



# 5G Intelligent Communications for V2X ecosystems

5G; Intelligent communications; V2X; Platooning; Network slicing

**White paper**

**Version 1.0, July 2020**

# Introduction

We are experiencing an increasingly connected and digital world. Industries are no exception, undertaking a digital transformation where external and internal communications are essential.

5G differentiates from previous cellular generations and other wireless technologies by providing business-to-business (B2B) vertical sectors (called “verticals”) with enhanced private and public communications, over a common infrastructure. 5G high bandwidth, low latency and high reliability, are the enablers for a new generation of services, to be anchored in natively supported edge computing. Embedded slicing mechanisms provide tailored connectivity to be used, for instance, in e-Health, energy, education, agriculture or transportation use cases.



The emerging 5G ecosystem will be distributed and heavily based in virtualised environments. A complete vision of the entire system and a holistic orchestration will be required, eventually across different administrative domains. The adoption of artificial intelligence (AI) and machine learning (ML) mechanisms, at network and services levels, will be of paramount importance to fine-tune the system, forecast events and anticipate actions.

Vehicle-to-everything (V2X) is one of the most relevant and promising verticals to exploit 5G. The creation of the 5G Automotive Association (5GAA) [1] reflects this. Besides interconnected autonomous vehicles, many other use cases are possible by ensuring vehicles have the right connectivity to (1) other vehicles, (2) with the surrounding environment and (3) with remote service platforms.

This document starts presenting the emerging 5G ecosystem characteristics, positioning it to be the service platform for cellular vehicular (C-V2X) use cases. The following section describes the role of AI/ML at 5G network level and as an enabler of advanced vehicular use cases. The final section presents vehicular platoons as an example of the need and the advantages of having a close interaction of AI/ML mechanisms operating at those two layers.

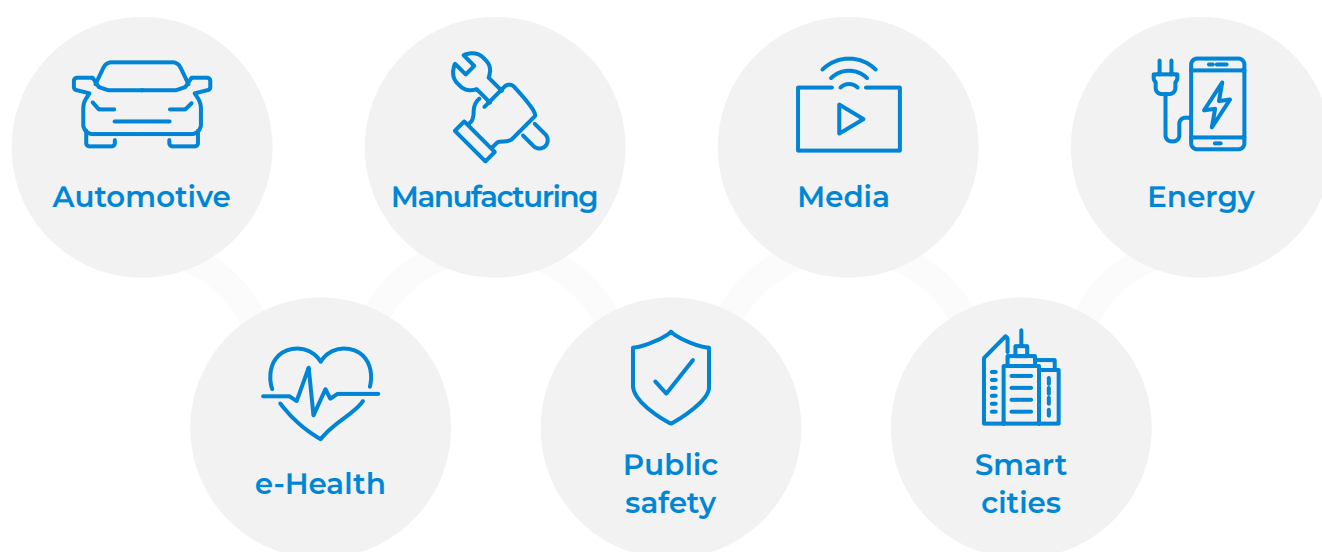


## 5G: the next generation services platform

5G represents a new era in cellular communications, presenting the functionality and the performance improvements required to place it as a keystone in the digital transformation process. But exploiting all the 5G technology potential, impacts other components, like data centres, and requires the common adoption of AI and ML.

