Fifth Generation Communication Automotive Research and innovation

Deliverable D2.3
Automotive use cases and connectivity challenges, business models and Spectrum related aspects

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Executive summary

In this deliverable, an overall V2X use case roadmap has been built together between the automotive and the connectivity industry. Beyond some predictions exposed, a detailed analysis of the current 4G situation is explained, providing also the main advantages of 5G compared to 4G and its current limits for a successful deployment.

A business section is included where a summary of the new version of the automotive working group is analysed, deriving important conclusions both for the automotive and telecom industry. In the same section, 2 cost vectors are studied: security cost of the current pseudonym strategy proposed in the Delegated Act (DA) and Over The AIR (OTA) market size. Both can be seen as business opportunities for actors in the connectivity value chain as well as cost penalties for a V2X deployment in the automotive industry. In the same section, all the new features provided in 5GCAR are analysed under a business perspective, providing a qualitative vision of the technological components and remarking the value chain, the customer value and the business possibilities of each.

Finally, the current status of 5G new spectrum bands auction is provided with a comparison between different countries and how they have evolved. The frequency refarming is explained as one the future trends and the important event of the WRC2019 is described. The 5GCAR features spectrum impact is also studied as well as the spectrum used in the demonstration.

Contents

List of Abbreviations and Acronyms

2G	2nd Generation of Mobile communication technology standard
3G	3rd Generation of Mobile communication technology standard
3GPP	Third Generation Partnership Project
4G	4th Generation of Mobile communication technology standard
5G	5th Generation of Mobile communication technology standard
5G-PPP	5G Public Private Partnership
5GAA	5G Automotive Association
AA	Authorization Authority
ACC	Adaptive Cruise Control
ACK	Acknowledge
ADAS	Advanced Driver Assistance System
AD	Autonomous Driving
ARCEP	Autorité de Régulation des Communications Electroniques et des Postes
ASIL	Automotive Safety Integrity Level
AT	Authorization Token
BTS	Base Transceiver Station
C-ACC	Cooperative ACC
CAFE	Cleaner Air For Europe
CAM	Cooperative Awareness Messages

CAPEX	Capital Expenditure
CEPT	Conférence Européenne des Postes et Télécommunications
C-V2X	Cellular Vehicle To Everything (X)
DA	Delegated Act
DENM	Decentralized Environmental Notification Message
DOT	US Department Of Transportation
DSRC	Dedicated Short Range Communications
DTT	Digital Terrestrial Television
E2E	End to End
EA	Enrolment Authority
EC	European Commission
ECU	Embedded Control Unit
EEBL	Electronic Emergency Brake Light
eMBB	Enhance Mobile Broadband
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GDPR	General Data Protection Regulation
GSA	Global mobile Suppliers Association
ICV	Intelligent and Connected Vehicle

IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
ISO	International Organization for Standardisation
ITS	Intelligent Transport System
KPI	Key Performance Indicator
LKA	Line Keep Assist
LOS	Line Of Sight
LTE	Long Term Evolution
MNO	Mobile Network Operator
MWC	Mobile World Congress
NF	Network Function
NHTSA	US National Traffic Safety Administration
NLOS	Non Line Of Sight
NR	New Radio
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OTA	Over The Air
PA	Park Assist
PKI	Public Key Infrastructure

PTS	Swedish Post and Telecom Authority
QoS	Quality of Service
RAT	Radio access technology
REL	Release
RLAN	Radio Local Area Network
RSC	Radio Spectrum Committee
RSPG	Radio Spectrum Policy Group
RSU	Road Side Unit
SDU	Service Data Unit
SPAT/MAP	Signal Phase and Time and Map Data
UE	User Equipment
URLLC	Ultra Reliable and Low Latency communication
V2I	Vehicle 2 Infrastructure
V2N	Vehicle 2 Network
V2V	Vehicle 2 Vehicle
V2P	Vehicle 2 Pedestrian
V2X	Vehicle 2 Everything
Wi-Fi	Wireless Fidelity
WRC	World Radio Communication

1 Introduction

This report is the last report of the work-package in 5GCAR project dealing with scenario, requirements, spectrum and business perspective. It provides an update of this global context identified in the beginning of the project. Indeed, the overall context of the connected vehicle has evolved since the last two years.

Vehicles have been connected to the OEM backends using the cellular networks since several years back, these connections are used for telematics and to some extent for ITS services, e.g. sharing warnings. Technologies for short range technologies in vehicle exist since more than 10 years (for instance the old 802.11p technology originally defined for ITS system, or more recently the LTE based Cellular V2X) but none of them were deployed apart from public founded trials mostly because there was not any valid business model justifying the level of investment required to enable them. In the recent years, two drivers are changing the overall picture of connected vehicle. The first driver is the rapid evolution and adoption of cars becoming more and more autonomous: we reached nowadays level 3 of autonomy moving forward to level 5, following the well-known taxonomy of driving automation levels defined by SAE (Society of Automobile Engineers). It is understood that above level 3, connectivity will become almost mandatory to support long-lasting autonomy.

The second driver is the universal and massive deployment of cellular technology and the advent of 5G. Though first 5G trials and deployment target the mobile broadband use case (smartphone), 5G opens the door to imagine and prototype future uses cases for the automotive industry. Going much beyond initial Intelligent Transportation System (ITS) services (the so-called DAY1 services), cellular based connected vehicle could support more advance use cases, supporting more and more the road of autonomous car towards level 5 of autonomy.

Still, rapid and wide deployment of such novel use cases could happen if and only if the context becomes favourable. In this report we analyse main elements of this context: use case roadmap, business opportunities, spectrum aspects and to some extend key regulatory elements.

Commercial deployment of connected vehicle, towards autonomy level 5 is a very complex problematic like a long hurdle path, some barriers being technical, others economical, others political, etc. Within the 5GCAR project, technological components were proposed to solve some of these barriers, proposing and demonstrating wise approaches. More precisely, this report tries to provide a snapshot of the status of project's member consideration with respect to actual deployment of such technology, not hiding the forthcoming difficulty.

1.1 Objective of the document

The objectives of this report are therefore:

- To provide an update of the previous report, considering the latest evolution of external context as well as the maturing opinion of project members;

- To propose a list of V2X use cases deployment in the 2020 to 2030 horizon according to the 5GCAR project opinion;
- To identify challenges preventing fast deployment of connected vehicle;
- To discuss business opportunities and illustrate the technological components worked out in 5GCAR project can help in facilitating their deployment;
- To provide an up-to-date overview of spectrum landscape while the new 5G bands auctions are ongoing with a special zoom in Europe, and a focus on the spectrum impacts of the technical solutions proposed in 5GCAR.

1.2 Structure of the document

Section 2 is devoted to the automotive use case and the connectivity challenges and it is divided into 5 subsections. These subsections are:

- Section 2.1 gives an overall forecast of the automotive use cases and connectivity features with a vision of the market trends and expectations
- Section 2.2 provides the 4G possibilities and its limitations for V2X use cases
- Section 2.3 gives a vision of 5G advantages compared to 4G
- Section 2.4 remarks the main stoppers for a 5G successful deployment in the automotive industry
- Section 2.5, makes a summary of 5G PPP KPIs and the KPIs used in 5GCAR

Section 3 is devoted to the business, it is divided into 2 subsections. These subsections are:

- Section 3.1, provides some business market opportunities related to Connected and Automated Mobility and network sharing options, security costs and OTA market possibilities
- Section 3.2, is a business model analysis of the technological components proposed in 5GCAR.

Section 4 is devoted to the spectrum analysis, it is divided into 2 subsections. These subsections are:

- Section 4.1, covers an updated vision of the 5G auctions worldwide with a special focus in Europe.
- Section 4.2, provides spectrum considerations about the technological components provided in 5GCAR

Section 5 joins the conclusions of the three previous sections combining the 5G status for V2X deployment, the business key aspects and the main spectrum remarks.

2 Automotive use cases and connectivity challenges

The automotive sector is today under an important revolution due to two main changing factors: electrification and connected and autonomous driving. It is always complicated to define a roadmap, but in the current automotive situation is even harder. In section 2.1 a 10 years roadmap of automotive use cases and connectivity is presented. Then, in sections from 2.2 to 2.4 4G and 5G are compared, remarking the advantages and difficulties of 5G. Finally, in 2.5 a vision of the 5GCAR KPIs is made under the global definition of 5GPPP KPIs.

2.1 Use case roadmap in the 2020-2030 time horizon

In this section an updated vision of the automated driving use cases in Europe will be given based on the public elements available, the trends in the market and the vision of the members of the project from different sectors: mainly automotive and telecommunication worlds.

Independently of communication standard evolution, or rather in parallel, there is a roadmap of deployment of automated vehicle features

There are several systems for Automated Driving level 0 and level 1 (As classified by SAE: [SAE J3016]) on the market today:

ACC – Adaptive Cruise Control

The cruise control system with “automatic distance control ACC” uses an on-board sensor to measure relative distance and relative speed of vehicles driving ahead. The driver sets the speed and the required time gap with dedicated commands. The ACC target relative position can be shown on a dedicated display.

ACC / Stop & Go

Adaptive cruise control with stop & go function includes automatic distance control (speed range 0–150 km/h) and, within the limits of the system, detects a preceding vehicle. It maintains a safe distance by automatically applying the brakes and accelerating. In slow-moving traffic and congestion, it governs braking and acceleration.

C-ACC (Cooperative ACC)

In addition, if V2X is deployed on a consequent number of vehicles, the ACC function can take benefit of vehicle to vehicle communications or infrastructure to vehicles to enhance its longitudinal control. A NLOS/LOS detection of V2X vehicles and their manoeuvres can allow a smarter and more predictive reaction of ACC. If the vehicle also is connected, some contextual speeds and headways can be suggested to the V2X vehicles. The deployment of this type of function has been announced recently by Toyota, but it is not yet available on the market.

PA – Park Assist

Park Assist automatically steers the car into parallel and bay parking spaces. The system assists the driver by automatically carrying out the optimum steering movements in order to reverse-park on the ideal line. The measurement of the parking space, the allocation of the starting position and the steering / longitudinal movements are automatically undertaken by the Park Assist through the embedded sensors (ultrasonic, body cameras) to actuators control chain. Like all other Level 0 and 1 systems, this means that the driver supervises the control of the car at all times.

LKA – Lane Keeping Assist

Lane Assist automatically becomes active from a specific speed (normally from 50 km/h) and upwards. The system detects the lane markings and works out the position of the vehicle. If the car starts to drift off lane, the LKA takes corrective action, or informs the driver of the need to take corrective action.

Some premium OEMs like AUDI have claimed to have begun to deploy Level 3 Automated vehicles, even if some recent information contradicted that, concerning the US market [CNET19], where main functionalities are the following:

Traffic Jam Chauffeur (Level 3)

Conditional automated driving in traffic jam up to 60 km/h on motorways and motorway similar roads. The system can be activated in case of a traffic jam scenario. It detects slow driving vehicle in front and then handles the vehicle both longitudinal and lateral. Later version of this functionality might include lane change functionality. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at all times override of switch off the system. Note: There is no take over request to the driver from the system.

Highway Chauffeur (Level 3)

Conditional Automated Driving up to 130 km/h on motorways or motorway similar roads. From entrance to exit, on all lanes, including overtaking. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at all times override or switch off the system. The system can request the driver to take over within a specific time, if automation gets to its system limits. An electronic horizon provided through an embedded HD map is necessary to enhance ADAS sensor's perception and to allow smoother and more predictive automated control of vehicle. This HD map has to be refreshed as often as possible, to warn the system about road modifications (roadworks, road geometry…). For that a highly reliable connectivity (e.g., 4G or 5G) has to be used along all the Highway Chauffeur trip.

Furthermore, there are foreseen use cases that can benefit from higher automation level.

Highway Pilot (level 4)

This mode is basically a Level 3 automation which would have a more strategic control of the vehicle. There is no request from the system to the driver to take over when the system is in normal operation area (i.e. on the motorway) so before any Level 4 trip activation a predictive knowledge of connectivity quality along the planned trip can be taken as a strong advantage to determine whether to authorize Level 4 or not.

Driverless (level 5)

This mode is the full autonomous mode, where no driver is needed. For the deployment of this level, 3 steps are identified. First, in private or close roads (a campus, a factory, etc), with a controlled environment and with a well-known start and end of the trip. There are today many initiatives already ongoing in such environments. Second, in certified roads, ie in part of public roads where safety requirements are fulfilled. Finally, in open roads and in different environments: highway, rural and urban. Remote driving is the solution proposed to fill the gaps of the level 5, taking the control remotely in the situations where the autonomous car will not be able to follow.

In [5GCAR-D21] V2X use cases have been classified in Use cases classes, now the idea is to make a relationship of their deployment according to a multiaxis vector and for the next ten years.

The autonomous driving level will be the base of the roadmap. All the levels will coexist due to the automotive life cycle. As it has been already highlighted in 5GCAR, 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 to respect the requirements of this level, where the car has to be able to drive without any intervention of driver.

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. For instance, it can take several months from a consumer grade equipment to the availability of the equivalent module being automotive grade. The example of release 14 and release 15 could be a good approach to estimate the arrival of future features. Release 14 started its development in September 2014 and was finalized in June 2017. Moreover, the next release (Rel.15) started its development in June 2016 and ended in June 2018. If both releases are compared in terms of chipset availability and market arrival there is an important difference. On one side, automotive grade chipsets for release 14 mode 4 have arrived in the market in late 2018 or the beginning of 2019. These chipsets must be integrated by a tier1 into a communications module which will be adopted in a commercial vehicle. So far, in the US only Ford [FORD119] has made a public announcement for a C-V2X deployment in 2022, however in China 13 national OEMs will deploy this technology between the end of 2020 and the beginning of 2021 [HUAW19]. On the other side, release 15 Non-Stand Alone (NSA) was approved in December 2017 and in early 2019 smartphones 5G ready were already presented in MWC2019 and are now available in the market. Currently, Rel16 is being developed (started in August 2018) with a sidelink procedure and it is expected to be finished by June 2020. It has been already decided to have the next release (Rel. 17) in March 2018, but both the development starting date and the potential end date have not been decided yet.

GSMA, in its latest mobile economy report [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. Important conclusions can be derived from these figures. 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.

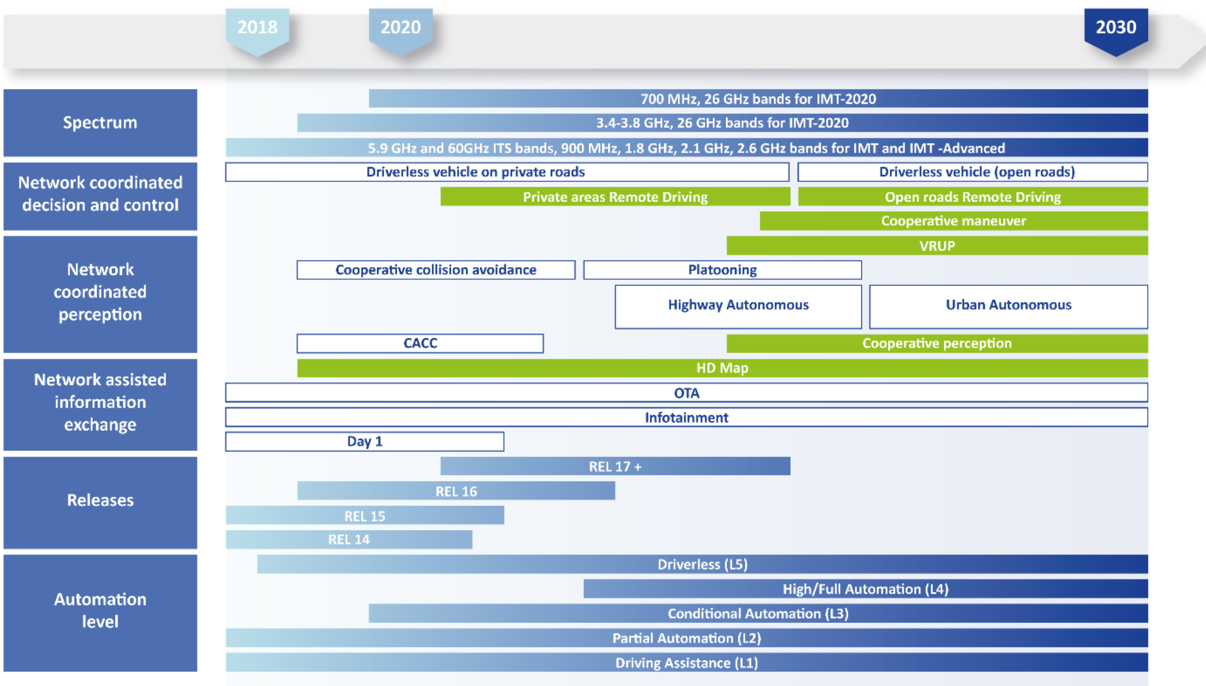


Figure 2.1: Automotive Use case roadmap.

In Figure 2.1 the AD levels and the 3GPP releases are represented as the base of the roadmap. On the top of it, appear the spectrum bands and a time reference. The releases are represented based on the specification dates, until the expected arrival into the automotive market. Use case classes are positioned in the roadmap in white boxes, highlighting in green those analysed in 5GCAR.

In the AD levels, level 5 start 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.

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 V2X. In Europe, hard debate occurred, as for instance the discussion around the delegated act can witness. Finally, it seems that ITS-G5 (EU equivalent of DSRC) was finally preferred for short term deployment, which does not prevent major companies and EC to endorse C-V2X based technology to support more advance use cases. 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.

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]. This new legal framework has defined ambitious emission level reductions over the next decade with a first milestone in 2021. The EU fleet average emission target for new cars will be 95g CO_2/km while the average value in 2017 was 118,5g CO_2/km. This limit will apply to each OEM according to the average emission of the vehicles sold in the market. The penalty for not respecting this limit will be of 95€ per each g/km of target exceedance. As an example, for 1 million cars, keeping the same average emission of 2017 in 2021 would suppose a penalty of 2.232 million €. The challenge for the industry is huge and it is currently the main technical and economical priority in the development product cycle.

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. Some of the costs evoked in the business section, will need strong arguments from a business perspective in order to be included in the product.

2.2 4G current situation

2.2.1 Performance limits

Today the practical End-to-End (E2E) latency in typical Long Term Evolution (LTE) networks is tens of milliseconds in the connected state, and longer when starting from an idle state. As discussed in [5GCAR-D21], to support demanding V2X use cases, the achievable E2E latency should be substantially reduced, down to 5 ms or even shorter; which will require the introduction of new technologies.

Although 3GPP LTE is capable of offering solid performance to mobile devices, supporting mobile broadband and current multimedia applications, it fails satisfying requirements of certain demanding new automotive applications, which arose after its definition. In particular, there are several aspects wherein LTE represents a bottleneck for Vehicle-to-Everything communications (V2X):

Latency – certain safety-critical automotive applications require the delivery of messages with latencies lower than those that are supported by the current LTE frame structure and the radio access protocols;

Throughput – vehicles are expected to host several data-rate demanding applications, including evolved Mobile Broadband (eMBB) to support, e.g., remote driving applications. Combined, these data flows can generate more traffic than what LTE can support in a scalable manner, both in uplink and in downlink.

Reliability – certain safety-critical applications require ultra-high reliability coupled with very low latencies, which cannot be guaranteed by the LTE radio access and core networks. LTE technology lacks the end-to-end notion of reliability with a strict deadline (i.e., maximum tolerable latency), although it offers a hybrid retransmission mechanism which is used to handle error correction when the applications can tolerate some delays.

Quality of Service (QoS) – the variety of applications involved in the vehicular domain implies that at any given moment, a vehicle might be transmitting and receiving multiple data flows, each with its own QoS requirements. The LTE core network lacks the required granularity to manage the QoS per each flow, and does not provide the instruments to provision the QoS in a scalable way.

Non Flexible Radio Configuration: new use cases and services with diverse requirements should be supported at the same time, which requires more adaptable radio and core network solutions than those offered by LTE.

Packet Core Constraints: in LTE the authentication and session management is access dependent as it is connection-oriented and uses a bearer concept clamping on a single network serving all devices regardless of their requirements. An improved core network is needed to address unified procedures for authentication & session management, flow-based QoS and devices to support multiple network slices. A cloud-native solution for an explicit linkage to cloud-based mechanism will be needed.

Roaming and Multi-operator: In a pan-European definition of telecommunication services, roaming is a feature of paramount importance, particularly in the case of V2X communications, where the terminals move over large distances. Due to the design of the LTE architecture, two main challenges arise in this context: seamless transition of a service between countries, and roaming devices using home routing, meaning that traffic from a roaming device is routed all the way through the core network of the home operator. Clear drawbacks are identified in the current home routing procedure, including the delay introduced due to the longer communication path and the fact that QoS agreements established with the home network might not be honored for roaming UEs. Moreover, the LTE core network does not provide any distributed computation capability to bring the server closer to the network.

Surface Coverage: The EU has very good LTE coverage and data rates when related to the population, [OPE18]. However, if coverage is rather measured in terms of surface, the values falls to very poor or even non-existing coverage in many areas, e.g., in rural areas. This makes supporting V2X communications along highways in rural areas very challenging or even impossible due to poor coverage.

Spectrum: The frequency bands currently used by LTE cannot meet future demand driven by exponential growth in mobile data demand as well as the increased reliability and latency requirements arising from automotive and V2X applications. The spectrum bands agreed worldwide are mainly focused in three different bands: 700-900 MHz, 2.3-2.6GHz and 2.1GHz (for Asia). The concentration of the frequencies around these bands limits the number of future use cases that can be enabled using LTE.

Physical Layer: The LTE framework is quite rigid in terms of subcarrier spacing numerology, since it was primarily designed for mobile broadband services on traditional cellular bands with carrier frequencies up to a few GHz. However, to accommodate new and diverse services a flexible numerology strategy is needed.

Interface Selection: A vehicular OEM has to define rules for the usage of the different interfaces available (Wi-Fi, LTE, etc.) that depends on different considerations, such as economical prioritization, service level agreements, and bandwidth requirements. LTE networks lack features to enable optimum interface management according to the service definition needs, which creates difficulties for the vehicular OEM to manage V2X use cases, infotainment, and telematics services efficiently.

2.2.2 V2X ITS services supported by 4G

4G provides a mobile environment suitable for Day-1 basic safety messages in the V2N (vehicle to network) scenarios or even in the V2V by transforming them into V2N2V with lower performances. Examples of these services are given in Table 2.1.

Table 2.1: ITS uses cases possible over 4G.

