Fifth Generation Communication Automotive Research and innovation

Deliverable D2.2
Intermediate Report on V2X Business Models and Spectrum

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Executive summary

The business models and spectrum are two of the key aspects that may look very different in their context but are very much correlated especially when it comes to 5G and V2X services. Therefore, both of them require a thorough analysis to understand the spectrum needs, the cost benefit analysis, their joint effects and impact on the full-scale deployment of V2X communication services. This 5GCAR intermediate report presents the analysis of the V2X business models and spectrum aspects.

The objectives of the business model part of this study are to identify how 5G could enable new business models, based on new technologies and features of 5G. The study has discovered:

- There are technical features in 5G that can enable new business models for various stakeholders in the value chain. Network slicing and mobile edge computing are examples of such features.
- Existing services as well as autonomous driving features and convenience services may be enhanced by 5G technologies, thereby building added value in these services.
- The value chain as it looks today (Q1 2019), may be disrupted by 5G, driven by new 5G technologies, as well as changing eco-systems around the connected car, where a rapid digitization of existing industries is complemented by new types of digital and industrial stakeholders.

The objectives of the spectrum analysis part are to identify appropriate spectrum usage options for enabling advanced ITS and automotive services applications using 5G technologies, we survey already designated frequency bands and frequency bands that are under consideration for 5G technologies on their suitability for V2X communications in different regions of the world. The survey discovers:

- The usage of 5.9 GHz band for ITS services applications using short-range vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is harmonized in many regions of the world.
- Licensed frequency bands for mobile networks over the world are available suitable for providing vehicle-to-network (V2N) communications.
- The combination of 5G candidate frequency bands in the low, middle, and high band ranges in different regions of the world will enable ITS and automotive services that have requirements of both large coverage range and high system capacity.

This 5GCAR intermediate report suggests that the value chain of automotive and connectivity may strongly evolve into becoming more complex and less linear than what we have so far. Several spectrum bands, including both licensed and unlicensed bands, have been identified suitable for V2X communications. It should be emphasized that the usage of licensed spectrum is up to the licensees, e.g. the MNOs, who need justified business models to take appropriate decisions.

Contents

List of abbreviations and acronyms

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G-PPP	5G Private Public Partnership
5GAA	5G Automotive Association
5GCAR	5G Communication Automotive Research and innovation
ACMA	Australian Communications and Media Authority
AD	Autonomous Driving
ADAS	Advanced Driver-Assistance System
API	Application Programming Interface
ARIB	Association of Radio Industries and Business
BRAN	Broadband Radio Access Networks
CACC	Cooperative Adaptive Cruise Control
CAD	Connected and Automated Driving
CAM	Cooperative Awareness Messages
CAPEX	CAPital EXpenditure
CEPT	European Conference of Postal and Telecommunications Administrations
CEN	European Committee for Standardization
CENELEC	Comité européen de normalisation en électronique et en électrotechnique
C-ITS	Cooperative Intelligent Transport Systems
CITS	ITS Communication Standard
D	Deliverable
DA	Driving Assistance
DSRC	Dedicated Short Range Communications
E2E	End-to-end

ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
FA	Full Automation
FR	Frequency Range
FAD	Fully Autonomous Drive
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAD	Highly Autonomous Drive
HD	High Definition
ICV	Intelligent Connected Vehicle
IEEE	Institute of Electric and Electronics Engineers
IMT	International Mobile Telecommunication
ITS	Intelligent Transport System
ITS-S	ITS vehicle Station
ITU	International Telecommunications Union
ITU-R	ITU Radio communication Sector
KPI	Key Performance Indicator
LOS	Line Of Sight
LTE	Long Term Evolution
LTE-V	LTE for Vehicle
MAC	Medium Access Control
MBB	Mobile Broadband
MIIT	Ministry of Industry and Information Technologies China
MNO	Mobile Network Operator
mMTC	massive Machine Type Communications
NHTSA	National Highway Traffic Safety Administration
NR	New Radio
OBU	On Board Unit
OEM	Original Equipment Manufacturer
OPEX	OPerating EXpense
OTA	Over The Air

PHY	Physical
PRtime	Perception-reaction time
RSPG	Radio Spectrum Policy Group
QoS	Quality of Service
RAT	Radio Access Technology
RD	Reaction Distance
RED	Radio Equipment Directive
RR	Radio Regulations
RSU	Road Side Unit
RU	Road User
SAE	System Architecture Evolution
SDN	Software Defined Network
SDU	Service Data Unit
SNR	Signal-to-Noise Ratio
SRS	Supplemental Restraint System
SW	Software
TCO	Total Cost Ownership
TOD	Tele Operated Driving
TS	Technical Specification
TTC	Time To Collision
UC	Use Case
UE	User Equipment
UICC	Universal Integrated Circuit Card
USB	Universal Serial Bus
V-UE	Vehicle User Equipment
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to Anything
VRU	Vulnerable Road User
WAVE	Wireless Access in Vehicular Environments

1 Introduction

The arrival of the connected vehicles has supposed by itself an important revolution for the car industry. The car can no longer be seen as an electronic device with wheels. Actually, in the automotive industry the new paradigm is called the “Extended Vehicle” where the car is represented by the vehicle and its representation into the cloud. Both worlds, on-board (the embedded electronics) and the off-board (the backend of the original equipment manufacturer (OEM) or any other partner) have to be seen as an overall thanks to the connectivity which acts as a bridge between both sides. The connected car is bringing new business opportunities such as data exchange, application programming interfaces (APIs), applications interacting with the vehicle. This deliverable highlights the services which can be modulated by the arrival of 5G. The comparison is made with the previous technology (and not from a connected or non-connected car vision).

The automotive is a very competitive sector, where costs are analyzed, and innovations are adopted only if there is a business case supporting it or through a regulatory mandate. As an example of a regulatory mandate [Regulation (EU)], in Europe from April 2018, the sim card will become a regulatory obligation at least for the e-call service. This means that all cars in the market will be equipped with sim card (physical or virtual) from now on. It is also important to remark that generally the features related to safety should be made available to everybody and enforced by regulation. Comfort driving features may be a brand difference but also needs to be safe.

In this deliverable there is an analysis of how 5G may boost current services or enable new ones not possible or not optimized with the current cellular technologies. Right now, with the autonomous driving vehicle both items are always mentioned together as the autonomous and connected vehicle. This is a disruptor feature transforming completely the automotive business. So far, several demonstrations and even some products are available in the market showing the feasibility of the autonomous driving (AD) under certain circumstances. The AD is fully supported by embedded electronics (Lidar, radar, cameras, etc.) but it is widely accepted that for level 3 on, the limitations of the embedded sensors have to be complemented by wireless connectivity. This opportunity is in the core of the new specification methodology of 5G where the vertical sectors have expressed their requirements.

The radio frequency spectrum is a scarce resource, which is allocated to different services having different usage parameters, e.g. mobile service, fixed service, etc. Usually, the use of certain spectrum is permitted with the specific authorization or license, often some cost is associated to it. Some spectrum bands, known as unlicensed or license-exempt frequency bands, can be used without a license under pre-defined technical requirements. The spectrum dedicated for public mobile networks is typically licensed, where dedicated bands are designated for mobile network operators. Currently identified spectrum may not be sufficient to fulfill future needs of mobile services including those services for improving the safety and traffic efficiency situation of road transportation systems. Therefore, new spectrum including licensed and unlicensed bands is under consideration for evolving mobile services. To identify appropriate frequency bands for use cases and V2X technologies developed in the 5GCAR project, this deliverable investigates both licensed and unlicensed spectrum in different regions of the world, including those frequency bands being considered for 5G technologies.

1.1 Objective of the document

To understand the evolution of the relationship between the stakeholders of the automotive value chain due to the arrival of 5G and the apparition of new actors and relationships in the market. This will be done through some examples of the automotive sector. Even if the deliverable focus on the business model, a first approach for cost estimation and income flows will be analyzed.

The objectives of the spectrum study in 5GCAR are threefold: 1. To establish a comprehensive and up-to-date understanding of the spectrum resources usable for V2X communications; 2. To perform suitability analysis of spectrum resources for V2X communications; 3. To identify spectrum usage alternatives supporting V2X use cases selected by 5GCAR and technical components yet to be developed in the project. This intermediate report addresses the first two objectives.

1.2 Structure of the document

Section 2 is devoted to the business model V2X communication study and it is divided into five subsections. These subsections are:

- Section 2.1, covers the different services enhanced by 5G or which will arise only with this new communication technology. This provides a vision of how connectivity will shift the current functionalities of some services or will enable other non-existing today. The main stakeholders of the value chain are identified as well as the customer benefit, the potential business model impact, the main challenges and barriers for each service.
- Section 2.2, explains the main technological components under definition in the 5G standardization which may modulate the current business model. This analysis is made based on the main technical bricks of 5G, in the final deliverable of WP2 a similar exercise will be done based on the technological solutions proposed by 5GCAR in WP3 and WP4.
- Section 2.3, remarks the practical aspects to be considered when building any connectivity business model for the automotive sector. Elements like the sim provisioning, the roaming technical and economic impacts and the regulation are aspects that shall jeopardize the connectivity business model definition.
- Section 2.4, explains the business model evolution and relation through two examples (Over the air updated and autonomous driving). Starting from current linear business models, new dependencies and relationships between different stakeholders are graphically shown and explained and new actors which may arise are identified for the examples considered.
- Section 2.5, provides a deployment cost analysis for V2X based on the automotive working group of 5GPPP led by the 5GCAR project. The example service considered is an automated driving connectivity enabled in highway. An estimation of a deployment cost

scenario is presented as well as four different scenarios according to different value parameters.

- Section 2.6 summarizes the key findings of the business models study.

Section 3 contains spectrum analysis for V2X communication and it is divided into five subsections. These subsections are:

- Section 3.1, provides an overview of today's radio frequency spectrum.
- Section 3.2, discusses the methodology of studying V2X spectrum in 5GCAR.
- Section 3.3, contains a detailed survey of spectrum resources, licensed and unlicensed, that are usable for V2X communication worldwide.
- Section 3.4, presents the suitability analysis of spectrum for V2X communications in the case of 5GCAR use cases considering the frequency propagation conditions and the needs expressed in terms of range in [5GCAR-D2.1].
- Section 3.5 summarizes the key findings of the spectrum study.

Section 4 combines the knowledge from the business model study conducted in Section 2 and the spectrum analysis conducted in Section 3 and concludes the main part of this intermediate deliverable.

In addition, this deliverable contains six Annexes ranging from Annex A to Annex F.

2 Business models

2.1 Service definition

This section contains a high-level description of a number of services that can be used when examining business models. These services will differ from the use cases developed in [5GCAR-D21], to extend the scope of which elements in 5G that will have an impact on the business model. The services identified here, should expose all the different elements that constitute a complete business model, and specifically highlight new features in 5G that have not been available in previous generations of mobile technology. Actually, 5G will enable new way to consume existing services and new services. It should be noted that this is by no means an exhaustive list of services. The services included in this section have been selected as examples. The services have been divided into three different categories:

- Existing services,
- Autonomous driving features, and
- Convenience services.

Existing services, are services already available on the market for the connected car. There are opportunities to enhance the quality, lower costs or in other ways modify the delivery and value chain using 5G technologies, for this category of services.

Autonomous driving features, are a set of services intended to enable the use of autonomous driving vehicles. Some autonomous driving features could be mandatory for higher levels of autonomy; other services may be used to enhance the user experience. This document will examine how 5G can enable new business model elements in supplying this type of service.

Convenience services, are services intended to enhance the user experience, not directly related to the task of transportation. These are services that in some cases could only be supplied by the use of 5G, other services could be enhanced by the use of 5G.

The core part of the document provides a high-level summary of the services.

2.1.1 Business model elements

Each service is described with a number of business model elements that will be relevant when assessing suitable business models for each service. Due to the dynamic nature of the telecoms and automotive industries, and the need to protect business secrets in order to comply with competition law, it is not possible to describe the whole business models. What we do in this study, is to highlight what are the important elements for creating innovative business models for each service. For each service, the following elements are identified:

- **Goal**: What is the overarching goal of the service.
- **Short description**: Description of how the service works.
- **Properties**: What are the business and functional needs for various properties of the service.
- **Challenges**: What are the challenges that have to be overcome to successfully take the service to market.
- **Needs**: Specific non-functional needs that have to be fulfilled
- **Parties involved in value chain**: Who are the parties necessary to create the service
- **Customer**: Who is the customer for the service. May be different than the person using the vehicle.
- **Customer benefit** (Value): What is the value created by the service that will drive the business for the service.
- **Potential 5G business model element impact**: What are the new features in 5G that could affect the business model of the service.

2.1.2 Existing services

Emergency call

Emergency call is a service that automatically reports an accident, triggered by the Supplemental Restraint System (SRS) in the vehicle. Information related to the accident event is sent to an actor that can take suitable measures to assist the passenger(s) of the vehicle. The actor could be private call center or a public call center, known as public safety answering point (PSAP). 5G could enrich this service by e.g. providing:

- Very low latency and high reliable connection to the call center or to the emergency services.
- High definition video communication support to improve deployment and operation of emergency services.
- Data communication on top of voice call to provide information related to the car and environment prior to the accident.
- Accurate positioning information.
- Notification of the event towards other road users.

Table 2.1: Emergency call

Service Name	Emergency call
Goal	To increase traffic safety and minimize effects of traffic incidents.
Short Description	When a crash is detected (through an event triggered by the vehicle's Supplemental Restraint System (SRS)), a message is transmitted to the call center. The message typically contains information about location, heading, number of airbags deployed, speed at time of accident, etc. Normally a voice call is also set up, to allow an operator to communicate with the car passengers before dispatching suitable resources (ambulance, police, etc).

Properties	Coverage	Very high
	Availability	Very high
	Bandwidth	Very low
	Latency	Medium
	Data volume	Very low
	Target endpoint(s)	Public PSAP, Private call center
	Special properties	Support for voice
Challenges	• Legally required service for certain markets (e.g. EU), mandating technical solution • Service needs to be supported for the whole lifetime of vehicle • Very cost sensitive, as standard in all vehicles • Should not cause un-necessary traffic/signalling in the mobile network • Should minimize false alerts	
Needs	• Network service should have maximum coverage • Very high requirements on availability • As service is mandated by authorities, there is low value for OEMs. This in turn means that there is high cost pressure on service delivery	
Parties involved in value chain	• Car OEM • Regulators • Mobile network operators • Public safety answering points (PSAPS)	
Customer	• End customer • Authorities	
Customer benefit (Value)	• End customer – Safer experience • Authorities – Lower costs for medical care, shorter response times	
Potential 5G business model element impact	• Network slicing / QoS levels • Autonomous data connection to the network (Car Data context when eCall is invoked. This feature should be available with high bandwidth and coverage.) • Potential new feature: Video to improve information to authorities and location (event can happen in tunnels)	

Remote diagnostics

Remote diagnostics is the ability to remotely analyze car information and potentially remedy certain failures. It consists of the combination of uplink data transmission from the car to an off-board service center through the wireless network, intelligent data processing at this service center and downlink communication to the car, e.g., to modify internal settings of the car, provide information messages to the user, etc. It should be noted that the difference between remote diagnostics and predictive maintenance is that remote diagnostics is initiated on request by the end user. 5G could enrich this service by e.g. providing:

- Lower latency and reliable higher data rate connection between car and “service center”.
- Enable local distributed “service center’ thanks to mobile edge computing.

Table 2.2: Remote diagnostics

Service Name	**Remote diagnostics**	
Goal	To provide the end customer with a more convenient way of getting support for problems with his car.	
Short Description	Remote diagnostics is the ability for a workshop or other service organization to read out diagnostic trouble codes (DTC) from an end user’s vehicle. It may also include the ability to start a diagnostic session where more advanced queries can be sent to the vehicle, and also the ability to change certain parameters for ECUs in the vehicle. The advantage of being able to do diagnostics remotely, is the convenience for the end customer who may not have to schedule an appointment with a service center to solve certain vehicle problems and the problem can be solved in a fast way.	
Properties	Coverage	High
	Availability	High
	Bandwidth	Low
	Latency	Low
	Data volume	Low
	Target endpoint(s)	Service center, OEM
	Special properties	Not applicable
Challenges	• Cost sensitive, as standard feature in all connected vehicles • High availability requirements as customer is using service when experiencing a problem with the vehicle, and expecting good service	
Needs	• Cost efficient service delivery	
Parties involved in value chain	• Car OEM • Workshop/Service center	

	• Mobile network operators
Customer	• End customer • Workshop/Service center
Customer benefit (Value)	• End customer – Better service/support experience • Workshop – Additional sales channel to end customer
Potential 5G business model element impact	• Network slicing / QoS levels

Car sharing

Car sharing consists of the possibility to share a car between several users. When using the car, a given user could have its preference, background information, specific configuration loaded according to its profile. 5G could help scaling up this kind of service by providing massive connectivity to cars, as well as secure low latency high reliability wideband communication to the car, enabling instantaneous user's preference transferred to the car. Conversely, during the car operation, user's related data could be collected to e.g. ease further billing (based on the actual distance travelled, the speed etc.).

Table 2.3: Car sharing

Service Name	**Car Sharing**	
Goal	Providing new mobility solution with secure, personalized and customized experience for the customer.	
Short Description	The car may change the configuration according to the user needs or preferences in terms of onboard elements (climatization parameters, seats configuration etc.) and infotainment contents (radio, video etc.).	
Properties	Coverage	High
	Availability	High
	Bandwidth	Low
	Latency	High
	Data volume	Low
	Target endpoint(s)	Service provider, Vehicle, User
	Special properties	Not applicable
Challenges	• Identity management and authentication for accessing and using the vehicle	

Needs	• Track the usage and responsibilities • The needs evolve depending on the customer: B2B, B2C or C2C
Parties involved in value chain	• OEM • End customer • Renting companies • Fleet managers • Mobile network operators (MNOs)
Customer	• End customer • Renting companies • Fleet managers • Mobility as a Service (MaaS) operators
Customer benefit (Value)	• Easy access to mobility solutions • Total Cost of Ownership reduction
Potential 5G business model element impact	• Customer profile download including car parameters and infotainment parameters

Over the air (OTA) software updates

Over the air software upgrade consists in upgrading or modifying a piece of SW in the car without bringing the car back to a garage. With previous communication system (2G, 3G, 4G or WiFi) OTA could mean for the user to download a SW on a USB stick when at home, and then to plug the stick into the car to make the SW upgrade to achieve the reliable data delivery. With 5G, OTA SW update will become truly available over the air, and without active user's participation (although it is possible that for certain type of updates the user may still need to provide explicit consent). Indeed, using wireless 5G capability of high speed reliable data transmission, the OTA could be made in an efficient way.

Table 2.4: OTA Software updates

Service Name	**OTA software updates**	
Goal	Provide new features, evolve services and/or correct as soon as possible and without interfering the customer vehicle usage.	
Short Description	Define different ways for downloading new software versions from cybersecurity updates, default correction, new features, service evolution, maps updates, etc.	
Properties	Coverage	Medium
	Availability	Medium
	Bandwidth	High
	Latency	High
	Data volume	High

	Target endpoint(s)	OEM backend
	Special properties	Reliable transmission of the information
Challenges	• Different types of connections shall be used • Different types of updates shall be managed with different criteria in terms of volume, reliability, delay or cost • High data volume expected	
Needs	• Exchange between the on-board and off-board systems • Easy deployment for a vehicle fleet (whatever the model, the location, type of connectivity, etc)	
Parties involved in value chain	• Car OEM • Tier1 vehicle control unit supplier • Mobile network operators	
Customer	• End customer • Car OEM • Tier1 vehicle control unit supplier	
Customer benefit (Value)	• End customer – Higher satisfaction due to the automatic correction of defaults and the fact on counting on an updated vehicle with new services and features. • OEM & Tier1 – Important reduction in the default correction cost without going to the garage. • Functional growth – The vehicle can receive new functionality after leaving the factory. Potential to sell new features after the car is produced.	
Potential 5G business model element impact	• Network slicing, the updates could be done independently of the data size, the car situation (national or roaming) and with the suitable service level agreement • Mobile Edge Computing: For local repositories. Only in safety or cybersecurity updates that require immediate and massive distribution	

Predictive maintenance

Predictive maintenance consists of analyzing the behaviour of the car and car component(s) in order to anticipate any fault, failure or misbehaviour of the vehicle. Based on sensing, car data surveillance, machine learning and big data analysis, and multisource information processing (history of car, warranty etc.), almost real-time warning information could be provided, or simpler message to the user about possible maintenance operation. Examples of such 5G enabling technologies are:

- Massive sensing and data collection, real time or as background (low rate, low power).
- Mobile edge computing to bring analysis close to the car.
- Data fusion and network slicing.

