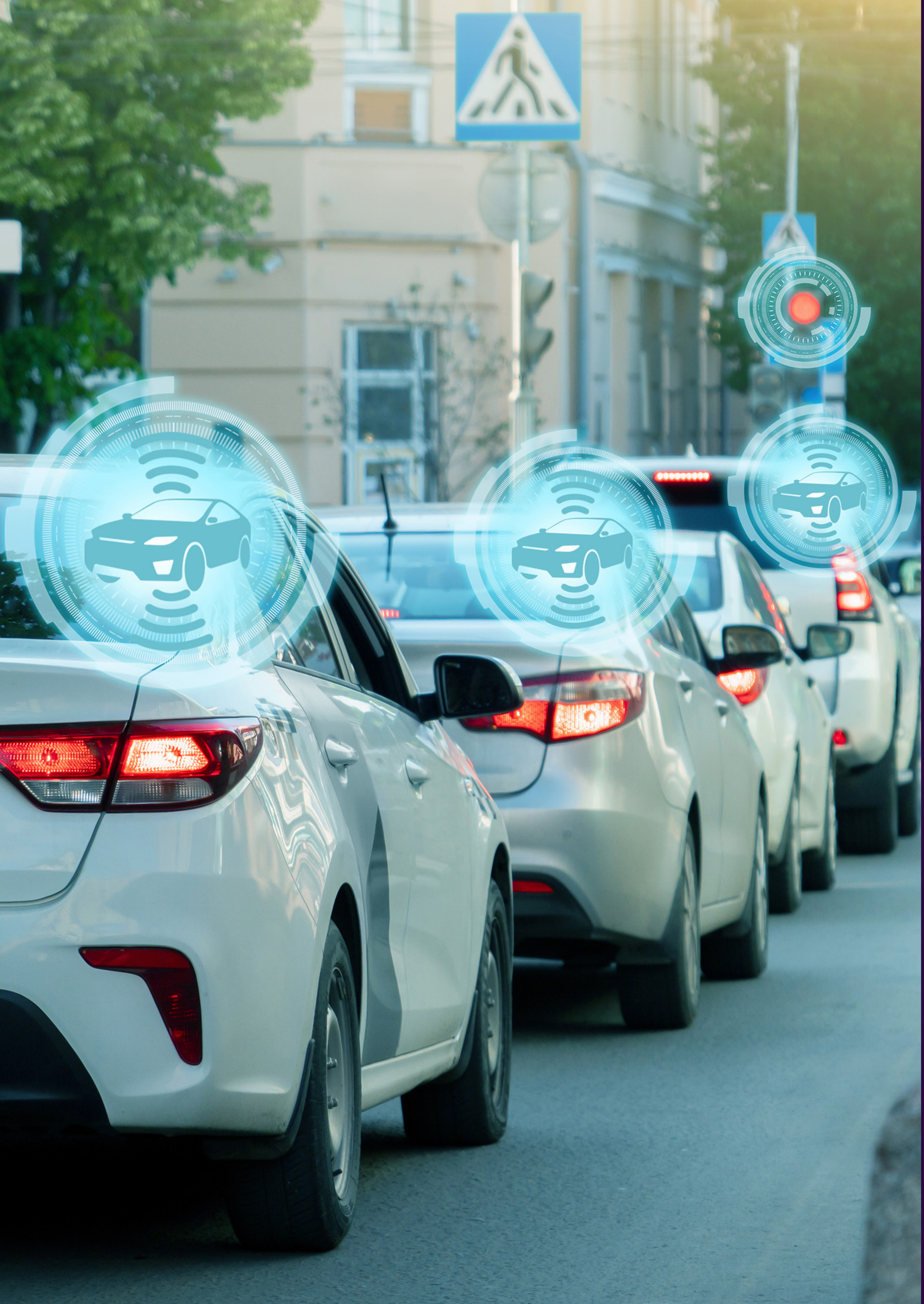
C-V2X : THE PATH TOWARDS AUTOMOTIVE 5G



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EXECUTIVE SUMMARY

The steady evolution of the automotive industry towards autonomous and connected vehicles holds highly promising prospects for the future of vehicles. This evolution is supported by robust technological progress in the industry, particularly Cellular V2X (Vehicle to Everything) technology. A key contributor to the expansion of vehicle automation, C-V2X, as shown in Figure 1 establishes lines of communication between vehicles, roadside units, and pedestrians, making the vehicle more aware of its surroundings and exchanging time-sensitive and safety-critical information.

C-V2X circumvents autonomous driving capabilities and complements existing Line of Sight (LOS) sensors (LiDaR, radar & camera) abilities by offering non-line-of-sight 360° awareness. This expands the vehicle's 'vision' to greater distances, including even blind turns and low-visibility weather conditions. The industry should leverage this technology to deliver smart mobility solutions of the future.

