5GMOBIX

5G for cooperative & connected automated **MOBI**lity on **X**-border corridors

D6.7

Final Report on the Standardisation and Spectrum Allocation Needs

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ABBREVIATIONS

Abbreviation	Definition
3GPP	3rd Generation Partnership Program
5GAA	5G Automotive Association
5GC	5G Core
5G IA	5G Industry Association
ANACOM	Autoridade Nacional de Comunicações
ARCEP	The Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse
ARIB	The Association of Radio Industries and Businesses
ATIS	The Alliance for Telecommunications Industry Solutions
AV	Autonomous Vehicle
BS	Base Station
BSI	British Standards Institution
CALM	Continuous Access to Land Mobiles
CAM	Connected and Automated Mobility
CAS	Cooperative Awareness Service
CAV	Connected and Autonomous Vehicle
CBC	Cross Border Corridor
CBN	China Broadcasting Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electro-technical Standardization
CEPT	The European Conference of Postal and Telecommunications Administrations
CPS	Collective Perception Service

C-V2X	Cellular-Vehicle to Everything
CV	Connected Vehicle
D2D	Device to Device
DoA	Description of Action
EC	European Commission
eMBB	enhanced Mobile Broadband
eMTC	enhanced Machine Type Communication
EPC	Evolved Packet Core
eSIM	embedded-SIM
ETSI	The European Telecommunications Standards Institute
EU	European Union
FACS	Flexible Access Common Spectrum
FDD	Frequency Division Duplexing
FG-AI4AD	Focus Group on AI for autonomous and assisted driving
FG-VM	Focus Group on Vehicular Multimedia
GNSS	Global Navigation Satellite System
GSMA	GSM (Global System for Mobile Communications) Association
H-PMLN	Home - Public Land Mobile Network
ICEC	In Car Emergency Communication
ICN	Information Centric Networking
ICT	Information and Communication Technologies
ICTA	Information and Communication Technologies Authority
IMT	International Mobile Telecommunications

IoT-NTN	Internet of Things - Non-Terrestrial Networks
ISO	The International Organization for Standardization
ITC	Inland Transport Committee
ITS	Intelligent Transport System
ITU	International Telecommunication Union
KCC	Korea Communications Commission
KPI	Key Performance Indicator
LBT	Listen Before Talk
LCS	Location Services
LTE-M	LTE for Machine-Type-Communication
MEC	Multi-access Edge Computing
MNO	Mobile Network Operator
mMTC	massive Machine Type Communications
NB-IoT	Narrow-Band - Internet-of-Things
NFAT	National Frequency Allocation Table
NGSO	Non-Geostationary Orbit
NRA	National Regulatory Authority
NSA	Non-Standalone
NTN	Non-Terrestrial Networks
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RedCap-UE	Reduced-capability User Equipment

RSU	Road Side Unit
SA	Standalone
SAE	Society of Automotive Engineers
SDN	Software Defined Networking
SDO	Standards Developing Organisation
SG	Study Group
S-ICN	Software defined ICN
SI	Study Item
SIB	System Information Block
SID	Study Item Descriptions
SIM	Subscriber Identity Module
SPS	Semi-Persistent Scheduling
SSIG	Standardisation Special Interest Group
TC	Technical Committee
TDD	Time Division Duplexing
TS	Technical Specification
TSDI	Telecommunications Standards Development Society
TSG	Technical Specification Group
TTA	Telecommunications Technology Association
UN	United Nations
UNECE	The United Nations Economic Commission for Europe
URLLC	Ultra-Reliable Low Latency Communications
V2G	Vehicle to Grid

V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VNF	Virtual Network Function
V-PLMN	Visitor - Public Land Mobile Network
WG	Working Group
WI	Work Item
WP	Work Package
WRC	World Radio Conference
X-border	Cross-border

EXECUTIVE SUMMARY

This report is the 5G-MOBIX deliverable D6.7 "Final report on the standardisation and spectrum allocation needs" which is the last of the two deliverables generated within the scope of Task 6.3. The purpose of Task 6.3 is to evaluate the 5G-enabled connected and automated mobility (CAM) use case categories and user stories in the 5G-MOBIX project across two Cross-border corridors, in Spain-Portugal and Greece-Turkey, as well as the six local trial sites in Germany, Finland, France, Netherlands, China and Korea, from the point of view of standardisation and spectrum allocation. The standardisation relevant issues and challenges encountered or observed during trials and research activities during the project are highlighted and the considered recommendations are also provided whenever applicable.

In the first phase, the focus was basically to identify the gaps that exist in the standards, analyse the spectrum requirements of the various CAM services, and introduce the ecosystem, which was reported in D6.3. As for the current document, the main approach is to present ultimate situation regarding the standardisation of 5G-enabled CAM services, and offer recommendations to the relevant standardisation and regulatory bodies as a means for effective deployment of these services in the EU.

In this context, the principal approach of the 5G-MOBIX partners is to monitor and internally report on the activities of the respective groups of the standards developing organisations (SDOs) for the most up-to-date discussions on the identified technical gaps and issues. To influence future standards in the 5G-V2X and CAM ecosystem, 5G-MOBIX partners have participated in the discussions and also organised dissemination activities with a focus on having an efficient and significant impact in terms of international standardisation in the industry. Thus, it is expected that the project partners try to employ the project outputs from the perspective of standardisation and spectrum needs for the CAM services, and take the achievements and key points, learnt during the project trials, to the relevant SDO meetings, which are arranged by the work or study groups, as recommendations. This report herein presents such events and contributions provided during these activities.

Several 5G based technologies and features were trialled, and their findings were observed during the project towards addressing the identified cross-border issues for CAM. From standardisation perspective, this deliverable presents those key 5G technologies needed for service continuity across CBC, together with the insights from the deployments carried out in 5G-MOBIX, as summarised below:

- *Release with redirect* – Current roaming agreements and the associated steering mechanisms among MNOs try to direct subscribers to a certain network by denying access to certain visited networks and updating in-time the SIM information with a preferred visited PLMN. Care must be taken to ensure that these UE-based steering mechanisms do not collide with cross-border network-based steering mechanisms and potentially cause extra disconnection time. For proper CAM operation, MNOs need to exchange basic cell information on neighbouring cells. The base stations at the borders need to be adapted with special configurations, changing over time as the network evolves. Therefore, more enhanced standardisation is needed to enable the release and redirect based on measurements between different PLMNs in a consistent manner.

- *S1/N2 handover through S10/N14 interface* – eNBs / gNBs at the border need to contain references to each other beyond just the channel numbers and cell IDs. They must provide the involved MMEs the required identifiers so the information required for handover preparation and execution can be exchanged with the MMEs and the S10 interface between them serving as relay. Based on the standards, automated exchange of RAN data across operators is strongly recommended.

- *Local Break-out roaming* – As known, most of the current roaming architectures are using home routed roaming. All the data traffic is routed back to the home operator. The further away the user is from the home network, the higher the latency of data traffic. To overcome this, local breakout architectures can be used. The data traffic stays with the visited network.

- *Multi-SIM setup for SA and NSA* – The make-before-break approach for stateful CAM applications, enabled by the multi-SIM setup, requires more intelligence and control being placed into the OBU application as well as network-side support to minimize the impact of breaking the connection. Trial site tests have shown that the multi-SIM solution under passive and link-aggregation modes can reduce the service interruption time down to 4.7 and 3.7 seconds respectively, from 20s when using single SIM. Further, custom multi-SIM solution have revealed viability of utilizing the GPS position to implement mobile network switching decisions for applications that can tolerate reconnections.

Furthermore, the other essential contribution of 5G-MOBIX is a 5G spectrum allocation study, tailor-made to the CAM services deal with in the project context. Based on this way, Task 6.3 also aims to investigate the network technologies or mechanisms needed for interference elimination, 5G service continuity and seamless mobility when crossing borders, which strongly require a cooperation among the neighbouring mobile network operators (MNOs) for the relevant configurations/specifications throughout their infrastructures from end to end.

Overall, globally integrated efforts on defining and realizing 5G deployment activities provided valuable insights that will serve to identify and respond to standardisation gaps as well as spectrum allocation needs towards next generation CAM applications.

The general flow of the document is organised as follows:

- **"Section 1: Introduction"** gives an overview of the 5G-MOBIX project, and explains the purpose and intended audience of the deliverable.
- **"Section 2: Objectives, Methodology and Ecosystem"** is concerned with the approach taken within the project consortium to come up with the standardisation and spectrum allocation needs of the 5G-MOBIX use cases and user stories.

- **"Section 3: Standardisation"** elaborates the project works centred around the standardisation activities, with a specific focus on the SDOs that aim to deliver 5G technology and its features necessary for the vehicular communications and CAM services.
- **"Section 4: Spectrum Allocation for 5G-enabled CAM"** mainly discusses the study on spectrum needs of the 5G-MOBIX user stories, along with the up-to-date status in terms of regulations in the 5G-MOBIX countries, where trials have been performed. Moreover, spectrum issues encountered during the project trials conducted at the cross-border corridors are interpreted in this section as well.
- **"Section 5: Conclusion"** summarises the final findings for addressing the standardisation and spectrum allocation needs of the CAM use case categories and user stories covered in the project.

1. INTRODUCTION

1.1. 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G for vehicle-to-everything (V2X) communications by validating the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). The potential applicability of various 5G capabilities to advanced connected and automated mobility (CAM) services are being demonstrated by executing trials along cross-border corridors (CBCs) on real European roads and highways, using 5G core technological innovations to qualify 5G and evaluate its benefits in the context of the strategic objective of the European Commission for having all European major transport paths covered by 5G connectivity in 2025 [1].

First, critical scenarios in need of advanced connectivity provided by 5G are defined, and then the required 5G features to design 5G-enabled CAM user stories are identified (WP2). The matching of these user stories with the relevant use case categories allowed grouping of and close cooperation between the partners, conducting trials on different 5G corridors in several EU countries as well as in Turkey, China and South Korea, towards assessment of the cross-border impact of the 5G-enabled CAM services under consideration. For the trials, 5G-MOBIX utilises upgraded existing key assets such as infrastructure and vehicles while new components are developed as required (WP3), where the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as satellite communications, C-V2X (Release 14) and possibly ITS-G5 are ensured.

The trials (WP4) allow 5G-MOBIX to perform technical evaluations, cost/benefit analysis and impact assessments (WP5), as a result of which, 5G-MOBIX delivers sustainable business models and opportunities for 5G corridors (WP6). Derived from studies of the 5G trial sites in the project, these business models structure the basis for the to-be-proposed deployment options, scenarios and recommendations that create 5G corridors across the EU for 5G-enabled CAM services.

Two essential and intrinsic factors for the deployment of 5G are (1) the availability of standards and spectrum, and (2) an accurate estimation of the related costs to bring it to the market, which guarantee well-performing CAM services in the 5G corridors targeted by the EU. Through its findings on technical requirements and operational conditions at border crossings, 5G-MOBIX expectedly contributes to standardisation activities (Task 6.3), which helps realise cross-border mobility for V2X services. The spectrum allocation discussion, on the other hand, is much more convoluted due to the plethora of options to choose from, and the pursuit for the optimum assignment of spectrum to CAM services with greatly varying properties and transmission characteristics in the presence of non-CAM traffic from other 5G users has to be covered in 5G-MOBIX (Task 6.3).

1.2. Purpose of the deliverable

The present document delivers the final results of the work on the standardisation and spectrum management towards 5G for CAM, carried out as a part of Work Package 6 on "Deployment Enablers". Previously, the intention in D6.3 was to set the initial plan and methodology for implementing the standards development and spectrum allocation activities of 5G-MOBIX as a basis. As known, a refined analysis of the standardisation and spectrum allocation aspects of the 5G-enabled CAM use case categories and user stories of 5G-MOBIX depends partially on the output of the trials, and especially those obstacles encountered in the technical domain, where additional standards are deemed necessary, as well as the actual observed metrics for user data rates, latencies and handover success rate that will dictate the amount and choice of spectrum for CAM services. Currently, the deliverable D6.7 encompasses the results of this type of analysis based on the experiences of the trial sites and corridors handled within the project.

1.3. Intended audience

The dissemination level of D6.7 is public (PU), and hence will be used publicly to inform all interested parties about the standardisation and spectrum allocation needs of the use case categories and user stories that are addressed in the 5G-MOBIX trials. Therefore, this document is of special interest to the following groups:

a. 5G-MOBIX project consortium members: An internal technical report for all consortium members regarding the relevant standardisation developments as well as the on-going activities for the proper spectrum allocation per trial site.

b. The European Commission (EC): A reporting method towards the EC for monitoring the project progress and for keeping up to date with the latest standards and spectrum regulations. Parts of this document may also be used as a reference for future European policies or calls for research.

c. European telecom operators & vendors: A first insight into the 5G for CAM standards and specifically to the issues of proper spectrum allocation.

d. All CAM/V2X stakeholders: A concise view of the specifications and spectrum allocation aspects of CAM in general, and 5G for CAM with cross-border settings in particular.

2. OBJECTIVES, METHODOLOGY AND ECOSYSTEM

In this section, the main purpose is to summarise the objectives, methodology and ecosystem of Task 6.3, that is previously elaborated in D6.3 to explain the role and position of the task within the project. The general form of work and output expected from the task is figured out with the help of exploring the ecosystems in terms of standards development and spectrum management.

2.1. Objectives

The objective of Task 6.3 is to identify the gaps that exist in the standards and spectrum regulations that should be addressed for a viable deployment of 5G-enabled CAM services at 5G cross-border corridors, ensuring seamless and reliable mobility across and beyond the EU. Within this landscape, the specific objectives of Task 6.3 are providing the following items:

- **Recommendations and requirements to standardisation work groups and government policymakers in the telecommunications domain for development of standards and spectrum allocation regulations.**
- **Spectrum management discussions in a "glocal" fashion, where the partners will contact the regulatory entities in their own countries, without losing the overarching goal of connecting the whole European continent.**

Both objectives are strongly linked with the designed user stories, the internal technical discussions and the observations/conclusions reached during the trials in the project.

2.2. Methodology

The steps in Task 6.3 are shown in Figure 1 based on the sequential methodology when defining the relevant stakeholders. It is planned to develop concrete recommendations, which are closely related to and builds on the results obtained from the 5G-MOBIX technical discussions and the trials which effectively begins at the end of Q2 2021.

