FROM R&I TOWARDS ACTUAL DEPLOYMENT

UPDATE ON 5G TRIALS AND PILOTS FOR CONNECTED AND AUTOMATED MOBILITY

A perspective from the 5G-PPP and SNS JU Ecosystem

June 2023

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INTRODUCTION

Based on the first issue of this brochure, which was published in May 2021, this updated version reflects on the lessons learnt from recently finished ICT-18 call CAM projects in 2022, plus updates from the ongoing ones under the 5G-PPP programme, such as the ICT-53 call projects. Since the middle of 2022, the Smart Networks and Services Joint Undertaking (SNS JU) framework has succeeded the 5G-PPP programme in the European context, and all continuing 5G-PPP projects are also inspired by 5G evolution and 6G topics discussed at SNS JU level and worldwide. Along this path, 5G technology used in the projects has been the first communication technology, the first generation that has tried to systematically integrate and support many CAM services which can be supported by 5G (3GPP Rel.15/16/17). In addition, the 5G ecosystem has also been developing an end-to-end analysis of the different elements that must come together for a successful deployment of advanced CAM services; this includes, among many other aspects, all regulatory requirements and rules, deployment options and cooperation models, legal and business implications, as well as cross-vendor, cross-operator, and cross-national/cross-border considerations.

5G is now entering into a phase of massive deployment. However, many challenges are still to be solved and it can already be anticipated that, even though 5G is going to create a revolution in many sectors, including CAM, and bring a huge positive impact into the European economy and society, some limitations for end-to-end solutions will prevail. As a broader take-away, one of the biggest challenges in the CAM domain lies on the requirement of a deeper 5G-V2X integration into the existing and evolving ADAS (Advanced Driver-Assistance Systems) across the vehicle manufacturers. Also, internationally agreed network profiles for 5G slicing and other network deployment requirements and configurations are needed to enable an interoperable and cross-border European, respectively global, CAM mass market.

As it was stated in the 5G Strategic Deployment Agenda for Road Transportation (5G SDA) released in 2020 by key stakeholder associations, 5G will be a booster for the realization of CAM and, therefore, bring all societal benefits to reality. An update of the 5G SDA is currently being prepared for release in late Q4 2023, also considering the synergies of 5G communication between Road and Rail Transportation, and further transportation modes, such as inland waterways, costal maritime and eventually lower airspace.

For this reason, the 5G Public Private Partnership (5G PPP) and its successor 6G-SNS JU, which aim at ensuring that Europe leads the development and deployment of 5G and beyond in Europe, has been continuously funding since 2015 several projects which contribute to designing, developing, testing, validating, and promoting the potential of 5G-based vehicular communications (so-called V2X communications) for CAM. It is worth noting that the term V2X refers to communication between a vehicle and anything else, including V2V (vehicle-to-vehicle), V2N (vehicle-to-network), V2I (vehicle-to-infrastructure), and V2P (vehicle-to-pedestrian / vulnerable road user). The focus of these projects is on V2N CAM based on 5G networks, while direct short-range communication on the side link (LTE PC5) has been used as a complement, but not in all projects and their respective use cases and not for ITS Day-1 safety scenarios.

This brochure aims at providing an updated schematic and visual summary of the key use cases, key performance indicators, and tests and pilots being conducted in the context of research and innovation projects funded by 5G-PPP, which contribute to enabling efficient and reliable 5G-V2X communications for CAM. Moreover, first lessons learnt from finished projects are summarized at the end.

The 6G-IA 5G for CAM Working Group Chairs

V2X USE CASES

What follows is a brief description of the different use cases being studied, analysed, and tested across the various projects. Detailed description of the use cases and particular implementations of these use cases, the so-called user stories, can be found at the websites of the respective projects.

Tele-operated Driving (ToD): is defined as remote control of an automated vehicle through a mobile radio network. ToD is meant to complement automated driving by bringing the tele-operator, located in the Vehicle Control Centre (VCoC), into the control loop in situations where an automated vehicle cannot handle on its own.

