5G Strategic Deployment Agenda for Connected and Automated Mobility (5G SDA for CAM)

Road chapter

Approved by the SNS JU Governing Board on 18 December 2025

Published on 8 January 2026

This document is an update of the first 5G SDA for Road published on October 2nd, 2020.

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Table of contents

Table of figures

Executive Summary

Connected Mobility for Road Transport is a reality today. The share of connected vehicles will reach approximately 40% of the total vehicle fleet in Europe in 2025. As of 2022, there have been almost 290 million vehicles (cars, vans, trucks and buses) registered in the European Union. While the majority of this connected vehicle legacy is still using primarily 4G connectivity, the shift to 5G-capable vehicles is significant, similar to the growth rate of vehicles supporting higher levels of assisted and eventually automated driving. As a consequence, there is a need to ensure continuous 5G coverage and sufficient 5G network capacity on the European road networks, not only in cities, but also on roads connecting the municipalities and countries in both the EU and the European continent.

The **5G Strategic Deployment Agenda (SDA) for Connected and Automated Mobility (Road chapter)** is providing guidance on investment in the deployment of 5G connectivity infrastructure along motorways, also known as "5G corridors 'roads'" with the view to ensure uninterrupted coverage and seamless service provision for connected and automated services and more broadly for transport, logistics and all road users. For this purpose, the 5G SDA proposes a **cohesive framework to achieve that vision** and foster **collaboration among stakeholders through the definition of cooperation models and deployment roadmap scenarios.**

In a fast moving technology and market environment, transitioning from 4G/5G Non-Stand Alone to full-fledged 5G Stand Alone and the development of Software-Defined-Vehicles and AI-enabled connected and automated Mobility (CAM) solutions, the 5G SDA addresses in particular key deployment challenges such as the co-funding of **high 5G investment levels**, the search for synergies with associated vertical services**, the fragmented EU regulatory landscape and related administrative processes** as well as complex operational tasks.

The **EU Connecting Europe Facility 'Digital' programme,** initiated in 2022, has been a major trigger to kick start and catalyse investment in 5G network deployments along Trans-European Network (TEN-T) transport corridors. The first wave of co-funded deployment projects provides **critical insights** for optimal deployment strategies**, public-private collaboration** and **best practices, with a particular focus on cross-border 5G coverage** of transport networks with the view to ensure seamless and uninterrupted CAM service provision throughout Europe.

Successful 5G deployment requires **innovative approaches** for achieving effective **network coverage and spectrum utilization**, **seamless handover and roaming**, **service differentiation**, **Multi-Access Edge Computing (MEC)**, **precise positioning, etc**. In addition to these technologies, a **supportive regulatory framework shall encourage private investment, leveraging co-funding schemes, while addressing safety, data access/sharing, and infrastructure challenges** for a successful 5G CAM deployment in Europe.

The emerging 5G-enabled CAM ecosystem brings together a broad range of stakeholders from different industries and supporting economics and business models, i.e. vehicle manufacturers (OEMs) and automotive suppliers, road operators (ROs), road infrastructure managers, communication service providers/mobile network operators (CSPs/MNOs), tower companies/neutral host providers (NHPs), telecom vendors and service integrators. In this rich and diverse environment, it is essential to define options for cooperation models among all the ladders of the value chain, ranging from passive network infrastructure and associated services to active network elements and beyond CAM service provision. For this purpose, the 5G SDA explores the various possibilities offered by network sharing, including neutral host provision **in shared passive infrastructure** leased to multiple MNOs and **network slicing** and **active network sharing** that enable a faster service provisioning for differentiated services and revenues, further optimize costs and ensure scalability.

The proposed models **enable cost-sharing, accelerate deployment, and optimize infrastructure usage, ensuring the economic viability and scalability of 5G CAM services**. Successful implementation depends on aligned priorities, transparent agreements, and supportive regulations across stakeholders and shall be explored on a case-by-case basis.

Three **phases of deployment are envisaged**:

1. **Past and ongoing:** leverage **4G LTE and 5G Non-Standalone (NSA) coverage** for connected vehicle services including next-generation emergency call, connected passenger services.
2. **2025–2028**: expand to **5G Standalone** (SA) for advanced mobility services. The focus shall be on achieving coverage including 5G SA roaming.
3. **2029 and beyond**: full-fledged 5G SA and integration of all necessary innovations to support advanced traffic management services. Focus will be put on **achieving network capacity extensions to support mass-market usage.**

1 5G for CAM: a key driver for Europe’s Green and Digital Transition

The 5G Strategic Deployment Agenda for Connected and Automated Mobility (5G SDA for CAM) builds upon European policies that are at the cross-road between Digital and Transport areas:

EU Initiatives to achieve digital transformation and high-level sustainability of transport

On 21 February 2024, the Commission presented a White Paper on “How to master Europe’s digital infrastructure needs? [1], which analyses the challenges Europe currently faces in the rollout of future connectivity networks, and presents possible scenarios to attract investments, foster innovation, increase security, and achieve a true Digital Single Market. In this White Paper, the Commission sets the vision of “Connected Collaborative Computing Network”, or “3 C Network”, a future ecosystem that spans over the entire computing continuum, from semiconductors, computational capacity in all kinds of edge and cloud environments, radio technologies, to connectivity infrastructure, data management, and applications. The Commission proposes to move towards the 3 C networks on the basis of Large-Scale Pilots that set up end-to-end integrated connectivity-edge-cloud infrastructures and platforms in a number of verticals of which mobility. The EU Council of Ministers supports this vision and orientations.