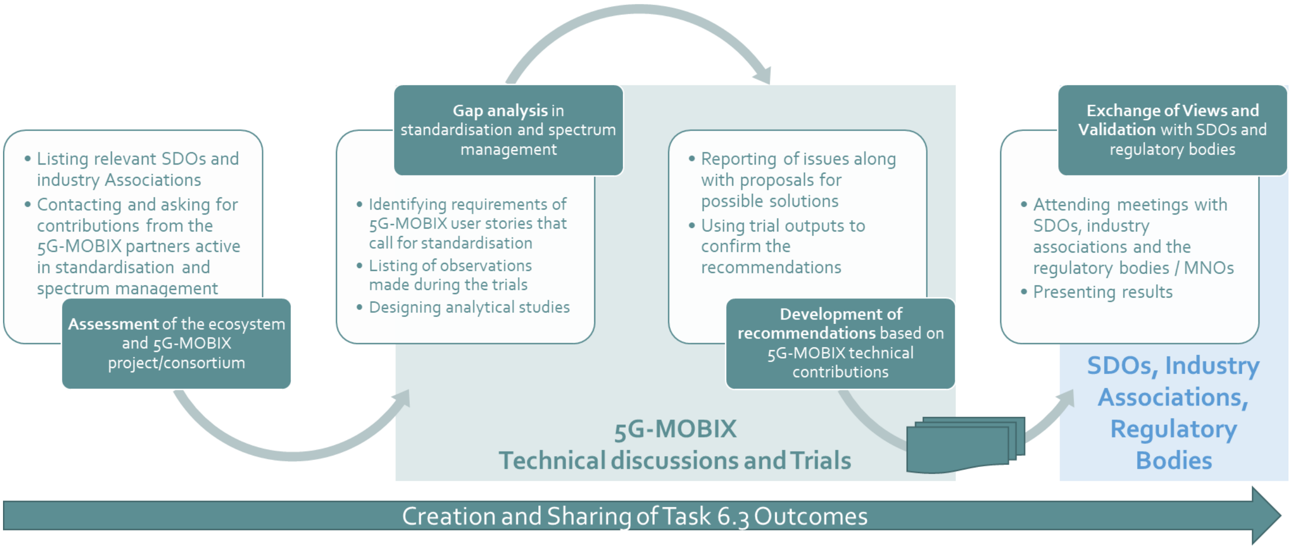


Figure 1: Task 6.3 methodology

In brief, the methodology of Task 6.3 has five stages as follows: assessment, gap analysis, development of recommendations, exchange of views and, lastly, sharing of task outcomes.

2.3. Assessment of the Ecosystem

The goal of this stage was, first of all, to find out the specific external organisations related with this task, by separately characterising the ecosystems around standardisation and spectrum regulations. Using this characterisation as an input, the 5G-MOBIX partners either actively participating in the ongoing work within these organisations or having developed ideas that can be taken to these bodies/institutions are identified and invited to join the task if they have not already done so before.

2.3.1. Standardisation Ecosystem

The standards for CAM are comprise a broad range of categories such as control systems, mobile communication, data management, security, human factors and artificial intelligence. In the context of 5G-MOBIX, the main approach will be based on the cellular connectivity aspect of CAM which is obviously required in 5G-enabled CAM services. Therefore, SDOs such as the 3GPP, ETSI, CENELEC, ISO and ITU-T, which are developing standards for 5G and vehicular communications, as well as associations like 5GAA, GSMA and NGMN, that support these SDOs with their industry-driven requirements and field work, are the most relevant institutions for 5G-MOBIX as illustrated in Figure 2. General information about these SDOs/associations, their internal organisational structure and an overview of their work towards 5G-enabled CAM have been given in D6.3.

Figure 2: The most prominent SDOs and industry associations for 5G-enabled CAM

The partners which are not directly involved in standardisation groups, and thus do not appear in Table 1, can also contribute through:

a) Identifying unique results stemming from the project activities. All partners involved in the cross-border corridors and trial sites may offer solutions.

b) Bringing up existing standards and recommendations that may affect 5G-MOBIX development.

c) Participating in workshops, fairs, congresses etc. organised or endorsed by SDOs with 5G-MOBIX related presentations. ETSI Plugtests/Hackfests are especially interesting, as they provide opportunities for hands-on experimentation.

d) Attending workshops, fairs, and congresses organised or endorsed by SDOs, and identifying possible impacts to 5G-MOBIX.

Table 1: 5G-MOBIX partners' participation to standards development

Standards Organisation / Alliance	Group	Involved Partners
3GPP	SA2 - Architecture	FRAUNHOFER
	RAN1 - Radio Layer 1	FRAUNHOFER, TURKCELL
	TSG RAN	TURKCELL
	RAN 2 - Radio Layer 2 & 3	FRAUNHOFER, TURKCELL
	RAN 3 - Iu, Iub, Iur, S1, X2, UTRAN/E-UTRAN	FRAUNHOFER
	3GPP Standardization special interest group (SSIG) on Non-Terrestrial Networks (NTN) -SA2	CATAPULT
ITU-T	Focus Group on AI for autonomous and assisted driving (FG-AI4AD)	TURKCELL
NGMN	Project Portfolio	TURKCELL (Board Member)
5GAA	WG1: Use Cases and Technical Requirements	VALEO
	WG2: System Architecture and Solution Development	FRAUNHOFER, TNO
ETSI	Technical Committee (TC) Intelligent Transport Systems (ITS)	VEDECOM, VTT, Siemens
	Industry Specification Group (ISG) IPv6 Integration (IP6)	University of Luxembourg
	Industry Specification Group on IPv6 Enhanced Innovation (IPE)	University of Luxemburg, TURKCELL
CAR-2-CAR Communication Consortium	WG Deployment	SIEMENS

2.3.2. The Regulatory Ecosystem for Spectrum Management

As expected, one of the ultimate aims of the project is the "identification" of the most appropriate frequency bands for delivering 5G-enabled CAM services. For this purpose, the field trials allow to access to the real traffic patterns and resource requirements of the services, which translate into the coverage and capacity plans of MNOs as well as the required spectrum allocation.

Promising 5G technology is different from its predecessors in the sense that there are a large number of bands with unique features, characteristics and bandwidth to choose from, and hence the regulation activities should be coordinated across neighbour countries to ensure service experience continuity (e.g. X-border scenarios defined within the project).

In spite of the efficient international spectrum allocation recommendation efforts in ITU-T and ITU-R platforms, it is the national governments which eventually decide on the services to be allowed in certain bands. Last but not least, it is the National Frequency Allocation Table (NFAT) of the governments that have the final word on the bands allocations, the conditions and the future plans for each service. This is the underlying reason why 5G-MOBIX target a "glocal approach" when covering spectrum allocation discussions of the 5G-enabled CAM services, to get the final decision makers on-board first and be ready for the next World Radio Conference (WRC) of the ITU-R.

3. STANDARDISATION

This section presents the final result of the gap analysis that has been performed by the 5G-MOBIX partners to identify a set of topics, which require standardisation contributions in view of current and future cross-border connected and automated mobility enabled through 5G technology. The final activities of the partners with respect to standards development for these topics are listed to further specify the organisations pertinent for each of these areas as well.

3.1. Input to Standardisation Work

To pinpoint the missing parts within the standards and explain what needs to be done, this section identifies the gaps in standardisation for a particular topic of interest and refers to the relevant organisations, work groups and also 5G-MOBIX activities, followed by a more in-depth summary and evaluation of the final status.

In line of this perspective, the prominent topics included in this part are as follows:

TOPIC-1. Satellite Communications

TOPIC-2. Cross-border Roaming

TOPIC-3. IPv6-based 5G

TOPIC-4. Network Slicing

TOPIC-5. ITS Services

TOPIC-6. TDD Synchronisation

3.1.1. Satellite Communications

ETSI 3GPP NTN Context

The 3rd Generation Partnership Program (3GPP) standardisation has acknowledged the relevance of integrating a non-terrestrial (i.e. satellite-based) segment into the dominant 5G radio access standards for both broadband access and IoT. This has been taking place in a phased approach, spanning Releases 15, 16, 17 and beyond. Satellite Applications Catapult, being a member of the 3GPP Standardisation special interest group (SSIG) on Non-Terrestrial Networks (NTN), has been involved in and supporting the standardisation process of integrating NTN with 5G NR, especially contributing to the current work items for Release 18 on NR-NTN enhancements and co-sourcing the contribution RP-221472 on NR-NTN deployments. They have also supported the Release 18 WID for IoT-NTN. As a result of the trials and the associated work undertaken at the French Trial, contributions will be made towards the upcoming Release 19 study items, which are aligned with the work undertaken within the project, such as Study on satellite access - Phase 3 (SP-220679) and Study on Upper layer traffic steering, switching and split over dual 3GPP access (SP-220445).

Three major groups of use cases for integrated satellite terrestrial 5G systems have been defined by the 3GPP. Firstly, satellites can significantly enhance the **5G network reliability** by ensuring service resilience, in cases where it cannot be offered by a single or a combination of terrestrial cellular networks. This is relevant to support critical CAM data exchanges for safety (e.g. at a junction). Secondly, non-terrestrial networks can guarantee the **5G service ubiquity** in un-served (e.g. cross border) or underserved areas (e.g. rural areas), where a terrestrial cellular network does not exist, or it is too impractical/cost-ineffective to reach. Finally, NTN can enable the **5G service scalability** due to the efficiency of the satellites in multicasting or broadcasting over a very wide area. This can be used for massive map update or SOTA services. Also, 3GPP RAN has approved a study item for satellite to be supported by 3GPP-Narrow-Band-Internet-of-Things (NB-IoT) as well as LTE-for-Machine-Type-Communication (LTE-M) standards. This is reflected by the need to support highly critical low-bandwidth V2X data exchanges.

Even though the work undertaken by 3GPP on the use of satellite technology for backhauling is quite mature, some of the major technological gaps are still needed to be addressed to ensure direct connectivity to user terminals, especially under mobility, which are currently being investigated within 3GPP. The 5G-MOBIX project has also served to bridge some of these gaps, thereby contributing to the 3GPP standardisation activities and the corresponding technical areas and work items described in detail in the present section.

3GPP Release 17 NTN Standardisation – Main Features and Activities within 3GPP

The recently concluded 3GPP Release 17 specifications support New Radio (NR) based satellite access deployed in FR1 bands serving handheld devices for global service continuity. Release 17 work is based on the findings of earlier studies performed in Release 15 and Release 16, where NTN channel models and necessary adaptations of the NR technology to support NTN were identified. The main challenges identified in Release 16 and addressed in Release 17 are related to the adaptation required due to the mobility and orbital height of the satellite. Release 17 has established basic mechanisms to manage these challenges and provides a first set of specifications to support NTNs based on NR. Release 17 focused on a transparent payload architecture with FDD systems where all UEs are assumed to have Global Navigation Satellite System (GNSS) capabilities. The main features investigated in this release are adaptation to the physical and access layer aspects (RAN1 and RAN2 groups), RAN and system architecture including feeder link switch over and country specific routing aspects (RAN3 group), radio resource management (e.g. Timing compensation and GNSS accuracy) and RF requirements for targeted satellite networks operating at different orbits (RAN4 group), system level aspects (e.g. Mobility management and satellite backhauling) (SA2 group) and network protocols (e.g. PLMN selection).

The Release 17 standardisation also studied the feasibility of adapting NB-IoT and enhanced Machine Type Communication (eMTC) to support satellite access to address massive Internet of Things (IoT) use cases in areas such as transport, logistics, agriculture, etc. To further widen the range of use cases for NR, Release 17 introduces support for Reduced-capability user equipment (RedCap UE). RedCap UEs have less complexity than the regular 5G UEs and will satisfy moderate service requirements (between the relaxed mMTC requirements and highly stringent URLLC requirements) at the same time with additional benefits such as better latency and the capability to operate in high NR frequency bands.

The feasibility of NTN integration with mobile 5G systems is recognised as a result of the 3GPP-Release-17 NTN standard, supporting all 5G features like slicing, energy saving, mobility, 3rd party management, application and service platforms, across the access technologies.

Release 18 and further releases – Undertaken activities and features

Release 18 is currently evolving and aims for improved support of satellites in smartphones and introducing Ka band (above 10 GHz) for very small aperture terminal applications, including mobility enhancements. The focus areas that are studied in the ongoing Release 18 3GPP NTN standardisation are relevant to the 5G-MOBIX project from a contribution-to-standardisation perspective. The findings of the project will be input to relevant work items and technical reports related to these activities within Release 18 and those potential areas are discussed in the present section.

The main activities within Release 18 aim to:

- Support access with discontinuous coverage and backhaul with variable latency and bandwidth;
- Support network verified UE location including coverage and mobility enhancements;
- NB-IoT/eMTC with mobility enhancements and discontinuous coverage aspects;
- Satellite-UE specifications for above 10GHz bands.

Cellular Vehicle-to Everything (C-V2X) technology was incorporated in Release 14 by 3GPP, in June 2017, by leveraging standard cellular technologies and has evolved further with Release 15, which was finalised in June 2019. Incorporation of a satellite component in the V2X architecture is interesting for the use cases, especially where a vehicle has no terrestrial cellular connectivity. In the current 3GPP standards for V2X, satellites are mainly used for localisation purposes. With the findings of the project, we will be able to recommend incorporating the new use case of V2X with dual access for Release 19 associated with the study item SP-220445 on upper layer traffic steering, switching and split over dual 3GPP access incorporating 5G NR and NTN.

3.1.2. Cross-border Roaming

Within 5G-MOBIX we have trailed several methods to enable seamless roaming and 5G service continuity. Each of them is meant to reduce the interruption time when crossing the border. While we see that in a trial setup it is possible to limit the interruption time significantly or even completely, doing this at a larger scale requires planning, clear arrangements between MNOs and scaling of infrastructure. In D6.3 an overview is given of the measures needed to create a scalable roaming infrastructure. In the present section the relevant learnings from the trials are collected and future work on standardisation is recommended.

The main technologies trailed within 5G-MOBIX to limit the **interruption time**, then improve the **roaming** as well as **handover** performance to provide **5G service continuity** when crossing border, are:

- Release with redirect

- S1/N2 handover using the S10 or N14 interface
- Multi-sim setup for SA and NSA
- Inter-Frequency measurement threshold parameters

Table 2: 5G-MOBIX technologies trailed to improve performance when crossing borders

Technology	Limitations	Recommendations
Release with Redirect	• Single vendor • Single direction • Only HPLMN-VPLMN • No network selection	• Proof this setup can work (we did not get it working in the time available). Also, for a wide range of devices and different scenarios (e.g. handover to same frequency cross the border). • Add a selection mechanism to enable handover to a specific operator (based on HPLMN profile). • Standardise the trigger to perform the redirect. • Agree within GSMA on how to enable this feature. • Create a data service making a device aware of an upcoming handover. • Automate exchange of RAN data across operators.
S1/N2 handover using the S10 or N14 interface	• Single vendor • Only HPLMN-VPLMN (no VPLMN-VPLMN) • No network selection	• Proof this technology can function cross between VPLMN-VPLMN. • Add a selection mechanism to enable handover to a specific operator (based on HPLMN profile). • Agree within GSMA on how to enable this feature across the operators.

		• Analyse the data transferred between operators and assess impact on privacy and security. • Create a data service making a device aware of an upcoming handover. • Automate exchange of RAN data across the operators.
Multi-SIM setup for SA and NSA	• Single border with SIMs of both countries/networks • VPN service connecting to a single server (no edge capabilities) • No network selection, each SIM is fixed to a network.	• Enable this technology using only two sims on multiple borders. • Enable data breakout at operator (without VPN). • Create a central function to steer the modem to the best next network.
Inter-Freq measurement threshold parameters	• Single vendor • End user devices (i.e. modems/modules) might have different behaviours in terms of radio performance and so, handover location point.	• Configure IF measurement threshold parameters to fix the area of cross-border handovers based on ETSI standards (TS 36.331). • Keep the threshold values equalized for events A1, A2 and A5 in both radio networks across the operators.

Based on these recommendations given in Table 2, 5G-MOBIX project has proposed the following future works on the standardisation:

Local Break-out roaming (compared to Home Routed roaming)

As known, most of the current roaming architectures are using home routed roaming. All the data traffic is routed back to the home operator. The further away the user is from the home network, the higher the latency of data traffic. To overcome this, local breakout architectures can be used. The data traffic stays with the visited network.