### 5G performance and functionality

Current 5G commercial deployments, based on 3GPP Release 15 specifications [2], add a 5G radio data plane to existing 4G networks, classed as a non-standalone (NSA) architecture, mainly providing more bandwidth to be used by the business-to-consumer (B2C) market. These deployments fall into the enhanced mobile broadband (eMBB) use cases. The 5G-PPP Vertical Engagement Task Force (VTF) identified the following industry sectors, or “verticals”:



Some of these verticals are already organised around the 5G topic, such as automotive, with the 5GAA, and industry, with the 5G Alliance for Connected Industries and Automation (5G-ACIA) [3], reflecting the importance to influence 5G definition and regulations, and consistently take the maximum benefit of it.

Aiming at serving all those, requires 5G to improve performance over 4G significantly, beyond mobile Internet requirements. Besides higher bit rates (up to 20Gbps), a 5G standalone (SA) system, based on 3GPP Release 16 specifications [4], will support a larger number of simultaneous connections and devices (up to 1 million per square kilometre), provide ultra-low latency at radio level (down to 1ms) and high reliability (up to 99.9999%), opening the floor to massive machine type (mMTC) and ultra-reliable and low latency (URLLC) communications, addressing the B2B market.

Higher frequencies (above 24GHz) operation, a denser set of antennas and integrating mechanisms such as multi-user multiple-input and multiple-output (MU-MIMO), guarantees **high bandwidth**. However, 5G is also able to operate at lower frequencies (below 1GHz), with lower bandwidth but broader and deeper coverage. A new radio interface, e.g. via a new frame structure, and system architecture, clearly separating the control and user planes (CUPS), guarantee **low latency**. **High reliability** is achieved by incorporating mechanisms in the architecture and in the radio interface to provide spatial, frequency and time diversity.

Functionally, 5G emerges with native, built-in, support of **slicing** and **edge computing**. Slicing allows the creation of complete virtual end-to-end networks, from the radio interface to the service platforms, which can be managed individually (see **Figure 1**). These slices have the appropriate characteristics and are assigned with the right resources, tailored to the type and level of connectivity services they need to provide. Edge computing allows the placement of computing resources close to the network edge, as much as the 5G radio units, allowing services to be provided with minimal latency.

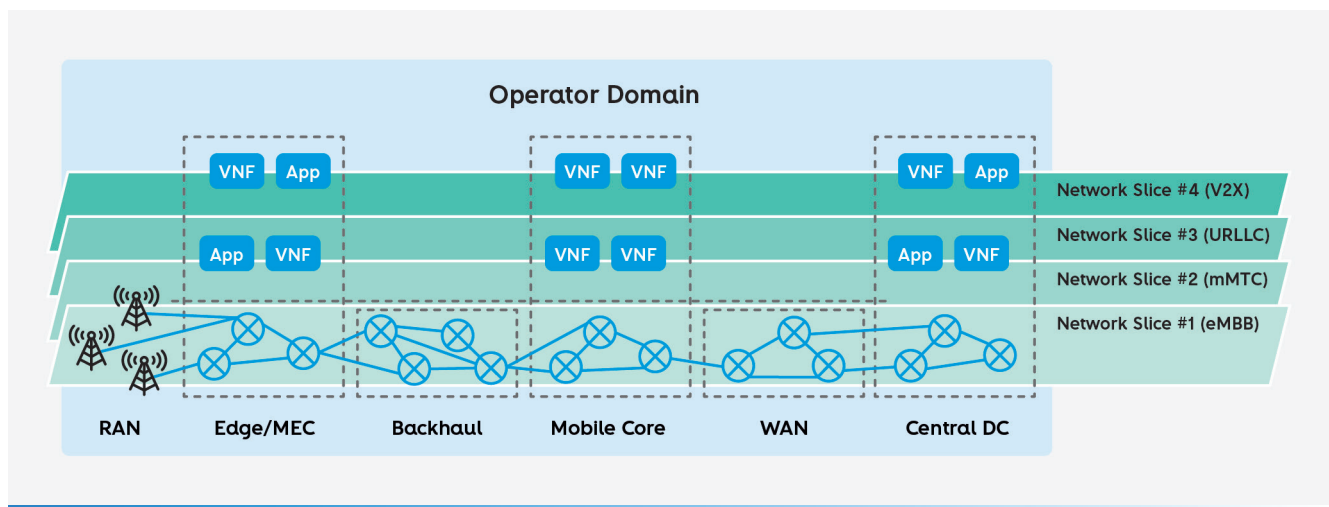


Figure 1 – 5G slices

3GPP specified three main types of standard slices, later adding a V2X one, which is intended to address the specific requirements of the automotive vertical, resulting in the following [5]:

1. **eMBB**, providing high bandwidth, with faster mobility (e.g. fast trains or drones);
2. **mMTC**, for more connections, widespread and deep coverage, even if at lower bitrates;
3. **URLLC**, for extremely low latency communications and guaranteeing strong reliability;
4. **V2X**, for the specific support of cellular vehicular communications use cases.

