV2) communication services - enabling innovative use cases [34]

$\Rightarrow$ *5G is the answer for new V2X requirements.*

5G-V2X - NR V2X

5G-V2X = C-V2X based on 5G (3GPP from Rel. 15.)

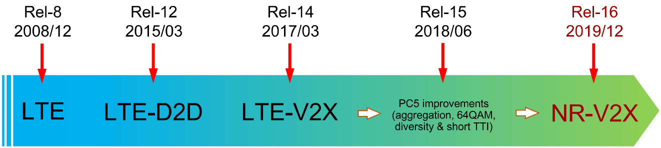
- also called as New Radio V2X (NR-V2X) or 5G NR-V2X,
- is the complete integrated road safety solution,
- is an extension, not a replacement of LTE-V2X,
- can be used in automated driving mode and automated driving mode by integrating it with other existing vehicle technologies.

C-V2X evolution to 5G maintains backward compatibility.

5G-V2X timeline

3GPP time plan: from LTE-V2X to 5G NR-V2X

- Current version of C-V2X is called LTE-V2X as part of 3GPP Rel-14 & 15.
- NR-V2X as part of Rel-16 comes as an improvement to support automated driving.
- NR-V2X will complement, co-exist and support interworking with LTE-V2X i.e. operation of NR-V2X alone is not considered.



- NR-V2X study item started in June 2018.
- Subsequent NR-V2X work item by December 2019.

Source: 5GAA [35]

5G-V2X Communication modes

5G-V2X Communication modes

- standalone mode - only 5G and
- non-standalone mode - LTE-NR dual connectivity.

NR V2X Study investigates

- coexistence of LTE-V2X and NR V2X,
- best RAT selection for NR/LTE sidelink/Uu and
- needed enhancements for sidelink design and Uu interface.

5G-V2X sidelink characteristics and transmission types

- Sidelink transmission technique:
  - Cyclic-Prefix Orthogonal Frequency-Division Multiplexing (CP-OFDM) instead of
  - Single Carrier Frequency Division Multiple Access (SC-FDMA) used in LTE-V2X.
- Sidelink modes - like in LTE-V2X:
  - mode 1 - in network coverage and
  - mode 2 - in case of out of overage.
- Transmission types - differs to LTE-V2X (it has only broadcast):
  - unicast and
  - group cast (including aslo broadcast cases).

5G-V2X core technologies

- Flexible and highly scalable framework.
- Transmission technique: OFDM with enhancements.
- Ultra-reliable Low-latency Communications.
- Novel wireless technologies: mmWave technology + MIMO antenna. techniques

5G-V2X network slicing - I.

- Network slicing - a type of network architecture enabling the management of independent logical networks on the same physical network.
- Realization of network slicing - builds on the experiences of SDN and NFV.
- More network slicing designs are possible in 5G-V2X, e.g. slicing according to services/service groups having the same service level requirements (SLR).
- Point of Attacment (PoA)- controls the slicing handover of a UE.
- Types of slicing handover
  - intra-slicing handover - an UE changes its PoA within the same slice and
  - inter-slicing handover - an UE changes its slice.

5G-V2X network slicing - II.

Example slicing design - according to service groups with the same SLR

- Autonomous driving slice - ensures
  - low latency V2V communication and
  - high reliable and low latency V2I communication.
- Tele-operated driving slice - guarantees
  - high reliable and low latency communication between the controller outside the core network and the controlled vehicle.
- Vehicular infotainment slice - ensures
  - high throughput data communication with the V2X infotainment application server.
- Vehicle remote management and diagnostic slice - enables
  - low frequency data exchange among the vehicles and the V2X application server.

5G-V2X edge computing - I.

- Edge computing - distributed computational paradigm, in which computation occurs close to the origin of the data to be processed.
- Benefits - comparing to cloud computing
  - low latency - in case of latency sensitive data and
  - less network traffic - in case of large amount of data.
- Properties - edge computing needs
  - decentralized security concept and
  - management of failovers to ensure reliability.

5G-V2X edge computing - II.