One of the 5G-MOBIX focuses is the investigation of different 5G deployment options throughout the cross-border corridor by trialling the roaming options (i.e. HR: Home Routed, LBO: Local Break-out) and analysing their technical capabilities, limitations, and also exposing the significance of the core networks' interconnection to achieve minimum service disruption and optimum performance in terms of latency. Figure 3 depicts a generic architecture of a 4G or 5G system interacting with a UE and application server. Each PLMN has its own gateway connecting the mobile core to the internet, PLMN services or private networks. To have benefit of a local breakout architecture, the application to which the UE will connect must be present close to the gateway. Also, if for instance the application helps vehicles to interact with each other, it stands for reason that a connection is needed between the application servers at the different PLMN's.

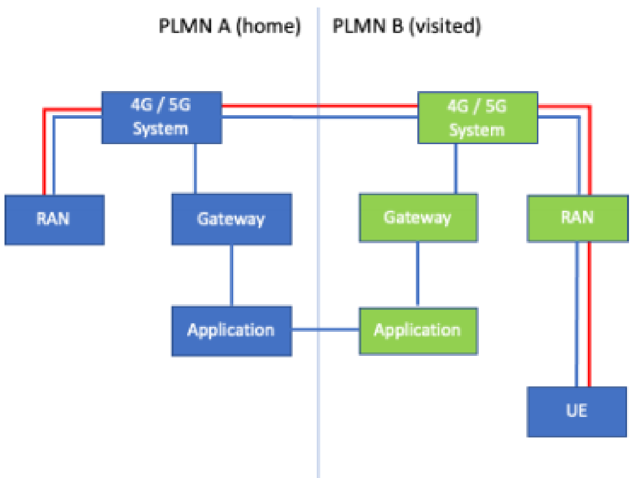


Figure 3: The architecture of Local Break-out and application

The outputs achieved during 5G-MOBIX cross-border trials have indicated that Local Breakout Routed Roaming in conjunction with Edge Computing allows latencies in Visited networks to be identical with those in the Home network.

Table 3: RTT Comparison between Different Configurations

Test Results	(HR with Internet Connection)		(HR with Leased line Connection)		(LBO with Leased line Connection)		
	Home NW (GR)	Visited NW (TR)	Home NW (GR)	Visited NW (TR)	Home NW (GR)	Visited NW (TR)	Visited NW (TR)
E2E Avg. RTT (ms)	16,35	97,24	17,38	35,9	17,57	36,05	17,27

For instance, when enabling LBO Routed Roaming, the average round-trip-time has been measured around 17 ms and the same in Home and Visited PLMN. Nonetheless, in order to reach LBO Routed Roaming after Inter-PLMN handover, the PDN connection needs to be disconnected and connected again, and this process results in a service interruption with potentially negative impact on CAM applications that need to be accounted.

LBO functionality has been tested at both the GR-TR and ES-PT cross border corridors. The visited MME is configured to select the visited PGW for certain IMSI's and a specific APN. In the MME, the APN Local Breakout Control function is used. These trials took place using a 4G NSA system. Since both cross-border corridors have implemented a handover, the question arises when to switch to the local network. During a handover, the data session is kept alive without interruption. To connect to the local network, using the local breakout architecture, an interruption is needed. The network is configured to connect the UE to the local network when a new data session is established. In order to establish a new data session, the existing data session to the home network needs to be gracefully disconnected. There are two ways to trigger a disconnect of the home routed data session:

- Triggered by the network, e.g. on a tracking area update
- Triggered by the UE when the local situation allows this

If we would have the network trigger the disconnection, this would have directly happened by following the handover. Then, this would negate the benefit of having a handover in place and possibly happen at the wrong moment (e.g. when the vehicle is relying on the network). This leaves the trigger by the UE. For this the UE needs to select a moment in time to gracefully disconnect the data session after which setting up a new data session immediately.

Above difficulty can be overcome with the 5G Core system, implementing SSC mode 3. This way the network can trigger a new data session without the application losing the old connection (make before break). This functionality is however not available for testing with current networks and UE's. Besides setting up a new data session, the application still needs to be triggered to connect to the closest network application. More on this can be found in D3.7 report.

From an MNO perspective, there are still some difficulties to allow for a local breakout at a visited PLMN. Metering for instance, takes place at the PGW. A home PLMN would need to trust the visited PLMN to provide correct metering data and be able to audit the correctness of the data. Also, operators are required to facilitate the legal interception of data if requested by the government. There are no EU processes in place to facilitate the legal interception of data cross borders.

It is expected that there are different types of connections needed to facilitate the applications running in a vehicle. Some applications might need regular internet traffic, others might need voice services and yet others local messages with a low latency. It is unclear if all these applications can be serviced with a single APN or data network. It is expected that a more complex architecture is needed to facilitate this. The vehicle would need to be aware of different APNs or data networks to use, be able to selectively route traffic and have the required hardware to enable these requirements.

Interconnection configurations in roaming

To measure handover interruption duration when crossing border, all trials have been performed with Home Routed Roaming within 5G-MOBIX trials. In this case, direct interconnection (i.e. leased line) and indirect interconnection (i.e. public internet) between border location and core network centre have been compared in terms of end-to-end round-trip-time in average.

According to these findings, there had been no significant difference which lines are used to interconnect the PLMNs. The reason is that the S10-interface is only used to prepare and initiate the handover. Delays on that interface only change the point where the handover happens, but not the interruption duration.

Within ES-PT, a direct connection has been established between NOS in Riba d'Ave and Telefonica in Vigo, preventing the need to route traffic through the main core network using a central but distant location in both countries to interconnect both PLMNs. The main benefit is that traffic is kept in the same region. If the direct interconnect would have been made on a central level, the benefit would have been relatively small compared to the existing IPX interconnect. The main benefit of creating a local interconnect is to keep the latency low when a handover takes place to the other country. However, when the vehicle moves further into the country other measures are needed to keep to latency low, like for instance a local breakout.

Measurements at the Spain – Portugal border show a round-trip time of 17 milliseconds using the direct connection. When using an interconnection over Internet the round-trip time is 48 milliseconds. The 30 milliseconds of difference are due to increased distance because of typically centralized internet exchanges.

In case of the GR-TR trial a direct connection has been established between the two edge sites Alexandroupoli and Kartal (Istanbul), allowing both networks related (e.g. S6, S10, S8, interfaces), as well as application 85 related signalling and traffic to enjoy shortest delays (in the range of 45-50 ms) compared to an internet-based interconnection, which is a significant gain for delay sensitive applications.

For home routed scenario though such a benefit would be diminishing in significance as the distance between the visited edge and home edge increases as the truck moves away from the border in his path within the visited country. Further the question as discussed above about the scalability would remain. In case of local break-out the benefit of meshed interconnection between edge sites would not provide significant gain related to shortest signalling and data paths.

The benefit for a local interconnect is large when also using a handover. The latency is kept low and the applications in the vehicles can keep the low latency connection as required during the handover. For the MNO, however this may have a large impact. Currently most operator networks have designed with a mind for availability, using load balancing technologies to route traffic between regions to keep the highest availability possible. A complete redesign might be needed by the MNO to allow for this regional approach with local interconnects across the borders.

PLMN selection

With none of the network-based handover methods, the home PLMN has influence on the selection of the next PLMN (when a UE moves from a current VPLMN to the next VPLMN). It is expected that the home PLMN has the best information available on the services the subscriber requires. In addition, the home PLMN must allow roaming in a certain network; currently operators have specific rules in place to steer subscribers to a specific visited network.

To enable PLMN selection, the VPLMN where the UE is roaming must be aware of the preferred VPLMN. Moreover, the RAN must be able to steer the UE to the best VPLMN based on this information. Since no standards currently exist to enable a network based PLMN selection, 5G-MOBIX has proposed that based on the cross-border roaming trials and field experience during the project.

Release with redirect

As explained thoroughly in D3.7, TS 36.304 Section 5.2.7 specifies the UE-side of the Release with Redirect procedure and TS 36.331 Sections 5.3.8.3 & 5.3.12 the interaction between UE and gNB. It is not subject to standardization what triggers the gNB to send a Release with Redirect message to the UE. Radio equipment used in trials allows to use the measurement reports, normally intended for handover, to trigger a Release with Redirect.

It is not fully clear how network and UE will react if the packet data network session cannot be resumed as the core context cannot be transferred from the source to the target network as there is no S10 interface between them. The working assumption, to be confirmed in trials, is that the packet data network connection is re-established. In case of Local Break-Out (LBO) roaming, it would result in using a P-GW in the VPLMN.

Release and redirect for cross-border

The release and redirect are currently only deployed in a single operator network and used to optimise handovers between different technologies or at specific places (e.g. tunnels). Within the defined standards, the release and redirect is not related to handover process. The behaviour of the UE may be unpredictable or the UE might not be capable of measuring other specific radio frequencies while maintaining a data connection. Therefore, more enhanced standardisation is needed to enable the release and redirect based on measurements between different PLMNs in a consistent manner.

Multi-sim setup for SA and NSA

The contemporary multi-SIM solutions, such as, those being considered in 5G-MOBIX, are typically based on proprietary solutions, and implemented without standardised support of multi-SIM feature from the associated 3GPP systems. In that case, networks serving a particular multi-SIM device may do so with degraded performance on one or more of the connections. In response to the increased adoption of multi-SIM devices, 3GPP has included in Release 17 an ongoing work item for standardisation of enhanced support of multi-SIM devices (physical or embedded SIMs) associated with multiple 3GPP system, scope being Evolved Packet System (EPS) or 5G System (5GS). This includes study of system impacts of legacy multi-SIM device implementations and potential enhancements on aspects, such as, efficient monitoring of multiple paging channels (of each associated 3GPP system) by a multi-SIM device and coordinated departure of the multi-SIM device from one of the 3GPP systems.

RAN data

To enable handovers across borders, mobile network operators need to know the RAN details of the networks at the other side of the border. To activate and utilise this information at larger scale, automation of network management is definitely needed. Thus, the standardisation is necessary to identify the network interfaces between the operators for the exchange of these data.

Informing UE's of upcoming handovers

Network directed handovers will probably emerge in the coming years. In the meantime, car manufacturers will probably find other means to lower the interruption time. To prevent different mechanisms working against each other the upcoming handover should be known by the UE. Standardisation can enable this cross UE's, routers, etc.

Cross operator alignment on network-based handovers

Within the GSMA alignment takes place between the different operators. Until now the network-based handover has never been part of these alignments. To enable handovers by the network this should be taken up by the GSMA.

Edge close to the border

In 5G-MOBIX, the advanced cross-border use cases (such as assisted zero-touch crossing border) have utilized the detailed data provided by the CAM enabled truck's sensors (e.g. Lidar, radar, GPS, etc.) as well as the data from surrounding heterogeneous information sources such as traffic cameras, road side sensors, smartphones, wearables and more, increased intelligence can be created based on a cooperative awareness of the borders' environment. Service continuity during the inter-PLMN handover is of utmost importance in such cases, and the existence of intelligent functionality deployed at the edge close to the border greatly facilitates continuous service by identifying imminent handovers and helping the MNOs prepare for it based on the available information. Therefore, the standardisation is required to identify the edge network architecture for such CAM enabled services across borders.

3.1.3. IPv6-based 5G

The faster a cohesive strategy for 5G and IPv6 is developed and applied in standardisation and research, the sooner the benefits and risks of using IPv6 in 5G will be validated. Overall, this will enable the fast deployment and success of 5G.

Mobile operators are currently being stimulated to deploy IPv6 in their 4G mobile networks due to:

- the performance improvements seen in IPv6 deployments;
- support of multi-layered secure networking;
- the deployment of IPv6 by a large content provider.

This trend is expected to be continued for 5G mobile networks. However, it is expected that IPv4 and IPv6 will co-exist also in 5G deployments due to the fact that only a few applications or services are currently available in IPv6. This means that even in the presence of IPv6 deployments, IPv4 provisioning needs to be considered. It is important to note that one of the operators in the USA announced that in the new 5G deployments, only the IPv6-only solution will be applied.

The aim of the ETSI paper on IPv6-based V2X communications is to describe the IPv6 Transition Strategies in Vehicular Network (IPv4 only, Coexistence of IPv4 and IPv6, IPv6 only, Enhanced IPv6 only + NAT64, Enhanced IPv6 only + 464XLAT).

3.1.4. Network Slicing

In addition to 5G technology, CAM applications also rely on other technologies, such as big data analytics, IoT, and machine learning to process the massive amount of data generated by the roadside infrastructure and create situational perceptions for the AVs. One important but less mentioned feature of 5G is its role as an integration platform for those technologies. A core part to attain this vision is the integration with multi-access edge computing (MEC), bringing compute nodes close to the roadside and AVs, and using it for the deployment of low latency CAM applications, e.g., for object detection, traffic analysis, and 5G VNFs themselves.

Given these aspects, 5G allows for novel solution approaches implemented as special NSs to be integrated into and enhance 5G core functionalities, e.g. a NS with network functions for information-centric networking (ICN) communication, which can be combined with and take advantage of the 5G core VNFs. In line with this thought, the future CAM scenarios with high mobility and data intensive requirements expose the limitations and inefficiencies of the predominantly host-centric IP-based communication in current mobile vehicular networks, i.e., limited support for one-to-many communications, requiring identities of the communication endpoints to be known in advance or relying on the host resolution service (DNS) with high delays.

Above all, a typical requirement of the wireless edge networks for CAM is the co-existence of heterogeneous radio technologies and routing protocols required by different applications and devices, which are not integrated and managed by 5G systems. This poses significant challenges for the end-to-end management of application data flows, e.g., sensor data streams and control signals, across the cloud, edge, 5G, and sensor network domain. Further, the IP-based connectivity requires protocol translation to be carried out at each network domain border, i.e., from the sensor network to IP broadband, 5G core to data centre virtualized network. As the result, the added transmission delays and mobility management complexity make it challenging to provision CAM applications with the required latency and other Quality of Experience (QoE) parameters.

By taking advantage of the ICN paradigm, herein we propose a S-ICN overlay on top of a C-V2X network slice, which connects and manages the content exchange among the MEC infrastructure, AVs and road sensors. Figure 4 shows a hybrid network architecture to support V2X and D2D communication, which extends the 3GPP's 5G architecture for V2X [2] with a Software Defined ICN (S-ICN) segment. The S-INC V2X is an effective access network (AN) consisting of point of attachments (PoA) with multiple interfaces of different wired and wireless technologies, i.e., the RSUs with Wi-Fi, mmWave, 5G, and BLE to connect with road sensors and vehicles. On each PoA, the interfaces are managed by an S-ICN router, which controls data flows based on the information being transferred, e.g., sensor data, control information, application data, etc. The PoA may also contain a mobile far-edge host providing storage and computing capability for local data processing or local SDN control applications.

