Fifth Generation Communication Automotive Research and innovation

White Paper
5GCAR: Executive Summary

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Abstract

In order to reduce the number of road accidents and enhance road safety, vehicles should be able to observe what is happening around them, foresee what will happen next, and take protective actions accordingly. This requires that vehicles have the ability to exchange messages with each other. V2X is one kind of solution which can be considered as a wireless sensor system that allows vehicles to share information with each other via communication channels. Compared with standard onboard sensors (such as radar, LIDAR, lasers, ultrasonic detectors, etc.) the utilization of a V2X system can get information out of sight, testing hidden threats, expanding the scope of the driver's perception, and as a result improve driving safety, efficiency and comfort as a result of driving automation. Cellular-V2X (C-V2X) is therefore also considered more than ever to be one of the key enablers of cooperative automated driving. Today, vehicles are equipped with a range of sensors, driver assistance and safety related systems. Safety and comfort have been further improved by adding cellular communication capabilities to millions of cars and this number is growing rapidly. Many of the use cases described in existing specifications and other documents are already implemented using existing cellular network connections. For example, cellular networks already enable features like slow or stationary vehicles in traffic ahead warnings, road works warnings, weather conditions, hazard warnings, in-vehicle signage and speed-limits. The telecom industry and the 3GPP standards organization in particular have analyzed the ITS use cases and have derived related requirements to LTE and 5G. The 5G V2X, complements cellular connectivity between vehicles and networks/cloud (V2N) with connectivity between vehicles and other vehicles (V2V), road side infrastructure (V2I) and also pedestrians (V2P). In particular, enabling direct V2V and V2I communications in and off network coverage as well as the availability of a proven evolution of cellular network generations are essential steps to support all ITS use cases with a single cellular network technology, keeping the costs in the vehicle at a minimum. C-V2X which refers to smooth evolution from LTE-V2X to 5G V2X will not only support existing use cases but will also enable completely new applications which will increase traffic safety, transport efficiency and driving comfort to a level which cannot be achieved with the traditional ITS communication technologies. Since C-V2X relies on 3GPP cellular technologies which have proven ability to adopt to market needs and retain continuous compatibility over several generations of systems, Cellular industry believes that C-V2X is a superior technology which has the potential to realize the full benefits of C-ITS. It also takes into consideration the huge investment which has already gone into the deployment of cellular networks and will continue to go into their evolution, the large and further growing number of vehicles connected via cellular networks as well as the huge 3GPP based ecosystem of equipment, devices and applications. All those factors will guarantee cost efficient evolution and increasing benefits such as road safety, comfort and traffic optimization.

This white paper describes the V2X roadmap in Europe, architecture to support V2X communications, gap analysis and finally we provide our recommendations for the major stakeholders.

Contents

List of Abbreviations and Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G PPP	5G Private Public Partnership
5GAA	5G Automotive Association
5GCAR	Fifth Generation Communication Automotive Research and innovation
ACC	Automated Cruise Control
AD	Autonomous Driving
ADAS	Advanced Driver Assistance System
AF	Application Function
AI	Artificial Intelligence
AMF	core Access and Mobility management Function
AR	Augmented Reality
ASIL	Automotive Safety Integrity Level
AUSF	Authentication Server Function
AWS	Amazon Web Services
B5G	Beyond 5G
C-ACC	Cooperative Adaptive Cruise Control
C-ITS	Cooperative ITS
C-V2X	Cellular-V2X
CACC	Cooperative Adaptive Cruise Control
CAD	Connected Automated Driving
CAFÉ	Cleaner Air For Europe
CAM	Connected Automated Mobility
CAPEX	CAPital Expenditure
CES	Consumer Electronics Show
CP	Control Plane
CPM	Cooperative Perception Message

DSM	Digital Single Market
DSRC	Dedicated Short-Range Communications
ECU	Embedded Control Unit
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
FCC	Federal Communications Commission
GDPR	General Data Protection Regulation
GSA	Global mobile Supplier Association
GSMA	Global System for Mobile Communications Association
GW	Gateway
HD	High Definition
HMI	Human-Machine Interface
IaaS	Infrastructure as a Service
ICV	Intelligent and Connected Vehicle
IoT	Internet of Things
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunication
IP	Internet Protocol
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
KPI	Key Performance Indicator
L	Level
LIDAR	Light Detection And Ranging
LTE	Long Term Evolution
MEC	Multi-access Edge Computing
mmW	millimeter Wave
MNO	Mobile Network Operator
MUX	Multiplexing

NF	Network Function
NFV	Network Functions Virtualization
NFV-O	NFV Orchestrator
NGMN	Next Generation Mobile Networks
NLOS	Non-Line-Of-Sight
NRF	Network functions Repository Function
NSSF	Network Slice Selection Function
NW	Network
OEM	Original Equipment Manufacturers
ONF	Open Networking Foundation
OPEX	OPerating EXpense
OS	Operating System
OTA	Over The Air
PC5	Proximity Services (ProSe) direct Communication interface 5
PCF	Policy Control Function
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RAT	Radio Access Technology
Rel	Release
RRM	Radio Resource Management
RSU	Road Side Unit

SAE	System Architecture Evolution
SDA	Strategic Deployment Agenda
SDN	Software Defined Network
SL	Sidelink
SM	Smart
SMF	Session Management Function
SP	Service Provider
SPAT	Signal Phase and Timing
TC	Technical Component
TSP	Telecom Service Provider
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
Uu	Air interface between base station and UE
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User
VRUP	VRU Protection
WLL	Wireless Local Loop
WRC	World Radio Conference

1 Introduction

Research and Innovation efforts in Connected Automated Driving (CAD) and automation have been significant in the last ten years to develop, test and validate several technologies, systems and applications aiming at increased road safety and better traffic efficiency Technological solutions are available but they have reached different levels of maturity; they need to be integrated in the ecosystem of automated transport and we still need to make a significant step going from Advanced Driver Assistance System (ADAS) to higher levels of Automation where connectivity helps a lot for cost-efficiency.

CAD comprises of a large set of challenges as complex automotive technology, but also human behaviour, ethics, traffic management strategies, fair competition, or liability issues. For this reason, the development of policies and regulations are needed that allow to blend the new reality of mobility with industrial policies, ecologic and energetic transition, social and employment challenges or the evolution of the logistic chains to intermodal smart models. CAD must therefore take a key role in the European Transport policy, since it can support several of its objectives and societal challenges. In particular, traffic safety is of key importance and CAD shall ensure safe interaction with all road-users in mixed traffic environments, especially with Vulnerable Road Users (VRUs). Likewise, acknowledging the challenges related to cross-border interoperability, the public sector recognises the need to foster mutual recognition policies and coordination for the development of cross-border and cross-sector experiences. In this sense, it must be pursued to guarantee the interoperability in relation to infrastructure elements, positioning systems and signalisation, among others. Additionally, common certification criteria and its mutual recognition for the implementation of open road tests is considered of key importance as a homogenization element and for the reduction of technical and bureaucratic barriers.

5GCAR has pioneered 5G radio and network improvements which will help to realise reliable 5G networks needed for the support of CAD as characterised above. The project has proven the suitability of improving purely sensor-based driving by increased safety and comfort of drivers and passengers. In terms of costs, 5GCAR believes in a more cost-efficient and powerful solution for Non-Line-Of-Sight (NLOS) scenarios at 5G enabled perception ranges, see Figure 1-1.

