**HOCHSCHULE
HANNOVER**
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS
–
*Fakultät IV
Wirtschaft und
Informatik*

5G for V2X Communication

Lecture 9: Fahrzeugvernetzung – V2X

Hugues Tchouankem, 30.11.2022

Lecture 9
Previous Lecture

- ► Cellular Network Basics
- ► Device-to-Device Communication
- ► C-V2X Communication
- ► C-V2X Communication Modes
- ► Sensing-based Semi-Persistent Scheduling
- ► C-V2X Decentralized Congestion Control

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Outline

- ► 5G Communication Basics
- ► 5G Communication Usage Scenarios
- ► 5G New Radio (NR)
- ► 5G-V2X Features
- ► 5G-V2X Sidelink Modes
- ► Coexistence of C-V2X and 5G-V2X
- ► V2X Applications supported by 5G-V2X

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Towards the fifth Generation of Cellular Network Technology 5G

1980s	1990s	2000s	2010s	2020s
1G	2G	3G	4G	5G
Analog Voice	**Digital Voice**	**Mobile Broadband**	**Fast Mobile Broadband**	**Enhanced Mobile Broadband**
AMPS	GSM	UMTS	LTE	
Analog voice calls Mobile connectivity	Voice transmission Text messaging (SMS) Basic data services	Voice and data transmission Mobile Internet	High quality streaming	Wireless for industry Internet of Things (IoT) Connectivity fabric

AMPS: Advanced Mobile Phone Service

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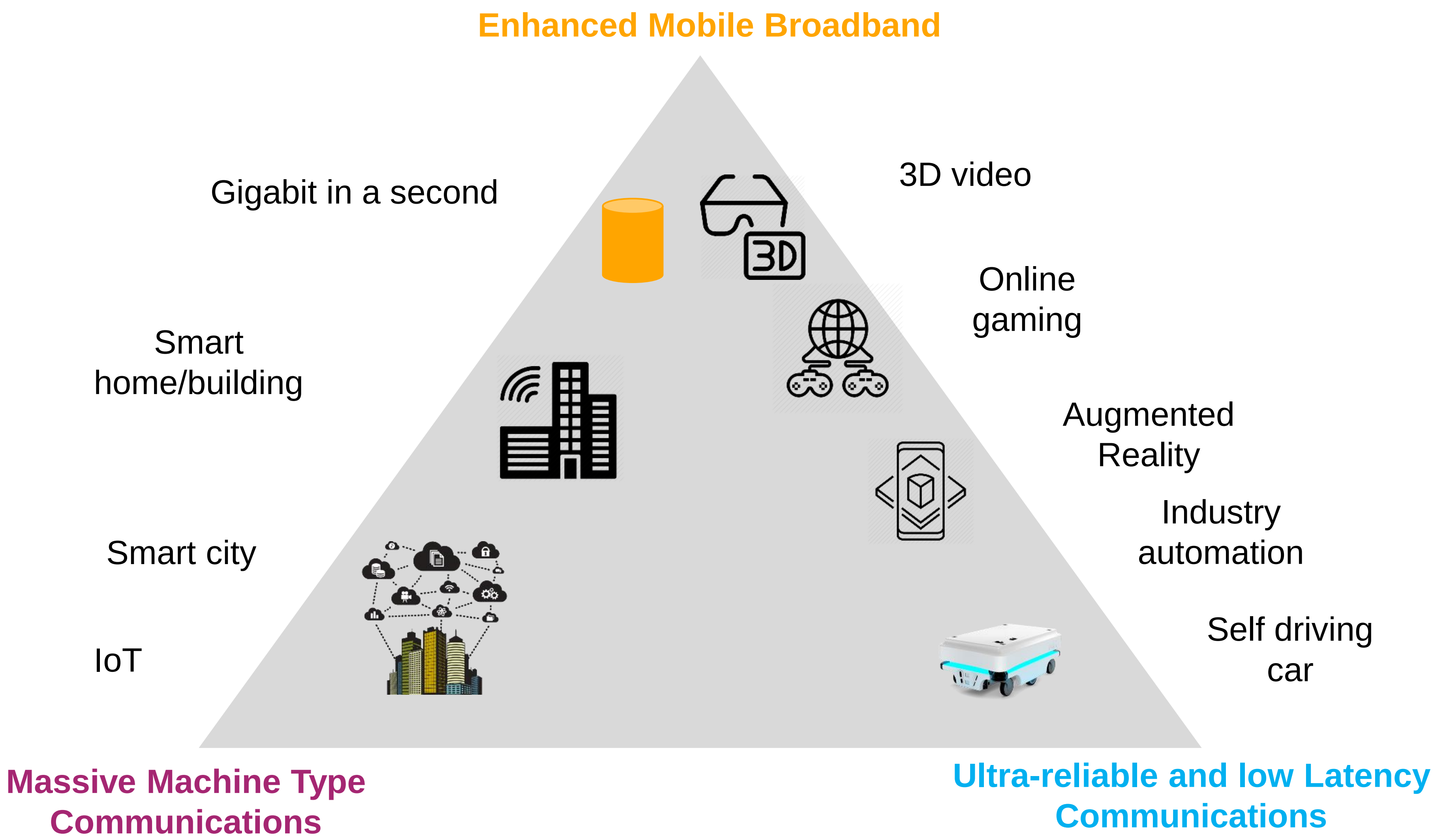
5G Promises



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5G Usage Scenarios - Enhanced Mobile Broadband (eMBB)

- ► Address the **human-centric use cases** for access to **multi-media content** and services
- ► New application areas and requirements for an increasingly **seamless user experience**
  - ► Augmented reality (AR)
  - ► 360° video streaming
  - ► Truly immersive Virtual Reality (VR)

- ► **Requirements:**
  - ► **Higher capacity**: broadband access must be available in **densely populated** areas, both indoors and outdoors, like city centres, office buildings or public venues like **stadiums** or conference **centres**
  - ► **Enhanced connectivity**: broadband access must be **available everywhere** to provide a consistent user experience
  - ► **Higher user mobility:** mobile broadband services in **moving vehicles** including cars, buses, trains and planes

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5G Usage Scenarios - Ultra-reliable and low latency communications (uRLLC)

- uRLLC Address the **stringent requirements** for capabilities such as throughput, latency and availability
- **New application areas**
  - Autonomous driving
  - Wireless control of industrial manufacturing or production processes
  - Remote medical surgery / Remote driving
- **Two challenging requirements**
  - **Ultra-low latency** < 1 millisecond
  - **Ultra-high reliability** < 10^{-5} packet drop rate
  - **Trade-off latency and reliability** → try to improve the reliability required the use of more resources for **signaling**, **re-transmission** and **redundancy** resulting in an **increase** of the **latency**

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5G Usage Scenarios-Massive Machine Type Communications (mMTC)

- mMTC is characterized by **a very large number** of connected devices typically transmitting a relatively **low volume** of **non-delay-sensitive** data
  - Provide wireless connectivity to **tens of billions** of often **low-complexity low-power** machine-type devices
  - Devices are required to have a **very long battery life**
- **New application areas**
  - Smart cities (smart networked household)
  - Networked internet of things (smart agriculture)
- **Requirements**
  - **Scalable** and **efficient connectivity** for a massive number of devices sending very short packets
  - **Low latency** and **High reliability**
  - **Availability**