This whitepaper is intended for developers of V2X-based systems including Auto Tier 1/OEMs, Communication Service Providers, and smartphone and smart device manufacturers. It covers the evolution of C-V2X to support advanced use cases, the associated challenges, and the solutions Capgemini offers. An overview of use cases and the requirements to support these use cases is discussed.

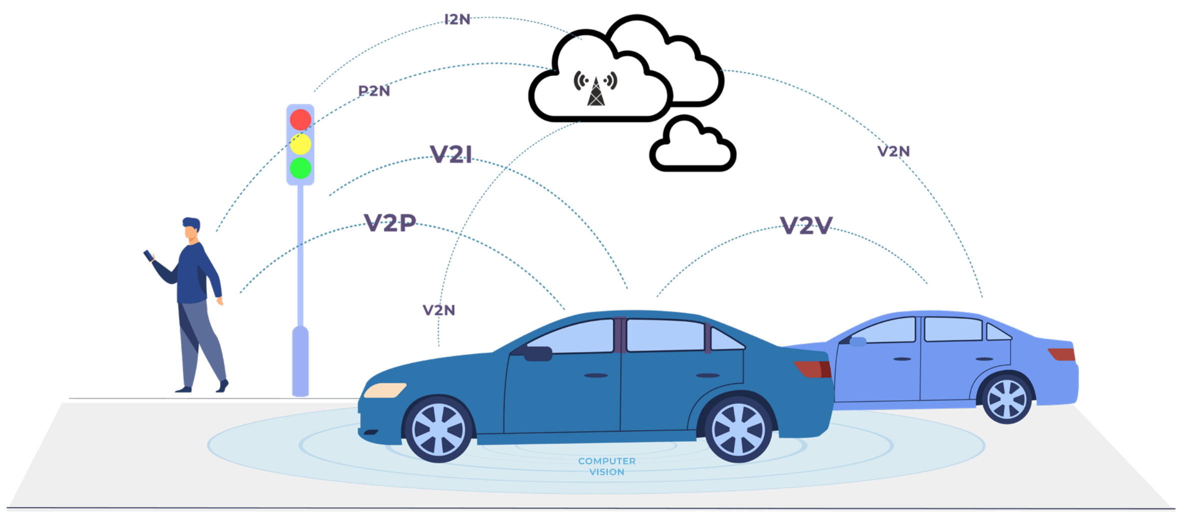


Figure 1: V-2-X ecosystem (Source: 5GAA)

C-V2X TECHNOLOGY EMERGENCE AND EVOLUTION

Today's car systems use Advanced Driver Assistance Systems (ADAS) to enhance safety in vehicles. ADAS technology leverages vision/camera systems, sensor technology, and car data networks to provide a safer driving experience. With the advent of newer technologies, these systems are improving rapidly, but they are still limited by the range of their sensors and can be degraded by inclement weather or obstacles like buildings. Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) technology, collectively known as V2X, overcome the limitations faced by today's ADAS systems and will serve as the foundation for intelligent transport systems (ITS).

V2X technology has evolved from 802.11p-based DSRC (Dedicated Short-Range Communications) to C-V2X, which is based on 3GPP standards, an evolution intended to address the needs of advanced use cases as shown in **Figure 2**.

C-V2X is an umbrella term for 3GPP-defined V2X technologies (Release 14 onwards), providing device-to-device PC5 communications (see figure 3) based on unlicensed ITS 5.9GHz band and leveraging existing cellular infrastructure based on 4G/5G technologies. C-V2X communication is possible over PC5 or Cellular Network Infrastructure as shown in **Figure 3**. 5G connectivity also enables Ultra Low Latency (URLLC) applications. The convergence with 5G is referred as 5G C-V2X.

Figure 2: Advanced safety use cases (source: Qualcomm)