Use Cases	Type	Message over 4G cellular*
Slow or stationary vehicle	V2N2V	DENM
Traffic jam ahead warning	V2N2V	DENM
Road works warning	N2V	DENM sent by traffic management
Adverse Weather conditions	V2N2V	DENM
Slippery road	V2N2V	DENM
In-vehicle signage	N2V	Msg. sent by traffic management
Probe-vehicle data	V2N	Msg. sent by vehicles
Traffic sign priority (designated veh.)	V2N	Msg sent by emergency vehicles
Green Light Optimal Speed Advisory	N2V	SPAT/MAP sent by traffic light control
Pedestrian/ animal on the road	V2N2V	DENM
Wrong way warning	N2V	Msg. sent by traffic management

These use cases do not need ultra-low E2E latency. One of the main reasons is that Day-1 services provide information to the human driver who cannot notice the difference between single and two digit millisecond latencies. Both are perceived as “instantaneous”. Based on this, even other pure V2V use cases like e.g. Electronic Emergency Brake Light (EEBL) or emergency vehicle warning could also be deployed over 5G with lower performances. Furthermore, also in case of information not intended for the human driver, suppose we require that a V2X event has to be announced in a shorter time than the temporal horizon provided by embedded sensors (camera, radars), that implies that a maximum latency of 4 seconds (equivalent to a distance of 150 m at 130 km/h) would be acceptable. However, as explained above, there are important limitations: 4G is not able to cope with some more demanding use cases.

2.3 5G advantages

2.3.1 Performance

The coming 5G networks are not only bringing an incremental step in network performance, but a transformation in capacity, latency, throughput and flexibility far beyond what can be delivered by today’s networks. 5G provides a very ambitious set of improved performances:

- Targeted data rates up to 20 Gbps.
- Low end-to-end latencies about 5 ms.
- Ultra-high reliability with block error rate of 10^{-5}.
- Very large density of connected vehicles (for urban environments, the vehicle density can be up to 3000 vehicles/km^2).
- Positioning accuracy in the order of cm.

Since the very beginning of 5G design, vertical use case and applications are taken into consideration. As one specific example, Ultra-Reliable Low-Latency Communication (URLLC) is developed to support critical machine-type communications. Applying URLLC to V2X, a significantly lower E2E latency than today's 4G networks is achievable, enabling advanced use cases.

In addition to the clear advantage in terms of reduced latency and enhanced reliability, 5G networks also have high potential to deliver many times higher peak and average data rates than 4G networks that are adaptable to support an extreme diversity of use cases at massive scale. Thanks to network slicing, separate virtual networks will be defined for different services, making it easier to fulfill the reliability and availability needs.

2.3.2 New architecture paradigms

5G architecture breaks ground with respect to the previous generations starting from its very definition: the design of the control plane in 5G is centred around services rather than around interfaces, and Network Functions (NFs) are defined, instead of network entities.

The flexible architecture offered by 5G will enable the deployment of a range of new connectivity paradigms, involving the connectivity with multiple links over multiple Radio Access Technologies (RATs). Notably, three novel paradigms are considered: link selection, dynamic link switching, and convergence. Link selection is a control plane mechanism, enabling the UEs and the network to choose the most optimized link to support a given application. This mechanism is extended by the dynamic switching, wherein the link is dynamically changed to better respond to the application requirement, considered the instantaneous traffic conditions at any point in space and time. Finally, convergence is an architectural pattern enabling the simultaneous exploitation of multiple links over multiple RATs, with the different flows being combined higher in the protocol stack.

The flexibility offered by 5G further opens to architectural extensions enabling latency reduction and ensuring QoS stability over different network load conditions. Notably, low level routing and local breakout will significantly shorten data path, maintaining it closer to the UEs thus reducing packet delivery delay. Network slicing will significantly optimize the core network and radio resource management, enabling the simultaneous support of diverse traffic flows with different requirements over a shared infrastructure.

This new architecture still faces technical challenges and issues for the management of V2X applications. Some of the major problems are managing multiple access connectivity, slice management, network resiliency, security and data privacy, accurate location and roaming between operators. 5GCAR has provided several technological components to face these issues and improve the 5G architecture definition for V2X. The technological components available in [5GCAR-D33] and in [5GCAR-D42] are mainly defined for link and network related innovations dealing with seven major categories of contributions, namely "radio interface", "communication-aided positioning", "network orchestration and management", "network security", "multi connectivity cooperation", "edge computing enhancements", and "network procedures", to push the advantages of 5G for V2X communications.

2.3.3 5G roadmap

LTE V2X features were specified in 3GPP starting from support of basic safety use cases in Rel-14 (finished in June 2017). In particular, the V2X support provided by Rel-14 makes LTE a suitable technology for meeting the requirements of the ETSI for delivering traffic safety messages such as Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM). Cellular-V2X direct communications (technically known as PC5) or sidelink benefits from being based on technology intended for high-speed mobile applications and has been further improved specifically for automotive use cases.

To expand the LTE platform to meet the evolving requirements of the automotive industry, the initial set of technical enablers provided by Rel-14 was enhanced in Rel-15. The first release of 5G NR specified in 3GPP Rel-15 (finished in June 2018) is targeted to support enhanced mobile broadband (eMBB) and ultra-reliability low-latency communication (URLLC). No specific features are defined for V2X in 3GPP Rel-15 5G NR specifications, although deploying V2X services via 5G cellular network can enjoy the basic NR features for eMBB and URLLC. Based on that background, 3GPP RAN plenary #80 in June 2018 [3GPP18] approved a study item on NR V2X. This study item aims at enhancing the NR system and designing a new and more flexible sidelink (i.e., direct communication link between vehicles) to meet the stringent requirements of the advanced V2X services that cannot be supported in earlier 3GPP releases or other technologies, e.g., those based on 802.11p.

Starting from 3GPP Rel-16, NR V2X features will be supported and continuously enhanced in the later releases to enable more advanced vehicle related services, covering frequency ranges for both below 6GHz and above 24GHz (up to 52.6GHz). It should be noted that NR V2X is not designed with the intention to replace services offered by LTE V2X. Instead, the NR V2X will complement LTE V2X for advanced V2X services and support interworking with LTE V2X. From the compatibility point of view, NR V2X will be designed to support forward compatibility, i.e., the NR sidelink framework would allow easy extensions to support the future development of further advanced V2X services.

The NR V2X Sidelink (SL) design reuses some of the basic LTE SL schemes to support both UE autonomous resource allocation and network scheduled resource allocation. The UE autonomous resource allocation can be enabled either in network coverage or out-of-coverage with pre-configured or network configured resources pool respectively. The network scheduled resource allocation can only be applied in network scenario, but is expected to provide better support of QoS due to coordination of the resource usage by the network.

The 5G/NR SL design will enable all transmission types, including unicast, groupcast and broadcast, in order to support more variable and advanced V2X services, while LTE V2X SL technology only supports broadcast V2X services. In addition, 5G/NR SL design will introduce the physical layer feedback for SL link adaptation and efficient ACK/NACK feedback based HARQ as well as more sophisticated QoS management over SL rather than only priority based QoS control as in LTE V2X SL. All of these aspects will make 5G/NR V2X technology outperform LTE V2X as well as 802.11p, which has worse performance in terms of reliability according to the study in [5GAA18].

2.4 Show stoppers

2.4.1 Lack of deployment, coverage, and road infrastructure upgrades

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. Investments on such infrastructure upgrades are required and are highly dependent on the existing conditions and infrastructure already deployed. 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.

In the context of C-V2X technology (5G including R16), road operators and telecom operators will have to deploy their infrastructure in compatible conditions with the requirements of the OEMs. Particularly, for telecom operators, the challenge will be to support, through their communication networks, different types of requirements in term of latency, throughput and quality of service. This will depend on the customers and the services to be provided, ranging from Automated Driving (with stringent reliability and latency requirement), to next generation infotainment services (associated to high amount of data, such a video streams). 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. According to the former study, which is based on simplified assumptions, a good return on investments has been observed under certain conditions, particularly if there is some level of infrastructure sharing. But it also depends on connectivity costs and the expected market demand in terms of ITS services.

2.4.2 Complex status of 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 has been released in January and it still raises concerns by some industrial players since it is not committed to technology neutrality in its first release, as it favors a specific and single-purpose Wi-Fi based technology path (ITS-G5). However, the Delegated Act in article 33 states that the EC shall analyze technical specifications and information on degree of maturity and compatibility of any innovative solutions to the one contained in the Delegated Act without undue delay and start discussing the file in an expert group within two months, in view of a possible amendment of this delegated Act for ITS. The implication of interoperability requirement on the technical solutions cannot be clearly interpreted and it may become a blocking point for C-V2X introduction in Europe. The Delegated Act was approved by EU parliament with thin majority. It does not come into effect since the European Council decided [DACT219] to extend the time limit for raising objections by two months until the 13th of July 2019.

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 the USA, development for V2X has so far been focused on Dedicated Short-Range Communication (DSRC), which is based on the IEEE 802.11p standard. From the US National Highway Traffic Safety Administration (NHTSA), there has been a notice of a proposed rulemaking [NHTSA17] to mandate V2V communications for new light-duty vehicles and to standardize the format and performance requirements of V2V messages, where DSRC was seen as the primary candidate technology. It does however not rule out other technologies. Now, the US Department of Transportation (DOT), is opening up a Request for Comments: V2X Communications [DOT18], requesting information from all stakeholders in light of the development of C-V2X, which indicates an open attitude from US authorities to continue evaluating the best technology for V2X services. 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.

The Delegated Act also has a section about “Fundamental Rights”, which emphasizes that C-ITS services must comply with the EU law on the protection of personal data, in particular the General Data Protection Regulation (GDPR). Unfortunately, the Delegated Act missed the opportunity to lay down the legal bases for a compliant usage of V2X.

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.

2.4.3 Lack of automotive industry adoption

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 financial cost of the 5G enabled modem can be soften if a worldwide approach adopting only 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.

2.4.4 Missing 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, acknowledge actions etc.

Due to the fact that 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.

2.5 5GCAR KPIs in the context of 5G

5GCAR is an H2020 5G PPP project that is part of a joint public and private effort for the definition of upcoming 5G networks. As a single project, it needs to collaborate with other projects in order to fulfil the desired and publicly available Key Performance Indicators (KPIs). In this section we relate, map and discuss the previously described KPIs in [5GCAR-D21] towards this whole program KPIs.

2.5.1 Performance KPIs

Performance KPI focus on the KPI related to technical improvement of 5G networks and their performance. For 5GCAR two significative performance KPIs are addressed:

- Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
- Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision

Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010

In 5GCAR, we are focusing on the development of novel services to be supported by 5G networks, which include V2X communications. It is in this aspect, where network requirements that are being improved such as data rate or latency, provide the necessary foundations for the upcoming car-to-car and car-to-infrastructure communications.

Data rate

Definition of KPI: Data rate is the number of bits sent per unit of time, typically measured in bit/s. For the transmission of a single SDU, this is given as (Service data unit size)/(Latency requirement). For a stream of SDUs that arrive with a rate R SDUs/s, then the average data rate is R×(Service data unit size).

- Context/Use case: Data rate KPI of any of the 3 use cases that will be demonstrated
- Enhancement work: Adaptive and Robust Beam Management in mmWave Spectrum Bands
- Where to measure: In the radio level by measuring how many MB/s can be supported
- How to measure: With a network system simulation
- How to evaluate: Changing the number of UEs and / or changing the traffic density

Latency

Definition of KPI: Latency is defined by ITU-R as the contribution by the radio network to the time from when the source sends a packet to when the destination receives it (typically expressed in ms). The intended layer in focus has to be indicated when the term latency is used. Unless specified otherwise, this would be the default value used.

To be precise, the latency of layer-n is defined as the time from when the layer-(n+1) entity as the transmitter node requests transmission of a SDU until the SDU is delivered to the layer-(n+1) entity at the receiver node. In case an SDU is not delivered, due to transmission errors or other circumstances, the SDU is said to have infinite latency.

For example, the time it takes to transmit a frame (i.e., a MAC layer SDU) from the ingress of the physical layer of node A to the egress of physical layer of node B should be specified as Physical Layer Latency of node A to node B.

The Application Layer Latency, which is the time it takes to transmit an application message from the application layer of the source node to the application layer of the destination node, can also be referred to as “end-to-end delay” or “end-to-end latency”.

- Context/Use case: Lane merge
- Enhancement work: Network Orchestration and Edge computing enhancements
- Where to measure: In the UE comparing the latency E2E from the application to the UE
- How to measure: By using the timestamps on the messages
- How to evaluate: With a demo

Creating a secure, reliable and dependable Internet with a “zero perceived” downtime for services provision

Towards the creation of a novel 5G network which is able to provide a “zero perceived” downtime for services provision, 5GCAR focuses on two significant KPIs: availability and reliability.

Reliability

Definition of KPI: Reliability is the probability that the actual layer-n latency is less or equal to the latency requirement, subject to the other relevant requirements and conditions, e.g., SDU size and Communication range, transmit power, propagation conditions, and mobility.

- Context/Use case: See through
- Enhancement work: Meeting Low Latency and High Reliability Requirements in V2X Communication Scenarios and Network procedures
- Where to measure: In the UE verifying that different traffics in the network does not affect the UE
- How to measure: Verifying the % of messages arrived in the good delay condition.
- How to evaluate: With a demo

2.5.2 Societal KPIs

5GCAR has envisaged a strong impact towards societal challenges. Thus, all proposed societal KPIs are related with 5GCAR proposed use cases and KPIs.

Enabling advanced User controlled privacy

5GCAR use cases have considered several security issues regarding V2X communications, being the most significant privacy, confidentiality and authenticity.

Privacy or information: privacy is often related to personal data. It is an individual's right. It aims to ensure that whoever is handling personal data is applying the right level of security allowing individuals to control what information is collected, identifying how it is used, who can access it, and what purpose it is used for. It is also applying to the protection of UE identity to avoid the vehicle to be tracked or identified by any other UE or non-V2X entity beyond a certain short time-period required by the V2X application.

Confidentiality: is a security principle that ensures that information is not disclosed to unauthorized parties. This could be ensured by the use of cryptography schemes.

Integrity is a strong security feature to ensure data/messages will not be corrupted during the transmission. This requirement becomes very sensitive for V2X road and traffic safety applications.

Authentication: is a pillar in information security. It proves that a subject is what it claims to be. It's often linked to other pillars such as identification (claiming to be someone or something) and authorization (defining the access and actions that a subject can do on the system). Authentication is based on one of the three methods a subject: knows, has or is. Combining more than one authentication method is often referred as strong authentication or a multi-authentication.

Reduction of energy consumption per service up to 90% (as compared to 2010)

Power consumption is an important requirement from network infrastructure standpoint, user standpoint, even in a car since high power consumption may generate thermal dissipation issue in the car and drain the battery (e.g. for electric cars or when cars are unused).

European availability of a competitive industrial offer for 5G systems and technologies

One of the key aspects to consider regarding European availability of 5G technologies is cost, which has been considered in 5GCAR technical components.

Cost refers to all additional investments and expenses needed to construct the considered scenario setting. Hence, already existing legacy components are not included in the cost while new technology components are included in the cost.

Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications

5GCAR has also considered localization as one of the novel services, which might provide and stimulate new economical business models.

Localization

- Definition of KPI: The localization is the needed geographical position accuracy.
- Context/Use case: Vulnerable Road User protection
- Enhancement work: Accurate and Ubiquitous Real-time Positioning
- Where to measure: In the location server.
- How to measure: Compare the estimated position with the position from GNSS
- How to evaluate: In a practical test in the field

3 Market opportunities and 5GCAR contribution to V2X business

This chapter is divided into two sections: one devoted to the business market opportunities for V2X and the other to the business analysis of the technological components proposed in 5GCAR. In the first section, three different market opportunities are analysed: the 5G deployment scenarios for Connected and Automated Mobility services based on the automotive whitepaper, the security cost of the current certificate strategy proposed for V2X communications and an exercise about the size of the updates over the air market.

In the second section, the different technological components of the project are grouped, classified and analysed under a business perspective. Among other items, the value provided by the innovation, the stakeholders involved and the customer benefit are identified.

3.1 Business market opportunities for V2X

3.1.1 Automotive whitepaper V2.0

This second version of the white paper from the 5G-PPP Automotive Working Group [AWG219] includes further work targeting the description of the 5G V2X ecosystem and stakeholder relationships, different sharing models for network infrastructure, as well as a business setup and finally a techno-economic assessment of the investment. The scope of the paper is in line with the Strategic Deployment Agenda (SDA) driven by the European Commission and, therefore, for simplicity purposes, it builds the discussion around Connected and Automated Mobility services, 5G V2X deployment costs and potential revenues.

The exemplary highway environment considered through this work is taken from real conditions and the deployment under consideration includes 5G radio base station sites, civil work and fiber backhaul connections. It is further assumed that this investment could be used to provide enhanced Mobile Broadband (eMBB) and other relevant services, since 5G effectively enables a multi-service environment.

Particularly in the early phase of the 5G network deployment, synergies between the private and the public sector could speed up the deployment. Different sharing models are discussed, based on [SHARE3]:

- **Passive infrastructure sharing**: each network operator deploys its own network in the service area. Only passive infrastructure elements are shared between operators, e.g. space, masts, power generators, and air conditioning equipment.
- **Active infrastructure sharing, excluding spectrum sharing**: active elements of the cellular network such as base stations are shared. Each operator is still transmitting on his own spectrum.

- **Active infrastructure sharing, including spectrum sharing**: active elements such as base stations are shared. One single operator operates the dedicated spectrum.
- **Core network sharing:** elements of the core network are shared by more than one network operator. Savings: the savings corresponding to just sharing elements of the core network are reported as very low.

But the methodology could be considered to include other services for revenues, as shown in the adapted Figure 3.1.

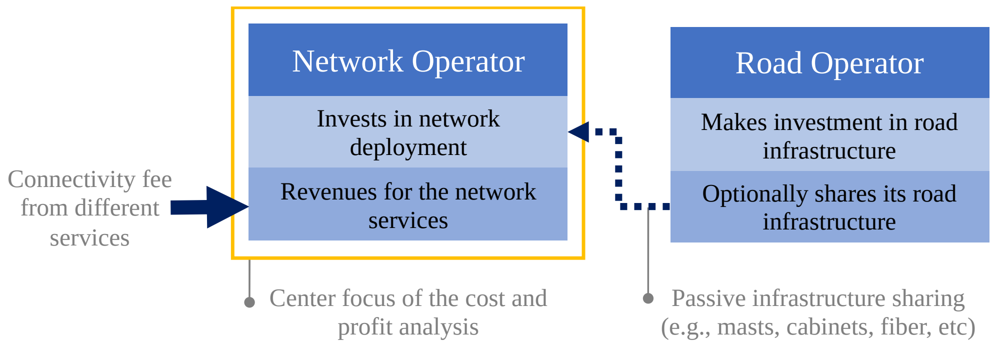


Figure 3.1: Main business setup for the network deployment analysis. The roles of "Network Operator" and be covered by different actors in the stakeholder ecosystem.

The Total Cost of Ownership (TCO) includes CAPEX and OPEX. The main cost contributions for the network investment are [11]:

- CAPEX: Site infrastructure: gNBs, network equipment, cabinets, civil works (physical cabinets, fences, antenna masts, etc), fibre backhaul provision along the highway.
- OPEX: Network operation, maintenance and replacement, and site lease.

In addition, the source of income from the perspective of the network operator is a percentage of the Connected and Automated Mobility service fee, the part associated to communication aspects.

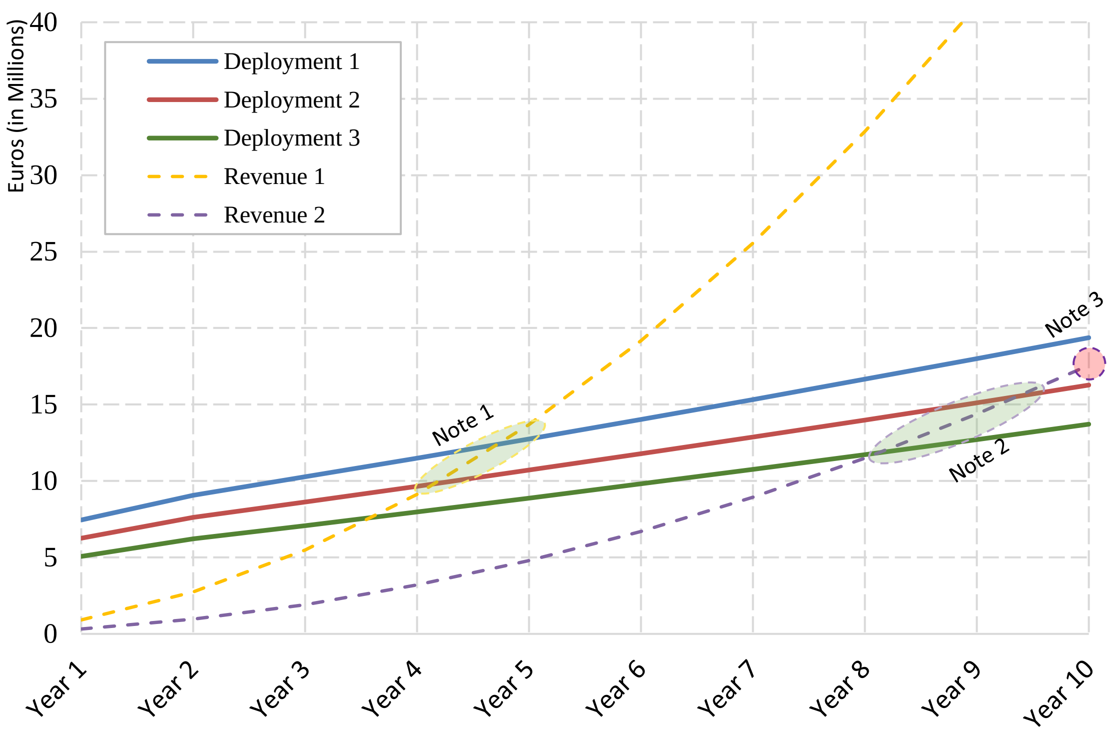
Three deployment alternatives are considered:

- Deployment 1: the CAPEX and OPEX investment for the network and fiber backhaul is carried out by a single actor (no infrastructure or network sharing is considered).
- Deployment 2: the active elements of the network are deployed by a single actor. The passive elements of network infrastructure are shared with the road operator (
- Deployment 3: besides sharing passive elements, the active elements in the radio access network are shared by more than one network operator.

Also, two different pay per use revenue alternatives are considered with different values of Connected and Automated Mobility service fee and traffic density:

- Revenue 1: baseline scenario with 50 000 thousand vehicles using the highway segment each day and a revenue of 0.5 Euro per vehicle on each use of the highway segment. All vehicles are served by a single network operator.
- Revenue 2: it is assumed that several network operators provide connectivity along the highway; a single network operator only captures 35% of the vehicle penetration rate.