Incorporating insights from this White Paper, the Competitiveness Compass for the EU [2] report, published by the European Commission in January 2025, outlines strategic initiatives to strengthen Europe's economic dynamism and growth. It highlights the vital role of digital infrastructure in boosting competitiveness and, through its second pillar, focuses on integrating decarbonization policies with industrial and economic strategies to drive sustainable growth. The report introduces key initiatives to modernize Europe’s transport infrastructure through digitalization—enhancing connectivity, reducing emissions, and reinforcing the EU's global competitiveness. By fostering investment, regulatory support, and innovation, it contributes to the green transition and the future of smart mobility.

The Competitiveness Compass for the EU report and Draghi's report, The Future of European Competitiveness – A Competitiveness Strategy for Europe [3], both address Europe's need to bolster its competitiveness, particularly in the realms of digital infrastructure and technological innovation. Both reports emphasize the necessity of substantial investments and strategic initiatives to enhance Europe's position in the global digital economy.

EC instruments and funding programmes supporting digitalization

The funding programs Connecting Europe Facility Digital (CEF2 Digital) [4], Digital Europe Programme (DEP) [5], and InvestEU [6] directly support the goals outlined in the previous reports by contributing to:

- ✓ Supporting Next-Gen Connectivity – Investing in fibre networks, AI, and advanced digital technologies to close Europe’s digital gap.
- ✓ Encouraging Public-Private Synergies – Mobilizing private investment, which the report highlights as essential for future-proofing infrastructure.
- ✓ Optimizing Resources Across EU Programs – Ensuring synergies among EU funding mechanisms.

By coordinating funding through **CEF2 Digital, DEP, and InvestEU**, the EU ensures **faster 5G rollouts** for industries and transport, **lower deployment costs** through shared infrastructure, and a **stronger**

digital resilience by supporting **AI, cybersecurity, and smart city initiatives**.

The EU's trans-European transport network policy (TEN-T) is a key instrument for planning and developing an efficient, multimodal, and high-quality transport infrastructure across the EU. The network comprises railways, inland waterways, short sea shipping routes and roads linking urban nodes, maritime and inland ports, airports and terminals. The synergy between TEN-T and CEF2 Digital is centred around the digital transformation of Europe's transport infrastructure. While TEN-T focuses on building physical transport networks, CEF2 Digital provides the digital infrastructure needed to make these networks smarter, more efficient, and sustainable. By funding the deployment of digital technologies like 5G, broadband, and intelligent transport systems, CEF2 Digital complements TEN-T's goals, making Europe's transport networks more connected, efficient, and environmentally friendly.

The Industrial Action Plan for the European Automotive Sector

On March 5, 2025, the European Commission published the Industrial Action Plan for the European Automotive Sector [7]. This plan outlines measures to strengthen the competitiveness of the European automotive industry and to accelerate the transition to zero-emission mobility in the EU. The Action Plan, part of the EU's industrial strategy, focuses on maintaining the European automotive industry's global competitiveness amidst rapid transformations towards clean, connected, and autonomous vehicles. It aims to boost innovation, digitalization, and clean mobility, improve supply chain resilience, and enhance skills. Key measures include developing **cross-border testbeds for autonomous driving, enhancing EU regulations, and fostering collaborative innovation in software, AI, and vehicle technologies**. The plan also emphasizes building EU-specific industrial capacities and reducing dependencies on non-EU suppliers. The **EU Automotive Action Plan** highlights the **rapid integration of digital technologies, such as AI, software, sensing and communication devices, together with the increasing importance of digital services and connectivity for the automotive sector**.

Alignment with key European Partnerships

The 5G SDA for CAM aligns with the **Smart Networks and Services Joint Undertaking (SNS JU)** to coordinate pan-European 5G corridors and guide the CEF2 Digital program, fostering synergy across initiatives and sectors. In addition, the 5G SDA for CAM mission needs to establish synergies with key initiatives with direct impact in the mobility sector: the **Chips Joint Undertaking (Chips JU), the Vehicle of the Future initiative**,, the **European Connected, Cooperative and Automated Mobility (CCAM) Partnership** and the **Towards zero emission road transport (2Zero) Partnership**.

1.1 Benefits of 5G for Road

5G will be a **key enabler** in the **green and digital transformation** of Europe's transport sector by:

- Enhancing connectivity for **autonomous and electric vehicles**.
- Enhancing the **efficiency of public transport, logistics, and traffic management** to support sustainable and green mobility.
- Supporting **smart infrastructure** and **eco-friendly urban mobility** solutions.
- **Enhancing safety** and supporting Vision Zero by reducing road accidents and minimizing human error through automation.
- **Enabling** user-centric, inclusive, and integrated transportation systems.

- **Unlocking new economic opportunities,** which are the axis for new services. For instance, drivers, as "passengers," could use their time for other activities, like working in mobile office spaces.

5G connectivity, in parallel with other advanced digital technologies, is a powerful combination that will enable the digital transformation of mobility among many other industry verticals, providing the advanced platform and networks to ease the deployment of such technologies and services.

In the future, the seamless interaction between terrestrial (TN) and non-terrestrial networks (NTN) is also expected to play an essential role in achieving CAM service continuity based on ubiquitous coverage.

Overall, 5G is not just an upgrade over previous network generations—it is a critical enabler for transforming transportation. Its capacity to support real-time, high-volume data exchange with high reliability and at low latencies makes it indispensable for advanced safety systems, autonomous vehicles, and comprehensive smart traffic management solutions. Without the capabilities provided by 5G, many of the innovations in transport technology, like teleoperation, would be significantly hampered, making its deployment a key factor in driving the evolution of modern mobility.