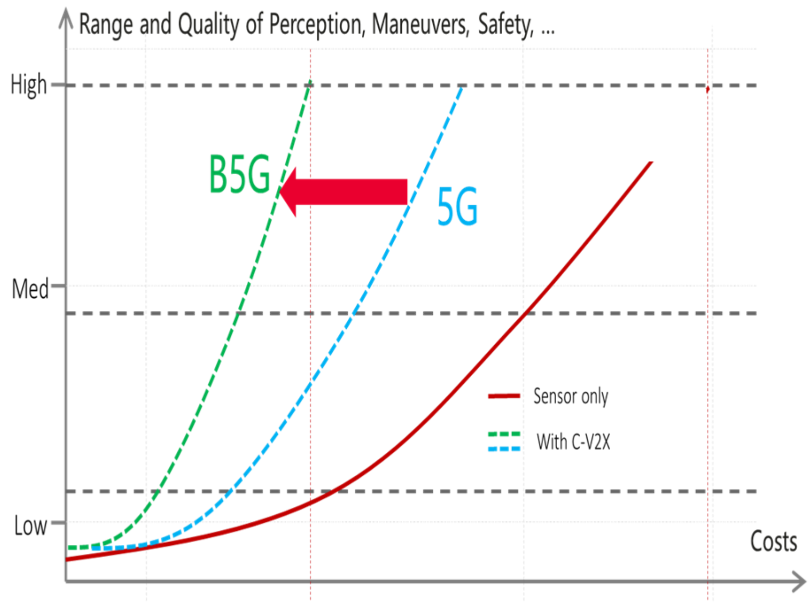

Figure 1-1: More cost-efficient solution at 5G (B5G) enabled perception ranges.

For the updated business and regulatory environment in 2nd half of 2019, we have stated several major topics which will be further addressed in 2020 and potentially beyond:

A. For business aspects, 5GCAR had a large impact on 3GPP Rel-16 contributions where 40 technical proposals (Tdocs) helped to drive the timely completion of the SI in February 2019 and WI by end of 2019.
B. 5GCAR created the business vision for 5GCAM highways with a profound technical and financial analysis which was published twice with a worldwide resonance and is now the kernel of the baseline document for the Strategic Development Agenda (SDA) being maintained now by DG CONNECT.
C. Through its worldwide visibility, 5GCAR helped to reject the proposed Delegated Act on 8th July 2019 which has ensured that 5GCAR visions are relevant to the C-V2X long term strategy for Europe. Many partners are also active in 5GAA which is perceived as the major show stopper of the DA.
D. FCC chairman has recently proposed to use 20 MHz for C-V2X and another 10 MHz channel for either C-V2X or DSRC [FCC19].
E. In October 2019, Volkswagen has officially launched the latest Golf model equipped with ITS-G5 technology. The European Association of Automotive Suppliers has published a position paper [CLEPA18] on short range technologies remarking the need of supporting the coexistence, the interoperability and compatibility of the different technologies and against the segmentation and segregation of the 5.9 GHz, a vision opposite to the latest public statement form the FCC chairman on this regard.

In Europe one of the future challenges is transportation and infrastructure. We believe that the results from 5GCAR provides an important piece of the puzzle to address these future challenges.

2 V2X roadmap in Europe

In [5GCAR19-D23] V2X use cases have been analysed and depicted into a multi-axis vector roadmap for the next decade. The autonomous driving level is the base of the roadmap. All the levels will coexist due to the automotive life cycle. Connectivity is a complementary sensor to fill the gaps of the on-board sensors, increasing safety and comfort. Automotive industry agrees on considering level 4 as the first one where connectivity may become a must.

The 3GPP natural evolution with coming releases will provide new features to enable the most stringent automotive driving levels. However, it has to be remarked that there is a delay between completion of a 3GPP release and the arrival of first chipset on the market that naturally impacts the adoption by the automotive market which prefers to consider mature technologies.

GSMA, [GSMA419], provides several interesting figures for 5G deployment and adoption forecasted in 2025. In the short term, over a fifth of the world's markets will have launched 5G by 2020. On the coverage perspective, a third of the world population will be 5G covered by 2025 and referred to the 5G mobile phone subscription penetration, an overall 15% is expected in the same year. Focusing by regions, this rate goes up to the 50% in some countries (58% in South Korea, 48% in Japan and 47% in North America) and will be around 30% in Europe. Even if the mobile market is very dynamic, the 5G footprint will not be the majority of the subscriptions in 2025. Due to the automotive product cycle, this will be slower in the case of the 5G adoption for V2X. Moreover, no specific coverage is forecasted, the figures provided are in terms of population and not in terms of surface or even roads covered. Even if in some countries (like in Germany or France) the latest frequency auctions has come with requirements about throughput availability in roads and highways.

Use case classes are positioned in this roadmap in white boxes, Figure 2-1, highlighting in green those analysed in 5GCAR [5GCAR19-D23]. In the AD levels, level 5 starts before than level 3 or 4 due to the deployment of driverless level already now in private road or campus, mainly used in shuttles. However, the real level 5, i.e. on open roads, is expected in the second half of the decade. Level 3 can be considered close in the market arrival for some OEMs even if the legal framework of this level is not available yet. Level 3 will not be conditioned by connectivity. Level 4 should arrive to the market in the first half of the next decade.

In [5GCAR19-D52], real-world challenges of the use cases from [5GCAR19-D21] are summarized, based on field tests executed in scope of the project. In essence, the use case realizations showed good potential in the field tests, but it's also clear that the performance impact and implications of protocols above IP must be considered and understood, especially when considering scalable and inter-operable backend solutions with a natural evolution path, as is envisioned for the future of V2X.

Having a look at the two other main regions for the connected and autonomous driving deployment: US and China, it seems clear that China will be faster in their roadmap deployment due to the plan defined and committed by different actors. Indeed, China selected V2X technology and thanks to government push, it is moving forward quite fast. In the US, the selection of technology was originally favouring DSRC (Dedicated Short-Range Communications), though since the new administration has arrived, discussion was blocked and reopened the door for C-V2X. In Europe, hard debate occurred, as for instance the discussion around the delegated act can witness. A possible effect of this debate, in US and in Europe would be to slow down the adoption of any of these technologies and a delay in the roadmap deployment, at least compared to Asia.

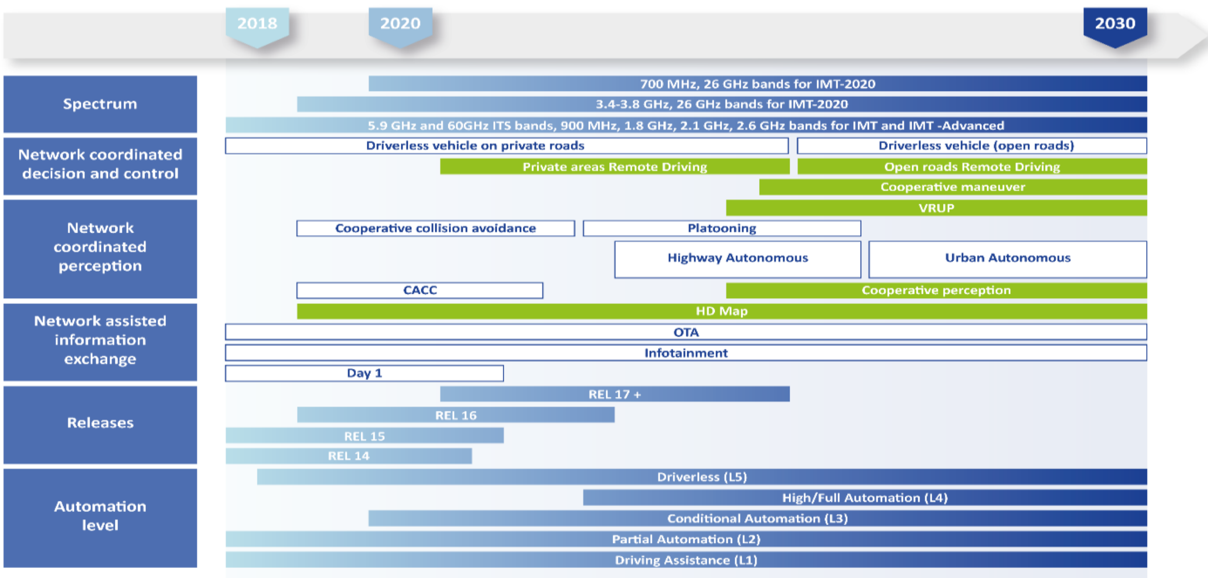

Figure 2-1: Automotive use case roadmap [5GCAR19-D23].