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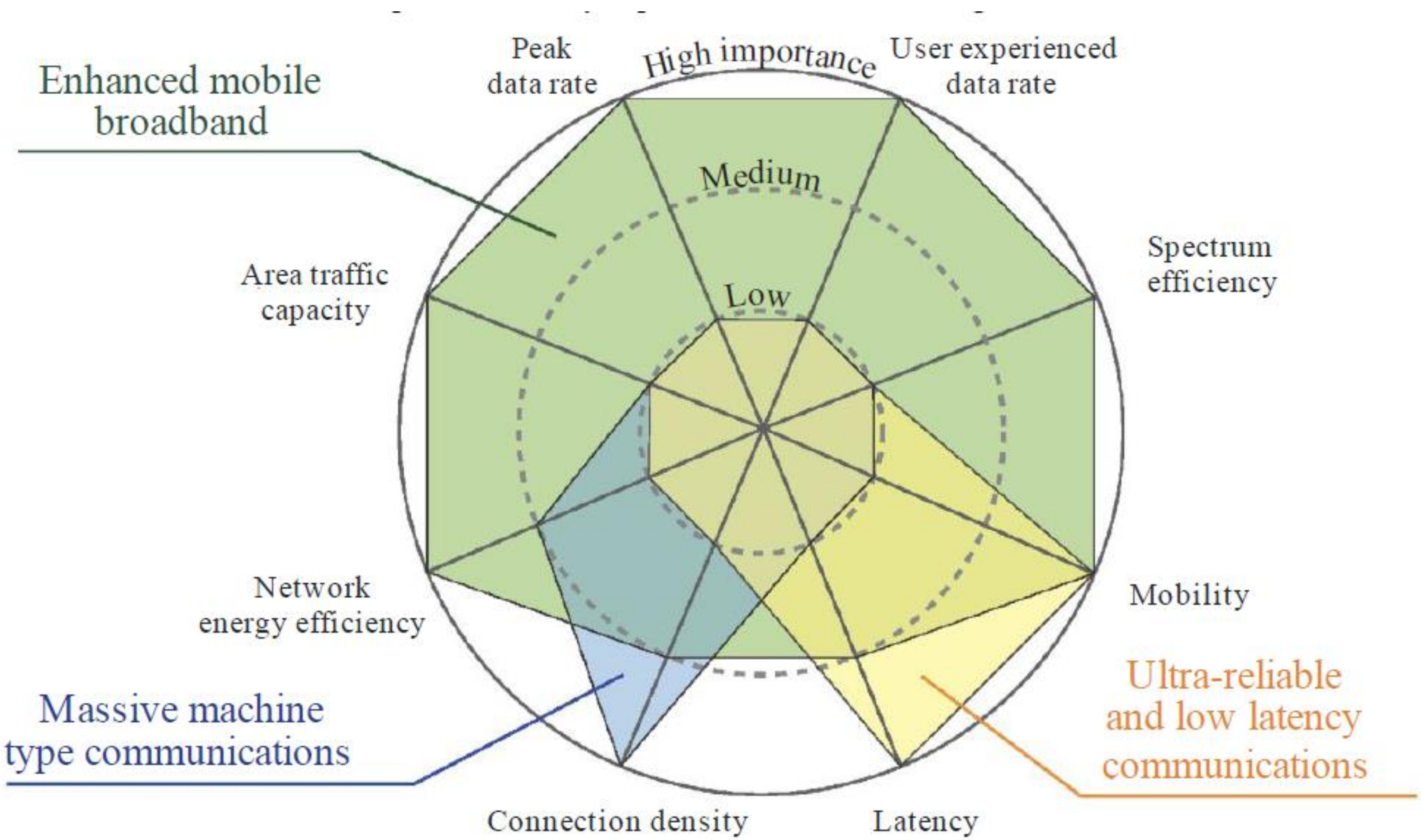
5G Usage Scenarios



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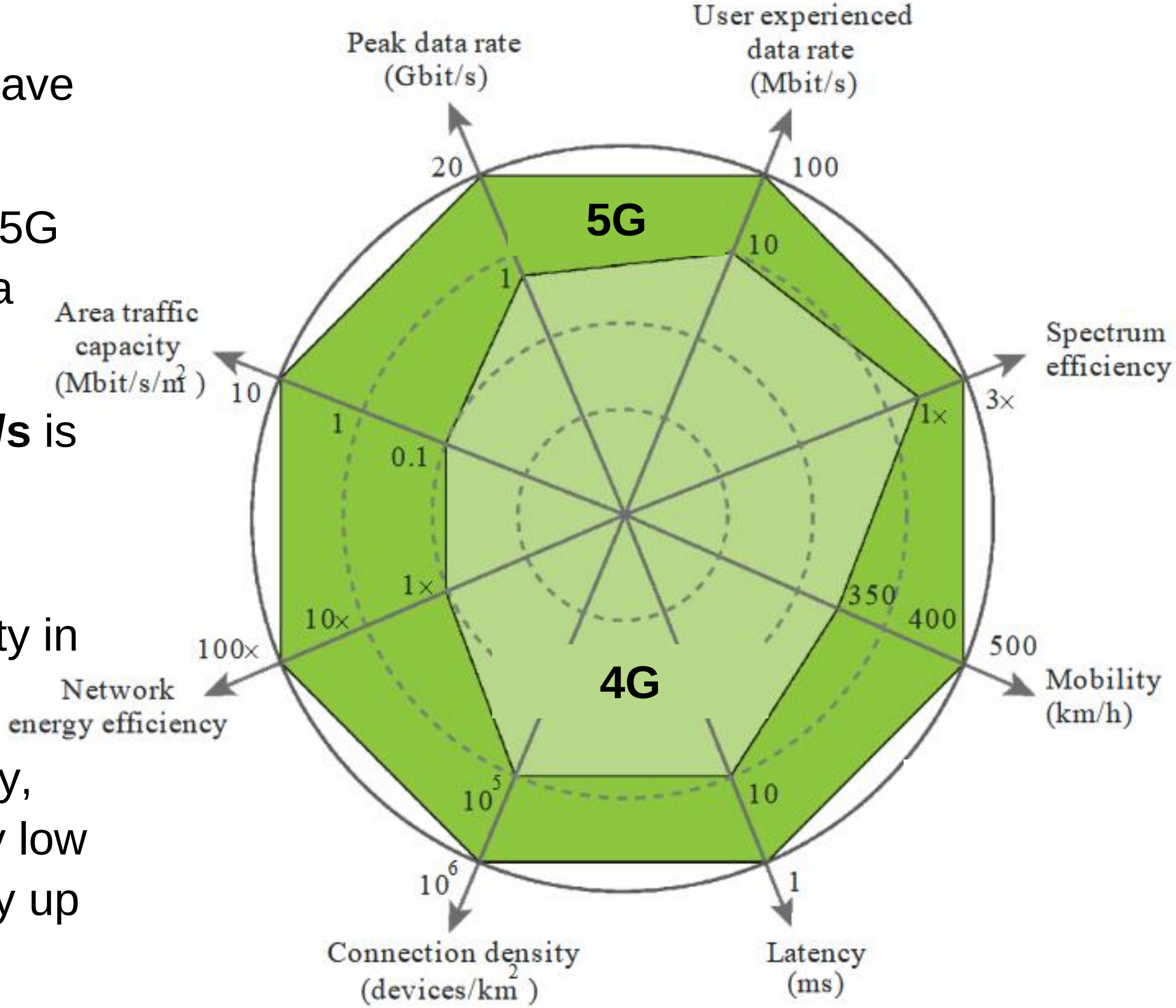
5G Performance Targets