Operators will instantiate multiple slices of these standardised types and other tailored ones, answering the needs of specific use cases and verticals. Those needs may span from performance (e.g. latency, throughput, availability), to functional (e.g. security and identity management) and operational (e.g. self-management) requirements.

## The new 5G data centre paradigm

Aligned with current IT trends, 5G brings new technologies, new architectures and new topologies, associated with a new development culture, new deployment methods and new delivery challenges. The virtualisation of compute, network and storage resources has leveraged the success of cloud computing services, decoupling software functions from the physical bearer.

The degree of automation and orchestration (enabled by a programmable infrastructure) brings higher control and flexibility to the deployment and management of the infrastructure resources. In particular, network function virtualisation (NFV) service platforms, jointly with the software-defined networks (SDN) end-to-end network control capabilities, provide the tools for the creation and deployment of innovative network services and application in a short time, most likely organised as slices (as referred in the previous section), and addressing the time-to-market business demands.

Cloud computing capabilities (e.g. application and service orchestration, and device management) are gradually moved to smaller, distributed datacentres with identical characteristics but placed near the end-user to fulfil the latency requirements for specific services. By moving the intelligence closer to the edge, enriching received raw data, creating metadata and sending back the information relating to the vertical or the actions/decisions to be taken, can be done in a much faster way. Operators also take own benefit of this infrastructure, running virtualised components of disaggregated wireless and wired access components for mobile, fibre or cable networks, on this infrastructure. Independently from 3GPP work on 5G, the Broadband Forum (BBF) is proposing a Cloud Central Office (CCO) architecture to address this [6].

Edge computing will benefit from solutions which bring efficient infrastructures, running on open commoditised platforms, enabling solutions that run on standard processors rather than hardware silos. The degree of openness of the platform and its provisioning, relying on open-source software and commodity hardware, are the drivers for the solutions being designed and are critical to success. The approach being adopted by the majority of manufacturers is to commoditise the hardware aspect and, at the same time, increasingly use software to differentiate and drive competition.

As it turned out, edge computing is a highly distributed network of infrastructure resources, possibly organised in network slices. NFV and SDN solutions can leverage its deployment, placement, rule-based autoscaling, self-healing, rollout updates, onboarding and the full life cycle management.

Several standard definition organisations, open-source communities and industry fora, like the OpenStack Foundation (OSF) [7], Cloud Native Computing Foundation (CNCF) [8], Telecom Infra Project (TIP) [9], Open Compute Project (OCP) [10] and the European Telecommunications Standard Institute (ETSI) multi-access edge computing (MEC) [11] and NFV [12], are actively working on the edge computing definition, architectures, APIs, guidance, best practices, management, interworking, security and business models.

ETSI NFV Release 3 [12] features related to 5G include: “Support for network slicing in NFV”, “Management over multi-administrative domains” and “Multi-site network connectivity”. These features are essential to address the variety of applications expected to run on top of a 5G system, whether using distributed resources over multiple sites, centralised or a combination of both.

Actually, commercial solutions like Vapor IO [13], EdgeMicro [14] and Dell/EMC Micro Modular Data Center [15] were designed to deploy a nationwide network of small modular edge data centres, either on a fixed location or as nomadic units, to address unexpected calamity, traffic rush or sports event with thousands of consumers sited on a large stadium.

TIP is an engineering-focused initiative driven by operators, suppliers, developers, integrators, and start-ups to disaggregate the traditional network deployment approach. Although the various TIP Project Groups are independent, their work is complementary. Among others access network initiatives, the Edge Computing [16] is one of the working areas: focus on lab and field implementations for services/applications at the network edge, leveraging open architecture, libraries, software stacks and MEC.