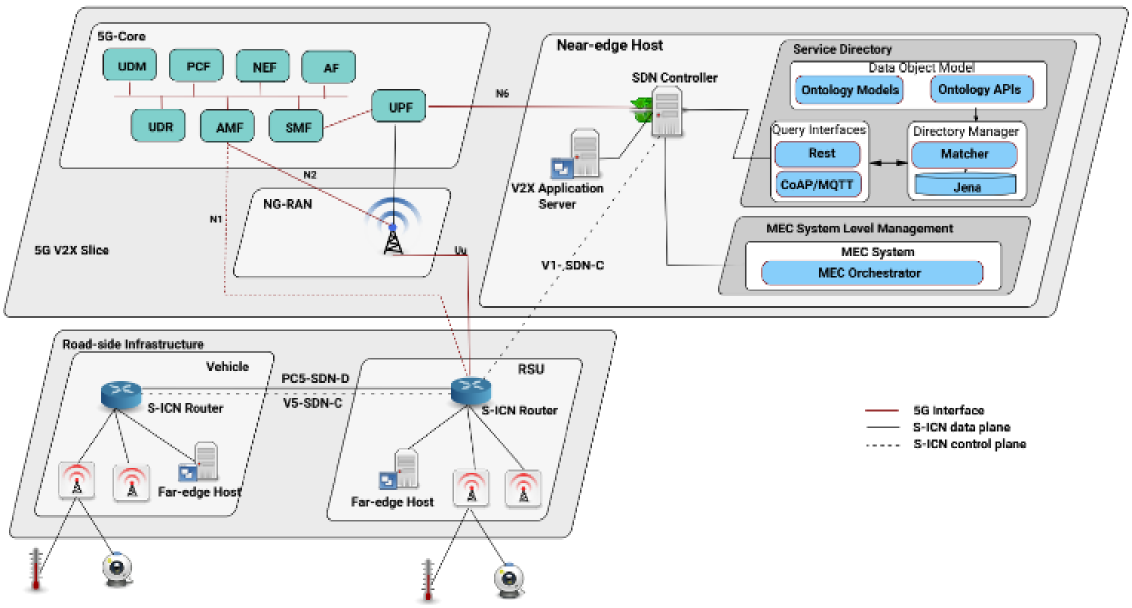


Figure 4: Architecture of a Software Defined Information Centric Network Slice for C-V2X Application

It is obvious that the proposed infrastructure allows most generated data to be processed and communicated in the RAN resulting in very high throughput, low latency, and reduced load on the cellular network. To fully support mobile applications, a mobile PoA (installed on vehicle or user equipment) must be fully integrated with guaranteed QoS requirements for on-board sensors and applications. The resulting challenges for mobility management, session continuity, and end-to-end flow control are addressed within the C-V2X slice.

3.1.5. ITS Services

VEDECOM is involved in ETSI/ITS WG1 (Application Requirements and Services) and thanks to the lessons learned while experimenting with Advanced & coordinated driving in 5G-MOBIX Use Case of the FR Site, has been able to provide relevant input to ETSI/ITS standards related to the Collective Perception Service (CPS) and the Manoeuvre Cooperation Service (MCS).

Table 4 presents an overview and the status of the two related standards CPS and MCS.

The text below the table elaborates on the remaining issues in those standards and how 5G-MOBIX has contributed to progress on the topics.

Table 4: Overview of standardisation activities on ETSI ITS Services

TOPIC-5: ETSI ITS Services	
Identified Gap	ETSI TC ITS WG1 is currently developing technical specifications (TS) of the Collective Perception Service (CPS) and the Manoeuvre Coordination Service (MCS), which are facilities layer protocols to support applications in the domain of road and traffic safety. 5G-MOBIX has been implementing and testing finalised draft versions (almost issued) of CPS and early draft versions of MCS for its different CAM use-cases. The results and lessons obtained from 5G-MOBIX development and testing activities can provide useful insights to build stable long-standing standards of CPS and MCS.
Relevant WG/SI/WI	ETSI ITS TC ITS WG1 Upcoming Meetings: every month
Reference Documents	• ETSI TR 103 562, ETSI TS 103 324 – CPS • ETSI TS 103 561, ETSI TR 103 578 – MCS
Related User Stories (if applicable)	Advanced Driving, Extended Sensors
Active Partner(s)	VEDECOM
Cross-border issue	Telecom and application: Session and service continuity

- **Collective Perception Service (CPS):** Cooperative Awareness Service (CAS) is specified in 2011 to improve the perception of Connected Vehicles (CVs) (including CAVs). The benefits of CAS can be obtained only when the penetration of CVs is relatively high. Unfortunately, in the early phase of the C-ITS deployment, the penetration of CVs will be low i.e., most vehicles on the road will be non-connected vehicles and other non-connected road users. The CPS, which is currently being specified by ETSI, is expected to extend vehicles' perception particularly during the early phases of C-ITS deployment by providing data about objects (i.e., other road participants, obstacles and alike) detected by sensors mounted in vehicles and roadside infrastructure. The ETSI ITS WG1 has published a technical report ETSI TR 103 562, which presents a draft CPM format and different strategies of message generation rules (message generation frequency and content/container inclusion management). The group is currently working on a technical standard which is very close to being published as version 1.0. While the benefit of CPS is obvious, the following list contains some open issues requiring careful thought, validations, and experimentations in order to develop a solid standard:

  - CPM generation frequency,
  - object inclusion management,
  - the maximum number of objects that can be announced by a single CPM,
  - redundancy control,
  - infrastructure capability of providing CPS w.r.t that of a vehicle, and
  - data processing overhead induced by CPS.

Because CPS has been integrated and tested in different trials sites of 5G-MOBIX, the project is able to provide valuable contributions for the future standard.

- **Manoeuvre Coordination Service (MCS):** Automated driving is an important future topic for the automotive industry. Current designs of automated driving systems are only reactive to traffic situation. Therefore, automated vehicles are only able to react to manoeuvres of other vehicles which are currently executed and recognised. Alternatively, it is possible to predict future manoeuvres and react to them. Unfortunately, a prediction is based on assumptions which can be wrong and therefore the prediction can also be erroneous. ETSI is currently specifying the Manoeuvre Coordination Service (MCS), which is intended to reduce prediction errors by exchanging detailed information about intended and/or desired manoeuvres between vehicles and infrastructure. Furthermore, the MCS provides possibilities to coordinate a joint manoeuvre if several vehicles intent to use the same space at the same time. Even though the CPS and MCS work items (WI) have started at the same time, the progress of the MCS WI is much slower; the TR is still in an early draft version. Indeed, the concept of MCS is more complex since it has a direct impact on vehicle control, and hence functional safety, as well as on intelligence distribution (among vehicles and infrastructure), leading to responsibility issues. 5G-MOBIX is testing both the vehicle-oriented and the infrastructure-oriented manoeuvre coordination service, and hence the results will be helpful for progressing the MCS WI.

3.1.6. TDD Synchronisation

When 5G technology promises a ubiquitous, super-fast, reduced-latency and seamless connectivity for CAM services, 5G NR specification proposes a flexible spectrum usage by using Time Division Duplexing (TDD) technique. Currently, the majority of 5G commercial networks have been deployed at the 3.5 GHz frequency band (3.300-4.200MHz) as a cost-effective balance between coverage, capacity and network investments. Thus, the combination of the 3.5 GHz range and 5G NR is thus becoming the first major rollout of TDD networks in many countries as previous mobile network generations used Frequency Division Duplexing (FDD) spectrum.

In practice, different frame structures correspond to different trade-offs relatively to key performance aspects. The MNOs need to carefully consider the selection of the proper frame structure to optimize their service offerings at local or wide ranges and according to market demands. At the same time, the use of TDD frames that inherently mandate time and phase alignment between gNBs, add complexity in the process of preventing interferences and related loss of traffic, mandating a particular level of synchronisation with neighbouring networks. At a national level, alignment between operators can be facilitated through legislation and national regulation that administer the spectrum allocation and can publish guidelines to facilitate the necessary synchronization. However, in cross-border network deployments, achieving network synchronization is a difficult task since a common framework may not be possible in most cases.

For this purpose, GSMA and the Electronic Communications Committee of the European Conference of Postal and Telecommunications Administrations (ECC/CEPT) have investigated the importance of TDD synchronization in the 3.5 GHz range, with the objective to inform policymakers and mobile operators on relevant aspects. 5G-MOBIX has investigated the background on existing TDD patterns recommendations for national, international and cross-border coordination, as provided by the ECC/CEPT. It then assessed in practical terms the application of the recommendations in the Cross-Border Corridor and discussed the performance tests on different TDD patterns utilisation carried out at the GR-TR site.

In principle, in neighbouring TDD deployments base stations are in a close proximity and even if they are phase synchronized, it is very likely to interfere with each other. To avoid interference, at least 25 MHz of guard band between operators is recommended. Upon such insights from previous research and based on the GSMA recommendations, a guard band of 50 MHz has been allocated for the CBC deployment, as seen in Figure 5.

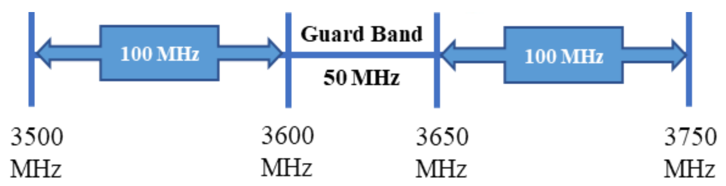


Figure 5: Spectrum Allocation at 5G Cross-Border Corridor

To generate input for standardisation work, 5G-MOBIX has performed inter-PLMN interference tests, and performance tests with neighbouring PLMN OFF/ON using same TDD structure as well as using different TDD structures across the border. The UL throughput was selected as the most suitable metric as most networks are UL limited in terms of various CAM applications and services. During these tests, two different TDD patterns (4+2+4 and 4+1+3+2) were utilized.

In the context of the 5G-MOBIX, the following brief results have been obtained and exploited as an important part of standardisation inputs:

- It seems that the operation of the neighbouring network has practically no impact on the measured performance, independently of the TDD frame structure selected by each MNO, a fact that can be attributed to the agreement between the two MNOs to use adjacent frequencies with a large guard band between them.
- The guard band of 50 MHz has proven minimal to zero interference between the two networks, irrespective of the TDD patterns, to be selected by either side. This is so significant and required when considering that a common framework cannot be always achieved in cross-borders, especially when decisions on the TDD patterns to be employed have business impact.
- Significant variation in UL performance was noted according to the slot allocation of the different TDD patterns, and improvement of UL performance has been observed utilising NR and LTE carrier aggregation.
- Even though TDD frame of 4+1+3+2 has a better UL performance, TDD frame 4+2+4, used widely in 5G commercial network deployments, is also proven suitable for advanced CAM services.

3.2. Activities of 5G-MOBIX Partners within the SDOs and Industry Associations

The technical aspects related to the work undertaken within the 5G-MOBIX project for providing ubiquitous connectivity for the seamless operation and proper deployment of CAM applications are relevant and aligned with the on-going and future standardisation activities by various SDOs. The major technical areas undertaken within the project that are significant to the standardisation are hybrid satellite cellular connectivity for V2X, satellite as backhaul solution with local MEC breakout, intelligent traffic steering and traffic switching aspects, etc. The V2X standardisation will leverage 3GPP standardisation mainly for next generation access part and other SDOs like ETSI-ITS, ISO, SAE, etc., mainly for the upper layers. The potential future inputs to various SDOs based on the outcomes of the project are listed below.

ETSI Technical Committee (TC) on Intelligent Transport Systems (ITS) – ETSI is one of the seven SDOs which work in transposing the 3GPP technical specifications into standards and for enforcing IPR policy on those standards. Within ETSI, specific technical groups like ETSI TC ITS work on V2X standardisation on areas such as enabling interoperability, harmonisation of standards, coexistence of standards and spectrum.

The outcomes of experimental evaluation of the project can be potential contributions to these ETSI standards. The specific work item and report that is currently being progressed within ETSI TC ITS for contribution from the project is provided below.

- ETSI EN 303 798 V1.1.9 (2022-06) (Release 2): Intelligent Transport Systems (ITS); LTE-V2X and NR-V2X Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band.
  The scope of the technical report is to define the physical layer and the data link layer, and radio resource configuration, grouped into the access layer of the ITS station reference architecture ETSI EN 302 665. The document applies to implementation of LTE-V2X, NR-V2X, or both. The work undertaken within the project will also potentially influence the SDO to include a satellite component along with the legacy terrestrial cellular technology for CAM support. From a physical layer perspective, Satellite Applications Catapult also regularly attends the ETSI meetings and contributes to the report related to the physical layer waveform (DVB-S2x/RCS2 versus 3GPP New Radio) for unified satellite terrestrial systems.

ETSI Multi-Access Edge Computing Industry Specification Group (ETSI ISG MEC): ETSI MEC Industry Specification Group has been working on standardising the MEC to facilitate cloud computing capabilities in proximity environment at the edge to satisfy delay and computational requirements simultaneously and is vital for efficient V2X content delivery. After the work on MEC Vehicular-to-Everything (V2X) Information Service (VIS), to facilitate V2X interoperability in a multi-vendor, multi-network, and multi-access environment, ETSI ISG MEC has currently moved forward with the Phase 3 work and to provide additional support for V2X use cases. It is expected that future work will consider heterogeneous networks including satellites. The use cases, solutions and findings addressed in the 5G-MOBIX project related to satellite as a 5G backhauling solution with local MEC break-out will be a potential contribution to ETSI MEC standards.

3GPP: 3GPP combines the endeavours of different SDOs and has been supporting the standardisation of cellular V2X from LTE-V2X (Release 14) to NR-V2X (Release 15 and further releases). 3GPP introduced NR-V2X to address the stringent requirements for connected autonomous vehicles like URLLC (Ultra Reliable Low Latency Communications). The integration of satellites to the 5G ecosystem to close the terrestrial coverage gaps are also being addressed by 3GPP, which will cover many critical issues in V2X scenarios. Satellite Applications Catapult participates regularly in 3GPP SSIG meetings in the context of scoping new work while at the same time supporting the technical deliverables. The contribution to the 5G-MOBIX project related to Hybrid-Satellite-Cellular support for CAM is significantly relevant to the on-going Release 18 and upcoming Release 19 3GPP SSIG standardisation activities. Some of the specific technical reports and the corresponding component from the project as contributions are listed here.

1) 3GPP TR 23.700-28 V0.3.0 (Release 18) – The work related to architectural enhancements in the project to support mobility using hybrid satellite terrestrial networks will be an input.

2) 3GPP TR 23.700-27 V0.3.0 (Release 18) – The work undertaken in the project related to satellite as backhaul solution with local MEC breakout will be a contribution.

3) RP-221806 (Release 18 work item) – The application IoT (Internet of Things) and Redcap aspects in CAM can be an input to the Release 18 work item.

4) SP-220679 (Release 19 Study item) – The aspects of IP (Internet Protocol) based seamless satellite-5G connectivity, especially use of temporary satellite connectivity in the absence of cellular connectivity for delay tolerant communications will be an input.

5) SP-220445 (Release 19 Study item) – The work undertaken within the project related to multiple radio bearer selection through intelligent routing and traffic steering and switching according to the connectivity requirement and availability of terrestrial bearer will be a significant contribution to the upcoming Release 19 study item.