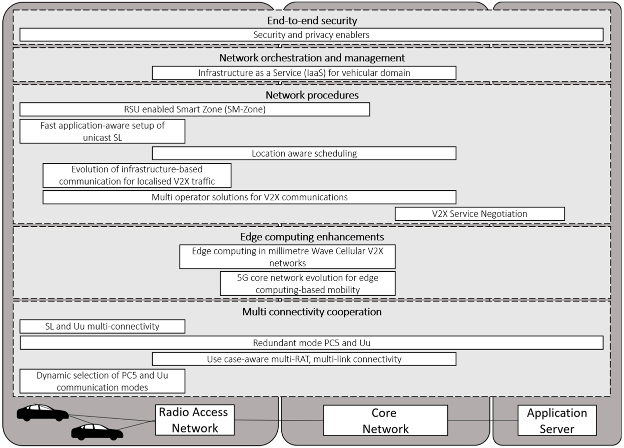
- 5G-V2X - edge computing capabilities of RSUs and base stations are assumed.
- 5G-V2X edge computing is applied to
    1. processing real-time data with strict latency constraints, like e.g. in use case autonomous driving and
    2. processing a large amount of data sent to edge computing entity by the help of mmWave technique, like e.g. in use cases cooperative perception (to handle HD-maps) and cooperative maneuver (to process task only with local relevance).
- Features
    - Handover of edge computing server needed - when vehicle changes base station.
    - Task offloading to edge computing server is decided by an optimization process counting for relevant constraints, like e.g. total latency (estimated based on dynamic channel model), total energy consumption.

5G-V2X architecture - I.

Architecture proposed by 5GCAR project [36]

1. Goal: enhancements of the 3GPP 5G service-based architecture (SBA) [23]. in order to support the large set of requirements of V2X applications
2. Identified technical areas of V2X requirements again the SBA
   1. V2X main characteristics (mobility requirements for reliable, low latency and high bandwidth communications).
   2. Multiple access network connectivity (including network slicing).
   3. Security and data privacy.
   4. Roaming.
3. Result of the project: proposed enhancements, called technical components.

5G-V2X architecture - II



Technical component groups:

- end-to-end security,
- network orchestration and management,
- edge computing enhancements,
- multi-connectivity cooperation.

Source: [36]

5G-V2X use cases - different views

Several organization provided 5G-V2X use cases, their groupings and examples

- 3GPP identified innovative use cases [26].
- 5GAA provided C-V2X use case groups together with a methodology to describe
  - the use cases (Use Case Description Template) and
  - the service level requirements of the individual uses cases [37].
- 5G-PPP and NGMN also identified 5G-V2X use cases, NGMN provided also 5G-V2X groups [27] [28].
- 5GCAR provided use cases with examples [38].

Use case grouping - in general I.

1. Road Safety and efficiency
   - Also included in V2X use cases before 5G
     - Road warning use cases.
     - Cooperative driving use cases (e.g. cooperative collision avoidance).
   - New 5G-V2X use cases
     - Extended sensors use cases.
     - Advanced driving use cases semi-automated or fully automated driving
       (e.g. intersection movement assists, cross-traffic left-turn assist).
     - Remote driving use cases (remotely control an autonomous vehicle).
     - Platooning (e.g. in order toreduce number of drivers).

Use case grouping - in general II.

2. Telematics (including Traffic management)
   = services based on application server - vehicle communication
   - Also included in V2X use cases before 5G
     - Parking slot discovery.
     - Navigation provision.
   - New 5G-V2X use cases
     - Health monitoring of the vehicle.
     - Remote precise position provisioning.
     - Speed harmonization.
     - Automated parking.
3. Infotainment - also included by V2X use cases before 5G.

Use case grouping - 5GAA

5GAA defined the following C-V2X use cases

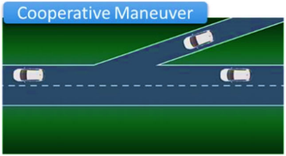
- Safety
- Traffic Efficiency and Environmental friendliness
- Vehicle Operations Management
- Platooning
- Autonomous driving
- Convenience
- Society and Community

Use cases with examples - 5GCAR I.