The evaluation results for the accumulated profit are depicted in Figure 3.2 for a fixed user penetration rate of 10% per year. As observed, payback periods between four and eight years are expected, depending on the deployment and revenue alternatives considered.



Note 1: if a single network operator is able to capitalize on all vehicles in the highway segment (revenue model 1), all deployment options break-even within the first 5 years of service.

Note 2: if there is more than one network operator and the vehicle subscriptions are split, the deployment options allowing network sharing break-even after 8 to 10 years of service.

Note 3: if no network sharing is allowed and the number of subscribed vehicles is divided among different network operators, there is no profit reached within 10 years.

Figure 3.2: Accumulated cost and revenues for different scenarios.

As it has been showed above, the Automotive WG whitepaper presents a business case for Connected and Automated Mobility services based on network deployment cost and service income.

For the network deployment cost model presented in the whitepaper no previous network deployment is assumed in the highway considered. In Europe however, current 4G deployment levels, confirms that this is not the case for any important highway. This situation will naturally evolve for eMBB due to the deployment of 5G with the new bands already auctioned. Moreover, some countries like Germany (see Section 4.1.1 for more details), have included in these auctions specific conditions to reinforce the cellular service level in the main highways.

On the other side, this cellular available network in the main roads may not be able to provide the service level needs for Connected and Automated Mobility especially in terms of density, throughput per surface (in some use cases), reliability and availability. Compared to eMBB, a URLLC slice may be required where the network densification could be the solution to enhance the service level provided. According to this, an important network deployment cost may be foreseen as it is proposed in the whitepaper. 5G eMBB deployments would likely not bring an important change regarding the way of deploying network comparing to regular 4G deployment. 5G will widely reuse resources already deployed for 4G (passive infrastructure). New deployment approaches will likely occur with URLLC deployment where the business model for URLLC could be different from eMBB. A specific slices or slices could be required with network resource orchestration using SDN will allow this flexibility.

As indicated in the BEREC report [SHARE3] the main objective is the cost saving. BEREC emphases on the fact that network sharing should not reduce too much the investment effort of MNO and competition by infrastructure.

It is worth analyzing three of the network sharing models proposed to divide the overall cost between different actors.

Passive infrastructure sharing

For France, for instance, passive sharing in already used by operators to share network cost. In that configuration the mast will have to support several antennas (one for each operator). MNO will have certainly regulatory constraints concerning the coverage of highways in 5G as it is the case for 5G for EMBB services. For instance, by the year 2027 in France 100% of principal road have to be covered by every operator in the 800 MHz band [SHARE4]. Passive Network sharing will not allow to reduce the number of antennas, constraints could appear on the available room on the mast. It will not allow to densify the network in an efficient way.

Active infrastructure sharing, excluding spectrum sharing

In case of sharing excluding spectrum sharing, the available spectrum which could be used in a given area is only a sub-part of the global among of spectrum, and then QoS problems could appear. An example of such sharing could be find in UK between Telefonica (O2) and Vodafone or in Spain between Orange and Vodafone. They have signed a network sharing (active, passive) agreement for medium town. This will be extended to 5G for smaller towns [SHARE2].

In the active sharing family with or without spectrum sharing, we can add geographical sharing which could be interesting. It could be interesting for reliability enhancement purpose. Inside a given country, it is called national roaming. It would be interesting to consider it in a cross-border perspective.

Active infrastructure sharing, including spectrum sharing

Some examples of network sharing in Europe are available, for instance in Poland PTK Centertel (Orange), is sharing network infrastructure with PolskaTelefoniaCyfrowa (T-Mobile). Access network and base stations are shared for 15 years with an estimated saving of €356 million [SHARE1].

Apart from safety and improved traffic flows use cases, more advanced services can be envisioned, built to provide an improved value for the end customer in terms of increased efficiency, convenience, safety, etc. These are services that go beyond the public benefits, and that have the potential to create commercial value for the actors in the value chain. In this section, we will study an example of such an advanced service using Connected and Automated Mobility as the model service.

Conclusion

The automotive white paper [AWG219] assumes in the economic model that the end-user (car driver, car owner, car passenger) will pay for Connected and Automated Mobility service to a Connected and Automated Mobility service provider. Some other models could exist. A Connected and Automated Mobility service is related to road-safety and traffic efficiency and thereby provide a value also to other stakeholders than the end-user, e.g. to public authorities, which will get more efficient use of the road infrastructure, lower costs for treating casualties of road traffic accidents, etc. This value could be translated into a business case where e.g. authorities support the network by providing additional infrastructure for different service providers.

The automotive white paper has also explored different scenarios of how to share the necessary infrastructure between multiple operators. 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.

3.1.2 Security

Any connected service, including ITS, V2X or Connected and Automated Mobility services, rely on secure connections between various stakeholders to exchange information. The exchange of information is what creates the value in these services, and must be protected, as well as the end-users' privacy must be protected. Security, however, is not for free, and can be seen as an additional service layer that must be included in the total service delivery model. This section will examine the costs related to security, and how they may impact the total business model for the discussed services.

IT-S « Intelligent Transport System » is a European standard built to provide an autonomous public communication system for cars and road infrastructures. The system provides messages advertisement between ITS-Stations, with different levels of information. Globally all messages are broadcasted when using short range technology. The main security requirement is authentication (signature) of the base stations and vehicles messages, as well as anonymity of the true vehicle ID (pseudonymisation). The IT-S communication system will be globally a peer to peer communication system that relies on PKI certificates to provide messages authentication and integrity.

As a general rule, all messages, should be signed with an Authorization Ticket certificate for authentication of the IT-S sending station. In this system an "ITS station" can be a vehicle or a road infrastructure. Communication can be V2V (vehicle to vehicle) or V2I (vehicle to infrastructure).

For these communications there are different levels of security services provided. The main certificate hierarchy authority is the European Policy Authority which appoints a TLM (Trust List Manager). The TLM provides the European Certificate Trust List with the list of the different Trusted Root CA. The different trusted Root Certificate Authorities can be: EU RootCA, State-owned RootCA, or private organizations RootCA. In such a hierarchy the car-constructor will have to provide only certificates for its own vehicle fleet, as we can suppose IT-S infrastructure to be state-owned or EU-owned.

For each message there is a strong need of authentication (signature) a mid-level need of integrity (hash signature) and for some messages that contain personal data there is a string need for confidentiality. Therefore, all security services provided by traditional PKI systems will be assumed as provided, but it should be noticed that the authentication (signature) and integrity service with anonymity of the vehicle will be the most common in IT-S.

The PKI workflow is as follows:

- IT-S infrastructure road station:
  - Public PKI: RootCA Country / EU delivers authentication certificate
- IT-S vehicle:
  - Private owned PKI RootCA PSA delivers EA and AA certificates
  - Infrastructure EA (Enrolment Authority) delivers enrolment certificate, for its enrolment Domain, to an IT-S vehicle
  - Infrastructure AA (Authorization Authority) delivers authorization token (certificates with pseudonymisation), for an authorization context, to an IT-S vehicle that provides an enrolment certificate

Enrolment of an IT-S station

The Vehicle identifies itself with a private key and an IT-S Id. This initial authentication can be a specific IT-S certificate installed in factory, or the built-in certificate of ECU. The IT-S station builds an Enrolment certificate request (EC request) by providing a signature with its private key. The car manufacturer should provide the public keys of its IT-S vehicle to the Enrolment authority. The Enrolment Authority verify the validity of the request with the corresponding public key. The Enrolment authority provides the long-term IT-S certificate named “Enrolment Certificate”. EC timelife = 3 years.

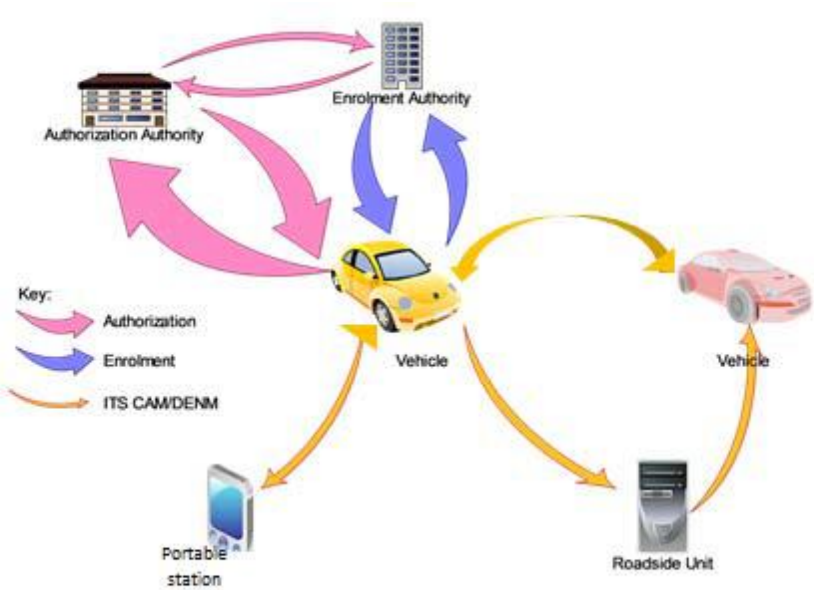


Figure 3.3: Authorization token request procedure.

As it is shown in Figure 3.3, the IT-S station sends an AT certificate request to the Authorization Authority. The request credentials provided by the IT-S station are transmitted securely to the Enrolment authority to check their validity. The request is signed by the IT-S station and the signature is checked by the AA. When the validity of the request is established the AA delivers an AT. The Authorization Token can be a single token or a pool of tokens.

Use of autorizations tokens

Authorization Token (AT) also named “Authorization Tickets” are pseudonymised certificates that are used to provide signature of the IT-S messages emitted by an IT-S station. The signature shall be in ECDSA algorithm and with Secure Message (SM) protocol. Authorization tickets have a high rate of usage and therefore should be renewed frequently. Different scenarios are taken into account. AT life time = 1 week (depending on the scenario). The certificate volume that needs to be defined is about on-board certificates required by the vehicles to be IT-S compliant or IT-S capable. The major cybersecurity requirement is to ensure vehicle anonymity, and at the same time signing and authenticating sent IT-S messages, and occasionally enciphering messages that contain personal data.

Once this question mentioned, it has been determined that vehicle anonymity would be achieved by emitting multiple certificates, depending on time (x certificate per week), distance (x certificate / km), and reuse condition (true or false). In the DA [DACT19] released in January 2019, the recommendation is to use 100 certificates per week.

For this system the OEM can defined their own PKI infrastructure for the certificate usage and delivery. AA and EA will be owned by the constructor /OEM PKI in this approach. Multiple certificates volume scenarios can be derived but in this analysis, only the option of 100 certificates per week, will be analysed.

The cost hypothesis takes the following elements into account

- License for certificates
- HSM (hardware) for generating the keys off-board.
- The certificate is used for pseudonymisation. 1 certificate = 1 pseudonym.
- Extra expenses such as PKI integration, deployment and maintenance are also included, etc.

Taking all those elements into account and considering with this approach that the service will be provided by the OEM infrastructure, a value of 0,0007€ per pseudonym has been estimated. This value is a reference based on the infrastructure needs for an OEM in Europe to provide the certificate generation demanded by ITS. This value is a theoretical estimation with no market reference. The certificate generation could be a service provided by a third party where the service level and the optimization of the resources needed could led to a higher or lower value. The purpose of this exercise is to provide a vision of the economic impact of the pseudonym strategy defined so far.

Table 3.1: Cost estimation of the pseudonym certificate policy in Europe.

IT-S year N	car / year	IT-S car on roads	AT certificates / year	Total certificate cost
1	17.000.000	17.000.000	88.400.000.000	61.880.000,00
2	17.000.000	34.000.000	176.800.000.000	123.760.000,00
3	17.000.000	51.000.000	265.200.000.000	185.640.000,00
4	17.000.000	68.000.000	353.600.000.000	247.520.000,00
5	17.000.000	85.000.000	442.000.000.000	309.400.000,00
6	17.000.000	102.000.000	530.400.000.000	371.280.000,00
7	17.000.000	119.000.000	618.800.000.000	433.160.000,00
8	17.000.000	136.000.000	707.200.000.000	495.040.000,00
9	17.000.000	153.000.000	795.600.000.000	556.920.000,00
10	17.000.000	170.000.000	884.000.000.000	618.800.000,00
100% penetration		298.900.000	1.554.280.000.000	1.087.996.000,00

Cost chart assumptions and remarks

- A linear penetration rate has been adopted, using the reference of the cars sold in 2017 in Europe [ACEA117], any other vector could be used
- A final figure is provided for the 100% market penetration according to the information available of cars in use in 2016. The purpose of the chart is to provide an overall vision of the market size related to the current ITS certificates strategy.
- If the cost is estimated for only one car, there will be 100 certificates per week during the 52 weeks of the year, so 3120 certificates. This provides a cost per year and car of 2,18€. From the OEM perspective, to cover the 15 years average car lifecycle a cost of 33€ per car must be taken into account. This is will be a major stopper for the ITS adoption unless it will become regulated. This cost will be then probably affected to the final customer.

Conclusion

Two main conclusions may be derived from this exercise showed in **Table 3.1**. On one side, the cost per car (more than 30€) will be a stopper for the OEM adoption. This is one of motivation why 5GCAR has proposed a technological component with a different and less costly solution [5GCAR-D42]. On the other side, the pseudonym generation, as it is defined today, is an opportunity as a service for the telecommunication sector. Current actors or new ones can optimize the cost and the service level provided thanks to the synergies of the resources available for providing this service.

3.1.3 Over the air

One of the services identified and explored in Deliverable [5GCAR-D22], Intermediate Report on V2X Business Models and Spectrum [5GCAR-D22], was over the air software updates, Over The Air (OTA). 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 in being able to fix quality or other issues in the software, without having to bring the vehicle in for expensive workshop visits.

The intented use of the mobile network to enable the remote update and/or configuration of the electronic control units in the cars via OTA. This is an oportunity both for the automobile industry and for the telecomunication industry. A brief reminder of the main benefits:

- Reduce the resources needed to do the physical manipulations in the cars
- Avoid the need of having physically the car in a garage to do the update and, if the car is already purchased, the annoyance to the client when he is called for a recovery campaign.
- Accelerate the application of the updates and the correction of bugs, specially the critical ones
- Increase the frequency of the updates and new functionalities
- Allow the remote activation of new services contracted by the client, as, for instance, a map update.

With the arrival of 5G the capacity of the network to handle data traffic is improved using eMBB, but the cost of this volume of data using the mobile carrier network is key parameter to take into account for the OTA deployment over the cellular network. There may be a potential business case, but it has to be profitable both for the automotive industry and for the telco industry. If this is not the case, then OTA will be deployed as it is today, based only on unlicensed frequencies or the driver/owner data plan stopping the possibilities of this use case.

To have a perspective of the size of the opportunity, an estimation of the millions of TBytes involved has been made as a first step. It will be assumed a constant volume of cars for the next 10 years in Western Europe, 17 million per year. All of them connected to the cellular network and ready for OTA updates. Regarding the upgrades, several assumptions are made:

- Only one upgrade per year is considered
- No roaming charge is taken into account. All over the air updates are only considered in a national environment
- The cars will be updated during the 5 first years. For the rest of their lifetime only minor updates are foreseen. Two different scenarios for the data volume are studied the conservative scenario and the non-conservative scenario.
- Conservative Scenario (CS): The size of one car update starts in 5 GB and is increased 5GB every 3 years. The normal product cycle of a car is around 6 years and there is normally an embedded electronics update in the middle of it. This is reason for the 3 years period.
- Non Conservative Scenario (NCS): The size of one car update starts in 10 GB and is increased to 30 GB for cars manufactured the following 3 years, and then reach 100 GB in the next 3 year period.

The Figure 3.4 shows the evolution of millions of TBytes during the next 10 years in both scenarios.

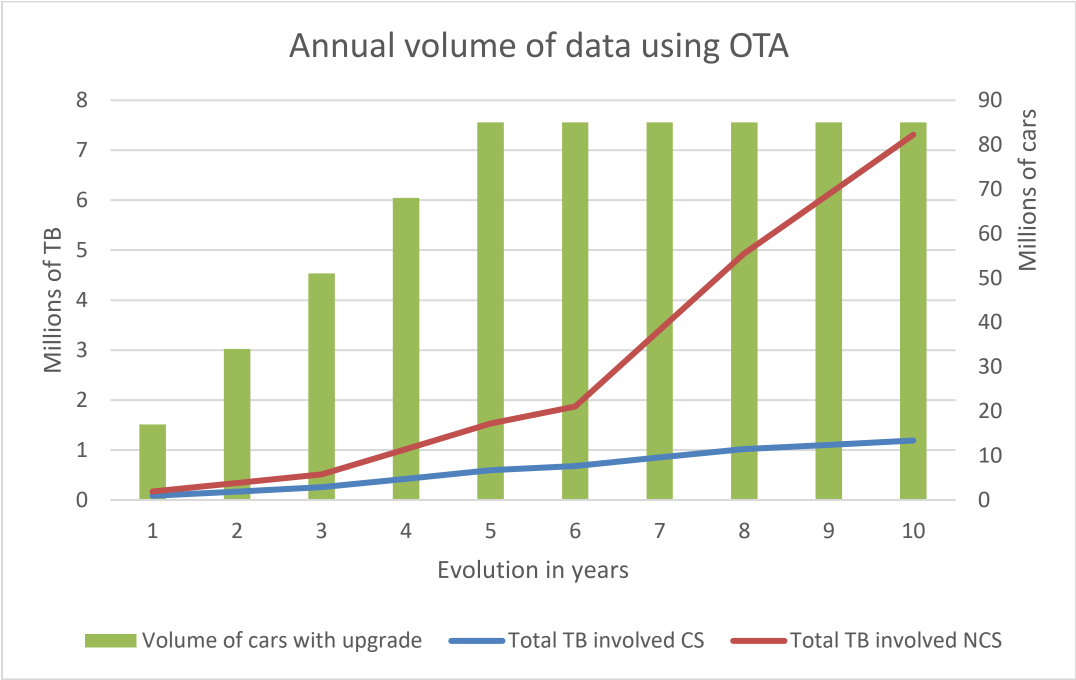


Figure 3.4: Estimation of the annual volume of data in the next ten years for over the air updates.

It is important to note that this volume of millions of TBytes is a new consumption in the mobile market which does not exist right now. To avoid any concern in the MNO side in terms of network collapse for a simultaneous update of such a big quantity of information, OEMs confirm that most of the updates could be timeless (within a margin of weeks) and the main focus should be done in the price and not in the speed of the update. Obviously, there will also be critical updates (those related to safety and cybersecurity) where the OEM will be willing to pay a higher price for a faster update.

In order to translate this volume into an economic indicator, it is always difficult to get a price per Megabyte. These prices are confidential between MNOs and OEM, so to follow with this exercise, another assumption is needed. The hypothesis used is to apply the cost of the DATA paid nowadays in consumer mobile contracts. As we can see in the Figure 3.5 (designed using the data of the 2018 research done by Cable in 230 countries [GSMCAB18], the average cost of 1 GByte paid by users in each country is far from being a standard in Europe.

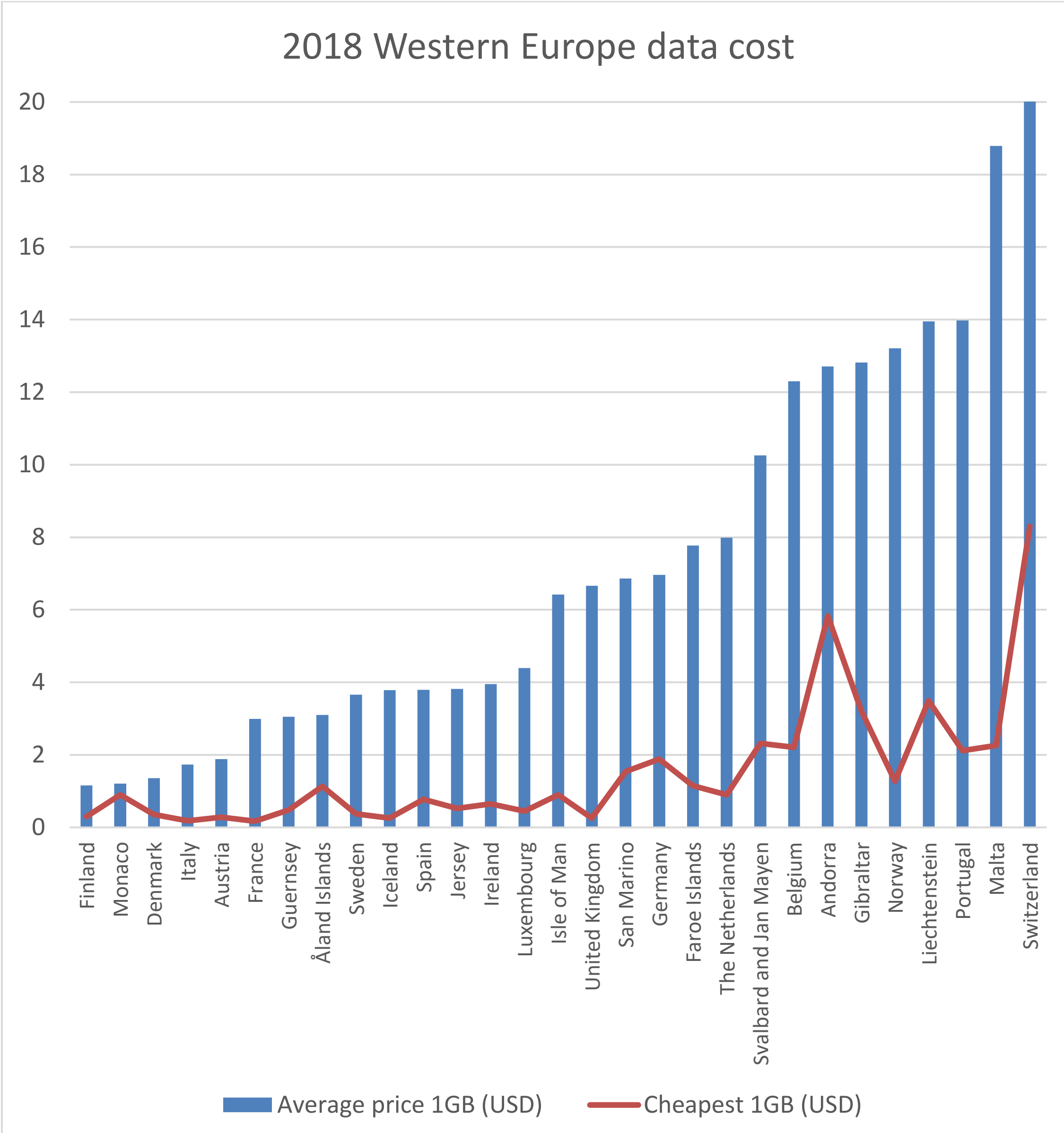


Figure 3.5: Mass Market mobile price per GibaByte in the different countries of Western Europe.