ISO TC204 Intelligent transport systems: ISO's technical committee 204 is responsible for the overall system aspects and infrastructure aspects of intelligent transport systems (ITS), as well as the coordination of the ISO work programme in this field, including the schedule for standards development based on the work of existing international standardisation bodies. Specific working groups under the direct responsibility of ISO TC 204 work on ongoing standards that are under development which are related to communication aspects of intelligent transport systems, which can be considered for prospective contributions. The standardisation undertaken by ISO TC204 is also aligned with the standardisation activities carried out by the European Committee for Standardization CEN Technical Committee 278 on road transport and traffic telematics in the ITS area. A relevant standard for potential contribution that is in-progress is the ISO/DIS 23374-1 "Intelligent transport systems — Automated valet parking systems (AVPS) — Part 1: System framework, requirements for automated driving, and communication interface". This document investigates specific technological solutions for the communication interface (e.g., communication method, message protocol) for the realisation of safe and reliable level 4 driverless operation of vehicles within parking facilities.

ISO TC22 SC31 Data communication – The outputs of the project will also be potential input to the standardisation reports being developed by the ISO TC22 SC31 committee for data communication for vehicle applications spanning the areas data buses and protocols (including dedicated sensor communication), V2X communication (including V2G), diagnostics data transmission, test protocols, interfaces, and gateways (including those for nomadic devices).

Table 5 lists further WIs to which 5G-MOBIX partners actively contributed to:

Table 5: List of contributions of 5G-MOBIX partners

SDO/ Industry Association	1. Title and Document Number 2. Place / Date	Related topic / issue	Involved Partner(s)
3GPP	TR 22.822, "Technical Specification Group Services and System Aspects; Study on using Satellite Access in 5G;(Release 16)"	Integration of NTN/ Satellite Access in 5G	Catapult
3GPP	TR 38.811, "Technical Specification Group Radio Access Network; Study on New Radio (NR) to support non-terrestrial networks (Release 15)"	Integration of NTN/ Satellite Access in 5G /	SSIG on NTN
3GPP	TR. 38.821, "Technical Specification Group Radio Access Network; Solutions for NR to support non-terrestrial networks (NTN) (Release 16)"	Integration of NTN/ Satellite Access in 5G	SSIG on NTN
3GPP	TR.23.737, "Technical Specification Group Services and System Aspects; Study on architecture aspects for using satellite access in 5G (Release 17)"	Integration of NTN/ Satellite Access in 5G	Catapult
3GPP	TR.28.808, "Study on management and orchestration aspects of integrated satellite components in a 5G network "	Integration of NTN/ Satellite Access in 5G	SSIG on NTN
3GPP	TR.24.821, "Study on PLMN selection for satellite access "	Integration of NTN/ Satellite Access in 5G	SSIG on NTN
3GPP	TR.36.763, "Technical Specification Group Radio Access Network; Study on Narrow-Band Internet of Things (NB-IoT) / enhanced Machine Type Communication (eMTC) support for Non-Terrestrial Networks (NTN)"	Integration of NTN/ Satellite Access in 5G	SSIG on NTN
ETSI	ETSI GR IP6 030 V1.1.1 (2020-10), "IPv6-based Vehicular Networking (V2X)"	IPv6-based Vehicular Networking	University of Luxembourg
ETSI TC ITS	1. Intelligent Transport Systems (ITS); Vehicular Communications;	CP Message Format and Data Elements, Sensor	VEDECOM

	Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2, ETSI TR 103 562 V2.1.1 2. Sophia Antipolis, France December 2019	Information Container, Perceived Object Container	
ETSI TC ITS	Intelligent Transport Systems (ITS); Vehicular Communications; Informative Report for the Manoeuvre Coordination Service, ETSI TR 103 578	General description of the Manoeuvre Coordination Service, Use Cases	VEDECOM

3.3. Workshops, Conferences and Webinars on Standardisation Discussions

5G-MOBIX has already covered the latest standardisation inputs fed back into these relevant SDO bodies (i.e. GSMA, ITU, ETSI and NGMN) to influence future standards in the 5G-V2X and CAM ecosystem. To achieve these, 5G-MOBIX partners have participated in such discussions and also organised dissemination activities with a focus on having an efficient and significant impact in terms of international standardisation in the industry.

The total list of public workshops, conferences, special sessions and webinars can be found in the exploitation report D7.7. Below Table 6 lists the following events which have particularly dealt with standardisation perspective, and 5G-MOBIX partners have actively contributed to.

Table 6: List of workshops, conferences and webinars on standardisation discussions

Session Type	Event Name	Related session / Publication title	Date & Place
Public Workshop	ITS World Congress	Connecting to Future Mobility	Hamburg 13 October 2021
Public Workshop	EuCNC & 6G Summit	5G for CCAM for Cross Border Corridors	Virtual 8 June 2021
Public Workshop	5G-MOBIX Workshop	Deployment Methodology of 5G for CAM on Cross-Border Corridors	Virtual 26 March 2021
Conference	IEEE Conference on Standards for Communications and Networking	Standardization Activities by 5GPPP Research Projects (5G-MOBIX)	Virtual 15 December 2021

Conference	ITS World Congress	Ubiquitous 5G Deployment for CCAM: Observations and Lessons Learned	Hamburg 11 October 2021
Conference Special Session	EuCNC & 6G Summit: On the Road to 6G	5G NSA Roaming Challenges and Prospects for Latency-Critical Applications with Strict Service Continuity Requirements	Virtual 8 June 2021
Conference Special Session	EuCNC & 6G Summit: On the Road to 6G	Seamless roaming with 5G SA deployments	Virtual 8 June 2021
Conference	IEEE 5G for Connected and Automated Mobility Summit	TDD Synchronization Testing Over Neighbouring 5G Networks in a Cross-Border Corridor	Virtual 11 May 2021
Webinar	5G PPP Webinar: 5G for Cooperative, Connected and Automated Mobility	5G Trials for CCAM along European 5G Cross-Border Corridors - Challenges and Opportunities	Virtual 6 November 2020
Webinar	ETSI Webinar: IPv6 Enhanced Innovation: the IPv6-Only Future in the 5G, IoT & Cloud Era	IPv6 Standardization in 5G-MOBIX	Virtual 13 September 2021

4. SPECTRUM ALLOCATION FOR 5G-ENABLED CAM

As mentioned earlier, the 5G NR bands under consideration by the regulatory bodies responsible for spectrum management are an indicator of the limits of the performance that can be achieved with 5G-enabled CAM services, and essential input for any study that aims to assess whether the spectrum needs of these services can be commercially met in the near future. Firstly, the current frequency bands assigned to 5G in the 5G-MOBIX countries are presented in Section 4.1. Then, the use cases and their spectrum needs including connectivity requirements and analysis methodology are elaborated in Section 4.2. Next, specific spectrum issues encountered at cross-border corridors are discussed in Section 4.3. Finally, other deployment considerations that can be contingent on standardisation to support them are introduced in the last section.

4.1. The Current Situation in 5G-MOBIX Trialling and Testing Countries

In the present section, the status of spectrum regulations in the countries where 5G-MOBIX trials were carried out is described, starting with the cross-border corridors (CBCs). Even though not established within the project as a CBC trial site, Germany has borders with the Netherlands and France, which is also a neighbour of Spain. Therefore, the spectrum regulation discussions in these countries are essential for a number of other 5G corridors, as well.

4.1.1. Spain

In the Spanish part of the cross-border corridor Telefonica is using 40MHz baseband bandwidth in the band of 2600 MHz which is used for the LTE anchoring of 5G NSA radio. This band is currently covering the Spanish corridor with 4G coverage.
The spectrum status of this band in Spain is depicted in Table 7.

Table 7: LTE Spectrum bands in Spain

	Bandwidth (MHz)	Frequency DL (MHz)		Frequency UL (MHz)
Telefonica	2 x 10 2 x 10	2620 - 2630 2630 - 2640		2500 - 2510 2510 – 2520
Vodafone	2 x 10 2 x 10	2660 – 2670 2670 – 2680		2540 – 2550 2550 – 2560
Orange	2 x 10 2 x 10	2640 – 2650 2650 – 2660		2520 – 2530 2530 – 2540

The 5G frequency that is going to be used in 5G-MOBIX is the n78 5G NR band (3400 – 3800MHz). This band was auctioned in two different phases making non-continuous spectrum allocations for the majority of the operators in the first phase.

The status of this band during the first phase is shown in the following table:

Table 8: 5G NR bands in Spain – phase 1

	Bandwidth (MHz)	Frequency (MHz)
Telefonica	20 + 20 + 50	3440 – 3460 3540 – 3560 3750 – 3800
Vodafone	90	3660 – 3750
MasMovil	40 + 40	3400 – 3440 3500 – 3540
Orange	20 + 20 + 60	3460 – 3480 3560 – 3580 3600 – 3660

After some negotiations between the Spanish regulator "Ministerio de Economía y Empresa" and operators, the band was relocated to ensure larger continuous spectrum blocks, which would help to implement high throughput services.
The status of this band during the second phase is showed in the following table:

Table 9: 5G NR bands in Spain – phase 2

	Bandwidth (MHz)	Frequency (MHz)
Telefonica	100	3500 - 3600
Vodafone	90	3710 – 3800
MasMovil	80	3420 – 3500
Orange	110	3600 - 3710

Once the relocation was done, Telefonica has up to 100 MHz continuous bandwidth to provide 5G services within the n78 band.

4.1.2. Portugal

As the project deployment took place before the 5G spectrum auction, the Non-Standalone 5G network was initially deployed on trial spectrum provided by the Portuguese Regulator, ANACOM, with an LTE anchor layer on band 3 (1800 MHz) and 5G NR on band n78 (3600 MHz). After the end of the auction, the 5G radio hardware had to be exchanged because those units did not support the part of spectrum that was allocated to NOS. Currently, the 5GMOBIX network in Portugal is configured in the NOS commercial spectrum, using 20 MHz of bandwidth on band 7 (2600 MHz) and 100 MHz on band n78 (3600 MHz). The 5G-MOBIX network is a test network segregated from the commercial network, so the use of this spectrum can only be secured as long as there are no sites on the border using band 7 and band n78.

Results of 5G auction

The main bidding phase of the Auction of 5G and other relevant bands ended after 1,727 rounds[1], with NOS paying EUR 165.1 million for a combination of 700MHz, 900MHz, 2100MHz and 3.6GHz spectrum, Vodafone spending EUR 133.2 million for spectrum on 700MHz and 3.6GHz bands, followed by MEO that paid EUR 125.2 million for spectrum on 700MHz/900MHz/3.6GHz. In terms of the 'new' bidders, Nowo bid EUR 70.2 million for 1800MHz, 2.6GHz and 3.6GHz spectrum, while Dixarobil paid EUR 67.3 million for spectrum in the 900MHz, 1800MHz, 2.6GHz and 3.6GHz bands. Finally, Dense Air spend EUR 5.8 million for frequencies in 3.6GHz band. The 26 GHz auction is expected to occur in 2023.

Table 10: Spectrum allocation for the n78 band in Portugal as of October 2021

	Bandwidth (MHz)	Band	Frequencies until end of 2025 (MHz)	Frequencies after 2026 (MHz)
MEO	90	n78	3520 - 3610	same
NOS	100	n78	3610 - 3710	same
Vodafone	90	n78	3710 - 3800	same
Dense Air	40	n78	3400 - 3500	3440 - 3480
Dixarobil	40	n78	NA	3400 - 3440
NOWO	40	n78	3500-3520	3480 - 3520

Table 11: Spectrum allocation for the n28 band in Portugal as of October 2021

	Bandwidth (MHz)	Band	Frequency (MHz)
MEO	2 x 5	n28	703 – 708, 758 763
NOS	2 x 10	n28	723 – 733, 778 - 788
Vodafone	2 x 10	n28	713 – 723, 768 778
Dense Air	0	n28	NA
Dixarobil	0	n28	NA
NOWO	0	n28	NA

[1] https://anacom.pt/render.jsp?contentId=1709636

Auction coverage obligations

The 5G auction included in the rules obligations associated with the allocation of the 700 MHz band. The obligations were defined in annex 3 of auction conditions that impose on incumbents a coverage target, by the end of 2025:

- of 95% of the total population of the country, each **highway**, the metro networks of Lisbon, Porto and Sul do Tejo and each of the rail routes included in the Atlantic Corridor, within the national territory, in the Braga-Lisbon link, the Lisbon-Faro link and the urban and suburban links of Lisbon and Porto;
- of 85% of each **main road route**, of National Road 1 and National Road 2 and each of the remaining rail routes.

Additionally, the coverage obligation requires 75% (by the end of 2023) and 90% (by the end of 2025) of the population of each of the parishes classified as low-density and each of the parishes of the Autonomous Regions of the Azores and Madeira. Moreover, the coverage obligation for the population of each of the parishes not classified as low-density, but belonging to municipalities with low-density parishes, is 70% (by the end of 2024), and 90% (by the end of 2025).

5G reports and status

According to the 5G report published by ANACOM on 4 June 2022[2], the total number of 5G base stations reported to ANACOM until the end of first half of 2022, amounts to 2918 spread over 198 municipalities (64% of the municipalities in the country) and 859 parishes (28% of the parishes in the country). NOS was the operator that so far installed the largest number of 5G stations, 1937 stations (66%), followed by Vodafone with 534 stations (18%) and MEO with 447 stations (15%). The vast majority of 5G stations, 79% of the total, corresponding to 2316 stations, are located in Predominantly Urban Areas. Only 11% (325 stations) are installed in Medium Urban Areas and 10% (277 stations) in Predominantly Rural Areas. The analysis of the distribution of 5G stations across the country's parishes, taking into account their population density, leads to the conclusion that only 13% of the total (372 stations) is installed in low-density parishes.

According to Ookla Q1—Q2 2022 report, NOS is the Portuguese fastest 5G Mobile Network[3], with median download speeds of 362.84 Mbps and median upload speeds of 34.12 Mbps. MEO achieved median download speeds of 330.36 Mbps and median upload speeds of 26.04 Mbps, followed by Vodafone with median download speeds of 203.37 Mbps and median upload speeds of 28.00 Mbps. These high median throughput results are obtained after the first 6 months of network rollout with a low percentage of 5G network users, but it is expected to become lower as the penetration rate of 5G services increases.

[2] https://www.anacom.pt/render.jsp?contentId=1724988

[3] https://www.speedtest.net/awards/portugal/2022/?award_type=5g&time_period=q1-q2

4.1.3. Greece

The multi-band 5G auction in Greece ended on December 16, 2020 after six rounds of bidding. The three current MNOs (COSMOTE, Vodafone, WIND) got spectrum in all bands for sale (700 MHz, 2 GHz, 3.4-3.8 GHz and 26 GHz). Specifically, for the n78 band which is of interest for the 5G-MOBIX GR-TR deployment, the allocation is as depicted in Table 12. The 2.6 GHz LTE band is used for anchoring.

Table 12: N78 NR band allocation in Greece

	Bandwidth (MHz)	Frequency (MHz)
COSMOTE	150	3450 - 3600
Vodafone	140	3410-3450, 3600 – 3700
WIND	100	3700 – 3800

COSMOTE, based on the experience of GR-TR deployment is seeking to explore its available spectrum, as depicted in the table below, for CAM services, especially the 700 NR, that safeguards coverage requirements.