Table 2.5: Predictive maintenance

Service Name	Predictive maintenance	
Goal	Anticipate the default detection of the car in order to decrease the non-quality costs and improve customer satisfaction.	
Short Description	Analyzing the behaviour of the vehicle in order to detect the vehicle problems before they arrive, based on the car-data surveillance and machine learning with the historical multisource data (warranty, diagnosis, quality repositories…).	
Properties	Coverage	Medium
	Availability	Medium
	Bandwidth	Very high
	Latency	Low
	Data volume	Very high
	Target endpoint(s)	OEM backend
	Special properties	Dynamic definition of the environment
Challenges	• Real-time information to be treated • Artificial intelligence to be integrated • High data volume expected	
Needs	• Exchange between the on-board and off-board systems • Short reaction time as soon as one bad behaviour is detected for specific requests	
Parties involved in value chain	• Car OEM • Tier1 vehicle control unit supplier • Mobile network operators	
Customer	• End customer • Car OEM	
Customer benefit (Value)	• End customer – Higher satisfaction with the product usage and optimizes the TCO • OEM and tier1- non quality cost reduction	
Potential 5G business model element impact	• Network slicing • Mobile Edge Computing (MEC): to increase and improve the exchanges between the on-board and off-board systems. It could be used for a specific road or situation (urban environment, motorway)	

Real-time road traffic management and vehicles guidance

This service consists of providing to the vehicle all the information towards autonomous driving. It spans from basic information to support smart decision for traffic management (e.g. selection of proper itinerary based on local traffic information or road status), to almost real time information of nearby events. 5G technology will enhance existing information exchange by the capability to provide low latency and high volume of reliable information to the cars.

Table 2.6: Real-time road traffic management and vehicles guidance

<table>
<tr><th>Service Name</th><th colspan="2">Real-time road traffic management and vehicles guidance</th></tr>
<tr><td>Goal</td><td colspan="2">Reducing congestion, improve road traffic fluidity, reduction probability of accident, improve global fuel consumption etc.</td></tr>
<tr><td>Short Description</td><td colspan="2">This service is provided by V2X (ITS) architecture to vehicles which could be autonomous or not, helping drivers/vehicles to make the good decision by choosing the route taking into account traffic conditions. This information shall reduce vehicles speed for traffic jam and pollution and organize an emergency mode. Directives could also be given to RSU for the traffic light status. The vehicle could propose a journey plan and then the path is optimized at local, medium and/or large area.
This service would be operated by a public or private (with public service delegation) actor. Interconnection between administrative areas will have to be provided. In areas like highways, this service could be offered by highway operator due to regulatory obligation.</td></tr>
<tr><td rowspan="7">Properties</td><td>Coverage</td><td>High/Very high</td></tr>
<tr><td>Availability</td><td>High/Very high</td></tr>
<tr><td>Bandwidth</td><td>Medium/Low</td></tr>
<tr><td>Latency</td><td>High, medium, low (depend on the service)</td></tr>
<tr><td>Data volume</td><td>Low for one UE/important globally</td></tr>
<tr><td>Target endpoint(s)</td><td>Vehicle, RSU</td></tr>
<tr><td>Special properties</td><td>Small/medium size messages</td></tr>
<tr><td>Challenges</td><td colspan="2">• Potentially all vehicles have to be managed by the system, thus this could raise scalability problems for centralized sub-services
• Hierarchy of platforms to deal with heterogeneous sub use case with different time constraints</td></tr>
<tr><td>Needs</td><td colspan="2">• Depending on the sub-service
• High latency/medium availability and coverage for traffic control
• Low latency/high availability for platooning control</td></tr>
<tr><td>Parties involved in value chain</td><td colspan="2">For funding :
• Car Manufacturer (value added to the vehicle)
• State/local authorities/ funding deployment
• Private road operators (highway companies, value added to toll)
• At the end of the value chain : road (highway) user, car owner or renter, ratepayer,
For implementation :
-Mobile Operators,
-Car OEM, car manufacturers,
- Private road operators (highway companies)</td></tr>
</table>

Customer	• End customer • Administrations
Customer benefit (Value)	• End customer: optimal journey in time, cost and environmental impact • Administrations: less CO2, better road safety
Potential 5G business model element impact	• Distributed cloud with hierarchy to implement several types of traffic management service with different time scales and ranges • 5G enhanced access to minimize latency (for instance platooning)

2.1.3 Autonomous driving features

Environment perception through wireless connectivity and sensor sharing

Even if the car has many on-board sensors, these sensors can only perceive local environment. As a result, to better support autonomous driving, it is useful to add a communication service as kind of "a new extended sensor" to get information beyond the local environment.

This wireless communication service can provide information from the network, the road infrastructure or neighbouring vehicles. This type of communication is often referred to as Vehicle to Network communication (V2N), Vehicle to road Infrastructure communication (V2I) and Vehicle to Vehicle communications (V2V). Then, communication between Vehicle to Pedestrian (V2P) could be also added to the list. The environment perception service could be provided by one or a combination of those different communication techniques, and as a useful way to capture this, it is often referred as V2X (Vehicle to anything).

5G will provide advanced V2X technology, thanks to low latency high reliable communication between the car and the network or the infrastructure or direct communication link between the devices, with or without network support.

Table 2.7: Environment perception through wireless connectivity and sensor sharing

Service Name	Environment perception through wireless connectivity and sensor sharing	
Goal	Enables the vehicle towards higher automated levels thanks to the use of sensor data shared by other vehicles.	
Short Description	A future fully automated driving solution has to consider wireless communication between cars and between cars and infrastructure simply in order to extend the horizon of the sensor, provide direct access to the manoeuvre planning of the other cars, avoid delays in sensor data processing and get an independent information source connected to the car computer to perform more efficient data and sensor fusion.	
Properties	Coverage	Very high
	Availability	Very high

	Bandwidth	High
	Latency	Ultra low latency
	Data volume	High
	Target endpoint(s)	V-UE
	Special properties	Road connectivity deployment
Challenges	• Fusion of collected sensors data with radio information, and decision making • Technology to be used	
Needs	• Network service should have maximum coverage. • Very high requirements on availability, latency and reliability	
Parties involved in value chain	• Car OEM • Regulators • Mobile network operators • Road operators • Chip and device makers • Telecom infrastructure vendors	
Customer	• End customer	
Customer benefit (Value)	• End customer: Safer experience.	
Potential 5G business model element impact	• Network slicing / QoS levels • Mobile edge computing capabilities • Side Link	

Dynamic map (HD Local Map Acquisition)

This service consists of providing to the autonomous driving control a real time up to date map of the car environment. Actually, the local map is reconstructed from the various flow of information collected by the car which includes local information from sensors as well as remote information coming from the communication links to the vehicle.

Table 2.8: Dynamic map

Service Name	Dynamic map	
Goal	Update the local dynamic map of vehicles on the move	
Short Description	The dynamic map is built of different layers of information. E.g. base road geometry, road signs, traffic information. An off-board system gathers information from different sources according to different layers. From the map provider to the cooperative sensing of the different vehicles available. This information is organized and divided into polygons or other information elements for distribution by push/pull methods to the vehicles. Push/pull on a regular frequency and push/pull by major changes or hazardous events.	
Properties	Coverage	Very high
	Availability	Very high
	Bandwidth	High
	Latency	Low
	Data volume	High
	Target endpoint(s)	Application server, Infrastructure
	Special properties	Not applicable
Challenges	• Very high requirements on coverage and availability as AD cars may have limited functionality without updated dynamic map data	
Needs	• Network service should have maximum coverage • Very high requirements on availability	
Parties involved in value chain	• Car OEM • Application/service provider (OEM or other) • Mobile network operators • Infrastructure providers	
Customer	• End customer • Application/service provider • Infrastructure provider	
Customer benefit (Value)	• End customer: Convenience (AD functionality) and enhanced user experience • Application/service provider: Sensor data from vehicle • Infrastructure provider: Sensor data from vehicle	
Potential 5G business model element impact	• Network slicing / QoS levels • Mobile edge computing capabilities • High speed data exchange	

2.1.4 Convenience services

Multimedia services and gaming services

With the advent of autonomous driving, the driver may need more and more expectation with respect to infotainment services, and gaming services as it will be less and less active in the driving task. Similarly, the passengers would like to consume similar services compared to the one available at home from regular Internet. As a result, there is an increasing demand in terms of bandwidth especially at downlink in order to enable high quality user's services (video, audio, gaming, content push, content download, etc.). We have to note that gaming requirement in terms of bandwidth depends on implementation: for onboard implementation, the requirement will be weaker in terms of bandwidth than for cloud implementation. In anyway cloud gaming and social/network gaming require low latency on the UL. Similar requirements for downlink due to video streaming would be put forward by V2X use cases such as See-through (UC2) or Remote driving (UC5) [5GCAR- D2.1]. These use cases require in addition an important bandwidth on the uplink in contrary to multimedia services.

5G technology in the EMBB component is a required evolution of 4G in order to provide capacity, bitrates and low latency. Furthermore slicing capability as well as contents and CPU implementation closer to the users thanks to MEC could be interesting for some use cases.

Slicing is important, because the EMBB component for multimedia service will have to rely on slices isolated from more critical services such as road safety services. The question of adapting EMBB component to transportation domain is putt on the table in order to be able to manage important speed for instance especially for train.

MEC server could be interesting for cloud gaming or network gaming in order to reduce latency. In case of network gaming: gamers should be located in the same area. MEC server could also be used for high speed content download using for instance short range waves (millimeter ones). Theses contents could be the most popular contents for a large population in a content push service perspective, or pre-provisioned in advance at customer request in coherence with the journey of the car for instance.

Table 2.9 : Video streaming/gaming

Service Name	Video streaming/gaming
Goal	To entertain passengers in all cars, and potentially also drivers in AD cars.
Short Description	There is an increasing expectation that consumers should be able to access their entertainment services regardless of technical platform. This also includes the car. With the increasing quality of screens, and the development of HD and 4K video when specific terminal are used such virtual reality glasses, high demands are put on bandwidth. It is also likely that on-line games will be required to entertain (or activate) future car passengers. In AD Level 4-5 cars, requirements

	on entertainment services will be even higher as the driver is not active in the driving task.	
Properties	Coverage	Medium
	Availability	Medium
	Bandwidth	High for high speed content download, 4K, high for multimedia
	Latency	Weak (video)/Important (cloud gaming)
	Data volume	Very high
	Target endpoint(s)	Commercial video and game services
	Special properties	NA
Challenges	• Competition/co-existence with brought in devices (smartphones, tablets) • Unpredictable usage patterns and behaviour in case of traffic jam • Creation of simple customer experience over embedded devices • Digital rights management in “roaming” situation	
Needs	• Network service should support high data rates with an important density of UE	
Parties involved in value chain	• Car OEM • Content providers • Mobile network operators • Content delivery networks (CDNs like Akamai)	
Customer	• End customer	
Customer benefit (Value)	• End customer – Entertainment when driver deactivation	
Potential 5G business model element impact	• Network slicing / QoS differentiation from Internet access and critical services • Distributed data centers/Mobile edge computing	

Parking reservation/payment

The driver should not need to bother anymore about parking reservation and payment. It should be included into its own driving experience. So, not only the service could help identifying best parking, availability of place, reserve and pay for it, but it should also be able to help the driver to find the place on on-street/off-street parking places and actually park the car into it. 5G will help enabling such service by the capability to exchange real time information with parking and city database as well as by providing specific dedicated car control or assistance to being able to autonomously drive the car to the identified place.

Table 2.10: Parking reservation/payment

Service Name	Parking reservation/payment	
Goal	Provide real time services for an end to end mobility experience including the parking reservation and payment.	
Short Description	The parking service should be fully integrated in the driving experience: identify the need of parking, choose the best place, reserve and pay for it and finally automatically drive the car to the proposed place.	
Properties	Coverage	Medium-low
	Availability	High in the parking zone
	Bandwidth	Low
	Latency	Very low
	Data volume	Medium
	Target endpoint(s)	Valet parking
	Special properties	Location, HD maps, security
Challenges	• Simultaneous communications between car, parking providers (such as smart city) and payment solutions • Usage of personal data with high security requirements	
Needs	• Real time secured in the exchanges between all the stakeholders	
Parties involved in value chain	• Car OEM • Parking providers or smart city • Payment solutions providers • Mobile network operators	
Customer	• End customer • Car OEM • Parking providers	
Customer benefit (Value)	• End customer – Seamless mobility experience • OEM – Additional business • Parking provider – optimized usage and park space brokerage (parking space becomes more expensive in case of scarcity)	
Potential 5G business model element impact	• Network slicing / distributed payment of traffic • Distributed data centers/Mobile edge computing	

2.2 Technological components

Holistically, it is widely envisioned that 5G will act as a technology enabler for the creation of innovative business models on top of newly appeared services or existing services. To be more specific, it is possible to say that the 5G will contain **technology enablers** that allow for the creation of **new technological components** which can be used to **create new services** or enhance existing services (as it has been described in the previous section) upon which **business models** will be created. It is important to create this separation between technology enablers, which are transversal innovations, and technological components, which be built on top of the technology enablers.

On the high level we could argue that the two key technology **enablers** are:

1) An innovative Radio Access Technology (RAT) for V2X communications, enabling both infrastructure based and sidelink based communications (direct communication between devices, a.k.a. Device to Device, D2D, communications). **This enabler, together with high accuracy positioning techniques, is being studied and further developed in 5GCAR, especially targeted for future scenarios.**
2) The virtualization of the communications network, from the radio to the core. The virtualization of all the elements of the end-to-end communication network allows for a highly dynamic and reconfigurable setting of the infrastructure. **This technology enabler is being studied and further developed in 5GCAR.**

These two technology enablers allow for the definition of innovative **technological components** which can be used to support new services. In the Annex A an overview of the key technological components is provided that may bring opportunities to devise new services from which elaborate new 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.

Key technological component highlighted here and detailed in Annex A are:

- **Network Densification,** the ambitious requirements of some use cases may need a small cell deployment. This could be costly for operators and may threat the business model possibilities.
- **Network Slicing,** is the possibility to have “various simultaneous and different instances of a communication network” running on top of a common infrastructure. This feature shall help to boost new business models by reducing the infrastructure costs and improving the flexibility to cope with dynamic demands from services**.**
- **Mobile Edge Computing,** consists of installing and operating computing capabilities closer to the final user of a radio communication technology. Having computing capabilities closer to the user reduces latency, improves reliability, and off-loads the core and transport networks.
- **Cellular radio-based positioning and tracking,** 5G radio technologies can provide better performance than LTE and complement existing solution based on GNSS. This feature may become crucial for autonomous driving**.**

- **Sidelink,** appears as a complementary link to operator cellular network, without using the infrastructure at least for the user traffic. These direct communications can enable new use cases and business models.
- **Integrated Moving Networks,** enabling moving vehicles to act as temporary and nomadic infrastructure for the communication network, can bring effective extension of the cellular coverage and improve a dynamic network deployment. Sidelink communications and its business model have to be defined.

2.3 Practicalities

In this section, a brief vision is given of the main practical aspects which shall affect the business model definition for the automotive. Elements such us the provision of the connectivity, the continuity of the service in roaming (much more when an European digital single market is now available) and coverage availability are crucial and may jeopardize any new business.

2.3.1 Profile/SIM card provisioning

Cellular communication systems are relying on unique identity provided by UICC (the SIM card). It ensures integrity and security and could embed with several services. It usually has to be provisioned and associated to a given operator. However, with embedded UICC (eUICC or eSIM) [SGP.02], the SIM is not a separate piece anymore but is directly embedded into the device as a chip and support remote provisioning of credentials. Integrated SIM (iUICC) provides a further integration step (the SIM functionality is by design integrated into the TCU HW), but the concept is still under development and not fully endorsed yet e.g. by GSMA.

In this document, we assume that an eUICC will be used, as this is current best practice in the automotive industry. We do not foresee that 5G will change this. The physical component will be sourced by the car OEM directly from a eSIM vendor and be under the control of the car OEM but allowing different profile management for fleet managers or service providers. The eSIM device will be integrated in the OBU by the OBU vendor, on behalf of the car OEM. The eUICC will be provisioned with an initial profile ("Boot strap profile") when supplied from the eSIM vendor. This initial profile will be supplied by a Mobile Network Operator (MNO) contracted by the Car OEM. Nevertheless, the eUICC will have the capability to store multiple profiles. There may be cars/OBUs equipped with multiple SIM cards and eSIM, under control of Car OEM and/or end-customer. Furthermore, the end-customer could be able to use a private profile on the eUICC to connect to a Mobile Network Operator of his own choice, i.e. private eSIM.

2.3.2 Routing strategy

The connected vehicle has several interfaces available, in terms of connectivity a global strategy has to be defined to decide the type of connectivity to be used depending on the service and the connectivity technologies available.

The core of the 5G architecture design is the integration of different radio access technologies. This should be understood in a wide sense. The purpose is to provide the best performances available depending on the frequency bands used (licensed, unlicensed), the needs of the service (throughput, bandwidth, etc.) and the environment (high/low density traffic area, rural vs cities area etc.).

The network control will be able to coordinate several interfaces belonging to different MNO's networks. The network performance and continuity of service of a given MNO will be improved in order to fulfill with specific service level agreements defined by the car OEM in a cooperative way with other MNOs.

From the automotive perspective, the connected vehicle has started with a 2G interface, but right now in the market all vehicles have at least capabilities for connecting to the 3G-4G mobile network and to wifi. With the arrival of the release 14 compatible components, a new interface providing direct communications between vehicles will be available.

Then, there may be at least three interfaces (cellular, wifi and sidelink) to be taken into account. Each OEM will define rules for the usage of the different interfaces available. These criteria will depend on different elements: economical prioritization, Service Level Agreements, bandwidth requirements, etc. The impacts of these interface selection policies will be different for several service domains:

- Safety,
- Infotainment,
- Autonomous vehicles.

2.3.3 Roaming and inter-operator co-operation

To provide a seamless experience for automotive services, global roaming is highly desirable, much more in the case of the European Union. There are several considerations to keep in mind. For instance, on one hand, the impact cost of handling all possible bands can be restrictive in a car. From the automotive perspective, the possibility to roam is a must for any pan European service imagined.

Besides the evident concern for global or pan-European roaming, there is a concern regarding the interoperation of different vehicles connected to different mobile network operators, especially when considering the possible direct link between vehicle (without going through the network infrastructure), and when using licensed spectrum. There should be a clear and homogenous solution to enable such interoperation, which could be provided on the communication plane when possible or service plane respecting the required performances.

The topic of coordination should also consider any possible alignment between the unlicensed 5.9GHz and licensed spectrum operation. 5.9 GHz could be used for direct V2V, V2I communication in certain cases, while operating in the licensed bands for V2N, V2V and V2I communication. However, it is not clear if there should be any actor coordinating the communication between license and unlicensed spectrum.

Finally, we underline that licensed spectrum may be used for V2I as well as for V2V communications, since license bands have the benefits of being able to offer (a higher) SLA. The main challenge is to find viable options to find the right business models in order to justify the use of licensed bands for V2V.

2.3.4 Network technologies and OEMs status

V2X technologies are classified into short range and wide area technologies [Mason2017]. The short-range technologies are designed to meet high availability/requirements of V2V and V2I services (dedicated to low power RSU deployment), it includes IEEE 802.11p (WAVE/DSRC in

USA and ETSI ITS-G5 in Europe) and LTE direct mode (PC5, 3GPP Release 14), both radio technologies operate in the 5.9 GHz spectrum (Europe and USA). The wide area technology (cellular networks over licensed spectrum) is best suited for V2N services requirements. As the deployment of C-ITS is expected to be susceptible to costs, cell technologies should provide deployment benefits given the existing/available 4G cellular network with possible evolution to 5G. The crucial advantage of C-V2X is its backward compatibility.