Worldwide the timetable for high autonomous driving levels is being postponed with no clear engagement on the market dates availability [DESI19]. This confirms the difficulty of the exercise done in the previous figure. In Europe, one important regulation factor is deriving an important part of the R&D engineering and economical resources of the OEMs in the short term. From the First of January 2020 the regulation 2019/631 will start applying. It is known for its acronym CAFÉ which stands for Cleaner Air For Europe [CAFE19].

The car industry is very cost sensitive, despite the relatively high product price compared to other consumer products. Additional cost on material/software/licensing side, that makes up the total product cost, is not added without a rigorous review and business justification (business case; legal/regulatory, customer functional value) process.

In its latest mobility transformation manifesto [ACEA19], ACEA asks the regulators to adopt a roadmap for the introduction of increasing levels of automation. This roadmap provided in the project can be used as one of the sources for this task.

3 Architecture: RAT, core and application

In this section we have outlined the potential involved stakeholders of a CAD ecosystem:

1. Content / Service Provider for navigation, maps, tolling. In particular HD maps need continuous updates by vehicles and must be aggregated and re-distributed to others in a certain time span.
2. Travel Service Provider (SP) for car sharing, ride sharing, platooning partners. This SP organizes which vehicles will collaborate for a certain period like platooning, will provide trust and payment processes.
3. ITS service provider for ITS platform and enabling assisted / automated / autonomous driving. Traffic incidents or traffic efficiency information must be collected, processed and distributed for local road users. This covers day 1, 2, 3 and 4 (safety, sensor sharing, trajectory exchange, maneuver alignments) use cases being supported by ITS SPs.
4. Traffic management service provider. These stakeholders provide path recommendations for road users to minimize or avoid traffic congestions. It includes public information for road construction zones, traffic incidents and other city restrictions defined by local authorities.
5. V2X network operator. Besides providing connectivity it provides computational processing power for distributed data centers including MEC. It can be a Virtual MNO which provides global roaming agreements and provides a single point of mobile access for vehicles.
6. RSU network operator. Operating RSUs usually falls into the domain of road operators or traffic authorities by providing e.g. services like SPAT (Signal Phase and Timing) used by traffic lights. These RSUs are located at intersections or at hazardous road sections to avoid accidents. However, MNOs can also provide such services in a much more cost efficient manner.
7. OEM with 5G connectivity. Basically, all new cars will carry 4G and later 5G V2X modules which can benefit from CAD services.
8. Platform operators for aggregating all stakeholders. Stakeholders are usually independent of platform providers (e.g. data centers). A concrete example is Amazon Web Services (AWS) as neutral host.

In the following architecture, Figure 3-1, we have integrated all stakeholders and show their role. To be defined are the exact service (level) agreements and business case for each stakeholder. As a consequence, it could be that some services will be provided by one business stakeholder to increase cost efficiency and revenue.

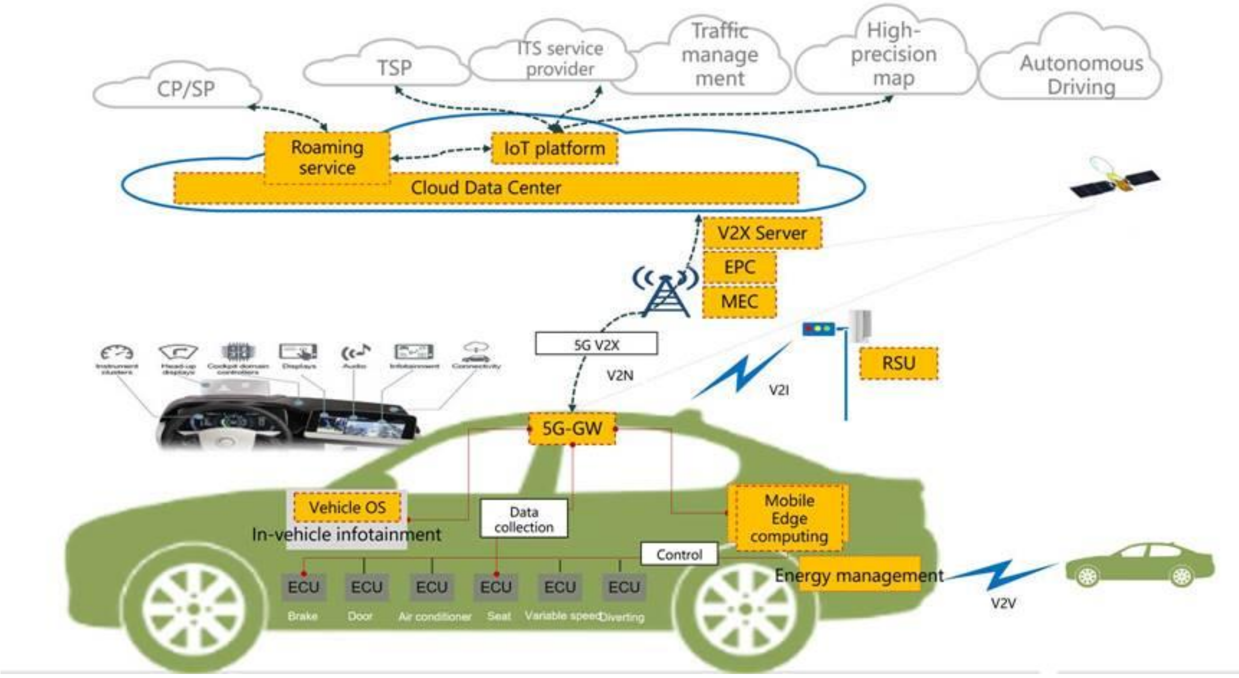

Figure 3-1: Integrated network and stakeholder architecture.

In the following we detail the 5GCAR network architecture which can be seen as a sub-architecture to the integrated network and stakeholder architecture:

Automotive applications include a wide set of services, offered by different stakeholders (as illustrated just before), each imposing a specific set of requirements. Network slicing has been recognized (3GPP, ETSI, GSMA, NGMN, ONF) as a key element to realize widely different services on a common and shared infrastructure. Given that these services impose specific set of requirements, for V2X scenarios, vehicles shall be served, at any given time, by a collection of network slices, each instantiated by the mobile service provider with characteristics appropriate to support the related service.

The concept of multi-tenancy is notably leveraged in vehicular applications, wherein the tenant is the subject (company, vertical, or service provider) who benefit from the services supported by one slice, or one set of slices. In the 5GCAR project we considered a network slicing architecture with MEC capabilities serving three tenants: a MNO, a local road authority player and a generic car manufacturer. This example solution of network slicing configuration for V2X services is depicted in Figure 3-2.