High Definition (HD) maps: being considered one of the corner stones of an autonomous car, the generation and distribution of these maps allow integrating information such as lane markings, barriers and other information which can be used by the automated driving functions. The HD maps can also be used as the base upon which more dynamic information can be stored, e.g., road works and accidents.

Anticipated Cooperative Collision Avoidance (ACCA): this use case relates to the possibility to anticipate certain road hazards to reduce the probability of collisions, particularly in situations when these hazards are out of the field of view of the vehicles' sensors. It allows to build a situational awareness of the road in quasi real-time manner, and to notify nearby vehicles about collision risks.

www.5gcroco.com

Automated driver-in-loop docking functionality: Within this use case, 5G-Blueprint explores a driver assistant system for docking articulated vehicles within warehouses and distribution centres, as a well as enabling a mobile harbour crane with teleoperation functionality, so that it can be operated from a remote-control centre by a teleoperator. Communicating optimal driving paths to the tractor and manoeuvring the crane in safety-critical situations will be highly time-critical.

Cooperative Adaptive Cruise Control based platooning: Platooning of trucks has been a widely discussed topic in logistics for a while now. However, this use case revolves around the fundamental strategy of platooning by relying of 5G, while the driver is removed from the cabin of the truck and placed in a remote location from where they can control the vehicle. The system is aimed at being partly automated wherein the lead vehicle can be driven by a driver in the cabin or a teleoperator and the following vehicle(s) can be automated.

Remote takeover operations: Remote takeover defines the process in which a remote operator takes control of a distant vehicle. To enable remote takeover, it is necessary to monitor and adjust the vehicles to steer and drive remotely from the control centre. Remote takeover operations are integration tests verifying the function of all major components (vehicle, remote station, teleoperation centre) of the teleoperation solution.

Automated Barge Control: the channel navigation of the barges will be teleoperated along with partial automation. Cross-border passing will be given a priority whereas channel navigation, port entry, and exit efficiency will be enhanced by reducing crew requirements for barge navigation.

www.5g-blueprint.eu

Cooperative and automated lane-change manoeuvres: a vehicle needs to change lane from overtaking to first lane or vice-versa, and it performs lateral control in level 4 (L4) automated driving thanks to a very accurate and timely awareness of the surroundings, enabled by 5G.

Cooperative and automated in-lane manoeuvres: a vehicle is on the first lane and plans to exit the motorway in moderate-high traffic situation, with vehicles in front obstructing the view. A queue or obstacle on the exit lane would require the driver to take over. Thanks to 5G, however, the vehicle can sense what the vehicle in front senses and thus decide to keep L4, and stay in lane, re-planning the exit without disturbing the driver.

Cooperative Lane Merge: Vehicles orchestrate a lane merging operation by exchanging information via PC5 direct communication (localized case) and via 5G network using MEC-based Services (centralized case).

Back Situation Awareness: Emergency vehicles inform other vehicles of their arrival through 5G connectivity (both V2N and V2V), giving them enough time to take relevant actions (create a clear corridor for the emergency vehicle).

Second priority use cases

Vehicle Sensors and State Sharing: Dangerous conditions (e.g., fog, icy roads, traffic jam) are detected by sensors in Road-Side Units (RSU) or vehicles on the road and communicated to nearby vehicles using 5G connectivity (both V2N and V2V).

Video Streaming: Using predictive network Quality of Service capabilities (pQoS), more pleasant experience on board can be granted to passengers in the fruition of multimedia content, exploiting proactive adaptation of streaming to minimize interruptions of service or low data-rate conditions, especially at country borders

Green Driving: it increases the sustainability of mobility, suggesting virtuous driving behaviour (e.g., via speed recommendations) based on the environmental and traffic characteristics of the motorway section that is being traversed or better exploiting the hybrid traction systems on hybrid vehicle.

www.5gcarmen.eu

Teleoperated driving: 5GMED will demonstrate that a teleoperator can control the car from a remote location and ensure the Dynamic Driving Task Fallback with full safety, adding a new reliable mode to the dynamic driving task (DDT) fallback procedure specified by SAE J3016.