To establish the reference GByte price:

- The average cost calculation is done by reducing the geographical perimeter to 6 countries: France, Spain, Germany, UK, Italy and Sweden, major countries that are not in the low or high price borders of the list

- For each one of these six countries, the lowest price available is considered, as it is assumed that the volume of the data for car OTA updates is so important that the better price could be obtained in the mobile carrier negotiation.

That gives a reference Gbyte start price of 0,54€. We also consider that the price of data will be reduced during the next years, as the mobile telephony cost did in general with an annualized average of 9% discount during the last decade, as the last studies of ARCEP in France [GSMARC17] and CNMC [GSMCNM18] in Spain show. Therefore, we assume this discount as a reference for the future and we apply this discount of 9% per year for the next decade.

In the Figure 3.6, we can find the final estimation for the previous estimated volume of data using OTA, with the total amount cost per year, in both conservative (CS) and non-conservative scenarios (NCS).

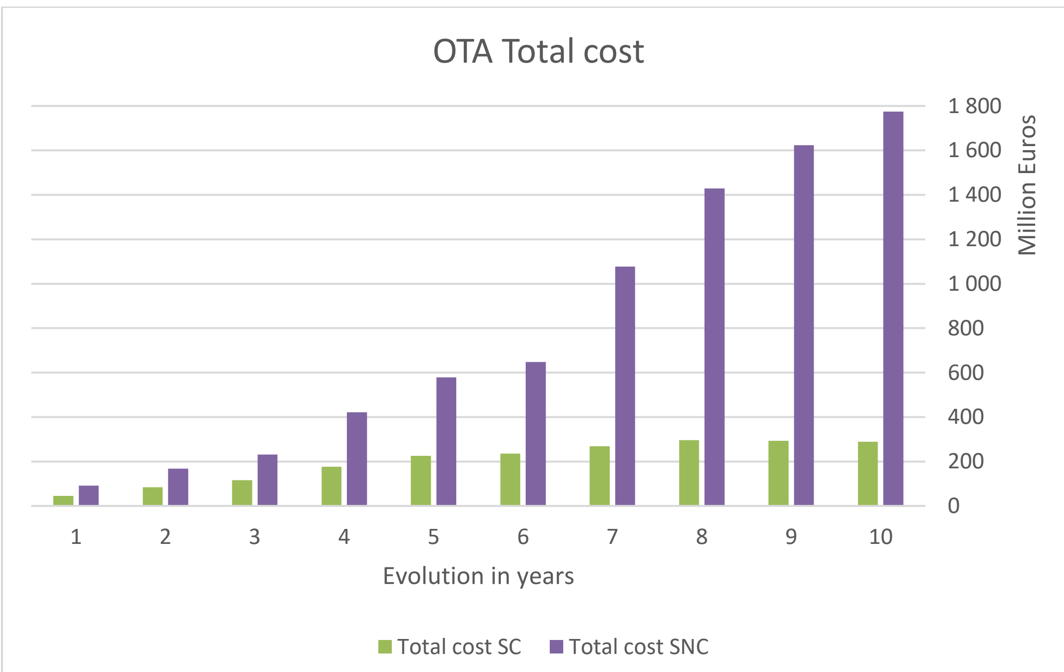


Figure 3.6: Overall cost estimation in the next ten year for over the air updates

The two factors involved, augmentation of data and discount per year, have opposite effects on the cost. This explains why in the conservative scenario the cost will decrease towards the end of the period. The annual cost in the non-conservative scenario grows from 91 to 1.774 million Euros during the next ten years, showing the high impact of this new business.

Conclusion

This exercise helps us to understand the business impact of using Over The Air (OTA) for the updates of the embedded head units. Per car, with the estimation made in this section and without any roaming traffic, the cost could start from 10€ for the 5 years update in the conservative scenario or 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 total amount payed for the data traffic in ten years from now, could be between 288 (CS) and 1.774 (NCS) million Euros, forcing a huge negotiation with mobile operators in order to obtain lower prices that could make OTA a viable business case for OEMs. The data used for OTA, and the negotiation leverage of this, will also drive down the cost for data for other services bringing up the possibility to increase the data offloading from the embedded architecture to the cloud.

3.2 Business model analysis of 5GCAR technical components

5GCAR has previously looked at how innovative business models are enabled by certain Technical Enablers, which in turn constitutes Technical Components [5GCAR-D22]. The work on defining these Technical Components can be found in Deliverable D3.3 Final 5G V2X Radio Design [5GCAR-D33] and in Deliverable D4.2 Final Design and Evaluation of the 5G V2X System Level Architecture and Security Framework [5GCAR-D42].

This section will analyze these technical components from a business model perspective, to understand how they can impact the possibilities to create innovative business models. For each of the technological components, the following items are discussed:

- **Description**: brief summary of the technology.
- **Disruption**: **E** for evolution; **R** for revolution, from already existing 3GPP Releases (Release 14 onwards).
- **Value Provided**: examples of value that can be attained from this technological component; this would be the basis for the creation of new services.
- **Requirements/Challenges**: what are the negative factors from a business perspective.
- **Parties involved in value chain**: which parties are involved in realizing the value
- **Customer**: who is the customer(s) that benefits from the value created
- **Customer benefit (value)**: What is the perceived value for each customer
- **Potential 5G business model element impact**: What element(s) of the business model is impacted by the technical component

The technical components have been grouped into broader categories where possible, i.e. where technical components do not differentiate the result of the analysis, and where the technical components are related to the same area.

3.2.1 Positioning

As highlighted by the ecosystem (see for instance [3GPP18b]), 4G positioning techniques may not be sufficient to serve new uses cases "*In the case where relative positioning information is transposed into absolute 3D positioning information using LTE positioning technologies, the resulting accuracy would not be sufficient for the proposed use case.*"

To satisfy the new use cases, vehicle and vulnerable road user (VRU) position must be provided with a higher accuracy [5GCAR-D21], and the project has worked to define novel positioning solutions [5GCAR-D33], namely the following technical components:

- Trajectory prediction with channel bias compensation and tracking
- Tracking of a vehicle's position and orientation with a single base station in the downlink
- Beam-based V2C positioning
- Data-aided beam-based C2V positioning
- Enhanced assistance messaging scheme for GNSS and OTDOA positioning
- Multi-Array 5G V2V Relative Positioning

All these technical components aim at providing more accurate position of the vehicle UEs or other type of UEs and can contribute in the same way to the business model.

It should be noted that in automotive context, cars are equipped with on-board GPS and know their positions with the GPS accuracy. So, the technical components may appear useless at least for the OEM perspective already having the knowledge of the position thanks to on-board GPS. However, some of the technical component not only provide instantaneous position but also provide trajectory prediction and more importantly collision prediction. Such technical components can have a value for the OEM.

As a result, we could split the positioning related TC into two groups:

- TC providing radio-based positioning
- TC providing trajectory prediction

Table 3.2: Positioning**.**

Technological component	Positioning
Description	Methods to provide accurate positioning of vehicle UE and other UE types
Disruption	E: Radio based positioning. No need of GPS, position can be computed by the network or by the UE.
Value Provided	Accurate position
Requirements / Challenges	Communication based positioning rely on the use of some specific communication feature (either some specific pilots, or messaging) that must be enabled by the equipment. Higher density of antennas and higher carrier frequencies to be used in order to get a better accuracy
Parties involved in value chain	• Telecom Vendor • Tier 1 • Possibly new actor providing positioning support over the top (data base of reference geo-points; computer power and knowledge to compute triangulation etc.)
Customer	• Third party (insurance company), service company (e.g. guide, hotel chain) • Public authority may like to access to accurate position (e.g; emergency services)
Customer benefit (Value)	Accurate and reliable position opens the door to new services
Potential 5G business model element impact	Possibly disruptive service enabled by accurate and reliable position information

Table 3.3: Positioning and trajectory prediction**.**

Technological component	Positioning and trajectory prediction
Description	Methods to provide accurate positioning of vehicle UEs or other type of UEs and to predict trajectory and thus possibility of collision
Disruption	R: Radio based positioning. Learning techniques to predict trajectory

Value Provided	Accurate position and trajectory prediction
Requirements / Challenges	Reliability of trajectory prediction; collision detection false alarm or misdetection
Parties involved in value chain	• Telecom Vendor • Third party doing the trajectory prediction. It could be the Telecom vendor but could be as well a third party.
Customer	• OEM • Third party (insurance company) • Public authority may like to access to accurate position and trajectory history / prediction • Mobility Provider, this could be an added off board service independent of the elements provided by the on-board sensors.
Customer benefit (Value)	Trajectory prediction to anticipate collision or accident
Potential 5G business model element impact	Possibly disruptive service

3.2.2 V2X radio design

The TCs proposed in 5GCAR for the radio interface can be grouped in two different categories: the infrastructure based and the sidelink based solutions. The first group is defined by all TCs where the network infrastructure is involved. In this group, at least an MNO will be definitely needed to provide the service. In the second group, the infrastructure could be involved or not and according to this, two different sub-groups have been provided: out of coverage sidelink TCs and in coverage sidelink TCs. In the first group the OEM will be a final customer and no MNO is involved in the value chain. It should be pointed out that the TCs in the first group can be extended to be applied in the case with MNO involvement as well. However in the second group, a network service provider is needed to enhance the sidelink characteristics, this may become interesting for a Mobility Provider (MP), supposing a competitive advantage compared to another using the same OEM vehicles.

The following technical components are included in this category:

- Predictor antenna TCs
  - Sensitivity Analysis of the Predictor Antenna System
  - Rate Adaptation in Predictor Antenna Systems
  - Predictor Antenna for Massive MIMO Adaptive Beamforming
- Beam forming TCs
  - Genetic-Algorithm Based Beam Refinement for Initial Access in Millimeter-Wave Mobile Networks

- Beam-Domain Broadcasting for V2N/V2I links
- Beam-based Broadcast Schemes for V2X Applications
- Beamformed Multi-Cast with HARQ feedback and retransmission

- Efficiency TCs
  - Efficient Preemption-based Multiplexing of Services
  - Decentralized Pilot-to-Data Power Ratio Configuration in Multi-Cell Multi-User MIMO Systems
- Reliability TCs
  - Joint Optimization of Link Adaptation and HARQ Retransmissions for URLLC Services in a High-Mobility Scenario
  - Enhancing V2N Reliability by Sidelink Cooperation
  - Enhancing Control Channel Reliability by Using Repetitions
- Sidelink out of coverage
  - Reference Signals Design for Direct V2X Communication
  - LOS MIMO Design for V2V
  - Distributed RRM for Direct V2X Communication
  - Full Duplex Collision Detection in V2X Networks
  - Full Duplex Impact on V2X Performance
- Sidelink in coverage
  - Power Control and Scheduling to Mitigate Adjacent Channel Interference in Vehicle-to-Vehicle Communication
  - Sidelink Resource Allocation with Network Assistance using Multiple Antennas
  - Sidelink Assisted Reliable Communication
  - Code-expanded Random Access for Reliable V2X Discovery
  - Radio resource management in 5G-enabled vehicular networks
  - V2V Resource Allocation and MAC Capacity
    - Cognitive Full Duplex Communication in V2X networks

Infrastructure TCs

Table 3.4: Predictor antenna TCs**.**

Technological component	**Predictor antenna TCs**
Description	The predictor antenna concept is used to obtain the accurate channel state information at the receiver side which is the key for robust links.
Disruption	E
Value Provided	Adaptive M-MIMO works for very fast moving connected vehicles.
Requirements / Challenges	Antenna cost and size of antenna array are always important restrictions for the successful deployment in the automotive industry

Parties involved in value chain	• Telecom Vendor, as the provider of the antenna • Tier 1, as the integrator of the overall communication module to be integrated in the car • OEM
Customer	OEMs, in order to improve the performances of the connected vehicle while moving.
Customer benefit (Value)	The communication performances will be better for fast moving connected vehicles
Potential 5G business model element impact	None, normal linear business. A new type of antenna will be provided by the telecom vendor, integrated by the tier1 and finally included in the vehicle.

Table 3.5: Beam forming TCs**.**

Technological component	**Beam forming TCs**
Description	Different techniques to improve the management of the beam forming in e.g. mmWave bands from the infrastructure side (the gNB) to optimize the performances of the system
Disruption	E
Value Provided	Improves interference of the system and energy "usage"
Requirements / Challenges	The integration of mmWave antennas in the car are under investigation before the industry adoption The spectrum band is not yet harmonized the auction plans may arrive in a few years.
Parties involved in value chain	• Telco vendors • MNO
Customer	MNO
Customer benefit (Value)	The performances of the mmWaves communication system will be improved
Potential 5G business model element impact	Reduced. So far no clear use cases are identified for mmWaves in the V2X domain. Today mmWave are initially foreseen to cover the MNOs last mile and increasing system capacity.

Table 3.6: Efficiency TCs**.**

Technological component	Efficiency TCs
Description	In these TCs the multiplexing and preemption mechanisms are used to improve power, latency and link efficiency
Disruption	E
Value Provided	Improve spectral efficiency and throughput
Requirements / Challenges	No specific challenges
Parties involved in value chain	• Telecom Vendor • MNO
Customer	MNO
Customer benefit (Value)	The performances of the system are better in terms of bandwidth available for the final customer
Potential 5G business model element impact	No important impact. This is the normal linear business model. It may be a competitive advantage for one MNO compared to another

Table 3.7: Reliability TCs**.**

Technological component	Reliability TCs
Description	Increase the reliability of the system by using alternative links (V2V as well as V2I2V) or by changing the code modulation to look for a trade-off between latency and reliability or enhanced control channel reliability.
Disruption	E
Value Provided	Maintain reliability for URLLC traffic by exploiting link diversity through UE collaboration. Enable Quality of Service (QoS) guarantee for URLLC services in V2N communication.
Requirements / Challenges	No specific challenges

Parties involved in value chain	• Telecom vendor • Tier 1 • MNO • OEM
Customer	Mobility provider. The reliability in the network communications will benefit the mobility provider and could suppose a competitive advantage between two MP using the same OEM cars. The added value is off-board, so the customer is not the OEM but the mobility provider.
Customer benefit (Value)	Reliable communications for autonomous driving
Potential 5G business model element impact	An element which may enhance the service of the MP compared to an OEM directly. Change in the linear business as it is defined today.

Sidelink TCs

Table 3.8: Out of coverage sidelink**.**

Technological component	**Out of coverage sidelink**
Description	In this chart are grouped those TCs devoted to enhance the sidelink characteristics in out of coverage situations. Optimization of the synchronization signals, DMRS signal, distributed resource selection strategy, MIMO design, full duplex operation as well as increasing the robustness against adverse propagation conditions.
Disruption	E
Value Provided	These TCs provide essential sidelink functions and/or better sidelink performances (throughput, resource efficiency and/or reliability)
Requirements / Challenges	No specific challenges
Parties involved in value chain	• Telco Vendor • Tier1 • OEM
Customer	OEM: Any improvement of the sidelink performances without the need of the network will be interesting for the OEM.
Customer benefit (Value)	Sidelink may act as an off-board sensor regardless of the network deployment increasing safety and comfort.

Potential 5G business model element impact	None, linear value chain with a feature provided by a telco vendor and integrated by the OEM through a tier1

Table 3.9: In coverage sidelink**.**

Technological component	**In coverage sidelink**
Description	In this chart are grouped those TCs devoted to enhance the sidelink characteristics in coverage situations. Optimization of the sidelink channel interference, discovery signaling overhead and resources allocation thanks to network assisted mechanisms, and an increased reliability thanks to the combination of sidelink with network links.
Disruption	E
Value Provided	These TCs provide essential sidelink functions and/or better sidelink performances (throughput and reliability) and reliability
Requirements / Challenges	Interest from the MNOs, due to the complexity of the function and the lack of interest from the OEMs to pay for a service available in unlicensed frequency
Parties involved in value chain	• Telco Vendor • Tier1 • OEM • MNO
Customer	MP: Any improvement of the sidelink performances linked to the cellular network availability will become a service from the MNO to be sold to the MP
Customer benefit (Value)	Sidelink may act as an off board sensor regardless of the network deployment, increasing safety and comfort.
Potential 5G business model element impact	This service may suppose a difference for an MP compared to another one even if they use the cars from the same OEM.

3.2.3 Network procedures

Network procedures are an important aspect of managing a network of connected devices. They describe how various network services will be managed, and could have a large impact on the effectiveness of service delivery, which in a vehicle environment may be particularly critical, e.g. in terms of introducing latency.

Some of the TCs identified by 5GCAR could have major impact on the overall service quality experienced by the end-customer.

In this analysis, some of the TC have been grouped together (TC Group), as they are related and target the same customers with similar values.

The TCs included in this section are:

- TC Group: Local standalone Network procedure
  - RSU based smart zone
  - SL and Uu multi connectivity for high reliable and/or high data rate V2V communication
  - Fast application aware setup of unicast SL
- TC Group: Network service relationship enhancement
  - Location aware scheduling
  - V2X service negotiation
- TC: Multi operator solutions for V2X communications
- TC: Network orchestration and management

Table 3.10: Local standalone Network procedure.

Technological component	Local standalone Network procedure
Description	• Integrating RSU inside 5G V2X architecture, acting as UE or as local BTS. • Maping SL on 5G RAN by using Uu link. Radio protocol is simplified allowing only local routing in order to support SL like connection • Assisting an UE in order to set up SL (3GPP SL, or PC5) link in unicast (preferred), or in multicast mode in a more efficient (improving set up time and QoS). This assistance will be performed by a server at gNB side.
Disruption	• R: a new element (active RSU) is added to provide road safety, road efficient services, network infrastructure as to be deploy to support direct connection between vehicles • E : If TC is not available, V2V link establishment and regular mode should continue to work in a degraded way.
Value Provided	Improvement of D2D direct communication for a better QoS, availability, enhancement of network coverage (macrocells), offering multi-MNO solution, offloading macro-network,
Requirements / Challenges	• Deployment of many RSU(s) with smart zoning capability, all along the road, • Adaptation to network infrastructure for that specific purpose (local routing, simplification)

Parties involved in value chain	• RSU provider possibly embedding tier 1 technology • Road operator who are deploying smart zone • MNO who are connecting RSU smart zones and deploying features (op1) • Telecom equipment provider (op2) • OEM • Tier 1 (implementing specific UE behavior)
Customer	• The customer will depend of the service provided, customer will be different from user (this remark is general to road safety/road efficiency). • Customer could be OEM : that could pay MNO for this specific TC (op1) • Road operator could deploy simplified BTS to support TCs, in that case customer will be the road operator for a telecom equipment provider (op2)
Customer benefit (Value)	• Road safety enhancement as well as traffic efficiency • Better connectivity for cooperative perception use-cases
Potential 5G business model element impact	• Customer of MNO will probably be Road Operator instead of car driver or car OEM (op1) • Telecom equipment (op2) provider could be directly integrated in the value chain as local road service provider (in a restricted area)

Table 3.11: Network service relationship enhancement.

Technological component	**Network service relationship enhancement**
Description	These TCs will: • Allow guaranteeing transfer of messages and files for a relevance area to a targeted UE. The location aware scheduling will take into account network condition, vehicular context to orchestrate messages (files) transfer demands in order to optimize resource allocation. • Allow transmitting specific service requests with specific requirements (service descriptor) towards Network Control. The Network Control will be able to send back information towards the service about the status of the requested service execution, as well as the network condition in order to adapt the service.
Disruption	E: TCs will run on a specific server (MEC server). This requires an adaptation of network architecture, an additional cost for this function.
Value Provided	• Guarantee of message/file transfer in a relevant area, in the right time, • Optimization of network resources allocation • Adapting service to network conditions
Requirements / Challenges	• Deployment of distributed servers. • Being able to retrieve and correlate in real time information from network (QoS, occupancy) and from ITS application (SLS : service level specification)

Parties involved in value chain	• ITS Application provider (ITS-AP) (car OEM consortium?) • MNO who will deploy these TCs
Customer	• Customer will be different from user (this remark is general to road safety/road efficiency), car Driver will not likely pay for that TC. • Customer could be (ITS-AP) which could pay MNO for this specific TC • Customer could be nobody if TC is seen as a way for he MNO to optimize resource allocation,
Customer benefit (Value)	ITS Application provider has the guarantee for the service delivery matching potentially with SLA, he could negotiate and monitor service
Potential 5G business model element impact	• This TCs could give an additional value for the network usage, but it will bring some constraints on ITS application provider side (ITS-AP) • This TC could enable the existence of an independent actor in charge of service "ITS Application provider"

Table 3.12: Evolution of infrastructure-based communication for localized V2X traffic.

Technological component	**Evolution of infrastructure-based communication for localised V2X traffic**
Description	This TC addresses the problema of local V2X traffic routing and forwarding. The kind of traffic which are taken into account are unicast, multicast, broadcast. Core network control plane is nevertheless mandatory.
Disruption	E: Low in terms of business
Value Provided	Improvement of QoS (latency…), Offload of user plane of core network
Requirements / Challenges	Specific feature at eNB side.
Parties involved in value chain	• MNO who will deploy this feature
Customer	• MNO: Method to optimize QoS KPI thereby increasing service value • This TC will be embedded in a global service infrastructure. Thus customer for this global service could be ITS Application provider for critical applications (for road safety, autonomous car assistance, etc…)
Customer benefit (Value)	• No specific value for customer for this TC which will be embedded in a global package of infrastructure ITS service. The TC will be used to increase the value of the complete service package.