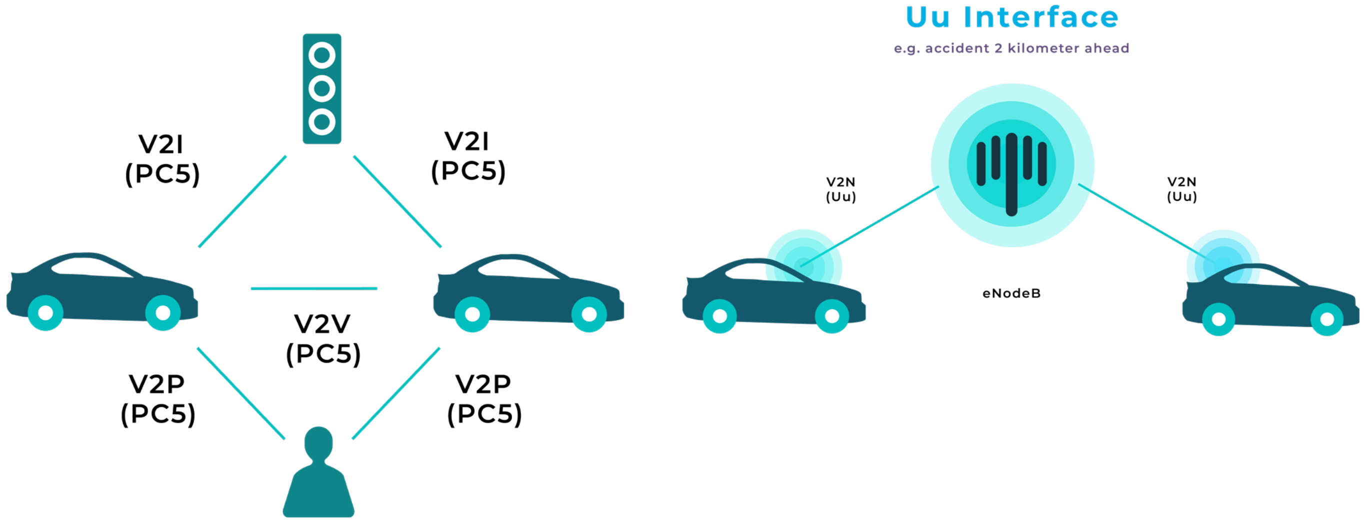


Figure 3: Communication interfaces (source: Qualcomm)

Today's V2X applications are focused on Day 1 applications based on static and dynamic vehicle states. Static information refers to the physical aspects of a vehicle such as its length and breadth, while dynamic state refers to changing parameters like speed and acceleration. Most of these applications require sending periodic messages in the range of 1-10Hz frequency and end-end latency of 50-100ms. To cater to the needs of advanced use cases, Day 1 use cases like collision avoidance will evolve towards Day 2+ use cases, such as cooperative automated driving applications that share information on detected objects or perform cooperative maneuvering, with high reliability, low latency and high throughput requirements as shown in **Figures 4a & 4b**.

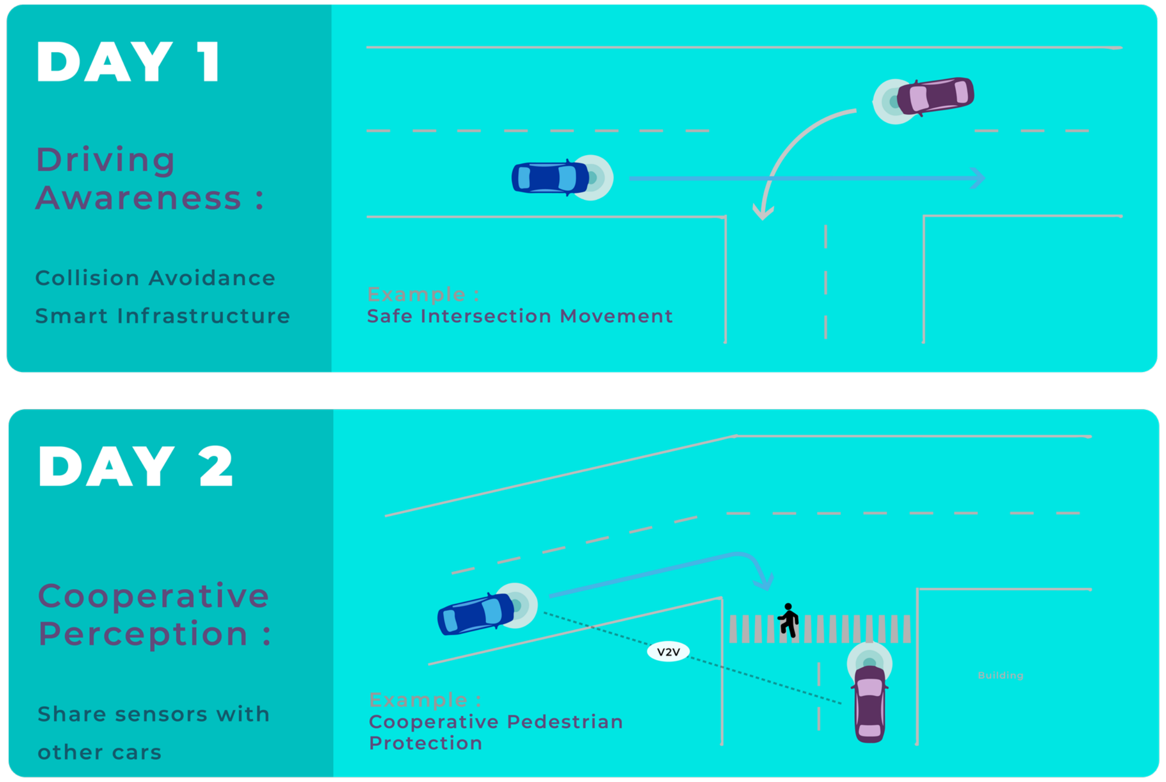


Figure 4: Day 1 and Day 2 use cases (source: Autotalks.com)

One vehicle can produce up to

100GB

of data over a period of one month, which requires both high bandwidth communications and storage/compute capacity.