Road infrastructure digitalization: 5GMED will move forward the road infrastructure closer to Inframix level A. Two different services will be tested: 1) automatic incident detection, with a 5G connected camera processed by an IA in the Edge, and 2) Traffic Flow Regulation in Real time by providing speed recommendations to a selected group of Connected Autonomous vehicles, improving road safety.

Follow Me infotainment: 5GMED will demonstrate service continuity of intense infotainment and media applications in cross-border situation with dynamic service migration from MEC to MEC.

www.5gmed.eu

As the number of use cases distributed in the different 5G-MOBIX Test-Sites is very high, they have been classified in some Use Case Categories (UCCs), classification extracted form 3GPP technical specifications.

Advanced driving use case: Advanced driving enables semi-automated or fully-automated driving. Each participant shares its local data and driving intentions on the vehicles case, with cooperating entities in the proximity. This allows the participating vehicles to coordinate trajectories and manoeuvres.

Platooning use case: Enables vehicles to form groups dynamically while traveling together. Information is exchanged among members and manoeuvres being coordinated by the platoon leader, allowing them to drive as compact groups and the following vehicles to be driven autonomously.

Extended sensors use case: This use case contemplates raw sensors data and live video to be exchanged among participating members. This enables every participant to be aware beyond what can be perceived by its own sensors, enabling a more complete view of the local environment.

Remote driving use case: Remote driving enables a vehicle to be commandeered from a remote location for when the occupants cannot drive themselves or for vehicles on hazardous environments. This use case is also considered for cloud-enabled public transportation.

Vehicle quality of service reporting support use case: This use case enables V2X applications to be informed on the CCAM system status. Notifying participants on current quality of service and expected variations, delivering a smoother experience.

www.5g-mobix.com

The use cases of 5G-ROUTES have been grouped into categories according to the environment that are going to be experimented. The clustering of the use cases into different categories is:

Cluster 1: Maritime:

- The Goods Tracking Visibility in Multimodal Cross-Border Logistics whose task is to enable continuous monitoring of goods with IoT systems
- The smart Ferry whose aim is to provide a situational information awareness during a ferry trip
- Real time virtual collaboration and immersive multi-user gaming on the go whose aim is to provide AR and video gaming during the ferry route

Cluster 2: Automated Cooperative Cross-Border Driving:

- Dynamic Vehicles Platooning for automated vehicles to dynamically form a platoon
- Cooperative Lane Change where automated vehicles perform automated lane change manoeuvres
- See-Through View for Safe Automated Overtake whose aim is to provide enhanced visibility of road awareness

Cluster 3: Enhanced Cross-Border Situational Awareness for CAM:

- Real-Time Traffic Information and Cooperative Intersection Collision Control whose aim is to enable a reliable exchange of road traffic status data between VRUs, autonomous “drivers” and TMC through enhanced real-traffic video feed
- Traffic Jam Chauffeur that focuses on highly automated vehicles
- Sensor Info Sharing for Cooperative Situation Awareness whose aim is to enhance the perception of the car environment beyond what its own sensors can detect to have a more holistic view of the local situation and
- VRU collision avoidance whose aim is to improve driving safety in the presence of VRUs.

www.5g-routes.eu

Automated & Remote Vessel navigation in busy port environment: Demonstration of Port Digital Twin based on 5G connectivity and slicing will be used to control semi-autonomous vessels in the challenging environment of a port area. High-bandwidth (preferably full HD) camera feeds and sensor data are sent in real-time from the vessels to the command centre, and real-time steering commands are sent to the remote vessel. KPIs: Port safety, reduced dwell times, reduced personnel, etc.