- ► Targets for research and investigation have to be further developed
- ► Under certain conditions and scenarios 5G would support up to **20 Gbit/s** peak data rate
- ► User experienced data rate of **100 Mbit/s** is expected to be enabled for wide area coverage cases
- ► Support **10Mbit/s/m²** area traffic capacity in hot spots (stadium, etc.)
- ► Able to provide **1 ms** over-the-air latency, capable of supporting services with very low latency requirements under high mobility up to **500 km/h**



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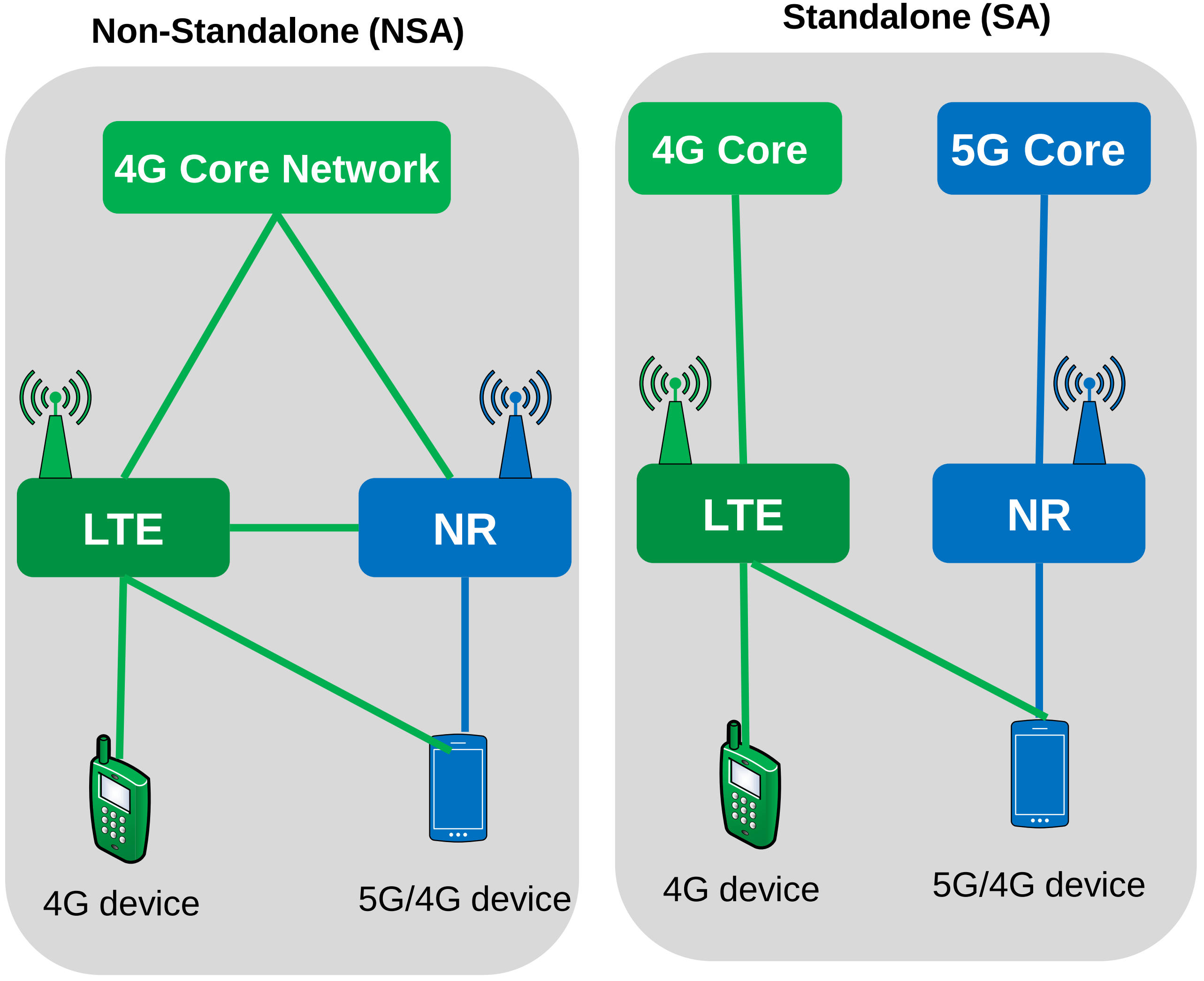
5G Deployment Scenarios

- **5G Non-Standalone (NSA)**
  - 5G will be aided by existing 4G infrastructure
- **5G Standalone (SA)**
  - Easier and better efficiency reducing the cost of the devices

- First roll-out of 5G networks and devices will be brought under Non-Standalone (NSA)



NR: New Radio

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5G-New Radio (NR)

- **5G NR** includes major advances over LTE
- It encompasses agile **frame structure**, **high frequencies**, new **multiple access techniques** for
  - **High capacity**
  - **Massive connectivity**
  - **Ultra-low latency**
  - **High reliability of autonomous driving use cases**

- 5G NR supports **adaptive** bandwidth
  - Devices move to a **low-bandwidth**, **low-power** configuration when appropriate, and gearing up to **higher bandwidths** only when necessary
  - Very **low average power devices** that can still deliver **high performance** → IoT networks

Source: Ericsson

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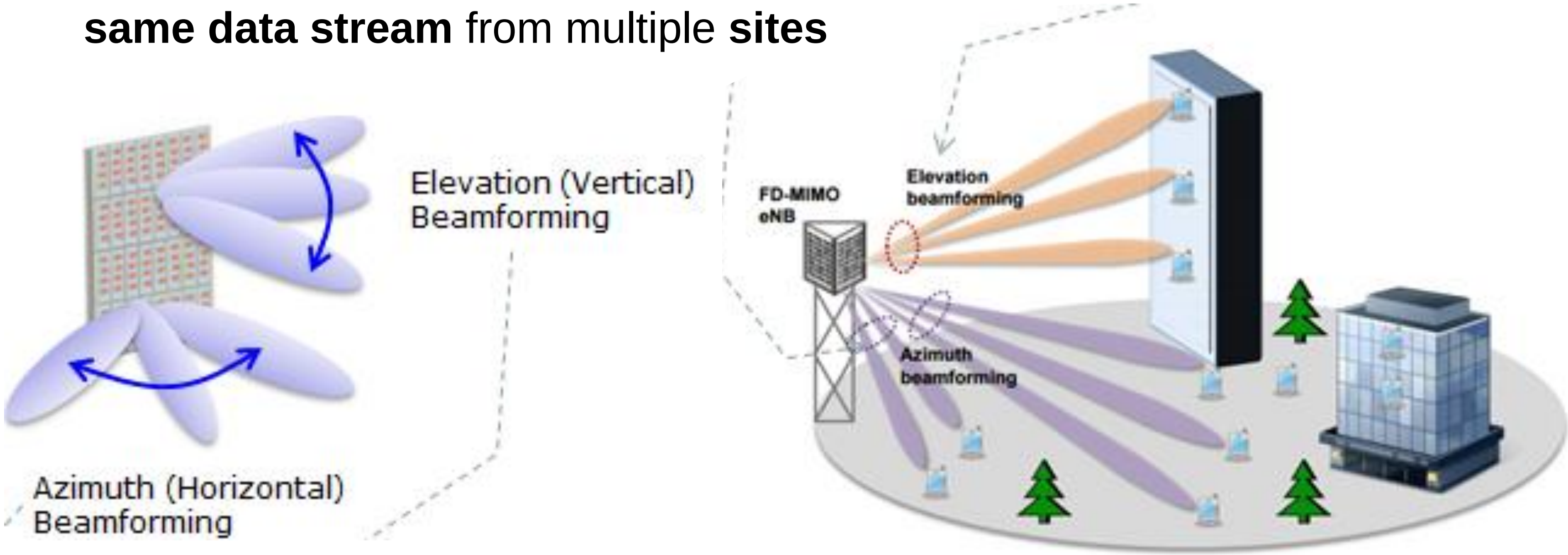
5G-New Radio (NR) - Beamforming

