C-V2x
Intelligent Transportation Systems

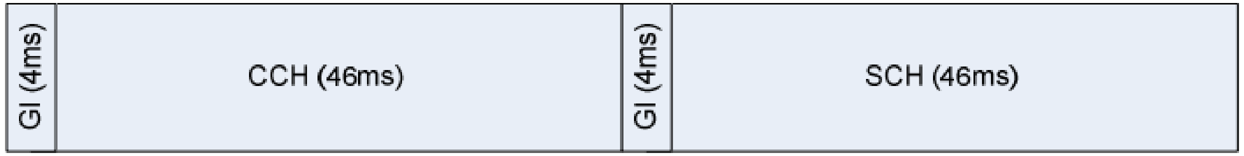
Rolland Vida

IEEE 1609.x

- IEEE 1609.2 – security services
- IEEE 1609.3 – management services
  - Channel usage monitoring
  - Received channel power indicator (RCPI)
  - Management parameters
- IEEE 1609.4 – QoS and multi-channel access
  - User Priorities mapped to Access Categories in EDCA
  - Multi-channel access for single radio 802.11p devices

IEEE 1609.4 channel swithcing

- 7 FDMA channel frequencies
- **Multi-channel radios** can send and receive over several channels simultaneously
  - Might have problems with interferences between channels
- **Single channel radios** to access both CCH and SCH
  - Either transmit or receive on a single 10 MHz channel
- **Alternating access**
  - Repetitive periods of 100 ms
    - 46 ms allocated to the CCH channel
    - 46 ms allocated to the SCH channels
    - 4 ms guard interval for switching between CCH and SCH
      - Nodes should wait for a random backoff after the end of the guard interval, before starting to transmit
  - Time synchronisation needed to an external time reference
    - Coordinated Universal Time (UTC) from GPS or other devices
      - **WAVE Time Advertisement (WTA)** frame

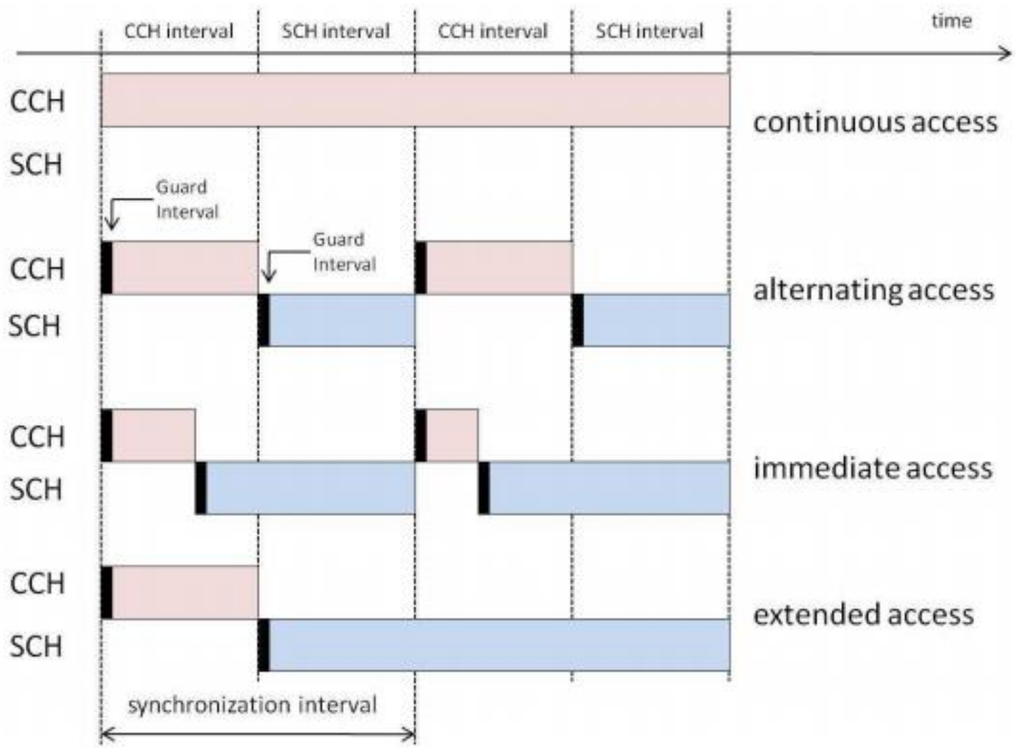


IEEE 1609.4 channel switching

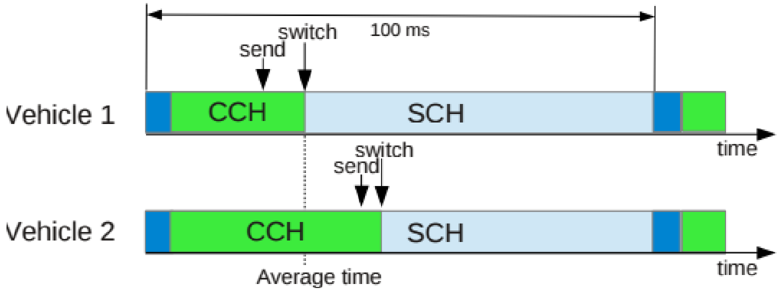
- **Continuous access**
  - Transmission can be continuous on the CCH and all SCHs
  - It cannot be guaranteed that all other stations will listen to the CCH outside the CCH slot
  - Safety messages sent over the CCH in the SCH slot might be ineffective
  - The usage of SCH not efficient if nodes listen to the CCH 50% of the time

- Alternative solutions to minimise the impact of channel switching?

IEEE 1609.4 channel switching



- **Immediate access**
  - The node does not have to wait until the CCH slot is over
  - After the CCH transmission is over, switch to SCH
  - Improve the performance of bandwidth-demanding non-safety applications in SCH, at the expense of the CCH
- **Extended access**
  - Transmission on the SCH without waiting for the CCH
- **Adaptive Independent Channel Switching**
  - If more vehicles, more beacons on the CCH
  - Nodes can change their average switching time based on vehicle density
    - Long SCH intervals if not many vehicles
    - Fewer collisions at the start of the SCH, as nodes switch independently of each other
  - Drawback is that not all nodes on the CCH in the same time
    - Vehicle 1 will miss the beacon of Vehicle 2



IEEE 1609.4 channel switching

- **Fragmentation**
  - To better utilise the residual time at the end of the SCH interval
  - An extra fragmentation header should be used, which is a drawback
  - Works for large packets (TCP)

- **Best-fit scheme**
  - Send the packet that best fits the residual time at the end of the SCH interval
    - Better than fragmentation only if packets of different sizes are present in the queue
  - Hard to know in advance the actual duration of transmission
    - Frequent changes in the channel congestion
    - Stochastic nature of backoff

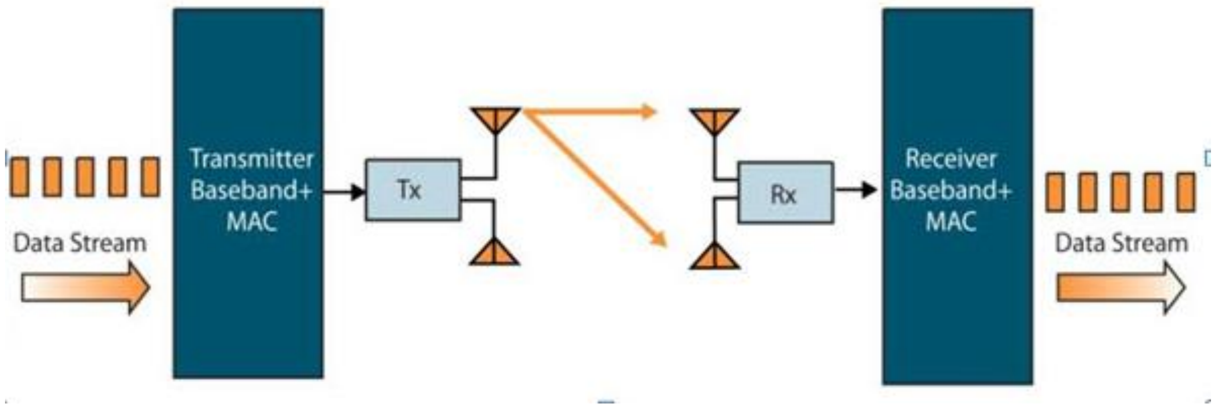
IEEE 802.11bd

- **IEEE 802.11p (2010)**
  - Based on IEEE 802.11a
  - Since then, new standards, more efficient, higher throughput, lower latency