Potential 5G business model element impact	No impact specifically for this TC, it will give more value to infrastructure service in the way that high level QoS KPI could be achieved

Table 3.13: Multi operator solutions for V2X communications**.**

Technological component	**Multi operator solutions for V2X communications**
Description	This TC addresses the problematic of fast roaming/handover from an MNO A to a MNO B for instance when the car is getting out the coverage of MNO A and entering in the coverage area of MNO B. In one of the proposed solution one UE is able to listen to two radio control channel is the case of shared frequencies, or to two radio frequencies. The UE will be able to register to several operators in a given area.
Disruption	R: High at UE side when the UE has to be populated with two RF module, High for network management is the case of shared frequencies High in term of deployment scenario is TC is used as a way to split a geographical area between several operators
Value Provided	• Improvement of network availability and system resilience when coverage is not at the level of 100% in a given geographical area : this TC should reduce cost deployment when several MNO are willing to cover the same area. • Reduction of deployment cost, when TC is used to share a given geographical area between several operators • Solution for cross administrative domain (for instance cross border)
Requirements / Challenges	Deploying this feature at UE side in coherence with deployment scenario: for instance geographical split will not work in proper way if some UE doesn't implement the TC.
Parties involved in value chain	• MNO(s) • OEM
Customer	• OEM • Inter MNO roaming market (one MNO customer to other ones)
Customer benefit (Value)	• Car OEM: better service level (coverage, latency, availability, seamless service,…) • MNO will offer a connectivity service without deploying an entire network (depending of coverage scenario)
Potential 5G business model element impact	• This TC could allow to share network deployment cost between several MNO • New way of competition between MNO based on the geographical coverage as well as the percentage of coverage in a given area

Table 3.14: Network orchestration and management**.**

Technological component	Network orchestration and management
Description	This TC corresponds to a set of processes to automate the behavior of the network in order to coordinate hardware and software elements to further support applications and services. The idea is to separate the network services from the network components, allowing automated network configuration as per the service specifications. Network orchestration requires automation in the operation that can be achieved in different steps: • With the introduction of Network Functions Virtualization (NFV) to reduce costs by reducing the amount of dedicated hardware and bringing agility in time and efforts to launch new application. • In order to handle the mix of physical (PNF) and virtual network functions (VNF), the automation of the network should be taken to the service level. Thus, increasing efficiency. • Adding cloud native applications in order to enable continuous integration and delivery. At this point operators can realize the full potential of the new services and address new revenues.
Disruption	E
Value Provided	Optimization of the network resources
Requirements / Challenges	It is not an easy migration process since it effectively changes the way a network in managed. To realize the orchestration of 5G networks, operators needs to start their automation journey now.
Parties involved in value chain	Telecom Equipment Vendors and Mobile Network Operators
Customer	Mobile Network Operators
Customer benefit (Value)	Improved network management: possibility to support varied applications while reducing operational costs
Potential 5G business model element impact	The potential is large, both in saving and in the efficiency supporting novel services

3.2.4 End to end security

Security and privacy are of utmost importance for any connected service, including V2X, ITS and Connected and Automated Mobility services. As discussed in section 3.1.2 Security, this is something that could add substantial cost to the end-to-end solution, thereby inhibiting the adoption of the related services.

5GCAR has proposed a solution to reduce the cost and transmission overhead by using a scheme (for certain suitable applications) where only the initial messages in a communication are signed and permissions verified, and further messages are only encrypted.

TCs described in this section: Security and privacy enablers.

Table 3.15: End to end security.

Technological component	**End to end security**
Description	TCs to ensure secure communication between UE and UE, or between UE and V2X server is secure and private.
Disruption	E
Value Provided	Privacy and security in communication is an absolute requirement in a V2X system. As the entire system is based on trust between various stakeholders, which are not previously known to each other. For the end user, it is critical that the V2X service can be trusted, therefore there is an inherent value in network security, which is realized by the trust and usage of the service by the end customer. 5GCAR's proposed innovative scheme of only signing the initial messages in a communication session, and then using encryption for further messages, has the potential to reduce the cost for end to end security.
Requirements / Challenges	Maintaining a high level of security, typically creates overhead in in the communication protocol, leading to longer latency in communications, and/or increased amount of data to be transmitted. This in turn leads to higher costs for the data transmission (if licensed spectrum is utilized). Increased consumption of shared transmission resources, due to the security overhead. Scalability of encryption may be a challenge if the number of keys (driven by the number of UEs) becomes very high. There is both a cost for the storage of keys, as well as a cost to generate keys themselves (Ref section 3.1.2).
Parties involved in value chain	• End customer • UE manufacturer, including USIM • Mobile Network operator

	• V2X service provider (Could be Car OEM)
Customer	• End customer • V2X service provider
Customer benefit (Value)	• End customer – Access to a trusted V2X service • V2X service provider – Trusted V2X service that is possible to sell • V2X service provider – Protection against liability claims
Potential 5G business model element impact	• Additional cost to extend 5G cryptographic/security functions in the network, to cover the specific V2X case (Key Management Function.) • Additional costs due to overhead if using licensed spectrum (Uu).

3.2.5 Edge computing enhancements

The availability of edge computing capabilities is one of the really innovative new technologies in 5G, which has a large potential impact on automotive use cases. Edge computing has the potential to move services running in the back end (cloud) much closer to the actual UE (vehicle), thereby greatly reducing latency, and opening up for new ways of distributing functionality between vehicle and back end. It could potentially even allow for functionality that today runs in the in-vehicle systems, to be executed in the edge of the back-end infrastructure instead, thereby opening up new ways of launching new services and functionality.

TCs described in this section: Edge computing in millimeter Wave Cellular V2X networks

Table 3.16: Edge computing enhancements.

Technological component	**Edge computing enhancements**
Description	Edge computing is a core new technology concept in 5G, and several benefits for V2X use cases can be seen: • Lane merge, traffic coordinator can be located close to intersection. • Cooperative perception based on see-through. • VRU protection
Disruption	R
Value Provided	Edge computing enhancements provide value in enabling certain use cases with very low latency requirements. It also provides value in being a part of the total off-board computing resource necessary to provide a V2X service. The low latency and high computing capacity offered by edge computing, also has the potential to create new possibilities for Car OEMs to offload in-vehicle

	functionality to the edge compute platform, where certain functions could be developed. Typical advantages could be seen in functions requiring data from multiple vehicles or RSUs in the same limited geographic area.
Requirements / Challenges	Challenges: Handover between base stations connected to different MEC-local data centers. The applications and their internal state need to be transferred to the next data center in the shortest delay possible. This should ideally be performed before the handover is completed. Handover between networks (roaming), inter-operator roaming (between MNOs from different countries). Both technical and commercial challenges. May look different depending on what type of service provider supplies the MEC service. MNOs are typically restricted by national borders, due to spectrum licenses, whereas other over the top providers may be more international in how they could provide a MEC service.
Parties involved in value chain	• Car OEM • Mobile Network Operator • Network Equipment vendor • Cloud service provider • Data center provider
Customer	• Car OEM • MNO
Customer benefit (Value)	• Car OEM: Access to additional computing resources (low latency functions) • Car OEM: Possibility to create new functions (low latency, multiple local data sources) • MNO: Frees up resources in transport link towards central data center
Potential 5G business model element impact	• The business models for MEC is so far very uncertain. MNOs see this as an opportunity to increase the value provided to their customers, and also operates (sometimes also owns) important parts of the required infrastructure. MNOs are however most often national entities, whereas the required services to be provided by MEC are international, and need to function cross borders. This could open the market for Cloud-, or data center providers who already operate international service platforms. A MEC service offer could be seen as a logical extension of their more centralized computing platforms. Network equipment vendors could potentially also take a role in providing MEC services, although this may be less likely due to their existing relationship as suppliers to MNOs. They would likely not want to disturb that existing business.

3.2.6 Summary and conclusion

The Technical Components (TCs) identified by the 5GCAR project can be divided into the following major categories:

- Positioning
- V2X radio design
- Network procedure
- End to end security
- Edge computing enhancements

Of these categories, some contain TCs that has the potential to "revolutionize", i.e. strongly effect existing business models (Network procedure), or create new business opportunities with major revenue potential (Positioning, Edge computing enhancements).

Other categories contain TCs that will enhance existing business models, and potentially add new value to existing services by enhancing capabilities, or by adding new features to an existing base technology. (V2X radio design, End to end security, Positioning, Network procedure).

It is not possible to predict in detail how the value of TCs will be realized in actual business cases. The value will likely be created on the service level, where multiple TCs may be included as parts of a single service. The value is determined by negotiations by the actors in the value chain, and may be very different depending on the use case, the business model of each actor in the value chain, time, regulatory landscape and many other factors. The analysis in this section, however indicates that, most of the technical components will create value by the vendor or the integrator of the technologies. For instance, a technical component will increase the cost and consequently the value of the car, the module in the car or the network. These technical components will thus have an impact on the pricing of the car, the connectivity and/or the network equipment. A partial list of the TCs with more expected business impact can be found below. Part of them will open the ecosystem for new stakeholders: ITS application provider, localization providers, etc., finally some TCs could change the place of stakeholder in the ecosystem (MNO, OEM). The value chain/eco-system is very immature, and we will most likely see multiple different attempts at creating new business models from various stakeholders.

Creating Value (new service):

For MNO:

- Positioning/Collision and trajectory Prediction,
- Network procedure/Network Service Relationship enhancement,
- Edge computing enhancements

For service or application provider (could be Tier1, Car OEM, or other) :

- Positioning, Positioning and Trajectory prediction
- End to End Security
- Network procedure/Network Service Relationship enhancement

- Multi operator solutions for V2X communications
- Edge computing enhancements
- Out of coverage sidelink

For MNO equipment provider

- Local standalone Network procedure

Impacting the place in the existing ITS ecosystem

For MNO:

- Local standalone network procedure
- Multi operator solutions for V2X communications
- In coverage sidelink
- Edge computing enhancements

For OEM:

- Edge computing enhancements

4 Spectrum

This chapter is devoted to the spectrum analysis of 5G under different perspectives. First with a vision of the current situation of the 5G auctions in different countries, focusing in the European market. Second with a comparative vision of the auction costs in 5G per band and country. Finally, the 5GCAR spectrum impacts are described related to the needs of the technological components proposed in 5GCAR.

4.1 Spectrum auctions and regulation

The ITU's World Radiocommunication Conference 2015 (WRC-15), held in Geneva in November 2015, has triggered off internationally, and consequently also at European level, within the framework of the *Conférence Européenne des Postes et Télécommunications* (CEPT) a rapid technical and regulatory process aimed at promoting the development of wireless and mobile 5G systems, not only in the IMT future designation and harmonization bands [5GITU17], but also in those already designated (in use or already harmonized). Among these, particular attention was paid to both the 700 MHz band and the 3.4-3.8 GHz band, presumably also due to the fact that these bands had not yet been widely assigned and could therefore have been used, in line with technological developments and standardization, through the deployment of 5G networks.

As part of this activity, in November 2016 the Radio Spectrum Policy Group (RSPG) provided the first indications on the frequency bands that can be used for the development of 5G systems, identifying, together with the 700 MHz band, the 3.4-3.8 GHz band and the 26 GHz band (24.25-27.5 GHz) as priority bands to support the introduction of 5G systems. In particular, the RSPG considered that 5G systems will need to be developed primarily in bands already harmonized in the range below 1 GHz, with particular reference to the 700 MHz band, in order to obtain good levels of 5G coverage on national scale, even in indoor environments. With reference to the 3.4-3.8 GHz band, the RSPG opinion highlights its primary role in enabling the introduction of 5G services in Europe by 2020, as this band already harmonized for mobile networks offers the possibility of exploiting up to 400 MHz of contiguous spectrum, allowing wide bandwidth of the frequency blocks, therefore suitable for providing performance capabilities (especially in terms of transmission speed) in line with the requirements of certain applications / services of the 5G type.

Regarding the 700 MHz band, the European Parliament and of the Council of 17 May 2017 establishes that by 30th June 2020 the Member States will authorize the use of the 700 MHz band for terrestrial systems in able to provide wireless broadband electronic communication services according to the harmonized technical conditions referred to in the Commission Implementing Decision (EU) 2016/687 of 28 April 2016 [5GCIM16]. Regarding the 26 GHz band, the RSPG considers it a pioneer band for 5G in the spectrum range above 24 GHz. RSPG recommends its harmonization by 2020 and the provision by the Member States for 5G.

Ten countries have recently completed 5G licensing procedures in at least one spectrum band. These include Australia, Finland, Italy, Ireland, Latvia, Mexico, South Korea, Spain, the United Kingdom, and the United Arab Emirates. Czechia, Germany, Greece, Norway, Saudi Arabia, Slovakia, Spain, Sweden, Tanzania, Thailand, and the U.S. have also completed spectrum allocations that could include, but does not necessarily require, 5G. Moreover, as a step to achieve a better performance for 5G, the European Union has started the plan of spectrum harmonization for the 3 relevant bands for 5G (700 MHz, 3.4-3.8GHz and 26 GHz). During 2016, the band of 700MHz was already harmonized and the availability of these frequency bands is expected to be in mid-2020. Additionally, in 2019 it was decided to harmonize both the band of 3.4-3.8 and 26 GHz allowing the European members to reorganize their spectrum and use these new frequencies by the end of 2020 [5GOBS19].

In this section, the spectrum situation in Europe and in other leading countries in different geographical areas is analyzed in detail highlighting the results of the auctions [5GTEL18], along with the main spectrum bands resulting for each of the operators and the consequences regarding regulation and harmonization.

4.1.1 Europe

In this section, we have selected six different European countries where spectrum auctions have been done or are ongoing in 2019.

Italy

Italy is the only European country were all the different spectrum bands relevant for 5G have been awarded. Therefore, the current status of the spectrum bands is final, and the total cost of the spectrum can be obtained.

Current status of spectrum bands in Italy

700 MHZ band

In response to the Commission's study mandate concerning the technical harmonization of the 700 MHz band for broadband wireless land-based electronic communications services, this band is made up of the main portions of coupled spectrum FDD 703-733 MHz and 758-788 MHz (60 MHz in total) intended for wireless broadband applications of interest for the development of mobile networks. Within these portions, the blocks are assigned according to multiples of 5 MHz. Additional spectral resources contained within the 700 MHz band are represented by the additional portions positioned in the guard bands (694-703 MHz and 788-791 MHz) or in the central range of the band, (733-758 MHz), in which the aforementioned Commission indicates the possibility for Member States to implement a series of options at national level (so-called "national options")) which include SDL (supplemental down link) applications for mobile, M2M (Machine to Machine) and PPDR (public protection & disaster relief).

3.4-3.8 GHz band

Regarding the 3.4-3.8 GHz band, the rules for assigning and using the frequencies available in this band for terrestrial electronic communications systems are based, in addition to the applicable technical and regulatory legislation, on the availability status of the aforementioned 3.4-3.8GHz band on the national territory, deriving from a partial process of liberation of the band in question from the existing uses. In fact, the Italian government had defined, on the basis of the state of occupation of the band, a national progressive refarming action on the existing fixed service utilizations, limited to some 30 MHz radio channels positioned in an approximately corresponding portion with the upper part of the band, i.e., the sub-band 3700-3800 MHz. In the lower sub-band 3600-3700 MHz, on the other hand, the persistence of the fixed service channels made it possible to identify local areas where even making available some portions of the spectrum did not allow generalized use of mobile systems or fixed communications networks.

26 GHZ band

This band has been used in Italy, according to the provisions of the CEPT for applications of the fixed Wireless Local Loop (WLL) service, whose measures for the release of rights to use frequencies available for networks broadband radios have recently been updated by the Italian Government. The current rights of use in this band will expire on 31st of December 2022 in order to make it available for 5G.

5G Auction in 2018

The Italian government officially authorized the auction for the assignment of 5G frequencies on May 8th 2018, with the resolution 231/18CONS [5GITA18], which unlocked 1275 MHz of spectrum partitioned as follows:

- 1000 MHz in the 26 GHz band
- 200 MHz in the 3700 MHz band
- 75 MHz in the 700 MHz band (FDD)

The aforementioned assignments are meant to be effective for 15 years, from 2022 to 2037. This information is available at the official website of the Italian 5G Ministry of Economic Development 5G [5GIT218] website.

During the preauction phase, the following companies were prequalified to the auction (in alphabetical order): Iliad Italia, Fastweb, Telecom Italia (TIM), Vodafone Italia, Wind Tre, Linkem and Open Fiber. However, at the start of the bidding phase in September, only the first five contenders of the list remained as auction participants, i.e., Iliad Italia, Fastweb, Telecom Italia (TIM), Vodafone Italia and Wind Tre.

The final assignment was made on October 2nd, 2018, and involved two different types of frequency blocks which definition can be found in [5GIT318]:

- **"specific block"** (*it: lotto specifico*), a frequency block among those that can be assigned whose position in the spectrum is specified at the moment wherein bids start;
- **"generic block"** (*it: lotto generico*), a frequency block among those that can be assigned whose position in the spectrum is not yet specified at the time bids start but will be at the end of the frequency assignment procedures.

The overall amount after 171 rounds of bidding have reached 6.550.422.258 Euros, well over the 4 Billion minimum base amount established by the government by law. Licenses in the 3.6 GHz-3.8 GHz band were the most attractive ones, achieving combined bids of 4.35 billion Euros. TIM and Vodafone obtained the two largest packets of frequencies in this band, while Wind Tre and Iliad acquired smaller allocations.

The 700MHz auction, which was completed in the first days of the sale process, brought in 2.04 billion Euros, with the spectrum won by TIM, Vodafone and Iliad. All five were successful in securing 26GHz frequencies, with the five available blocks raising 163.7 million Euros. Three extra blocks on the 700 MHz band for SDL (Supplemental Downlink) to enhance FDD 4G network downlink capacity (from Realese 10) were also offered but no operator presented an offer for them.

The final assignment has the following blocks repartition and costs [5GIT418]:

Table 4.1: Italy final blocks repartition and costs.

Frequency	Winning Bidder	Amount (€)
700 MHz reserved block (10 MHz)*	**Iliad Italia S.p.a**	676 472 792
700 MHz generic block (5 MHz)	**Vodafone Italia S.p.a**	345 000 000
700 MHz generic block (5 MHz)	**Telecom Italia S.p.a**	340 100 000
700 MHz generic block (5 MHz)	**Telecom Italia S.p.a**	340 100 000
700 MHz generic block (5 MHz)	**Vodafone Italia S.p.a**	338 236 396
3.7 GHz specific block (80 MHz)	**Telecom Italia S.p.a**	1 694 000 000
3.7 GHz specific block (80 MHz)	**Vodafone Italia S.p.a**	1 685 000 000
3.7 GHz generic block (20 MHz)	**Wind Tre S.p.a**	483 920 000
3.7 GHz generic block (20 MHz)	**Iliad Italia S.p.a**	483 900 000
26 GHz generic block (200 MHz)	**Telecom Italia S.p.a**	33 020 000
26 GHz generic block (200 MHz)	**Iliad Italia S.p.a**	32 900 000
26 GHz generic block (200 MHz)	**Fastweb S.p.a**	32 600 000
26 GHz generic block (200 MHz)	**Wind Tre S.p.a**	32 586 535
26 GHz generic block (200 MHz)	**Vodafone Italia S.p.a**	32 586 535

* *this block was reserved to Iliad, since it is a new player on the Italian market*

As a summary of the auction, this is the total repartition by band and contender:

Table 4.2: Summary of bandwidth by MNO.

Band	Winning Bidder	Price (€)	Total Spectrum Won
700MHz	**Vodafone**	683.236.396	10 MHz
	TIM	680.200.000	10 MHz
	Iliad	676.472.792	10 MHz
3.7GHz	**TIM**	1.694.000.000	80 MHz
	Vodafone	1.685.000.000	80 MHz
	Wind	483.920.000	20 MHz

	Iliad	483.900.000	20 MHz
26GHz	**TIM**	33.020.000	200 MHz
	Iliad	32.900.000	200 MHz
	Vodafone	32.586.535	200 MHz
	Wind	32.586.535	200 MHz
	Fastweb S.p.a	32.600.000	200 MHz

Reactions to the auction and impacts

The Italian government has received criticism for the way it set up the auction as in the 3.7 GHz band they offered two larger blocks of spectrum along with two smaller packets, which forced the operators to fight for the bigger blocks, raising the price around €0.42 per MHz per head of population (per MHz pop), which is well above what was raised in other countries.

One very vocal critic of the Italian government's approach has been the CEO of U.K.-based Vodafone Group that expressed: "*Auctions should be designed to balance fiscal requirements with the need for investment to enable economic development…it is critical that European governments avoid artificial auction constructs which fail to strike a healthy balance for the industry*" [5GIT518].

There are also worries that Wind Tre will struggle to compete with long-standing rivals TIM and Vodafone without access to a larger block of 3.7MHz spectrum. And Iliad finds itself with a sizable license fee to pay when it's still trying to find its market in the Italian communications sector. On the other hand, consumer groups expressed that they fear that end users will be finally impacted by this overrun, as operators will look to recover their outlay via higher tariffs.

Sweden

Current status of spectrum bands in Sweden

700 MHZ band

This band was auctioned in December of 2018 [5GSWE19]. PTS (Swedish Post and Telecom Authority) announced results for the first stage of its 700 MHz spectrum auction for 5G. The auction generated a total of SEK 2.825 billion (274 million euros) for a total of 40 MHz. After 46 rounds and six days, Telia Sweden won 2×10 MHz FDD for SEK1.383 billion (~132M €), while Net4Mobility won 2 licenses of 2×5 MHz FDD for a total price of SEK1.442 billion (~138M €). The reserve price was set at 50 MSEK (~5M €) per 5 MHz. The operator 3 Sweden did not take part of the auction. Moreover, coverage obligations are included in the Telia's licence with a reserved amount planned for this subject.

A summary of the auction is given in Table 4.3.

Table 4.3: Summary of bandwidth by MNO.

Bidder	State	Price (€)	Amount for coverage (€)
Telia Sverige AB	2 × 10 MHz, FDD 713-723 MHz 768-778 MHz	131.988.500	28.638.000
Net4Mobility HB	2 × 5 MHz, FDD 723-728 MHz 778-783 MHz	68.823.643	-
Net4Mobility HB	2 × 5 MHz, FDD 728-733 MHz 783-788 MHz	68.823.643	-

3.4-3.8 GHz band

This frequency band is still not auctioned but some public consultation has been performed achieving some general coordination and recommendations. During December 2019, PTS intends to carry out an allocation of several frequency bans in the 2.3 GHz and 3.5 GHz range. Additionally, to these bands, PTS is also targeting to assign the frequency space 3.7-3.8 GHz for local states. During the public consultation done by PTS, the term 2.3 GHz band is used when the frequency space 2300-2380 MHz is meant, and the 3.5 GHz band is used when the frequency space 3400-3700 MHz is meant. The frequency ranges 3400-3700 MHz and 2300-2380 MHz are available to terrestrial systems capable of providing electronic communications services.

Before awarding the spectrum to the different companies, PTS is planning to prepare the allocation of local block permits with the aim of being assigned without selection procedure, if possible, and with the aim of making 3.7-3.8 GHz band frequency space available to terrestrial electronic communications service providers. 2.3 GHz and 3.5 GHz will be national licenses, and 2.3 GHz will have certain restrictions for protecting other radio applications. For 2.3 GHz band there will be eight national licenses of 10 MHz each.

As an important aspect for the awarded spectrum bands, the license duration will be 25 years for both 2.3 GHz and 3.5 GHz (until Dec 31st of 2044, since the expected date for the auction is late December 2019). Noting that there are existing regional/local licenses in the 3.5 GHz band, some spectrum may become available later (2020–2023), with the consequence that the license duration will be shorter, in order to have expiration date which is the same for all licenses.