Table 13: 5G Frequency Bands Allocated to COSMOTE

Frequency Band	Acquired Bandwidth (MHz)	UL Frequencies	DL Frequencies
700 MHz (FDD)	2 x 10	778 – 788 MHz	723 – 733 MHz
2100 MHz (FDD)	2 x 20	1960,3 – 1980,3 MHz	2150,3 – 2170,3 MHz
3400 – 3800 MHz (TDD)	150	3450 – 3500 MHz, 3500 – 3600 MHz	
26 GHz (TDD)	400	26700 - 27100 MHz	

4.1.4. Turkey

For the last couple of years, mobile operators in Turkey have been making their preparations to ready their networks for a smooth 5G transition as soon as new 5G spectrum is made available by the ICTA (Information and Communication Technologies Authority), the Turkish national regulatory body. Whereas the ICTA has yet to announce the auction date, auction format, spectrum bands involved, auction conditions and amount of spectrum for each band, it is expected that all primary 5G frequency bands (i.e. 700 MHz, 3.5 GHz, and 26 GHz) will be included in the auction to be held in the upcoming years (most probably in 2023 based on the current policy followed by the government).

Meanwhile, as a first step before nationwide availability of 5G, the ICTA granted the operators some temporary licenses in 3.5 GHz band to commence their 5G services in the Istanbul Airport so that domestic and international users can experience 5G services within the airport. For this purpose, all three mobile operators are provided with temporary spectrum licenses of 100 MHz (only valid within the airport). In this direction, a limited 5G commercial launch took place on July 29th, 2022 in Turkey.

4.1.5. Germany

The preliminary status of the spectrum regulations was given in D6.3 at the beginning of 2021 when 5G in Germany was already active by some MNOs. The last status is listed below:

- The 700 MHz frequencies assigned in June 2015.
- "5G for Germany", autumn 2016.
- 5G spectrum roadmap, 2018.
- Final conditions for 5G Auction, November 2018.
- 4-3.7 GHz (300 MHz) and 2 GHz (2×60 MHz) 5G auction ended in June 2019 raising 6.55 billion EUR (of which 4.18 billion EUR for the 36 GHz spectrum). Licences include coverage obligations.
- 100 MHz reserved for local and regional purposes in 3.7-3.8 GHz spectrum. Applications opened on November 21st, 2019.
- 26 GHz spectrum expected to be potentially awarded upon application.
- Vodafone and Deutsche Telekom launched 5G in July 2019, Telefonica in October 2020. The new player 1&1 Drillisch has not launched 5G yet.
- Federal Network Agency, n78, 3.7-3.8GHz for experimental networks.

In Germany, the spectrum for 5G networks has been allocated mostly in two bands, which are the n1 band at 2.1 GHz (5G NR n1) and the n78 band at 3.6 GHz (5G NR n78). During 2022 Deutsche Telekom plans to deploy and use 5G Standalone network working at the 700 MHz band.
In addition to the commercial licenses mentioned above, experimental networks and 5G campus networks can get a temporary license valid for one year from Federal Network Agency on n78 band, in the range of 3.7 to 3.8 GHz.

4.1.6. Finland

The 5G spectrum assignment has primarily occurred in three bands, namely, 700 MHz, 3.5 GHz (3.4 - 3.8 GHz) and 26 GHz (24 – 28 GHz) bands. The assignment for the 700 MHz band (2 x 10 MHz paired FDD bandwidth) was conducted in November 2016, whereas, for the 3.5 GHz band the auction was concluded in October 2018 with 15-year commercial licenses (each 130 MHz TDD bandwidth) were awarded to three operators (Telia, Elisa and DNA) from January 2019.
Furthermore, the auction for the 26 GHz band occurred in June 2020, with 15-year spectrum licenses eventually being awarded to the three main operators (Telia, Elisa and DNA) valid from July 2020. The allocation in each of these licenses was 800 MHz TDD bandwidth. Moreover, 850 MHz bandwidth (also TDD) at the lower part of the 26 GHz band was reserved for education and research purposes, as well as local private usage for different verticals.

A summary of the spectrum allocation for the public commercial operators is shown in Table 14. It is noted that the 700 MHz band may also be reused for LTE by different operators in Finland. This is also the case for bands, such as, the 2 GHz and 2.6 GHz FDD bands (originally intended for UTRA and LTE), which may also be leveraged for 5G.

Table 14: Summary of the spectrum allocation for commercial operators in Finland in July 2022

	Bandwidth (MHz)	Band	Frequencies until end of year 2033 (MHz)
DNA	2 x 10	n28	UL 703 – 713 DL 758 – 768
Elisa	2 x 10	n28	UL 713 – 723 DL 768 – 778
Telia	2 x 10	n28	UL 723 - 733 DL 778 – 788
DNA	130	n78	3670 – 3800
Elisa	130	n78	3540 – 3670
Telia	130	n78	3410 – 3540
DNA	800	n256	26700 – 27500
Elisa	800	n256	25100 – 25900
Telia	800	n256	25900 – 26700

It is noted that a significant number of 5G-MOBIX CAM trials in the FI-TS were conducted in a multi-PLMN environment with overlapping Elisa and Telia network coverage with networks operating in NSA mode in the n78 band shown above. Moreover, AALTO which hosted the test site has had an additional test license (60 MHz TDD bandwidth) in the n78 band for additional testing and experimentation.

4.1.7. France

The preliminary status of the spectrum regulations was given in D6.3 at the beginning of 2021 when 5G in France had just started to be launched:

- 5G launch by SFR in November 2020, by Bouygues Telecom and Orange France in December 2020
- 700 MHz frequencies assigned in December 2020
- Consultation on 5G
- Trial licences and trial cities, 2017-2020
- 5G pilot window, January 2020
- Provision of mid-band spectrum for trials in selected
- 5G roadmap, July 2020
- 5 GHz auction completed on October 1st, 2020. Results of the positioning auction published on October 20th, 2020.

Updates are quarterly provided by the regulator ARCEP. The last update is from June 2022 with figures at the 31st of March 2022 and can be found on their website[4].

The main figures for the 4 French MNOs are in Table 15.

Table 15: Overview French MNOs

	Bouygues Telecom	Free Mobile	Orange	SFR
Nombre de sites 5G	**7132**	**14404**	**3491**	**5721**
Progression des sites depuis le 31/12/2021	+402	+934	+456	+737
dont sites équipés en bandes :				
700 & 800 MHz	0	14404	0	0
1800 & 2100 MHz	6812	0	442	2596
3500 MHz	2998	2860	3204	3125

Furthermore, spectrum can be allocated for private networks, especially in the bands 38 and 41 (2.6GHz in TDD). However, at this moment, it is allowed only for experimentations, and soon to come authorisation for commercial private 5G in those bands.

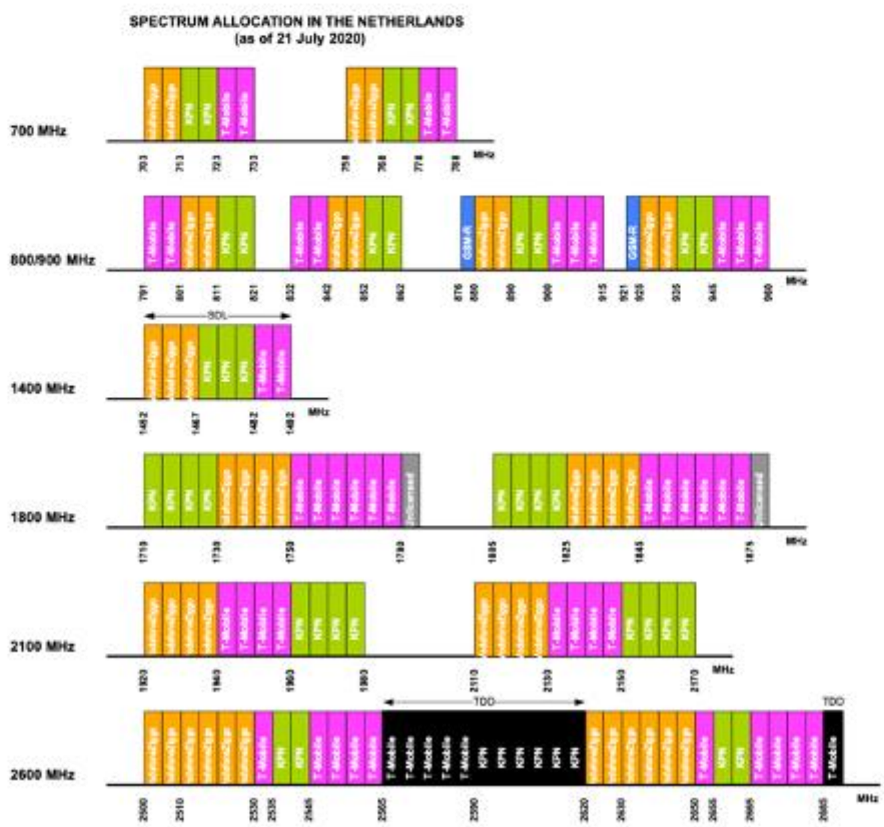
Regarding 5G mmWave in 26GHz (bands n257, n258), there are only experimental networks with 100MHz blocks, as the spectrum has not yet been put on the market.

4.1.8. The Netherlands

Currently in the Netherlands frequencies in the lower – and mid-band are available for mobile communication. The first 5G frequencies in the 700MHz band have been auctioned in July 2020 [3]. Table 16 gives an overview of the current frequency allocations. The other 5G bands (3500MHz and 26GHz) will be auctioned at a later date. The first auction for 3,5GHz is expected in 2023 with an availability of licenses in December 2023 [4]. The spectrum is devised for private and public use. The first 100MHz will be available for private use. The 300MHz located above the 100MHz spectrum for private use will become partially available at first and fully available from 2024. For the mmWave frequencies no auctions are planned yet. Discussions are currently ongoing on the health impact and the national health council has advised to do more research on the impact of mmWave frequencies on health [5].

[4] https://www.arcep.fr/cartes-et-donnees/nos-cartes/deploiement-5g/observatoire-du-deploiement-5g-juin-2022.html

Table 16: Spectrum allocations in the Netherlands as of July 21th, 2021.



The licenses in the Netherlands are not bound to a specific technology, this way also the previously auctioned spectrum can be used to provide 5G coverage. With the auctioning of the 700MHz band extra rules have been imposed on the providers acquiring at least 2x10MHz of spectrum in that band. These rules impose that:

- Every municipality in the Netherlands needs to be covered for 98% (two years from acquiring the spectrum). The coverage can also be provided with previously acquired spectrum. Natura 2000 areas are excluded from this.
- A minimum speed of 8 Mbps needs to be available. Also, for this the previously acquired spectrum is included.
- A minimum area needs to be covered by each band. The size of this area is different for each band and gives a minimum size to be reached in two and five years.

The "Antenne Bureau" keeps record of all mobile sites deployed in the Netherlands [6]. In May 2022, 11.934 5G sites were operational. For comparison, on the same date 15.487 LTE sites were operational. This would indicate that 77% of the sites in the Netherlands have 5GNR deployed on site. Two operators (KPN and T-Mobile) have used the 700MHz band to deploy 5GNR. Vodafone has used the 1800 MHz band to deploy

5GNR (utilizing dynamic spectrum sharing with LTE on the same band). Figure 6 shows the 5G NR sites currently deployed in the Netherlands[5].

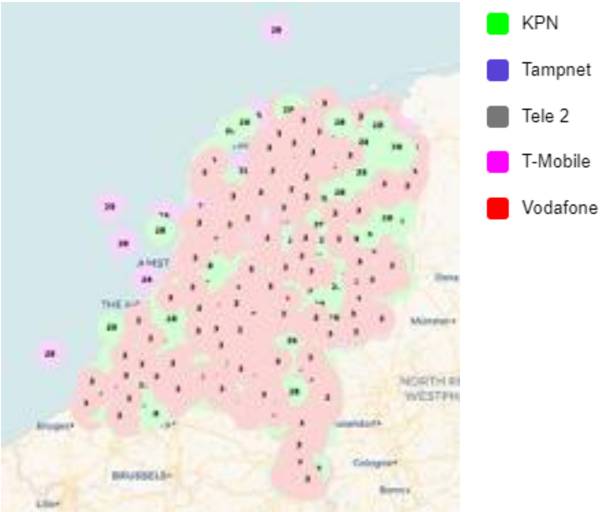


Figure 6: 5G NR deployment in the Netherlands

Umlaut has published a report on the mobile network performance of the three operators in the Netherlands at the start of 2022 [7]. This report shows the competition in the Netherlands is fierce; all operators try their best to offer the best possible performance and coverage. The report contains a "Roads drive test", comparing the performance of the three mobile network operators on the road.

Table 17: Road drive test results

	Upload (Mbps)		Download (Mbps)	
	90%	10%	90%	10%
KPN	15.2	63.5	32.3	218.5
T-Mobile	12.2	60.8	30.9	188.5
Vodafone	6.1	54.7	17.5	127.8

These results show that the network in the Netherlands is downlink oriented; the uplink has about 40% of the capacity available for the downlink. Tests done in 5G-MOBIX (see D3.7 section 2.8) show that also the 3.5GHz band is mainly downlink oriented. Since the 3.5 GHz NR band will only partially cover the roads in the future (with the current site densification) it will mainly help to offload traffic at the cell centre, also increasing the capacity a little at cell edges. Still the uplink will be limited and (not taking a possible increase in use into account) be somewhere between the 90% and 10% point of the best performing operator (15.2 – 63.5Mbps). When looking at for instance the remote driving use case with an uplink requirement between 25 and 50Mbps we are at the limits of what is possible with a single vehicle. When such a remote driving use

[5] https://antennekaart.nl

case is needed on a larger scale, further densification is needed of our mobile networks using higher frequencies.

4.1.9. China

In China, 5G services are provided by three telecom operators in Mainland China: China Mobile, China Unicom and China Telecom. China Mobile has 160MHz bandwidth of 2515-2675MHz on the 2.6GHz frequency band, of which 2515-2615MHz (100MHz) will be used to deploy 5G, and 2615-2675MHz (60MHz) will be used to deploy 4G. It also has a 5G frequency band of 4800-4900MHz (100MHz), which may be used for 5G supplementary hotspot, private network, etc. The 5G frequency bands of China Telecom and China Unicom are continuous, and the two have announced that they will jointly build and share a 5G wireless access network based on the continuous 200MHz bandwidth of 3400MHz-3600MHz. In granting 5G licenses, China Mobile and China Broadcasting Network (CBN) have opted to jointly develop a 700MHz 5G network. In March 2020, the 700MHz frequency band's 2×30MHz large-bandwidth technical solution formulated by CBN was adopted and included in the 5G international standard, becoming the world's first low-frequency band and large bandwidth 5G international standard.

The overall spectrum resources of 5G can be divided into the following two frequency ranges (FR) with 3GPP protocol. In FR1, 450 MHz – 6000 MHz frequency band is the low-frequency band for the main 5G frequency band. Among them, frequencies below 3GHz are called sub3g, and the rest are called C-band. FR1 has the advantages of low frequency, strong diffraction ability and good coverage effect as the main spectrum of 5G currently. n41, n77, n78, n79 are the mainstream frequency bands in China for the current test networks. With extending frequency band of 5G and rich in spectrum resources, the FR2 ranges from 24250 MHz – 52600 MHz millimetre wave called the high-frequency band. The current version of millimetre wave defines only four frequency bands, all of which are TDD mode, and the maximum cell bandwidth supports 400MHz. The advantages of FR2 are its ultra-large bandwidth, clean spectrum, and less interference, which can be used as a follow-up extension frequency for 5G. In China, only the frequency bands in FR1 are allocated, and the frequency bands supported by the three major domestic operators are as follows:

Table 18: FR1 bands in China

MNOs	5G frequency (MHz)	Bandwidth (MHz)	Frequency Number
China Mobile	2515 - 2675	160	n41
	4800 - 4900	100	n79
China Telecom	3400 - 3500	100	n78
China Unicom	3500 - 3600	100	n78

4.1.10. South Korea

In many countries, the 5G rollout will be initiated in diverse frequency ranges corresponding to distinct coverage/capacity objectives:

- low frequency bands (around 700 MHz) for large coverage;
- mid frequency bands (around 3.5 GHz) for urban coverage/high capacity;
- mm-wave range (26 GHz typically) for hot spots/very high capacity.