The IEEE 802.11p technology has been slightly adopted [Mason2017], few automotive OEMs have conducted trials or announced plans to deploy IEEE 802.11p standard in vehicles, e.g. General Motors, in May 2017, Cadillac held demonstration to show 802.11p based V2I communication between vehicles and traffic signal. VW, from 2019, will provide its vehicle with 802.11p capabilities as a standard feature and plans to provide embedded cell connectivity.

Cell technology has also been deployed in vehicles for some time [Mason2017]. Some automotive OEMs have implemented pre-release 14 LTE (V2V), e.g. BMW. The BMW connected drive (launched in 2001) enables radio access information for in-car use. In 2008 BMW was the first automotive OEM to allow unlimited in-car internet usage, since 2015, all new BMWs on certain markets are equipped with BMW connected drive, the standard features include access to vehicle information and remote-control feature via smartphone application, and an additional premium feature including real-time information concierge, service remote personal assistant and infotainment. Since 2014, Mercedes Benz provides most of its new car models with cellular connectivity offering a suite of services (navigation, infotainment and remote costumer support).

Qualcomm is the first chipset manufacturer to announce an LTE direct-mode/PC5 chipset, others like HI-Silicon, Samsung and Datang have also announced their products. PSA will perform obstacle signaling tests by a first vehicle to a second one, and alert when an emergency vehicle approaches another car. These tests illustrate PSA's work on the intelligent transportation system, called ITS, which is supposed to improve safety in its cars. C-V2X will be ready for commercial deployment in vehicles for 2019. 5GAA has helped to define/test the protocols/specifications of C-V2X technology by bringing together diverse players from different industries (automotive OEMs, vendors, operators and regulatory).

The first commercial deployment (release 14-based C-V2X in vehicles and infrastructure) is expected to be in China by 2020. In Europe, C-V2X-enabled vehicles is expected from 2020-2022.

Without any regulation, the evolution of C-V2X penetration will rely only on the interest that automotive OEMs have in pushing this technology according to their time scale to implement it in their new vehicles. Automotive OEMs have not yet announced adoption time frames but in 5GAA a market roadmap for C-V2X adoption has been agreed. Regarding the status for C-V2X, the chipset vendors which are 5GAA members (CATT, Huawei, Intel, Qualcomm and Samsung) have expressed their commitment to provide C-V2X chipsets [5GAA17]. By the end the 2017, 3GPP release 14 chipsets were available for tests, which coincides with planned validations and testing activities by ASs and OEMs (Audi, Continental, Ford, Nissan, PSA, SAIC, Bosch etc.). In addition, interoperability tests among suppliers and OEMs are planned for mid-2018 [5GAA17].

C-V2X technology (5G including release 16) is expected to enable C-ITS services (including see-through, platooning, TOD, HAD and FAD), but the required rollout investments, business models and revenues – on which 5G V2X deployment is strongly dependent are still unclear. Without clear benefit, MNOs (including Road infrastructure operators) will not be encouraged yet to start 5G deployments dedicated to ITS. The 5G-PPP WG Automotive has provided a white paper providing first insights concerning the deployment costs for 5G V2X and revenue analysis for financially and socially beneficial commercialization [5GPPP-AWG18]. More details on this topic are provided in Section 2.5.

2.4 Business model examples

2.4.1 General

In this section we analyze two applications from a business relationship perspective. The applications will contain a number of actors and describe how the actors' relationships may evolve over time. Such applications would serve as the enablers to meet 5GCAR use-cases requirements defined in [5GCAR-D21].

In order to highlight the impact of the arrival of 5G into automotive on a business model perspective, two representative applications have been selected, namely: over the air updates and autonomous driving. In each application, an evolution will be given from the traditional business model towards the new possibilities enabled by the technological components coming with 5G.

Automotive is a very competitive sector, where margins are narrow and technological adoption has always to be justified by a purpose, mainly profitability and regulatory compliance. The connected vehicle is already a full reality in the market based on 2G/3G/4G technologies. In order to boost the adoption of 5G in the automotive vertical sector, an effort must be done to emphasize the benefits of it. Not only on the OEM side, but also in the whole value chain (MNOs, telecom vendors, etc.) which will be shown in this delivery through different possibilities.

To create solutions in the connected car ecosystem, actors need to define their positions, establish business relationships, and coordinate the needed activities. Cooperation is needed between telecom and automotive actors. The traditional value chains for these industries are transforming into value networks where actors share knowledge and resources to accomplish new services. This transition and different possible ecosystems that can emerge are illustrated in Figure 2.1 [AZL18]. Four different possibilities are shown, depending on who will become the main actor orchestrating the business relationships (highlighted circle).

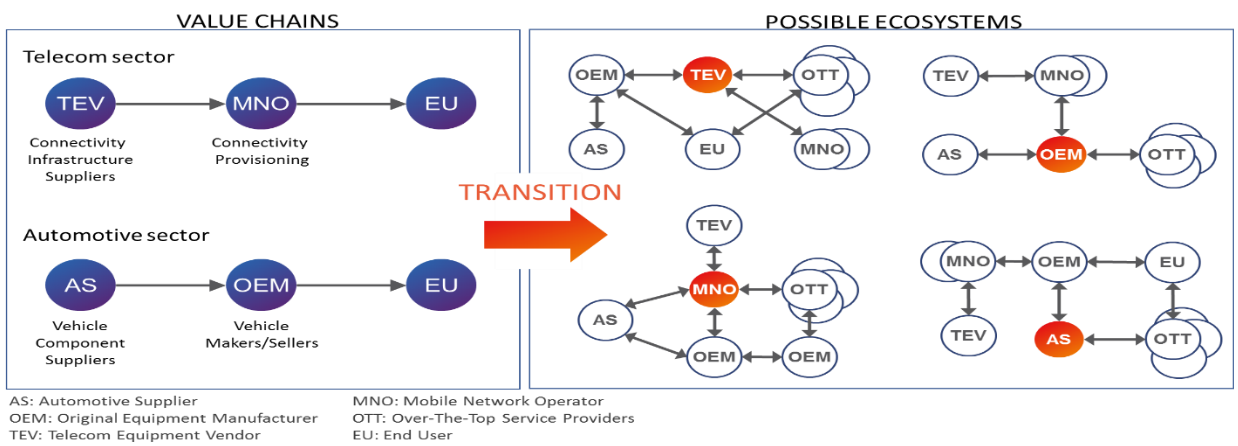

Figure 2.1: Different perspectives on how connectivity and new services can change the automotive and telecom value chains (Adapted from [AZL18])

For the elaboration and discussion of the business relationships in the cases presented below, the EcosysVisual tool developed by Ericsson has been used as a mechanism to facilitate the discussion between partners involved in the task. The tool is presented in Annex B.

2.4.2 Icon legend

This section contains a legend for Section 2.4 (Business model examples) charts. This information is presented in Table 2.11.

Table 2.11: Legend for the charts in Section 2.4

AS	Automotive Supplier
IC	Insurance Company
MSC	Mobility Service Cloud
MSP	Mobility Service Provider
OEM	Original Equipment Manufacturer
SS	Sensor Supplier
WS	Workshop
CP	Cloud Provider
MNO	Mobile Network Operator
MP	Map Provider
OTT	Over The Top (service provider)
SO	Satellite Operator
TEV	Telecom Equipment Vendor
RO	Road Operator
TA	Transport Authority
TR	Telecom Regulator
	Car
	Software
	User

2.4.3 Over the air updates

This is a business model example with high potential benefits for the OEM. The need was initially based on the car flaws found from an OEM which must be corrected, or in some cases the need to change or add new functionality. Initially these problems were only solved by visiting the garage and replacing a specific module of the car. The organization of these module replacing campaigns are extremely expensive and negative for the OEM. Expensive due to the mobilization of resources in the garages next to the customer and negative in terms of brand image because of the customer disturbance for going to the garage and leave the car available for the intervention. With a re-call procedure, it is also not possible to reach 100% of all affected vehicles. Some customers will choose or not have the ability to go to a workshop to get updated software.

Thanks to the progressive softwarization of the vehicle, new possibilities have arisen in this application. On one side, an important part of the indicated flaws can be corrected by a software update. On the other side, the software itself let the OEM create new services or new features which the customer may profit during the lifetime of his/her vehicle. The car modules which can be updated by software have the roll-back feature which may lead to the previous software version if the case of a faulty upgrade.

On both situations and without connectivity three main stake holders are involved (Step 0), see Figure 2.2: the automotive supplier (many times known as Tier1) providing the new software, the OEM responsible of its validation and distribution and the garage as the actor of the update in the customer's vehicle.

For this business model analysis, the focus will be done only on the software distribution cost (and not the costs related to the software development) which is the one where connectivity and more precisely 5G shall have an added value. In this exercise the software update will be delivered from the automotive supplier to the OEM and from this to the vehicle. This is the normal situation so far, due to validation needs and liability of the OEM. Other situations may be foreseen, but this is out of the scope of connectivity applied to over the air updates.

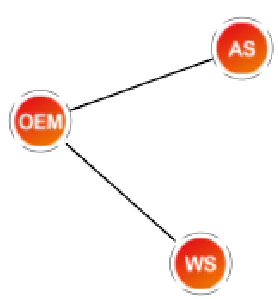

Figure 2.2: Step 0

With the arrival of connectivity, Figure 2.3, two new applications are added to the first "value chain" described in the previous figure. The connected vehicle implies the car equipped with a SIM card and OBU which is mandatory in Europe from April 2018 (reference to the mandate for e-call). The connectivity is provided by an MNO. The OEM will pay the connectivity costs and the update will be made seamless to the customer, only by granting the permission and being notified at the end.

This MNO connectivity however has limitations: the software distribution cost business model is based on the volume of data transmitted, the coverage and the bandwidth available are limited and/or unknown depending on the geographic location of the vehicle. Also, the business relationship between actors in the value chain was very rigid, e.g. the MNO migration was difficult while using a physical sim card (the sim card with the nominated MNO's profile was "locked" to the vehicle for its lifetime. Last models are now coming with eSIM a programmable sim card which may be remotely programmed to migrate from on operator to another. Note that this will be a factor to dynamize the connectivity market for OEMs) (see Section 2.4.1). These and other factors have led OEMs to propose a different software update possibility where the customer is involved. This could be done by downloading off-board the software from the OEM cloud by the customer at home and then using an USB stick to perform the update or to use a private Wi-Fi network to get "free" connectivity. This application has not the best customer experience, but it is still more comfortable than the traditional visit to the garage and much more cost effective for the OEM than the connectivity provided by the network operator. This application will change with the arrival of 5G.

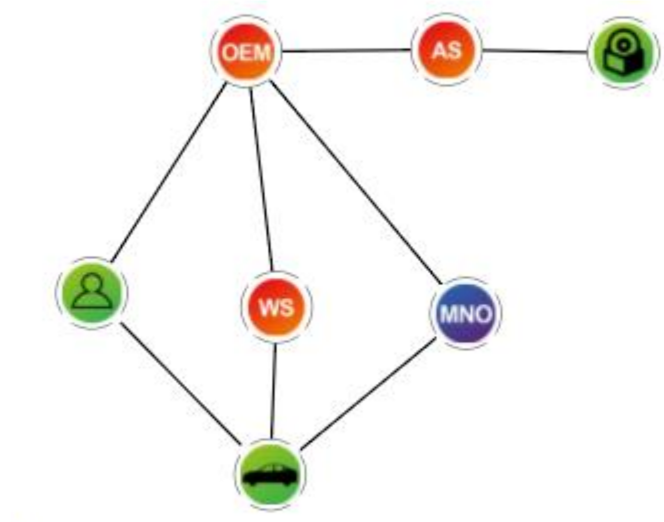

Figure 2.3: Step 1

It is time to analyze the arrival of 5G and its technological components and how they may affect the value chain defined so far. For the purpose of showing the transition, the garage and customer updated are kept in Figure 2.4.

In 5G there are three important technological components which shall modify the business model definition for automotive connectivity:

- Mobile edge computing: this feature shall bring higher performances in terms of reactivity and there are software upgrades only interesting with this type of technology available, such us HD map distribution. However, due to the very high data volumes required for an HD map, only local segments of the map should be downloaded to the vehicle as required. These local segments could be stored at the local edge of the network. This means that the OEM shall bring the software to be updated next to the cars to download the new patch. In terms of the value chain, the network load and end to end connectivity could be reduced due to the proximity of the download by increasing the MEC capacity side. This function will be provided by the telecom vendor but initially through the MNO.

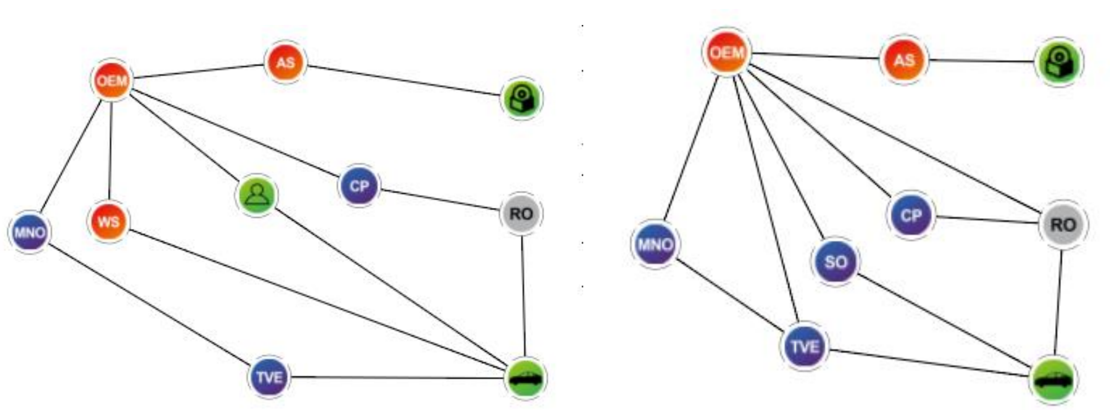

Figure 2.4: Step 2 and Step 3

- Network slicing: this is another promising feature which shall modulate business model for connectivity. There are many questions to be solved about the way it will be deployed but it may help to reserve resources according to specific needs and this shall arrive to an optimization in the usage making the connectivity more competitive for some applications. Slices may create virtual networks which shall be then used for specific services. Today, it is not common for OEMs to go beyond a customer/supplier relationship with MNOs, but this shall change in the future with the arrival of network slicing
- Sidelink: in 5G the possibility of a direct dialog between vehicles is also possible. This type of communication could be deployed on licensed or unlicensed spectrum, with and without network control, only for ITS or beyond this usage. All these options will strongly modify the connectivity value chain as it is known today. Taken this into account new actors shall emerge providing connectivity without the need of being network operators.

These three disruptor factors have been depicted with a new branch where the OEM counts on a cloud provider and then on a road operator to provide the connectivity. Part of this is already happening and the OEMs no longer talk about their own cloud but about a provided service (the OEMs in the project are good examples with VCC partnering with Ericsson [PR1] and PSA Group partnering with Huawei [PR2]). The road operator could be, depending on the three components evoked, a network operator on a restricted area or any other stakeholder not related to the standard connectivity business.

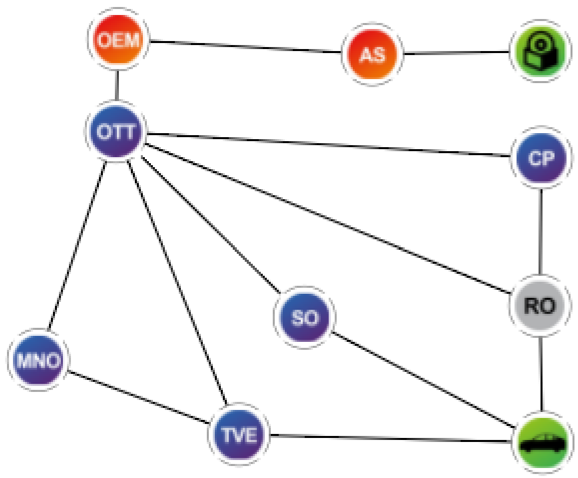

Figure 2.5: Step 4

A natural evolution of this model is the arrival of a main stakeholder (an Over The Top player) for connectivity, responsible of providing the whole over the air update service to the OEM with an abstraction layer completely agnostic of the connectivity technology or the cloud provider. This role could be played by a network operator, by a cloud provider or by any other company interested in this market.

2.4.4 Autonomous drive

AD Level 0 and 1

By AD levels in this context, we refer to the levels as defined by SAE in [SAE J3016]. AD Level 0 means that no functions of the driving task are automated. The driver is in full control of all functionality. AD Level 1 means that one task is automated, typically be the introduction of adaptive cruise control, which means that the vehicle can control its own speed in traffic, and the driver has full control of the steering.

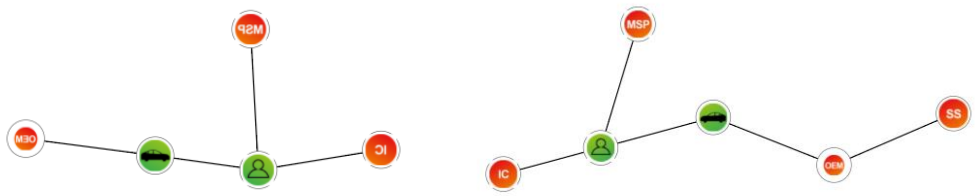

Figure 2.6: AD Level 0 and AD Level 1

In these applications, connectivity is not required. The automated functions are provided by sensors and data processing performed in the vehicle itself. Connectivity could still enhance the driving experience, by e.g. providing real time traffic information, but that is not considered in this analysis. The driver/user has relationships with the car OEM (typically through a dealer) for car ownership. He also has relationships with an insurance company as well as independent mobility service providers, unrelated to the drivers' vehicle, e.g. taxi.

AD Level 2

AD Level 2 means that both steering and acceleration/deceleration are automated under certain circumstances. The driver is however always responsible for the control of the vehicle and must be able to take control at all times. A typical example of AD Level 2 would be a vehicle with adaptive cruise control and lane centering functionality.

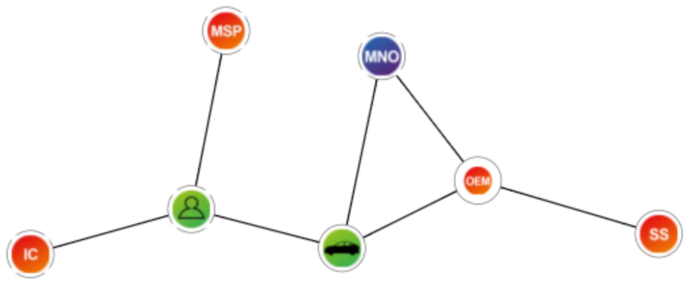

Figure 2.7: AD Level 2

In this application, connectivity is not per definition mandatory. For the purposes of this study, we have however selected to include connectivity to provide e.g. real time traffic information, emergency call and other functionality, not related to the driving task. The connectivity is typically provided by the OEM, who signs contracts with MNOs to provide the required services. The connectivity provider is typically unknown to the end customer, who is only interested in the services provided on top of the connectivity. As discussed in Section 2.4.2, the business relationship between OEM and MNO has previously been inflexible and remained for the lifetime of the vehicle, which has sometimes hindered development of new services (due to high connectivity costs), as well as roll out to new markets. In this study, we anticipate the introduction of eSIM as described in Section 2.3.1, to facilitate a more flexible relationship.

AD Level 3

With AD Level 3, vehicles are able to take control of all safety critical functions required for driving under certain conditions. The driver must still monitor the driving and be ready to take control after a certain time if the vehicle indicates that it cannot handle the situation. This is the first step where the driving responsibility, while being in autonomous driving, is shifted from the driver to the OEM.