C-V2X is the key technology for telematics and ADAS systems, and comprises network elements including onboard units (OBU) and roadside units (RSU), and associated 4G/5G cellular network infrastructure, which needs to support QoS requirements (data rate, latency, and reliability) for various use cases. The device-based and network-based edge computing platforms enable multiple automotive applications, with V2V and V2I, for example, becoming fast-growing use cases for edge computing and 5G technology. The largest bottlenecks so far have been the transmission of data from vehicles to external servers and cloud platforms. One vehicle can produce up to 100GB of data over a period of one month, which requires both high bandwidth communications and storage/compute capacity. To enable V2X protocols, companies therefore need edge-based devices installed across the car ecosystem.

- A **device-based edge computing platform**, also known as an e-cockpit platform, can make decisions based on processing local data received in real-time from different sensors, cameras and wireless networks enabled by the in-car network. This capability improves the overall driving experience for passengers and enhances safety by avoiding accidents, reducing traffic congestion, and aiding stranded drivers.

- A **network-based mobile edge computing (MEC)** is an integral part of a 5G network and enables low latency V2X applications, where the 5G spectrum operates in the range of 3-300 GHz, at a data rate of up to 20 Gbps, a spectral efficiency of 30 bps/Hz, mobility of up to 500 km/h, a U-plane latency of 0.5 ms, and a C-plane latency of 10 ms. It covers various vehicle applications that comprise of voice, data, video calls, OTT (UHD Videos), video chat, and V2X. Network-based MEC provides real-time driving services by utilizing high-definition real-time maps, real-time traffic monitoring and alerts, as well as offering a richer passenger experience. MEC applications can run on MEC servers deployed at a 5G/LTE base station. These provide roadside functionality, to support the ability of vehicles to drive cooperatively, to be aware of road hazards, and to provide a better user experience and greater trust among drivers and passengers.

C-V2X NETWORK ARCHITECTURE

The following are the key components of C-V2X architecture as illustrated in Figure 5:

1. **V2X Things:** Devices with V2X/V2N capabilities, such as vehicles, pedestrians, traffic lights etc. C-V2X supports PC5 for V2V/V2I/V2P applications and Uu/NR interfaces for V2N applications.

2. **Service Provider Network** components are hosted in the access and core network of cellular infrastructure as illustrated in Figure 5:
   - **C-V2X RSU:** A V2X device either located on cellular infrastructure as a standalone device or co-located on MEC. Supports both PC5 and Uu/NR interfaces
   - **MEC:** An edge computing platform with CPU and GPU capabilities hosting multiple applications like RSU, computer vision, and 4G/5G RAN applications for low latency applications
   - **V2X Control Function:** Provisions V2X devices and related services
   - **V2X Application Server:** A gateway to push data to V2X devices. Could be located on MEC for applications like HD map updates to reduce network latency

3. **Third Party Service Providers** enable a rich set of applications to be developed:
   - **OEM data center:** Stores vehicle data for analytics and insights. It is hosted either on a public or private cloud platform
   - **Infrastructure services:** Provide services related to infrastructure applications like traffic management centers (TMC) or emergency response (ER)
   - **Cloud platform:** Public or private cloud platforms to store and process vehicle data
   - **SCMS server:** PKI services for V2X security
   - **Third party applications:** These include maps, fleet management, and others, and are hosted on cloud platforms