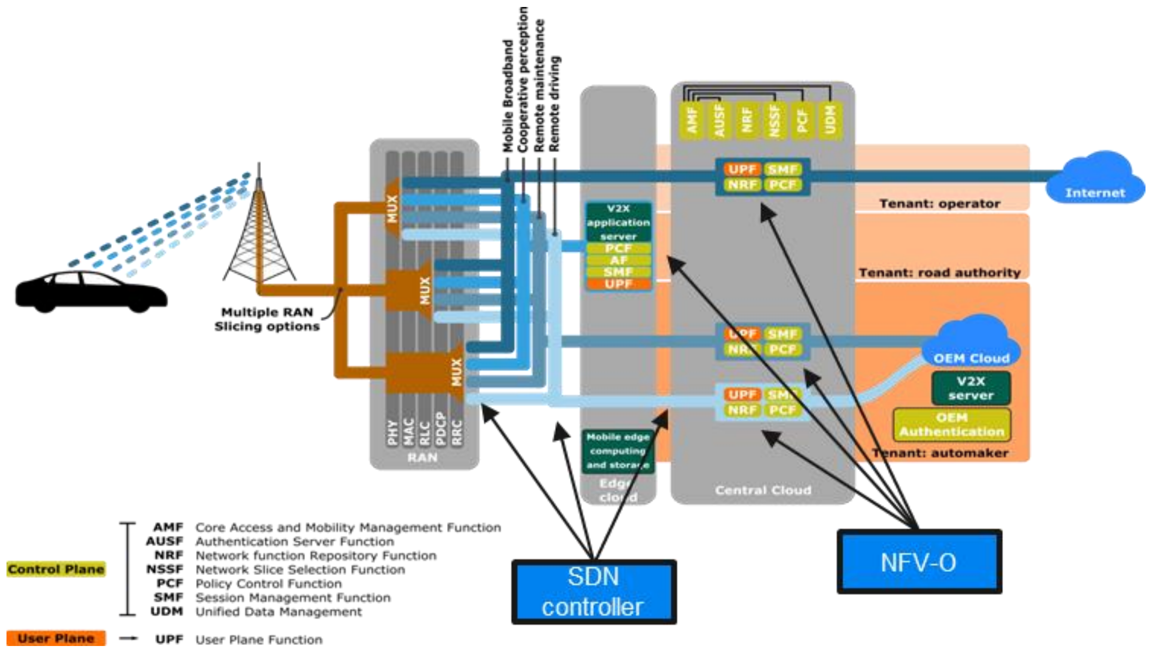

Figure 3-2: Example of typical V2X network slicing configuration [5GCAR19-D42].

The system illustrated in Figure 3-2 provides an example configuration of a sliced communication system consisting of multiple logical networks for different automotive service domains. Both the RAN and the core network domains are shown, with the latter being split into edge cloud and central cloud, to reflect the geographical locations where network functions can be deployed. The RAN illustrates the three possible option for RAN slicing we briefly introduced in [5GCAR19-D42]; the edge cloud contains the network functions that may be allocated in proximity of the UEs, such as the Multi-access Edge Computing (MEC) and storage; finally, the central cloud contains the control functions common to all the slices within the same network (illustrated in the upper part of the figure), and the slice-specific NFs for use cases that require connectivity with the Internet or with a public network.

This solution relies on a set of slices which are already standardized by the 3GPP. Indeed the current set of 3GPP slices were considered enough flexible to address V2X services and applications. The 5GCAR project proposed also an integrated NFV/SDN architecture for V2X network in connection with the proposed network slicing solution for V2X.

Within 5GCAR project, technical and non-technical issues brought by V2X requirements that challenge the current architectural conception were identified. Then 5GCAR elaborated technical components each dealing with a specific limitation, and finally combined them into the 5GCAR architecture. These technical components can be seen as modules, each dealing with a specific limitation of the current 5G service-based architecture. In that way, they were developed considering the 3GPP Rel-15 architecture as baseline. The impact of each technical solution on the existing service-based architecture was studied.

The following categories, also illustrated in Figure 3-3, have been the focus of the architectural enhancements introduced by 5GCAR architecture technical components:

- End-to-end security, addressing security and privacy enablers
- Network orchestration and management, incorporating Infrastructure as a Service (IaaS) for vehicular domain
- Network procedures including Road Side Unit (RSU)-enabled Smart Zone (SM-Zone), Fast application-aware setup of unicast sidelink (SL), Location aware scheduling, Evolution of infrastructure-based communication for localized V2X traffic, Multi operator solutions for V2X communications, and, V2X service negotiation
- Edge computing enhancements, incorporating edge computing in millimeter Wave Cellular V2X networks, and 5G core network evolution for edge computing-based mobility
- Multi connectivity cooperation including SL and Uu multi-connectivity, Redundant mode PC5 and Uu, Use case-aware multi-Radio Access Technology (RAT), multi-link connectivity, and Dynamic selection of PC5 and Uu communication modes
- Radio interface (Uu and Sidelink interfaces design)
- Communication-aided positioning

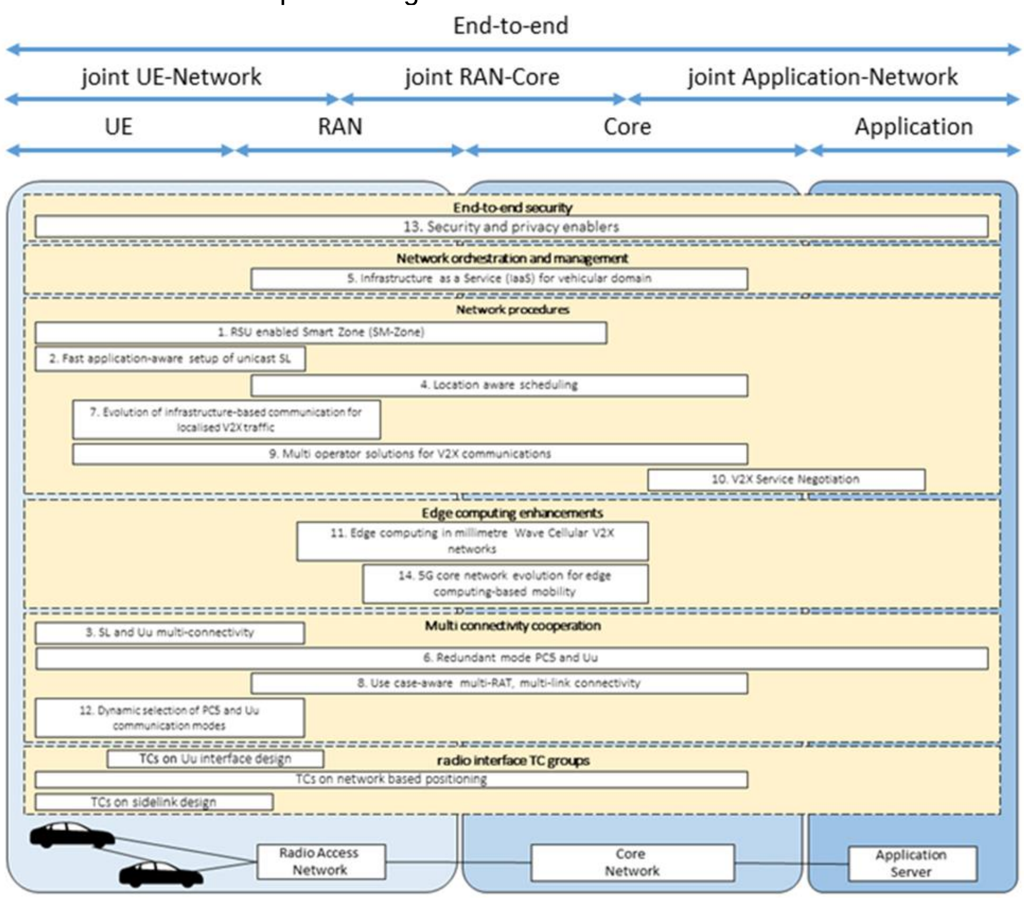

Figure 3-3: 5GCAR end-to-end architecture.