In this regard, a supportive public policy context shall create a favourable environment to encourage private investments in large-scale deployment of 5G infrastructures, paving the way to future Connected and Automated Mobility.

2 Road vision and goals for mobile communication

5G Corridors are designated transport routes—such as motorways or rail lines—equipped with continuous, high-performance 5G connectivity. They are primarily designed to support connected passenger services, connected and automated mobility (including autonomous driving), and real-time communication for transport, logistics, and emergency services.

At the core of 5G Corridors is 5G Standalone (SA) technology, which provides the advanced network architecture and features necessary to enable next-generation mobility. **The deployment of 5G SA and 5G Corridors follows a top-down, network-led approach, where foundational infrastructure is built in advance of widespread adoption**. This ensures that a **robust, future-ready platform is in place to support emerging CAM services as the broader transport ecosystem evolves**.

5G Corridors are designed to integrate a comprehensive suite of technologies—including terrestrial 5G, Non-Terrestrial Networks (NTN), short-range communications, and Multi-access Edge Computing (MEC). Working in concert, these technologies together can provide seamless, intelligent, and resilient connectivity along key transport routes, maximizing the performance and impact of connected mobility use cases.

The **convergence of connectivity, 3C Networks (communication, computing, and control), Multi-access Edge Computing (MEC), and Artificial Intelligence (AI) will be also crucial:** connectivity enables real-time data exchange; 3C Networks manage information flow and system responsiveness; MEC reduces latency by processing data closer to the source; and AI drives intelligent automation through data analysis and prediction. Together, these elements will form a **transformative, multi-service foundational infrastructure** that will accommodate the diverse connectivity requirements of future-ready, adaptive services across a wide array of sectors including transportation, healthcare, manufacturing, and smart cities.

2.1 Objective of the SDA for road transport

The 5G SDA aims to provide a cohesive framework and recommendations for 5G deployment in road transport, ensuring seamless connectivity, cross-border service continuity, and mutualised costs. The following principles underpin the stakeholders’ common vision for the 5G SDA for CAM:

1. **Incremental deployment:** the deployment of 5G Radio Access Network (RAN) infrastructure is incremental and shall leverage the existing and mature 4G LTE RAN deployments, to safeguard uninterrupted coverage.
2. **Transition from 4G/5G Non-Standalone (5G NSA) to 5G Standalone (5G SA):** the 5G CAM services deployments need to progress exploiting the powerful capabilities offered by the mature 4G and 5G NSA networks, focusing on the e2e service validation and optimisation. At the same time, it is important to prepare for leveraging the emerging service differentiation capabilities of 5G SA networks as these are being rolled out.
3. **Seamless Integration of Advanced Radio Technologies within 5G Networks:** 5G technology is highly flexible and designed to enable the seamless integration of diverse radio communication systems, including Non-Terrestrial Networks (e.g. based on orbital satellite constellations). This flexibility allows 5G to cater to a wide range of service needs—from mission-critical applications like automated driving and road safety to non-mission critical such as Infotainment, either embedded using 5G service options or “over-the-top” as Internet/cloud-based services for ease of deployment.
4. **Service Roadmap:** it is key that the community develops a convergent roadmap identifying 5G-enabled CAM services for the road transport industry and operators. It is also key to consider User Equipment (UE) adoption of 5G capabilities.

5. **Ubiquitous, transparent Connectivity:** the 5G infrastructure shall aim at ensuring seamless services across borders, MNOs, vendors/OEMs, traffic managers, road operators, and service providers.
6. **Integration of Edge Computing:** 5G network roll-out shall be complemented by the integration of edge computing facilities along 5G corridors and within smart communities to enhance service delivery. Edge computing will play a crucial role in AI-driven mobility by enabling real-time decision-making, reducing latency, and improving efficiency in autonomous vehicles and smart transportation systems. By processing data locally, it ensures faster responses, enhances safety, and reduces reliance on cloud connectivity. This optimization lowers bandwidth costs, improves cybersecurity, and enables personalized in-vehicle experiences.
7. **Collaboration with Road Operators:** Road operators should engage actively with MNOs to improve 5G coverage and Quality of Service (QoS), establishing synergies across sectors.
8. **Business clarity and investment:** it is key to determine the most viable business models, with flexibility and cooperative planning, to deliver future networks innovatively and with optimal economics. One of the main benefits of 5G is the “mutualisation” of costs between various services and sectors based on slicing with differentiated capabilities and QoS, using the same underlying network infrastructure and thus improving the overall economic case.
9. **Blueprint for deployment:** it is necessary to develop a European 5G for CAM blueprint, based on outcomes from ongoing 5G Corridors deployment projects, to consolidate best practices and methodologies for interoperable and expandable deployment.
10. **Guideline for European Funding Programmes:** since 2019/2020, MNOs have been deploying 5G NSA networks, with full-scale 5G SA networks now complementing them. However, gaps remain in certain parts of the road network, particularly in less economically attractive areas. In this context, the EU allocated €1 billion from the Connecting Europe Facility (CEF) Digital Programme (2022-2027) to co-finance 5G corridors, focusing on low-investment-attractive areas like rural and cross-border regions. The SDA shall provide guidance to CEF Digital projects and to future EU funding instruments, ideally also to related Member State-level co-financing programmes.