Data-enabled assisted navigation in severe weather/water conditions: Demonstration of remote inspection, fraud detection, insurance by implementation of a data-enabled assisted navigation application using IoT sensing system and video cameras installed in port and on a ship and barges (cargos). The UC application that we propose will permit a safer port operation and more security regarding navigation of ships with the help of assisted operation / navigation even in severe weather and water conditions. KPIs: Increased safety, electronic map accuracy, etc.

Smart warehouse / freight logistics: Demonstration of lean warehouse, human-AGV collaboration, remote monitoring & control the feasibility by applying the 5G technology in an overall logistics context, for optimizing warehousing operations through an integrated state-of-the-art operational system based on Automated Guided Vehicles (AGVs). KPIs: Increased operational efficiency, productivity, warehouse capacity, etc.

www.vital5g.eu

Remote driving: the aim of this UC is to control remotely a vehicle connected through 5G via a teleoperation platform. The vehicle shares camera and LiDAR streams that are processed at the end-user side providing a 360° environment view using Virtual Reality glasses.

Manoeuvres coordination for autonomous driving: this UC showcases a manoeuvre coordination service capable of lowering the risk of collision in complex junction scenarios by describing suitable paths and priorities for connected, eventually automated, vehicles directed by a shared coordination system.

Virtual bus tour: This UC facilitates an immersive virtual bus tour experience for virtual reality headset users. The users receive on their Head Mounted Display the video of the tour surroundings, streamed through a high resolution 360° camera mounted onto the bus, while it performs the “real-life” tour.

Augmented Reality (AR) content delivery for vehicular networks: this UC provides “high-quality AR content streaming” taking advantage of the future web AR applications, the MEC and 5G connectivity. The user receives information in the form of “high-quality” virtual 3D objects that are embedded on the 3D map of the user’s mobile device.

High-risk driving hotspot detection: hazardous events are identified exploiting ML models that analyse driving behaviours for detecting aggressive and distracted driving. Real-time warning notifications on road risk-level are transmitted to the vehicles.

Network status monitoring: the goal of this UC is to provide a network monitoring service that can be used to increase the efficiency of other applications through providing distributed predictions of QoS and in general of network conditions at various locations.

Situational awareness in cross-border road tunnel accidents: this UC aims to implement a situational awareness system that can enable first responders to understand specific conditions of the tunnel incident such as number of involved vehicles, temperature, humidity, gases levels..

www.5g-iana.eu

Crowd-sourced dataset generation and ML model update through connected vehicles: the 5GMETA platform is used to provide new relevant vehicle sensor data to a third party for refining a CCAM machine learning (ML) model. Instead of storing locally or streaming the entire sensor data, the vehicle selects the data that makes the ML model perform below an established threshold and it sends them to the 5GMETA platform. Then, the third party, which is subscribed to this dataflow, receives the data through the 5GMETA platform. The data are anonymized in the 5GMETA MEC, blurring faces and car plates, offloading from this task to the vehicle.

Dynamic route planning & parking support: 5GMETA pipelines the required information to accurately and dynamically predict the departure time and the optimal path to reach a destination in a target arrival time and to quickly find a free parking lot. The data delivered by the platform generate revenues from the added value to the users of dynamic route planning and parking support services that are re-scheduled in real-time to avoid any incident meaning a late arrival.

Driving safety & Awareness: The 5GMETA platform helps drivers to correct their behaviour and assist in bringing the vehicle to safety mode before a dangerous event can occur. It is a solution for safely stopping the remotely assisted vehicle in the closest available parking lot detected. The video camera stream can be processed at the infrastructure to quickly detect available parking lots, required for the success of the rescue manoeuvre.

www.5gmeta-project.eu

1/3

USE CASE	TELE-OPERATED DRIVING	HD MAPPING	ANTICIPATED COOPERATIVE COLLISION AVOIDANCE	VEHICLE PLATOONING	ADVANCED DRIVING
KEY 5G KPI	RELIABILITY	DATA RATE	DELAY, LOCALIZATION ACCURACY	RELIABILITY/ E2E LATENCY	E2E LATENCY
5GCroCo	√	√	√		
5G-CARMEN			√		
5G-MOBIX	√	√	√	√	√
5G-ROUTES			√	√	√
5G-Blueprint	√			√	√
5GMED	√		√		
VITAL-5G		√	√		
5G-IANA	√		√		
5GMETA					