## 5G-based cellular-V2X

In the vehicular communication ecosystem, there is a variety of required communications. The first ones are vehicle “direct links”, including **vehicle-to-vehicle** (V2V), **vehicle-to-infrastructure** (V2I) and **vehicle-to-pedestrian** (V2P). The second ones are “network links”, for **vehicle-to-network** (V2N) communications, supported by LTE/5G technology, suitable for both local and long-distance applications. A single or a combination of such links need to be considered when designing a cooperative vehicular application, depending on factors like the application's architecture (local or cloud-based), requirements (small latency, long-distance communication) and availability of the technologies supporting the various types of links.

Wireless local area network (WLAN) [17] based solutions have been proposed for a long time to address V2V and V2I needs. Specifically, IEEE 802.11p [18], often referred to as dedicated short-range communication (DSRC), provides ad hoc device-to-device communications. It is the technical foundation of two regional protocol stacks, the Wireless Access in Vehicular Environment (WAVE) stack in the USA [19] and the ETSI Intelligent Transportation System (ITS-G5) in Europe [20]. It leverages the physical (PHY) and medium access control (MAC) layers of IEEE 802.11 and operates in the 5.9GHz Industrial, Scientific and Medical (ISM) band, offering a maximum bitrate of 27Mbit/s, and typical line-of-sight ranges are up to 1km [21]. The current lack of dedicated 802.11p-enabled roadside infrastructure means that connections from the vehicle to the network need to be mediated by an onboard cellular interface. In 2018 IEEE started the Next Generation V2X study group [22] to address identified limitations.

C-V2X is a 3GPP reference for vehicular communications. It answers both performance and functional requirements, leveraging the defined cellular radio technology for the direct communications between vehicles (device to device or D2D). C-V2X guarantees communications to the network, providing ubiquitous connectivity via the built-in handover and roaming mechanisms.

While 3GPP Release 14 specified LTE-based C-V2X, Release 15 introduced 5G New Radio (NR) to C-V2X use-cases and Release 16 extended it. The most demanding requirements for autonomous driving [23], to be answered by NR-V2X, are presented in **Table 1**.

| Use cases          | E2E latency (ms) | Realiability (%) | Data rate (Mbps)          |
|--------------------|------------------|------------------|---------------------------|
| Vehicle platooning | 10               | 99.99            | 65                        |
| Advanced driving   | 3                | 99.999           | 53                        |
| Extended sensors   | 3                | 99.999           | 1000                      |
| Remote driving     | 5                | 99.999           | upload: 25<br>download: 1 |

**Table 1** – NR-V2X requirements for autonomous driving [23]

These are organised in four areas [24]:



Vehicles platooning



Extended sensors



Advanced driving



Remote driving

An analysis produced by Qualcomm [25] informs about how LTE/C-V2X and IEEE 802.11p compare in a highway emergency breaking scenario, with C-V2X outperforming the IEEE standard.

Thus, 5G has the potential to become a game-changer in C-V2X rollout, benefiting from the ubiquity of the cellular infrastructure and mature industrial foundations, inherited from decades of standardisation work in 3GPP. It is able to support all V2X communication “flavours”, either between vehicles, vehicles to pedestrians, vehicles to infrastructure or network, with services running at the edge or at centralised platforms.

Besides technology, policymaking organisations play an important role regarding C-V2X support by the networks and by vehicles, with the European Commission (EU) setting up the target for the main European transport paths to have 5G coverage by 2025 [26].