The **5G SDA for CAM (Road chapter) and the 5G SDA for CAM (Rail chapter)** [8] **integrate a 5G deployment path and recommendations from the Road and the Rail sectors**, with a particular focus on policy, regulations, business models, and deployment scenarios. In addition, emphasizing both the similarities and differences between the two transport modes will help to find common opportunities and create a cohesive framework for smarter, more connected transport systems across Europe. The collaboration between stakeholders, the integration of new technologies like 5G, and the standardization of services and regulatory practices will be key drivers of success.

The 5G SDA chapter for road provides guidance on deployment planning and co-funding for 5G mobile infrastructure, to support the roll-out of six service categories: **Road CAM services, Logistics, Digital Twins, Connected Passenger Services, Software-defined Vehicles and Associated vertical services**.

2.2 Current challenges and opportunities

The evolution from Advanced Driver Assistance Systems (ADAS) to SAE Level 4 Automated Driving Systems (ADS) across geographies relies on advanced mobile communication technologies, with 5G poised to play a pivotal role in shaping the future of road transport. Alongside cellular networks, direct short-range communication technologies will provide complementary capabilities, forming an integrated communication ecosystem. In addition, as demand for connected driving experiences grows, 5G emerges as a critical enabler—offering ultra-fast, low-latency, and highly reliable connectivity essential for the next generation of connected vehicles. Nevertheless, realizing this vision involves overcoming a range of technical, operational, and regulatory challenges that must be addressed to unlock the full potential of 5G in road transport.

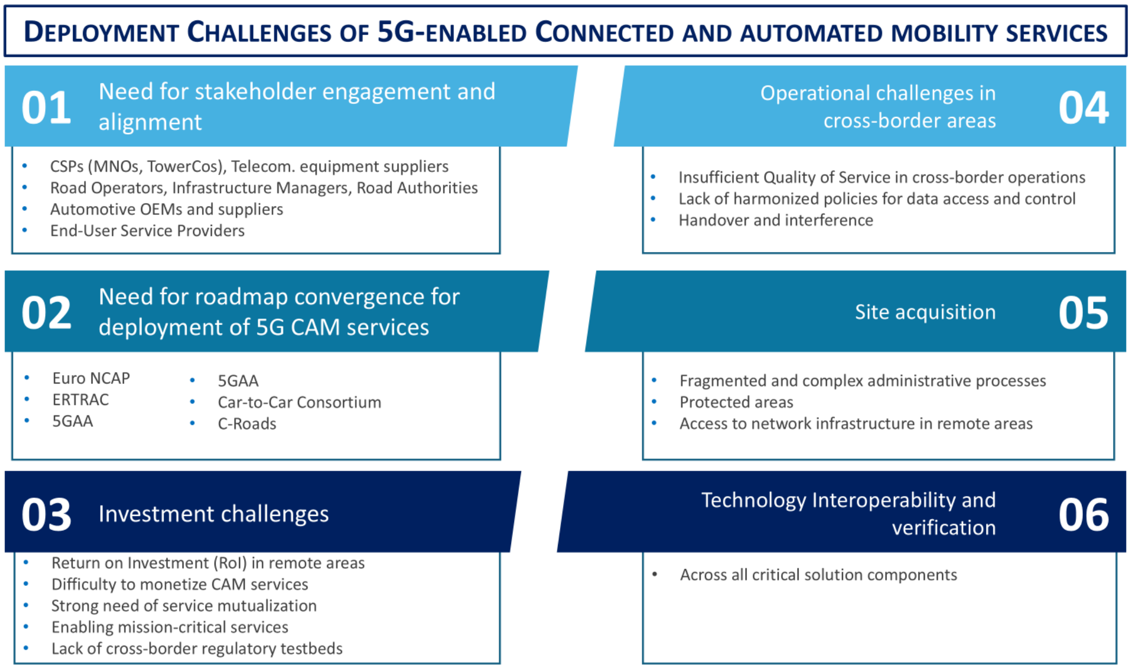

Figure 1: Deployment challenges of 5G-enabled Connected and Automated Mobility services

2.2.1 Need for stakeholder engagement and alignment

Bringing all the involved stakeholders together is key to build a common vision, encourage collaboration and ensure a successful deployment of 5G in Road transport. The key stakeholders in the Road Transport sectors are:

- **Communication Service Providers (CSPs):** include mobile network operators (MNOs) and tower companies (TowerCos).
    - MNOs plan, roll out, and operate 5G networks and telecommunication infrastructures in cities and along roads. Provide cellular services using granted spectrum rights. Handle billing and deliver customer service.
    - TowerCos manage RAN sites, including towers and related infrastructure. Handle planning, investment, deployment, and maintenance. They can operate as Neutral Host Providers (NHPs), leasing shared infrastructure (e.g., cell towers, fibre-optic networks) to multiple service providers.
- **Telecommunication Equipment Suppliers** provide hardware and software integral to 5G networks, including essential upgrades. They collaborate with MNOs to enable telecommunication services.
- **Road operators** are in charge of the cooperation and promotion of improvements to the road system and its infrastructure, as well as road management.
- **Vehicle Original Equipment Manufacturers (OEMs) and Tier1/Tier2 suppliers** integrate telecommunication devices and software into connected vehicle systems. They enable CAM-related features and mobility for vehicle users and are responsible for User Equipment 5G adoption.
- **End-User Service Providers** develop, test, and deploy innovative mobility services for consumers. These include providers of Mobility-as-a-Service (MaaS), shared mobility services, E-mobility platforms, Logistics and freight operations.