2/3

USE CASE	EXTENDED SENSORS	COOP. & AUTOMATED MANOEUVRING	BACK SITUATION AWARENESS	VEHICLE SENSORS AND STATE SHARING	VIDEO STREAMING
KEY 5G KPI	E2E LATENCY	LATENCY	COVERAGE, RELIABILITY	LOCALIZATION ACCURACY	LATENCY, DATA RATE
5GCroCo				√	
5G-CARMEN		√	√	√	√
5G-MOBIX	√				
5G-ROUTES	√	√		√	√
5G-Blueprint				√	
5GMED					
VITAL-5G	√			√	√
5G-IANA		√	√	√	√
5GMETA				√	√

3/3

USE CASE	GREEN DRIVING	ROAD INFRASTRUCTURE DIGITALIZATION	FOLLOW-ME INFOTAINMENT	DISTRIBUTED PERCEPTION	VEHICLE QoS SUPPORT	IOT CONNECTIVITY
KEY 5G KPI	SERVICE CONTINUITY	RELIABILITY	DATA RATE, CONTINUITY	DATA RATE, LOW LATENCY	DATA RATE, RELIABILITY	RELIABILITY, LATENCY
5GCroCo						
5G-CARMEN	√					
5G-MOBIX					√	
5G-ROUTES						√
5G-Blueprint				√		
5GMED		√	√			
VITAL-5G						
5G-IANA					√	
5GMETA		√				

TESTED 5G TECHNOLOGIES

	RELEASE TESTED	5G DEPLOYMENT		TECHNICAL FEATURES					
		NSA	SA	5G NR	MEC	SERVICE DIFFERENTI-ATION	pQoS	AI	PC5
5GCroCo	15	√		√	√	√	√		
5G-CARMEN	15	√		√	√		√		√
5G-MOBIX	15/16	√	√	√	√	√			√
5G-ROUTES	16/17	√	√	√	√	√			
5G-Blueprint	16/17	√	√	√	√	√		√	√
5GMED	16		√	√	√	√	√	√	√
VITAL-5G	15/16		√	√	√	√			
5G-IANA	15/16		√	√	√	√	√	√	
5GMETA	15/16	√	√	√	√	√	√		

TERMINOLOGY

- **NSA:** Non-standalone;
- **SA:** Standalone;
- **5G NR:** 5G New Radio;
- **MEC:** Mobile Edge Computing;
- **Net. Slicing:** Network Slicing;
- **pQoS:** predictive Quality of Service;
- **AI:** Artificial Intelligence;
- **PC5:** interface to allow direction communication between devices in a 5G network.

LESSONS LEARNT FROM ICT-18 PROJECTS

The combination of the results obtained by the three ICT-18 projects has yielded valuable insights into the capabilities and potential of 5G technology for CAM. Most significantly, trials in cross-border contexts have demonstrated that even seamless service continuity in cross-border areas can be achieved. The solutions proposed in the three projects improve, with respect to service interruption times, from tens of seconds and even up to minutes that must be endured today, down to a few seconds or even in the order of a hundred milliseconds, with the necessary additional interfaces in place between the operators on both sides of the border. 5G can significantly improve the performance compared to previous technologies, mainly 4G, in terms of reduced latency, higher capacity and spectral efficiency. As a result, 5G based on Rel. 15 Non-Standalone can already support today about 80 % of CAM services including ITS Day-1 services, as their requirements are in line with the commercially available performance.