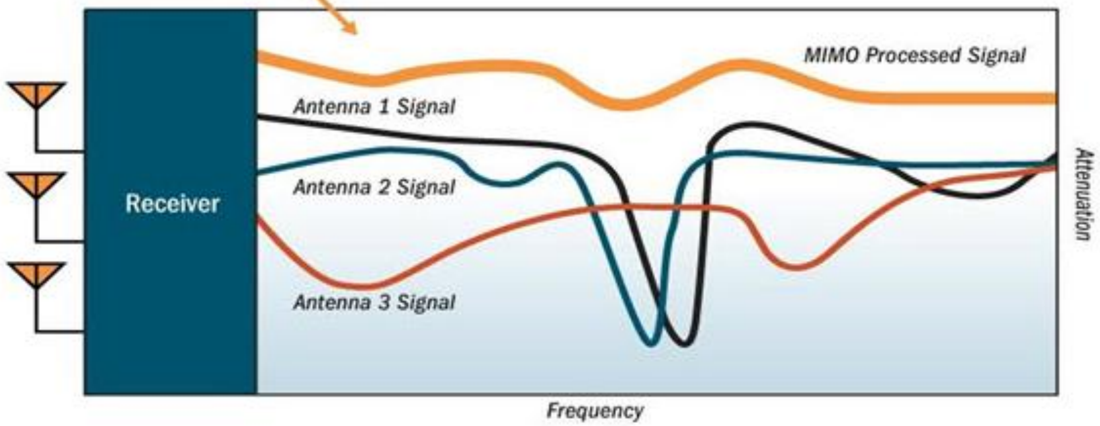
- **IEEE 802.11bd**
  - Working group established in 2019
  - Standardisation ongoing, expected to end in 2022 végére
  - Based on IEEE 802.11ac (WiFi 5)

MIMO – Multiple Input Multiple Output (WiFi 4, 2009*)

- More transmitting and receiving antennas (e.g.. 3 x 3)
- **Traditional sending:** 1 sender, 2 receiver antennas
  - The receiver processes only the best quality signal



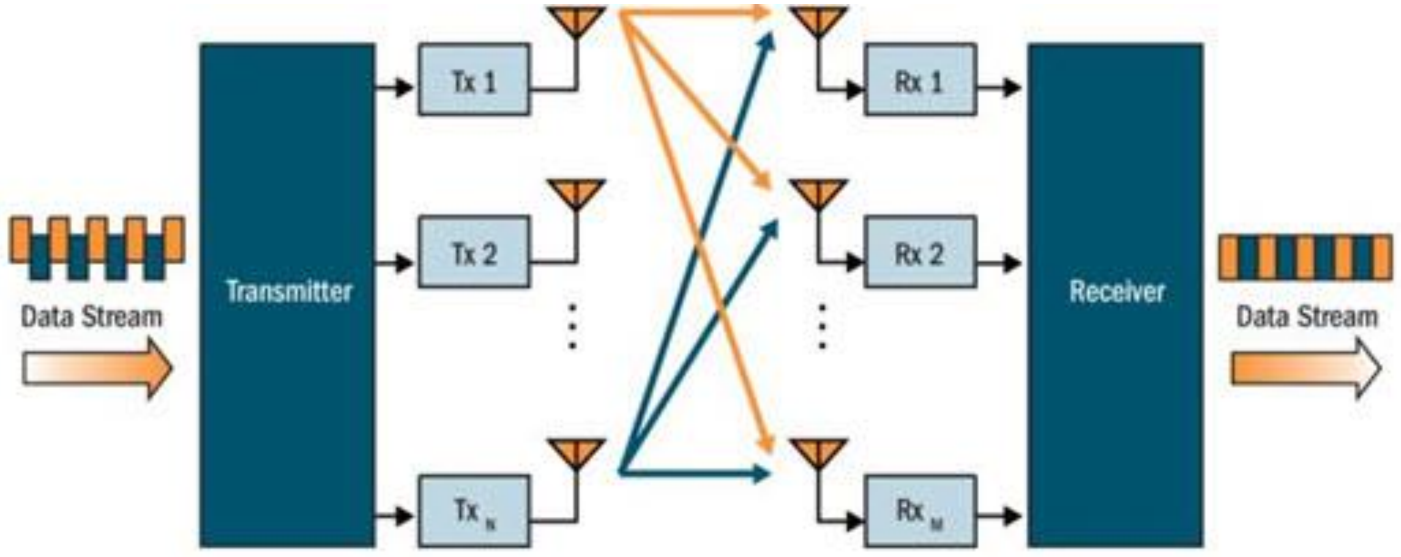
- **MIMO sending**: e.g., 3 sending, 3 receiver antenna
  - Each sender sends the same signal
  - Each receiver hears each sender
    - Different quality, antenna diversity
  - Each signal is processed

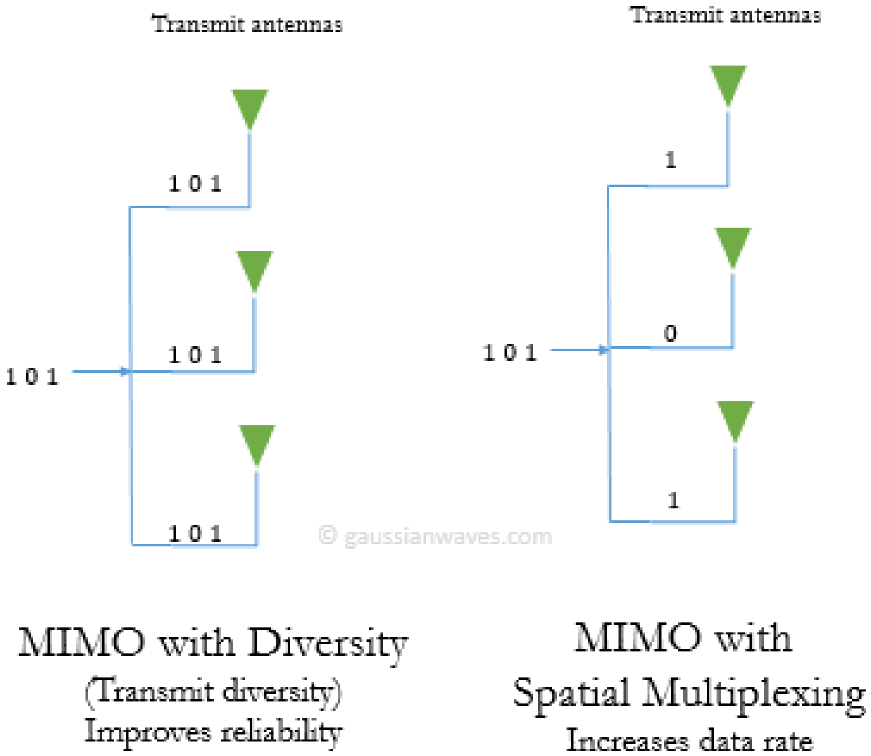


* The frst iPhone appears in 2007-ben, more and more WiFi enabled devices since then, need for higher data rates

Spatial multiplexing (WiFi 4)