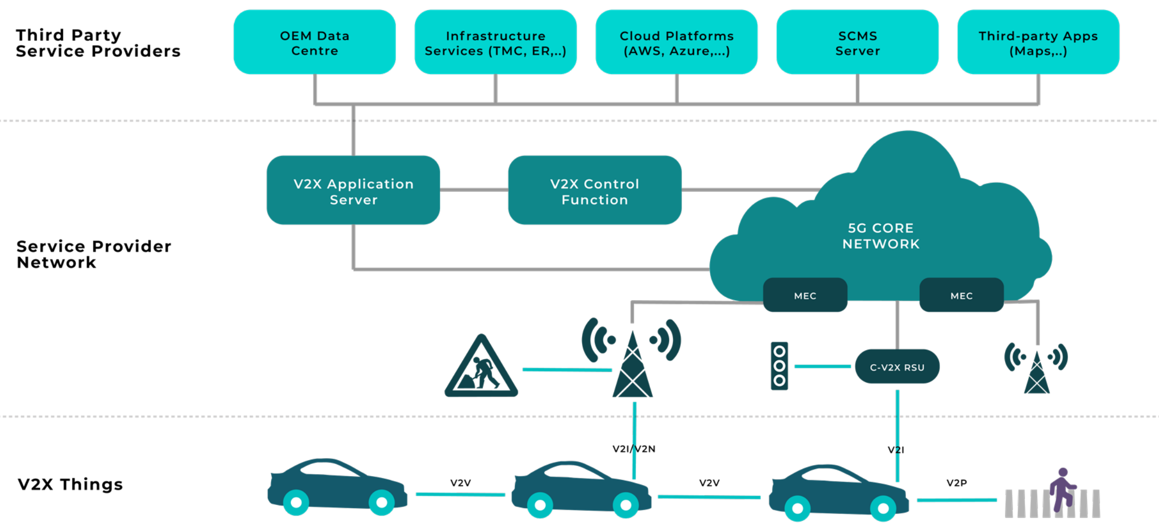


Figure 5: C-V2X Network Architecture (source: Capgemini Engineering)

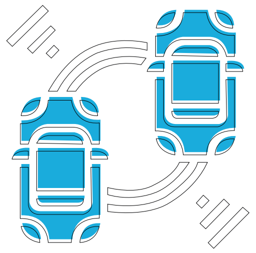
DAY 2+ USE CASES: REQUIREMENTS AND CHALLENGES

3GPP Release 15/16 defines enhanced V2X service requirements to support the following V2X Day 2+ use cases:

- **Vehicle Platooning:** This enables vehicles to dynamically form a group travelling together. All the vehicles in a platoon receive periodic data from the leading vehicle, to maintain platoon operations. This information allows a significant reduction in the distance between vehicles, where the size of the gap translated to time can be as low as sub seconds. Platooning applications may allow the vehicles following the lead to be driven autonomously.

- **Advanced Driving:** This enables semi-automated or fully automated driving. A longer distance between vehicles is assumed. Each vehicle and/or RSU shares data obtained from its local sensors with vehicles in its proximity, thus allowing those vehicles to coordinate their trajectories or maneuvers. In addition, each vehicle shares its driving intention with vehicles in its proximity. The benefits of this use case group are safer travelling, collision avoidance, and improved traffic efficiency.

Figure 6: Day 1 and Day 2+ use cases (source:C2CC)



The benefits of this use case group are safer travelling, collision avoidance, and improved traffic efficiency.

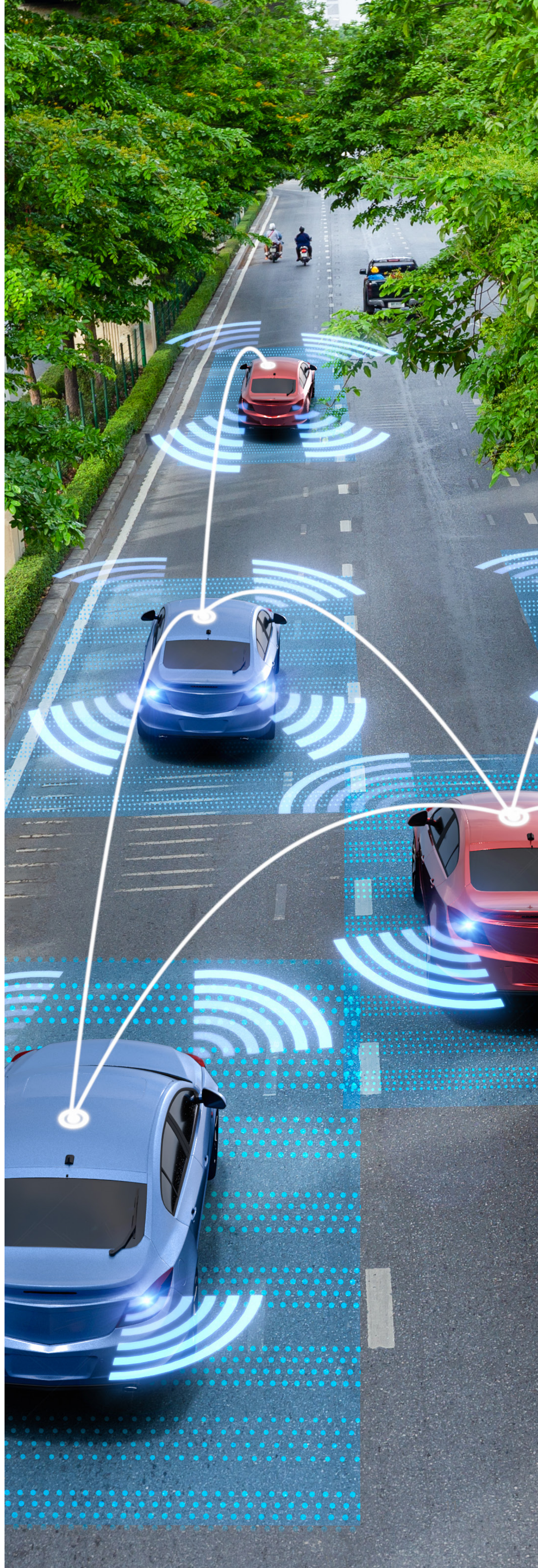
- **Extended Sensors:** These enable the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, pedestrian devices, and V2X application servers. They enhance the perception of a vehicle's environment beyond what its own sensors can detect and provide a more holistic view of the local situation.