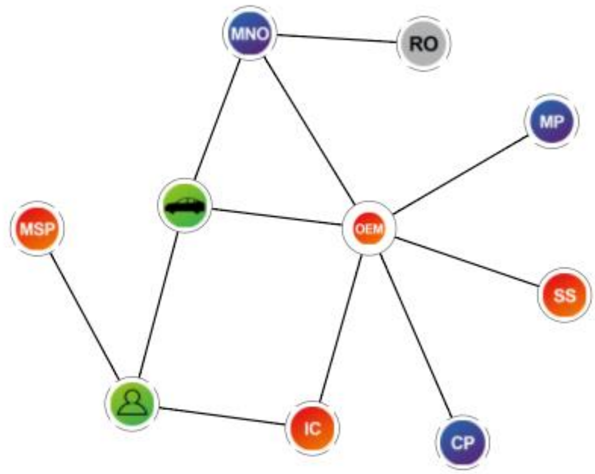

Figure 2.8: AD Level 3

In AD Level 3, connectivity becomes a mandatory component of providing the required functionality. Connectivity is required to monitor and control the geographic area where the vehicle is allowed to operate autonomously. Here we see a number of new actors in the value chain appearing, cloud providers providing the computational infrastructure for service production and delivery, map providers and road operators to provide geo coded information to facilitate the autonomous functionality. In this application, we see that it is the OEM that would have direct relationships with cloud providers and map providers. The relationship to the road operator is more uncertain and could depend on the roll-out of standardized V2X services, and what role the MNOs sees that they will take. We also see that the OEM could have a direct relationship with insurance companies to provide insurance while the vehicle is in autonomous mode.

5G could affect this value chain in several ways, e.g. through MEC in MNOs taking an active part of providing a V2X infrastructure. Network slicing could enhance the QoS and thereby the trust of the information received from off-board, potentially allowing the vehicle to operate in autonomous mode more frequently. AD Level 3 is however possible to reach using earlier generations of mobile technology, e.g. LTE.

AD Level 4 and 5, Private vehicle

AD Level 4 means that the vehicle is completely autonomous under all normal driving circumstances, and the driver is not expected to intervene. There may however be certain conditions where the vehicle is not able to operate in autonomous mode, e.g. severe weather conditions, dirt roads, etc., and the driver will have to take control. In AD level 5, the vehicle is truly autonomous in all driving conditions and situations. The driver is no longer required to operate the vehicle. In this application it is assumed that the overall business model does not change from previous applications, the driver (end customer) still buys (or leases) a vehicle from an OEM, directly or through re-sellers, and operates this vehicle as his own.

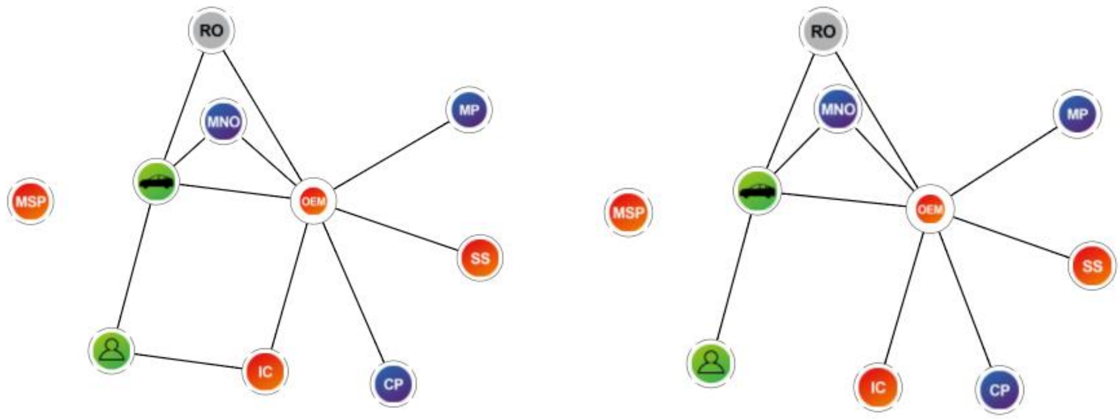

Figure 2.9: AD Level 4 (Left) and Level 5 (Right)

We do not see the value chain change dramatically from AD Level 3. In AD levels 4 and 5, the importance of getting information from the environment surrounding the vehicle is increased, and therefore, it becomes vital that the OEM, who is assumed to have responsibility for the vehicle in AD mode has access to information from the road operator. With AD Level 5, it could be possible that the customer may no longer need a relationship with an insurance company, as the responsibility of driving the vehicle will reside with the OEM that provides the AD functionality.

The impact of 5G will likely be significant. Network slicing will make it possible to dedicate slices for different services, e.g. a high availability slice/low latency slice for V2X functionality, a high bandwidth slice for entertainment services, etc. Costs for connectivity could be distributed to different actors in the value chain. MEC and low latency access would be vital for building efficient V2X services, potentially creating new business models, and actors taking new positions in the value chain.

AD Level 5, Mobility service provider

With AD Level 5, where vehicles are fully autonomous, new disruptive business models around mobility are a possibility. One such model being discussed is the situation where customers start buying “mobility as a service” rather than a vehicle.

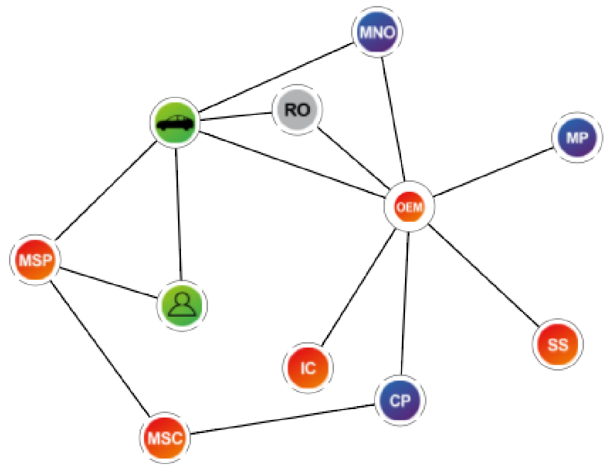

Figure 2.10: AD Level 5, Mobility service provider

In this application, it is the mobility service provider (MSP) that takes the central role. The MSP has the main business relationship with the end customer, as well as relationships with the service providers necessary to provide mobility. Here we need to evaluate who will provide the connectivity to the vehicle, or whether there may even be multiple connectivity links to the vehicle. One for OEM services, like over the air software updates, described in Section 2.4.2 and other services like emergency call, closely related to the vehicle itself. Another connectivity link between vehicle and MSP, for providing both the services required for autonomous drive as well as services for managing the mobility service, like booking, payments, etc. We will investigate how 5G could enable this more open eco-system of stakeholders wanting and needing access to connectivity to the vehicle, with various requirements on QoS, coverage, availability, bandwidth, etc. at the same time as security and integrity requirements must be met.

2.5 5G V2X deployment cost analysis

The 5GPPP published a white paper [5GPPP-AWG18] as a first outcome of the automotive working group led by 5GCAR project concerning analysis of the 5G V2X deployment cost, triggering a discussion on revenue and benefits, and taking into consideration that advanced driving solutions will be first applied in highways (deployment of 5G digitalized highway) to enable safe transportation. The launching and success of 5G V2X, expected to enable ITS services, is directly related to the investments costs and expected revenue, mainly during first years of deployment. The business case is built under a commercial vision, any regulation on this topic would affect the bases of this study. There is still a lack of understanding of the required rollout investments, business models and revenues – on which 5G V2X deployment is strongly dependent – in order to provide future ITS services. Without clear benefits mobile network operators (including road infrastructure operators) are not encouraged yet to start 5G deployment. The white paper [5GPPP-AWG18] provides a 5G ITS landscape including the main stakeholders and relationships and proposes an investment and business model to describe the cash flow. The Automotive industry, 5G industry, Road infrastructure operators, policy makers, standards developing organizations and users have been identified as principal stakeholders. The relationships among the stakeholders are categorized in form of collaboration, deployment, interaction and regulation; they are illustrated in Figure 2.11 [5GPPP-AWG18].

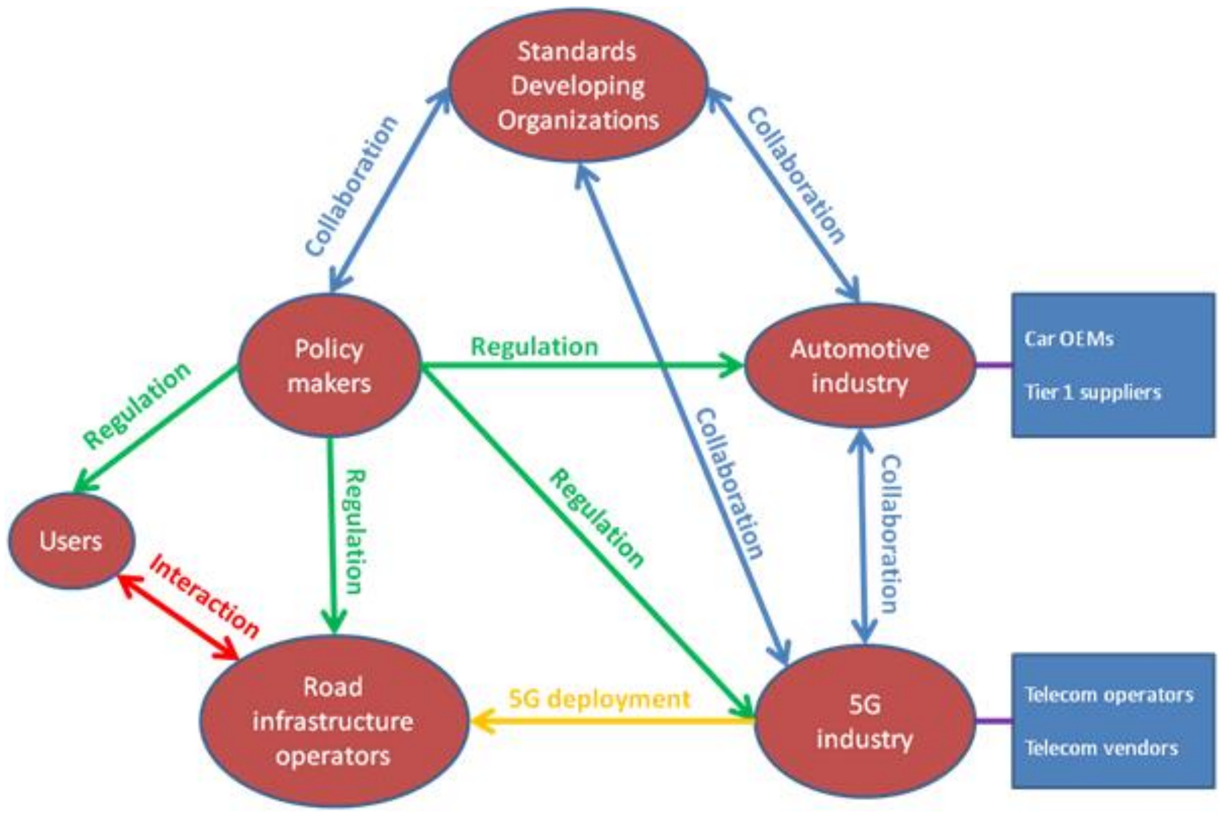

Figure 2.11: Stakeholders and relationships

The end users are not only drivers or passengers but also mobility providers as the trend of mobility as a service may become more natural with the arrival of automated driving adoption. The road operator role may have a different nature depending on the European country (private/public companies) and the applied regulation is not harmonized. As it can be seen in the figure, policy makers and regulation play a major role in the definition and modulation of the relationship between the stakeholders represented. As an example, the auction spectrum conditions may impose coverage in the highways.

Those stakeholders may assume different roles identified in the application of the network slicing feature:

- The tenant, the entity renting and leveraging 5G connectivity. Road operator, OEMs or other organization may have this role
- The Mobile Service Provider (MSP), providing slices for different services to different tenants
- The 5G infrastructure providers (5GInP) which can be divided into cloud and RAN providers, they offer the elements needed for the MSP to implement the slices.
- The non-V2X (supplementary) service provider, the entity providing passenger targeted services such as enhanced infotainment, mobile office, etc …

In this cost analysis, a positive return on investments has been estimated under certain conditions: over a horizon of 10 years (from 2020 to 2030), depending on costs of site infrastructure, digital road infrastructure (CAPEX), charged fees, percentage of investment usage for ITS services (OPEX equal to 10% of CAPEX per year) and TCO. The 5G OBU and spectrum costs are excluded, and the auxiliary services for CAD services (HD map services) are taken into account. The main parameters are summarized in Table 1. To get coarse estimates of deployment costs, a suggestion of a one-hour trip of 100Km highway (with traffic density of 100.000 vehicles per day [AUTOBAHN_A9]) at a speed of 100Km/h has been considered resulting into a rough service fee estimate of 1Euro/hour per vehicle per 100Km covering the connection and estimated HD map fees of 0.5Euro/hour per vehicle. A 10% yearly penetration of new CAD users has been adopted as a realistic market behaviour.

Table 2.12: Estimation of deployment costs for the baseline scenario

Parameter	Value
5G site (CAPEX)	40 kEuro
Digital infrastructure (CAPEX)	35 kEuro / km
Fibre (CAPEX)	100 kEuro / km
OPEX	17.5 kEuro / km / year
Inter-site-distance (ISD)	1 km

Evaluation results are illustrated in Figure 2.12. Four different scenarios, illustrated in Table 2, are considered to gain more insight into the influence of individual parameters on the overall profit. We can see a payback period between three to eight years is expected depending on the service fees, the traffic density and the deployment costs (CAPEX and OPEX), resulting into a shift of the curves to left or right translated to a shorter or longer payback periods, respectively.

Table 2.13: Deployment costs and parameter values for different scenarios

Parameter \ Scenarios	1 (Baseline)	2	3	4
CAPEX – 100 km (kEuro)	17,500	17,500	17,500	8,750 (-50%)
OPEX – 100 km (kEuro for 10 years)	17,500	17,500	17,500	8,750 (-50%)
CAD service fee (Euro per 100 km)	1	1	0.5	1
Income (% of the CAD service fee)	50%	50%	50%	50%
Traffic density (vehicles/100 km/day)	100,000	200,000	100,000	100,000

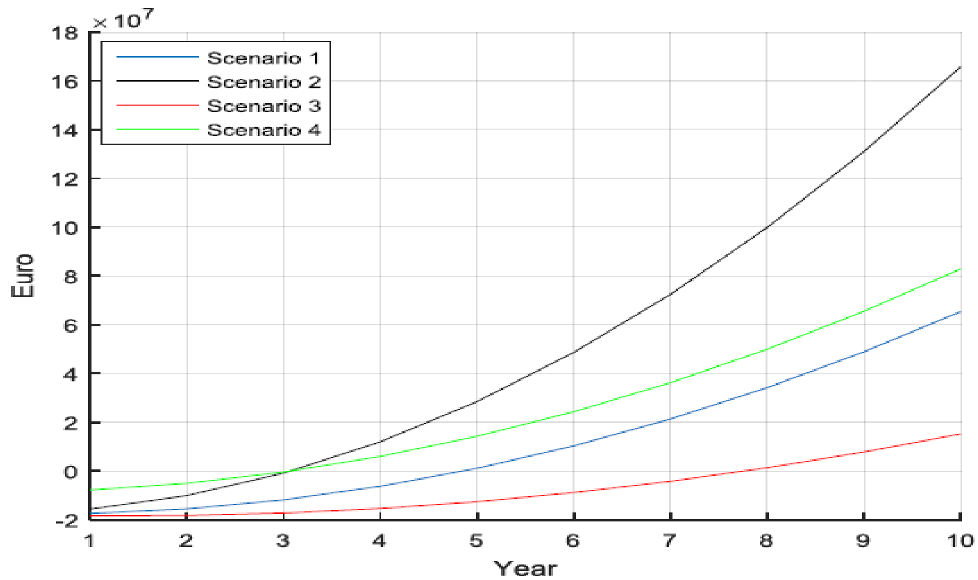

Figure 2.12: Accumulated profit for different scenarios and 10% penetration rate yearly

One of the main findings is that the OPEX/CAPEX cost has the strongest effect on the profit of CAD services, then, in descending order of impact comes percentage of usage of the infrastructure for ITS services, the CAD service fees and the number of users. Therefore, the roads with high density of vehicles are expected to generate a positive business and for the roads with limited capacity the success of investment will rely on charging level for CAD services. This analysis could show a positive total business case with positive profit over a 10 years business period. How that profit would be distributed among the stakeholders in Figure 2.11, has not been analyzed.

2.6 Summary of business models study

This section summarizes the discussion and key findings of our study on business models. The business models part of this study analysis on how 5G could enable new business models, based on new technologies and features of 5G. To ensure that all relevant new technologies in 5G are covered while the study has expanded the scope of services investigated beyond V2X services. Instead, three main areas of services have been used as a base for the investigation:

- Existing services
- Autonomous driving features
- Convenience services

The study has found that for most of the services under these three categories, 5G will provide enhanced functionality that could contribute to an increased service value. That value could be generated by e.g. a guaranteed quality of service, more efficient delivery of high data volumes, lower latency – enabling new types of services.

Technological components new in 5G have been analyzed and evaluated in how they could impact the business models. The study has found that some new 5G technologies have the capacity to disrupt current eco-systems and value chains. Other technologies will enhance existing business models.

The study has also looked at various practicalities, e.g., profile and SIM card provisioning, routing strategy, roaming and inter-operator co-operation, network technologies and OEM status. They may not immediately be related to 5G, but necessary to understand to get a complete picture of the total value chain(s). Elements such us the provision of the connectivity, the continuity of the service in roaming and coverage availability are crucial and may lay on the line any new business. It is evident that 5G in itself will not generate new business model opportunities without the surrounding connectivity service eco-system and technologies also being developed to support new service delivery models.

Finally, in order to highlight the impact, on a business model perspective, of the arrival of 5G into automotive, two representative applications have been selected, namely: 1) over the air updates and, 2) autonomous driving. The applications study considers a number of actors and describes how the actors' relationships may evolve over time. Both services have been used as models to analyze how the value chain and business model could develop over time as services and technologies evolve. It is clear that 5G could have a major impact in enabling new features in these services, and also enable new value chains. The study finds that value chains will change from being fairly linear with traditional customer/supplier roles, to being more dynamic and network oriented.

An effort to explore the financial business cases has been performed in the analysis of 5G V2X deployment costs. This analysis indicates that a positive business case for CAD (HD map services) can be found, even if penetration of CAD enabled vehicles and infrastructure grows slowly over time.

3 Spectrum

From the regulation point of view, spectrum resources are designated to different services, e.g. broadcasting service, satellite service, and mobile service, based on their specific spectrum demands. Services discussed in Section 2.1 of this deliverable belong to the mobile service and cover the following two types of applications:

Intelligent Transport System (ITS) applications: applications to support improved safety and more efficient usage of the transportation infrastructure for transport of goods and humans, particularly for using the means of road transportation. Typical existing ITS applications include the Day-1 applications identified in the European Commission communication on the strategy of Cooperative-ITS (C-ITS) roadmap [EC16_COM766].

Commercial automotive applications: applications provided to vehicle users, usually by automotive OEMs, for improving the driving experience and comfort. Commercial automotive applications usually include infotainment and other value-added services using public mobile networks.

The 5GCAR project has identified five categories of use cases covering both ITS applications and commercial automotive applications to be enabled by 5G technologies, see [5GCAR-D21].

In this study, we mainly address vehicular communication and the spectrum needs associated to that. Vehicular communication or Vehicle-2-Everything (V2X) communication refers to the radio communication enabling data information exchange among vehicles, road users and the environments including the ICT infrastructure. V2X includes the following types of communications: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N), and Vehicle-to-Pedestrian (V2P).

Basic safety-related applications may be deployed in unlicensed spectrum. However, safety-related applications have strong requirements in terms of quality of service and spectrum interference, which can be achieved through the well-coordinated use of the frequency bands, e.g. the synchronized scheduling of 3GPP Cellular-V2X technology [5GAA17].

In the following, we discuss the general overview of radio frequency spectrum, the future needs and availability of spectrum, as well as the research approach adopted in 5GCAR project for the spectrum study.