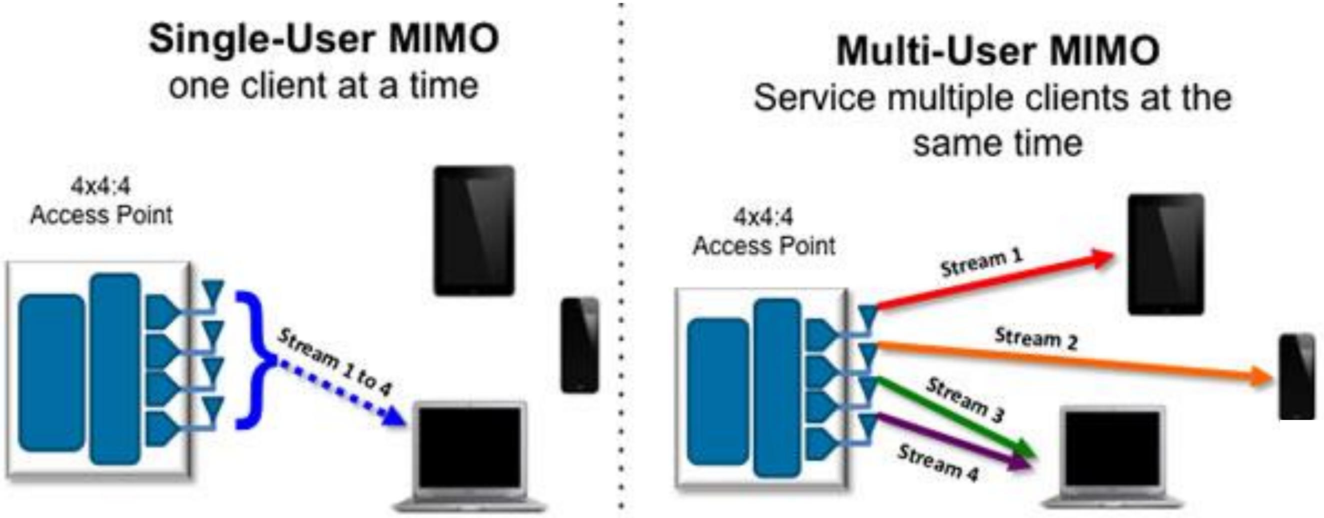
- Data is divided, each antenna sends a different data stream
  - Similarly to OFDM, where different data on each carrier
- Each receiver receives data from each sender, with different quality



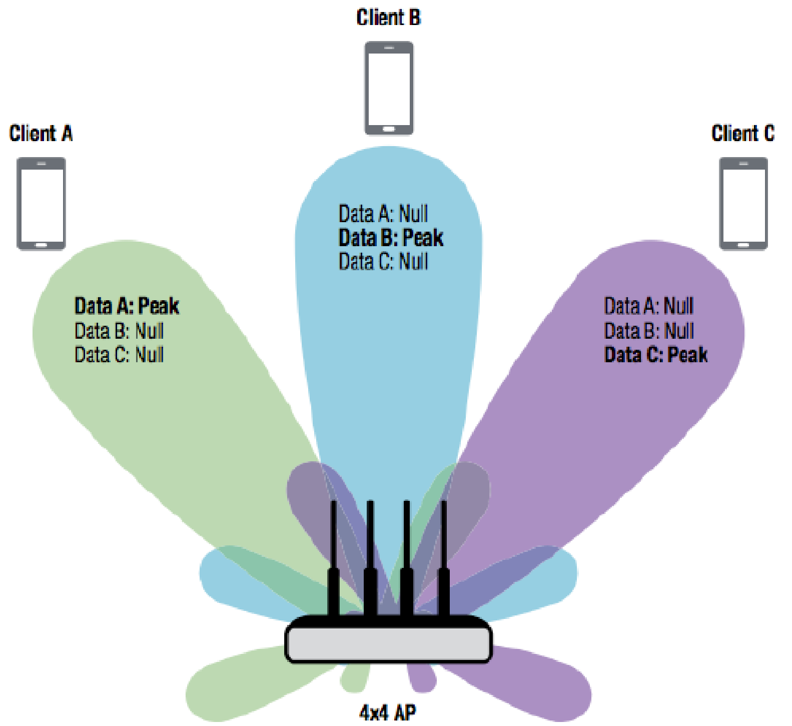


Multi-User MIMO (MU-MIMO) and Beamforming (WiFi 5, 2013)

- **MU-MIMO:** More receivers in parallel, streams divided among them



- **Beamforming:** data streams focused on different receivers
  - Needs accurate positioning of receivers



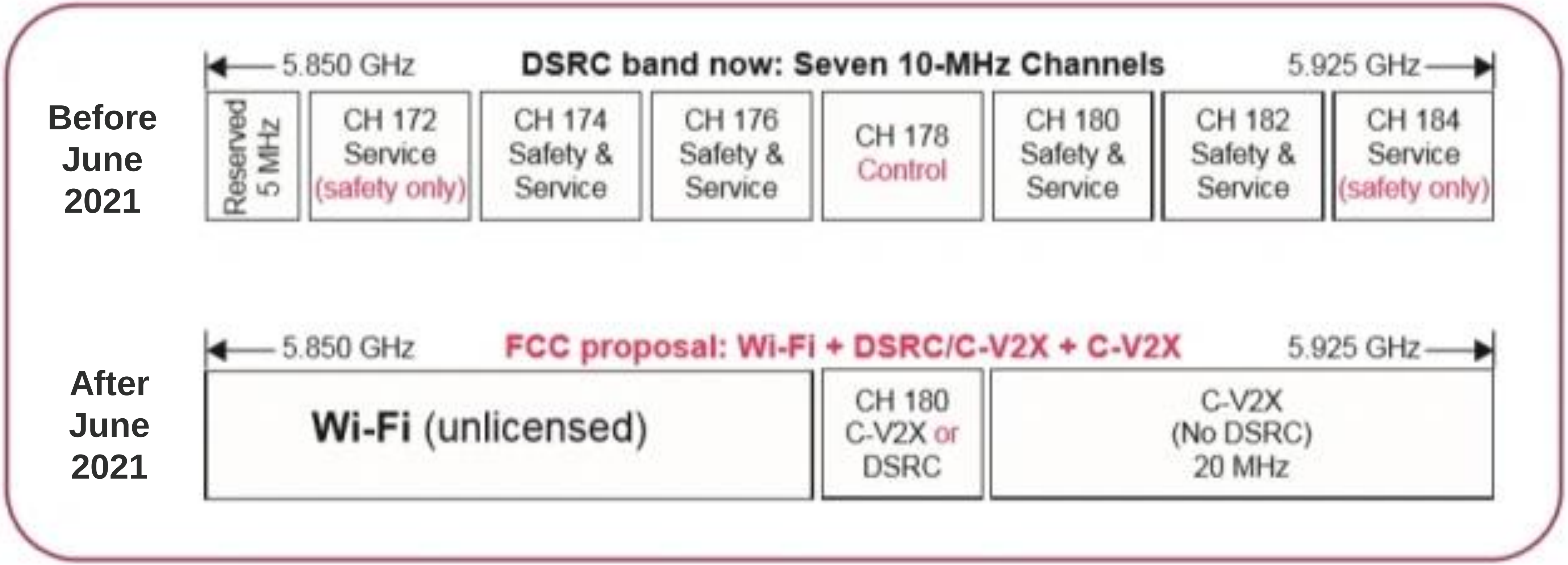
802.11bd (based on WiFi 5)

- 20 MHz channels instead of 10 MHz
- 256-QAM instead of 64-QAM modulation
- Support for MIMO and spatial streaming
- Twice as large transfer speeds as in 802.11p
- Twice as large communication distance as in 802.11p
- Works for larger vehicle speeds as well (max. 500 km/h, instead of max. 200 km/h)

IEEE 802.11bd^DC

- DC – Dual Carrier Modulation
  - On the 20 MHz channel, each signal is transmtted over two subcarriers in parallel
- More reliable transmission
- Based on the IEEE 802.11ax (WiFi 6) standard

New FCC rule (effective of June 2021)