However, it is also important to note that CAM services with higher requirements can be adapted to network states to ensure smooth automated driving based on Predictive QoS. This requires close collaboration between telecom operators, service providers and vehicle OEMs to tailor their needs and solve technical challenges, e.g., related to configuration provisioning and service discovery. This cooperation is particularly required to cover the period until general offerings are available and can be implemented, e.g., through joint living labs and field operational tests (FOTs), as natural next steps for commercialization after TRL 6 is achieved in EC-funded Innovation Actions.

In addition to the immediate benefits that 5G will bring, the potential of further 5G evolution for CAM was identified, with 5G Standalone (SA) being the relevant basis in terms of capabilities and performance for CAM in mass deployment. By using a 5G Core instead of an Evolved Packet Core and discarding the need for control signalling over 4G LTE radios, 5G SA simplifies network architecture. Furthermore, 5G SA supports Session and Service Continuity (SSC) mode 3, which enables seamless Local Breakout Routed Roaming necessary for re-anchoring: once a seamless Inter-PLMN handover has been executed, all traffic is efficiently routed through the visited network without cumbersome home routing as existing in today's commercial networks. Finally, 5G SA adds Network Slicing as a refined capability to achieve QoS service differentiation. As validated by the ICT-18 projects, this feature, like other QoS differentiation features, can be effectively used for the support of guaranteed end-to-end QoS especially in the case of network congestion.

Concerning deployment-related lessons learnt, the work carried out by the three ICT-18 projects concludes that the most suitable 5G network deployment to provide CAM services along corridors sections would be to start with low-band spectrum (e.g., 700 MHz band) for quickly achieving wide-area coverage, by leveraging primarily existing RAN sites. These sites can be upgraded to include a capacity layer based on mid-band spectrum such as, the 3.x GHz band or other legacy capacity bands. A significant number of new sites along the corridors will be required to deploy such a capacity layer – as 5G for CAM and non-related eMBB data traffic will grow.

While 5G network infrastructures are the first and foremost foundation of enabling CAM, the low-latency computing element must not be neglected, especially for more advanced 5G for CAM services. Here, the deployment of regional MEC data centres in reasonable proximity to the 5G RAN "network edge" will become pivotal for completing the enabler infrastructure elements required for CAM services, as implemented, and demonstrated by the ICT-18 projects. As a start, regional and scalable MEC deployments hosting orchestrated CAM services like one per region within the respective corridor sections of the involved countries have been suggested.

In general, solutions for universal support of CAM services already exist and incentivizing their deployment will greatly contribute to increasing their penetration rate. Joint development between telecom network and service providers can also boost performance by using the current capabilities within the services and levelling the differences in technical knowledge of the cooperating partners. Moreover, detailing how 'value' is co-created will help defining organizations' roles, identify synergies, and allow for cost-efficient investments, complemented by a regulatory perspective. By continuing to innovate and collaborate, 5G can help to create a safer, more efficient, and more sustainable transportation system for achieving societal and commercial benefit.