More details on these architectural enhancements can be found in [5GCAR19-D42].

4 Gap analysis

Within 5GCAR, different concepts have been proposed covering various aspects from radio interface to network architecture. From radio interface point of view, the proposed technology components cover three main aspects: Uu interface, sidelink interface and positioning. If looking a bit more in detail, from technical point of view, we have the technology components mainly covering: enhanced multi-antenna techniques, RRM, sidelink design, full duplex, reliability enhancement and positioning [5GCAR19-D33]. It should be pointed out although we have been studied quite broad aspects from radio interface design point of view, there are still quite some work to be completed before applying the proposed concept into real CAD system. From radio interface design point of view, at least the following points need further investigation:

- Performance evaluation of different technical concepts considering legacy restriction
- Implementation efforts: impacts on hardware design have not been addressed
- Deployment restriction certainly will bring impact of the achievable performance
- Co-existence with other potential technologies for example short range communication like Bluetooth in the vehicle
- Integration of 5G radio technology in vehicles for example communication antenna design especially considering high frequency band like mmW.
- Distributed ad-hoc network (especially in case without network coverage)
- Accurate positioning and mobility predication for VRU UEs, HD maps and electronic horizon

From network architecture point of view, [5GCAR19-D42], a list of potential topics of architecture enhancements for further investigation are given below:

- Privacy-related aspects still require further discussions. 5GCAR highlighted that further discussions are needed to understand compliance to GDPR of e.g. CAM/CPM and other issues such as implications of driver/owner consent, etc.
- Multi-link exploitation is a key feature in order to support different use cases with heterogeneous requirements. 5GCAR has proposed enhancements covering optimized network-driven link selection and utilization. Additional work needed to understand implementation challenges
- Multi-operator support is necessary to enable seamless and low latency communication between vehicles and road users in general, regardless of the MNO each single actor is subscribed to. Additional work is needed to understand feasibility of solutions for network re-selection, required agreements, etc.
- Exchange of information between the network and applications is necessary for application adaptation and network optimization to enhance service delivery. Additional

work is needed considering how to tailor the exchange of information for different use cases

- C-ITS messages will be exchanged through multi-domain transport infrastructures and between different actors. Each infrastructure has its own characteristics for example in terms of bandwidth and latency. It is, however, not clear today which are the authorities that should take responsibility to ensure interoperability through multi-domain transport infrastructures and between different actors

In the following we summarize most important points for CAD from technical and non-technical enablers perspectives.

Development and integration of additional technical enablers

In 5GCAR we have addressed methods to improve radio and network KPIs for 5G V2X and in the following we see the need for more improvements:

- Upgrade of existing physical and deployment of digital road infrastructure for future vehicles
- Distributed Functional Safety (involving more than one vehicle)
- Decision and control including AI techniques (object classification and decision strategies)
- Big Data Collection (for example offloading of car sensor data to MEC or backend for storing and analysis needs more public discussions and appropriate solutions)
- HMI (how to avoid overloading of drivers and how to avoid mistakes by driver alarms)
- Distributed vehicles UEs
- Improved positioning including radio and other sensors
- Deterministic networking to guarantee delay limits
- Improved ad-hoc networking for deterministic data exchange
- Context based 5G RRM

Development and integration of non-technical enablers

In the following we enumerate further points and give examples. It is not the intention to have a comprehensive analysis but to outline important aspects:

- Cyber-security (hacking of CAD vehicles must be avoided)
- Regulations (legal driving limitations for CAD vehicles used in different environments / scenarios)
- Harmonized standards for transport protocols in vehicles and V2V (avoid different transport delays due to use of different protocols or parameters)
- Mixed traffic management (manual / automated) – Separate lanes for robots cars only
- Collaboration agreements / methods / data (cross OEM and stakeholder related for harmonized data formats and processing)
- Privacy (keep anonymity of vehicle data when send to other road users or network)
- Data government & exchange (e.g. cross-border)
- Road users interaction (in particular VRUs)

- Traffic management (optimize traffic efficiency)
- Liability (responsibilities of stakeholders and arbitration agreements for malfunctions)
- Mandatory training of drivers / passengers for automated vehicles
- Business models
- Identify additional V2X spectrum
- Centralized fleet management of automated vehicles
- Public acceptance (use of robot cars might lead into higher congestion in some scenarios)

For all these technical and non-technical solution ingredients, we need to develop a test, certification strategy and plan, which organizes CAD testing with efforts and resources from many stakeholders. This can only be successful when all involved subscribe to common goals and aim for the same mobility targets, solutions, services or use cases. When they do, they can develop a shared roadmap, an agenda for testing, tackling the various elements needed to achieve the goals and serving as basis to maximize coherence and complementarities. The definition of common priority use cases; Identification of all functionalities, technical and non-technical enablers and other pre-requisites to make progress with these use cases.

5 Recommendations for stakeholders

In order to reach a successful deployment and adoption of 5G in the V2X domain, all the stakeholders have to be involved. First, the Mobile Network Operators (MNOs) responsible of providing the connectivity as a service with the required performance levels needed for the different use cases. Second, the Original Equipment Manufacturers (OEMs) in charge of defining the needs, equipping the vehicles and taken the advantages of the connectivity to foster the arrival of upper levels of automated driving. Third, the regulators with the key mission to provide a legal framework valid to motivate the infrastructure and service deployment needed for the success of the 5G network in the V2X domain.

Finally, other relevant stakeholders like the telecom vendors or the road operators, must belong to the equation, with the purpose of covering not only the innovation needed to make the technology progress but also to assure a stable and continue service level in the roads.

In this section, relevant recommendations are described for the main stakeholders formerly identified.

5.1 MNOs

5.1.1 Network sharing alternatives

The arrival of 5G will imply important telecommunication infrastructure investments. In order to have a short return over this investment, network sharing capabilities enabled by 5G are one of the key solutions. Four different network sharing possibilities have been identified, namely: passive infrastructure sharing, active infrastructure sharing, excluding spectrum sharing, active infrastructure sharing, including spectrum sharing and core network sharing.

In the active sharing family with or without spectrum sharing, geographical sharing can be added. It could be interesting for a reliability enhancement purpose. Inside a given country, it is called national roaming.

Depending on what national regulators will allow in terms of network sharing, and how willing operators are to use the opportunities provided by network sharing, we will see a major impact on the payback time of the necessary investments. As it seems unlikely that all users will use a single mobile network operator on a single stretch of road, either through regulation or through competitive pressure, network sharing will be important to drive down infrastructure costs in order to make Connected and Automated Mobility a viable business case.

One of the new features of 5G, is network slicing, which may be a good solution for sharing costs in the development where there will be network slice operator to provide a dedicated slice to ITS/ Connected and Automated Mobility services.