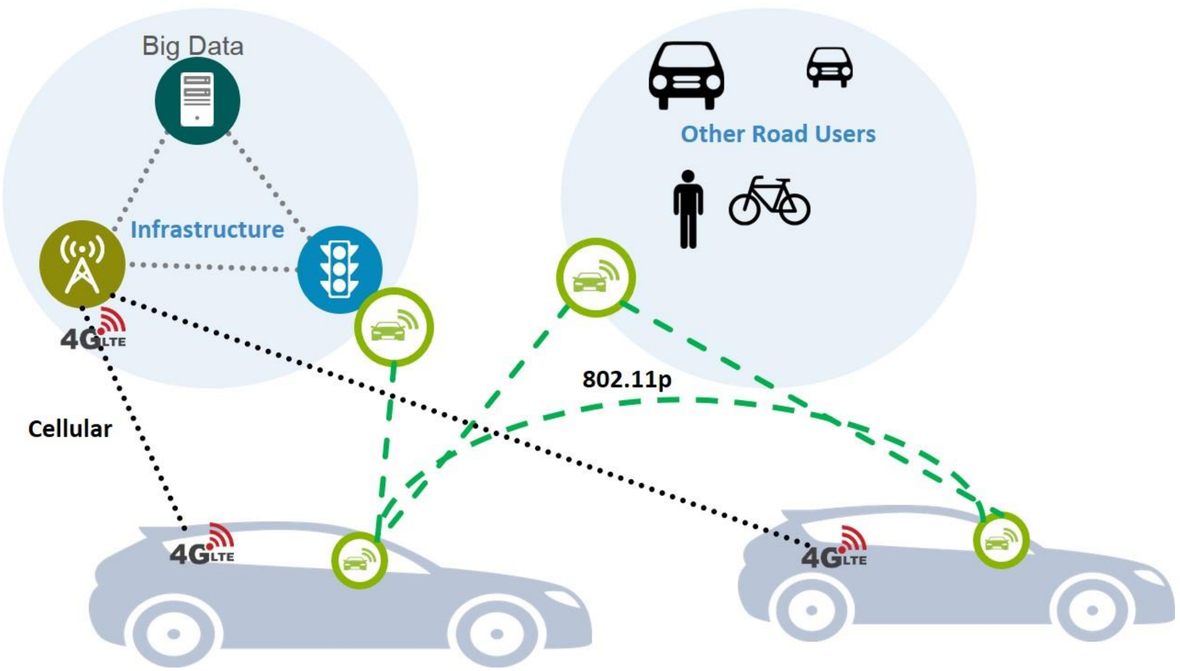


802.11p or C-V2x?

- Requirements for Cooperative ITS systems
  - High relative speeds between transmitters and receivers
  - Extremely low latency in safety-related applications (<50 ms)
  - Tolerate high load generated by periodic transmission of multiple messages, and high vehicle density
  - V2x messages are mostly local in nature, are important for nearby receivers

C-V2x: Cellular Vehicle to Everything

Cellular and IEEE 802.11p for C-ITS



802.11p or C-V2x

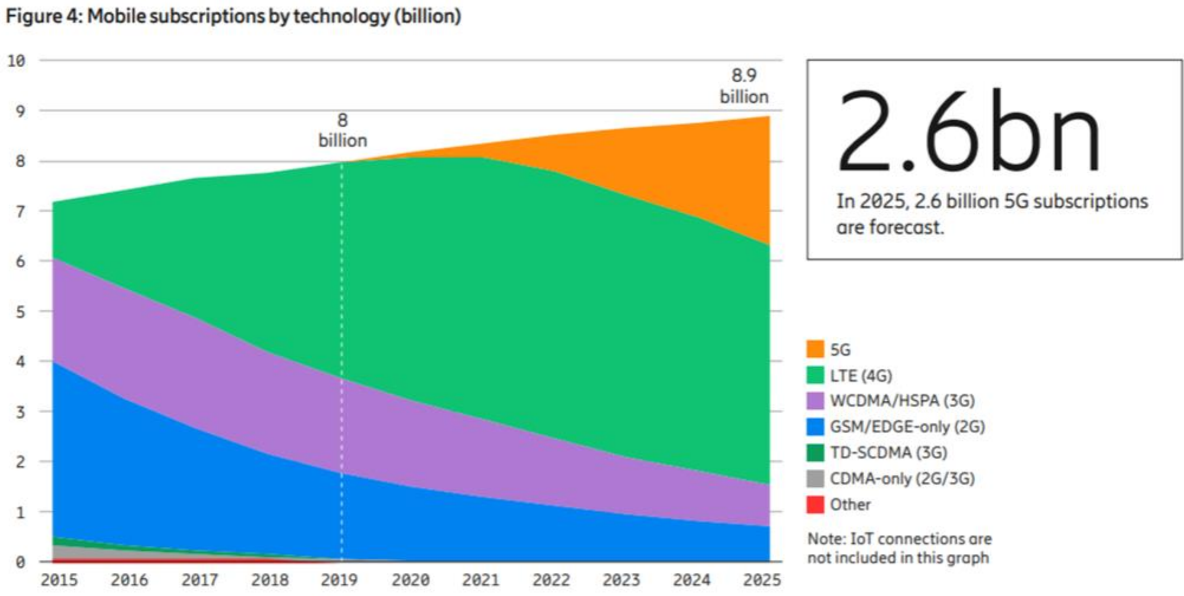
- **802.11p is here today**
  - Standard approved in 2009
  - Several ETSI ITS plug-test events
  - Extensive field trials
    - Safety Pilot, Drive C2X, Score@F, simTD, etc.

- Significant efforts in the last 10 years to validate 802.11p
  - This should be re-done for any other alternative technology

802.11p or C-V2x

- **Some argue that Cellular-V2x is still far out**
- Cellular technology is by far the most successful wireless standard
  - 5.5 billion mobile broadband subscriptions in Q2 2018
- LTE (Rel. 8) dates back to 2009, 5G under deployment in 2022
  - Extensive cellular infrastructure, it takes time to upgrade
  - ~ 5 billion LTE subscribers still in 2025, next to 2.6 billion 5G subscribers
- LTE Rel. 8. can only address basic ITS use cases
  - No support for low latency and high mobility use cases
  - 3GPP V2x study group established in 2015

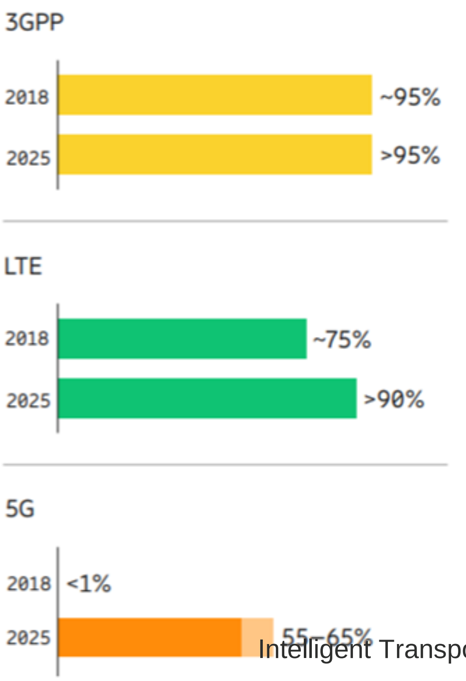
Mobile subscriptions worldwide.
Source: Ericsson Mobility Report, November 2019

