5G-MOBIX in a nutshell

5G-MOBIX is an EU-funded Innovative Action (2018-2022) that brings together 58 partners from 13 countries from the EU and Turkey, China and South Korea.

5G-MOBIX seeks to demonstrate the usefulness of 5G technology for advanced connected and automated mobility (CAM) applications in cross-border conditions. 5G-MOBIX has assessed the potential of various 5G capabilities, with real use cases, on highways and public roads, along two cross-border corridors (Spain-Portugal and Greece-Turkey) and six urban trial sites (France, Germany, Finland, Netherlands, China and South Korea), to provide and develop sustainable business models to establish 5G corridors.

5G-MOBIX work on evaluation was multi-faceted: on the one hand, a technical performance evaluation of a series of configurations and deployment options, both on a 5G network system and an application level; on the other hand, an assessment of the impact of 5G enabled CAM services on the Quality of Life (QoL), a Cost-Benefit Analysis (CBA), as well as an analysis of the overall 5G for CAM innovation ecosystem. Finally, the user acceptance of the upcoming 5G for CAM ecosystem of solutions and services was analysed, paying particular attention to the effect of cross-border corridor mobility.

The partnership of the ES-PT cross-border corridor (CBC) is composed of several complementary stakeholders that cover the complete value chain including vehicle manufactures as well as research institutions. It provides a realistic soft-border-crossing environment for the testing of 5G for CAM across the EU countries. On the other hand, the GR-TR cross-border corridor constitutes the south-eastern border of the European Union providing a challenging geopolitical environment due to the existence of actual, physical borders, where customs agents perform rigorous border checks. Additionally, the six local trial sites have contributed to the deployment and operations of the CBCs with e.g. application development efforts, infrastructure enhancements, offering different user stories, environments and configuration to complement the CBCs tests.

Key Challenges for Cross-Border 5G-enabled CAM Service Deployments

Technical and legal challenges were observed during 5G-enabled CAM service deployment efforts, as well as the reliability and availability of technical components.

Examples of **technical challenges** include physical implementation issues, coverage optimisation and configuration challenges, cross-network interconnectivity issues, seamless roaming activities and device/infrastructure availability can be mentioned.

Legal and regulatory challenges included e.g. temporal permission for experimental networks, spectrum license availability. Tight regulations, and complicated procedures with public institutions

required detailed prototype equipment working in a specific band that is agreed after an initial study. In some cases, the permission ended after some months, and it was dependent on arranged or unexpected commercial auctions. In certain sites, spectrum licenses were key enablers for institutional testbed networks. However, as the licenses were for research purposes, there were more stringent restrictions on geographical coverage and available bandwidth (for CAM use cases).

Best Practices for Cross-Border Deployments

The CAM applications realized in 5G-MOBIX exploit the capabilities of Multi-Access Edge Computing (MEC) infrastructures and explore the interworking of multi-operator deployments in the context of cross-border corridors. The trial sites operational management has brought valuable lessons learnt, new technical insights for future cross-border deployments and CAM application and edge service developers.

For mobile network operators, the cooperation with operators from neighbouring countries, as well as road operators, brings valuable insights for future trials, as well as unparalleled knowledge on current limitations, particularly in the field of seamless roaming and cross network interconnection. They also reveal missing functionalities and future developments needed for the configuration and deployment of 5G networks that enable cross-border corridors.

Technical evaluation results

The focus is to assess the impact of roaming and handover processes on CAM functions when driving in a cross-border area, and to correspondingly evaluate the performance of a series of system configuration options as a means against service disruption.

Pivotal to the evaluation process are the cross-border issues that have been identified by the project as a way to unify the areas of technical focus along the different 5G deployments options. An analysis was carried out of the different approaches deployed to overcome the effects of roaming/handover events on the delivery of seamless CAM services in cross-border environments. In several cases, the evaluation serves as a means to validate the applicability of a certain solution for the support of CAM services.

Some key findings are:

- Network slicing proved to provide performance guarantees in the presence of congested traffic.
- First studies on mmWave applicability show its viability for high capacity in data delivery.
- Satellite communication is presented as an alternative for low coverage areas but further studies are needed.

Impact assessment & cost-benefit analysis

The impact assessment on quality of life analysed the potential impacts of 5G technology for CAM in cross-border contexts on mode choice, travel time, traffic safety and CO_2 emissions.

Results show small improvements in traffic safety, efficiency and environmental impact. Impacts on personal mobility are likely to be negligible. However, substantial impacts might result for users of 5G enabled CAM services in specific contexts, such as border crossing of trucks.