On the medium term, all mobile bands currently used for 4G/LTE will be migrated to 5G NR. In ITU, two distinct streams of discussion are under way:

- Definition of new interfaces for IMT-2020 (ITU name for 5G);
- Identification of new frequency bands for IMT-2020.

In Korea, demand of development of the new radio technologies has been suggested to maximise the utilisation of radio spectrum resource in the wireless mobile network by related stockholders. Not only to meet industrial and research demand but also to prepare next generation mobile network, especially for the vehicular communication, new spectrum policies based on dynamic spectrum access technology such as flexible access common spectrum (FACS) have been adopted by the Korea Communications Commission (KCC) [8].

The mmWave band vehicular communication system operates in the unlicensed band of 22-23.6 GHz called FACS and aims to provide broadband mobile wireless backhaul (MWB) between base station (BS) and vehicle equipment (VE). In this band, any wireless service is possible while keeping the coexistence rules, as follows [9]:

- Maximum transmit power = 100 mW
- Maximum power spectral density (PSD) = 6 dBm/MHz
- Maximum antenna gain = 16 dBi

Based on the background above, the KR trial of the 5G-MOBIX has been launched to develop tethering and remote-control use case via millimetre (mmWave)-band vehicular communications system.

4.2. 5G-MOBIX Use Cases & Spectrum Needs

The spectrum needs for 5G-MOBIX Use Cases were initially addressed in T6.3 as a theoretical exercise to determine the minimum bandwidth necessary to comply with the requirements that each of the Use Cases – and Stories - impose on the network. A basic simulation including the transmission scenario, with communication data rates, number of road users, communication range and spectral efficiency was planned, in order to assess: 1) how current capabilities of the network at 5G-MOBIX sites are adequate for the implementation of the CAM services, and 2) what could be the necessary elements that would be required for complying with these required capabilities.

5G-MOBIX outcomes from the cross-border test sites, as well as additional studies made during the project, have approached this issue not only from the analytical point of view, as intended in this task, but from the direct deployment perspective. The results, in brief, point at the current network as being appropriate for the deployment of the 5G-MOBIX proposed CAM solutions. In the following pages, we will present a more detailed description of the main results of these activities, in alignment with the T6.3 goal of providing recommendations on spectrum needs for 5G CAM services. The detailed explanation of use cases and user stories based on their description and requirements can be found in D6.3 report.

4.2.1. CAM Connectivity Requirements

Described extensively in the previous D6.3 deliverable, section 4.6.1, and also part of the 5G-MOBIX Deployment Study, the assumptions and final requirements for the 5G-MOBIX Use Case connectivity requirements are the results of the analysis of the UCs themselves, and talks with test-site leaders and technical experts. The overview of these requirements is presented in Table 19.

Table 19: 5G-MOBIX Key Use Case connectivity requirements

Parameter	Advanced Driving	Platooning	Extended Sensors	Remote Driving	Vehicle QoS support
E2E latency (at app layer)	< 50ms	< 50ms	< 100ms	< 50ms	< 100ms
Vehicle bit rate	40 Mbps	30 Mbps (DL/UL)	20 Mbps (DL/UL)	36 Mbps (UL)	1 Mbps
Mobility	Up to 100 km/h	Up to 80 km/h	Up to 100 km/h	20 km /h	Up to 100 km/h
Reliability	99,99%	99,99%	99,99%	99,99%	99,99%

It should be noted that these figures are slightly different from those initially presented in D6.3, due to the fact that these are aggregated numbers, and also the result of discussions and confirmation from other stakeholders. D6.3 presented a first estimation on the figures for the 5G-MOBIX connectivity requirements.

4.2.2. Spectrum Needs Analysis Methodology

The following step of both the analytical assessment as well as in the deployment study was the estimation of the spectrum needs for the different scenarios taking into account a number of assumptions. These assumptions vary from the technical characteristics of the infrastructure and the vehicle communication components to the projected figures of traffic and its evolution in the following years, through the evolution in the penetration of L3+ CAM enabled vehicles, among other items:

- Base stations operating in the usual 700 MHz and 3500 MHz bands for ITS applications, and their respective technical specifications,
- Vehicle OBUs technical specifications in communications,

- 5G-MOBIX UCs requirements, as noted above,
- Road traffic: vehicles, hourly traffic distribution, and the corresponding proportion and projection of CAM-enabled vehicles, usage of existing network resources (5G or otherwise).

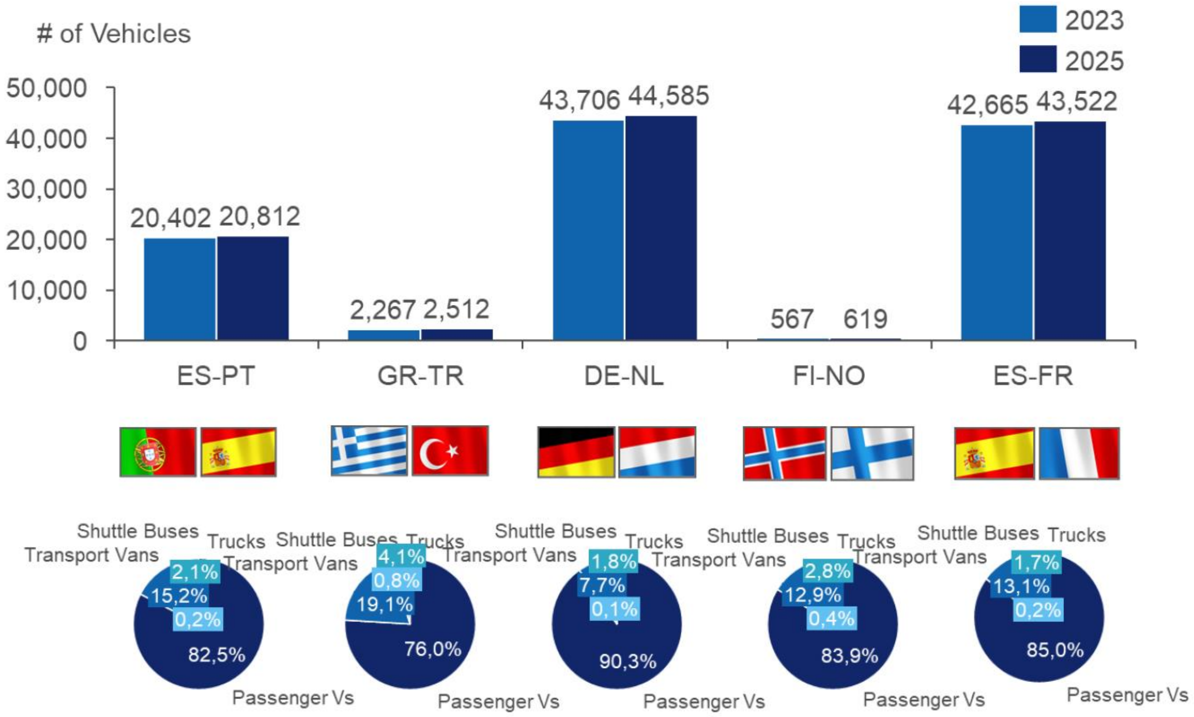


Figure 7: Traffic forecast and vehicle type shares by CBC [10]

The traffic forecast is used to determine the number of vehicles that might be requesting the use of the 5G network for CAM services. The projection of this number of vehicles, and their characteristics in terms of use of the network resources, is the key aspect for the deployment study to determine whether current infrastructures are enough for the upcoming years to support the proposed services. Sites with less expected traffic growth may be served with minimal changes to current communication infrastructures, while others in which a larger growth is expected might need to update their resources.

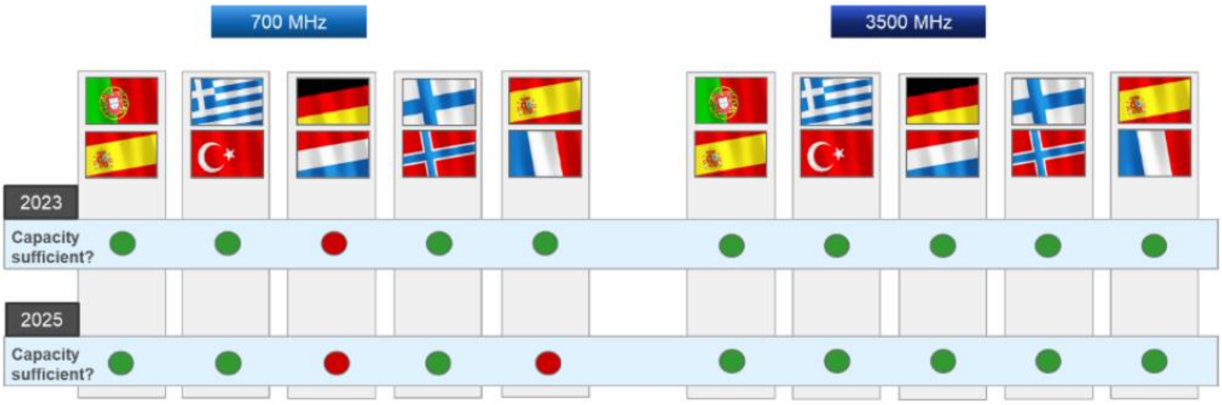
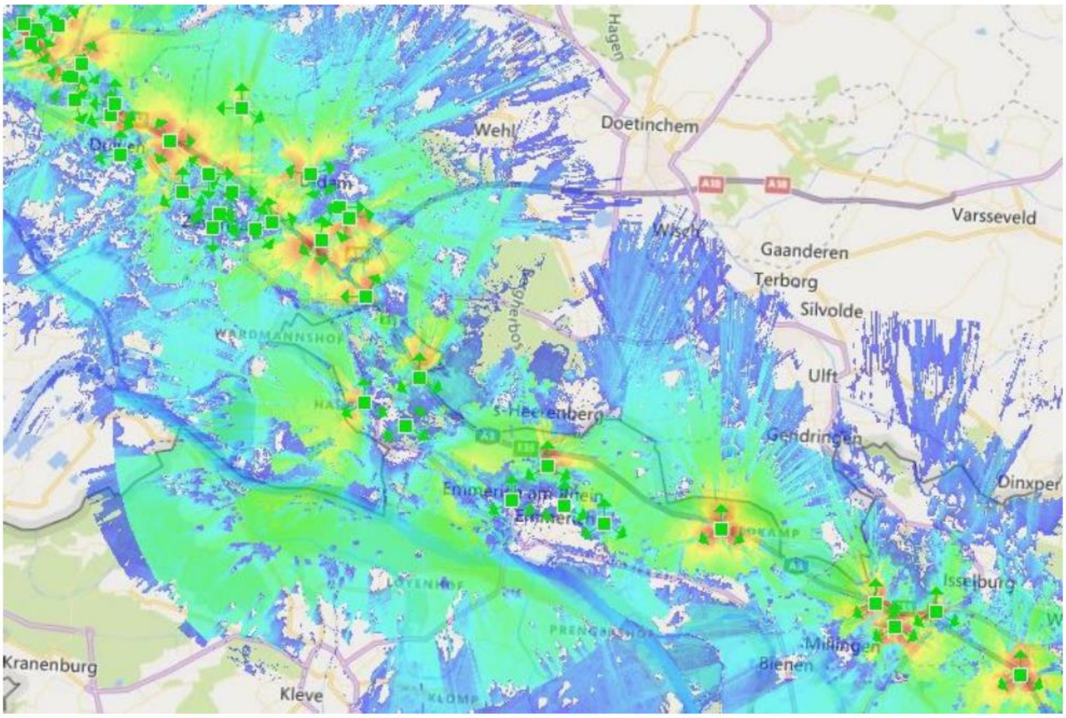


Figure 8: Overview of capacity sufficiency. 700 MHz and 3500 MHz bands, average load traffic and services use

Estimations for an average traffic load and average CAM services usage indicate that in most of the 5G-MOBIX test-sites, current 5G network is enough for the next few years. The deployment study, however, also contemplates cases in which the traffic load is considerably higher, as well as cases in which each of the vehicles makes use of more resource-intensive CAM services, taxing more as a consequence of the 5G infrastructure.

Very detailed simulations were included in the study, in which the specific location of the base stations, as well as the topography characteristics of each site, and the particular technical specifications of each of the bases were used. Current situation/coverage, as well as a plan to ensure adequate compliance with the expected requirements with traffic evolution, were carried out.

The following figures show an example of the simulation for the 700 MHz band in the ES-PT CBC site. It shows that there is essentially good signal in all the area, and excellent in the case of the border area itself, with almost no coverage gaps in the stretch considered. Similar assessments - positive or negative - are made in the case of the other CBC sites.



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 9: Existing sites in the area NL-DE Veldhuizen CBC, 5GNR 3500 MHz TDD radio coverage simulation [10]

4.2.3. Results

At the end of the spectrum needs assessment, the initial analytical study was superseded by the CBC sites tests and the focus group approach of the deployment study. However, it is interesting to note that both studies had similar assumptions from the 5G-MOBIX use cases. Almost from the first preliminary analysis, it was becoming clear that this was a very complex task, and that scaling up aspects would take predominance in the study, rather than any given use case requirements. The fact that the spectrum needs seem to go together with the willingness of MNOs to provide performance intensive CAM services, while not clear what is the added value of this over the ones that can be deployed in the majority of cases on the current infrastructure, does not make the things easier for this analysis. Even more, because for most of CBC scenarios current network infrastructures cover most of the needs of the UCs in the immediate future.

4.3. Spectrum Issues Encountered at Cross-Border Corridors

As targeted at the beginning, the 5G-MOBIX project stands in a position to pioneer identification of potential performance problems with such networks at cross-border corridor and its scenarios, which can be alleviated through a collaboration of the neighbouring MNOs. The need to agree on a common TDD frame structure to eliminate the excessive interference especially on the uplink (UL) channels is one of the main observations of the GR-TR corridor.

TDD, which is expected to be widely employed in mobile networks with the advent of 5G, is considered the prevailing technique to optimize spectrum usage and allow for flexibility in bandwidth allocation between the UL and downlink (DL). In FDD, already utilized in large-scale LTE mobile networks, different frequency channels are used for the UL and DL, separated by a guard band to avoid interference between the two. The channel size is the same for both, and in order to support the significantly higher download demands, advanced features such as 256 QAM modulation and 4x4 MIMO are employed on the DL. In TDD systems instead, transmission and reception occur in the same frequency channel, with different time slots assigned to the user equipment on the UL and DL, respectively. By changing the duration of these, and selecting the appropriate transmission pattern, network performance can be tuned to balance the UL and DL capacities as necessary. However, to avoid interference and subsequent deterioration of performance, any adjacent TDD networks –either 5G or LTE– need to be synchronized, neighbouring base stations must transmit at the same fixed time periods and all devices should only transmit in dedicated time periods.