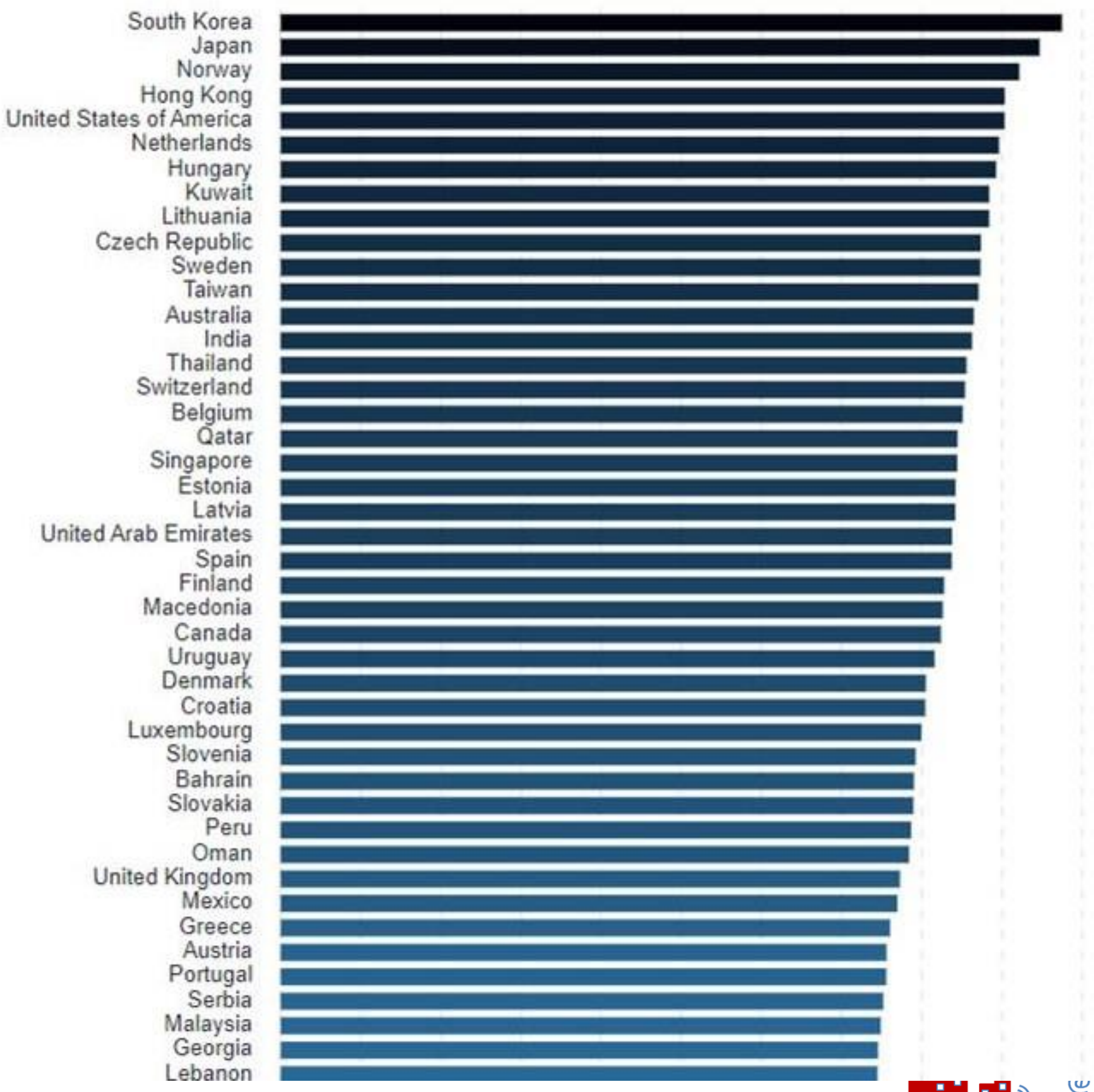


State of LTE in 2018

- LTE coverage still far from 100%
  - Not geographic coverage, but percentage of time when LTE signal available to users
  - Around 65-68% in Germany, France
  - Extensive 3G infrastructure

Figure 15: World population coverage by technology[2]





LTE support for V2x applications

- LTE Release 8 can cover most of the V2I – I2V non-safety use cases

- Problem with very congested scenarios
  - evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-A (Rel. 9)
    - Designed to support static scenarios – crowds in football stadiums
    - Not efficient when a large number of incoming and outgoing vehicles

- Problems with handovers between MNOs (mobile network operators) and cooperation between application service providers

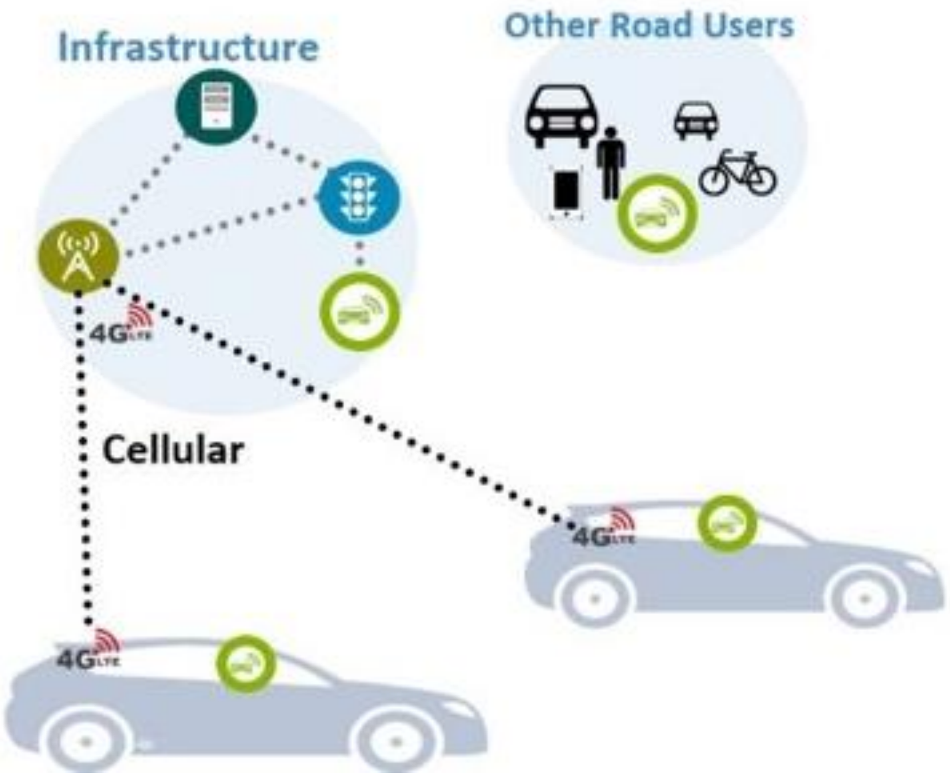
LTE support for V2x applications

- Safety-related use cases represent the real challenge
  - Need complete coverage along the roads (which is not yet the case)
  - Need to handle high bandwidth with very low latency
- Some V2V use-cases require **continuous information exchange** (1 – 20 Hz)
  - **Cooperative Awareness Messages (CAM) - autonomous cars**
  - Too much data for LTE networks to handle
    - **Example: 256 bytes/message, 10 Hz, 2 hours of driving/day = 0.5 Gbyte per month per car**
    - **At the receiver side, assuming 30 cars in the area of interest, roughly 15 Gbytes per month**
    - 1 autonomous car in 2020 – **4 Tbyte per day** **(generated inside the car, not transmitted entirely)**
- MNOs typically bill based on resources used ($ / bit / s), but V2V traffic should be free
  - Alternative business model to be developed to justify investments


THE COMING FLOOD OF DATA IN AUTONOMOUS VEHICLES
SONAR
~10-100 KB
PER SECOND
RADAR
~10-100 KB
PER SECOND
GPS
~50KB
PER SECOND
CAMERAS
~20-40 MB
PER SECOND
LIDAR
~10-70 MB
PER SECOND
AUTONOMOUS VEHICLES
4,000 GB
PER DAY... EACH DAY
intel