- **Remote Driving:** This enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or are located in a dangerous environment. In such cases where variation is limited and routes are predictable like public transportation, driving based on cloud computing can be used. In addition, access to a cloud-based back-end service platform can be considered for this use case group.

The **table 1** below summarizes latency and reliability requirements of Day 2+ applications

Use Case Group	Maximum Latency (msec)	Payload Size (bytes)	Reliability (%)	Data Rate (mbps)	Minimum 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	—

Table 1: Source (3GPP Release 15 / Release 16)



As shown in **Figure 7**, a layered architecture is required to realize these use cases.

- **Access layer:** C-V2X PC5 will evolve towards New Radio (NR) PC5 as defined in 3GPP Rel16. NR PC5 builds on top of 5G NR which was standardized in 3GPP Rel15. NR PC5 will provide options for direct communication within Gnb coverage and out-of-coverage scenarios. It will support unicast, groupcast and broadcast communication mechanisms

- **Facility layer:**
  - Enhance current standards to support collective perception rather than cooperative awareness. Information will be broadcast on a vehicle's current environment rather than on its current state
  - Extend existing message sets to support specific use cases like long term road works warnings (LWW), and cooperative adaptive cruise control (CACC), etc.
  - Enhance congestion control management

- **Security layer:** Evolve towards security reflex function (SRF)-based architecture as defined by 3GPP (under definition)