Spectrum cap will be applied to 3.5 GHz so that at least 3 licenses/operators can get spectrum, the cap will be 120 MHz for this band while for 2.3 GHz there will be no such limitation. The current use of 3.5 GHz will be protected until the licenses expire; if not used PTS intends to enable sharing for secondary use. The investigation on 3.7-3.8 GHz will be coordinated with the pre-study of 3.8-4.2 GHz, to determine among other things which band is more appropriate for this, and which form of licensing is best. If the answer is 3.8-4.2 GHz then 3.7-3.8 GHz could become available for national licenses. There were responses to the consultation in October 2018 on local licenses, proposing property-based licenses in urban areas, and property based and “regional” licenses outside of those areas. If this is applied the spectrum would be split between the two uses outside of urban areas.

Requirements

It has been agreed that there will be no requirements on coverage or similar, since the frequency bands are too high to be suited for such requirements. Moreover, it is understood that the offered bands and applications will primarily be used in cities and urban areas where the required coverage is already achieved. The licensing conditions for 2.3 GHz and 3.5 GHz should enable co-existence without geographical separation, implemented by a common frame structure, in case the licenses cannot reach an agreement themselves, and it should be re-considered every 5 years in order to follow technology development.

For 2.3 GHz there may be an interest in using LTE, so the frame structure proposed by PTS enables synchronization between LTE and NR, but also a frame structure for NR only in case there is no interest in LTE. For 3.5 GHz only NR is expected, and thus there is only a NR adapted frame structure proposed. Note again that this only applies if licenses do not manage to agree among themselves.

26 GHZ band

For the band of 24.25-27.5GHz there were two different options: to open 26.5-27.5 GHz for assignment in the future after the technical conditions for 5G usage in the band were clarified or to wait for international harmonization before starting the assignment for the entire band. Finally, Sweden government has decided to follow the second option. Therefore, nothing is decided yet in this band, waiting for completion of WRC-19.

Comments and reactions to the public consultation

GSA (Global mobile Suppliers Association) is supportive of auctions of the bands during 2019 but observes that 3700 – 3800 MHz would be suitable for national licenses, providing about 100 MHz per operator [5GSW219]. GSA would also suggest that an effort must be made to make as much of the auctioned spectrum available as soon as possible.

GSA supports the overall approach of obtaining synchronization in the frequency allocation, with operators being given a first chance to agree, but with fallback on a solution provided by PTS. The view that co-existence between different operators, should be enabled without geographical separation is important, but GSA also observes that there are deployment scenarios where there is no need for synchronization, such as for indoor deployments, and would like to stress the need to include provisions for such special cases. In particular, GSA encourages PTS to continue its investigation of spectrum in 3.8 – 4.2 GHz as an attractive alternative for vertical businesses. Strong support for national license in the entire 3.4 – 3.8 GHz, noting that mid-band spectrum in the range of 100 MHz, ideally more, is crucial for a competitive and complete 5G deployment framework. PTS notes that leasing can be an attractive alternative to spectrum sharing. GSA understands that there is an opportunity in Sweden to use part of 3.8 – 4.2 GHz for verticals and would suggest that compatibility studies are carried out for incumbents, considering that vertical business often have additional protection due to walls, to provide guidance on what spectrum in this range could be provided for national licenses.

Germany

Current status of spectrum bands in Germany

The President's Chamber of the Bundesnetzagentur (Federal Network Agency) is ordering an auction to be conducted for the 2 GHz and 3.6 GHz bands on account of the predicted scarcity of spectrum. The intention is to make available, for nationwide use, 2 x 60 MHz (paired) from the 2 GHz band and 300 MHz (unpaired) for the 3.6 GHz band in an auction in spring 2019. On 14 May 2018, the President's Chamber ordered that the assignment of spectrum for wireless access in the 2 GHz band and in the 3.6 GHz band is to be preceded by award proceedings in the form of an auction. On 26 November 2018, the President's Chamber of the Federal Network Agency determined the award rules and auction rules. Including the already awarded spectrum for 700MHz in 2015, the overall situation for the spectrum bands in Germany is as follows [5GGER19]:

Table 4.4: Auction done and planned in Germany.

Frequency band	Auction Details	Notes
700MHz (paired 703-733MHz/ 758-788 MHz)	2015	This band has been allocated in 2015 for usage by 4G LTE which can be refarmed for 5G.
2.1 GHz (60MHz paired 1920 MHz-1980 MHz/ 2110 GHz-2170 GHz)	Auction in Spring 2019 (March 2019)	
3.6 GHz (300 MHz @ 3.4-3.7GHz)	Auction in Spring 2019 (March 2019)	
3.7-3.8GHz (to be offered for local applications, such as network for industrial campuses)	Not announced yet	
24.25-27.5 GHz (to be offered for local applications, such as network for industrial campuses)	Not announced yet	

700 MHz and 1500 MHz auction in Germany (May-June 2015)

In May-June 2015 Europe's first 700 MHz ("second digital dividend") radio spectrum auction was completed in Germany along with the 900, 1800 and 1500 MHz bands. The frequency band of 700MHz has been allocated for 4G and it can be potentially used for 5G technologies with a validity of 15 years. The current situation of the 700 MHz frequency band is given in the following table [5GGER19]:

Table 4.5: Current status of bandwidth assignment by MNO.

Winning Bidder	Frequency Band (MHz)	Cost (M€)
Telefonica DE	703-708 & 758-763	166.397
Vodafone	708-713 & 763-768	165.509

Telefonica DE	713-718 & 768-773	166.847
Deutsche Telekom	718-723 & 773-778	166.657
Deutsche Telekom	723-728 & 778-783	171.649
Vodafone	728-733 & 783-788	163.476

Including the bands of 900MHz and 1800MHz which were also awarded during the same auction in 2015, the total allocated bandwidth was 270 MHz divided as follows:

- Telefonica Deutschland obtained 60 MHz divided in three bands (2x10 MHz in 700 MHz, 2x10 in 900 MHz and 2x10 in 1800 MHz) for a total of ~1.2 billion euros.
- Deutsche Telekom obtained 100 MHz divided in four bands (2x10 MHz in 700 MHz, 2x15 in 900 MHz, 2x15 in 1800 MHz and 20MHz in 1500 MHz) for a total of ~1.8 billion euros.
- Vodafone GmbH obtained 110 MHz divided in four bands (2x10 MHz in 700 MHz, 2x10 in 900 MHz, 2x25 in 1800 MHz and 20 MHz in 1500 MHz) for a total of ~2.1 billion euros.

2 GHz and 3.4-3.8 GHz

In March 2019 an auction to award the spectrum in 2GHz and 3.4-3.8GHz started in Germany. At the time of writing this document the auction is still not concluded and the round number is 366 for a total amount of 5.9 billion euros. The operators involved in the auction are: Telefonica DE, Vodafone, Deutsche Telekom and the newcomer 1und1 DRI.

Requirements for 2 GHz and 3.4-3.8 GHz auction

During the setting up of the spectrum auctions some conditions were established by Federal Network Agency in order to promote the rapid introduction of 5G. Some of the requirements are the following [5GGE219]:

- Coverage requirements to be supplied by the end of 2022 with at least 100 Mbit/s
  - at least 98 percent of households per federal state,
  - all federal highways,
  - the main federal roads and main railways
- Coverage requirements to be supplied by the end of 2024
  - all other federal highways with at least 100 Mbit/s,
  - all national and state roads with at least 50 Mbit/s,
  - the seaports and main waterways with at least 50 Mbit/s as well
  - all other railways with at least 50 Mbit/s.
    - In addition, a latency of 10 milliseconds is required for all federal motorways and federal highways.

        - In addition, each operator will have to set up 1000 "5G base stations" and 500 base stations in "white spots" by the end of 2022.
        - For a newcomer operator, separate coverage requirements are applied.
- Roaming and infrastructure sharing
    - Regarding the implementation of the aforementioned supply requirements, the Federal Network Agency expects cooperation between network operators in areas where the expansion by a single network operator is not economically viable. Increased cooperation, such as infrastructure sharing and roaming, can significantly reduce the costs of supplying space.
    - The network operators are required to negotiate on cooperation. The Federal Network Agency will actively accompany the process as a "referee".
- Service provider
    - Federal Network Agency also plans to create regulations to strengthen competition at the service level. Network operators have to negotiate with suitable service providers regarding the shared use of radio capacities. The Federal Network Agency will act as a referee in the event of a dispute.

Comments and reactions to the public consultation

The aforementioned requirements are strict conditions in order to allow any solvent company to bid for frequencies during the auction started in March 19, 2019. These strict requirements have attracted criticism from different parties such as business and other actors [5GGE319] [5GGE419]. While the idea of these requirements given by the Federal Network Agency promote an equal deployment of the 5G technology in all areas, not only picking up the business at major urban areas, it could potential be seen as a showstopper for the commercial deployment of 5G.

Due to this requirements Telefonica Germany, Vodafone and Telekom Deutschland GmbH have filled different applications to postpone the auction and additionally there are several open procedures that deal with the requirements to obtain the spectrum. However, this complaint by the mobile phone providers was not successful and the auction started in March. In support of the decision, the Court states that it is irrelevant when ordering an award procedure whether the frequencies are available at the time of the order. Nevertheless, the Federal Network Agency announced the four companies that qualified to bid for the 5G frequencies ranges at 2 GHz and 3.6 GHz. In this group are three major companies (Telekom Deutschland GmbH, Vodafone GmbH and Telefonica Germany GmbH & Co. OHG) and a newcomer such as 1 & 1 Drillisch network AG. The approval test is intended to ensure that the limited spectrum only applies to companies that are technically capable of commissioning a nationwide network. Besides the financial possibilities, also the technical know-how counts. For the first time now also 1 & 1 / Drillisch is part of the party. A total of 420 MHz is being auctioned, which will be used in future for the benefits of 5G. The federal government expects that the proceeds for the treasury will amount to about 5 billion euros [5GGE519].

Spain

Current status of spectrum bands in Spain

3.4-3.8 GHZ band

In Spain a part of 3.6 GHz spectrum band (3,400 MHz-3,600 MHz) was already been awarded for 5G services in 2016, with licenses valid until 2030, where Orange took the auctioned band for 20 million of Euros, better offer than Vodafone. Telefonica decided not to participate in this band because they already had 40 MHz obtained when they purchased the Internet provider Iberbanda.

Till 2018, this was the repartition by operator:

- Movistar 40 MHz (3440-3460 / 3540-3560 MHz)
- Orange 40 MHz (3460-3480 / 3560-3580 MHz)

This spectrum can already be used to deliver 5G services pursuant to the General Telecommunications Law 09/2014.

The National Plan 5G 2018-2020 [5GSP218] contemplates the reordering of the already occupied part of the 3.6 GHz band to establish larger and more contiguous blocks in line with what is recommended for the development of 5G technology and the first action was to auction this band.

700 MHz band

In 2020, new blocks of spectrum will be also auctioned in the 700 MHz band to cover 5G more extensive areas of territory and with lower user density. The Government has confirmed this auction, that was already announced for 2019, on Wednesday 21st of November 2018. The delay was announced in order to make the auction when the spectrum will be released because it is currently used for Digital Terrestrial Television (DTT) services, so that the MNOs can commercially dispose of the frequencies at the moment of winning the award. That is, the spectrum will be auctioned when it is available to operators, something that did not happen with the auction of 4G (which had been auctioned in 2011, but available to the winning bidders in 2015). The deadline for DTT services to release the spectrum is June 2020.

26 GHz band

In this band, 400 MHz are available for immediate use on the lower portion of the band and 500 MHz plus another 500 MHz with some limitations on the higher portion of the band. The remaining part of the band is used by radio links in point-to-point fixed services over mobile trunk networks. This band is also included in the National Plan 5G and will be tendered to operators in the medium term making more contiguous spectrum available.

3.7 GHz Auction in 2018

Spain’s Ministry of Energy, Tourism and Digital Agenda (Ministerio de Energia, Turismo y Agenda Digital, MINETAD) launched in 2018 the auction process for 200 MHz still available in the 3.7 GHz band, defined as the priority band. The auctioned spectrum was divided into 40 5MHz blocks, each of which will be valid for a period of 20 years (till 2038) and had a starting price of EUR2.5 million, with a minimum expected value of more than 100 million EUR.

The following companies were prequalified to the auction (in alphabetical order): Masmovil, Movistar, Orange and Vodafone. Vodafone has ended up being the operator which has more invested in the auction as they started with disadvantage because its rivals had already accumulated frequencies in the 3.5 GHz band.

MásMóvil, the 4th operator in the country, did not acquire spectrum in the process but they have purchased 40 MHz to Eurona (that has this spectrum since 2014) and acquired another 40 MHz with the acquisition of Neutra Network Services, although its validity is until 2030 (as it happens to Movistar and Orange with its previously acquired frequencies).

None of the MNOs has reached the limit of 120 MHz imposed by the Spanish government. As Vodafone has been the operator that has invested the most in the auction, it will have priority to choose and could have its 90 MHz in a common block making a better use of the spectrum. This is not the case for other MNOs awarded in the 3.7 GHz auction

The auction had 34 rounds and the total final amount raised was 1,410.7 million of euros. The final assignment [5GSPA18] has the following blocks repartition and costs:

Table 4.6: Summary of bandwidth auctioned in 2018.

Band	Winning Bidder	Price (€)	Total Spectrum Won
3.7GHz	**Movistar**	107.400.000	50 MHZ
	Vodafone	198.100.000	90 MHZ
	Orange	132.000.000	60 MHZ

In addition to the acquisition costs from the table above (437.5 million €), the operators will spend 104.6 million due to the interest fee and 868.5 million due to a spectrum reservation fee making the total cost for the operators of 1410.7 million.

The new situation of the spectrum adding the investments made in the recent auction stays as follows:

Table 4.7: Summary of bandwidth by MNO.

Band	Operator	Total Spectrum
3.7GHz	**Movistar**	90 MHZ
	Vodafone	90 MHZ
	Masmóvil	80 MHZ
	Orange	100 MHZ

In summary in the current 5G spectrum situation:

- Vodafone is the operator with the highest investment in the auction: 198 million.

- After the auction, Orange is the operator with more total licensed spectrum: 100 MHz.
- MásMóvil is the operator that has less spectrum and less investment has made: 80 MHz and 40 million because of their purchases outside the auction.
- MásMóvil is the operator that has paid less for each licensed MHz (0.57 million per unit).
- Vodafone is the operator that has paid more for each licensed MHz (2.2 million per unit).

Reactions to the auction and impacts

The auction was considered expensive in general [5GSP318]. In a statement to Mobile World Live MasMovil said it had paid an average of €0.57 million per MHz (rebuying), while the average in the auction was €2.2 million for the same amount. Telefonica said it "applied criteria of rationality in the auction that has allowed it to obtain the desired spectrum by paying the lowest price per MHz of all the bidders in it"

Following the acquisition of this 5G spectrum, Vodafone announced the launch of 5G trials in the cities of Madrid, Barcelona, Valencia, Bilbao, Malaga and Seville. Vodafone Spain also said it had already installed more than 30 antennas in collaboration with Chinese vendor Huawei in the six selected cities. In January this year, Telefonica unveiled its 5G technological cities project, which will pave the way for the future deployment of 5G technology in Spain. Under this initiative, Telefonica partnered with European vendors Nokia and Ericsson for the initial deployment of 5G capabilities in the cities of Segovia and Talavera de la Reina.

UK

Current status of spectrum bands in United Kingdom

700 MHz band

Freeview television and wireless microphones use the 700MHz band. The government has contributed with £500-600 million to clearing the spectrum, a process which began in March 2017 with the reconfiguration of a digital terrestrial television (DTT) transmitter in Selkirk. The aim is to migrate DTT to the 470-690MHz spectrum and making alternative spectrum available for wireless microphones. Currently Ofcom, the UK regulator, expects the process to be complete by May 2020 in order to auction 80 MHZ in this band that will include obligations to ensure improved rural coverage.

3.4-3.8 GHz band

Ofcom's auction of spectrum in the 2.3GHz (for 4G improvements) and 3.4GHz bands concluded in April 2018. The 2.3GHz - 3.4GHz spectrum was previously used by the Ministry of Defense, but has been freed up by the government to make it available for civil uses.

Part of the 3.4GHz spectrum is used for 4G wireless broadband, such as by Relish in London, which is now owned by Three following its acquisition of UK Broadband. The spectrum in the

3.6GHz - 3.8GHz bands is partially in use by fixed links and satellite services, but Ofcom plans also to auction 120Mhz of spectrum in this bandwidth.

26 GHz band
Ofcom has identified the 26GHz band as the next priority for global harmonization

5G 3.4 GHz Auction
Ofcom published its final rules for the 2.3GHz and 3.4GHz auction in July 2017, designed to reflect recent market developments and safeguard competition now and in the future.

The rules imposed two restrictions on bidders to limit the amount of spectrum dominant operators could win:

- No operator would be able to hold more than 255MHz of immediately usable spectrum, i.e. in the 2.3GHz band, following the auction.
- No operator would be able to hold more than 340MHz of the total amount of spectrum following the auction, equivalent to 37% of all the mobile spectrum that is expected to be useable in 2020. This includes spectrum available in the completed auction and in the 700MHz band.

Ofcom was not proposing any coverage obligations on the winning bidders like it did with the 4G auction in 2013. That is because the provision of these latest frequencies is more about boosting network capacity than expanding network coverage.

Industry observers have been waiting for the auction results of Three (property of Hutchison 3G), and O2 (property of Telefónica). These two subsidiaries attempted a merge to put them in a similar standing to the nation’s biggest players, EE and Vodafone, in terms of mobile subscribers and spectrum ownership. But O2 and Three’s deal was blocked by national and European courts due to concerns a reduction to just three major operators would reduce market competition and harm consumers.

Three made the biggest fuss ahead of the auction in a bold attempt to prevent EE and Vodafone gaining a greater advantage. The company launched the #MakeTheAirFair campaign and took Ofcom to court in a bid to impose stricter restrictions on the sale of 5G spectrum to its larger competitors.

Finally, Three failed a final court appeal to delay the auction which allowed it to continue unhindered.

Auction result
The following companies were prequalified to the auction (in alphabetical order):

- Airspan Spectrum Holdings
- EE
- O2
- Three
- Vodafone

The auction of spectrum in the 2.3GHz and 3.4GHz bands concluded in April 2018, with all four of the nation's existing mobile network operators securing new frequencies. The total amount of the auction was GBP1,355,744,000, where GBP1,149,844,000 was for the 5G band, well above previous estimates of GBP630 million to a billion. O2 UK emerged as the biggest spender after offering GBP205.9 million for all 40MHz of the 2.3GHz spectrum on offer, as well as paying GBP317.7 million for 40MHz in the 3.4GHz band. Vodafone UK made the largest offer for 3.4GHz frequencies, meanwhile, with its GBP378.2 million bid netting it a 50MHz block in that band. EE bagged a 40MHz block of 3.4GHz spectrum with a GBP302.6 million bid. Three UK walked away with a smaller allocation than any of its rivals, agreeing to pay GBP151.3 million for a 20MHz block of 3.4GHz spectrum, that they accumulate with the 124 MHZ they have already from the acquisition of UK Broadband.Only newcomer Airspan Spectrum Holdings failed to win any of the frequencies put up for auction.

Auction prices

The final 5G band assignment [5GUK319] has the following blocks repartition and costs:

Table 4.8: Result of the auction made in 2019.

Band	Winning Bidder	Price (£)	Total Spectrum Won
3400MHz	**EE**	302.592.000	40 MHz
	O2	317.720.000	40 MHz
	Three	151.296.000	20 MHz
	Vodafone	378.240.000	50 MHz

The new situation of the spectrum adding the recent auction stays as follows:

Table 4.9: Summary of bandwidth by MNO.

Band	Operator	Total Spectrum
3400 MHz	**EE**	40 MHz
	O2	40 MHz
	Three	144 MHz
	Vodafone	50 MHz

Reactions to the auction and impacts

Regarding the previous controversy, Matthew Howett, Founder & Principal Analyst at Assembly Research, comments [5GUK419]:

"Despite Three having made the most noise about the rules of the auction, it was perhaps O2 that had the most to lose, being the operator that probably needed more spectrum the most. The outcome is a particularly good result for them. Even though the auction raised a fraction of the amount of the 4G auction or even the 3G auction two decades ago, the prices paid are above expectation which shows how valuable these airwaves are to operators, particularly given the emerging hype around 5G. However, an unsatisfactory outcome in this auction was never going to necessarily spell the end to any one operator's 5G future given that the technology will ultimately work across a number of spectrum bands, both new ones and ones already held by the mobile operators."

France

Current status of spectrum bands in France

In January 2019, ARCEP had announced temporary frequency authorizations to develop 5G pilots in France. The regulator will allow for experimentation in the 3.5 GHz band (3400 – 3800 MHz) in the metropolitan areas of Lyon, Bordeaux, Nantes, Lille, Le Havre, Saint-Étienne, Douai, Montpellier and Grenoble.

The following bands are the main focused bands for 5G spectrum in France:

700 MHz band

This band has been already affected to operators during the 4G spectrum auction. It has a limited bandwidth but offers good propagation conditions. France raised €2.79 billion in a 4G spectrum auction in November 2015, according to the country's telecoms regulator. After 11 rounds of bidding, the price of the spectrum reached €466 million for each 5MHz block. Bouygues Telecom and SFR were awarded a block each while Free Mobile and Orange were awarded two blocks each. The different operators will pay two-thirds of the amount if they obtain their second choice and one-third if they get their third choice. They will pay nothing if they obtain their last choice. Under the rules of the auction, no bidder may win more than three blocks of 700 MHz spectrum.

For the French regulator [5GFRA18], 700 MHz band is neutral in terms of technology: that is to say, if one operator has licensed spectrum in that band, has the choice to deploy 4G or 5G. Furthermore, technological neutrality will be introduced on the 900, and 1800 MHz. After refarming (900 MHz band is used for GSM, 1800 MHz for LTE) these bands could be used for 5G.

3.4-3.8 GHz band

This band will not be completely free before 2026 (used by satellites, state and private operator). Some questions arise over the reorganization of the band. If a reorganization occurs, 280-340 MHz will be available before 2026, if not only 220 MHz will be available over 400 for the entire band.

The attribution process will be the subject of a second public consultation in the second half of the year 2019, then in autumn 2019 frequencies attribution process will be launched in the 3,5

GHz band. No details concerning the methods of attribution have been provided by the government. Because of the restriction in terms of spectrum availability, the mechanism of spectrum sharing has been envisioned by the regulator.