- **Road Infrastructure Managers** are entities (public or private) responsible for the day-to-day management, construction, maintenance, and operation of roads.
- **Road Authorities** are responsible for the care, control, or management of roads within a given jurisdiction.
- **Road infrastructure equipment providers** develop and provide infrastructure elements that benefit from connectivity. Taking their needs into account enables faster adoption and deployment of those elements.

2.2.2 Need for a consolidated roadmap for deployment of 5G Connected, Automated services

The ecosystem of stakeholders has outlined various roadmaps for deploying CAM services:

- The **5G Automotive Association (5GAA) visionary roadmap 2030** [9], updated in November 2024 addresses the deployment of advanced driving use cases. The document includes the expected timelines for mass deployment of different V2X use cases, leveraging 3GPP Cellular-V2X technologies, addressing challenges like global standards, security, and privacy regulations.
- **The European Road Transport Research Advisory Council (ERTRAC)** has published an update to Chapter 2 "Agenda 2030" on CCAM Innovation use cases [10] . focusing on realistic use cases in five different application domains: parking, confined areas, highways, urban and peri-urban transport for people and goods, and rural and secondary roads, where connectivity is presented as a transversal enabler for deployment.
- The 2nd edition of the **Intelligent Transport Systems (ITS) Market Radar Report** [11], **published by ERTICO** in January 2025, presents a cross-sector snapshot of ITS in Europe. It highlights a transition toward automated, electrified, and intermodal mobility—powered by AI and connectivity—but also underscores key hurdles: funding, regulation, public acceptance, and workforce readiness. The report offers actionable guidance for stakeholders to foster smarter, greener, and more inclusive transport systems.
- Published in 2022, the **Euro NCAP Vision 2030** [12] guides future automotive safety developments, recognizing car-to-network and direct car-to-car communications' critical role in crash avoidance and situational awareness. Protocols will be accommodated by evaluating each safety function in a technologically neutral way.
- In 2024, the **C-Roads platform** published its **C-ITS Roadmap** [13] , which aims to give infrastructure managers and OEMs an overview of existing and upcoming C-ITS use cases and services from an infrastructure perspective, and the related communication requirements.
- **In 2021, the Car-to-Car Communication Consortium (C2C-CC)** published a **deployment guidance and R&D needs for C-ITS in Europe** [14], adopting harmonized templates and ETSI standards.

The deployment of **5G networks** for **Road CAM** services needs to be **closely aligned** with these **roadmaps**, ensuring that 5G can fully support the vision of **smart, safe, and efficient transport systems**. Despite the existing initiatives, there is no unified vision or timeline for deploying CAM services. In fact, challenges and gaps persist in harmonizing priorities and timelines across regions and stakeholders. While governments are investing in 5G infrastructure, collaboration among ecosystem partners is critical for realizing 5G mobility goals. Working towards roadmap convergence must align public-private priorities with infrastructure investments and address gaps in understanding user needs, service demand, and economic feasibility.

Independent of the lack of a consolidated CAM services roadmap, individual vehicle manufacturers are increasingly equipping their vehicle models (new or facelift) with 5G communication capabilities to support their evolving portfolio of connected vehicle services, where vehicles communicate with vehicle cloud services provided by vehicle manufacturers or by vehicle cloud service providers of their choice. This is also driving demand for widespread 5G connectivity, capacity and capabilities along transport corridors and eventually on the entirety of the European road network.

2.2.3 Investment challenges

A major challenge in 5G network deployment is developing strategies to ensure successfully direct investments (€22 billion annual investments in mobile internet in Europe for the period 2019-2023, as per GSMA's **Mobile Infrastructure Investment Landscape report** [15][1]) to enable monetization, especially for the road transport sector, which requires justification for high capital and operating expenses (CAPEX and OPEX). Returns on 5G investments remain low (1.5%-4.5% Return on Assets), making cost and revenue management crucial.

Key challenges include:

- **Return on Investment (RoI) in remote areas:** it's difficult to justify investment in 5G networks along corridors far from population centres.
- **Monetizing CAM services:** efficiency and safety benefits are collective and societal, making it challenging to monetize them without large user bases or public authority intervention.
- **Service mutualization:** there is a strong need to focus on service mutualization to maximize efficiency, reduce costs, and enhance service availability across different industries. This involves sharing network infrastructure, computing resources, and service capabilities among multiple users and applications (CAM and non-CAM) to improve returns.
- **Enabling service differentiation for Mission-Critical Services (such as PPDR or certain CAM services like Tele-Operated Driving)** based on 5G capabilities (e.g., slicing).
- The **lack of cross-border regulatory testbeds** limits the ability to boost market readiness and commercialisation of connected and autonomous vehicles.

Addressing these issues is vital to improving the financial viability of 5G deployment.

2.2.4 Operational challenges in cross-border areas

The effectiveness of the EU's internal market depends heavily on a robust transport infrastructure for seamless cross-border movement of people and goods. Passenger transportation has greatly benefitted from the lowered administrative burdens associated with cross-border movement within the Schengen area. Nevertheless, the EU telecommunications market is characterised by a rich scene of MNOs and associated service providers that operate their mobile networks within the confines of national borders.

The **EU Roaming Regulation** [16] has ensured that people and businesses can use mobile services with the same quality of service as in their home country. Yet, some specific challenges await end users when crossing a border:

[1] Note that although there is no distinction within those investments, the number shows the investment potential for Road CAM services when adequate clarity on needs, directions, and return-on-investment are provided to justify the investments.