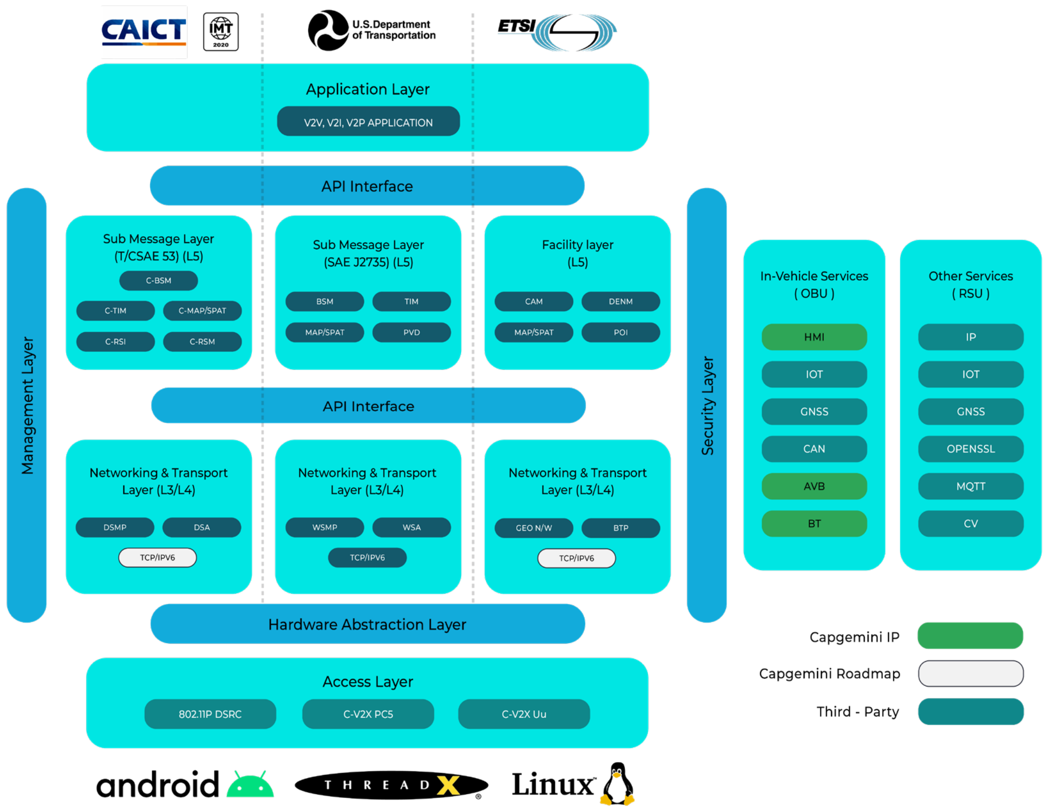
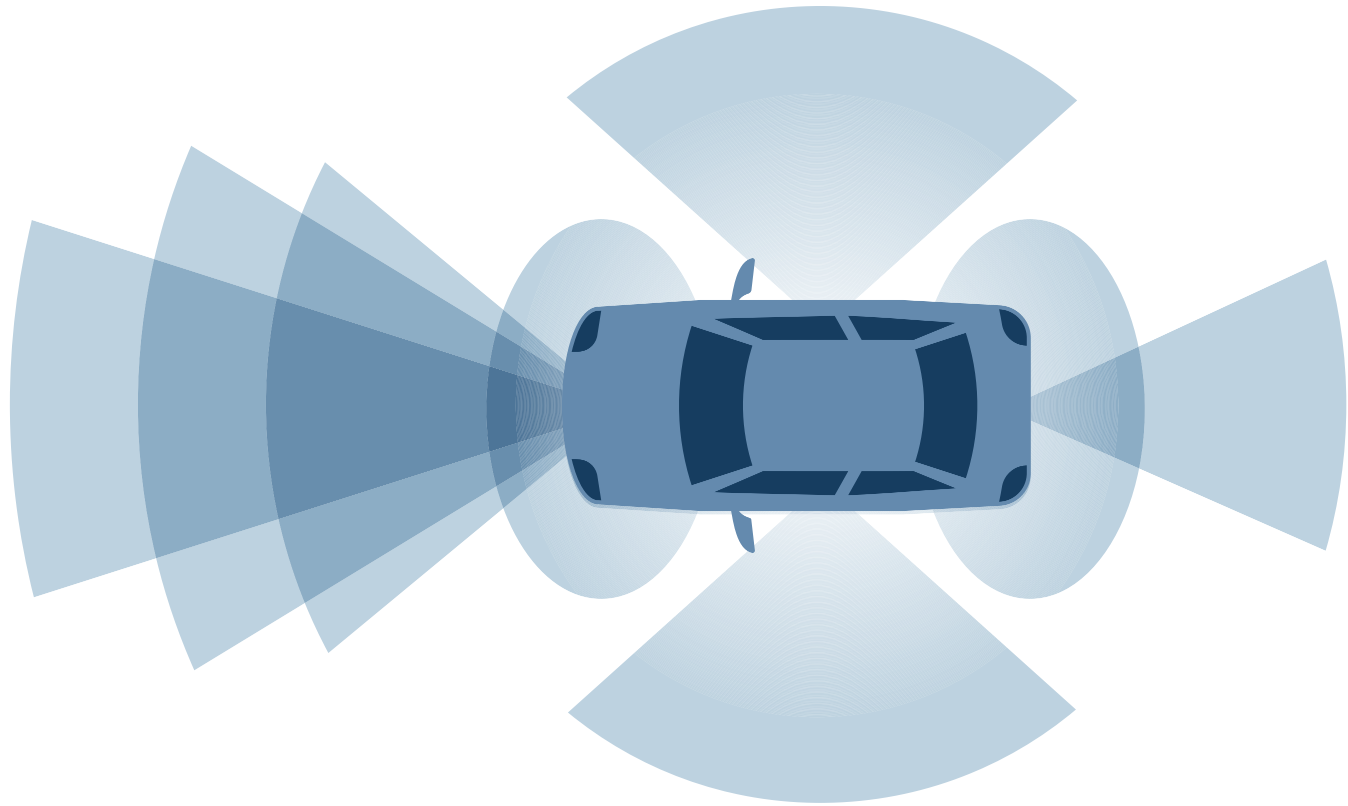


Figure 7: Layered Architecture (source: Capgemini)



Challenges:

1. C-V2X and NR V2X are not backward compatible. Vehicles should therefore be equipped with C-V2X and NR V2X radios with effective coexistence mechanisms
2. The backward compatibility of V2X services supporting Day 1 & Day 2 use cases
3. V2X stack enhancements and performance tuning are required to support the latency and reliability of Day 2+ use cases