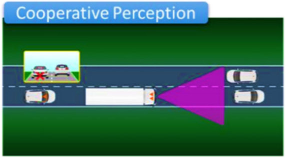
Use cases with examples defined by 5GCAR

- Cooperative Maneuver, example: Lane Merge.
- Cooperative Perception, example: See-through.
- Cooperative Safety, example: Network assisted vulnerable pedestrian protection.
- Autonomous Navigation, example: High definition local map acquisition.
- Remote Driving, example: Remote driving for automated parking.

Use cases with examples - 5GCAR II.

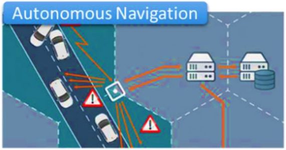


Lane merge



See-through

Network assisted vulnerable pedestrian protection



High definition local map acquisition

Remote driving for automated parking

Source: [24]

Automotive - 5G organisations: overview

Automotive organisation

- SAE - https://www.sae.org/

Related telecommunication organistaions

- NGMN Alliance - https://www.ngmn.org/
- IEEE Future Networks Community - https://futurenetworks.ieee.org
- 5GPPP - https://5g-ppp.eu/

Cooperation between automotive and telecomunication worlds - based on synergy/common interests

- 5GAA - https://5gaa.org/
- 5GCAR - https://5gcar.eu/
- China ITS Industry Alliance (C-ITS)

SAE - Society for Automotive Engineers

SAE - U.S.-based, global professional standards developing organization and association for engineering professionals.

- Emphasis is placed on transport industries such as automotive, aerospace, and commercial vehicles.
- Membership - over 138,000 global members, membership is granted to individuals, rather than companies.
- Areas of activity:
  - standardization - e.g. standards for rating automobile horsepower,
  - projects and programs in science, technology, engineering and math (STEM) education,
  - professional certification.,

Source: https://en.wikipedia.org/wiki/SAE_International

NGMN Alliance - Next Generation Mobile Network Alliance

NGMN - An open forum founded by world-leading mobile network operators.
The mission of the NGMN Alliance

- to evaluate and drive technology evolution towards 5Gs full implementation for 2021 and beyond,
- to establish clear requirements for mobile networks of the next generation,
- to give guidance to equipment developers and standardisation bodies, leading to cost-effective network evolution,
- to provide an information exchange forum for the industry and to share experiences and lessons learnt,
- to identify and remove barriers in order to enable successful implementations of attractive mobile services.

Source: https://www.ngmn.org/about-us/vision-mission.html

IEEE Future Networks Community

IEEE Future Networks - gathering the worlds experts, like researchers, scientists, engineers, and policymakers from industry, academia, and governments.

Goals of IEEE Future Networks Community

- Providing timely technical practical and theoretical content in public accessable channels, like e.g. in tutorials, externally published articles.
- Establishing a 5G and Beyond Technology Roadmap for short- (3 years), mid- (5 years) and long-term (10 years) research, innovation, and technology trends in the communications ecosystem.
- Organizing and leading technical conferences and workshops.
- Contributing to IEEE standards - in collaboration with IEEE Standards Association, .

Source: https://futurenetworks.ieee.org/about

5GPPP - 5G Infrastructure Public Private Partnership

The 5G Infrastructure Public Private Partnership (5GPPP) - a joint initiative between the European Commission and European telecommunication (ICT) industry.

About 5GPPP

- 5GPPP has many projects.
- 5GPPP's objective is to provide solutions, technologies, architectures and standards for realizing next generation communication infrastructures.

Abstract from 5GPPP challenges

- Developing up to 1000 times higher wireless area capacity.
- Establishing a secure, reliable and dependable Internet - a zero perceived downtime.
- Supporting very dense deployments of wireless communication links - connecting 7 trillion wireless devices for 7 billion people

Source: https://5g-ppp.eu/

5GAA - 5G Automotive Association

The 5G Automotive Association (5GAA) - a global, cross-industry organisation of companies from the automotive, technology, and telecommunications industries (ICT).