# AI and ML for 5G V2X scenarios

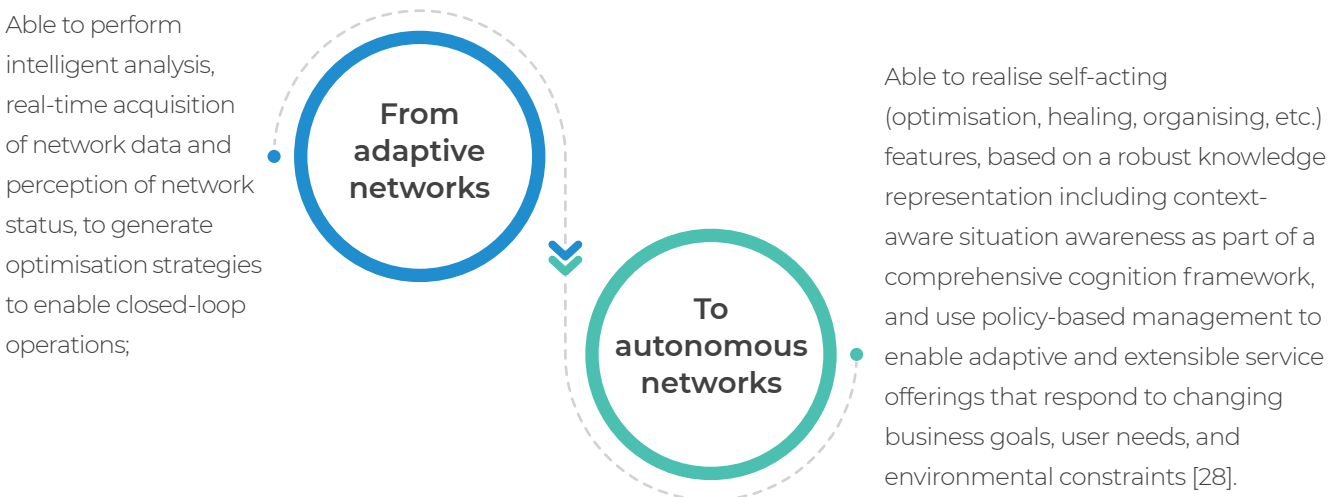
AI and ML are nowadays present in many applications and services. Operators are adopting them to have better-performing networks and the vehicular industry to provide more secure and efficient transportation systems. Vehicular use cases, requiring communications with the surrounding environment, need AI/ML processes running at both levels to coordinate for optimal performance.

## AI/ML in 5G networks

*“Many 5G aspects require analytical capabilities and responsiveness beyond human capacity. For instance, if operators want to optimise the connections for every device and application, they need to shift their network planning and monitoring tools from a network-centric to a user-centric view. That requires a continuous, end-to-end perspective of real-time network behaviour, which, in turn, demands the ability to correlate vast amounts of network testing and statistical data towards an accurate picture of the quality of experience”* [27]. Furthermore, the network topology, design and propagation models, along with user’s mobility and usage patterns in 5G, will be complex.

To assure the performance of the diversity of the supported applications (e.g. connected cars and industrial Internet of things), it will require continuous network monitoring, troubleshooting, and optimisation based on an accurate end-to-end view of network behaviour. It will also require collecting and processing data from a multiplicity of sources, simultaneously and in real-time. Such a vast amount of information will need complex analytical capabilities, supported on dedicated tools and practices, including AI and ML processes that will ensure efficient management of network resources and flexibility to meet user demands.

AI and ML will prove to be crucial in supporting the desired evolution:



ML techniques are enablers for the automation of network functions, through its capability of **sensing** (e.g., anomaly detection), **mining** (e.g., service classification), **predicting** (e.g., forecasting traffic trend or anomalies), and **reasoning** (e.g., the configuration of system parameters for adaptation). In an end-to-end perspective, it will provide capabilities to analyse a huge volume of data in a very short time, learn to adjust the system to time-varying environments, make predictions of future events with reasonable accuracy and prescribe proactive solutions [29].

For instance, embedding ML algorithms and AI into 5G networks can enhance automation and adaptability, enabling efficient orchestration and dynamic provisioning of network slices [30]. ML and AI can collect real-time information for multidimensional analysis and create a panoramic data map for each network slice, based on user subscription, quality of service, network performance, events and logs.

Different aspects where ML and AI can be leveraged, include [30]:



**Predicting and forecasting the network resources health** can enable wireless operators to anticipate network outages, equipment failures and performance degradation.



**Cognitive scaling**, to assist wireless operators to dynamically modify network resources for capacity requirements, based on the predictive analysis and forecasted results.



**Predicting user equipment mobility in 5G networks**, allowing for the update of mobility patterns data based on user subscription, historical statistics and instantaneous radio conditions for optimisation and seamless transition to ensure a better quality of service.



**Enhancing the security in 5G networks**, preventing attacks and frauds by recognising user patterns and tagging certain events to prevent similar attacks in future.

In the scope of verticals with real-time requirements (e.g. ultra-low-latency sensitive V2X applications), 5G network operators need to provide efficient and precise tools, many running at the network edge, to cope with the requirements mentioned above. Operators will rely on AI/ML to process its massive and diverse historical data to build the models supporting this multiplicity of features. It ranges from pre-emptively informing the applications about issues with the predicted network service quality so that it can take appropriate measures (i.e., adjust its internal processes to rely less on network service), to plan and deploy network adjustments (e.g., service migration from the initial edge datacentre) based on the information provided by the V2X application, like planned itinerary, traffic constraints, unplanned impacting events, etc.