- Manipulation of the **signals** fed to and received from complex antennas to **create beams** in space that **focus power** in a particular **direction**
- Beamforming will mostly be used at high bands to **increase range** by energy focus
- Beamforming will be used at the **mid** and **low bands** below **6GHz** to **increase bandwidth** for multiple devices in the same area
  - Using MIMO (Multiple input multiple output) where a user can receive **different parts** of the **same data stream** from multiple **sites**



Source: Sharetechnote.com

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5G-NR - Millimeter Wave (mmWave)

- ► MmWave refers to the spectrum between **30 and 300 GHz**
  - ► Licensed band: **28, 37** and **39 GHz**
  - ► Unlicensed spectra: **64 to 71 GHz**
- ► **Large** number of **antennas** at the **transmitter** and the **receiver** to form sharp transmit and receive beams
  - ► **Small wavelengths** of mmWave frequencies → **Ease** the deployment of a large number of antennas in a **small form factor**
- ► Enable a **large bandwidth** and **high throughput** for
  - ► V2V communications between **very close vehicles**
    - ► to support for e.g. cooperative sensing in a high-density platoon
  - ► V2I communications for **bulk data transfer**
    - ► for e.g. object detection and recognition, real-time high-definition maps to/from an RSU
- ► Available to consumers in the form of IEEE 802.11ad

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5G-NR - Millimeter Wave (mmWave)

- **Challenges for V2X environments:**
  - Overhead for the **beam training** under high mobility
    - Once beams **are properly aligned**, standard communication protocols, i.e., effective channel estimation and data transmission, can be performed using sufficient link margin
  - **Blockage effect** by e.g., pedestrian bodies

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Path towards 5G-V2X

D2D

- LTE Release 12/13
- Device-to-device communication
- Foundation for direct V2X communication over cellular

C-V2X

- C-V2X 14/15
- Enhance communication performance
    - Low latency
    - High reliability for V2X safety applications
    - Extended communication range

5G for V2X

- C-V2X 16
- Ultra-high throughput
- Ultra-low latency
- Ultra-high reliability
- Foundation for autonomous driving

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Evolution of C-V2X to 5G-NR V2X

- Design objective of *5G-NR V2X* is to **supplement** C-V2X in supporting those **use cases** that **cannot** be supported by **C-V2X**
  - Built atop of 5G NR
- C-V2X and 5G-V2X have to **coexist** in the same geographical region, where **newer vehicles** will have both C-V2X and NR V2X capabilities
- Designed to support V2X applications that have **varying** degrees of **latency**, **reliability** and **throughput** requirements
  - Some **basic use cases** require the transmission of **periodic traffic**
  - Large number of 5G-V2X **use cases** are based on reliable delivery of **aperiodic messages**

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Objectives of 5G-V2X

- ► **Enhanced sidelink design:** Re-design sidelink procedures in order to support advanced V2X applications
- ► **Uu interface enhancements:** Identify enhancements to the NR Uu interface to support advanced V2X applications
- ► **Uu interface based sidelink allocation/configuration**: Identify enhancements for configuration/allocation of sidelink resources using the NR Uu interface
- ► **RAT/Interface selection:** Study mechanisms to identify the best interface (among C-V2X sidelink, 5G sidelink, LTE Uu) for given V2X message transmission
- ► **QoS Management:** Study solutions that meet the QoS requirements of different radio interfaces
- ► **Coexistence:** Feasibility study and technical solutions for the coexistence of C-V2X and NR V2X within a single device, also referred to as in-device coexistence

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5G-V2X Sidelink Feedback Channel

- ► Blind re-transmission is used to **increase** the **success probability** of transmitting a message with low delay penalty
  - ► A node just **proactively retransmits** for a predetermined **number of attempts** rather than stop and wait for a **feedback upon** each transmission
- ► Such **blind re-transmissions** are resource **inefficient** if the initial transmission is successful

- ► **New features:**
  - ► Channel state of the destination can be leveraged to **adapt transmission parameters** → Source UE should have access to the channel state information of its receiving nodes
  - ► New feedback channel **Physical Sidelink Feedback Channel (PSFCH)** is introduced to enable **feedback-based re-transmissions** and **channel state information acquisition**

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5G-V2X Slot, Mini-Slot and Multi-Slot Scheduling

- In LTE and C-V2X, the transmission time is **tightly coupled** to the **sub-frame** duration
  - All UEs always transmit for a duration of **1 sub-frame (1 msec)**
  - In situations where a UE has **only a small amount of data** to send, allocating the entire slot for its transmission is **resource inefficient**
  - Whenever a packet is ready to be transmitted, the UE **has to wait until** the beginning of the **next slot** to **begin transmitting**

- **New Features:**
  - **Mini-slot** scheduling is used for **latency-critical** transmissions
  - **Slot-aggregation** - combining two or more slots to form a **multi-slot** - could be used to cater to use-cases that require exchange of **large-sized packets**

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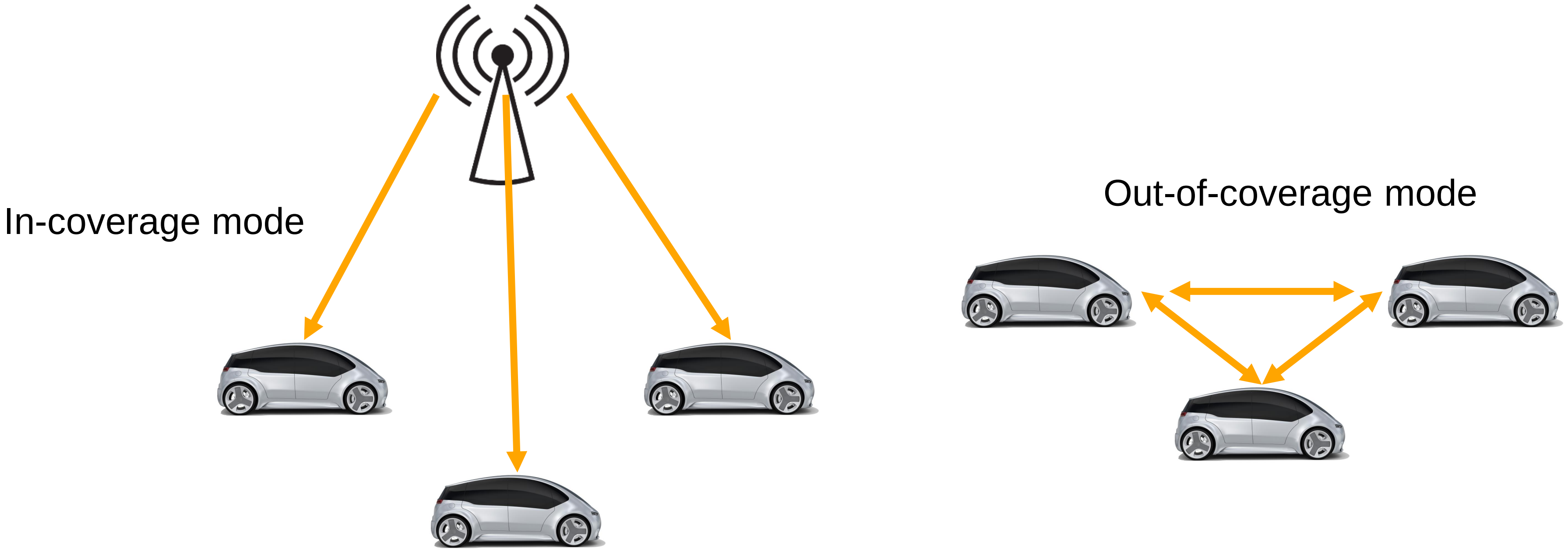
5G-V2X Sidelink Modes