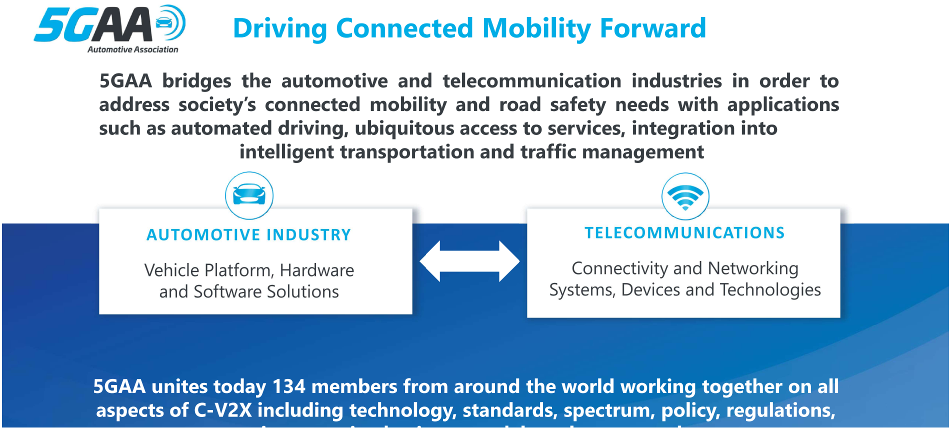
Facts

- 5GAA created on September 2016,
- it has 8 founding members: AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia, and Qualcomm Incorporated and
- over 80 member companies from the automotive and ICT industries.

Vision of 5GAA

- Vehicles share information in order to make transportation safer, greener, and more enjoyable - by using C-ITS technology.
- 5G to be the ultimate platform to enable C-ITS.

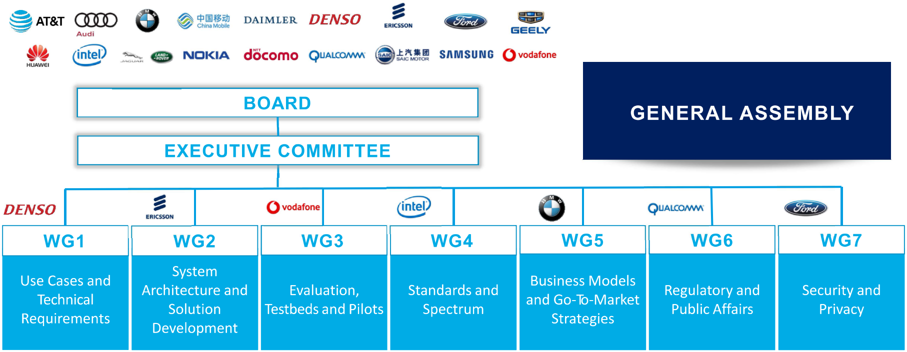
5GAA - Mission



Source: 5GAA [39]

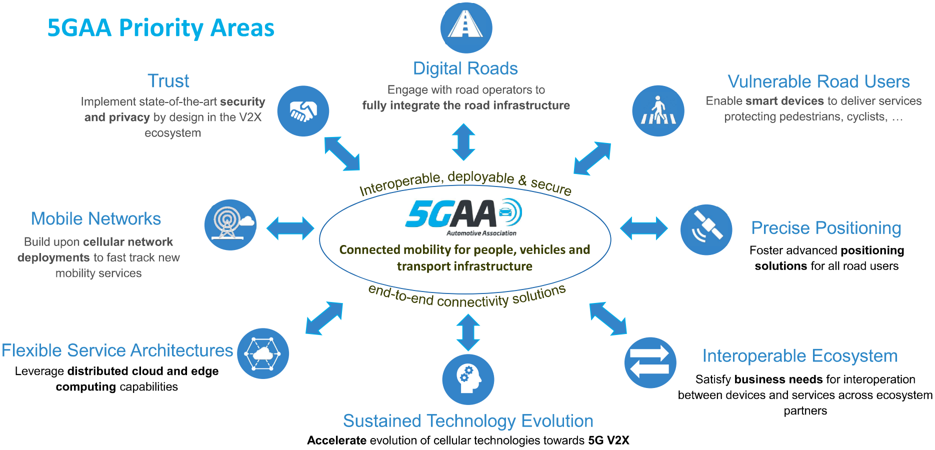
5GAA - Organisational Structure

5GAA Organisational Structure



Source: 5GAA [39]

5GAA - Priority Areas



Source: 5GAA [39]

5GCAR - European project

5GPPP - H2020 5G PPP Phase 2 project funded by the European Commission.