## V2X in intelligent 5G environments

V2X communications will be the technological basis to support an entirely new set of vehicular applications, operating as a service overlay that will extend the functionalities of existing or soon-to-be sensing and autonomous driving technology. In turn, AI is one of the quintessential elements of autonomous driving. V2X and AI will complement each other to support much more complex and mobility-disruptive interactions between vehicles, pedestrian users, and physical infrastructure.

The keyword is **cooperative**: V2X (e.g. through 5G) allows information sharing between vehicles, infrastructure and other road-users that is outside the reach of the sensors of individual road-users. The AI algorithms will take the wide variety of sensors available in the vehicles, processing the generated data to identify where other road users are, then sharing that information through a V2X channel; or receive information through a V2X link about the whereabouts of other road users and react accordingly.

In safety-critical applications, for instance, alerting for immediate collision danger, URLLC communication between vehicles will be required. Consider the following V2X use-cases (inspired by [25]):



### Forward collision warning (FCW)

A vehicle moving ahead informs a follower vehicle that a collision occurred and an emergency braking procedure should be initiated; for this, an AI algorithm needs to receive the video feed from the front-facing cameras of the vehicle, identify the event and decide to relay that information over V2X links.



### Do-not-pass warning (DNPW)

The vehicle warns the follower not to attempt an overtake as an oncoming car in the opposite lane approaches, after identification by the AI algorithm.



### Vulnerable road user (VRU) indication

An AI algorithm receives the vehicle's front-facing cameras video feed and on-going wireless communications. The algorithm understands the vehicle is approaching a blind spot and relies less on the camera, assigning more weight to other sensors. The algorithm identifies the presence of a pedestrian behind the blind spot by detecting the pedestrian's smartphone beacons.

The correct, safe, stable and coordinated control of vehicles is another vehicular application in which AI and V2X communications will have to operate hand in hand. Consider the following examples for platooning:



### Kinematic models

Kinematic specificities of each member (e.g. inferior braking power and leaning tendencies) can be sent to the leader through V2X links, and AI algorithms can incorporate the individual behaviours in the platoon's overall kinematic model.



### Efficient driving techniques

A platoon in a highway is preparing to engage in higher speed and smaller inter-vehicle distance. V2X links are used to coordinate the action, while AI algorithms must build situational awareness to greenlight the manoeuvre.

At a macroscopic scale, AI will also enable intelligent traffic management systems. By sharing information with other road-users and a centralised traffic management authority, goods freight will become more efficient, less risky and with reduced delays. Consider:



### Kinematic-aware route selection

AI mechanisms can identify the best routes, taking into consideration traffic density, received from a central system via V2X, and the truckloads (e.g. if trucks are loaded or not). This condition affects the kinematic properties of the platoon (e.g. if loaded, inferior speeds and less agility shall be expected).



### Last-mile logistics with drones

Platoons equipped with drones, known as unmanned aerial vehicle (UAV), can optimise their delivery routes by dispatching drones to deliver goods to nearby delivery points. Trucks and the drones must keep real-time communication so that the drone can be aware of the truck's position.



### Traffic conditions and services

Warnings about traffic jams, alerts about emergency vehicles and available parking spots and tariffs, can be shared.

# Platooning use case

Platoons will be the basis of future automated transportation systems, including passenger buses, fleets, freight, and trucks. Transportation of goods (supply chain management) will become more efficient, less risky and faster [31]. With platooning solutions, urban traffic flows will be more efficiently managed by relying upon regular structures of vehicles with similar routes, exchanging information between them and with the roadside infrastructure to safely coordinate their actions.

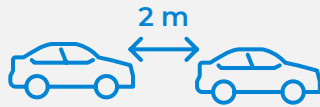
To support the use cases mentioned in section “V2X in intelligent 5G environments”, in particular platooning, the requirements to be fulfilled by network operators regarding 5G and edge computing technologies, are significant and challenging. The safety- and time-critical nature of many of those use cases, require ultra-reliable and low latency wireless connectivity with other vehicles, as well as with the infrastructure and with the edge cloud nodes. In turn, applications such as control (platoon coordination, efficient driving manoeuvres) and ITS (traffic coordination, route planning) may have a different set of requirements, e.g., demand continuous connectivity to edge datacentres that provide updated information.