- **Quality of Service (QoS):** Many CAM services demand enhanced QoS, which current networks struggle to provide during cross-border roaming between Public Land Mobile Networks (PLMNs).
- **Data Access and Control:** A lack of harmonized policies for cross-border data access and lawful interceptions creates regulatory and operational barriers. Each country adheres to its own national laws, complicating dynamic and secure cross-border data handling. This is also relevant in processes involving the verification of the identity of customers, for instance "Know Your Customer" (KYC) applications, which are important to prevent fraud and ensures compliance with regulations.
- **Handover and interference:** harmonized operations in the border areas across neighboring MNOs and Mobile/Fixed Communications Networks (MFCN), especially for 5G Time Division Duplex (TDD) operations, is pivotal for avoiding interference, which could otherwise lead to performance degradation, and also impacting seamless inter-PLMN handover. Relevant technical recommendations have been published by GSMA ("**Guidelines and Recommendations for the Coexistence of TDD Networks in the 3.5 GHz Range"** [17]) and CEPT/ECC, which provide at the European level the recommendations and EU harmonization decisions as a framework for synchronizing 5G networks and managing cross-border coordination.

Addressing these challenges requires the development of harmonized guidelines, enhanced QoS mechanisms, and streamlined cross-border coordination among telecommunications operators. This is crucial for ensuring seamless connectivity and the efficient deployment of CAM services across the EU.

2.2.5 Site acquisition process and related challenges

The deployment of 5G faces a major challenge related to **fragmented and complex administrative processes in Europe and at country level**, since permit approvals lack unification across regions. A proposed solution is to implement "corridor permits" to approve entire 5G layouts cohesively rather than site-by-site, which would reduce bureaucracy and accelerate deployment.

Additional challenges include site acquisition near protected natural zones, especially as higher-frequency bands (e.g., 3.4-3.8 GHz) require closer base stations with reduced inter-site distances.

In addition, **access to poles, fibre and power in remote areas is also a challenge**, hindering the business model in the affected areas. In addition, installation permits must be granted by different public administrations depending on the region, causing a high delay in the deployment process.

2.2.6 Technology Interoperability and verification

For the 5G Road CAM services to deliver the expected performance levels, it is important to verify the **interoperability across all critical solution components** i.e., Onboard Units (OBU), radio access and core configurations, and application servers, as well as to streamline the appropriate configurations.

Extended trials to verify the functional suitability and optimal use of the engaged technologies is pivotal to increase the confidence of the stakeholders for active engagement and can provide guidance for the extensibility and replicability of adopted best-practices.

In addition, for OEMs, the **current process of integrating with new MNOs is time-consuming and resource-intensive**: connecting to a new MNO involves a multi-stage certification process, starting at the NAD (Network Access Device) level and proceeding to the TCU (Telematics Control Unit) level. This process must adhere to each MNO's specific certification requirements, which introduces significant time and engineering effort.

Given the complexity and redundancy across MNO certification programs, it would be highly beneficial to establish a common certification framework beyond the **Global Certification Forum** (GCF) [18] — one that standardizes NAD and TCU validation across multiple MNOs. Such a harmonized approach would streamline onboarding, reduce duplication of effort, and accelerate time-to-market for connected vehicle solutions.

2.3 Road CAM services

Road CAM services use connectivity technologies to enhance traffic efficiency and safety in road transport. The deployment of Road CAM services is already delivering significant benefits to travellers through real-time traffic updates and improved navigation. In-vehicle systems provide information on congestion, safety hazards, and environmental zones, enabling better route choices and situational awareness. Widely implemented services, such as Automated Crash Notification (ANC/e-Call), mandatory in EU cars since 2018, enhance safety. Emerging services like traffic light priority for emergency vehicles and Green Light Optimal Speed Advisory (GLOSA) are also becoming increasingly available, further improving efficiency and convenience.

The promoters of the 5G SDA consider 5G to be a determining factor in the deployment of the following Road CAM services:

- **Highly automated driving functionalities**

Currently the Road CAM services available are largely targeting traditional vehicles and are mainly Day-1 (Awareness) services, which are basic safety services supporting the exchange of status information regarding local hazards and traffic information, and map updates.

With the increase of SAE L3-enabled vehicles in the market, connectivity will enable Day-2 (Sensing) services, allowing vehicles to share sensor data, providing more complete information about the detected objects and traffic. Safety benefits will be enhanced with respect to those of Day-1 services.

In a later phase of deployment, Day 3+ services will be implemented in Level 3 and Level 4 automated vehicles, providing the ability to plan and coordinate cooperative manoeuvres with other traffic participants and the infrastructure.

A combination of direct and network-based communications will cover the requirements to be met to provide these services.

Complementing the traditional vehicles, new types (e.g. shuttles, e-scooters) are emerging offering greater flexibility and choice for users; connectivity will allow these vehicles to be integrated into the CAM ecosystem to ensure road safety for all.

- **Remote management operations:**

Teleoperation is a form of vehicle control alongside human driving and automated driving, and it can support vehicles in unforeseen situations, providing different levels of support:

- Remote supervision and assistance
- Continuous remote driving
- Event-based remote driving

Remote management systems will require 5G capabilities that allow for priority service provisioning, low latency and high data transmission capacity. 5GAA has published a series of reports [19] on this topic.

- **Smart Traffic Management**

The integration of 5G technology, Artificial Intelligence (AI), and cloud computing is a game changer for traffic management and control systems and will be one of the key capabilities to make traffic safer, more efficient and sustainable. The benefits offered by 5G to traffic management include near instant communication, real-time high-volume data analysis, extensive device connectivity, segmented networks, and real-time traffic analysis.