Main objectives

- Develop an overall 5G system architecture providing optimized end-to-end V2X network connectivity.
- Investigating interworking of multi-RATs.
- Development of a secure, efficient and scalable sidelink interface.
- Proposing 5G radio-assisted positioning techniques for very accurate localization.
- Evaluating spectrum usage alternatives supporting 5G V2X services.
- Validation of the concepts and evaluating the benefits of 5G-V2X solutions.

Source: https://5g-ppp.eu/5gcar/

C-ITS - China ITS Industry Alliance

China ITS Industry Alliance - a global Non-Profit-Organisation (NPO)

- supported by the Chinese governments,
- having more than 288 global industrial members, mostly from ITS industry.

Main activities are

- standardization,
- technical testing and inspection,
- international exchange and cooperation,
- intellectual property transaction and protection,
- transformation of scientific and technological achievements and
- ITS related consulting.

Source: http://www.c-its.org.cn/en/Index/lists/catid/1.html

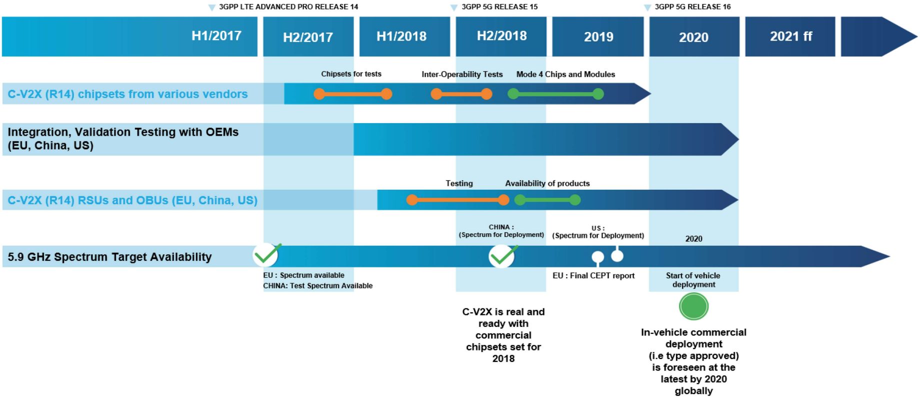
Preliminary - C-V2X deployment

C-V2X deployment.

- 30+ studies in Rel-14 LTE-V2X including study on ”LTE support for V2X services”.
- Deployment with commercial chipsets planned in 2018.
- Start of in-vehicle commercial deployment (i.e. type-approved vehicles) was expected for 2020/2021 globally.

5GAA Timeline for C-V2X deployment

5GAA Timeline for deployment of C-V2X (V2V/V2I)



Source: 5GAA [35]

LTE-V2X Rel-14 trials - I.