Different frame structures correspond to different trade-offs in terms of performance. For example, the more frequent the DL/UL and UL/DL switching, the lower is the RTT (Round Trip Time). A short latency improves the channel estimation quality (CQI) using TDD channel reciprocity properties and enables fast HARQ retransmissions. More frequent switching therefore has a positive impact on spectrum efficiency in high mobility conditions. The frame structure also affects coverage performance. The guard period (GP) between DL and UL must be large enough to compensate the propagation delay for large cells (and for coexistence with other cells in line of sight).

MNOs need to carefully assess the proper frame structure to optimize their service offerings according to market demands, while at the same time achieve the necessary synchronization with neighbours to avoid interference. The use of TDD frames that inherently mandate time and phase alignment between radio base stations (BSs) add complexity in the process of preventing interferences and related loss of traffic, demanding a particular level of synchronization with neighbouring networks. At a national level, alignment between operators can be facilitated through legislation and national regulation that administer the spectrum allocation and can publish guidelines to facilitate the necessary synchronization. However, in cross-border network deployments, achieving network synchronization is a difficult task, since a common framework may not be possible.

GSMA for 3.5GHz TDD Synchronisation

GSMA and ECC/CEPT have investigated the importance of TDD synchronization in the 3.5 GHz range, with the aim to inform policymakers and mobile operators on relevant aspects. GSMA provided a set of recommendations, including proposals on the preferred frame structure for initial 5G launches in 3.5 GHz as summarized in the following paragraphs:

- **Recommendation 3 [Synchronization at National Level]:** All networks should use the same frame structure at a national level, with the following recommendations:
    - Where incumbent systems such as LTE exist in the 3.5 GHz range, the LTE and NR systems need to use compatible frame structures. As the best compromise, LTE networks are required to use the frame structure DSUDDDSUDD, while 5G NR networks are required to use either DDDDDDDSUU (with a 3ms shift) or DDDSUUDDDD.
    - Where no incumbent systems are present, the preferred frame structure is DDDSU, with 30 kHz SCS. The Special slot "S" format should be configured with a ratio of 10 Downlinks, a 2 Symbol Guard Period and 2 Uplinks (10:2:2)
- **Recommendation 4 [Synchronization at International Level]:** Networks should be synchronized at an international level; nevertheless, priority is given to achieve synchronization at the national level. International alignment is difficult, due to the number of countries involved, the different migration and implementation timescales and the difficulty of negotiating per operator and neighbouring country. It is anticipated that the preferred frame structures are:
    - DDDSU with 30 kHz SCS;
    - DDDDDDDSUU (with a 3ms shift) or DDDSUUDDDD, only if LTE is present at the band.
- **Recommendation 5 [Cross-border Coordination]:** To manage cross-border coordination, even though the use of a common frame structure is favoured, it is considered unlikely due to the domino effect that shall involve a large number of countries. Localized alternatives are proposed:
    - In the border areas where neighbouring countries have selected the same frame structure, all the synchronized base stations can be used on either side of the border with limited coordination efforts.
    - In the border areas where neighbouring countries have not selected the same frame structure operators will need to engage in additional coordination efforts. Discussions and agreements of operators on bilateral or multilateral and in respective industry forums are necessary and the involvement of policymakers and/or administrations can be a useful complement.
- **Recommendation 6 [Co-existence of non-synchronized networks]:** Where no agreements on the frame structure can be reached, the following practical solutions to coexistence of networks are proposed:
    - Localized frame structure (i.e. indoor usage),
    - Network optimization (such as base station location, antenna, direction, and power limits),

- Downlink blanking where operators, on both sides of the border, agree to stop the use of some of their downlink slots when the other operators are using an uplink slot - although, this will impact performance and may not be supported,
- A step-by-step migration based on the regional timings of 5G deployments and 4G migrations; 4G networks to be migrated to a different band or to 5G technology,
- Commercial agreement between 5G operators and incumbent 4G operators (including acquisitions, re-farming, and reprogramming),
- Reduce capacity near the borders, i.e. by only using a part of allocated spectrum,
- Use alternative bands within the cross-border area,
- Avoid co-channel use and aim to use adjacent channels – temporary band plan at the border,
- Use club licenses, spectrum and infrastructure sharing.

ECC on National and Cross Border Synchronization

According to ECC report 296 [26], about the coexistence of MFCNs (mobile/fixed communications networks) in n78 band, synchronized operation avoids any BS-to-BS and Mobile Station (MS)-to-MS interference, therefore allowing coexistence between adjacent networks without the need for guard bands or additional filters. However, the deployment of synchronized networks means that all MFCNs in the same band should use a common phase clock reference and a compatible frame structure to avoid simultaneous UL/DL transmission. The report also underlines that the separation distance between two unsynchronized macro base stations/networks is up to 60km for a co-channel configuration and up to 14km for adjacent channel operation. Moreover, the ECC Rec 15(01) [27] on cross-border coordination for MFCN in (3400-3800) MHz, explicitly denotes that among the frame structures defined for NR by 3GPP, NR frame DDDSUUDDDD and DDDDDDDSUU are compatible with the LTE frame structure configuration. This is clearly reflected in GSMA Recommendations #3, #4.

To ensure nationwide outdoor deployment for NR mid band, technology experts advocate that the best coexistence method is to synchronize all networks in the same band independently of used TDD technology (ex. 5G, LTE, WiMAX). Synchronized operations mode maximizes spectral efficiency, minimizes implementation cost and is feasible/implementable from a technology (i.e. Active Antenna Systems - AAS) perspective. Advanced radio functionality such as LTE-NR aggregation, AAS beamforming and scheduling enhancements can further improve both user plane and control plane connectivity characteristics and the performance of the radio link, and shall be greatly beneficial for the V2X services. Future coming technologies, such as cross-link interference cancellation, will certainly improve the flexibility of operating different NR TDD frames in a local fashion or in a more wide-area network deployment.

In the context of the 5G-MOBIX project, the NR TDD DDDSUUDDDD (4+2+4) SFS 3:8:3 that is used widely in 5G commercial network deployments, is proven suitable for V2X applications, ensuring wide-area coverage for mobility as well as, very good performance in terms of UL and DL throughput. This frame structure is in alignment with GSMA Recommendations #3, #4 on synchronizing networks. At the same time, NR TDD DDDSUDDSUU (4+1+3+2) SFS 10:2:2, also in alignment with GSMA recommendations #3, #4 is offering better UL performance, an important advantage for the 5G-enabled CAM use cases.

4.4. Other Deployment Considerations

Below Table 20includes some of the deployment considerations that can be contingent on standardisation or regulatory innovation to support them.

Table 20: Other deployment considerations

Description		Possible solutions
Numbering resource exhaustion	Assignment of numbers for IoT/M2M may lead to exhaustion of numbering resources. According to The BEREC report on Enabling the Internet of Things [12], scarcity of E.164 numbering resources does not appear to be a barrier, but NRAs should analyse this and solve any occurring problems on national level.	**Use of eSIM and Over-the-air provisioning:** The current version of E.118 [11] allows the assignment of SIM numbering resources only to the Electronic Communications Networks/Services (CN/ECS) providers, more precisely to Operating Agencies OAs). Since the definition of embedded SIM (eSIM) by GSMA, E.118 has been opened by SG2 (as of July 2018) for review, mainly to take into account the assignment of these numbering resources to eSIM manufacturers for generating the EID. At the moment, the EU has legislated that assignment of numbering resources to non-ECN/ECS entities is permitted under the European Electronic Communications Code [13], although non-ECN/ECS entities need to satisfy certain preconditions. Member States, however, retain the right to permit or allow this on a national level. **Permissibility of extra-territorial use of E.212 and E.164:** It must be ensured that public interests like security, national sovereignty etc., are respected. The use of extra-territorial numbers is covered by the European Electronic Communications Code [13] which states that in the case of non-interpersonal communications, each MS is responsible to ensure that NRAs/ CAs make available a range of non-geographic numbering resources for use outside the territory of the assigning MS (but within the EU).
Supply chain security	According to the EU 5G Cybersecurity Toolbox [14], the role of National Regulators should be increased in order to ensure that some safeguards with respect to cybersecurity are in place. However, implementation of the 5G Cybersecurity Toolbox is moving at a	Key measures include: • Strengthening security requirements for Mobile Network Operators (MNOs) at Member State level. • Assessing the risk profile of suppliers, and applying restrictions in terms of key assets such as exclusion of a high-risk supplier. • Ensuring that MNOs adopt a multi-vendor strategy and avoiding dependency on a single supplier. • Maintaining a diverse and sustainable 5G supply chain. • Using relevant EU programs and funding. • Facilitating standardisation and certification.

	different pace among the Member States.	• Making use of other existing frameworks, e.g. relating to the screening of Foreign Direct Investment (FDI), etc.
Coverage & Resilience improvement	National regulators often impose coverage obligations as part of the spectrum licensing process. According to the trial site interviews provided within the project (T6.4) and interviews performed as part of the 5G-MOBIX deployment study [10], telco operators reported that coverage obligations are the main driving force for investment in 5G. This guides the telecoms in their roll-out of 5G services across each country, including its major transport corridors. The question however, remains, how to improve coverage in rural and cross border areas, along with areas with challenging topography that hinders roll-out or signal propagation.	**National Roaming** is another option to improve coverage, by allowing connections between providers within the same country. This ensures connectivity to a vehicle, as long as there is at least one provider operating in the area. ENISA [15] has reported on the use of national roaming to enhance resilience and protect from outages caused by faults, cyberattacks or natural disasters. An example is the recent implementation of national roaming by Ukrainian telco providers during the 2022 Russian Invasion of Ukraine [16], in order to prevent outages. However, as ENISA reports based on stakeholder interviews, national roaming can be costly for the providers, can drive up subscription costs for the subscribers and should be the last-resort solution in case of outage or significant drop in the Quality of Service of 5G for advanced CAM. **Infrastructure Sharing** can help provide better coverage and lower the costs for each telco provider, particularly in rural areas and difficult propagation environments (such as tunnels, mountainous areas etc.). Prior work within 5G-MOBIX [17] already provides some insight on the benefits and cost savings expected via infrastructure sharing: • Passive sharing can save up to 16%-35% CAPEX and 16%-35% OPEX. • Active sharing excluding spectrum can save about 33%-35% of CAPEX and 25%-33% of OPEX. • Active sharing including spectrum can save up to 33%-45% of CAPEX and 30%-33% of OPEX. • Core network sharing: core network sharing cost savings are limited. The 5G-MOBIX Deployment Study showed that site acquisition is often the most costly and time-consuming part of the roll-out process. Site sharing can help telecoms reduce that part of the deployment costs and brings environmental benefits as well. However, telecoms are often apprehensive towards adopting a sharing scheme, as there is misalignment among their strategic directions, concerns over operational complexity, etc.

5. CONCLUSION

To sum up, this deliverable presents the final report for the standardisation and spectrum allocation needs of the 5G-enabled CAM services of 5G-MOBIX performed at the two cross-border corridors of Spain-Portugal and Greece-Turkey, as well as the other activities carried out at the trial sites (France, Germany, Finland, the Netherlands, South Korea and China). As a part of WP6, Task 6.3 is an enabler for deploying CAM technology in cross-border regions by identifying the gaps in the standards and the spectrum regulations as well as taking the required actions to meet the needs and support the timing of the European 5G Action Plan for having all major transport paths covered with 5G technology until 2025.

Upon expansion of the ecosystem, the SDOs and industry associations that are relevant for CAM, the following topics have been also elaborated from the point of view of standardisation, satellite communications, cross-border roaming, IPv6 based 5G, network slicing, and ITS services at last. As for spectrum management domain, the ultimate status of spectrum regulations in the countries, where CBCs and TSs were carried out within the project, has been given in detail with the help of subsections of the deliverable. Furthermore, 5G-MOBIX spectrum requirements have been explained based on the use cases and CAM connectivity needs when identifying the analysis methodology for these spectrum needs in parallel.

As interpreted within the document, the national regulatory bodies make the final decisions to which bands will be used in their territories. This highlights the "glocal" discussions of spectrum allocation for 5G-enabled CAM services, which help homogenize the identification and assignment of sufficient spectrum for these services. Eventually, the 5G-MOBIX user stories and trial experiences, obtained during the project timeline, light the way for this purpose across the EU.

References

[1] Communication of the Commission, *"A 5G Action plan for Europe"*, COM(2016) 588.

[2] 3GPP TS 23.287, "Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services (Release 16)".

[3] Ministry Economics and climate (July 2020) Results multiband auction, available at: https://www.rijksoverheid.nl/documenten/kamerstukken/2020/07/21/kamerbrief-uitkomsten-multibandveiling

[4] Letter of Ministry economics and climate to the parliament (July 2022), available at: https://www.rijksoverheid.nl/documenten/kamerstukken/2022/07/08/appreciatie-advies-adviescommissie-verdeling-35-ghz-band-en-waarborging-nood-spoed-en-veiligheidscommunicatie

[5] Gezondheidsraad (September, 2020) Advies 5G en gezondheid, available at: https://www.gezondheidsraad.nl/binaries/gezondheidsraad/documenten/adviezen/2020/09/02/5g-en-gezondheid/Advies-5G-en-gezondheid.pdf

[6] Antenne bureau (May 2022) Mobile site installations in the Netherlands, available at: https://www.antennebureau.nl/documenten/rapporten/2022/06/22/antennetotalen-mei-2022

[7] Umlaut (February 2022) Mobile Network test Netherlands, available at: https://www.umlaut.com/stories/kpn-is-the-winner-of-our-mobile-network-test-in-the-netherlands

[8] Wang, Longhe et al. "Vehicular Channel in Urban Environments at 23 GHz for Flexible Access Common Spectrum Application." International Journal of Antennas and Propagation (2019)

[9] Stephan Jaeckel et al. "Deliverable D3.1 Spectrum usage analysis and channel model", 5G AgiLe and fLexible integration of SaTellite And cellular (5G ALLSTAR), Document Number: H2020-EUK-815323/5G-ALLSTAR/D3.1

[10] O.E. Segou, "5G-MOBIX: Deployment enablers and pre-rollout studies for Cross border 5G for CAM", Digital Around the World 2021.

[11] ITU, Recommendation E.118 (2006), available at: https://www.itu.int/rec/T-REC-E.118/en

[12] BEREC report on Enabling the Internet of Things, BoR (16) (2016), available at: https://www.berec.europa.eu/en/document-categories/berec/reports/berec-report-on-enabling-the-internet-of-things

[13] Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2012 establishing the European Electronic Communications Code, Official Journal of the European Union, L321/36, 17.12.2018, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L1972

[14] The EU Toolbox for 5G Security, Website, accessed in July 2022, available at: https://digital-strategy.ec.europa.eu/en/library/eu-toolbox-5g-security

[15] Rosella Mattioli, Dr. Marnix Dekker, ENISA, "National Roaming for Resilience", November 27 2013, available at: https://www.enisa.europa.eu/publications/national-roaming-for-resilience

[16] National roaming implementation in Ukraine, available at: https://visitukraine.today/blog/163/ukrainian-mobile-operators-launch-national-roaming

[17] 5G-MOBIX Consortium, Deliverable D6.1, "Plan and Preliminary Report on the deployment options for 5G technologies for CAM", available at: https://www.5g-mobix.com/resources/deliverables