2.4 Logistics services

As 5G networks continue to roll out, the logistics industry will also see significant advancements in connected and automated vehicle operations:

- Automated and connected vehicle fleets will be able to communicate with control centres, traffic systems and other vehicles.
- **Real-time vehicle diagnostics, vehicle monitoring, and predictive maintenance** will improve safety.
- Supporting **large data transfers**, 5G will allow logistics operations to be managed in real time and to perform data-driven decision making, optimizing delivery routes and reducing costs.
- 5G will also support **automated transport operations within hubs, and hub-to-hub**. This will bring significant benefits, such as greater efficiency, lower costs, improved safety and tracking, and reduced environmental impact.
- Multimodal transport systems will also require **interoperability between traffic management systems, geographical locations, automated vehicles and different modes of transport** in order to provide seamless mobility services. Logistics operations will require an optimal mobility network load balancing to fulfil the requirements of advanced traffic management systems, fleet management systems and information sharing processes that reach out to all the involved individuals.

2.5 Digital Twins for mobility

The deployment of 5G integrated with **advanced computing techniques, artificial intelligence and sensor networks have delivered a huge boost to digital twins**, which rely on the efficient movement of vast quantities of data in real-time and have high requirements towards latency, availability (no packet loss), privacy, and security.

Digital twins together with AI models offer many opportunities in the mobility sector, as they:

- facilitate traffic pattern prediction and decision-making.
- optimisation/predictive road maintenance (based on info collected by car sensors – if a contract exists with Road Operators). There are already deployment examples where a contract exists between OEMs and ROs, e.g. in Sweden.
- support eco-friendly transport by optimizing routes and EV charging infrastructure

2.6 Connected Passenger Services

In addition to Road CAM services, connectivity is increasingly becoming a crucial factor for customers' selection of car brand. There are high expectations on OEMs to bundle options for connectivity-enabled features and a highly tailored solution to specific regions and customer segments. Connected passenger services are, therefore, crucial for a co-funding roll-out

A combination of local (in-vehicle), edge, and cloud computing facilitates the delivery and operation of a comprehensive set of applications and services, such as:

- **User-centric mobility services:** insurance (pay-as-you-drive), Mobility as a service (MaaS), payments (parking, tolls, energy), EV services (charging/reservation/battery sharing), navigation/telematics.
- **User-centric non-mobility services**: infotainment and integration with existing and emerging ecosystems in the smart home/office environments (via virtual personal assistants), advertising, gaming, videoconferencing, e-commerce/app-stores.
- Some of the connected services (the ones not causing driver distraction) are expected to rapidly grow also for 2-wheelers (Motorbikes and Scooters).

By integrating 5G connectivity in upcoming vehicles today, coverage and throughput will improve; in addition, OEMs will be able to leverage new network functionalities and 5G-related technologies, such as edge computing, network slicing, regional breakout, precise positioning and multi-connectivity management. These technologies allow high-performance data-exchange, which enables seamless user experiences between the car (on-board) and the outside (off-board) worlds. Without 5G, OEMs risk missing opportunities to move functionalities from the car to the cloud, create new subscription-based services, or deliver software and AI/ML model updates efficiently.

5GAA White Paper on **Accelerating 5G Adoption for Connected and Autonomous Mobility Services** [20] explores the expansive business opportunities that 5G technology introduces to the connected mobility ecosystem, emphasizing innovations beyond safety and automated driving to enhance customer experiences. Many additional apps and services – beyond safety and automated driving – benefit from 5G such as in-vehicle entertainment, e-commerce and more.

2.7 Software-defined Vehicles (SDV)

Software-Defined Vehicles (SDVs) are advanced vehicles where software, rather than hardware, controls key functions and systems, enabling continuous updates, flexible customization, and seamless integration with cloud services. **SDVs leverage AI, machine learning, and advanced connectivity to provide enhanced performance, autonomous capabilities, and real-time adaptability**, making them more responsive to user needs, regulatory changes, and evolving technological advancements.

As Original Equipment Manufacturers (OEMs) scale up the adoption of 5G technology, **a transformative industry paradigm is emerging that connects Software-Defined Vehicles (SDVs) to powerful cloud and edge computing resources**. This seamless integration will not only enhance user experiences by enabling real-time updates, personalized services, and autonomous vehicle capabilities, but also unlock new revenue streams through the creation of data-driven services, subscription models, and Over-The-Air (OTA) updates, predictive maintenance, remote diagnosis / optimisation. Furthermore, it will allow for more agile service delivery, empowering OEMs to rapidly innovate, respond to market demands, and optimize vehicle performance in ways that were previously not possible. Ultimately, this shift will redefine the relationship between vehicles, their owners, and the broader digital ecosystem, creating a new era of connected, intelligent transportation.

The rise of Software-Defined Vehicles (SDVs) is fundamentally reshaping the automotive industry, driving the transition to electric, automated, and connected vehicles. This shift relies heavily on the **cloud-based service models like Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), and Network as a Service (NaaS).** These models enable the delivery of a seamless, flexible, and scalable user experience. By providing seamless integration across infrastructure, platforms, software, and networks, these models enhance the user experience and enable new business opportunities.

Taken together, the previous factors mandate **connectivity as a critical enabler of SDV architectures, facilitating continuous integration, real-time data exchange, and the orchestration of distributed computing resources across cloud and edge environments**.

2.8 Associated vertical services

Innovations brought by deploying 5G alongside European roads can also be driven across various industry verticals. This is the case, for instance, for connectivity services in **the rail sector as well as other transport modes**.