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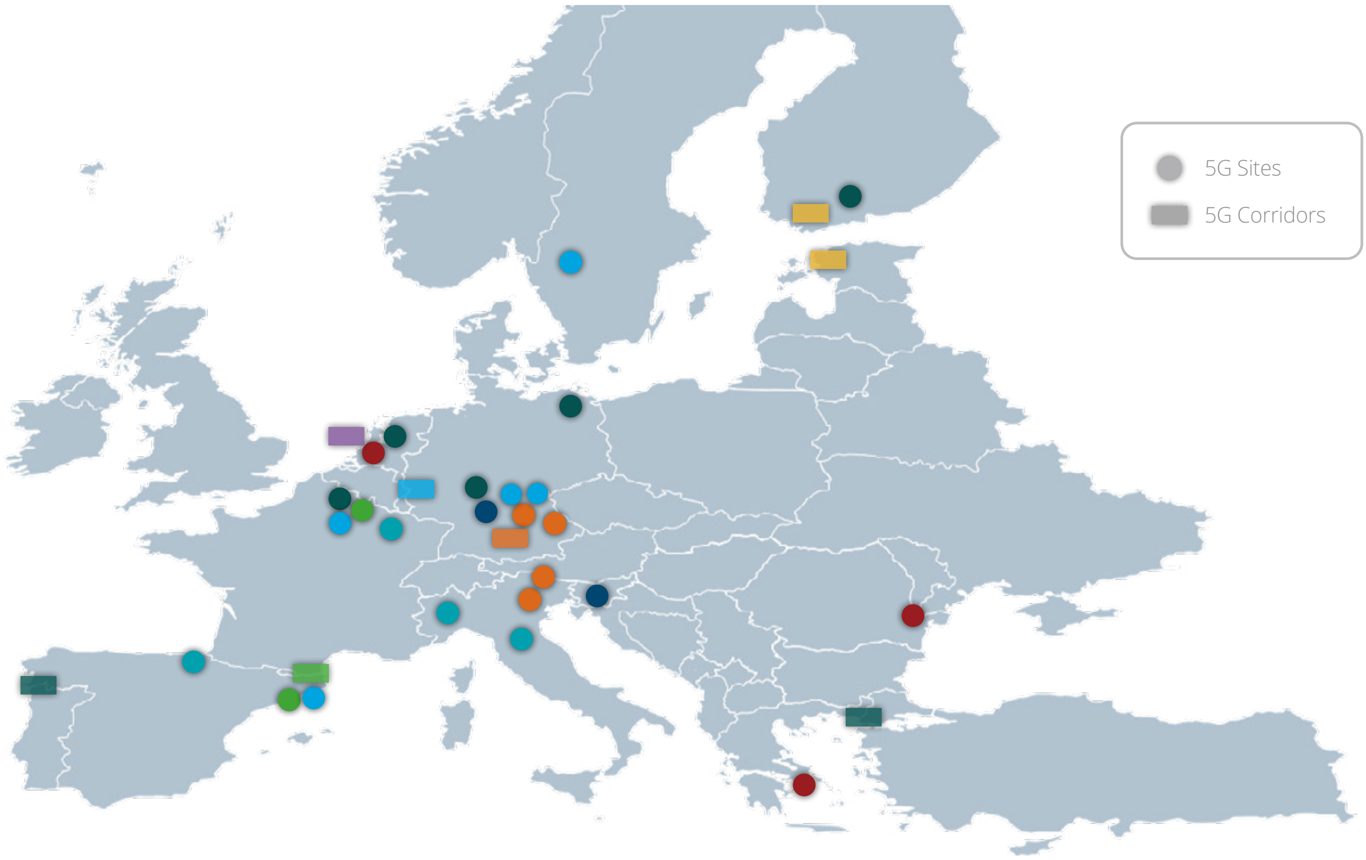
CARTOGRAPHY



5G-MOBIX

- **Vigo - Porto (Spain-Portugal Corridor)**
- **Kipoi - Ipsala (Greece-Turkey Corridor) Hard borders**
- Berlin and Stuttgart *(German)*
- Espoo *(Finland)*
- Paris *(France)*
- Eindhoven-Helmond *(Netherland)*
- China Test Site: Jinan
- South Korea Test Site: Yeonggwang

5GMED

- **Corridor E-15 Figueres – Perpignan**
- Castellolí Track *(Spain)*
- TEQMO Centre, Paris *(France)*

5G-CARMEN

- **Corridor Germany-Austria-Italy**
- Trento *(Italy)*
- Munich *(Germany)*
- Brenner Pass *(Italy-Austria)*
- Kufstein *(Austria-Germany)*

5G-IANA

- Ulm *(Germany)*
- Ljubljana *(Slovenia)*

5GCroCo

- **Corridor France-Germany-Luxembourg**
- Barcelona *(Spain)*
- Monthléry *(France)*
- Munich *(Germany)*
- A9 5G-ConnectedMobility Testbed *(Germany)*
- AstaZero *(Sweden)*

5G-Blueprint

- **5G cross-border in waterways and high-ways between Belgium and The Netherlands**