Capgemini C-V2X Solution Overview

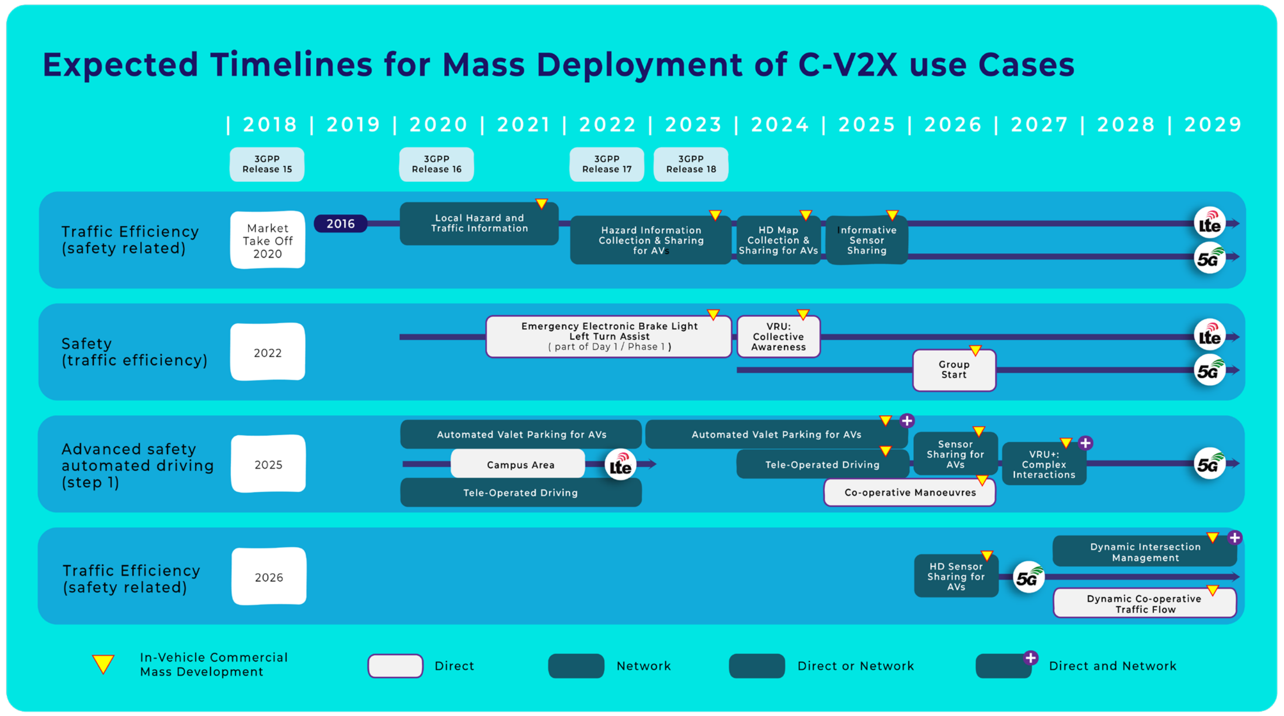
Capgemini C-V2X software framework enables faster time-to-market and rapid development of automotive and telecom applications. The software stack can reside on OBU / RSU / pedestrian devices or edge computing nodes to develop innovative V2X applications. The stack is compliant with regional standards, is interoperable, and pre-ported on industry-leading platforms based on C-V2X technologies. Our intelligent RSU architecture, based on Capgemini's edge compute platform ENSCONCE, combines C-V2X, computer vision, and 5G capabilities for smart city / smart intersection applications.

Extended sensor use cases which can be realized using ENSCONCE include intersection movement assist (IMA), vulnerable road user (VRU) , HD map sensor sharing , and many more.

Conclusion

Capgemini offers end-to-end OBU/RSU/VRU and edge platform solutions for the C-V2X market. This combined solution's capabilities are unmatched in the market and a key differentiator compared to other solutions available.

Auto Tier 1s, OEMs, and smart device manufacturers use a V2X stack to realize V2V/V2I/V2P applications. The auto grade stack is optimized for performance and reliability on industry leading platforms and will support Day 2+ applications as the standards evolve towards 5G C-V2X as illustrated in Figure 8.



Intelligent RSU offers an integrated 5G RAN, computer vision and V2X RSU solution on the ENSCONCE edge computing platform for communication service providers, smart city developers, and infrastructure providers. This provides a path for industry to develop innovative and feature-rich edge solutions for the market.

Capgemini has more than 25 years of experience in the cellular communications domain, from legacy 3G to current generation 4G/5G solutions. The C-V2X and edge computing capabilities complement these capabilities as the industry evolves toward automotive 5G C-V2X.These ready-to-use solutions offer a significant reduction in the cost of ownership and time-to-market, along with a global delivery model for optimized cost and timely delivery.

Author

Raghuraman BHEEMA RAO

Product Line Manager – Automotive Software Framework Solutions

Raghuraman BHEEMA RAO, is Product Line Manager for Automotive Software Framework Solutions. He has 20+ Years of industry experience, with last 17+ years in Capgemini

His responsibilities include V2X product activities, roadmaps, pre-sales, offerings development and partnerships. Experience in V2X include DSRC / C-V2X technologies, V2V/V2I/V2P use cases, Protocol layers and Silicon platforms. He has good understanding of market trends, ecosystem and key players in the V2X market across geographies.

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www.capgemini.com

Contact us at:
engineering@capgemini.com

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