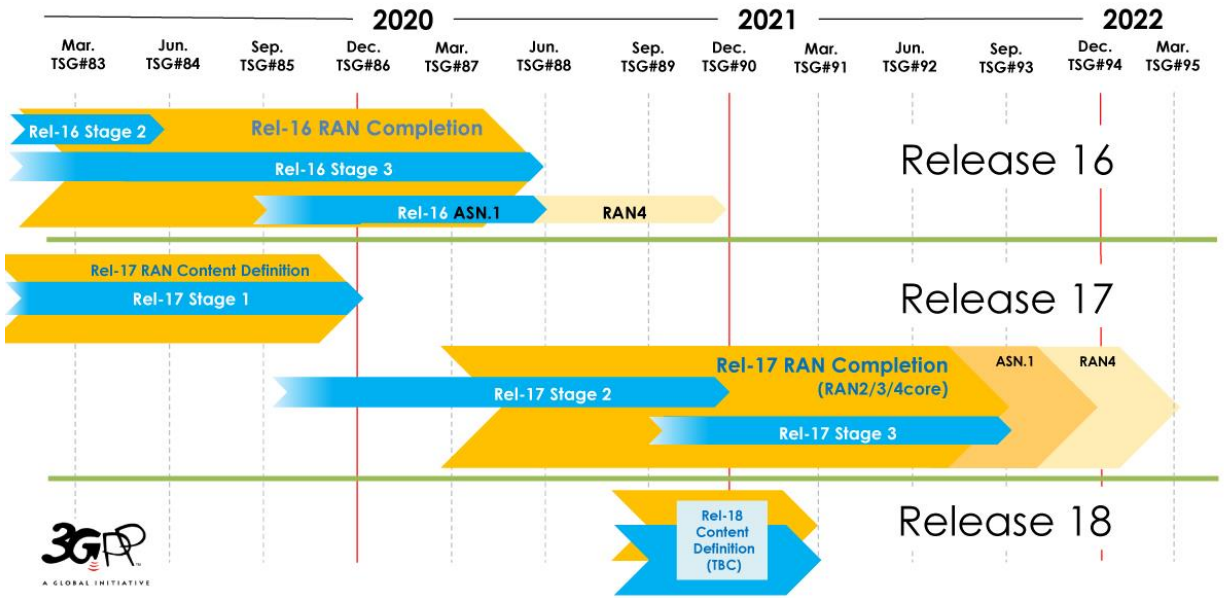
LTE support for V2x applications

- Some V2V use cases do not require high bandwidth, but **very low latency**
  - event-based broadcasting of Decentralized Environmental Notification messages (DENM) – e.g. fast braking
- Could work in the cellular network, but not always
  - Across multiple MNOs, across borders, across cells
- **Another solution: develop direct communication technology, as part of the cellular system**
  - **Device-to-Device** communication, part of Release 12, but not suitable for V2V
    - If two devices want to communicate directly, the network allocates the time / frequency resources
    - The network manages the interference generated by the D2D communication
    - Signalling/control via the eNodeB
    - Direct data sending between the UEs
  - D2D will not work if no continuous network coverage



C-V2x evolution

- LTE-D2D – Release 12 (2012)
- C-V2x Phase I– Release 14 (started in 2014, published in 2016)
  - V2V, V2I, V2N support
- C-V2x Phase II – Release 15 (published in 2018)
  - 5G support (called also 5G-V2x)
- C-V2x Phase III – Release 16 (2020)
  - Enhanced 5G support
  - Also called NR-V2X



Source: 3GPP TSG SA#87e, 17-20 March 2020, e-meeting document SP-200222

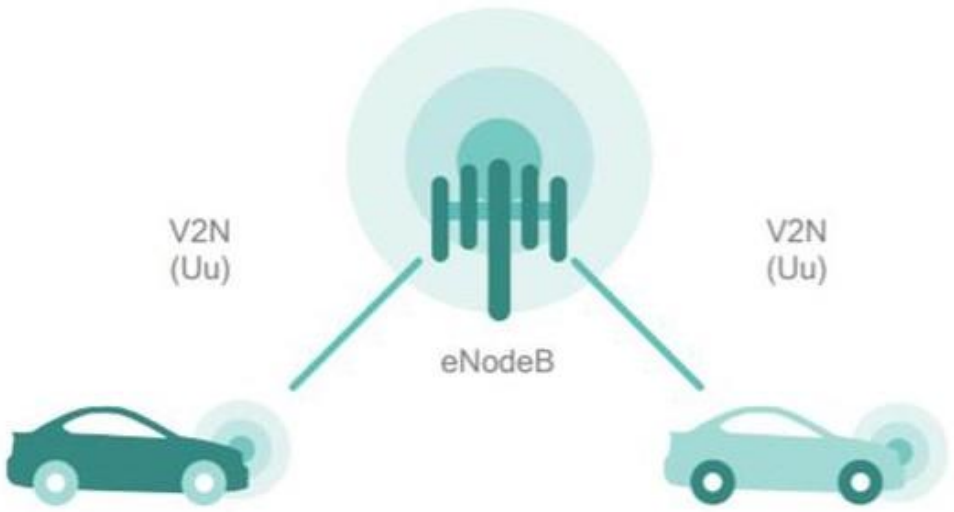
C-V2X defines two complementary transmission modes