MNO should explore and analyze the benefits of network sharing options further than what is has been done in the previous mobile generations, always conditioned by the regulatory framework.

5.1.2 New business models for connected vehicle services

In the latest report from Ericsson [ERIC19], while for the smartphone market the consumer is willing to pay up to 20% more for the arrival of 5G, there are also opinions in the telecom market which claim that the connectivity business opportunities of the connected homes and cars this will not happen if the current model of paying for a bucket of gigabytes is maintained.

In the research of a V2X profitable business case, let's use Over The Air (OTA) updates as an example. OTA is a service where a win-win approach should be possible for both parties: automotive and telecom stakeholders, but it needs a new business model definition to be viable. This is a service promising large value for both end customer, in realizing new features in the vehicle after its initial purchase, as well as for the OEM, as can be seen in Figure 5-1, in being able to fix quality or other issues in the software, without having to bring the vehicle in for expensive workshop visits.

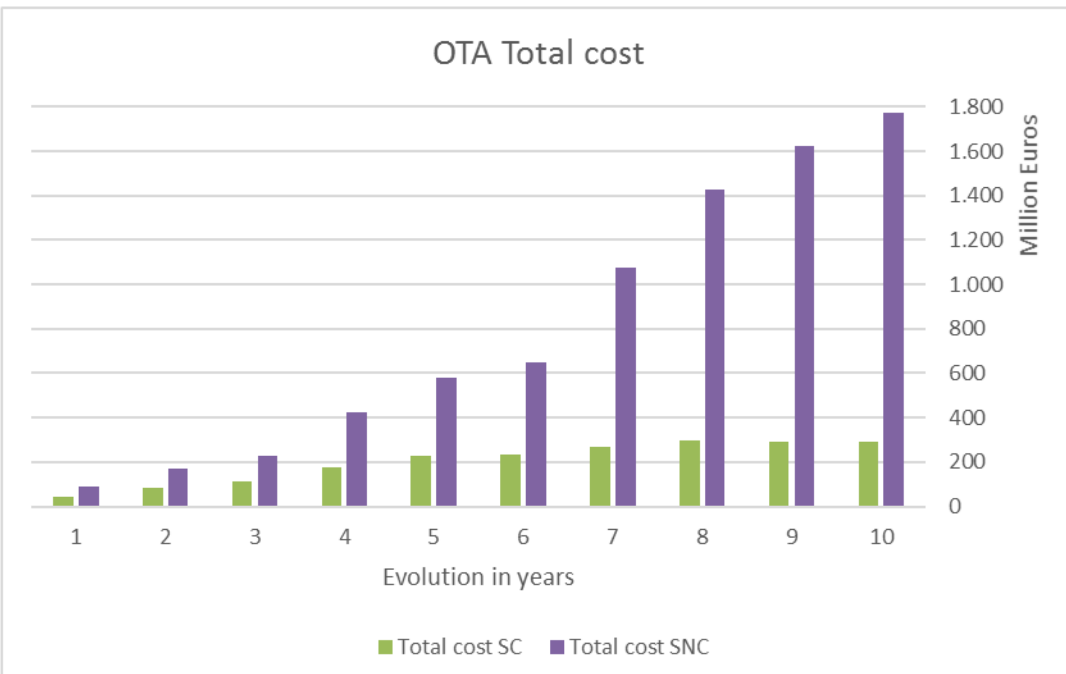

Figure 5-1: OTA total cost [5GCAR19-D23].

In [5GCAR19-D23] different scenarios have been considered and the cost could start from 10€ for the five years update in the conservative scenario to more than 100€ in the non-conservative scenario. The amount to pay is not a negligible cost and it will be the crucial element to evaluate an OTA based software update solution versus the traditional upgrades. The customer will not be willing to pay for this cost, especially if they are related to mandatory updates linked to safety, security or bug correction. Only in the case of new features added in the update, the customer vision of the update value may change.

The new on-board electronic and electric architecture of the next generation vehicles will be able to manage a huge quantity of data. As an example, GM [GMME19] has announced a capacity of processing power up to 4.5 terabytes per hour in its new electrical architecture. In a connected vehicle paradigm more data exchanged on-board will naturally mean an increase in the data off-loading needs towards the environment. This confirms the business opportunity for the telecom market in the incoming years.

5.1.3 Roaming and interoperator cooperation

The administration shall lead the DSM (Digital Single Market) strategy in order to facilitate the mobility for the connected vehicles among different countries reducing roaming impacts in terms of cost (as it has been started on the 15 of June 2017 with the mobile roaming charges abolition) and technical drawbacks. There should be a clear and homogenous solution to allow all vehicles in the same location to receive the same and complete information from a trusted source, which could be provided on the communication plane when possible or service plane respecting the required performances.

The cooperation between operators, vertical partners, equipment vendors, horizontal technology enablers and road operators will contribute to the sustained success of V2X deployments. In order to guarantee seamless service quality, inter-operator coordination would require integration of predictive QoS, protocols used to route high-priority messages with low latency in combination with MEC-enabled distributed computing services and 5G network slicing technology to manage differentiated services. In the case of V2X network slicing framework, the basic set of functionalities for V2X slices would be agreed among all operators through proper orchestration while unlicensed bandwidth could be used for direct V2V, V2I communication in absence of infrastructure. However, it is not yet clear whether there should be any actor coordinating the communication between licensed and unlicensed spectrum.

These important technical and legal challenges have to be solved and the 5G V2X projects such as 5GCROCO (https://5gcroco.eu/), 5GMOBIX (https://www.5g-mobix.com/) and 5GCARMEN (https://www.5gcarmen.eu/) will definitely help to clarify further the technical difficulties and work on the solutions.

5.2 OEMs

5.2.1 Consider connectivity as an off-board sensor enabling information exchange

The automotive industry will adopt 5G as a consumer electronics standard, however the deployment timeline of this technology will be conditioned by the customer benefit, the added value of the new use cases that are not possible with current 4G technology (e.g., automated driving). This is mainly due to the additional costs and the complexity related to the integration of new communication modules and testing them according to the safety critical automotive requirements.

The automotive industry, should not link V2X adoption to the arrival of the autonomous driving, it should be considered as another ADAS sensor, like the radar or the camera. The business model and costs of the AD arrival are not clear yet, so it is very difficult to make the decision of the 5G adoption based on this statement. On the other side, if V2X connectivity is taken into account as another ADAS sensor, enabling a way to easily exchange information of different vehicles could be analyzed as a complement for on-board sensors in human driving cars fostering its adoption in time and volume.

The financial cost of the 5G enabled modem can be soften if a worldwide approach adopting only one technology to be deployed in all regions for the new automotive applications. A fragmentation of the market by selecting different solutions will increase the investment needed for the technology development will in turns results in a delay in 5G adoption. Moreover, the contemporary adoption of different technologies will increase the cost and the technical challenges: physical space, antenna installation, etc.

5.2.2 Automotive standardization

For standardization requirements, it is also important to modify existing automotive standards by including cross-OEM data exchanges for cooperative driving. A lot of standards produced by ISO TC204 WG14 describe current Advanced Driver Assistance System (ADAS) functions, for instance the ISO standard 15622, which defines minimal performance requirements for ADAS, such as Automated Cruise Control (ACC) based initially on a pure on-board sensor/actuators system. During the last five years TC204 standards production is focused on cooperative ADAS such as Cooperative Adaptive Cruise Control (C-ACC) in ISO 20035, which will consider on-board and V2X information to perform a more predictive and enhanced ACC.