5G-ROUTES

- **5G cross-border Via Baltica-North corridor:**
  - Latvia - Estonia - Finland

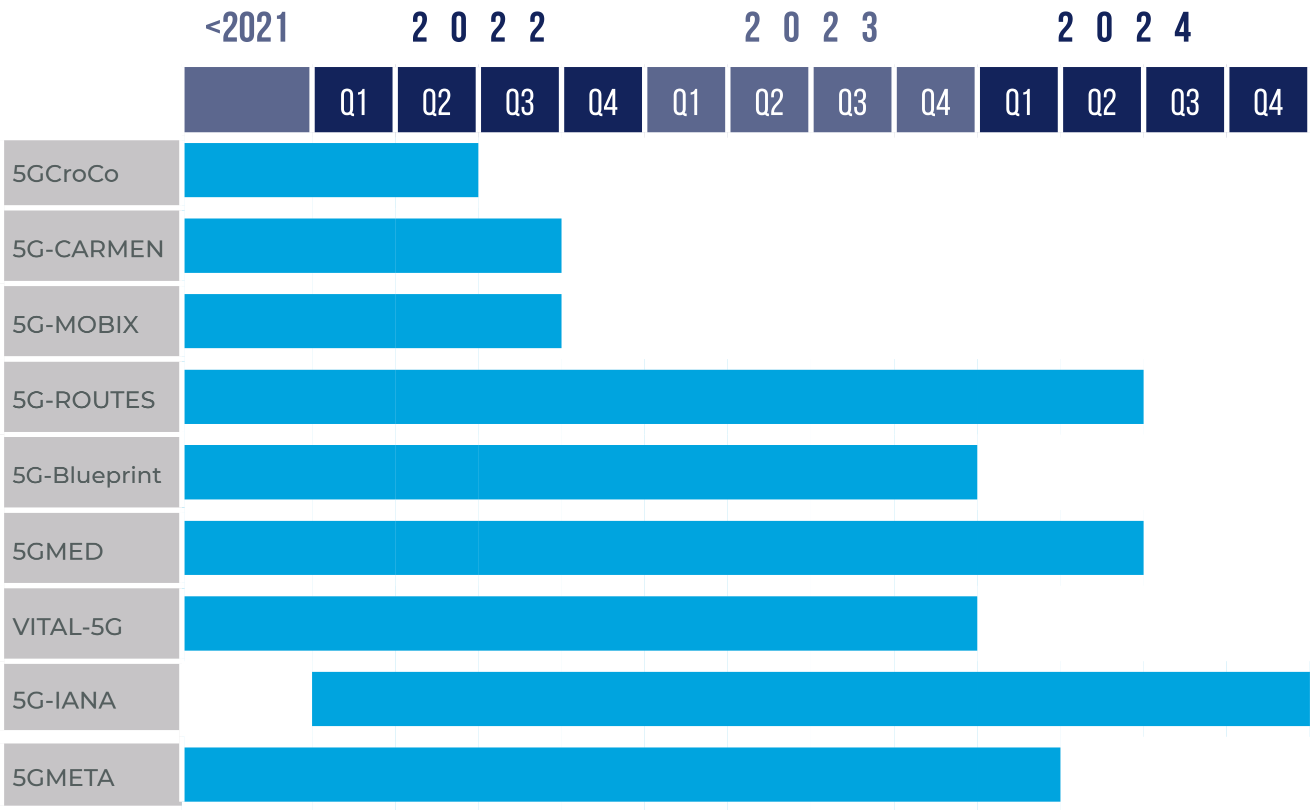
VITAL-5G

- Port of Galati *(Romania)*
- Port of Antwerp *(Belgium)*
- Port warehouse/logistics hub of Athens *(Greece)*

5GMETA

- San Sebastian *(Spain)*
- Satory *(France)*
- Turin *(Italy)*
- Modena *(Italy)*

TIMELINE



Please note that some projects had started before January 2021 and have experienced delayed periods due to Covid19 pandemic.

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