2.6 GHz band

ARCEP has decided to dedicate 40 MHz to professional use from 2570 to 2620 MHz. The rest of the band is used for 4G (LTE, LTE advance). A public survey has been launched by ARCEP (French telecom regulator) [5GFR219] for that piece of band (ie the 40 MHz) in mars 2018. Some professional stakeholders from civil society (outside operators) have shown interest for that spectrum. Vinci which is road operator (highway) in France has shown interest for this band, as well as Transdev a mobility provider. 4G, 5G technology could be deployed over that band.

26 GHz band

The band is already available. The condition of usage of this band is not today defined in France. The licence authorization could be restricted to a geographical area. The ARCEP (French telecom regulator) has opened in January 2019 a request for proposal for innovative projects willing to experiment 5G mm waves. This request is opened widely to several types of actors.

4.1.2 United States

The FCC is focused on making additional low-, mid-, and high-band spectrum available for 5G services. The overview for the 5G spectrum in the US is as follows (source FCC [5GUS19])

- High-band: The FCC has made auctioning high-band, millimeter-wave spectrum a priority. The FCC held its first 5G spectrum auction in 2018 in the 28 GHz band. In 2019, the FCC will hold an auction in the 24 GHz band starting on March 14 and auctions in the upper 37 GHz, 39 GHz, and 47 GHz bands later in the year. With these auctions, the FCC will release almost 5 gigahertz of 5G spectrum into the market—more than all other flexible use bands combined. The FCC is working to free up another 2.75 gigahertz of 5G spectrum in the 26 and 42 GHz bands.
- Mid-band: Mid-band spectrum has become a target for 5G buildout given its balanced coverage and capacity characteristics. With the work on the 2.5 GHz, 3.5 GHz, and 3.7-4.2 GHz bands, up to 844 megahertz could be made available for 5G deployments.
- Low-band: The FCC is acting to improve use of low-band spectrum (useful for wider coverage) for 5G services, with targeted changes to the 600 MHz, 800 MHz, and 900 MHz bands.
- Unlicensed: Recognizing that unlicensed spectrum will be important for 5G, the agency is creating new opportunities for the next generation of Wi-Fi in the 6 GHz and above 95 GHz band.

The US Federal Communications Commission (FCC) completed its first 5G auction, with a sale of 28GHz spectrum licenses raising $702 million. FCC chairman Ajit Pai [5GUS219] said the auction is a "significant step toward maintaining American leadership in 5G" adding that the commission "will continue to aggressively push more spectrum into the commercial marketplace." The 28GHz auction took 38 days and 176 rounds of bidding to complete.

A total of 3,072 licenses offered in 425MHz blocks were up for grabs in the 28GHz auction. Of these only 107 received no acceptable bids. The identities of the winning bidders will remain private until the close of the 24GHz auction. The FCC auctioned two 425 MHz bands, covering 27.500 to 27.925 and 27.925 to 28.350 GHz, by geographic county. The licenses for Upper Microwave Flexible Use Service authorize both fixed and mobile operation. Winners of the 28 GHz licenses (Auction 101) will not be announced publicly until after the 24 GHz auction concludes, when the names of the winners in both auctions will be released.

Earlier in the month the FCC had vowed to continue work on scheduled spectrum auctions [5GUS319], as it prepared to temporarily close down most of its other operations. In November 2018 the agency had said it will set strict performance requirements [5GUS419] for the licenses to encourage the swift rollout of 5G services and will take dim view on any attempt to seek a waiver of the requirements ahead of construction deadlines.

24 GHz auction in the US

The 24GHz auction is currently on-going and will be followed by auctions for three more spectrum bands later in the year. Auction 102 is the Federal Communications Commission's second auction of Upper Microwave Flexible Use Service (UMFUS) licenses [5GUS519]. Auction 102 offers 2,909 licenses in the 24 GHz band. The lower segment of the 24 GHz band (24.25–24.45 GHz) will be licensed as two 100-megahertz blocks, and the upper segment (24.75–25.25 GHz) will be licensed as five 100-megahertz blocks. The starting date for bidding in Auction 102 began on March 14, 2019. An overall description of the 2909 offered licenses is as follows including the different blocks of frequencies:

Table 4.10: Blocks of bandwidth auctioned.

Block Frequencies (GHz)	Total Bandwidth	Geographic Area Type	Number of Licenses
A	24.25–24.35	100 megahertz	PEA 416
B	24.35–24.45	100 megahertz	PEA 416
C	24.75–24.85	100 megahertz	PEA 416
D	24.85–24.95	100 megahertz	PEA 416
E	24.95–25.05	100 megahertz	PEA 416
F	25.05–25.15	100 megahertz	PEA 416
G	25.15–25.25	100 megahertz	PEA 416

*In PEA 75 (Albuquerque, NM), the G Block license will consist of 75 megahertz (25.150–25.225 GHz). In PEAs 15 (Phoenix, AZ), 26 (Las Vegas, NV), and 76 (Reno, NV), no G Block license will be available.

The auction for the 24GHz is still on-going as the writing of this document. The auction is currently at round 58 for a total amount of 1.988 billion dollars and it is foreseen to be concluded by the 28th of May 2019 [5GUS619]. The number of licenses that were offered is 2909 and at this moment 2904 are already awarded so only a small number of licenses are remaining unassigned.

4.1.3 Asia

China

The Ministry of Industry and Information Technology (MIIT) of China has allocated 5G frequencies to the tree major operators in China: China Telecom, China Unicom, China Mobile. There is no neutrality in terms of technology used which means that the deployed technology must be 5G technology. This has been made to fasten the 5G deployment in China.

Additionally, the attribution process for the spectrum is not clear: the licenses given to the operators are temporary and this allocation will be valid until 2020 [5GCHI18]. However, there is no clear vision of the counterpart given by the operators for having such a limited time allocation [5GCH218]. The government of China believes that 5G will boost the internal economy and their industrial development. In contrast to the situation in Europe and the United States, no auction has been organized by the government of China, and therefore, no spectrum cost has been published.

Hereafter the spectrum attribution in 2018 is as follows:

- China Unicom: 3.5 GHz to 3.6 GHz (100MHz) frequency range for a nationwide 5G trial rollout until June 2020. The telco said that it will gradually cease to use the frequency in the 2.555 GHz to 2.575 GHz range that it had been using for 5G trials and progressively return it to the MIIT.
- China Telecom: the 3.4 GHz to 3.5 GHz (100MHz) frequency range for 5G trials in mainland China. Under the agreement with the Chinese government, China Telecom will return its 2.635 GHz to 2.655 GHz spectrum in 2020.
- China Mobile: the 2515 MHz to 2675 MHz and the 4.8GHz to 4.9 GHz (260MHz in all) ranges for its nationwide 5G trials. The 2575-2635MHz spectrum frequency is re-farmed from China Mobile's pool of TD-LTE spectrum.

China Mobile is the biggest operator in the world encompassing 755 million subscribers while 200 million 4G users are subscribed to China Unicom. Moreover, China Telecom proved service to 153 million subscribers. Thus, spectrum distribution is coherent with the number of subscribers since China Telecom has more spectrum allocated than the combination of the other two operators. Nevertheless, it is worth mentioning that China Mobile has no spectrum available in the 3.5 GHz band.

Japan

The Ministry of Internal Affairs and Communications (MIC) announced on 10 April 2019 that all the four applicants (NTT Docomo, KDDI, Softbank and the newcomer Rakuten) have been awarded radio frequencies and licenses to rollout 5G services. Each licensee is awarded 400MHz spectrum on the 28GHz frequency, while three of them are awarded 200MHz on 3.7GHz except Rakuten, which has requested 100MHz. Spectrum distribution process is similar to what happened in China in terms of pricing where no spectrum auction was conducted. The difference is that the spectrum allocation has been organized by the government of Japan Ministry of Internal Affairs and Communications regarding some requirements that the operators need to fulfil. The distribution of spectrum was done in April 2019, and the criteria took into account the commitments of each operator in terms of 5G investments and percentage of population covered by 5G.

Table 4.11: Final spectrum assignment for the 3.5GHz and 4GHz bands [5GJAP19]

Operator	Spectrum Band	Bandwidth
NTT Docomo	3.6-3.7 GHz & 4.5-4.6 GHz	200 MHz
KDDI	3.7-3.8 GHz & 4.0-4.1 GHz	200 MHz
Softbank	3.8-3.9 GHz	200 MHz
Rakuten	3.9-4.0 GHz	100 MHz

Moreover, the spectrum band of 27 GHz was also awarded obtaining the following allocation for the four operators:

Table 4.12: Final spectrum assignment for the 27GHz band

Operator	Spectrum Band	Bandwidth
NTT Docomo	27.4-27.8 GHz	400 MHz
KDDI	27.8-28.2 GHz	400 MHz
Softbank	29.1-29.5 GHz	400 MHz
Rakuten	27.0-27.4 GHz	400 MHz

Requirements

NTT and KDDI committed on the coverage of population (> 90%), and on strong investments in 5G. Thus, results of spectrum attribution seem coherent with the investment commitments made by the four operators. The conditions for the allocation of spectrum included commitments to commence services in every prefecture of the nation within two years and set up 5G base stations in at least half the country within five years. The communications ministry also divided Japan into

4,500 blocks, requiring operators to set up base stations in at least half of them within five years. Docomo and KDDI each plan to achieve coverage of more than 90% in that time. SoftBank and Rakuten set less ambitious goals, at 64% and 56%, respectively. The requirement will force mobile operators to balance making heavy investments with attaining profits [5GJAP219]. In order to achieve the requirements stated by the MIC the four operators envision to invest the following amount in enhancing and deploying networks linked to the expected coverage [5GJAP319]:

Table 4.13: Investment engaged for coverage deployment

Operator	Estimated Cost for deployment	Expected Coverage
NTT Docomo	7 billion USD	More than 90%
KDDI	4.1 billion USD	More than 90%
Softbank	1.8 billion USD	64%
Rakuten	1.7 billion USD	56%

Moreover, the government is already pressing the carriers to cut their service rates. Regarding this aspect the entrance of the newcomer Rakuten into the market, which aims for 15 million subscribers, is expected to intensify the price competition.

Korea

Auction has been organized in summer 2018. All the three operators agreed to launch their 5G offer the same day (3th of April 2019). Korea is the first state in the world commercializing 5G subscriptions for the public.

280MHz bandwidth of 3.5GHz spectrum and 2400MHz bandwidth of 28GHz spectrum were available in block auction. The respective spectrum was divided into 28 blocks and 24 blocks. Each telco -- SK Telecom, KT, and LG Uplus -- had a 10 block cap per spectrum [5GKOR18]. SKT emerged as the biggest spender overall, bidding a total of USD1.10 billion for 100MHz in the 3.5GHz band (3600MHz-3700MHz), while it paid a further USD173 million for 800MHz of bandwidth in the 28GHz band (28.1GHz-28.9GHz). For its part, KT Corp offered a total of USD828 million for its 3.5GHz spectrum (3500MHz-3600MHz), although it spent the most of any operator on the 28GHz frequency band, obtaining the 26.5GHz-27.3GHz block with a bet of USD 175 million bid. For the final nationwide operator, LG Uplus spent USD680 million on an 80MHz block in the 3.5GHz band (3420MHz-3500MHz) and committed a further USD 170 million for its 28GHz allocation (27.3GHz-28.1GHz).

The overall attribution of spectrum in the 3.5GHz band is given in Table 4.13.

Table 4.13: Final spectrum assignment for the 3.5GHz band

Operator	Spectrum Band	Bandwidth	Cost	Period
SK Telecom	3.6-3.7 GHz	100 MHz	1.1 Billion USD	10 years
LG Uplus	3.42-3.5 GHz	80 MHz	680 M USD	10 years
KT Corp	3.5-3.6 GHz	100 MHz	828 M USD	10 years

For the 28 GHz band and overview of the spectrum situation is as follows:

Table 4.14: Final spectrum assignment for the 28GHz band

Operator	Spectrum Band	Bandwidth	Cost	Period
SK Telecom	28.1GHz-28.9GHz	800 MHz	173 M USD	5 years
LG Uplus	27.3GHz-28.1GHz	800 MHz	170 M USD	5 years
KT Corp	26.5GHz-27.3GHz	800 MHz	175 M USD	5 years

The spectrum allocation for 5G in Asia has been already completed showing the involvement of these nations in leading the 5G deployment. In China and Japan as opposed to Europe and USA there was no public auction and the frequency bands were allocated to the operators by a central government (China) or based on the expected coverage and expenditure of the 5G deployment (Japan). For the situation in Korea, the spectrum attribution for 5G is more balanced than for Japan, and China. It is coherent with the network sharing agreement between mobile operators in Korea being the priority the deployment speed rather than competition between operators which is contraposed to the situation in Europe.

4.1.4 Summary of auctions and cost comparison worldwide

After providing a worldwide vision of the 5G auctions done so far, it is clear that the European Union is leading 5G band auctions. Important telecommunication markets such us Italy, Spain or Germany have already done or are about to finish part of this process, with an important spectrum quantity made available, as it can be checked in Figure 4.1.

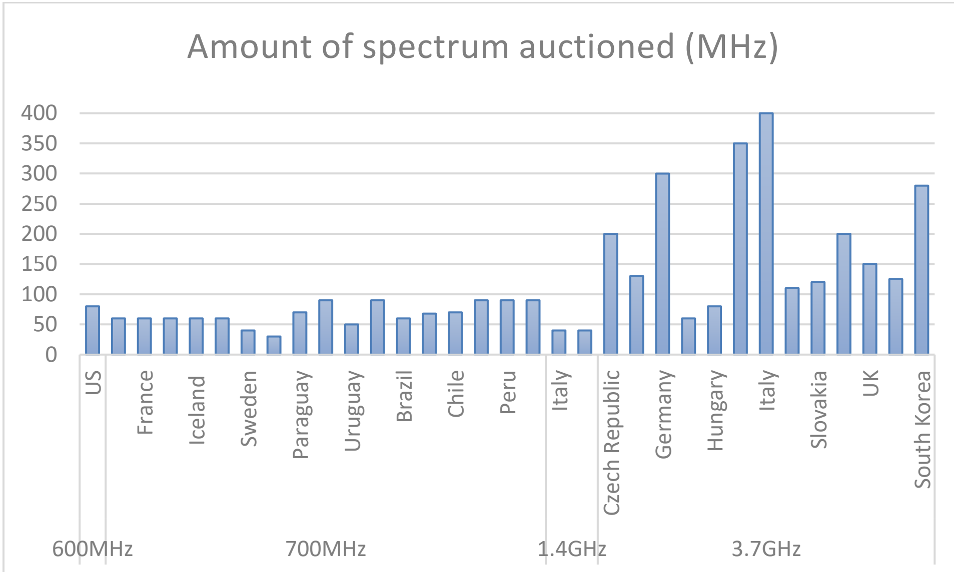


Figure 4.1: Amount of spectrum auctioned worldwide.

Beyond Europe, USA and South Korea are also having a leading role, making the different 5G bands available for the MNOs. China is also being dynamic on this topic, but the country is not included in the list because there was no auction but a frequency assignment for the different MNOs.

Regarding the price per Hertz in Figure 4.2, in big countries like USA, Canada, Brazil or Argentina, the price for the 600 and 700 MHz bands is more expensive than in any other band or country. These bands have a very good propagation and are especially important in big countries to fill the cellular coverage gaps. If the population is introduced as a factor for the comparison, then the most developed countries in the world lead the classification with special remarks for Australia and Canada.

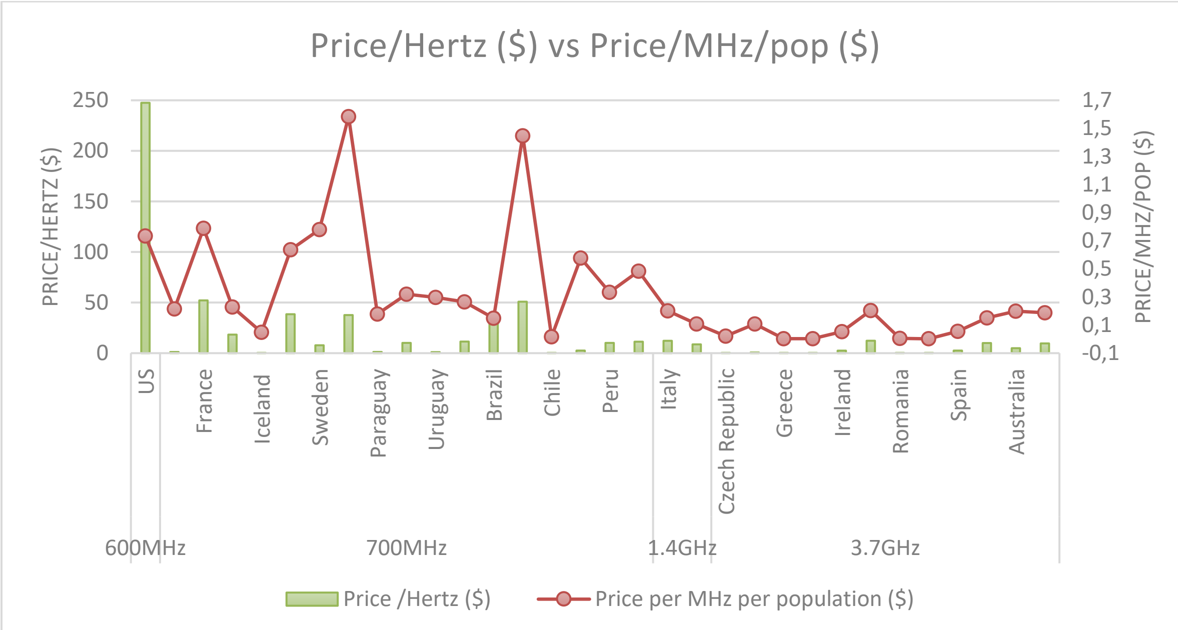


Figure 4.2: Comparison of the price paid per hertz in different countries.

Summary of European auctions

Focusing in the European market, several aspects must be highlighted. 5G is right now a trending topic with an important public media interest. However other 4G spectrum bands are also being auctioned, those from the last 5 years must also be taken into account to get the complete spectrum landscape. In average around 200Mhz are made available in the 3.5 Band and around 60 in the 700 band. Both 5G and 4G bands are reflected in Figure 4.3.

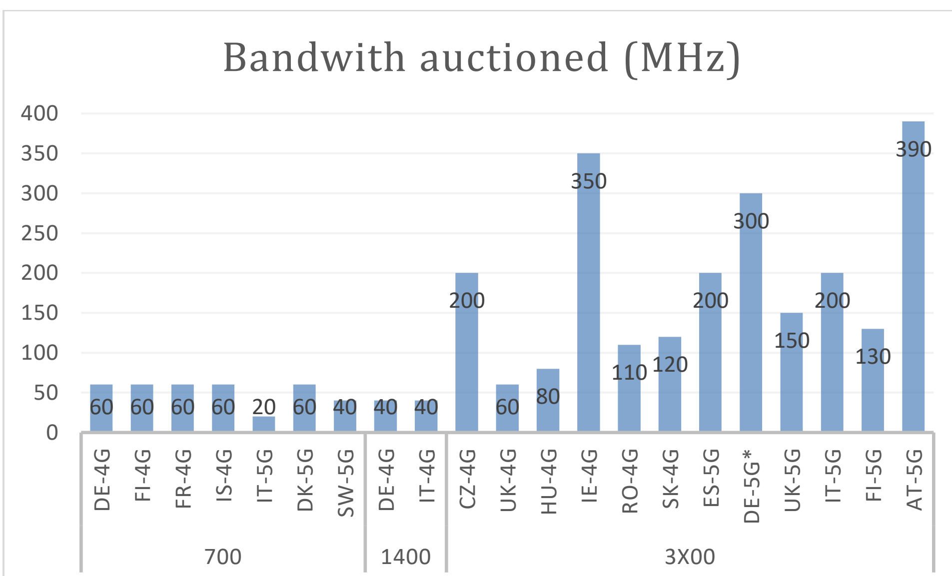


Figure 4.3: Bandwidth auctioned in European countries

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 2.6GHz since the allowed bandwidth in these bands is a good fit for 5G services. Moreover, it is interesting to consider the refarming of the 1.8GHz band once many of the existing systems have migrated to 5G technology [OVUM119]. The band of 1.4GHz, also denominated as L-band. 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].

The spectrum auctions are still ongoing in many countries, but for those already done or about to be finished (this is the case of Germany) a brief comparison is given in Figure 4.4.

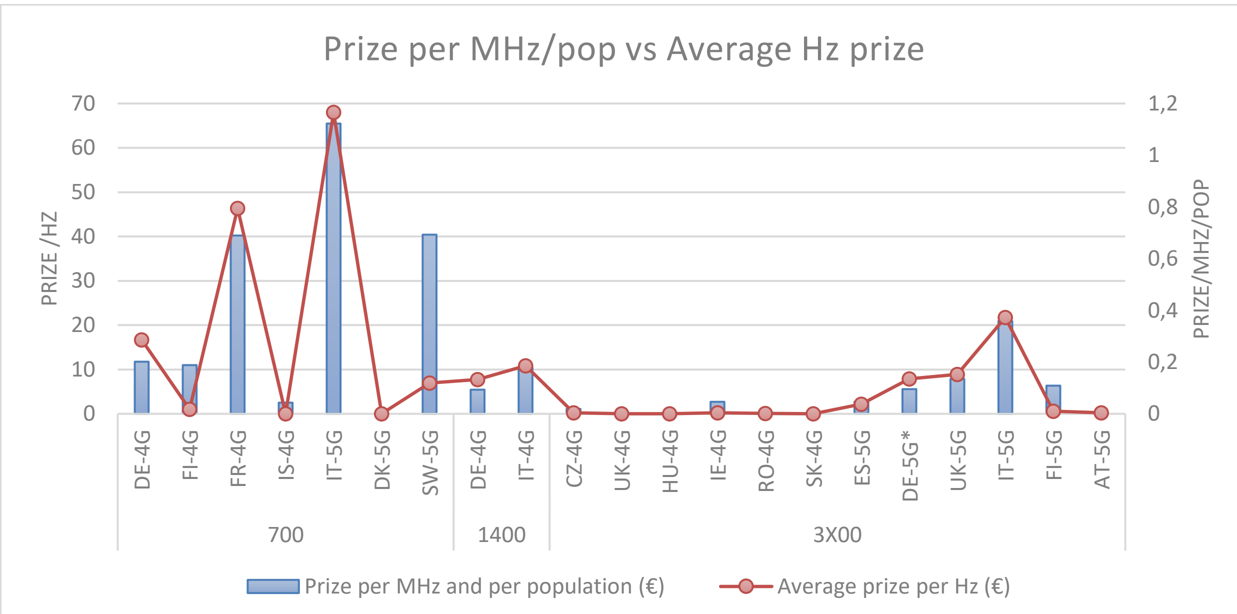


Figure 4.4: Comparison of the price paid per hertz in European countries.