Concerning V2X communication standards, ETSI in Europe and IEEE/SAE in US have produced from 2006 to these last years, all the standards necessary to describe the ITS stack, independently of any kind of radio technology. These standards can partly be reused in the context of C-V2X technologies (LTE and 5G), but some adaptations have to be done in the access layers and in stack management, especially to control Sidelink and Uu for an optimal routing of road safety and traffic efficiency messages. However new application protocols are needed to support advanced use cases, e.g. vehicles need to negotiate, and acknowledge actions.

As 5G technology will be used for communications of autonomous vehicles, Automotive Safety Integrity Level (ASIL) A or B software and hardware constraints will be taken in account with respect of an important standard like ISO26262.

5.2.3 Conceive vehicle applications for an on-board and off-board architecture

Since the arrival of the connected vehicle, OEMs have defined a new paradigm in the way of interacting with the off-board world through connectivity, the extended vehicle. The vehicle, can no longer be developed by the OEM as an isolated element, as it is depicted in the figure, now the car drives linked with a part of the OEM cloud thanks to connectivity. The OEM applications have been so far conceived for a central cloud to answer to the customer needs, remote configuration such as thermal precondition or charging activation for Electric Vehicles (EVs), the OEM needs (remote maintenance or OTA) or the traffic relevant information.

With the arrival of 5G, there are two main enablers that have to be considered: MEC and the connectivity as an ADAS sensor. MEC provides new places where the OEM applications can be located in a dynamic way. The architecture of the OEM applications should be ready to create, maintain and destroy instances based on different criteria like the traffic density, hazard events, weather conditions, network performances available or needed and for sure the costs.

On the other side, as it has been clearly highlighted in this section, connectivity is an off-board sensor. This means ADAS applications can no longer be developed with an only on-board vision, the decision-making will be done on-board but there will be complementary information coming from outside the vehicle providing non line of sight information consolidated from different sources as well as new rules learnt from other vehicles.

5.2.4 Millimeter wave experience

The millimeter wave band (26 GHz) has just been harmonized by the EC and shall be completed in all members by the end of March 2020 with effective usage of 1 GHz. In terms of use cases, the only one clearly identified so far is the Wireless Local Loop (WLL) while other possible use cases are related to high definition video and AR/VR. The V2X use cases planned on this band are not consolidated, and there are identified problems with on-board antenna integration that needs to be resolved. 5GCAR has proposed several technological components based on the usage of this band for V2X. The performances of this band are really important but the challenges of the infrastructure deployment and vehicle adoption needs to find a demanding use case. The huge potential needs of data off-load linked to AD and the new on-board electric and electronic architecture shall be considered as a first clue. Future research effort shall be devoted to this task in the OEM side but also from the telco stakeholders. Actually, in the conclusions of the WRC-19 new millimeter wave frequency bands are proposed to be harmonized by 5G [WRC19].

5.3 Regulators

5.3.1 Deployment, coverage, and road infrastructure

To enable the V2X ecosystem a telco infrastructure must be deployed and the roads must have cellular coverage. Some countries have defined strong performances and deployment requirements for the 5G frequency assignation in order to guarantee a minimum throughput in all roads.

Traffic signals and information are already available on the internet in some parts of Europe, but this differs between countries. In most cases, road infrastructures are only partially connected to central control centers and additional upgrades are required before more advanced safety services can be provided. Upgrades for traffic controllers available in the market include additional communication interfaces to allow management, analysis and the provision of more advanced safety services to vehicles. Concerning road infrastructure communication equipment, the policy will differ from one country to one another, and possibly in each country, road operators will have the possibility to choose different technologies to provide V2I safety messages distribution. The 5G Automotive Association (5GAA) have done a study on the economics of different ways to distribute traffic light info and have released a White paper [5GAA19] which shows clear benefits to use existing cellular networks for distribution of traffic light information.

ACEA has published in early September 2019, a 2019-2024 manifesto [ACEA19] describing the key elements of the mobility transformation, where a specific chapter is devoted to demand to the EU making road transport smart and convenient. The main recommendations are related to the removal of regulatory obstacles and enable rapid deployment of digital communications infrastructure (V2X).

The required rollout investments, business models and revenues–on which 5G V2X deployment is strongly dependent–are still unclear. Without clear economic benefits, MNOs (including Road infrastructure operators) will not be encouraged to start network deployments in areas where only ITS services are expected to be delivered.

A first estimation of network deployment costs in terms on investment in network infrastructure and operation (CAPEX and OPEX) and revenues of a 5G C-V2X roll out along a motorway has been provided by the 5G-PPP Automotive work group [AWG219]. This work can guide the 5G C-V2X community on the level of required demand and service fees.

There is an ongoing Strategic Deployment Agenda (SDA) work, [SDA19], on how 5G can support Connected Automated Mobility (CAM) in Europe.

5.3.2 Simplify and harmonize regulation

A topic that has been high on the agenda of the EU commission is the Delegated Act [DACT19] being drafted under the Intelligent Transport Systems Directive (Directive 2010/40/EU). This document sets the framework conditioning the uptake of C-ITS and AD in Europe. The final version for public consultation was released in January and finally rejected in July 2019 There were important concerns by some industrial players since it was not committed to technology neutrality, as it favored a specific and single-purpose Wi-Fi based technology path (ITS-G5). Meanwhile, Ford has made an announcement in January 2019 at the Consumer Electronics Show (CES) for massive C-V2X deployment from 2022 for USA. In Europe Volkswagen has launched the latest Golf generation equipped with ITS-G5. These facts will have important implications in terms of a desired interoperability requirement. In China, the government has taken the decision for C-V2X adoption, with a roadmap proposed in terms of 5G deployment for ICV (Intelligent and Connected Vehicle) strategy, 13 national OEMs will deploy this technology between the end of 2020 and the beginning of 2021 [HUAW19].

C-ITS services must comply with the EU law on the protection of personal data, in particular the General Data Protection Regulation (GDPR). This is a delicate topic not clearly solved yet, one example to be evoked is the CAM transmission. As a consequence, vehicles manufacturers may have to provide the ability for a driver to disable V2X. GDPR applicability to V2X should therefore be clarified, and for the sake of safety-related applications, regulation should allow a minimum set of information to be always sent by devices installed in vehicles or other road user equipment. The problem shall become also a barrier for MEC deployment. Inside Europe, if CAM corridors are promoted from the EC, the data from different servers in different countries shall move without restrictions.

As another example, the security strategy proposed for broadcasting ITS messages based on pseudonyms supposes an important market opportunity but at the same time there is a cost to be applied to each car which cannot be neglected [5GCAR19-D23] and shall become another barrier for the sidelink communications adoption on the OEM side.

5.3.3 Data sharing and monetization

GDPR has become a worldwide reference regulation for preserving the people privacy in the digital domain. This has provided a legal framework answering the concerns of many citizens in the use of their personal data from internet companies.

The internet giants successfully master the data monetization. OEMs, especially since the arrival of the connected vehicle, and MNOs manage a lot of data from its customers. These two sectors are strongly regulated domains with high demands, not applied at the same level to other communication services. This has already been recognized by the EU and there are activities ongoing to modify this situation, see e.g. [MWL17].