3.1 Overview of radio frequency spectrum today

3.1.1 IMT systems and 3GPP technologies

International Mobile Telecommunication (IMT) developed by ITU encompasses IMT-2000, IMT-Advanced, and IMT-2020. IMT specifies sets of requirements for high speed mobile broadband services and technologies that are marketed as 3G, 4G, and 5G worldwide. The ITU Radio Regulations (RR) [ITU-RR-2016] establish the allocation of frequency bands for each radio service including the Mobile Service enabled by IMT technologies. The frequency bands identified by ITU-R for IMT and the related channeling arrangements of those bands are documented in ITU-R Recommendation M.1036-5 [ITU-R-M1036-5]. In Annex C Table C.1 provides a list of IMT bands identified by ITU-R. It should be noted that in addition to those frequency bands in Table C.1 other frequency bands can also be used and deployed regionally for IMT systems. UMTS, HSPA, and LTE are mobile communication technologies developed by 3GPP meeting the ITU IMT requirements. 3GPP technologies are designed to operate in the IMT bands identified by ITU-R. As for the E-UTRA and UTRA, which are the radio interface technologies of LTE and UMTS respectively, 3GPP has defined the operating bands in specifications [3GPP-TS-36104] and [3GPP-TS-25104], as shown in Table C.2 and Table C.3 in Annex C. So far, 3GPP has specified more than 70 frequency bands for LTE within the IMT bands in specific national or regional areas.

Public mobile networks operating in IMT bands can already support automotive and ITS applications, e.g. infotainment applications, OEM cloud-based applications, etc. With improved system capacities and latency performance of 4G LTE systems, many ITS safety-related applications can already operate using 3GPP technologies based on V2I and V2N communications in IMT frequency bands.

3.1.2 Spectrum for 5G

The spectrum considered for 5G in Europe includes 703-788 MHz, 3.4-3.8 GHz, and 24.25-27.5 GHz. The 3.4-3.8 GHz is considered by Radio Spectrum Policy Group (RSPG), which is a high-level advisory group that assists the European Commission in the development of radio spectrum policy, to be “the primary band suitable for the introduction of 5G-based services in Europe even before 2020 given that it is already harmonized for mobile networks and offers wide channel bandwidths” [EC16-MAN-5G].

Several national regulators in Europe are already considering to auction the 3.4-3.8 GHz for 5G to mobile operators, e.g. trials in France authorized by French regulator Arcep [ARCEP2018] and auctions by Ofcom in UK [OFCOM2018].

Furthermore, according to RSPG, “5G will need to be deployed also in bands already harmonized below 1 GHz, including particularly the 700 MHz band, in order to enable nation-wide and indoor 5G coverage”. Note that the 703-733 MHz UL / 758-788 MHz DL band has already been auctioned in some countries, e.g. in France and Germany.

The RSPG recognized also “the 24.25-27.5 GHz (hereinafter '26 GHz') band as a pioneer band for Europe to be harmonized before 2020”.

By the end of 2017, 3GPP has approved the first 5G NR radio specifications [3GPP17NR]. 3GPP TS 38.101 [3GPP17-38101] defines two frequency ranges (FRs) for 5G NR operation: FR1: 450 MHz – 6000 MHz and FR2: 24250 MHz – 52600 MHz. In Annex C, the detailed lists of NR operating bands in respective FR are given. The lists contain both newly identified bands for NR, e.g. n77, n78, n79, n257, n258, n260, etc., as well as reused LTE bands, e.g. n1, n2, etc.

3.1.3 Dedicated spectrum for ITS applications

Intelligent Transport Systems (ITS) aim at improving road traffic safety and efficiency. In year 1999, the Federal Communications Commission (FCC) of the U.S. assigned 75 MHz from 5.850 GHz to 5.925 GHz for ITS applications. In Europe, the spectrum 5.855-5.925 GHz has been designated for ITS by the EC [ECC/DEC/(08)01]. In many other countries of the world, e.g. China, Korea, Australia, and Singapore, the 5.9 GHz ITS band has also been designated or under consideration for ITS applications. Above the 5.9 GHz band, European Conference of Postal and Telecommunications Administrations (CEPT) [ECC/DEC/(09)01] decided that CEPT administrations should designate the 63-64 GHz for ITS applications. The frequency band 5.770 - 5.850 GHz has been allocated in Japan for ITS applications, e.g. Electronic Toll Collection (ETC). Additionally, a single 9 MHz frequency channel in 755.5 – 764.5 MHz has also been designated for ITS safety-related applications using V2V and V2I communications in Japan. Different from the IMT bands discussed above, use of these dedicated ITS spectrum bands are license-exempt.

In Section 3.3 a detailed survey of worldwide spectrum is provided, including licensed and unlicensed bands that are usable by V2X communications.

3.2 Methodology of spectrum study in 5GCAR

There has been a considerable amount of activities to identify appropriate spectrum for 5G, which are currently considered in the on-going spectrum legislation and harmonization efforts of 5G spectrum. Annex D provides an overview of related work on 5G spectrum.

The current landscape of V2X Cellular Solution has been provided in [5GAm16]. In Europe the V2X related activities are referred to as cooperative ITS (C-ITS), where the V2X technologies include both ETSI-ITS-G5 based on IEEE 802.11p/DSRC and Cellular V2X using 3GPP LTE/5G. There are several regulatory actions supporting development of V2X systems, and the unlicensed spectrum at 5.9GHz has been reserved for ITS use in alignment with C-ITS spectrum in other regions of the world. For China, the V2X related activities are referred to as Intelligent Connected Vehicles (ICV) and intelligent transportation systems, LTE-based technology and DSRC are supported. The bureau of radio regulations, as a part of Ministry of Industry and Information Technologies China (MIIT), is leading spectrum research and promoting dedicated spectrum allocation for ICV applications to support ICV safety applications at 5.9 GHz where 20 MHz has been allocated for the trial of ITS safety applications.

In 5GCAR, to identify appropriate spectrum bands for enabling advanced ITS and automotive applications, such as those use cases identified in [5GCAR-D21], using 5G technologies, we adopt a study methodology consisting three steps: Firstly, a comprehensive understanding of available and optional frequency bands for V2X technologies is established through a detailed survey of spectrum for mobile services in different regions of the world. Secondly, a study of available frequency bands is performed with respect to their suitability to the requirements of 5GCAR use cases, e.g. communication range, data rate, reliability, etc. Finally, the appropriate options of spectrum bands for 5G V2X will be identified based on the spectrum survey and the suitability analysis and by considering the innovative technical components and architecture yet to be developed in 5GCAR. This intermediate deliverable reports the first two steps, i.e. the spectrum survey and the suitability analysis.

3.3 Survey of spectrum resource for V2X communications

Spectrum regulations are issued by regional regulators and can vary from region to region. In this study we investigate the spectrum resources that are usable for V2X communication to support ITS and automotive applications in different regions and countries, particularly in Europe.

Different systems and technologies operating in the same band or in bands in proximity require special attention to the coexistence and compatibility issue, particularly for safety-related applications such as ITS. In this survey, we also discuss compatibility and technology coexistence issues in the relevant frequency bands.

3.3.1 Spectrum for V2X communications in Europe

ITS spectrum at 5.9 GHz

In Europe, the spectrum 5855-5925 MHz, also known as the 5.9 GHz band, has been identified for ITS applications. More in detail, ECC/DEC/(08)01 amended 3 July 2015 [ECCDEC0801], decided (among others) that

- CEPT administrations shall designate the frequency sub-band 5875-5905 MHz on a non-exclusive basis for ITS traffic safety applications.
- CEPT administrations shall consider within a future review of this Decision the designation of the frequency sub-band 5905-5925 MHz for an extension of ITS spectrum noting that protection of ITS cannot be ensured in this band.

Further, the European Commission (EC) decision on 5 August 2008 adopted the designation of the frequency band 5 875-5 905 MHz for safety-related applications of Intelligent Transport System on a non-exclusive basis. [ECDEC2008] The spectrum band 5855-5875 MHz has been recommended to be made available for ITS non-safety applications in order to support and enhance ITS within CEPT in [ECCREC0801], amended 3 July 2015. According to [ECCDEC0801] and [ECCREC0801], ITS equipment complying with the European harmonized standard EN 302 571 [ETSI17_EN302571] should be exempted from individual licensing for using the 5855 – 5925 MHz ITS band. In Table 3.1 and Figure 3.1, an overview of the regulations and the channel layout of the European 5.9 GHz ITS band are provided.

Table 3.1: European 5.9 GHz ITS band.

Frequency range	Usage	Regulation
5855 MHz to 5875 MHz	ITS non-safety applications	ECC Recommendation (08)01 [ECCREC0801]
5875 MHz to 5905 MHz	ITS road safety	Commission Decision 2008/671/EC [ECDEC2008], ECC Decision (08)01 [ECCDEC0801]
5905 MHz to 5925 MHz	Future ITS applications	ECC Decision (08)01 [ECCDEC0801]

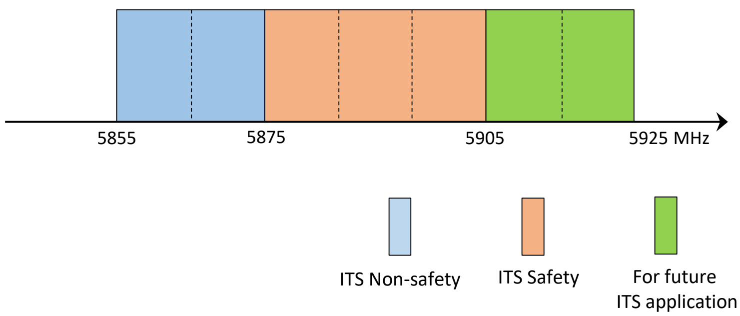

Figure 3.1: Dedicated 5.9 GHz ITS spectrum in Europe.

ETSI EN 302 571 is the harmonized standard for the European 5.9 GHz ITS frequency band. It specifies technical requirements and methods of measurement for radio transmitters and receivers of ITS products operating in this band. The technical requirements and methods of measurement in EN 302 571 are neutral to radio access technologies. Any ITS radio technology can operate in the 5.9 GHz ITS band, as far as it complies with the technical requirements specified in EN 302 571. Currently, both ETSI ITS-G5 and 3GPP C-V2X PC5 interface (including its first implementation in release 14 LTE-V2X) are considered as radio technologies operating in this band.

In Annex E more details are provided about this European 5.9 GHz ITS band including the supported applications in this band, details of the European harmonized standard EN 302 571, coexistence and compatibility of ITS with other systems at 5.9 GHz, as well as recent regulatory development about this band.

5.8 GHz frequency for toll collection

At 5.795 – 5.815 GHz there are four 5 MHz channels designated for the Road Transport and Traffic Telematics (RTTT) applications, e.g. electronic toll collection. The system uses the passive Dedicated Short-Range Communication (DSRC) technology defined by CEN standards EN 12253:2004, EN 12795:2003, EN 12834:2003, EN 13372:2004 and ISO 14906:2004. Due to closely allocated frequency bands the CEN DSRC tolling system may be interfered by ITS-G5 or LTE-V2X stations working in the 5.9 GHz ITS band. The technical solutions ensuring the co-existence between the 5.8 GHz tolling system and the 5.9 GHz ITS system is specified in ETSI TS 102 792.

60 GHz ITS band

Above 5.9 GHz, [ECCDEC0901] decides that CEPT administrations should designate the 63-64 GHz for ITS applications. The Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 has mandated SDOs like ETSI to develop technical standards related with corporate communications using radio transmitters and receivers for Intelligent Transport Systems (ITS), which may comprise V2V and V2I.

These ITS networks operate over a short range with very wideband communications using a variety of directional medium and high gain antennas to enable a high degree of spectrum reuse and may use a flexible bandwidth scheme under which they normally operate in a wideband mode, and periodically reduce their bandwidth (e.g. for antenna training and other activities).

The technical characteristics of these applications supposed to operate in the 63-64GHz band are described in ETSI TR 102 400. ETSI TC ERM TG37 has also developed the European harmonized standard EN 302 686 for the 60GHz ITS band. However, so far there is no ITS product on the market using this band.

To be noted that the current 63-64 GHz ITS band overlaps with the unlicensed 57.24-56.88 GHz spectrum to be used by the Radio LAN (RLAN) systems based on the WiGig technology. Currently, there is a discussion in ETSI and CEPT on aligning the channelization of ITS and RLAN in the 60GHz band.

IMT bands in Europe

According to [3GPP-TS-36101], currently the frequency band for direct V2X communication, known as the PC5 interface, is within Band 47 (5855 MHz to 5925 MHz). For cellular operation over the Uu interface, it can take place over various bands given in Table C.1 (in Annex C). In some of the bands, e.g. Band 3, 7, 8, 39, and 41, communication over the Uu interface can be combined with the communication over the PC5 interface in Band 47.

Bands in Table C.2 (in Annex C) are the standardized 3GPP bands worldwide. A list of the licensed bands used by mobile operators in Europe is presented in Table 3.2. In the right column (of Table 3.2) it is specified whether the band can be used in combination with the V2X PC5 interface according 3GPP specifications.

Table 3.2: Frequency bands licensed to mobile network operators for 3GPP Uu communication in Europe.

3GPP band standardized for Uu	UL operating band		DL operating band		Duplex mode	In Combination with Band 47 for V2X
	F_Uplink_low (MHz)	F_Uplink_high (MHz)	F_Downlink_low (MHz)	F_Downlink_high (MHz)		
Band 1	1920	1980	2110	2170	FDD	No
Band 3	1710	1785	1805	1880	FDD	Yes
Band 7	2500	2570	2620	2690	FDD	Yes

Band 8	880	915	925	960	FDD	Yes
Band 20	832	862	791	821	FDD	No

Note that 5G could operate ultimately in all bands licensed to MNOs (IMT bands) in particular through refarming process. The bands mentioned in **Table** 3.3 might be considered as 5G pioneered bands.

Table 3.3: Intended licensed bands for 5G communication in Europe.

UL operating band		DL operating band		Duplex mode
F_Uplink_low (MHz)	F_Uplink_high (MHz)	F_Downlink_low (MHz)	F_Downlink_high (MHz)	
703	733	758	788	FDD
3400	3800	3400	3800	TDD
24250	27500	24250	27500	TDD

Note:

- The 703-733 MHz UL / 758-788 MHz DL has already been auctioned to mobile operators in some countries like France [ARCEP2015] and Germany [BNETZA2015].
- The harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the European are currently being defined at CEPT level for the 3400-3800 MHz and 24.25-27.5 GHz bands.
- 3GPP is developing the 5G radio technologies operating in these bands.

For ITS and automotive applications, the public mobile operators' bands may be used for communication through the 3GPP Uu interface on the basis of an agreement between mobile operators and car makers.

3.3.2 Spectrum for V2X communications in other regions

U.S.

DSRC Spectrum in the U.S. for ITS Applications

In October 1999, the Commission allocated the 5.9 GHz band (5.850 to 5.925 GHz) for DSRC-based ITS applications and adopted basic technical rules for DSRC operations. According to the updates specified in 47 C.F.R in August 2017, only DSRC is allowed to use 5.9 GHz band in the US until the next update of these FCC rules. The Government's Radiolocation Service, which is for use by high-powered military radar systems, and non-Government Fixed Satellite Service (FSS) uplink operations are co-primary in the 5.9 GHz band as summarized in Table 3.4 (for details see 47 C.F.R. § 2.106, Table of Frequency Allocations).

Table 3.4: 5850-5925 MHz service allocation in the U.S.

ITU Region 2 (incl. North, Central, South America)	U.S. Federal Government (5 850 – 5 925 MHz)	U.S. Non-Federal Government
FIXED FIXED- SATELLITE (earth to space) MOBILE Amateur Radiolocation (radars)	RADIOLOCATION	FIXED – SATELLITE (Earth to space) US245 MOBILE NG160 Amateur

The band plan of 5.9 GHz DSRC spectrum in the U.S. is shown in Figure 3.2. The frequency band at 5.850-5.925 GHz consists of seven 10 MHz channels and a 5 MHz guard band. Two 10 MHz channels (5.855-5.865 GHz and 5.915-5.925 GHz) are designated by FCC rules for safety of life and property applications. One 10 MHz channel (5.885-5.895 GHz) is designated as the control channel. Optionally, the FCC rules allow two sets of 10 MHz channels being combined to create a 20 MHz channel (5.865-5.885 GHz and 5.895-5.915 GHz).

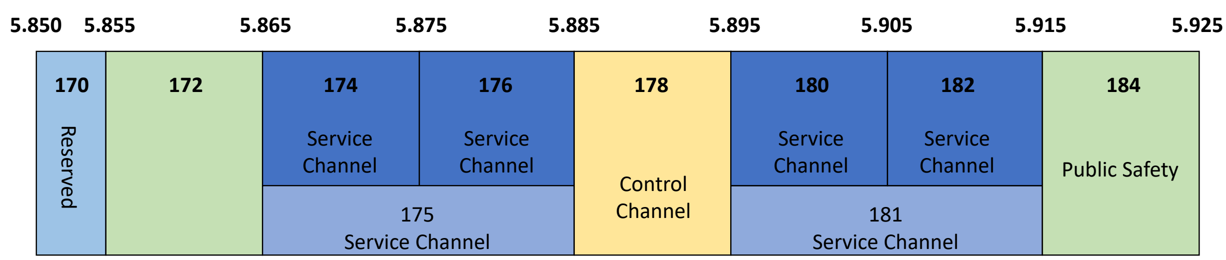

Figure 3.2: Band plan of 5.850 – 5.925 GHz DSRC band in the U.S.

IMT bands in U.S.

The usage of frequencies within the United States is regulated by the Federal Communications Commission (FCC) and the spectrum licenses are based on geographical areas. Considering different generation of mobile network communications, the allocated cellular bands are shown in Table 3.5.

Table 3.5: Licensed bands for mobile network communications in the U.S.

3GPP band standardized	UL operating band		DL operating band		Duplex mode
	F_Uplink_low (MHz)	F_Uplink_high (MHz)	F_Downlink_low (MHz)	F_Downlink_high (MHz)	
Band 2	1850	1910	1930	1990	FDD
Band 4	1710	1755	2100	2155	
Band 5	824	849	869	894	
Band 12	699	716	729	746	
Band 13	777	787	746	756	
Band 14	788	798	758	768	

Band 17	704	716	734	746	
Band 23	2000	2020	2180	2200	
Band 24	1625.5	1660.5	1525	1559	
Band 25	1850	1915	1930	1995	
Band 30	2305	2315	2350	2360	
Band 66	1710	1780	2100	2200	
Band 70	1695	1710	1995	2020	
Band 71	663	698	617	652	
Band 35	1850-1910				TDD
Band 36	1930-1990				
Band 37	1910-1930				
Band 41	2496-2690				
Band 48	3550-3700				

Note: Band 41 (for the LTE-V2X Uu interface) in Table 3.5 can be used in combination with Band 47 (for the LTE-V2X PC5 interface) for LTE-V2X operation.

In [5GAm17-1] the suitable spectrum ranges below 6 GHz and above 24 GHz for a variety of 5G applications are specified. As mentioned in the white paper, although the spectrum in the 6-24 GHz range hasn't been included in the table, the spectrum is definitely suitable for 5G applications as well. Considering the potential spectrum bands for 5G usage, depending on the usage scenarios, different spectrum can be considered. As a summary:

- Usage scenario eMBB: for ultra-high-speed radio link, >24 GHz can be used, and for high speed radio link, 3-6 GHz can be used. Basically, the entire spectrum band can be used for ultra-low latency services. Considering reliability, <6 GHz is preferred.
- Usage scenario URLLC: >24 GHz can be used for short range communication and <6 GHz should be considered for medium-long communication range.
- Usage scenario mMTC: in principle all frequency bands can be used to support mMTC.

China

An overview of regulation requirements of 5 GHz band in different regions of the world is presented in [LABIB17], including China. In China, the regulation status of 5 GHz band (5150 to 5925 MHz) is as follows:

- 5150-5350 MHz: WAS/RLAN Indoor only, Max EIRP: 200mW.
- 5470-5905 MHz: Under investigations.

The requirement evaluation methodology in 5G promotion plan started in 2016 [5G-MIIT]. The research on candidate frequency bands below 6 GHz started in 2015. The system design and technology evaluation started in 2016. 5G technology R&D trials have been started in 2016. By 2018, 5G product R&D trial will start.

For the 5G Spectrum Development in China, 5905-5925 MHz is assigned for LTE V2X trial, 2 x 2.3 MHz in frequency band 800 MHz are planned for NB-IoT (for private network). For 5G eMBB deployment scenarios, the business success of 5G eMBB deployment will be enabled by the harmonization of frequency bands and by finding larger contiguous bandwidth, supporting aggregation of frequency bands below and above 6 GHz.