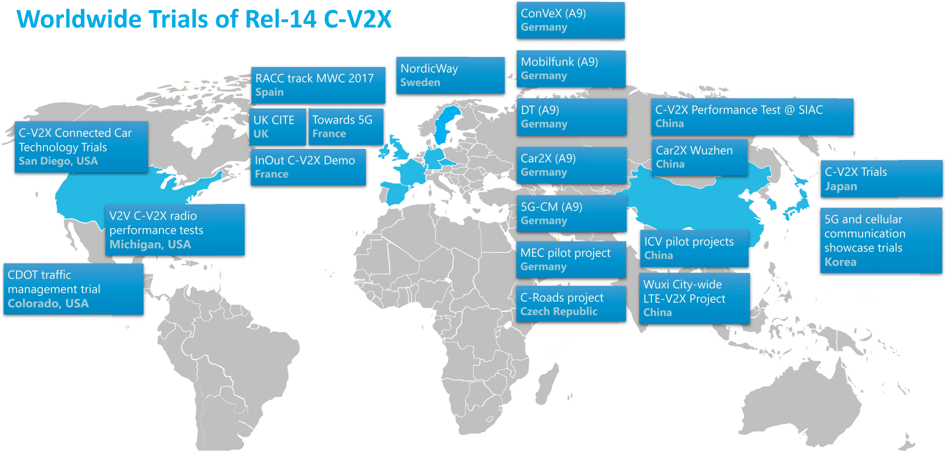
Several outstanding events

1. RACC track, MWC 2017 - Demonstration of use of C-V2X first time in Europe.
    - At the world famous Circuit de Barcelona-Catalunya race track.
    - Huawei and Vodafone, with support of Audi.
    - Use cases: Emergency brake, See through, Pedestrian warning, Traffic light warning.
2. LTE-V2X Rel-14 interoperability tests in Shanghai, Nov 2018.
    - First multi-vendor interoperabilty test of LTE-V2X applications $\Rightarrow$ interoperabilty at different levels (module, device,..).
    - PC5 interface - according to 3GPP R14 LTE-V2X PC5 standard.
3. 5GAA C-V2X testing event in Europe, April 2019, GermanyFirst $\Rightarrow$ demonstrated successful interoperability.

Source: 5GAA [35]

LTE-V2X Rel-14 trials - II.

Worldwide Trials of Rel-14 C-V2X



Mainly safety use cases.

Source: 5GAA [35]

Testing 5G-V2X - 5G modility labs

5G modility labs - testing innovative services enabled byy 5G, among others 5G-V2X.

- Vodafone 5G Mobility Lab - Aldenhoven Testing Center, RWTH Aachen
- Huawei R&D Centre in Shanghai
  - Real network simulation for testing technological solutions.
  - Demonstrating among others 5G-V2X services.
- Vodafone 5G Lab Düsseldorf, Germany
- 5G Lab in Dresden, Germany

Testing 5G-V2X - Automotive proving grounds

Automotive proving grounds - for testing connected cars with 5G-V2X

1. Nevada Automotive Testing Center United States
2. HORIBA MIRA, United Kingdom
3. UTAC CERAM, France
4. Applus IDIADA, Spain
5. Automotive Testing Papenburg, Germany
6. TRIWO Automotive Testing Center not far from Frankfurt, Germany
7. Digitrans Automotive Proving Ground, St. Valentin, Austria
8. ZalaZone proving ground in Zalaegerszeg, Hungary [40]
9. Lang Lang Proving Ground, Australia

NGMN 5G Trial & Testing Initiative (TTI) Project

Four phases

1. Technology building blocks
2. Proof of concept (PoC)
3. Interoperability
4. Pre-commercial networks trials phase - with equipment similar to commercial quality standard

Source: NGMN [41]

5G-V2X Trials - I.

Huawei German Research Center, Germany - 2017 [42] [42]

- Cooperative driving such as semi-simultaneous emergency brake, platooning and cooperative maneuver.
- Emergency brake: successful with 100 % rate and in ≤ 1 millisecond delay $\Rightarrow$ safety distance between vehicles and other trafc participants can be significantly reduced.

Wireless City Planning Inc., Japan - 2020 [43]

- Truck Platooning.
- Dynamic Mode Switching between In-Coverage and Out-of-Coverage modes for 5G-V2X Sidelink Communications $\Rightarrow$ seamless switching operation.

5G-Enabled Autonomous Driving Demonstration, Hungary - 2020 [44]

- Autonomous Driving.
- Demonstration on the M86 highway and the ZalaZONE proving ground.

5G-V2X Trials - II.

5G-DRIVE trial - from 2020

- For interoperability between EU and China 5G networks for V2X scenarios.
- European Union Horizon 2020 funded project.

Objectives - among others

- test specific 5G-V2X scenarios,
- investigate cyber/RF attacks from other vehicles/network.

Sites

- Espoo trial site, Finland.
- Ispra trial site, Italy.

Research topics

Potential research topics (an uncomplete list)

1. Architecture enhancements
2. Improvement demands at different levels
3. Cyber security and Privacy
4. Performance modeling/evaluation/optimization of radio interface
5. Optimal traffic management
6. Open standardization questions

Source: Most of the above issues are identified by 5GCAR [45]

Architecture enhancements

Multi-link utilization

- Improve the usability of different use cases with heterogeneous requirements.
- Optimize link selection and utilization.

Multi-operator capability

- To ensure seamless and low latency communication among vehicles and road users.
- Issues: network re-selection, required agreements, etc.