Let us contextualise the wide range of network requirements in a broader real-world application. Consider that a logistics company wishes to freight goods, leveraging on automated platoons for regular delivery missions to industrial or logistic locations for improved efficiency and savings. The platoon is supported throughout its itinerary by infrastructural the most technologies, such as 5G-enabled cell-towers, roadside units equipped with IEEE 802.11ac/ax/ad/p technologies, and edge data centres for low latency processing of offloaded applications. Under the framework of a VNF/slicing-enabled network, and tightly linked to edge-provided services, the network operator starts by deploying (one or more) network slices. These slices can be of different types, according to the operator strategy (e.g. URLLC, eMBB and V2X), devoted to providing tailored communication services to the V2X vertical. Applications requiring network-side processing, such as autonomous platoon driving support, and included in the network operator catalogue, are onboarded and instantiated at edge data centres, and the required network slices are activated. The selection of the target edge DC aims at simultaneously guaranteeing the V2X application performance requirements and efficient network usage. Finally, the vehicles connect to the network and the V2X network slices and initiate their mission.

To get a rough idea of the scale of delays at play, consider the example of a highway occurrence that requires emergency braking by the platoon, in the following conditions:



**Platoon cruising at  
a reduced speed of  
50km/h**



**Distance between  
vehicles of 2 meters**



**Maximum deceleration  
(braking) capability  
of 6m/s<sup>2</sup>**

Upon identification of, for instance, a stopped vehicle involved in a crash, the leading vehicle triggers and emergency brake action and communicates this action to the followers. If relying on a typical 4G network, a 100 bytes message and often assuming peak situations, a successful transmission could take around 100ms. Within such timeframe, the follower would have cruised 1.4 meters and the leader 1.1m (due to breaking). If the follower does not receive a transmission up to approximately 817ms, the follower will crash into the front vehicle (see **Figure 2**). 5G provides some milliseconds transmission delays, supporting even smaller inter-vehicle distances is possible, resulting in increased platooning efficiency. From the perspective of a 5G network, a lot is happening in the background so that this level of service can be provided (see section “AI/ML in 5G Networks”).