On January 7th, 2016, MIIT launched 5G compatibility trial using the IMT 3.4-3.6GHz band. Preliminary compatibility studies of 5G mmWave bands have been conducted on certain frequency bands to be studied for the Agenda Item 1.13 of WRC-19. LTE-V2X trials have been conducted in Shanghai and Chongqing at 5905-5925 MHz using the prototype supported by National Science and Technology Major Project.

The key points for 5G spectrum are to support aggregation of frequency bands, 3.3-3.6 GHz and 4.8-5.0 GHz will be the key 5G band for initial 5G deployment. Frequency band below 1 GHz is preferable for MTC. V2X will be a key application of 5G URLLC. Cooperation in ITU-R is important to ensure global/regional harmonization of 5G spectrum and licensing mechanism.

Other regions of the world

This section covers the spectrum allocation for ITS and automotive applications using V2X communications in countries and regions other than EU, US and China. Four countries including Japan, Singapore, Australia, and Canada are discussed and their V2X spectrum allocations are summarized.

In Japan, the frequency band 5770-5850 MHz is allocated for V2V communication system as well as for Electronic Toll Collection (ETC) using the Japanese DSRC technology [ARIB STD-T75]. Since the spectrum is very congested in that band in several parts of Japan, it is not a preferred band for V2V communication. Therefore, it was decided that the 760 MHz (755.5-764.5 MHz band) is allocated for ITS applications. In Japan, a new standard for ITS applications using V2V communication named ARIB STD-T109 [ARIB STD-T109] was developed for “Driving Safety Support Systems” in the 700 MHz band.

In the Singapore, Australia, and Canada the frequency band 5855-5925 MHz has been allocated for ITS applications. The Australian ITS radiocommunications class license has been finalized by the Australian Communications and Media Authority (ACMA) in 2017. According to this ITS class license, to operate in 5855 MHz – 5925 MHz, ITS stations in Australia must comply with ETSI Standard EN 302 571 [ACMA_ITS_2017].

Worldwide harmonization of spectrum

As introduced in Section 3.1.1, IMT spectrums for cellular technologies are harmonized in ITU-R. To consider possible global or regional harmonized frequency bands for the implementation of evolving ITS under the existing mobile service allocation, World Radio Conference (WRC) 2019 has an Agenda Item AI1.12 for ITS applications. [WRC-15-Res237-2015] The 5 855-5 925 MHz band has been discussed in different world regions for the harmonized use for ITS. In Europe, CEPT also considers the 63-64 GHz under this WRC-19 AI1.12. However, the road tolling in 5 795-5 815 MHz is not considered by CEPT under AI1.12.

3.4 Suitability analysis of V2X spectrum for 5GCAR use cases

The suitability of V2X spectrum for 5GCAR use cases is analyzed in this section and the results are provided in the following tables. Only a subset of bands is chosen, both below and above 6 GHz. As an example, complete derivation is also provided in Annex F. The link budget model used for this analysis is detailed in Annex F.

For V2N downlink transmissions, it takes in account the EIRP transmitted by an eNB, the propagation effects from a typical eNB antenna's height towards a typical automotive antenna, above a perfectly reflecting ground (worst case), and finally the receiving antenna gain of vehicle.

For V2N uplink transmissions, it takes in account the EIRP transmitted by a typical automotive antenna, the propagation effects between a typical automotive antenna's height and a typical eNB antenna, above a perfect ground, and finally the receiving antenna gain of eNB.

For V2V and V2I Sidelink transmissions, it takes in account the EIRP transmitted by a typical automotive antenna, the propagation effects between a typical automotive antenna's height and a typical antenna of a vehicle or a RSU, above a perfect ground, and finally the receiving antenna gain of a vehicle or a RSU.

The resulting minimum distance ranges between antennas, are determined for different level of sensitivity depending on required throughput and QoS of each 5GCAR use case (see details in Annex F).

Table 3.6: For bands below 6 GHz the following are the results.

Frequency	Scenario	Pt (dBm)	Gr (dBi)	UC1	UC2	UC3	UC4	UC5
Below 1 GHz	V2N DL	46	4	OK	OK	OK	OK	OK
	V2N UL	33	18	OK	OK	OK	OK	OK
	V2I	33	8	OK	OK	OK	OK	NO
	I2V	33	4	OK	OK	OK	OK	NO
	V2V	33	4	OK	OK	OK	OK	NO
From 1 to 3 GHz	V2N DL	46	4	OK	OK	OK	OK	NO
	V2N UL	33	18	OK	OK	OK	OK	NO
	V2I	33	8	OK	OK	OK	OK	NO
	I2V	33	4	OK	OK	OK	OK	NO
	V2V	33	4	OK	OK	OK	OK	NO
	V2N DL	46	4	OK	OK	OK	OK	NO

From 3 to 6 GHz	V2N UL	33	18	OK	OK	OK	OK	NO
	V2I	33	8	OK	OK	OK	OK	NO
	I2V	33	4	OK	OK	OK	OK	NO
	V2V	33	4	OK	OK	OK	OK	NO

OK: LOS + NLOS distance range, bit rate and QoS, specified for the UCx can be reached

OK: Worst case distance (LOS + NLOS effects) not reached for bit rate and QoS, but better case distance (LOS) reached.

NO: Worst case distance (LOS + NLOS effects) neither better case distance (LOS), not reached for bit rate and QoS.

Table 3.7: For bands above 6 GHz the following are the results.

Frequency	Scenario	Pt (dBm)	Gr (dBi)	UC1	UC2	UC3	UC4	UC5
26 GHz	V2N DL	46	12	OK	OK	OK	OK	NO
	V2N UL	40	18	OK	OK	OK	OK	NO
	V2I	40	18	OK	OK	OK	OK	NO
	I2V	40	12	OK	OK	OK	OK	NO
	V2V	40	12	OK	OK	OK	OK	NO
63 GHz	V2N DL	46	12	OK	OK	OK	OK	NO
	V2N UL	40	18	OK	OK	OK	OK	NO
	V2I	40	18	OK	OK	OK	OK	NO
	I2V	40	12	OK	OK	OK	OK	NO
	V2V	40	12	OK	OK	OK	OK	NO

More details are provided in Annex F.

3.5 Summary of spectrum study

Our survey of spectrum for ITS applications shows a clear trend of the harmonized use of 5855 MHz to 5925 MHz for ITS applications in different regions of the world. As shown in Figure 3.3, the 5.9 GHz ITS bands allocated in Europe, the U.S., Australia, China, Korea, and Singapore are well aligned, or partially aligned with each. In Japan, besides the single ITS channel in 700 MHz band, the 5770 MHz to 5850 MHz band is also considered for exchanging road safety information using V2V/V2I communications. In the millimeter wave range, 63 GHz to 64 GHz has already been designated in Europe for ITS applications using V2X communications.

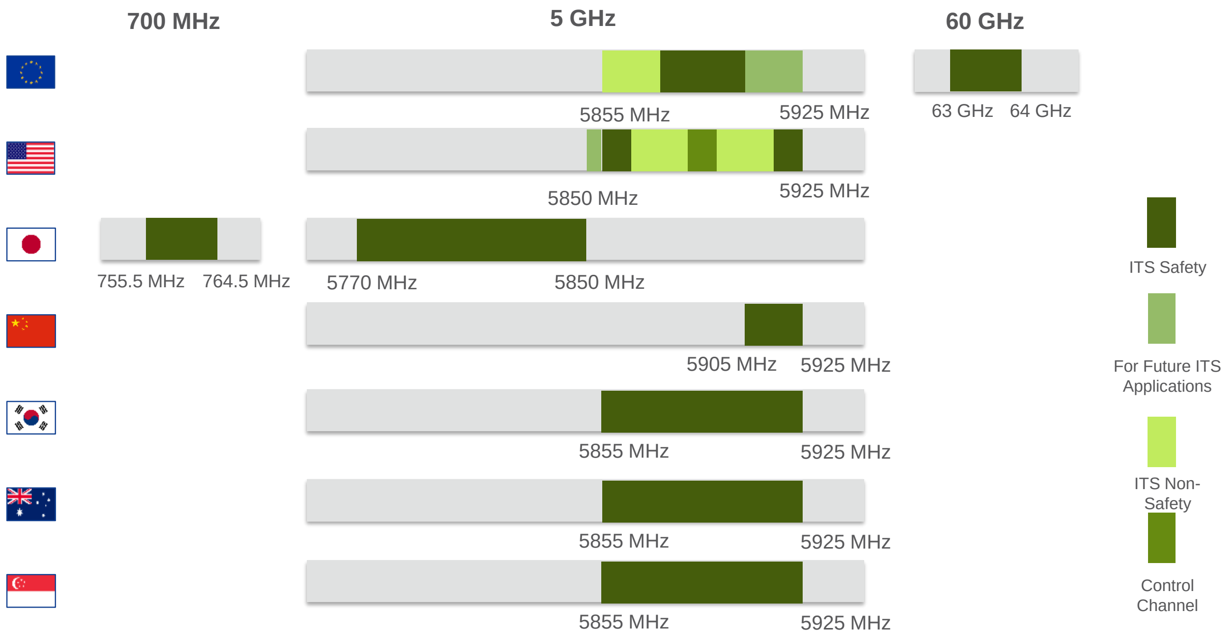

Figure 3.3: Spectrum dedicated for ITS in different world regions.

This study also reviews the IMT spectrum designated to mobile network operators. Many commercial automotive applications and ITS applications, particularly basic safety-related applications, are already supported in these bands using the 3GPP LTE Uu interface, i.e. through V2N communication. An example list of licensed LTE bands in Europe for the Uu interface is given in Table 3.8. As noted in the table, these LTE Uu bands can be used in combination with the LTE band 47, i.e. 5855 MHz – 5925 MHz for the LTE-V2X PC5 interface.

Table 3.8: Example of frequency bands for LTE Uu operation in Europe.

3GPP Band Number	Uplink (MHz)	Downlink (MHz)	Duplex Mode	Can be combined with Band 47
Band 3	1710-1785	1805-1880	FDD	Yes
Band 7	2500-2570	2620-2690	FDD	Yes
Band 8	880-915	925-960	FDD	Yes
Band 20	832-862	791-821	FDD	Yes

To fulfill the requirements of advanced 5G mobile services, including ITS and automotive applications, new 5G spectrum are being identified in different regions of the world. Examples of the frequency bands being considered for 5G in three regions and countries, EU, the U.S., and China, are presented in Figure 3.4. Since at the time this deliverable is developed identification of 5G spectrum is an on-going activity, Figure 3.4 does not provide a comprehensive overview and there are still uncertainties and matters under study in some example bands shown in this figure. These frequency bands mainly fall into three ranges: 600 MHz / 700 MHz in the low band range, 3.1-4.2 GHz and 4.4-5.0 GHz in the mid band range, as well as 26/28 GHz and 38/42 GHz in the high band range. Identifying 5G frequency bands in low, mid, and high band ranges will enable the 5G system to fulfill a wide range of requirements of applications, ranging from wide area coverage to high system capacity.

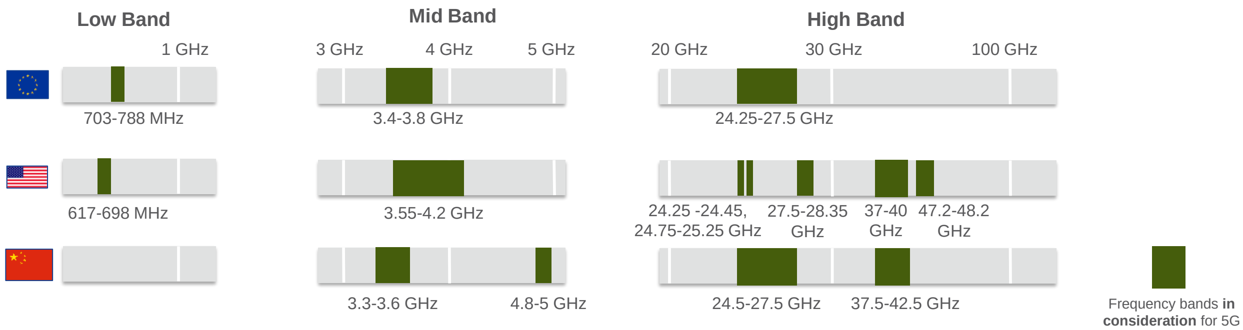

Figure 3.4: Examples of frequency bands considered for early deployment of 5G.

4 Conclusion

Based on the findings in this 5GCAR intermediate report on business models and spectrum aspects the main conclusions drawn are highlighted below:

- Basic safety applications such as e-call are likely to be regulated, to achieve approximately 100% penetration, and for that reason the telecommunication stakeholders and OEMs cannot build a business model on them. Other stakeholders may benefit from these regulation changes such as road operators or insurance companies for instance and end user.
- C-V2X compared to other technologies has defined a clear roadmap to serve basic safety features. It can provide a better spectrum usage and enabled other services beyond safety, i.e. comfort and efficiency. Moreover, thanks to the telecommunication ecosystem this can be naturally integrated into smartphones then enabling V2P communications.
- On top of meeting a set of requirements needed for V2X, e.g. low latency, availability and high reliability, there is still work to be done related to the cross-MNOs, cross-OEMs or cross-border communication aspects. These elements have high importance and shall be studied in the coming 3GPP releases.
- V2X as a social benefit, everybody needs to contribute to the deployment of these new services while high prices for frequency band allocation may become a penalty for V2X deployment. Cost-free renewal of the concession of current licensed bands with specific conditions applied to V2X could also be an option. According to the use cases analyzed in the 5GCAR, the better spectrum bands are medium or low frequencies with lower propagation loss and better coverage. Coverage has precedence over bandwidth for V2X use cases so far.
- A number of ways are identified to improve coverage expansion as fast as possible, e.g.
    - by contributing to roll out of the infrastructure deployment, facilitating it by proper regulations,
    - by the prioritizing the network deployment for highways or main roads where more advanced V2X use cases are anticipated in the initial phase and benefits are expected to be higher,
    - by introducing scenario specific feature like for rural areas where a huge effort is required to provide full coverage there we could aim for very basic day-1 type features using unlicensed spectrum and ad-hoc mode.
- There are some technical components which may disrupt the current business model definition, such as network slicing and MEC.
- On the other side, comfort driving features enabled and boosted (improved) by connectivity may become a brand difference and there is then a possibility for new business models.
- New services arriving thanks to the arrival of 5G (some examples were given in Section 2).

The value chain of automotive and connectivity will strongly evolve becoming more complex and less linear than what we have so far. Over the Top stake holders may arise in this new setting.

The spectrum regulation for the 5.9 GHz ITS band in Europe is technology neutral, and by the time this deliverable is developed CEPT is studying the coexistence solution for ETSI ITS-G5 and 3GPP C-V2X PC5. These two radio technologies support identical ITS applications in the same 5.9 GHz band, but they cannot directly communicate with each other at the radio layer. The uncertainty in spectrum usage remains, unless coexistence of multiple radio technologies in the same frequency band and interoperability among them are resolved, particularly for the safety-related ITS applications. This uncertainty in spectrum usage has also impacts that may slow down the market roll-out and business development of V2X technologies.

From a regulatory point of view, spectrum allocation should be technology neutral. This applies both to unlicensed spectrum, as for the EU 5.9 GHz ITS band discussed above, and to licensed spectrum. It is observed that the newly developed 5G NR technology in 3GPP release 15 plans to re-uses the IMT bands currently being used by the 4G LTE technology.

High reliability and availability of V2X communications are clear demands from the automotive industry for satisfying the functional safety requirements of safety-related applications including connected autonomous driving. Using redundant transmissions in distantly separated bands in the frequency domain is one way to achieve this, which is also supported by the findings of this study. Many spectrum bands, including both licensed and unlicensed bands, have been identified suitable for V2X communications. It must be emphasized that the usage of licensed spectrum is up to the licensees, i.e. the MNOs, who need justified business models to make appropriate decision.

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A Overview of technological components

This Annex contains an overview of the identified technological components and a high-level analysis of those. 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.

Table A.1: Network densification.

Technology	Network Densification
Description	ITS could raise some problems over spectrum occupancy for some use cases requiring for instance high throughput (see through), or wireless connected cameras (RSU) delivering video, dedicated entertainment services. Furthermore, ITS domain could raise some scalability problems in case of high density of vehicles in some areas. Densification of network could be an answer: in that case small cells would be deployed for vehicular domain. Another point is the high availability needs requiring on hierarchy of cells in the same area (wide range cells with low frequency-700, and MIMO for medium frequencies,…, small range cells with medium and high frequencies). And last point is the coverage of hidden area like tunnels in which dedicated/specific antennas will have to be deployed *Possible use of high frequencies (3,6 GHZ, 26 GHZ) will oblige to build smaller cells due to worse propagation conditions than 700 Mhz. *Massive MIMO could be used for downlink, as well as adapted antenna (MIMO like?) at car side *Concept of smart zone has been introduced using RSU to improve V2V communication: RSU could behave as a specific UE or as an eNB
Disruption	E
Value Provided	Densification of network will be costly for operators: economic viability of Vehicular services could be impacted. Synergies with others services should be search, partners for deployments (road operators, cities),

Requirements / Challenges	Finding right balance between requirement level and cost, finding the right economical model for deployments, …

Table A.2: Network slicing.

Technology	**Network Slicing**
Description	Network slicing consists in enabling the provision of different SLAs over a common infrastructure. These “slices” can be used for a single operator, and/or can be shared among different operators for different services. From the moment that the network hardware is operated from software, the concept of virtualizing functions (Network Function Virtualization) enables the possibility to have “various simultaneous and different instances of a communication network” running on top of a common infrastructure.
Disruption	R
Value Provided	Dramatic reduction of deployed infrastructure. Reuse of deployed infrastructure. Extremely high flexibility to deploy and operate services. Reduced time to market for new services. Possible existence of neutral hosts, providing infrastructure and being agnostic from the running software.
Requirements / Challenges	Capability to ensure QoS per slice so that SLA can be put into place. Need for agreements among MNO (mobile network operators) sharing infrastructure. New spectrum allocation schemes are needed if new sharing models are introduced into the network deployment.

Table A.3: Mobile edge computing (MEC).

Technology	**Mobile Edge Computing (MEC)**
Description	MEC consists of installing and operating computing capabilities closer to the final user of a radio communication technology. The key concept is to deploy a network with computing capabilities close to the communication edge of the network infrastructure, understood as the closest element possible to the user right after the radio access.

Disruption	R
Value Provided	Possibility to implement the concept of Cloud RAN, decoupling the radio fronthaul from the radio backhaul. This means that the baseband processing (BBP) can be executed on a computer device installed at the edge of the network, but not at the precise site where the radio infrastructure is mounted. This can reduce both OPEX and CAPEX for the deployment of new sites, as well as reduce the cost of upgrading the network infrastructure. Having computing capabilities closer to the user reduces latency, improves reliability, and off-loads the core and transport networks.
Requirements / Challenges	Centralizing all intelligence and processing capabilities can create bottle necks and single points of failure. Need for efficient management of a more fragmented infrastructure. Need for a greater number of deployment sites, increasing cost of deployment and facing social resistance to the presence of electronic equipment close to inhabited areas.

Table A.4: Cellular radio based positioning and tracking.

Technology	**Cellular radio based positioning and tracking**
Description	Positioning of road users with 5G radio technologies can provide better performance than LTE and complement existing solution based on for example GNSS because of a number of unique benefits: high carrier frequencies (enabling narrow beam, potentially enhanced ToA estimation with reduced CP length etc.), large bandwidths, possibility for sidelink communication, and large antenna arrays. The key concept for cellular radio based positioning is taking SoA TDoA based positioning as the starting point and extend it with channel bias compensation, tracking and map matching to predict the trajectories of the users., Beam based positioning can further improve the accuracy.
Disruption	E
Value Provided	Accurate and real-time knowledge of the position of a VUE or a regular user is a crucial requirement for enabling many V2X use cases and related business as well. With the help of accurate positioning, improved road user protection can be achieved by delivering the early notification about the positioning information in case of a critical situation to the vehicle in case of autonomous driving or to the driver.

	Targeted local HD map can be dynamically delivered to the VUE for autonomous driving.
Requirements / Challenges	Accurate TDoA estimation, availability of good motion models for the tracking, and high mobility.

Table A.5: Sidelink.