Network communications

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

Uu interface

e.g. accident 2 kilometer ahead



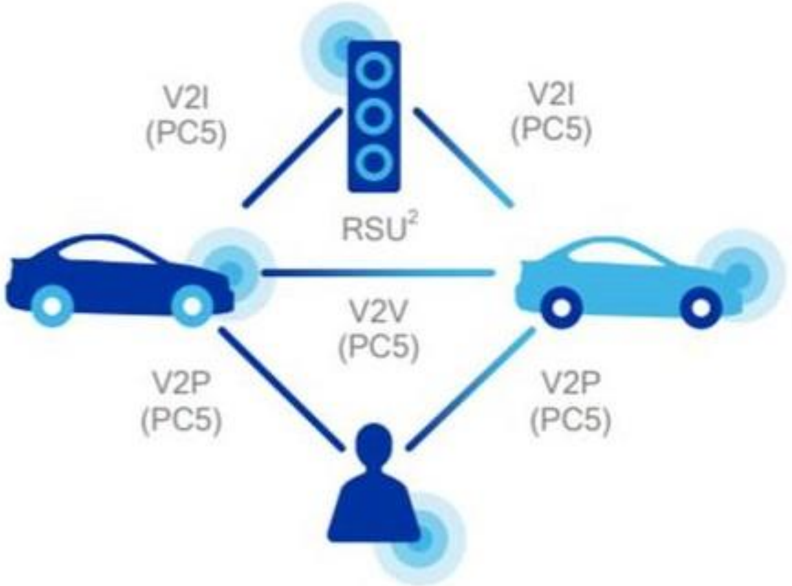
On the traditional cellular spectrum

Direct communications

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

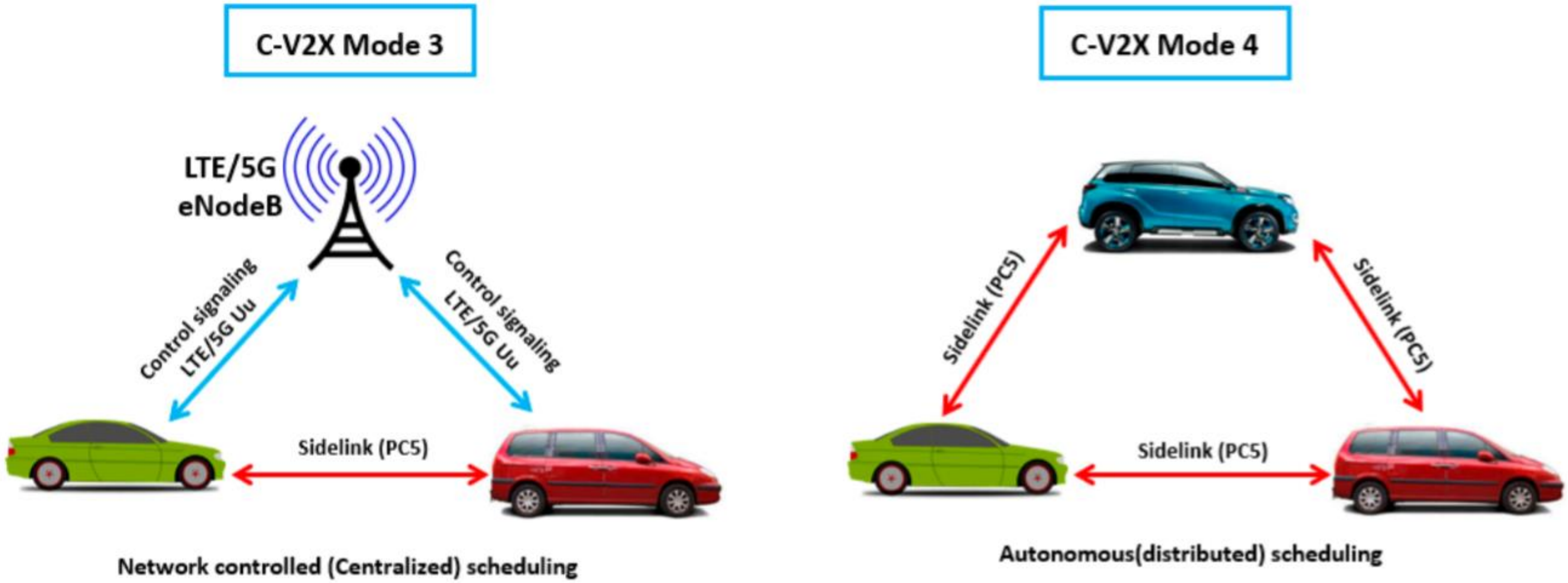
PC5 interface

e.g. location, speed



On 5,9 GHz

C-V2X Sidelink (PC5) Modes in Rel. 14/15

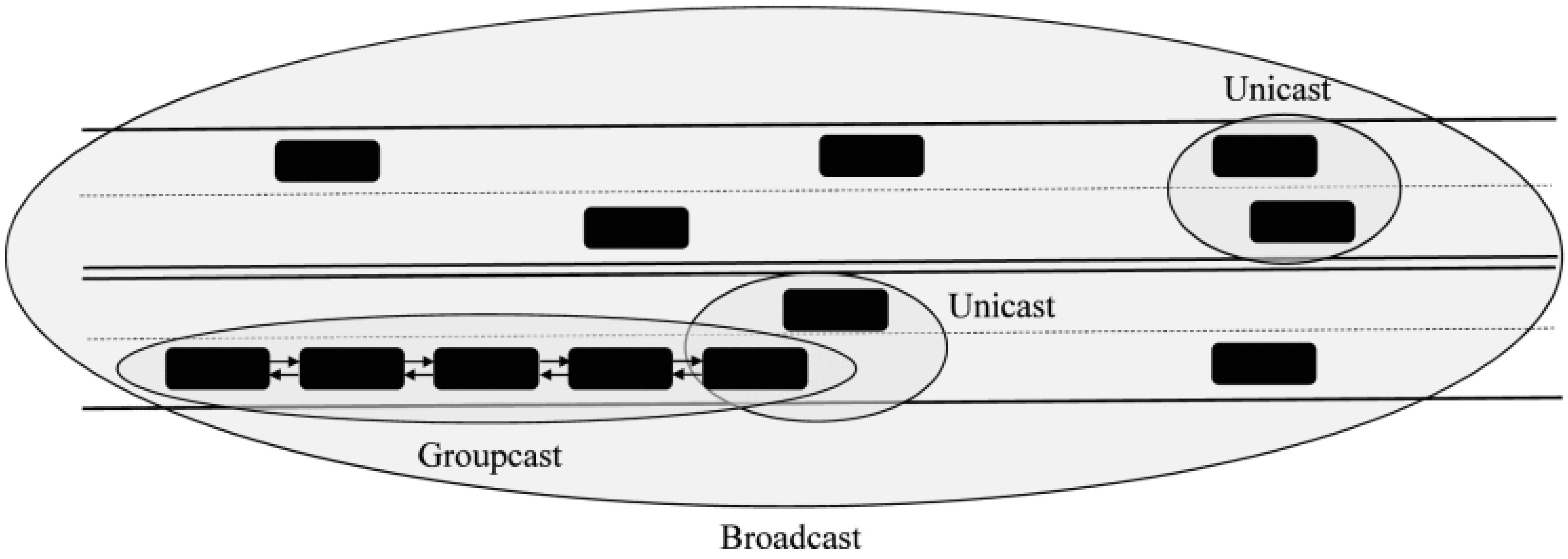


Communication modes

LTE-V2X – only broadcast communication

NR-V2X:

- Unicast – direct communication between two vehicles
- Broadcast – everyone within radio range
- Groupcast – e.g., platooning



NR-V2X frequencies

- NR-Sidelink (Rel. 16) frequencies
  - 5,9 Ghz – together with other technologies (pl. IEEE 802.11p/bd)
  - 2,5 Ghz – only NR-V2X
- Supported channel sizes – 10, 20, 30, 40 MHz
- **Carrier spacing**
  - For LTE-V2X fixed carrier-spacing (15 kHz)
  - For NR-V2X variable carrier spacing (15, 30, 60 kHz)
- **HARQ (Hybrid Automated Repeat Request)**
  - feedback from the receiving vehicle
  - ACK/NACK –based feedback in case of Unicast
  - NACK-only feedback in case of Groupcast

Sidelink optimization in Rel. 17

- **Power saving for Battery-powered UEs**
  - Typicaly for the NR-V2X devices carried by pedestrians, bikers
  - In Rel. 16 „always on” operation
- **Sidleink DRX mode (Discontinous Reception)**
  - Coordinating the sleeping cycles among UEs
- **Improving reliability and latency**
- **Sidelink Relaying**
  - UE-to-Network
  - UE-to-UE
    - In Rel. 16, only support for single-hop
    - Relay discovery, selection, authorization

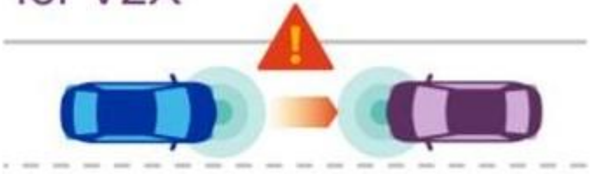
Continuous V2X technology evolution required

And careful spectrum planning to support this evolution

Evolution to 5G,
while maintaining backward compatibility

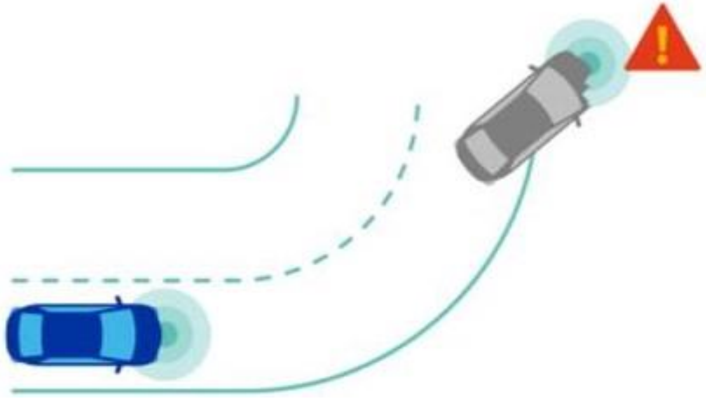
Basic safety
802.11p or C-V2X R14

Established foundation for V2X



Enhanced safety
C-V2X R14/15

Enhanced range and reliability



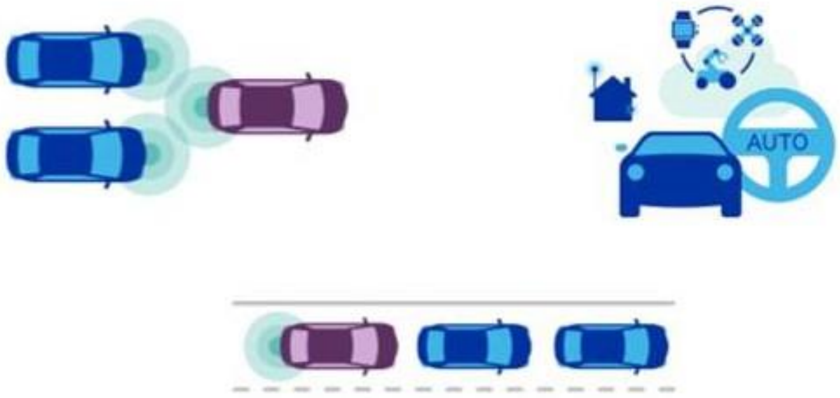
Advanced safety
C-V2X R16 (building upon R14)