The break-even cost-benefit analysis explored whether the potential benefits for society outweigh the costs of cross-border 5G for CAM solutions deployment. An estimation was made of the required cost reduction related to negative externalities (accidents, CO_2 emissions and delays) to offset the investments needed. The analysis builds on the cost data of the deployment study (also see the non-technical aspects section hereunder) that was conducted in 5G-MOBIX for five cross-border corridors: in Spain-Portugal (ES-PT), Germany-the Netherlands (DE-NL), Spain-France (ES-FR), the levels of the needed benefits to offset the investment costs seem possible, ranging between 0.44% and 1.99% (assuming equal reductions in all included externalities). Due to the low traffic volumes at the Finland-Norway (FI-NO) corridor, break-even is very unlikely to be achieved. Investments at the Greece-Turkey (GR-TR) corridor are not likely to be offset by the benefits included in this analysis, but benefits to trade and logistics might be expected and those could thus offset the costs.

USER ACCEPTANCE

The project also investigated how 5G connectivity issues (the CAM enabling technology addressed by the project), such as service interruptions and degraded quality of service, may impact user acceptability of said technology and CAM services.

The user evaluation was focused on the use cases (or user stories) trialled at the cross-border corridor between Spain and Portugal, i.e. driving manoeuvres such as lane merge, overtaking and driving with reliance on a High Definition Map, but also a passenger shuttle remotely driven through the border, receiving information from external sensors about the presence of nearby Vulnerable Road Users (VRUs), and a multimedia streaming service deployed on a long-distance bus.

Each user story was evaluated through either controlled trials in which test users were inside the vehicles as passengers; real world trials, for testing in which the users could experience the actual (multimedia streaming) service deployed on board of the long-distance bus; and online interviews in which participants were presented with simulations of different scenarios of service performance and asked to evaluate them.

Overall, the user evaluation of the CAM solutions was positive, even in situations hindered by connectivity issues. Participants stated that, if available, they would use the several proposed CAM

services. They considered them to be useful, easy-to-use, reliable and trustable, hinting to the added value of the 5G-enabled features.

Regarding the border context, results show that connectivity interruption or general service performance degradation may negatively impact acceptability, but that this will depend on how the CAM technology is designed to behave in cases of deficient connectivity. Degraded network conditions are regarded as worse than a complete network interruption, if the behaviour of the vehicle is somehow perceived as less safe.

Non-technical aspects

5G-MOBIX has also investigated non-technical aspects such as standards and regulations, which have a significant effect on the roll-out and development of 5G for CAM. An analysis of the EU regulatory landscape for autonomous vehicles (e.g. infrastructure requirements, rules for roaming charges, data privacy and security aspects) highlights the standardisation and policy gaps to enable better cooperation across the 5G for CAM value chain.

In addition to policy analysis, a comprehensive breakdown of the variety of costs associated with 5G roll-out has been performed, and recommendations provided on priorities for deployment on the basis of utility and cost. Furthermore, an estimation of the value chain and customer needs arising from 5G/CAM services was produced, including associated business models. This work points out the complexity resulting from the multi-stakeholder cooperation required in order to fully benefit from 5G for CAM.

The deployment study carried out across five major corridors[1] provides a good picture of current and planned deployments by major telecom operators, as well as the investment delta necessary to provide the coverage/ capacity required by advanced CAM services in cross border regions (up to 2025). Results showed a vast difference between the expected expenditures among the different countries, due to geographical and regional factors.

[1] Spain – Portugal (ES-PT): Tui/Valenca; Greece – Turkey (GR-TR): Kipoi/Ipsala; Germany – Netherlands (DE-NL): Veldhuizen; Finland – Norway (FI-NO): Kilpisjärvi; Spain – France (ES-FR): Le Perthus

ANNEX: Overview of all the components (networks, OBUs, vehicles, CAM infrastructure) that were developed, tested, integrated and deployed to create the CBCs/TSs used for the 5G-MOBIX trials

Table 1: Summary of vehicles and OBUs deployed

CBC/TS	Vehicles Used	Number of Deployed OBUs
ES-PT	1 Shuttle EV Bus (L4) 1 Citroën C4-Picasso (L4) 2 Citroën C4-Picasso (Lo) 1 Volkswagen Golf (L4) 1 ALSA bus (Lo) 1 PT connected vehicle (Lo)	10
GR-TR	2 Ford-MAX (L4)	2
DE	1 Volkswagen Passat (L1) 1 Volkswagen Tiguan (L1) 1 Toyota Prius (L1)	4
FI	1 Renault Twizy (L4) 1 Ford Focus (L1)	2
FR	1 Renault ZOE (L4) 1 Renault Scenic (L1)	5
NL	1 Volkswagen Touareq (L4) 2 Toyota Prius (L4)	6
CN	1 SDIA (L4)	1
KR	1 Renault XM3 (L4)	2
Total	**21 vehicles**	**32 OBUs**