Technology	**Sidelink**
Description	Sidelink appears as a complementary link to operator cellular network. Sidelink is dedicated to support short range communications of ITS domain. It could be operated on unlicensed spectrum dedicated to ITS, as well as licensed spectrum. 5Gcar is willing to use it as a specific component of architecture to address multi RAT multi-link and globally improve the communication link reliability. Sidelink could be controlled/assisted or not by the cellular network. Sidelink could be used in V2V mode, as well as V2I mode (I is in that case an RSU for instance). Use of licensed free spectrum for ITS domain : approx 5.9 GHZ, 63 GHZ.
Disruption	R
Value Provided	Multiple benefits brought by using SL: Offload of cellular network deducing global cost of ITS architecture, Deployment of local value added services using local, short range connectivity: toll, etc… Better reliability and capacity would be offered by using infrastructure + SL to serve vehicular applications Throughput could be important (tens of Mbps) allowing transferring data in an alternative way than cellular network when conditions match New actors : road operator would play a role in deploying sidelink
Requirements / Challenges	Service continuity and increased reliability in multi links configurations (tackle by 5Gcar). Problem of propagation when using millimeter waves, and not well placed antennas (elevation,…) which will impact availability of service if only based upon sidelink.

Table A.6: Integrated moving networks.

Technology	**Integrated Moving Networks**

Description	This concept consists in enabling moving vehicles to act as temporary and nomadic infrastructure for the communication network. These nodes are not deployed by any operator and enable relaying of data between mobile terminals and with base stations. These nodes could be, for example, cars belonging to a car-sharing fleet, or even privately-owned cars.
Disruption	E
Value Provided	The use of nomadic nodes can bring effective extension of the cellular coverage. This technology component would allow for a dynamic network deployment, thus reducing the need for network planning and fixed deployment. The possibility to have a moving "base station", facilitates the provision of on-demand services, increasing the network capacity or to extend the cell coverage area. Letting the infrastructure get closer to the final user, leads to a reduction of overall network energy consumption, both from the perspective of the infrastructure and the perspective of the devices.
Requirements / Challenges	Need for ultra-reliable V2X links, so that SLAs can be put into place. It is necessary to dynamically manage spectrum access. Security concerns when communications happen between devices. Need to monitor the use of sidelink for billing purposes.

B EcosysVisual tool

When discussing business relationships as part of business model research, a recurrent challenge is how to represent the interaction and evolution of business ecosystems. Ericsson has provided an internal research tool for the project discussion on business models. This tool allows the generation of dynamic visual representations of business relationships. The GUI is presented below, highlighting the main components of the tool.

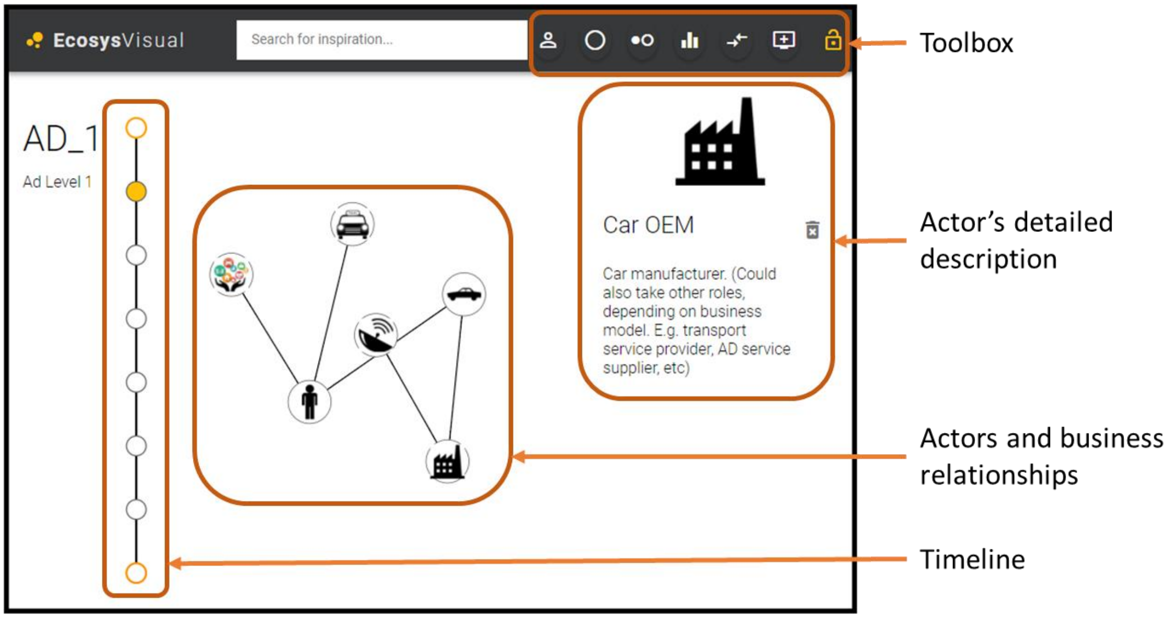


Figure B.1: EcosysVisual tool.

As anecdotal information, we highlight the positive feedback gathered by the users of the tool. It has a learning curve and it is still on a development stage, but it proved beneficial to share ideas around the cases considered in the study and it greatly facilitated online sharing and contributions.

C IMT and 3GPP E-UTRA frequency bands

Table C.1 provides the IMT bands identified by ITU-R. It has to be noted that this identification does not preclude the use of these bands by any application of the services to which they are allocated or identified and does not establish priority in the Radio Regulations, and different regulatory provisions apply to each band, as described in the different footnotes applying in each band. Also, administrations may deploy IMT systems in bands allocated to the mobile service other than those identified in the ITU Radio Regulations (RR), and administrations may deploy IMT systems only in some or parts of the bands identified for IMT in the RR.

Table C.1: Frequency bands identified for IMT systems in ITU Radio Regulations [ITU-RR-2016][1].

Band (MHz)	Notes
450-470	Identified for IMT in ITU Region 1[2], Region 2[1], and Region 3[1]
470-698	Identified for IMT in ITU Region 2[3] and Region 3[4]
694/698-960	Identified for IMT in ITU Region 1[5], Region 2[4], and Region 3[4,6]
1 427-1 518	Identified for IMT in ITU Region 1[7] , Region 2[8], and Region 3[9]
1 710-2 025	Identified for IMT in ITU Region 1[10,11], Region 2[9,10], and Region 3[9,10]
2 110-2 200	Identified for IMT in ITU Region 1[10], Region 2[10], and Region 3[10]
2 300-2 400	Identified for IMT in ITU Region 1[9], Region 2[9], and Region 3[9]
2 500-2 690	Identified for IMT in ITU Region 1[9], Region 2[9], and Region 3[9]
3 300-3 400	Identified for IMT in ITU Region 1[12], Region 2[13], and Region 3[14]

[1] This table is from the working draft document of M.1036
[2] See footnote 5.286AA in ITU Radio Regulations [ITU-RR-2016]
[3] See footnote 5.295 and 5.308A in ITU Radio Regulations [ITU-RR-2016]
[4] See footnote 5.296A in ITU Radio Regulations [ITU-RR-2016]
[5] See footnote 5.317A in ITU Radio Regulations [ITU-RR-2016]
[6] See footnote 5.313A in ITU Radio Regulations [ITU-RR-2016]
[7] See footnote 5.341A and 5.346 in ITU Radio Regulations [ITU-RR-2016]
[8] See footnote 5.341B in ITU Radio Regulations [ITU-RR-2016]
[9] See footnote 5.341C and 5.346A in ITU Radio Regulations [ITU-RR-2016]
[10] See footnote 5.384A in ITU Radio Regulations [ITU-RR-2016]
[11] See footnote 5.388 in ITU Radio Regulations [ITU-RR-2016]
[12] See footnote 5.429B in ITU Radio Regulations [ITU-RR-2016]
[13] See footnote 5.429D in ITU Radio Regulations [ITU-RR-2016]
[14] See footnote 5.429F in ITU Radio Regulations [ITU-RR-2016]

Band (MHz)	Notes
3 400-3 600	Identified for IMT in ITU Region 1[15], Region 2[16], and Region 3[17]
3 600-3 700	Identified for IMT in ITU Region 2[18]
4 800-4 990	Identified for IMT in ITU Region 2[19] and Region 3[20]

Note:

- ITU Region 1 comprises Europe, Africa, the former Soviet Union (FSU), Mongolia, and the Middle East west of the Persian Gulf, including Iraq;
- ITU Region 2 comprises the Americas including Greenland, and some of the eastern Pacific Islands;
- ITU Region 3 comprises most of non-FSU Asia east of and including Iran, and most of Oceania.
- The allocation of the frequency bands or part of the bands in Table 1 may vary in different regions. Please refer to the footnotes (in turn referring to ITU RR) in the Notes field of Table 1 for details.

E-UTRA is designed to operate in the operating bands defined in 3GPP TS 36.104: "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception". The E-UTRA frequency bands are presented in Table C.2.

[15] See footnote 5.430A in ITU Radio Regulations [ITU-RR-2016]
[16] See footnote 5.431B in ITU Radio Regulations [ITU-RR-2016]
[17] See footnote 5.432A, 5.432B, and 5.433A in ITU Radio Regulations [ITU-RR-2016]
[18] See footnote 5.434 in ITU Radio Regulations [ITU-RR-2016]
[19] See footnote 5.441A in ITU Radio Regulations [ITU-RR-2016]
[20] See footnote 5.441B in ITU Radio Regulations [ITU-RR-2016]

Table C.2: E-UTRA frequency bands.

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz	FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
6	830 MHz – 840 MHz	875 MHz – 885 MHz	FDD
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
9	1749.9 MHz – 1784.9 MHz	1844.9 MHz – 1879.9 MHz	FDD
10	1710 MHz – 1770 MHz	2110 MHz – 2170 MHz	FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
17	704 MHz – 716 MHz	734 MHz – 746 MHz	FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz	FDD
22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz	FDD
23[1]	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
27	807 MHz – 824 MHz	852 MHz – 869 MHz	FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
29	N/A	717 MHz – 728 MHz	FDD
30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz	FDD
32	N/A	1452 MHz – 1496 MHz	FDD
33	1900 MHz – 1920 MHz	1900 MHz – 1920 MHz	TDD
34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz	TDD
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz	TDD
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz	TDD
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz	TDD
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz	TDD
44	703 MHz – 803 MHz	703 MHz – 803 MHz	TDD
45	1447 MHz – 1467 MHz	1447 MHz – 1467 MHz	TDD
46	5150 MHz – 5925 MHz	5150 MHz – 5925 MHz	TDD
47	5855 MHz – 5925 MHz	5855 MHz – 5925 MHz	TDD
48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
50	1432 MHz - 1517 MHz	1432 MHz - 1517 MHz	TDD
51	1427 MHz - 1432 MHz	1427 MHz - 1432 MHz	TDD
65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
67	N/A	738 MHz – 758 MHz	FDD
68	698 MHz – 728 MHz	753 MHz – 783 MHz	FDD
69	N/A	2570 MHz – 2620 MHz	FDD
70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
72	451 MHz – 456 MHz	461 MHz – 466 MHz	FDD
74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
75	N/A	1432 MHz – 1517 MHz	FDD
76	N/A	1427 MHz – 1432 MHz	FDD

For 3G UTRA FDD, the operating frequency bands are shown in Table C.3 (from TS25.104: "Base Station (BS) radio transmission and reception (FDD)").

Table C.3: UTRA FDD frequency bands.

Operating Band	UL Frequencies UE transmit, Node B receive	DL frequencies UE receive, Node B transmit
I	1920 - 1980 MHz	2110 -2170 MHz
II	1850 -1910 MHz	1930 -1990 MHz
III	1710-1785 MHz	1805-1880 MHz
IV	1710-1755 MHz	2110-2155 MHz
V	824 - 849MHz	869-894MHz
VI	830-840 MHz	875-885 MHz
VII	2500 - 2570 MHz	2620 - 2690 MHz
VIII	880 - 915 MHz	925 - 960 MHz
IX	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz
X	1710-1770 MHz	2110-2170 MHz
XI	1427.9 - 1447.9 MHz	1475.9 - 1495.9 MHz
XII	699 - 716 MHz	729 - 746 MHz
XIII	777 - 787 MHz	746 - 756 MHz
XIV	788 - 798 MHz	758 - 768 MHz
XIX	830 – 845 MHz	875 -890 MHz
XX	832 - 862 MHz	791 - 821 MHz
XXI	1447.9 - 1462.9 MHz	1495.9 - 1510.9 MHz
XXII	3410 – 3490 MHz	3510 – 3590 MHz
XXV	1850 -1915 MHz	1930 -1995 MHz
XXVI	814-849 MHz	859-894 MHz
XXXII (NOTE 1)	N/A	1452 – 1496 MHz

Table C.4 and Table C.5 are the 3GPP NR operating bands define in [3GPP17-38101].

Table C.4: 3GPP NR operating bands in frequency range 450 MHz – 6000 MHz [3GPP17-38101].

NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL

Table C.5: 3GPP NR operating bands in frequency range 24250 MHz – 52600 MHz [3GPP17-38101].

NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD

D Related work on identifying 5G spectrum

Various efforts around the world are in progress to find harmonization of spectrum to be used for 5G, among them “5G Spectrum Recommendations” [5GAm17], “5G Spectrum Considerations” [5GForum], “Deliverable D3.1 5G spectrum scenarios, requirements and technical aspects for bands above 6 GHz” [METIS-II] and “V2X Cellular solutions” [5GAm16].

The 5G services expected to cover wide range of applications are generally categorized into eMBB, URLLC and mMTC [ITU-R_M.2083-0].

A wide variety of deployment scenarios will be driven by the applications [5GAm17] and, as different frequency bands have different propagations characteristics, some applications are more suitable in certain frequency ranges. There are roughly 3 frequency ranges (based on the different propagation characteristics): low range up to 3GHz (good coverage/limited capacity), mid-range 3 GHz to 6 GHz (urban deployment/increased capacity) and high range above 6GHz (limited coverage/high capacity). A single frequency band cannot meet every planned 5G use case. There are different factors affecting the spectrum needs of 5G applications i.e. peak data rate, spectral efficiency, user experienced data rate and device density. In addition, there are some factors that directly or indirectly impact spectrum needs as usage scenarios, coverage area, deployment environment and target application.

To develop a methodology for 5G spectrum requirement estimation and calculation, mmWave propagation characteristics (in the band 24.25-86GHz) and channel modeling studies have been conducted [5GForum] for the future development of IMT2020 and beyond by analyzing traffic attributes of typical 5G services. Actual used methodology follows technology-neutral approach and takes into account market, technology and deployment-related information. There is a possible new application-based methodology to estimate IMT-2020 (5G) spectrum requirement by determining individual application spectrum requirement and then combining the set of individual spectrum requirements together into a total spectrum requirement estimate. IMT-2020 is envisaged to expand and support diverse usage scenarios and applications which will bring furthermore capabilities. Peak data rate, user experienced data rate, spectrum efficiency, mobility, latency, connection density, network energy efficiency and area traffic capacity are the eight parameters that are considered as 5G key capabilities.

E Details of European 5.9 GHz ITS band

E.1 Services and use cases supported in EU 5.9 GHz ITS band

According to [ECCDEC0801], the frequency band 5875-5925MHz is designated for the ITS services using Inter-Vehicle Communication (IVC) and Infrastructure to Vehicle (I2V) Communication. Especially, this frequency band is to enable time critical traffic safety applications where fast information exchange is necessary to warn and support the driver without delay.

E.2 European harmonized standard EN 302 571

ETSI EN 302 571 is the harmonized European standard developed by ETSI TC ERM TG37 for the European ITS frequency band 5855-5925 MHz under the EC Radio Equipment Directive (RED) 2014/53/EU. EN 302 571 specifies technical requirements and methods of measurement, which cover the essential requirements of article 3.2 of RED 2014/53/EU, for radio transmitters and receivers operating in this band. The technical requirements and methods of measurement in EN 302 571 are neutral for radio access technologies. Any ITS radio technology can use the 5.9 GHz ITS band, as far as it complies with the technical requirements specified in EN 302 571. The latest release of the EN 302 571 is V2.1.1 that has been published in Feb. 2017. In June 2017, EN 302 571 V2.1.1 was cited in the Official Journal of European Union and started to be in force under the RED 2014/53/EU.

Figure 3.1 shows the channelization of European 5 GHz ITS band defined in EN 302 571 V2.1.1, where the overall 70 MHz ITS frequency band is divided into seven 10 MHz channels. For all ITS channels at 5 GHz, the maximum RF output power is 33 dBm e.i.r.p and the maximum power spectral density is 23 dBm/MHz e.i.r.p. [ETSI17_EN302571].

E.3 Compatibility and coexistence of ITS with other systems in EU 5.9 GHz ITS band

CEPT has performed the compatibility studies on the compatibility and interference of ITS systems with other radio systems in the same band or in adjacent bands. The study results are captured in reports [ECCREP101], [ECCREP228], [ECCREP109], and [ECCREP110]. These reports have been considered in the development of the European Harmonized Standard (HS) EN 302 571 for the 5855-5925 MHz ITS band. As a result, the compliance with EN 302 571 ensures the access of ITS systems in this band, as well as coexistence with other radio systems in the same band and in adjacent bands, e.g. the CEN DSRC system at 5795-5815 MHz for the road tolling application.

On coexistence of Radio LAN (RLAN) and ITS systems in 5 GHz spectrum, CEPT has requested ETSI BRAN a clarification on what mitigation technology RLAN systems intend to employ to protect other systems that operate in the 5 725 MHz to 5 925 MHz band and in adjacent bands. In response to this request from CEPT, ETSI BRAN performed the study of "Mitigation techniques to enable sharing between RLANs and Road Tolling and Intelligent Transport Systems in the 5 725 MHz to 5 925 MHz band" [ETSI_TR_103319]. Various mitigation techniques for RLAN to protect the ITS services in 5855 MHz to 5925 MHz have been investigated in this study, such as "Detect & Mitigate" and "Detect & Vacate". However, as concluded by CEPT based on the study in ETSI TR 103 319 [ETSI_TR_103319], none of the presented mitigation techniques alone is sufficient to protect ITS from WAS/RLAN and needs further investigation.

According to the statement from NATO, "the frequency band 5850-5925 MHz is not a NATO harmonized frequency band. It is however used by some NATO nations for dedicated military applications in the fixed, fixed satellite, radiolocation, and mobile services in support of NATO military operations. While current regulation for ITS and WAS/RLAN type applications in 5 850 - 5 925 MHz is without prejudice to military systems used in this frequency band, it is essential, from a military perspective, that any evolution of the regulation allows the continuation of the operation for military systems in-band and ensure the protection of the NATO harmonized band for radiolocation applications below 5850 MHz." [CEPT18_ AI1-12].

E.4 Recent development of EU 5.9 GHz ITS band

On Oct. 27, 2017, CEPT ECC received the mandate [EC17-MAN-5_9GHZ] from Radio Spectrum Committee (RSCom) of the European Commission to study the extension of the Intelligent Transport Systems safety-related band at 5.9GHz. The mandate asked CEPT to:

1. *Study the possibility to extend the 5 875-5 905 MHz frequency band to the range 5 875-5 925 MHz for use by safety-related road and rail ITS systems under harmonised technical conditions including sharing conditions. In this context, study measures which allow coexistence of LTE-V2X and Urban Rail ITS (such as technologies for CBTC already in operation in the 5 905-5 925 MHz frequency band) with existing ETSI ITS-G5 within the 5 875-5 925 MHz frequency band.*
2. *In relation to Task 1, assess the suitability of the existing harmonised technical conditions applicable to the 5 875-5 905 MHz frequency band for use by Urban Rail ITS (such as technologies for CBTC); amend these conditions, if necessary, so as to develop consistent technical, including sharing, conditions for the whole 5 875-5 925 MHz frequency band. This should not result in segmentation and segregation of the band. The principle of equal access to shared spectrum shall be applied taking into account the need to avoid harmful interference and the need for reliable safety-related operation in the whole band.*

Upon receiving the mandate, the Working Group Frequency Management (WG FM) of CEPT ECC started the work in Short Range Devices Maintenance Group (SDR/MG) in close cooperation with ETSI (TC RC and TC ITS). The outcome of this mandated study may result in a revision of the ECC Decision (08)01 and ECC Recommendation (08)01 to extend the 5 875-5 905 MHz band to 5 875 – 5 925 MHz and allowing both Urban Rail CBTC and road ITS system to share this frequency band. ETSI ITS-G5, LTE-V2X, and Communication systems for Urban Rail CBTC are foreseen to coexist in this band. This study is expected to be ready for EC in November 2018 (with an intermediate report scheduled in March 2018).