- ► 5G-NR V2X has defined two sidelink modes:
  - ► Sidelink mode 1: Mechanisms that allow **direct** vehicular **communications within** gNodeB **coverage**
  - ► Sidelink mode 2: Support **direct** vehicular **communications** in the **out-of-coverage scenario**



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5G-V2X Sub-Modes of Sidelink Mode 2

- New introduced sub-modes of sidelink mode 2:
  - **Mode 2 (a):** Each UE **autonomously** selects its resources
    - This mode is similar to C-V2X sidelink **mode 4**
  - **Mode 2 (b):** UEs **assist** other UEs in performing **resource selection**
    - Receiver UE, which can potentially **notify** the **transmitting** UE of its **preferred resources** using the PSFCH
  - **Mode 2 (c):** UEs use **pre-configured sidelink grants** to transmit their messages
    - This sub-mode will be facilitated through the design of two-dimensional time-frequency patterns
  - **Mode 2 (d):** UEs select resources for other UEs

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5G-V2X Sidelink Mode 2(a)

- Transmitting UE must select its resources in an **autonomous** fashion
- C-V2X sidelink mode 4 **resource reservation algorithm** leverages the periodicity and **fixed-size** assumption of basic safety **messages**

- **Enhancements** to the C-V2X sidelink mode 4 algorithm:
  - Flexible **duration of the sensing window** based on vehicular mobility
  - Elimination of **RSSI averaging procedure** might improved the performance of **long-term sensing**
- **Long-term** and **short-term** sensing can be configured so that UEs perform sensing and resource exclusion over the sensing window and select a transmission resource within the selection window
  - However, before transmitting, the UE must perform **short-term sensing** to detect the presence of **other signals** on its **selected resource**

    → Using e.g., **Listen Before Talk** protocol

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5G-V2X Sidelink Mode 2(b)

- UE performs **resource allocation** for a group of **UEs** in its vicinity
  - UE performing **resource allocation** is referred as **scheduling UE** (**S-UE**)
- Useful especially in **platooning applications** where vehicles move along the **same direction** with **small** relative **velocities**
- This mode can significantly **reduce the number of collisions** between group member as the S-UE can reserve the resources of UEs within its group

- **How to select the S-UE?**
  - **Geo-location based selection of S-UE:** Beneficial in platooning applications, where the vehicle **at the center of the platoon** is more likely to have an accurate estimate of radio environments of all vehicles in the platoon
  - **Pre-configuration based S-UE selection**: Vehicles with **additional hardware/processing capabilities** can take on the responsibility of resource allocation for surrounding vehicles

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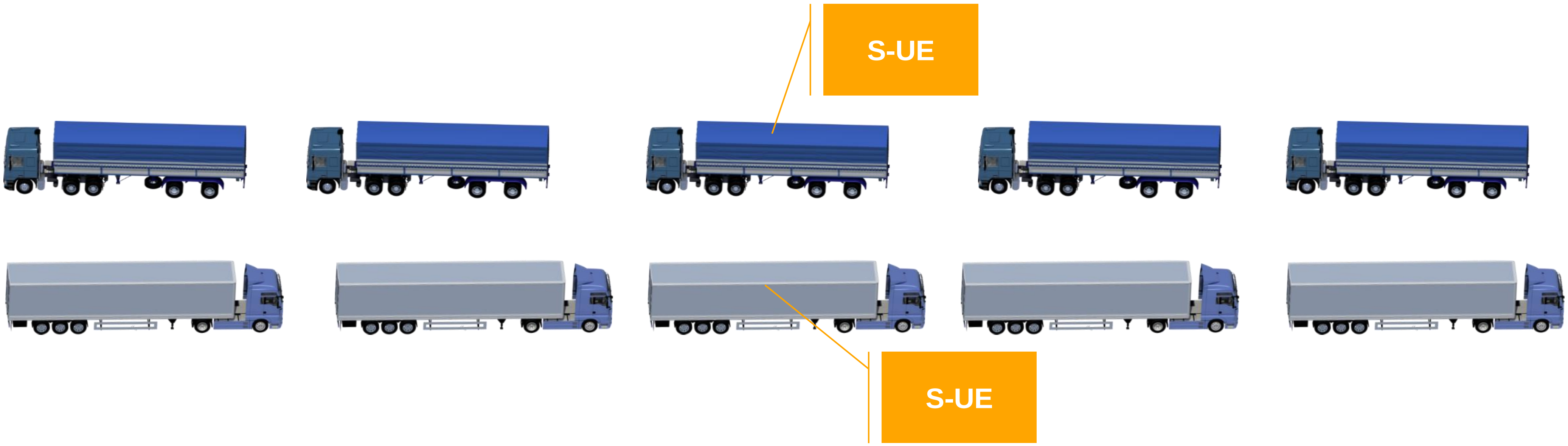
5G-V2X Sidelink Mode 2(b) - Challenges

- **Coexistence** of S-UE and other UEs using **mode 2 (a)**
- **Interference mitigation** between neighboring **UEs** that are assigned resources by different **S-UEs**
  - Platoons catch-up



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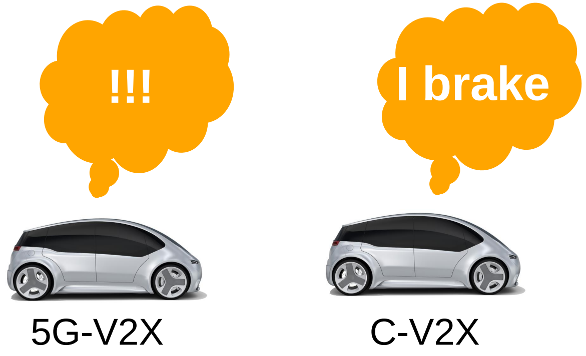
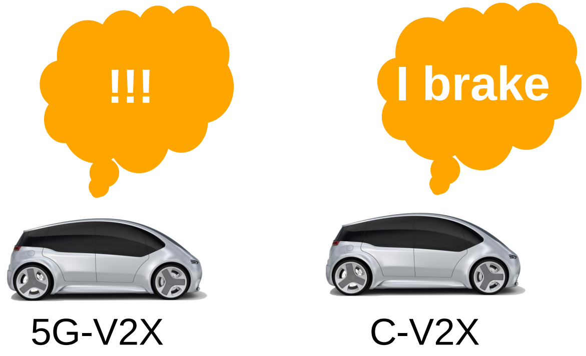
Coexistence of C-V2X and 5G-V2X (1/2)