Higher throughput

Higher reliability

Wideband ranging and positioning

Lower latency



C-V2X

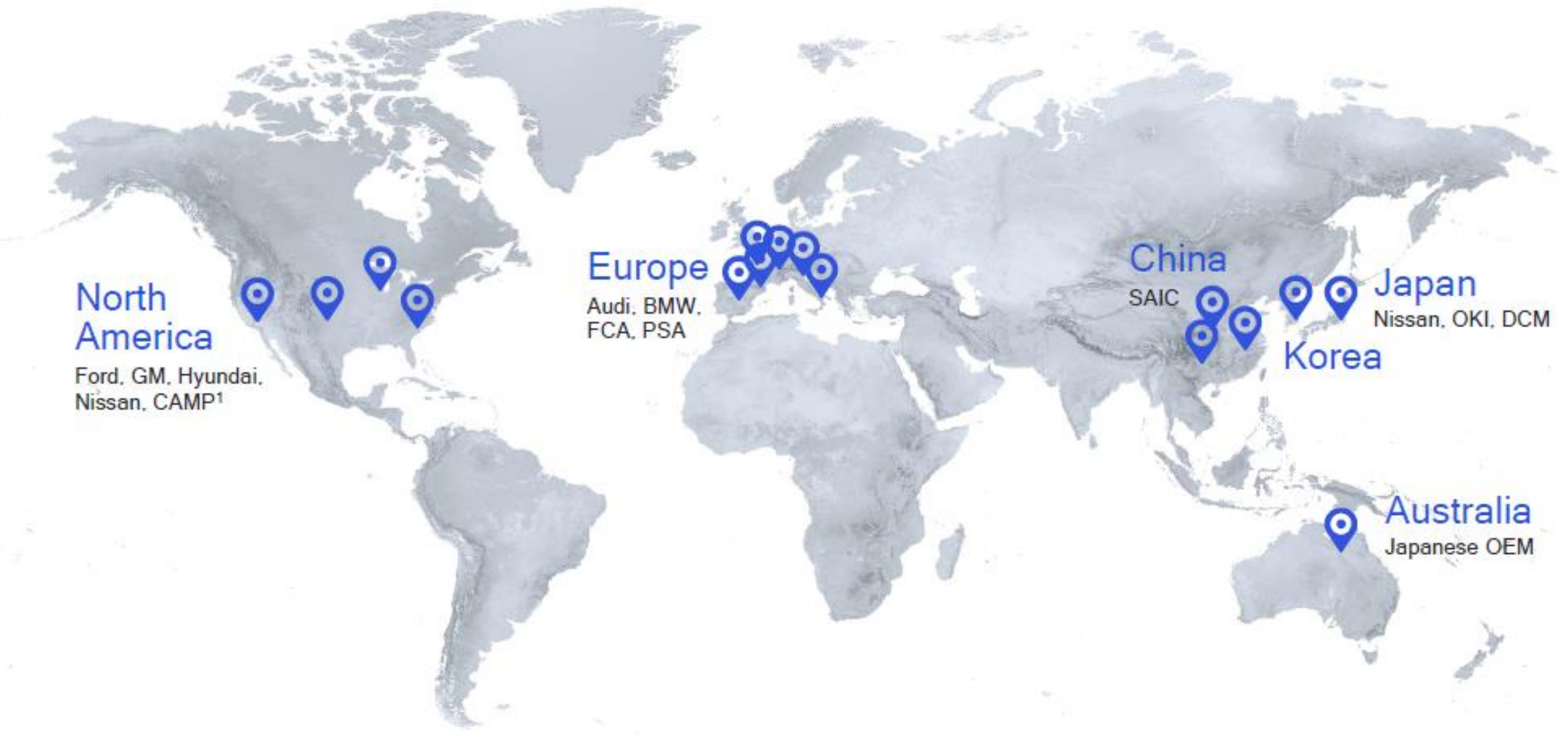
Rel 14/15 C-V2X established basic safety

Rel 16 NR C-V2X saw continued evolution for advanced use cases

- Release 14/15 C-V2X standards completed
- Broad industry support with 5GAA
- Global trials started in 2017; first commercial deployment expected in 2020
- Qualcomm® 9150 C-V2X chipset announced in September, 2017
- Integration of C-V2X into the Qualcomm® Snapdragon™ Automotive 4G and 5G Platforms announced in February, 2019

Qualcomm 9150 C-V2X and Qualcomm Snapdragon Automotive 4G/5G Platforms are products of Qualcomm Technologies, Inc. and/or its subsidiaries.

Driving C-V2X global presence with trials and demos



Gaining traction across numerous regions and industry sectors

From standards completion to independent field testing to initial deployments

Collaborating with key ecosystem players

CAMP	Ford	Quectel	Kapsch
PSA	Lear	SWARCO	Neusoft Reach
BMW	Valeo	Commsignia	Simcom
Daimler	WNC	Genvict	Sasken,
SAIC	CMCC	Nebulalink	Thundersoft
Continental	AT&T	R&S	Telit
Bosch	NTT DoCoMo	Datang	Lacroix
LG	CMRI	Ficosa	And more…
ZTE	McCain	Savari	

5GAA Automotive Association

- 8 of the top 9 global automakers
- Top automotive Tier 1 suppliers
- 9 of the top 10 global telecommunications companies
- Top 3 global smartphone manufacturers
- Top global semiconductor companies
- Top 5 global wireless infrastructure companies
- Top global test and measurement companies and certification entities
- Global representation from Europe, China, US, Japan, Korea, and elsewhere

1. CAMP = Crash Avoidance Metrics Partnership LLC and this project includes the listed OEMs and Qualcomm.

Strong C-V2X momentum globally

Sep. 2016
5GAA founded

Jan. 2017
ConVeX trial in Germany announced

Feb. 2017
Towards 5G trial in France announced

Mar. 2017
Rel-14 C-V2X spec finalized

Sep. 2017
First C-V2X chipset introduced

MDM 9150

Oct. 2017
San Diego Regional C-V2X trial

AT&T
NOKIA
McCain

Apr. 2018
First multi-OEM demo in D.C.

Jun. 2018
1st US deployment in Denver

FICOSA
WNC
kapsch
SAVARI
Panasonic

Jul. 2018
Europe's first multi-OEM demonstration in Paris

Oct. 2018
Multi-OEM performance evaluation of C-V2X

Oct. 2018
C-V2X functional and performance test report published

Nov. 2018
Reaches 100 members

Nov. 2018
China-SAE ITS Stack Compatibility

Jan. 2019
Cooperative driving live interactive demos in Las Vegas

DUCATI

Jan. 2019
Announcing C-V2X implementation in Las Vegas

commsignia
RTC

Feb. 2019
C-V2X integrated with Qualcomm® Snapdragon™ Automotive 4G/5G platforms

Feb. 2019
TELEFÓNICA/ SEAT's live C-V2X/ 5G demo at MWC Barcelona

Mar. 2019
SAIC project complete

Mar. 2019
Cross border demo

conVex

May 2019
C-V2X ecosystem demos

Nov. 2019
Live demos show C-V2X as a market reality

Nov. 2019
CAMP congestion control scenario testing by OEM consortium

Jan. 2020
ETSI European specifications and standards for C-V2X completed

Jan. 2020
C-V2X deployment in Virginia with VaDoT

Feb. 2020
C-V2X devices passed European Radio Equipment Directive (RED)