F Suitability analysis of V2X spectrum for 5GCAR use cases

The KPI of 5GCAR use cases has been defined in D2.1 [5GCAR-D21] and are resumed in Table F.1.

Table F.1: The KPIs (and their requirements) of the 5GCAR use cases.

	UC1: Lane merge	UC2: See-through	UC3: Vulnerable	UC4: HD Map	UC5: Remote driv.
Communication range	> 350 m	50 to 100 m	> 70 m	> 1000 m	Several kms
Max Data rate	6.4 Mbps	29 Mbps	0.128 Mbps	1.92 Mbps	29 Mbps
Reliability	99,9%	99%	99.99%	99.99%	99.999%
Bit Error Rate	10-6	10-5	10-7	10-7	10-8
Modulation scheme	QPSK 3/4	64QAM 3/4	QPSK 1/2	QPSK 1/2	64QAM 3/4
Sensitivity + S.N.R	-82dBm	-67dBm	-85dBm	-85dBm	-64dBm

The use cases (UC1, UC2, UC3, UC4 and UC5) can be served by Downlink, Uplink or Sidelink communications, using basically the different licensed and unlicensed frequency bands, below 6 GHz, which could be candidate are described in Section 3.3.

These bands can be compared, in term of range coverture, taking in account the maximum emitted power, the propagation conditions and the minimum sensitivity for different data rates and their associated modulation scheme (see Line 5 of Table F.1).

Reliability of communication is related with the Bit Error Rate (BER). A reliability of 99% corresponds with a Packet Error Rate of 1/1000 and consequently a Bit Error Rate of 10^{-6} if we consider 1000 bits/packet (see Line 4 of Table F.1). Required minimum sensitivity will depends on a SNR (signal to noise ratio), related with QoS and modulation schemes. Basically, a minimum sensitivity of -90 dBm + SNR is considered for each Use Case and reported in line 6 of Table F.1. The minimum SNR is extracted from Figure F.2.

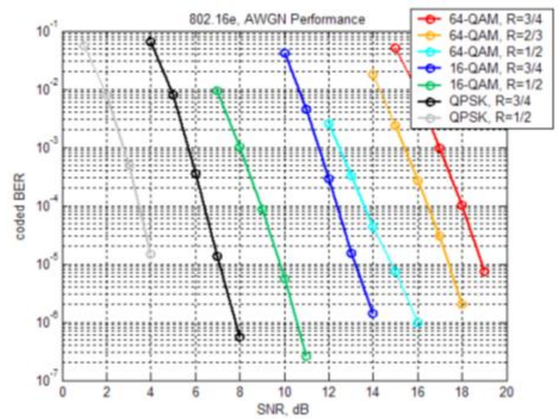


Figure F.2: Bit error rate and SNR relation.

The propagation conditions will depend basically on the implementation heights (Ht and Hr) of respectively transmitting and receiving antennas above the ground. The following propagation model can be used to estimate the receiving range, in a typical inter-urban scenario (motorways, rural roads) where multipath are due essentially to the ground reflection effects by the road.

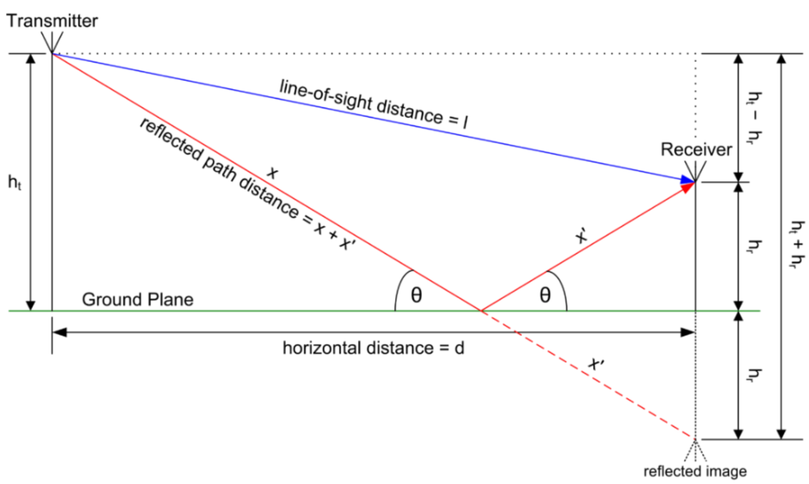


Figure F.3: LOS and NLOS paths from transmitter to receiver.

Wave reflected on the ground (Non Line of Sight: NLOS), combined with direct propagation (Line of Sight: LOS) can induce fading effects on the receiving antenna. The received power Pr mixing LOS and NLOS contributions can be represented by the following equations:

$$Pr = Pt * Gr * \frac{\lambda^2}{(4\pi D)^2} * 4[sin((2\pi * Ht * Hr)/(\lambda * D))\,]^2 \qquad \text{(Equ1)}$$

when $D^2 \gg (2\pi * Ht * Hr)/\lambda$, then (Equ1) can be transformed into

$$Pr = Pt * Gr * (Ht * Hr)^2 / D^4 \qquad \text{(Equ2)}$$

with

Pt: *Transmitted EIR power,*

Gr: *Receiving antenna gain,*

λ: *Wave length,*

D: *Distance between transmitter and receiver.*

We can observe that when $D^2 \gg (2\pi * Ht * Hr)/\lambda$, Pr/Pt does not depend on frequency.

Suitability analysis of V2X spectrum below 6 GHz for 5GCAR use cases

For frequencies below 6 GHz, we will consider the conditions that are provided in Table F.2.

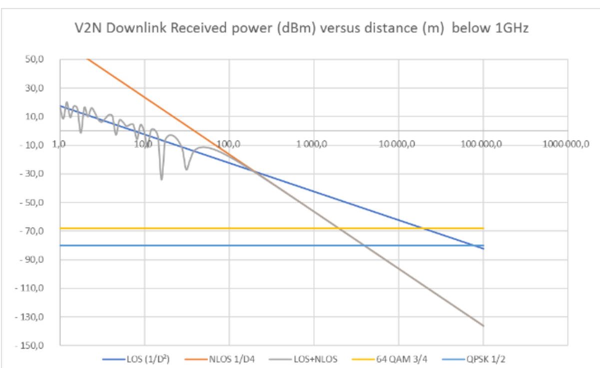
Table F.2: The considered conditions for frequencies below 6 GHz.

	Height (m)	Pt: EIRP (dBm)	Gr: Rec. gain (dBbi)
eNB antenna	20	46	18
RSU antenna	5	33	8
Vehicle antenna	1.5	33	4

The emitted power (EIRP) from the vehicle (uplink or sidelink), can be considered to have a nominal value of + 33 dBm, with a typical omnidirectional antenna gain of 4 dBi. Such antenna system can be integrated on the roof of vehicle, in a so called “Smart-Antenna”. Depending on roof shape, a perfect omnidirectional transmitting and receiving diagram is not easily fulfilled.

Concerning RSUs, the emitted power (EIRP) from the vehicle (uplink or sidelink), can be considered to have also a nominal value of + 33 dBm, with a typical omnidirectional antenna gain of 8 dBi.

To illustrate this propagation model, the V2N downlink communication, for 1 GHz, and 6 GHz, for a transmitted power (EIRP) of +46 dBm, and a receiving antenna gain of 4 dBi, gives the results presented in Figure F.4.



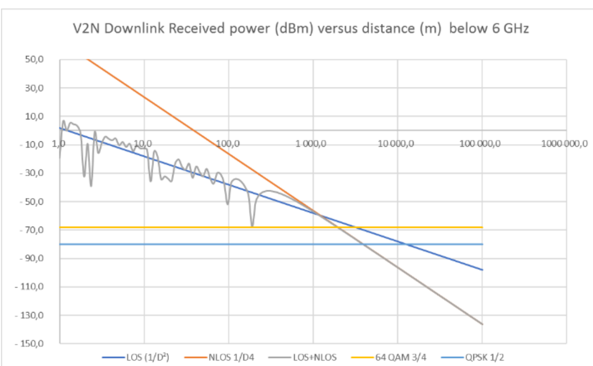


Figure F.4: Received power from 1 GHz to 6 GHz for a V2N downlink.

In Figure F.3, the blue curve represents the LOS attenuation versus distance, the grey curve represents the LOS + NLOS attenuation and the red curve represents the $1/D^4$ part (Equ2) of propagation model. We can see that the 1/D4 attenuation slope is always limiting the maximum V2N distance for standard sensitivity levels (e.g. -68 dBm and -80 dBm). This effect is due to the relative low height of vehicle's antenna (1.5 m). These attenuation effects, as the simulations results presented below, increase dramatically in the V2V context.

Table F.3: Complete results for 5GCAR UC1.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	350
V2N DL	1	20	1,5	46	4	-82	4 360	OK
V2N UL	1	1,5	20	33	18	-82	4 618	OK
V2I	1	1,5	5	33	8	-82	1 298	OK
I2V	1	5	1,5	33	4	-82	1 031	OK
V2V	1	1,5	1,5	33	4	-82	565	OK
V2N DL	3	20	1,5	46	4	-82	4 360	OK
V2N UL	3	1,5	20	33	18	-82	4 618	OK
V2I	3	1,5	5	33	8	-82	1 298	OK
I2V	3	5	1,5	33	4	-82	1 031	OK
V2V	3	1,5	1,5	33	4	-82	565	OK
V2N DL	6	20	1,5	46	4	-82	4 360	OK
V2N UL	6	1,5	20	33	18	-82	4 618	OK
V2I	6	1,5	5	33	8	-82	1 298	OK
I2V	6	5	1,5	33	4	-82	1 031	OK
V2V	6	1,5	1,5	33	4	-82	565	OK

The maximum usable distance (< 350 m), for every kind of V2X communications below 6 GHz is ensured with respect with the specified KPI.

Table F.4: Complete results for 5GCAR UC2.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	100
V2N DL	1	20	1,5	46	4	-67	1 839	OK
V2N UL	1	1,5	20	33	18	-67	1 947	OK
V2I	1	1,5	5	33	8	-67	548	OK
I2V	1	5	1,5	33	4	-67	435	OK
V2V	1	1,5	1,5	33	4	-67	238	OK
V2N DL	3	20	1,5	46	4	-67	1 839	OK
V2N UL	3	1,5	20	33	18	-67	1 947	OK
V2I	3	1,5	5	33	8	-67	548	OK
I2V	3	5	1,5	33	4	-67	435	OK
V2V	3	1,5	1,5	33	4	-67	238	OK
V2N DL	6	20	1,5	46	4	-67	1 584	OK
V2N UL	6	1,5	20	33	18	-67	1 777	OK
V2I	6	1,5	5	33	8	-67	548	OK
I2V	6	5	1,5	33	4	-67	355	OK
V2V	6	1,5	1,5	33	4	-67	238	OK

The maximum usable distance (< 100 m), for every kind of V2X communications below 6 GHz is ensured with respect with the specified KPI.

Table F.5: Complete results for 5GCAR UC3.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	70
V2N DL	1	20	1,5	46	4	-85	5 182	OK
V2N UL	1	1,5	20	33	18	-85	5 489	OK
V2I	1	1,5	5	33	8	-85	1 543	OK
I2V	1	5	1,5	33	4	-85	1 226	OK
V2V	1	1,5	1,5	33	4	-85	671	OK
V2N DL	3	20	1,5	46	4	-85	5 182	OK
V2N UL	3	1,5	20	33	18	-85	5 489	OK
V2I	3	1,5	5	33	8	-85	1 543	OK
I2V	3	5	1,5	33	4	-85	1 226	OK
V2V	3	1,5	1,5	33	4	-85	671	OK
V2N DL	6	20	1,5	46	4	-85	5 182	OK
V2N UL	6	1,5	20	33	18	-85	5 489	OK
V2I	6	1,5	5	33	8	-85	1 543	OK
I2V	6	5	1,5	33	4	-85	1 226	OK
V2V	6	1,5	1,5	33	4	-85	671	OK

The maximum usable distance (< 70 m), for every kind of V2X communications below 6 GHz is ensured with respect with the specified KPI.

Table F.6: Complete results for 5GCAR UC4.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	1000
V2N DL	1	20	1,5	46	4	-85	5 182	OK
V2N UL	1	1,5	20	33	18	-85	5 489	OK
V2I	1	1,5	5	33	8	-85	1 543	OK
I2V	1	5	1,5	33	4	-85	1 226	OK
V2V	1	1,5	1,5	33	4	-85	671	NO
V2N DL	3	20	1,5	46	4	-85	5 182	OK
V2N UL	3	1,5	20	33	18	-85	5 489	OK
V2I	3	1,5	5	33	8	-85	1 543	OK
I2V	3	5	1,5	33	4	-85	1 226	OK
V2V	3	1,5	1,5	33	4	-85	671	NO
V2N DL	6	20	1,5	46	4	-85	5 182	OK
V2N UL	6	1,5	20	33	18	-85	5 489	OK
V2I	6	1,5	5	33	8	-85	1 543	OK
I2V	6	5	1,5	33	4	-85	1 226	OK
V2V	6	1,5	1,5	33	4	-85	671	NO

The maximum usable distance (< 1000 m), for V2V communications below 6 GHz is not ensured with respect to the specified KPI.

Table F.7: Complete results for 5GCAR UC5.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	3000
V2N DL	1	20	1,5	46	4	-64	1 547	NO
V2N UL	1	1,5	20	33	18	-64	1 639	NO
V2I	1	1,5	5	33	8	-64	461	NO
I2V	1	5	1,5	33	4	-64	366	NO
V2V	1	1,5	1,5	33	4	-64	200	NO
V2N DL	3	20	1,5	46	4	-64	1 547	NO
V2N UL	3	1,5	20	33	18	-64	1 639	NO
V2I	3	1,5	5	33	8	-64	461	NO
I2V	3	5	1,5	33	4	-64	366	NO
V2V	3	1,5	1,5	33	4	-64	200	NO
V2N DL	6	20	1,5	46	4	-64	1 121	NO
V2N UL	6	1,5	20	33	18	-64	1 258	NO
V2I	6	1,5	5	33	8	-64	398	NO
I2V	6	5	1,5	33	4	-64	251	NO
V2V	6	1,5	1,5	33	4	-64	200	NO

The maximum usable distance (< 3000 m), for every kind of V2X communications below 6 GHz is not ensured with respect to the specified KPI. The solution could be to distribute an adapted network of RSUs to cover all the parking area.

Suitability analysis of V2X spectrum above 6 GHz for 5GCAR use cases

For an antenna being mounted somewhere on a vehicle, it is difficult to achieve a perfect Omni-directional pattern due to the shape of the car, curvature of the roof, if the antenna is mounted on the bumper or on the side mirror and so forth. Hence, it is very important that the maximum emitted power (E.I.R.P) shall correspond to the maximum gain of the antenna plus the transmitted power. If there is any cable between the TX hardware and the antenna element, the losses due to that cable shall also be included in the calculations. The cable loss is a function of frequency, which means higher frequencies have higher losses and vice versa, and for that reason at frequencies above 6 GHz the cable length should not be too long otherwise signal-to-noise ratio will drop significantly. For frequencies above 6 GHz, we consider the conditions that are provided in Table F.8.

Table F.8: The considered conditions for frequencies above 6 GHz.

	Height (m)	Pt: EIRP (dBm)	Gr: Rec. gain (dBbi)
eNB antenna	20	46	18
RSU antenna	5	40	18
Vehicle antenna	1.5	40	12

To assume a global omnidirectional millimeter wavelength vehicle antenna system, elementary antennas can be sectorial and distributed in adequate and optimal locations on the vehicle:

- On the roof, in a "smart antenna" box especially for V2N communications. Due to wavelengths (< 10 mm), more complex antennas (patch arrays) can be integrated in a same style of shark thin antenna. Such antennas can reach a minimum gain of 12 dBi.
- Distributed behind the wind screen and rear window areas (top area). To avoid any expensive coaxial cables, between antennas and the RF central unit, the associated RF stages of modems have to be closely associated with their antennas.

Table F.9: Complete results for 5GCAR UC1.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	350
V2N DL	26	20	1,5	46	12	-82	5 163	OK
V2N UL	26	1,5	20	40	18	-82	5 163	OK
V2I	26	1,5	5	40	18	-82	3 455	OK
I2V	26	5	1,5	40	12	-82	2 446	OK
V2V	26	1,5	1,5	40	12	-82	1 340	OK
V2N DL	63	20	1,5	46	12	-82	2 131	OK
V2N UL	63	1,5	20	40	18	-82	2 131	OK
V2I	63	1,5	5	40	18	-82	2 131	OK
I2V	63	5	1,5	40	12	-82	1 068	OK
V2V	63	1,5	1,5	40	12	-82	1 068	OK

Table F.10: Complete results for 5GCAR UC2.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	100
V2N DL	26	20	1,5	46	12	-67	918	OK
V2N UL	26	1,5	20	40	18	-67	918	OK
V2I	26	1,5	5	40	18	-67	918	OK
I2V	26	5	1,5	40	12	-67	460	OK
V2V	26	1,5	1,5	40	12	-67	460	OK
V2N DL	63	20	1,5	46	12	-67	379	OK
V2N UL	63	1,5	20	40	18	-67	379	OK
V2I	63	1,5	5	40	18	-67	379	OK
I2V	63	5	1,5	40	12	-67	190	OK
V2V	63	1,5	1,5	40	12	-67	190	OK

Table F.11: Complete results for 5GCAR UC3.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	70
V2N DL	26	20	1,5	46	12	-85	7 294	OK
V2N UL	26	1,5	20	40	18	-85	7 294	OK
V2I	26	1,5	5	40	18	-85	4 106	OK
I2V	26	5	1,5	40	12	-85	2 907	OK
V2V	26	1,5	1,5	40	12	-85	1 592	OK
V2N DL	63	20	1,5	46	12	-85	3 010	OK
V2N UL	63	1,5	20	40	18	-85	3 010	OK
V2I	63	1,5	5	40	18	-85	3 010	OK
I2V	63	5	1,5	40	12	-85	1 509	OK
V2V	63	1,5	1,5	40	12	-85	1 509	OK

Table F.12: Complete results for 5GCAR UC4.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	1000
V2N DL	26	20	1,5	46	12	-85	7 294	OK
V2N UL	26	1,5	20	40	18	-85	7 294	OK
V2I	26	1,5	5	40	18	-85	4 106	OK
I2V	26	5	1,5	40	12	-85	2 907	OK
V2V	26	1,5	1,5	40	12	-85	1 592	OK
V2N DL	63	20	1,5	46	12	-85	3 010	OK
V2N UL	63	1,5	20	40	18	-85	3 010	OK
V2I	63	1,5	5	40	18	-85	3 010	OK
I2V	63	5	1,5	40	12	-85	1 509	OK
V2V	63	1,5	1,5	40	12	-85	1 509	OK

Table F.13: Complete results for 5GCAR UC5.

	Freq. (GHz)	Ht (m)	Hr (m)	Pt (dBm)	Gr	Pr min (dBm)	Dmin (m)	3000
V2N DL	26	20	1,5	46	12	-64	650	NO
V2N UL	26	1,5	20	40	18	-64	650	NO
V2I	26	1,5	5	40	18	-64	650	NO
I2V	26	5	1,5	40	12	-64	326	NO
V2V	26	1,5	1,5	40	12	-64	326	NO
V2N DL	63	20	1,5	46	12	-64	268	NO
V2N UL	63	1,5	20	40	18	-64	268	NO
V2I	63	1,5	5	40	18	-64	268	NO
I2V	63	5	1,5	40	12	-64	134	NO
V2V	63	1,5	1,5	40	12	-64	134	NO

The maximum usable distance (< 3000 m), for every kind of V2X communications above 6 GHz is not respected.

Disclaimer: This 5GCAR D2.2 deliverable is not yet approved nor rejected, neither financially nor content-wise by the European Commission. The approval/rejection decision of work and resources will take place at the next Review Meeting, after the monitoring process involving experts has come to an end.