- C-V2X device operating at **15 kHz** sub-carrier spacing, cannot decode messages transmitted using the **30** or **60 kHz** spacing
- Newer vehicles have to be equipped with modules of **both technologies C-V2X** and **5G-V2X**
- Design of effective **coexistence mechanisms** is required in scenarios where C-V2X and 5G-V2X operate in **different channels**
  - **Frequency division multiplexing (FDM)**
    - (+) Transmissions can overlap in time → no need for tight time synchronization between the C-V2X and 5G-V2X modules
    - (-) Leakage due to out-of-band emissions from one radio terminal will impair the reception
      - Adjustment of the transmit power across the two technologies based on packet priorities



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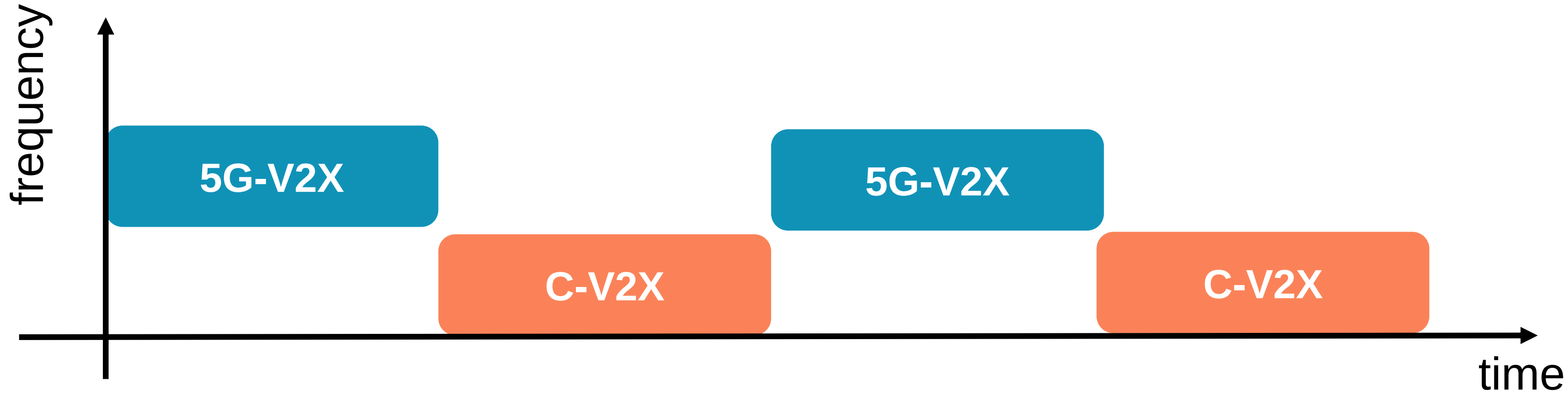
Coexistence of C-V2X and 5G-V2X (2/2)

- **Time division multiplexing (TDM)**
  - Transmissions on the two technologies occur in **different channels** and at **different time** instants
  - Maximum permissible transmission power can be used by both technologies as **only one interface** transmits at **any given time**
  - **(+)** No leakage across channels
  - **(-)** Increased **delays** as for latency critical use-cases one interface may **be off**
  - **(-)** severe restrictions on **time synchronization** between both technologies



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Spectrum Management Issues (1/3)

- **Coexistence between C-V2X and ITS-G5/DSRC**
  - **C-V2X** and **ITS-G5/DSRC** are not compatible with each other
    - Vehicles using a WiFi-based technology (ITS-G5/DSRC) will be **unable** to communicate with those using 5G-V2X/C-V2X
  - **Potential Solution:** Within a given geographical region, **regulatory agencies** must permit only one **V2X technology** (either DSRC or C-V2X) to operate in a vehicle

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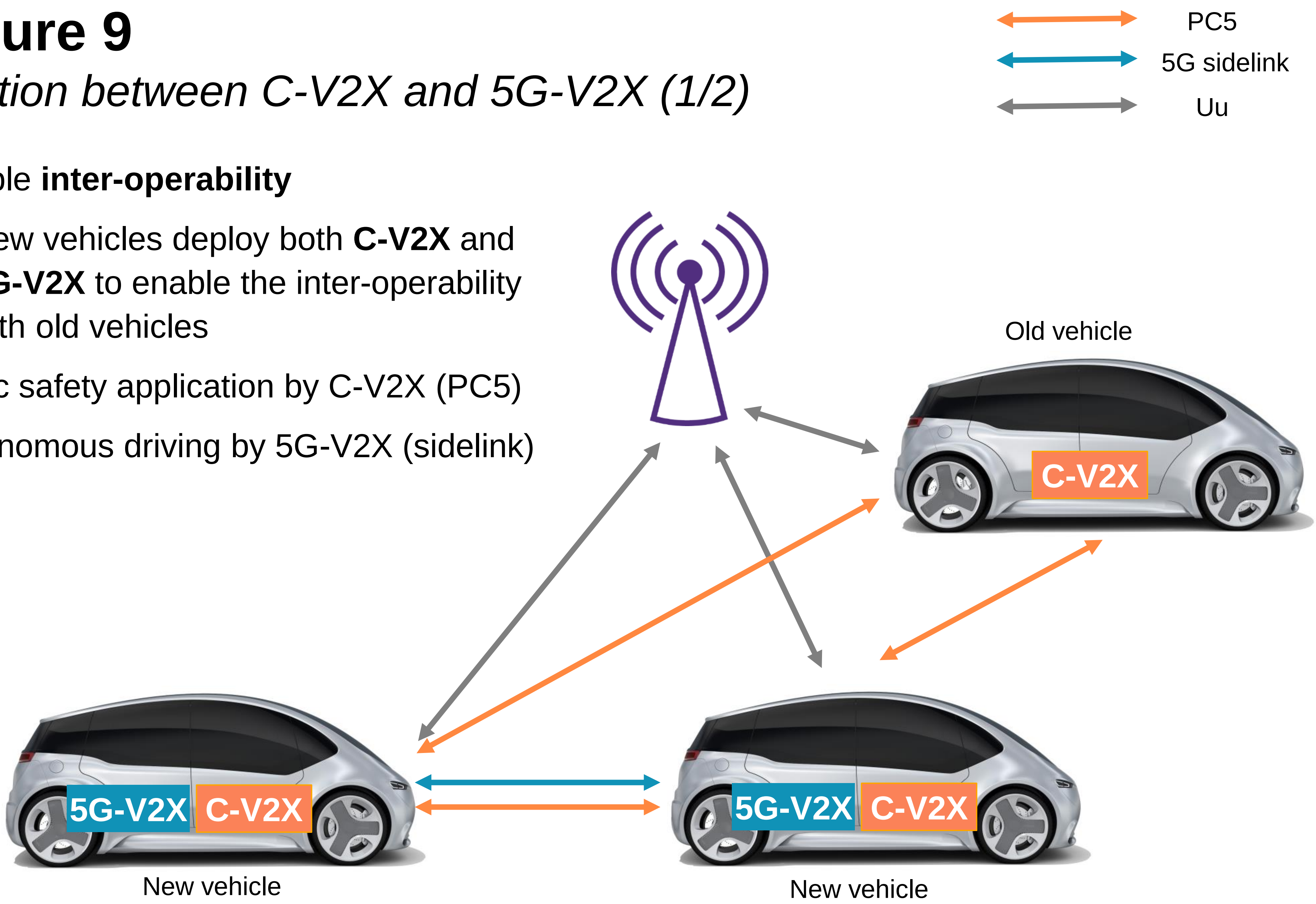
Selection between C-V2X and 5G-V2X (1/2)