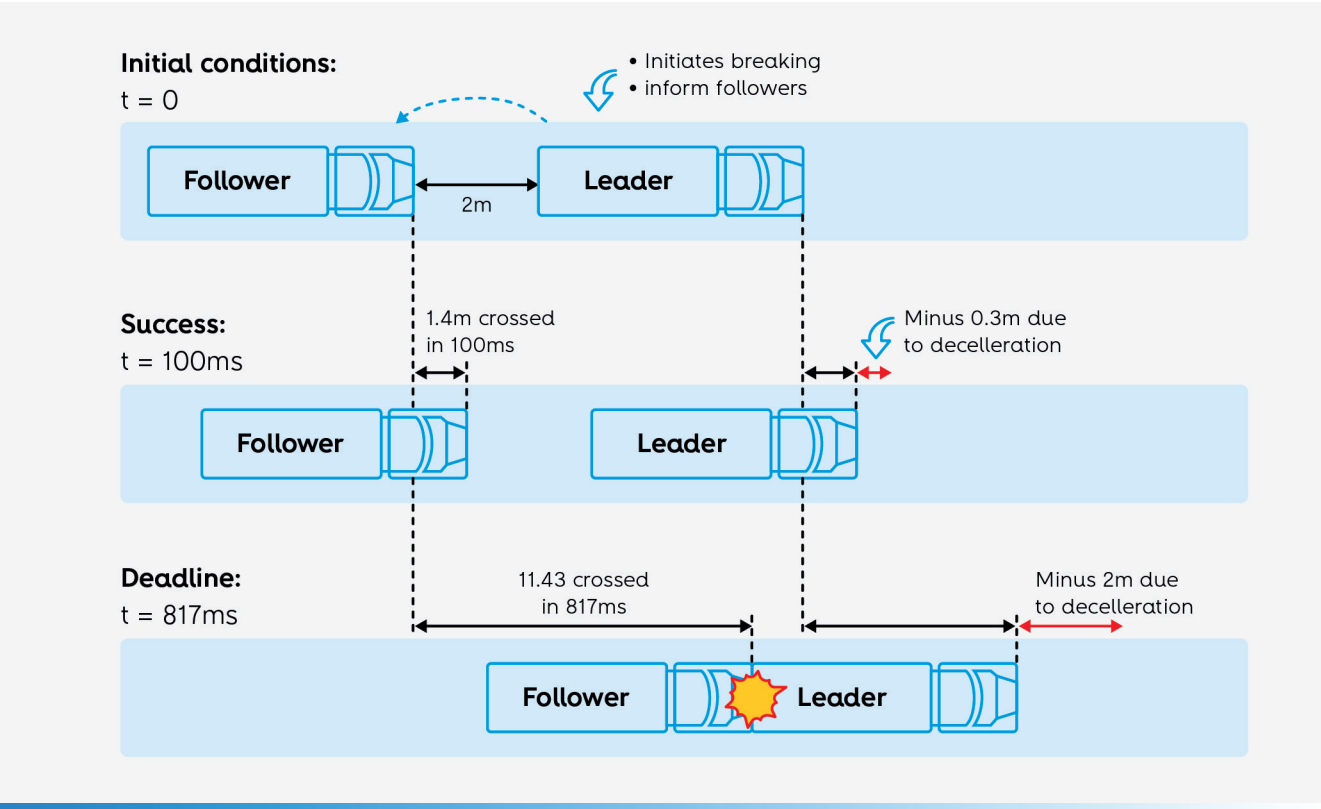


Figure 2 – Platooning emergency breaking



For most of its uneventful itinerary, the platoon will perform handovers between the different mobile 5G cells and/or open networks (e.g. according to signal strength, exact location, etc.). Nevertheless, the network must provide continuous connectivity to the edge datacentres supporting the platoons' internal control operations and coordination with the remaining traffic. Platoon operations include complex kinematics and trajectory prediction calculations that may be carried out at the edge nodes, and coordination with other traffic may consist of intersection coordination and route planning. On the one hand, by leveraging AI/ML technologies the operator will be able to correlate the planned itinerary of the platoon with the infrastructure topology, time of day and expected network traffic, and also making the network to predict when to perform service migration from the initial edge datacentre proactively. On the other hand, the network may continuously monitor and predict the connection quality to the platoon and its vehicles (e.g. if the platoon will enter an area of subpar connectivity). AI/ML will support the run-time operation, through the prediction of wireless channel variations and physical obstacles, the identification and mitigation of potential sources of interference or jamming attacks.

If the network's AI algorithms detects a potential loss of connectivity, it pre-emptively informs the platoon (the driver, if present and in control, and the remote human operator responsible for monitoring the status of the platoons) about the predicted network service quality. In turn, the platoon can adjust its internal processes to the network service level, reducing the connectivity performance requirements (latency and throughput). A safeguard may be in place, to safely immobilise the platoon or a subset of the platoon vehicles, in case this communication does not occur correctly.

In conclusion, this support infrastructure, enabled by 5G and edge computing, will be critical for a variety of applications where the platoon is required to engage in communication with the network and other vehicles, such as:

- **Transmission of tracking data to the logistics management site**, for safety and efficiency reasons, with rich multimedia content (e.g., live video feeds);
- **Engage with traffic management systems** (or ITS), for services such as lane merging, reversible lane or safe intersection management, and in coordination with other road-users;
- **Be alerted to unforeseen or dangerous events during these ITS processes**, such as unexpected obstacles, temporary roadblocks or accidents in a specific section of the itinerary.

## Conclusions

As presented in the section “5G: the next generation services platform”, 5G is expected to support use cases that need cellular connectivity. But it goes even further, defining a 5G Core able to connect other wireless (including non-3GPP, e.g. WLAN) and wired access technologies. Thus, 5G targets a wide range of use cases, even those currently suited to be served by fixed technologies. 5G, based in 3GPP Release 16 specifications, associated to edge computing and the latest implementation technologies, is deemed to provide the required performance to address the most demanding scenarios like the identified vehicular use cases (V2X). However, if in ideal conditions, 5G has all the ingredients to fulfil those requirements, the real world is more challenging, with internal and external factors affecting network behaviour. To overcome that, AI and ML components play an essential role, sensing, mining, predicting and reasoning situations, being relevant building blocks of future autonomous 5G networks.

Unexceptionally, many V2X applications will exploit AI and ML, complemented by advanced C-V2X communications. That will allow vehicles to sense and connect to the surrounding environment and remote service platforms, creating use cases that go well beyond the simple individual, isolated and autonomous vehicle, as presented in section “AI and ML for 5G V2X scenarios”.

The marriage of a universal communications platform, enabled by 5G based C-V2X communications, with correlated AI/ML algorithms, running at the network and services levels, is the only possible way for the consistent exploitation and smooth execution of advanced use cases, like vehicles platooning, described in the “Platooning use case” section.

As so, presented C-V2X based platooning use case, is one of the most demanding applications of 5G, edge computing and AI/ML-based management and orchestration mechanisms.

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