On the other hand, the regulation shall provide room for enabling profitable business models based on the digital data, always respecting the GDPR principles. As an example, let's consider the recent and pioneer study in Europe demanded by the Spanish government to the three main MNOs in the country (MOVISTAR, ORANGE and VODAFONE) [ELPAIS19]. The objective of the study was to analyze the mobility main trends of the Spanish citizens during a few days between July and December to learn important lessons to improve the public services. The data used is anonymized, and respects the GDPR requirements. However this has supposed a big controversy from the public opinion. If the EU wants to be relevant in the digital domain, the data exploitation has to be allowed respecting the needed controls and the legal demands. Data is the base of the artificial intelligence and machine learning technical domains and if this information source is not used, the EU will lag behind other world regions and its internet titans.

5.3.4 Spectrum aspects

The European Union is leading 5G band auctions with other regions like South Korea and USA. Important telecommunication markets such us Italy, Spain or Germany have already done part of this process, with an important spectrum quantity made available, as it can be checked in Figure 5-2.

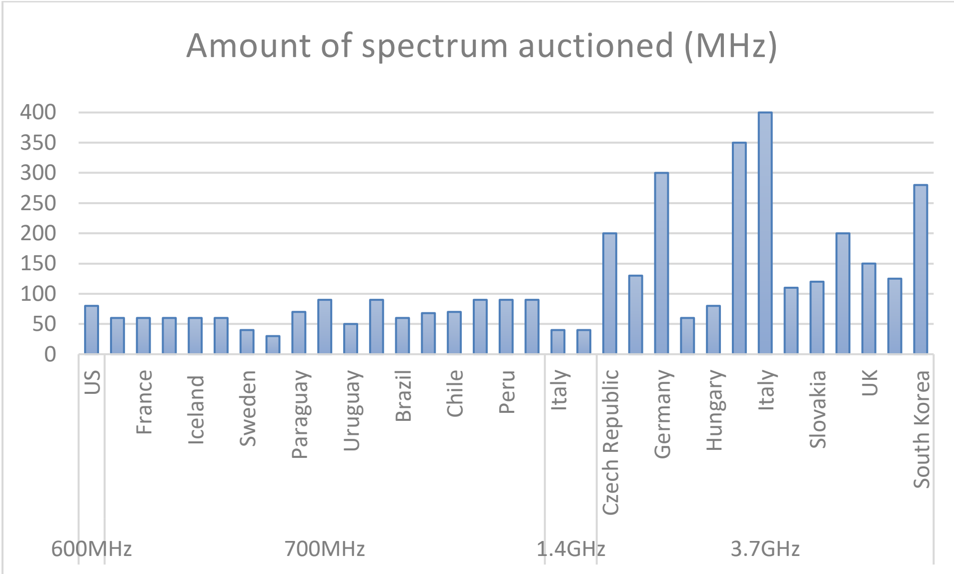

Figure 5-2: The amount of 5G spectrum actioned per country [5GCAR19-D23].

Focusing in Europe, the refarming of frequencies which are currently being used in 2G/3G and 4G is under consideration in many countries. The main candidates to be used for 5G are the 3G bands of 2.1 and 2.6 GHz since the allowed bandwidth in these bands is a good fit for 5G services. This band is harmonized in Europe and can be potentially refarmed to be used in 5G for supplemental downlink. It is widely used for IMT applications due to its good coverage in outdoors scenarios and buildings [GSMA115]. This should be promoted by the regulators and coordinated under the umbrella of the DSM framework.

The GSMA has released a report [GSMA217] centered in Europe where the main conclusions is that higher prices are associated with more expensive, lower quality mobile broadband and irrecoverable losses in consumer welfare. This is even more important for V2X communications, where the cost will become a major stopper for 5G adoption.

The 700 MHz band has interesting opportunities for improving the cellular network coverage, due to its propagation properties, and could be especially interesting for V2X use cases, as it was shown in [5GCAR19-D22]. This band will be made available in Europe from 2020 on. In the spectrum auctions made so far, the case of Italy should be remarked, because the prices per Hertz of this band reached a notably high value. This will be a barrier for new use cases in this band, such as V2X, due to the need for operators to get an important return over the investment made in these frequencies. The example from Asia should maybe be taken into account, where the deployment has been prioritized over the price of the frequency bands.

Some entities like GSA and FCC, are looking for new frequency bands beyond the ones described in the previous paragraph, but even if they are finally harmonized and assigned, there will be an important time to market for any of them.

In spite of the expectations of the DSM for a common framework in the frequency allocation, the truth is that there is no common European definition for the frequency auctions which are done at a national level. Some countries have defined strong performances and deployment requirements for the frequency assignation while others have no requirements at all. Even if entities like GSMA have provided some auction best practices [GSMA319], finally there is no harmonization in the process. This should be a priority for the regulators

On the unlicensed spectrum side, the 5.9 GHz band still provides doubts about the European adoption. After the Delegated Act rejection, the uncertainty remains. The contexts keeps evolving without any strategic vision which will delay the sidelink adoption and shall become a major issue for the automotive 5G adoption in the case of a ITS-G5 market deployment. In October 2019, Volkswagen has officially launched the latest Golf model equipped with ITS-G5 technology. The European Association of Automotive Suppliers has published a position paper [CLEPA18] on short range technologies remarking the need of supporting the coexistence, the interoperability and compatibility of the different technologies and against the segmentation and segregation of the 5.9 GHz, a vision opposite to the latest public statement form the FCC chairman on this regard [FCC19].

5.4 Other relevant stakeholders

5.4.1 Suppliers and certification

Due to new V2X requirements, we need new network and radio features which can be provided to mobile network operators, car OEMs, data center operators and road operators. Others like software providers for AI processing and HD map providers are part of the eco-system. The integrated CAD solution needs certification to ensure societal demands and safety. However, due to different regulations worldwide, we will see different market scenarios and involvement of before mentioned stakeholders.

All ingredients provided by equipment or software vendors must provide certified components for the CAD end-to-end solutions. However, it is still unclear which certification requirements and related business cases will be needed for CAD. A potential workflow for certified CAD vehicle and network is proposed in Figure 5-3.

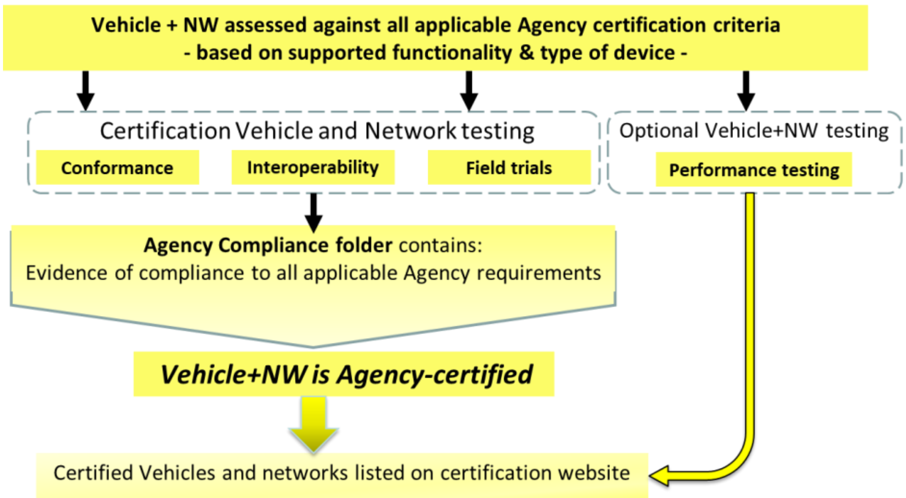

Figure 5-3: CAD certification process for combined vehicle and network (example).

We expect that there is no single body / agency today that can offer a global approach to the certification of C-V2X and involved vehicles. The CAD agency in specific countries must maintain a conformance assessment programme for CAD standards comprising of automotive and telecom standards.

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