- Enable **inter-operability**
  - New vehicles deploy both **C-V2X** and **5G-V2X** to enable the inter-operability with old vehicles
- Basic safety application by C-V2X (PC5)
- Autonomous driving by 5G-V2X (sidelink)



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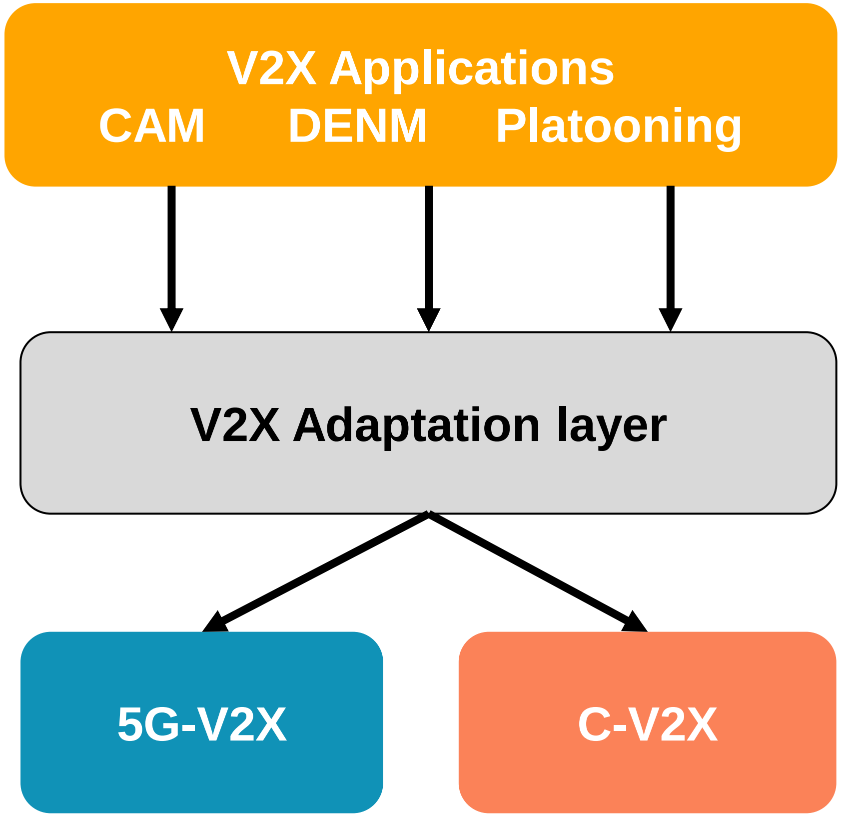
Selection between C-V2X and 5G-V2X (2/2)

- Adaptation **cross-layer** required
  - Provide policies/criteria to UE to assist **radio technology selection**
    - V2X application type
    - QoS requirements



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Spectrum Management Issues (2/3)

- **Coexistence with Wi-Fi**
  - 5.9 GHz band has been explored for Wi-Fi-like secondary operations
    - Because V2X applications demand **high reliability**, unlicensed Wi-Fi operations can be **permitted only** if they do not **cause interference** to the primary V2X technologies
  - **Potential solution for ITS-G5 and Wi-Fi**
    - Similarities in the MAC protocols of Wi-Fi and DSRC
    - **Adaption of MAC protocol:** Increase of the Contention Window size and/or Inter-frame space of Wi-Fi so that the priority of Wi-Fi transmissions is **reduced**

- **Coexistence** between **C-V2X and Wi-Fi** has not been well investigated
  - C-V2X uses a considerably different MAC protocol from Wi-Fi

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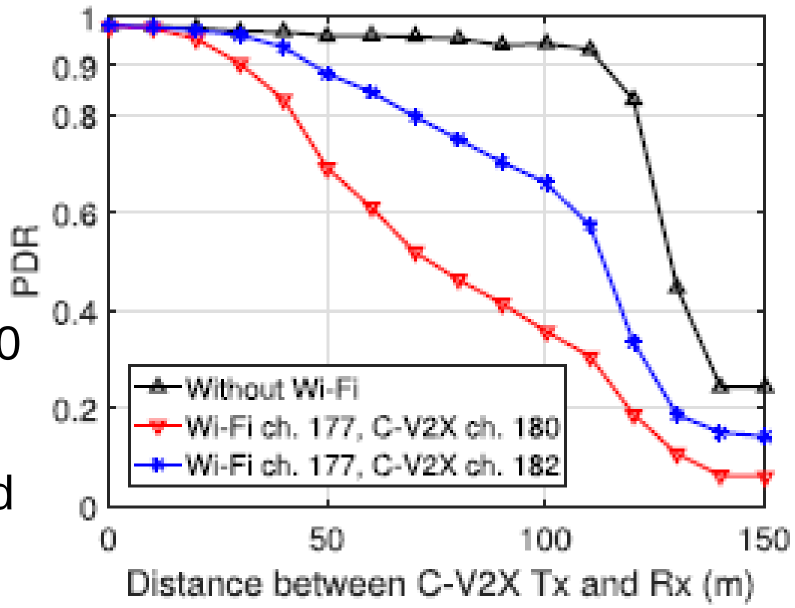
Spectrum Management Issues (2/3)

- **Interference from adjacent band**
  - if a Wi-Fi device operating in the **adjacent channel** is located very close to the V2X receiver, the noise floor of that receiver will be elevated
    - It inevitably leads to **a loss** in its **performance of V2X**
- Communication **performance** depends on the **frequency separation** between Wi-Fi and the ITS channel
- **Packet delivery ratio (PDR)** of C-V2X against the distance between the C-V2X transmitter and receiver
- The frequency separation between Wi-Fi and C-V2X is 0 and 10MHz for channels 180 and 182, respectively
- **90% PDR** range is reduced from approx. 115 m to 45 m and 25m for channels 182 and 180, respectively



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5G-V2X as Support for fully automated Driving

- **Connected** and fully **automated** vehicles combined to
  - improve road traffic safety
  - enhance traffic flow with the support of the roadside infrastructure
  - lower environmental impact
- **5G-V2X** might create a **vehicle's collective perception** of the surrounding environment
  - Help making more **informed decisions**, based on exchanged **local views** and **planned maneuvers** from nearby **vehicles**
  - **Instead** of relying on **local awareness** built upon on-board sensors only
    - Camera, radar, LIDAR
  - From a **simple awareness** to a fully **collective perception**

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Qos Requirements of Advanced V2X Applications

- Advanced V2X use-cases improve road safety and assist in better traffic management and cater to the infotainment needs of passengers

Use case group	Max. latency [msec]	Payload size [Bytes]	Reliability [%]	Data rate [Mbps]	Min. Range [meters]
Vehicle platooning	10 - 500	50 - 6000	90 - 99.99	50 - 65	80 - 350
Advanced Driving	3 - 100	300 - 12000	90 - 99.999	10 - 50	360 - 500
Extended Sensors	3 - 100	1600	90 - 99.999	10 - 1000	50 - 1000
Remote driving	5	-	99.999	UL: 25 DL: 1	-

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High Density Platooning

- Platooning, or the operation of a group of vehicles in a closely linked manner such that the vehicles move like a train
  - By **reducing distance** between vehicles following can be achieved
    - → Reduced overall **fuel consumption**
    - → Reduced **number of needed drivers**
- To support the platooning use case, vehicles **need to share status information** such as speed, heading and **intentions** such as **braking, acceleration**