Non-research architecture related issue: Identifying authorities to take responsibility to ensure interoperability between different actors through different transport infrastructures.

Improvement demands at different levels

- Distributed Functional Safety (more than one vehicle).
- Decision and control including AI techniques (object classifying and strategies for decision).
- Big Data Collection (appropriate solutions for offloading, storing and analysis of car sensor data to backend).
- Human-Machine Interface (HMI) (avoiding driver overloading, avoiding mistakes by driver alarms).
- Improved positioning by the help of radio and other sensors.
- Improved ad-hoc networking for deterministic data exchange.

Cyber security & Privacy - I

State of the art approach

- Task: keep anonymity of vehicle data during periodical packet broadcasting.
- Current approach: Public Key Infrastructure (PKI) system with using pseudonym certificates (=not containing any identifying information).
- Improvement: change between multiple pseudonym certificates
    - which are cryptographically unlinkable to each other
    - in order to prevent identification of indivuduals by means of geolocation profiles.

Cyber security & Privacy - II.

Still remaining issue:

- **Current pseudonym change strategy does not give perfect privacy protection.**
- $\Rightarrow$ Eavesdropper can exploit the circumstances under which vehicles change pseudonyms (e.g. can observe the time of particular pseudonym change) [46].

Related open reseach questions

- Propose better pseudonym change strategies (e.g. distributed ones).
- Identify technical measures to address the problem of changing pseudonyms.

Performance modeling/evaluation/optimization

Potential research directions

- Radio interface design -improved performance modeling/evaluation in 5G environment
  - Propagation modeling of mmWave.
  - Throughput/delay modeling in mobile Heterogenous Network (HetNet) environment.
- New use case proposal - based on performance modeling/evaluation of existing use cases
  - Study - existing use cases based on
    - existing statistics of road traffic fatalities and
    - probabilistic modeling of actions/events in the use case.
  - Proposal - a new use case.

Optimal traffic management and open standardization questions

Optimal traffic management

- Improved optimization strategies for traffic efficiency.
- Novel approaches for implementing otimization strategies.

Open standardization questions - investigate relevant technical issues

- Access layer mechanism for controlling Sidelink and Uu to achive optimal routing of road safety and traffic efficiency messages.
- New application protocols to support advanced use cases, e.g. vehicles need to negotiate, and acknowledge actions.

Deploying car connectivity - Challenges

Deploying car connectivity - Several involved challenges

1. Implementing 5G-V2X technology and innovative use cases.
2. Involving growing computing power, fast processing and decentralised data handling in future mobility solutions.
3. Providing security for connected vehicles against outside intrusion.
4. Achieving higher SAE level of automated driving together with
    - approving (functional validation & certification) it and
    - traffic management of mixed (manually driven and automated) cars.

Deploying car connectivity - Impact/Consequences I.

Deploying car connectivity - Impact/Consequences on several areas

- Business - enabling/ facilitating new emerging business models (e.g. car sharing, car pooling) are expected.
- Liability and insurance
  - Contribution to clarifying accidental situations (due to best quality sensors - as indirect use case) is expected.
  - However still there are open issues, like e.g. handling situations, when autonomous vehicles are in accidents (although it is expected that they reduce accident up to 80%, the situation can not be excluded).
- View on mobility - an entire change of user requirements and expectations for future vehicles can be expected, due to new mobility concepts for urban and interurban mobility.

Deploying car connectivity - Impact/Consequences II.

Deploying car connectivity - Impact/Consequences on several areas

- Health - contribution to preserve health of traveling persons is expected due to
  - health monitoring (trauma prevention, managing chronic diseases)
  - and safely bringing the car to a stop when needed.
- Role of driver
  - The change in driver's role depends on acceptance of autonomous driving, strongly correlating with the first experiences with it.
  - However a gradually transition "driver with full responsibility" $\rightarrow$ "driving with partial manual control" $\rightarrow$ user of the service "enjoyable transportation" gradually is expected - in long term.
- Society (overall impact) - depends strongly on customer's
  - acceptance of the new services and
  - initial experiences - regarding safety, traffic management, convenience services, infotainment services.

$\Rightarrow$ ***Deploying car connectivity in innovative use cases has far-reaching consequences on the different areas of life.***

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