Table 2: Advanced 5G technologies deployment comparison

Technology / Site	ES-PT	GR-TR	DE	FI	FR	NL	CN	KR
C-V2X	5G-V2X	5G-V2X (PC5 support)	5G-V2X (PC5 support)	5G-V2X	5G-V2X (PC5 support)	5G-V2X (PC5 support)	5G-V2X (PC5 support)	5G-V2X
MEC Deploy-ment	Yes, Nokia solution	Yes, Ericsson solution	Yes, near edge & far edge	Yes, MEC Service Discovery	Yes, Far/ Cloud Edge	Yes, MEC Discovery SSC M3	Yes, China Mobile solution	No
Network Slicing	No	No	No	Yes	No	Yes	Yes	No
Roaming	Cross-border	Cross-border	Multi-SIM in NSA/SA	Multi-SIM in NSA/SA, Lab SA-SA	Multi-SIM in NSA	Virtual cross-border	Multi-SIM in NSA/SA	No
Satellite Deployment	No	No	No	No	Yes	No	No	No

Table 3: Overview of 5G-MOBIX networks

CBC/ TS	Type	Commercial/ Test Components	Num. gNBs	Freq. Bands	Slicing
ES	NSA	Commercial: Transport network, 1x 4G RAN (MOCN) Test: 1x Core, 5G RAN, MEC	4	800 MHz (LTE B20), 1800 MHz (LTE B3) 2600 MHz (B7), 3.7 Hz (5G NR n78)	No
PT	NSA (SA)	Commercial: IP and Transport Network Test: 1x RAN, 1x Core, MEC	3	1800 MHz (LTE B3), 3700 MHz (5G NR n78)	No
GR	NSA	Commercial: IP and Transport Network Test: 1x RAN, 1x Core	1	LTE B7 (2600) 20MHz, NR n78F (3500-3600)	No
TR	NSA	Commercial: IP and Transport Network Test: 4x RAN, 1x Core	3 (+1)	LTE B7 (2600) 20MHz, NR n78G (3600-3700)	No
DE	NSA/SA	Commercial: 2x NSA Core + 2x RAN, 1x MEC Test: 1x SA Core + 1x RAN, MEC	2	NSA: 2.1 GHz (5G NR n1) + 800 MHz (LTE B20), 900 MHz (LTE B8), 1800 MHz (LTE B3) 3.6 GHz (5G NR n78) + 1800 MHz (LTE B3), 2600 MHz (B7) SA: 3.7 - 3.8 GHz (n78)	No
FI	NSA/SA	Commercial: 2x NSA Core + 2x RAN Test: 2xRAN, 2xCore, MEC	2	2600 MHz (B7), 3.5 GHz (n78)	Yes
FR	NSA	Commercial: 1x Core Test: 3x RAN + 2x Core, 2x MEC	3	700 MHz (4G), 800 MHz (4G), 1800 MHz (4G) 2100 MHz (3G/4G), 2600 MHz (4G) 3500 MHz (5G), 3700-3800 MHz (n77), 26 GHz (n258)	No
NL	SA	Commercial: 1x 4G RAN (MOCN), 1x 4G transmission Test: 3x 5G RAN, 3x Core, 3x MEC	6	3.7 GHz (5G NR n78) 27 GHz (5G NR n258), LTE: 800 MHz (LTE B20), 1800 MHz (LTE B3)	Yes
CN	SA	Commercial: 2x Core (China Mobile, China Unicom) Test: 2x RAN 2x MEC	3	3.5GHz(n78), 4.9 GHz(n79) 2.6GHz(n41)	Yes
KR	NSA	Test	3	22-23.6 GHz	No
Total			**29**		3+3

Table 4: CAM Infrastructure Components at Cross-Border Corridors and Local Trial Sites

CAM Infrastructure Components						
CBC/TS	**Road sensors**	**RSU**	**RSU MEC (Far edge)**	**MNO MEC (Near edge)**	**Cloud**	**CAM Services**
ES/PT	Traffic Radar, Pedestrian detector, 5G smartphones, ITS Centers, Remote Control Center, Cameras	Yes	No	Yes	Yes	Complex Manoeuvres, Automated Shuttle, Public Transport
GR/TR	Camera	Yes	No	Yes	Yes	See-through streaming, assisted border crossing, truck routing
DE	Camera, traffic analysis, road condition	Yes	Yes	Yes	Yes	EDM, GDM, Edge MANO, edge service discovery
FI	No	No	No	Yes	Yes	Remote driving, video streaming, video crowdsourcing, HD mapping, MEC service discovery
FR	Cameras, LiDAR	No	Yes	Yes	Yes	Infrastructure assisted lane change manoeuvre, different MEC Deployment options
NL	Cameras	No	Yes	Yes	Yes	Roadside assisted merging, Remote driving, Cooperative Collision Avoidance
CN	Data centre, Remote Control Center	Yes	No	Yes	Yes	Remote driving, Cloud-assisted lane change