Level 2 for partial driving automation

In level 4 vehicles can operate in self-driving mode

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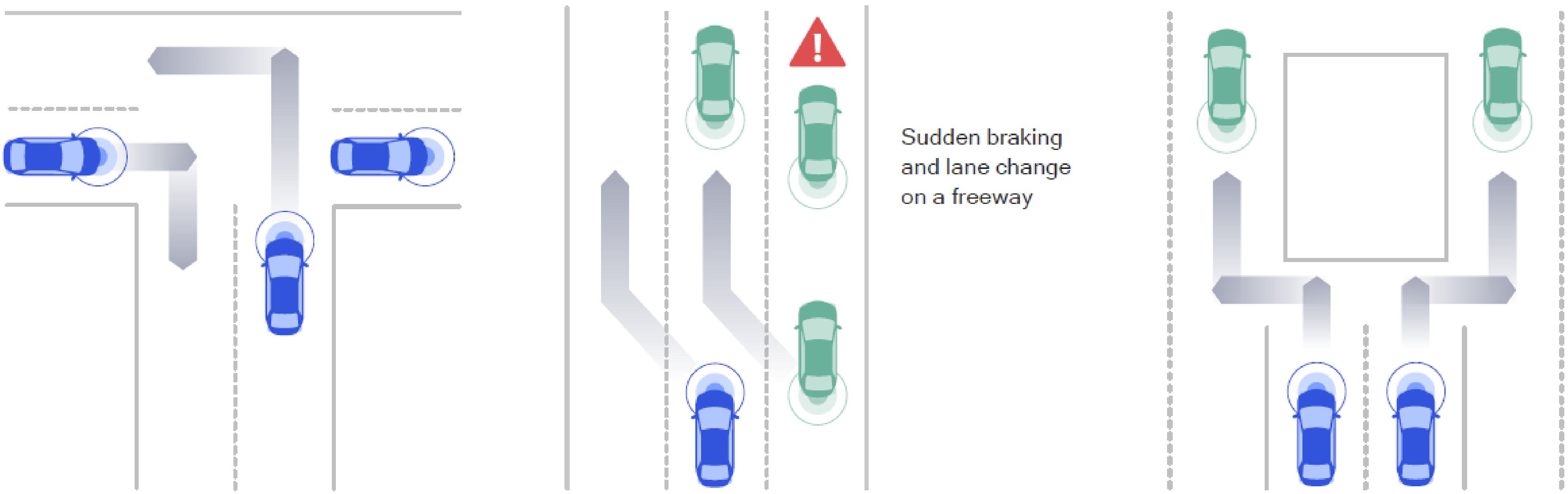
Advanced Driving

- Advanced Driving enables **semi-automated** or **fully-automated driving**
- Each vehicle and/or RSU **shares** data obtained from **its local sensors** with vehicles in proximity
  - This allows vehicles to **coordinate** their **trajectories** or **maneuvers**
  - Each vehicle shares **its driving intention** with vehicles in proximity



Efficient maneuvers | Advanced path planning | Coordinated driving

source: Qualcomm

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Remote Driving

- Remote driving enables a **remote driver** or a **V2X application** to operate a remote vehicle for those passengers who **cannot drive themselves** or a remote vehicle **located** in **dangerous** environments
  - Driving based on cloud computing can be used for a case where variation is limited and routes are predictable, such as public transportation
  - Access to cloud-based **backend service platform** is required
- Message exchange between a UE supporting V2X application and V2X application server for an absolute **speed of up to 250 km/h** shall be achievable
- Remote operator needs **HD video streamed** by the car from cameras located on the front, rear and side of the vehicle

source: 5GAA

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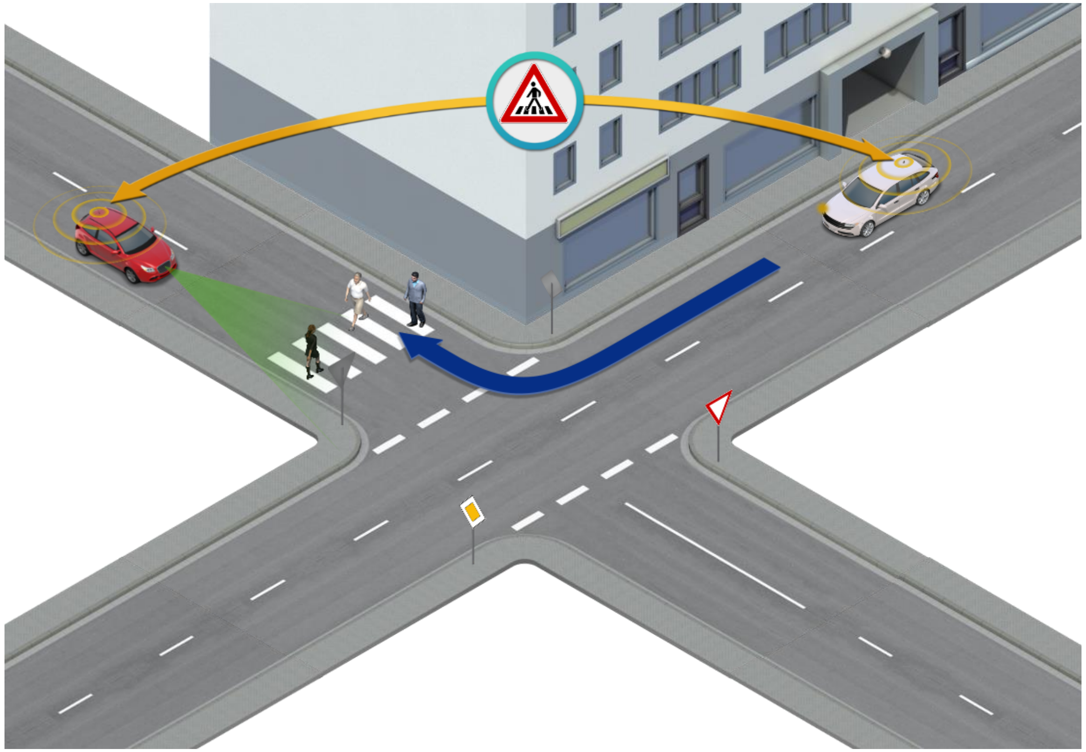
Extended Sensors and Intention Sharing



- Extended Sensors enables the **exchange of raw** or **processed data** gathered through local sensors or live video data **among vehicles**, RSUs, devices of pedestrians and **V2X application servers**
  - Vehicles can enhance the **perception of their environment** beyond what their own sensors can detect and have a more holistic view of the local situation

    → **Collective perception**

- Red vehicle's **local perception sensor** has a **line-of-sight** to pedestrians in a crosswalk
- Without collective perception, the ADAS applications of the white vehicle would not be aware of pedestrians until the vehicle's own sensors **perceive the object themselves**

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Challenges of connected and autonomous Driving

- Hard-to-meet **computing** and **communication demands** beyond current radio access technologies
  - Ultra-low latency **< 5 ms**
  - Ultra-high reliability near **100%** → intolerance to **packet losses**
  - High data rate in the order of **Gbps**

- Some future advanced V2X applications with stringent communication requirements
  - **Cooperative sensing and maneuvering**
  - **High-density platooning**
  - **Tele-operated driving**
  - **See-Through**
  - **Birds Eye View**

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Literature

- ► G. Naik et al.: “IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications”, 2019
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- ► ITU-R M.2083-0: “IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond”, 2015
- ► Maxime Flament: “Path towards 5G for the automotive sector”, 5GAA, 2018