As it has been explained in this section, Italy has leaded all the spectrum auction in all the 5G bands. The first consequence is the high price paid by the operators compared to other important telecom markets like UK or Spain. The case of Germany is still not finished and it has to be taken as an important reference due to the size of the market and the important technical requirements defined in the auction.

The GSMA is following the spectrum auctions worldwide and 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.

It can be observed that the price has been increased during the 5G auctions when compared with the auction in 4G. Moreover, using as a variable the population of the country, the value per MHz is quite similar in the different European countries standing in average around 0.75 euros/MHz/person.

4.1.5 Spectrum regulation in Europe and DSM

The Digital Single Market strategy aims to open up digital opportunities for people and business and enhance Europe's position as a world leader in the digital economy [REGEU18].

The main activity areas are:

- Shaping the Digital Single Market
- Boosting European digital Industry
- Building a European data economy
- Improving connectivity and access
- Investing in network technologies
- Advancing in digital science and infrastructures
- Support media and digital culture
- Creating a digital society
- Strengthening trust and security

Spectrum related aspects

In the EU the Member States coordinate their spectrum management approaches in a common regulatory framework to support the internal market for wireless services and to foster innovation in electronic communications and other sectors. The Member States harmonize spectrum access conditions at EU level to ensure efficient use of radio spectrum or to enable interoperability of underlying equipment and communications services. The European Commission works together with Member States to modernize spectrum management to facilitate spectrum access through more flexibility in usage conditions.

This concerns four main areas of activity:

- The identification of needs for spectrum coordination at EU level – including the monitoring of a wide range of EU policy areas which depend on radio spectrum, such as electronic communications, transport and research.
- Initiating harmonization of spectrum usage in individual bands across Europe where necessary.
- The establishment of policy priorities in cases where there is conflict between different requests for spectrum use.
- Setting the regulatory environment for access to radio spectrum, with the aim of easier and more flexible access by public and private users.

Tasks and Challenges

The allocation and management of radio spectrum in the European Union is administered by national administrations as radio spectrum remains principally the responsibility of Member States. While the European Commission does not manage radio spectrum directly, its task is to ensure that the use and management of radio spectrum in the EU takes into account all relevant EU policies. Therefore, the Commission addresses a number of specific goals that can only be achieved at EU level. Based on the Radio Spectrum Policy Programme (RSPP), which defines key policy objectives and sets up general principles for managing the radio spectrum in the internal market, the challenge for EU's Radio Spectrum Policy is to address a variety of important issues which have an impact on societal, consumer and industry needs on a pan-European basis. These include the development of innovative technologies and services to drive growth in the EU economy as well as overcoming the digital divide. Responding to this challenge requires effective collaboration between national authorities on the EU level.

Spectrum policy making in the EU

A framework for Radio Spectrum Policy in the EU was launched by the 2002 regulatory framework for electronic communications, and particularly by the Radio Spectrum Decision. The Radio Spectrum Decision defines the policy and regulatory tools to ensure the coordination of policy approaches and harmonized conditions for the availability and efficient use of radio spectrum for the internal market.

Policy advice, support and consultation

The Radio Spectrum Decision allows the Commission to adopt implementing decision to harmonize technical conditions with regard to the availability and efficient use of spectrum for the proper functioning of the single market. The Commission may issue mandates to the European Conference of Postal and Telecommunications Administrations (CEPT) for the preparation of such technical implementing measures. To assist the Commission, two complementary bodies were set up following the Radio Spectrum Decision in 2002, to facilitate consultation and to develop and support an EU Radio Spectrum Policy: The Radio Spectrum Policy Group (RSPG) is a group of high-level national governmental experts to help the Commission developing general Radio Spectrum Policy at Community level.

The Radio Spectrum Committee (RSC) is a committee under Regulation 182/2011/EU which assists the Commission in developing technical implementation measures to ensure harmonized conditions across Europe for the availability and efficient use of radio spectrum. In addition, the Commission has set up a Spectrum Interservice Group that provides coordination between the various Commission departments, which have responsibility for the wide range of other EU policies which may be affected by allocation policy for radio spectrum (e.g. in transport, research, aerospace, environment, audiovisual policy).

4.1.6 WRC 2019 agenda

In the next WRC that will take place in Egypt, from 28 October to 22 November, two items about intelligent transport systems (ITS) and radio local area networks (RLAN) spectrum will be discussed. These are the main points raised during the CPM19-2 meeting done on 18-28 February 2019 [5GWRC19].

ITS 1.12 Agenda Item

Recognizing that harmonized spectrum and international standards would facilitate deployment of ITS radio communications, WRC 19 agenda item 1.12 was approved by WRC-15 and Resolution 237 requested to consider possible global or regional harmonized frequency bands for the implementation of evolving ITS under existing mobile service allocations. The mobile service bands being used by the evolving ITS may also be used by other applications and services and some of the frequency bands are also being considered under other agenda items.

The technical and operational studies performed by ITU-R have indicated that the frequency band 5 850-5 925 MHz, or parts thereof, have been designated for the implementation of evolving ITS by some administrations. Consequently, the ITU-R has developed new Recommendation ITU-R M.2121, “Harmonization of frequency bands for Intelligent Transport Systems in the mobile service” and new Report ITU-R.2445, “Intelligent transport systems (ITS) usage”.

Three methods have been proposed to satisfy this agenda item:

- Method A: No change to the Radio Regulations because ITS continue to operate within existing mobile service allocations and the required harmonization of frequencies for ITS can be achieved through ITU R Recommendations and Reports.
- Method B: No change to the Table of Frequency Allocations in the Radio Regulations, and add a new WRC Resolution to encourage administrations to use 5 850-5 925 MHz, or parts thereof, as global harmonized evolving ITS frequency bands. Other harmonized frequency band(s) for evolving ITS applications refer to the most recent version of Recommendation ITU R M.2121.
- Method C: No change to the Table of Frequency Allocations in the Radio Regulations, and add a new WRC Resolution to encourage administrations to use globally and regionally harmonized frequency bands for evolving ITS applications by referring to the most recent version of Recommendation ITU-R M.2121.

That will lead to the suppression of the WRC 2015 Resolution 237.

The draft published for the new resolution includes:

- For Method B, to encourage administrations to consider using the frequency band 5 850-5 925 MHz, or parts thereof, when planning and deploying evolving ITS applications, for achieving frequency harmonization
- For Method C, to encourage administrations to consider globally or regionally harmonized frequency bands or parts thereof, which are listed in the most recent version of Recommendation ITU R M.2121, when planning and deploying evolving ITS applications
- For both Methods B and C, invites Member States and Sector Members to take into account, as necessary, possible coexistence issues between ITS stations and FSS earth

stations operating in the 5 850-5 925 MHz frequency band, and invites Member States, Sector Members, Associates and Academia to actively contribute to the ITU R studies on ITS,

RLAN 1.16 Agenda Item

RLANs have proven to be a success in conjunction with other fixed and mobile networks at providing affordable and ubiquitous broadband wireless access to the Internet. Introduced by some administrations in the 2.4 GHz band and subsequently expanded into some of the 5 GHz frequency bands, RLANs, specifically Wi-Fi devices, now carry approximately half of all global Internet Protocol (IP) traffic. In fact, mobile carriers have increased their reliance on Wi-Fi offload, voice over-Wi-Fi, and similar technologies. As technology evolves to meet increasing performance demands and traffic on broadband WAS increases, the use of wider bandwidth channels in order to support high data rates creates a need for additional spectrum.

This item aims to consider issues related to wireless access systems, including radio local area networks (WAS/RLAN), in the frequency bands between 5 150 MHz and 5 925 MHz, and take the appropriate regulatory actions, including additional spectrum allocations to the mobile service, in accordance with Resolution 239 (WRC 15). This Resolution states “that the results of ITU-R studies indicate that the minimum spectrum need for WAS/RLAN in the 5 GHz frequency range in the year 2018 is estimated at 880 MHz; this figure includes 455-580 MHz already utilized by non-IMT mobile broadband applications operating within the 5 GHz range resulting in 300-425 MHz additional spectrum being required” and called for ITU-R to:

- study WAS/RLAN technical characteristics and operational requirements in the 5 GHz frequency range;
- perform sharing and compatibility studies between WAS/RLAN applications and incumbent services in the frequency bands 5 150-5 350 MHz, 5 350-5 470 MHz, 5 725 5 850 MHz and 5 850-5 925 MHz while ensuring the protection of incumbent services including their current and planned use;
- consider enabling outdoor WAS/RLAN operations in the frequency band 5 150 5 350 MHz;
- consider potential MS allocations to accommodate WAS/RLAN operations in the 5 350 5 470 MHz and 5 725 5 850 MHz frequency bands; and
- identify potential WAS/RLAN use in the 5 850 5 925 MHz frequency band

In the CMP, for each one of the five bands: 5 150-5 250 MHz, 5 250-5 350 MHz, 5 350-5 470 MHz, 5 725-5 850 MHz and 5 850-5 925 MHz evolutions of the Resolution 229 (Rev.WRC-12) are proposed and finally the suppression of the WRC 2015 Resolution 237.

Regarding the 5 850-5 925 MHz band, applications under the mobile service in this frequency band have already been implemented in various countries throughout the world. Therefore any sharing analysis carried out under this agenda item should not prejudice usages of the mobile service while not imposing any additional constraints on other services to which the band is allocated. Some concerns were raised about different applications operating under the primary mobile service in this band. Some sharing studies carried out so far on a national or regional basis looking at WAS (RLAN) as an interferer into ITS showed the need for appropriate separation distances, in cases of co-channel operation. As a result, work by some administrations and regional groups on possible mitigation techniques, was initiated to help improve the compatibility between individual RLAN devices and ITS applications. However, based upon the results of these studies so far, conclusions under this agenda item could not be reached.

4.2 Spectrum considerations and impact from the technical components

In this section, the 5GCAR technical components are analyzed from a spectrum perspective. Already in [5GCAR-D22, Section 3.4 and Annex F] the five use cases of 5GCAR were evaluated from a spectrum perspective. In this document, a qualitative business vision for each of the technical components is given in Section 3, whereas in this section a spectrum impact analysis is provided. In this discussion, a similar classification as in Section 3.2 is followed by grouping the technical components in different areas.

4.2.1 Technical components from a spectrum perspective

Positioning and trajectory technical components

These technical components encompassed not only a higher accuracy in terms of positioning but also enable collision avoidance or trajectory prediction for vehicles. From the spectrum perspective these technical components have minimal, if any, impact. From a technical perspective, it is envisioned to add some specific pilots or reference signals (e.g. positioning reference signals) into the radio access network framework which could lead to a higher resource consumption but without impact in the overall spectrum usage (unless the reference signals are transmitted out-of-band), since the payload of these pilots or reference signal is assumed to be low when compared to the data transmitted by the vehicles.

Predictive antennas

This technical component involves the link between the base station and the vehicle mounting the predictor antennas. There is no impact in spectrum usage apart from the potential out-of-band reference signals sent between the different predictor antennas installed on the vehicles. Nevertheless, from a spectrum impact point of view, this technical component potentially enables M-MIMO configurations due to the higher accuracy in the channel estimation, and therefore, a larger bandwidth may be needed to fully exploit the advantages of M-MIMO. Additionally, predictive antenna could bring more gains with higher carrier frequency, and therefore, impacting the spectrum consumption.

Beamforming techniques

There is no direct impact in spectrum from this technical component, however, beamforming could enable optimized transmissions and less interference or retransmissions leading to a better spectrum coordination and usage. Moreover, since beamforming is specifically effective when the radio frequency is as high, e.g., mmWaves, it is reasonable to assume that beamforming will work better when the usage of carrier frequency is high, and therefore, the need for a higher available spectrum. Furthermore, the spectrum for mmWaves is not still harmonized making it a prerequisite to enable transmissions at this frequency range.

Power and link efficiency improvement

These technical components provide an optimization into the resource usage due to the different mechanisms such as preemption and multiplexing reducing the consumption. Using these optimizations, the resource consumption can be reduced from the radio transmission perspective. This better efficiency in the resource management has no impact into the spectrum consumption.

Radio link reliability (V2V and V2I2V)

Since it is considered to use link diversity the spectrum usage is potentially doubled, either by repetitions or by choosing different transmission paths. Nevertheless, since the reliability is increased, the number of lost transmissions, and therefore, the number of retransmissions is reduced helping with the spectrum usage. Additionally, a predefined guaranteed QoS is targeted potentially increasing the consumed bandwidth, and in consequence, the requirements in spectrum by the users since everyone will receive the negotiated quality of service.

Out-of-coverage sidelink communications

This group of technical components involves the spectrum usage in the designated band for sidelink and include mechanism to enhance this link, including synchronization mechanisms and distributed resource allocation. It has impact in the spectrum usage since it requires a different spectrum band for sidelink respect to the cellular one. Moreover, since out-of-coverage networks may need an increased reliability compared to the in-coverage networks, since there is no base station, a higher number of retransmissions may be needed consuming more resource.

In-coverage sidelink communications

This group of technical components aim to enhance the sidelink operation under the coverage of an infrastructure. Since the infrastructure is in charge of the different optimizations and resource allocations the impact in the spectrum is not really high, apart from the use of the sidelink band which brings impact on spectrum, for example as dedicated spectrum for sidelink or shared with cellular spectrum.

RSU based smart zone

This technical component includes a new network element. The spectrum impact depends on the spectrum used by the RSU smart zone. In the case of having the RSU operating in unlicensed spectrum, the impact in the spectrum is the usage of a different unlicensed band. In the case of operating in licensed spectrum, there is potentially an issue regarding the ownership of the spectrum license where an MNO could be the owner of the spectrum or a road operator could be the owner. This depends on regulatory decision about the kind of actors which could be the license owners and whether leasing the spectrum can be also considered as an option. Slicing represents a solution here, in that the road operator may lease a slice to serve its users. The network slicing may be agnostic of the spectrum.

SL and Uu multi-connectivity for high reliable and/or high data rate V2V communication

This technical component has a similar impact as the previous one where the spectrum impact depends on the spectrum used by the local eNodeB side. In the case of having the RSU operating in unlicensed spectrum, the impact in the spectrum is the usage of a different unlicensed band. In the case of operating in licensed spectrum, there is potentially an issue regarding the ownership of the spectrum license where an MNO could be the owner of the spectrum or a road operator could be the owner. This depends on regulatory decision about the kind of actors which could be the license owners and whether leasing the spectrum can be also considered as an option. Additionally, it has to be considered the impact in spectrum due to the higher reliability of the radio communications, which is similar to the reliability technical component. Moreover, it is expected to have higher data rate both for Uu and SL which will lead to a higher spectrum consumption.

Fast application-aware setup of unicast SL

This technical component has a similar spectrum impact as the two previous technical components. It enables a more efficient unicast or multicast SL utilization, and therefore, an increase in the spectrum consumption is envisioned due to the addition of using SL.

Location-aware scheduling

In this technical component, the network is divided in different geographical areas in order to obtain an optimized scheduling for the vehicles in the defined zone. Due to this optimization in the spectrum usage is possible and a lower interference created by neighbor areas is achieved. The optimization of the spectrum usage implies an higher reuse factor which impacts on the actual spectrum usage while the lower interference among the vehicles have a positive impact in the resource usage.

Evolution of infrastructure-based communication for localised V2X traffic

In this technical component it is taken into consideration a diverse type of traffic, i.e., unicast, multicast and broadcast. There is no significant spectrum impact.

Multi operator solutions for V2X communications

It has a high impact in spectrum. The impact could vary depending of the type of licensing scenario, i.e., whether one MNO has all the available spectrum in a specific geographical area or there is a need of having some coordination between MNO. This technical component foresees that operators will keep having their own spectrum, and vehicles will roam from one to the other based on the area they are driving through

V2X service negotiation

This technical component works along with the location aware scheduling since depending on the area/zone of the vehicle, a different service is needed. Using this feature the service offered to the vehicles can be adapted according to the network conditions and an optimal resource allocation can be achieved, decreasing the wasted resource usage, while having no impact in the spectrum.

Network orchestration and management technical components

This category of technical components has a similar impact in spectrum as the multi-operator solutions since orchestration and harmonization is needed in both technical components. Achieving an optimal management will lead to a more efficient spectrum usage.

End-to-end security technical components

This category of technical components brings no spectrum impact into the radio communication aspect. It is foreseen a possible impact in the optimization due to a higher number of exchange messages, i.e., encryption keys, that could affect the spectrum usage.

Edge computing enhancements technical components

There is no significant spectrum impact derived from this category of technical components.

4.2.2 Spectrum usage and limitations in demonstrations

An important aspect to consider is the spectrum usage and the limitations encountered during the 5GCAR demonstrations. For the demonstration three different features were implemented to test the different use cases, each one with different requirements regarding spectrum, i.e., LTE network, NR sidelink and NR positioning.

An LTE network is operated in Band 7 (2.6 GHz), where a 20 MHz band has been allocated for all demonstrations together. This LTE network involves only the connection between base station and vehicle.

The NR sidelink uses the frequency band 43 (3.6–3.8 GHz). Due to some limitations in the equipment which current setup only supports up to 4 GHz, 5.9 GHz is not a feasible frequency band.

The NR positioning system also uses frequency band 43. As a limitation for this demonstration, the frequency band 42 (3.4–3.5 GHz) was preferred but is reserved for military purposes in France where the tests are conducted, which is why this project could not get a license for it. Additionally, it is possible to tune the equipment to use a hybrid band 3.4-3.8 GHz (frequency band 42 and frequency band 43). Furthermore, potentially a split in frequency Band 43 between see-through and VRU protection use cases is foreseen to avoid interference.

Respect to the needed bandwidth for each of the components, for NR positioning it is needed 40-50 MHz where a maximum of 56 MHz is allocated in Band 43 (3.6-3.7GHz). In case of NR sidelink regarding spectrum, it is needed 15 MHz bandwidth where a license for 100 MHz between 3.6-3. GHz has been granted for the see-through and VRU. This license has been awarded only for trials on TEQMO test site and with no commercial use.

5 Conclusions

V2X provides social benefits, considering that it will create a positive impact in different domains: traffic efficiency, CO2 reduction and safety improvement. Thanks to V2X communications, the traffic information shared in urban environments, will become more precise and up to date, thus helping improve traffic efficiency and reducing CO2 emissions. The level of urbanization in the EU is above 75 per cent of the population and is expected to be over 80 per cent in 2020 [EUR14]. A reduction of 700.000 tons of CO2 is expected in cities per year thanks to V2X, valued over 22 million € per annum. There are also strong benefits for rural areas, where the arrival direct short-range communications will enable the V2X adoption for some use cases before the infrastructure deployment. For both environments, the information shared between vehicles will lead to a 5 per cent reduction in road accidents in 2025, with an estimated value of 4.1 billion €.

Thanks to the telecommunication ecosystem, V2X can be integrated into smartphones enabling V2P communications and providing protection to vulnerable road users (VRU). In particular, potential collisions with pedestrian could be predicted early enough, even in NLOS conditions, and avoided, hence helping to reduce pedestrian fatalities. In 2015 more than 5.000 pedestrians were killed in road accidents (21 per cent of all road fatalities) [ERSO18].

The automotive ecosystem has provided a clear definition of autonomous driving levels, from level 0 to 5. Currently, some car OEMs have introduced features to support level 3. It is also commonly shared view, that to support level 4 and above, the car must be connected.

In parallel, the cellular communication ecosystem progresses at its own pace, mainly driven by the work of 3GPP the standardisation body. 5G New radio was introduced with Release 15, and Rel. 16 includes the definition of advanced V2X features to complement the LTE V2X already available. We are now at the time where these two worlds, historically defining separately their roadmaps, are now discussing together, and jointly defining a common roadmap.

Roadmaps are however impacted in their execution by regional decisions, especially when regulation or spectrum are under discussion. Some regions have strongly decided to implement a clear V2X strategy, such e.g. China, while other regions are still evaluating various options. The Delegated Act or the CAFÉ framework are important legal regulations which will modulate in Europe the V2X automotive use case roadmap over the next decade.

The roadmap will be also conditioned by the network deployment. As presented in the 5G-PPP Automotive WG white paper (Section 3.1.1), the main takeaway is that opening up the possibility for network and infrastructure sharing has the evident effect of improving return on the network investment. Even if only passive infrastructure elements are shared between operators, e.g. space, masts, power generators, and air conditioning equipment.

In spite of the uncertainty in the timeline of the advance V2X use cases, there are other business opportunities that are available in the short term. On one side, the current security strategy proposed in the Delegated Act (more details in Section 2.4.2), may lead to a new important market for the certificate management for telecom companies, as it has been showed in Section 3.1.2. If finally this policy is confirmed, the market competition could be the only way of reducing the prices for the pseudonym adoption and mitigating its stopper effect in the OEM adoption decision.

On the other side, OTA is a service where a business case may be profitable for both parties: automotive and telecom stakeholders, but it needs a new business model definition to be viable. In its current status, the figures shown in Section 3.1.3, demonstrates how connectivity is unaffordable as an OTA solution. 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. 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.

5GCAR has proposed a list of significant TCs applied in different axis (radio interface, network architecture, security, etc). In this deliverable, these have been analysed from a business perspective and the result shows that some of them can create value for both telecom and automotive stake holders and others may lead to a change into the ITS ecosystem/value chain.

As it has been shown in Section 4.1, the 5G spectrum assignation is ongoing worldwide and more precisely in Europe where several countries have already completed auctions in different bands. Three main frequency bands are already defined for 5G technology: the 700 MHz, 3.4-3.8 GHz and the 26 GHz. Clearly the 3.4-3.8 GHz will be the first band commercially deployed focusing first in eMBB which is the current business model in the telecom market. The 700MHz 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 [5GCAR-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.

Finally, the millimeter wave band (26 GHz) has just been harmonized by the EC, completed in all members by the end of March 2020 with effective usage of 1 GHz by the end of 2020. Countries like Italy have already made the auction for this band. 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. At the time of writing this deliverable, 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.

Other bands which may be relevant for 5G are defined around 1 and 2GHz. These bands are not at all harmonized between different countries and were initially reserved for LTE. Part of them will be reserved for vertical industries (normally planned for factories). In these bands, the re-farming will enable the migration from LTE to 5G technology, increasing the spectrum availability and efficiency thanks to the new radio. 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. As it has been explained in Section 4.1 of this document, 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. The case of Germany must be remarked, with important demands related to the coverage, data rate and latency at different types of roads confirming the interest of the government to enable an important V2X infrastructure.

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