5G has also the potential to benefit road infrastructure managers and road operators among other stakeholders, by providing connectivity services for **(road) construction and maintenance works**, where uninterrupted on-site connectivity can enable a safer, more efficient and more productive work environment. Connectivity can also enable smart planning, the operation of autonomous machinery (paving, material handling, etc.), robotic survey and inspection, maintenance, etc. by providing real-time data, low latency, remote operations.

In addition, 5G offers the opportunity to significantly enhance multimodal coordination by enabling real-time, reliable communication between automated vehicles, infrastructure, and other transport modes through its ultra-low latency and high bandwidth capabilities, plus its ability to connect many devices simultaneously. This supports seamless data sharing—like sensor data, HD maps, and traffic updates—improving safety, efficiency, and synchronization across cars, public transit, bikes, and pedestrians. Additionally, edge computing and network slicing ensure fast local processing and dedicated service quality for different mobility needs.

5G enhances **cybersecurity services** like anomaly detection and threat simulation by enabling real-time data analysis, thanks to its ultra-low latency and high bandwidth. It supports edge computing for faster, localized threat response and reduces reliance on centralized systems. With its ability to connect massive numbers of devices, 5G improves visibility across complex networks, while also enabling advanced AI-driven threat analysis. Additionally, network slicing allows for secure, isolated environments, protecting critical systems and improving the effectiveness of simulations and responses.

Other opportunities lie in supporting e.g. smart farming and smart warehouse services along the road transportation network.

The following figure shows an overview of the CAM service categories considered in this document.

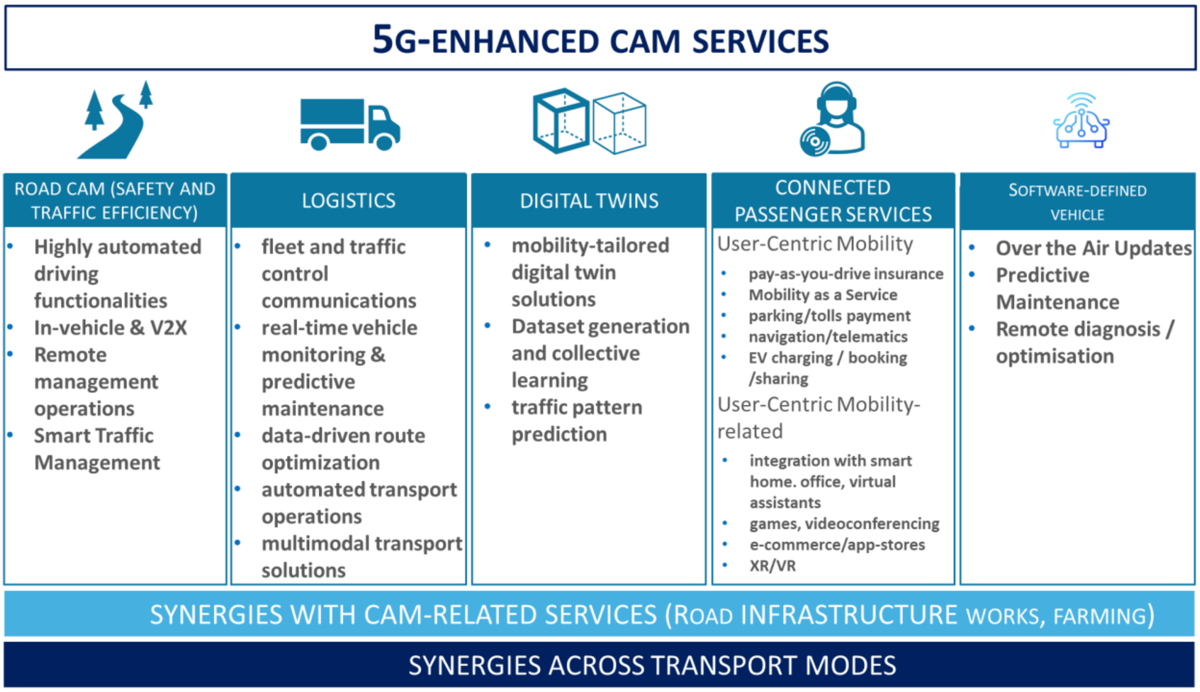

Figure 2: 5G-enhanced CAM services (Road transport)

3 Service requirements

A major challenge facing the deployment of 5G for CAM is to understand what the evolutionary path of 5G network deployment along corridors should be, to cope with the increasing requirements of future market services and the technological innovations required to achieve them. This chapter discusses the innovations necessary to fulfil the requirements of current and near-future CAM services in road transport corridors.

An aligned vision for investments is needed to fulfil the requirements, which respects the lifetime of technologies, whether deployed in roadside infrastructure, in automotive capabilities, or in network performance.

3.1 Road CAM service requirements

The use of intelligent transport systems requires a common architecture for digital data exchange to facilitate CAM services with a significant impact on traffic management, road safety and sustainable transport.

For short-range communications, such a common architecture has been defined by ETSI. C-Roads and the Car-2-Car consortium provide information for effective short-range communication and coherence with long-range, IP-based (i.e. cellular) communication of ITS- related messages as specified by ETSI, including methods and requirements to implement the regulated EU CCMS for C-ITS.

Deployment of effective cellular-based road CAM services requires the following:

- **Network coverage** to serve an area in which a device (vehicle) has access to the network. Usage of this coverage allows not only for vehicular use cases but also enables the deployment of infrastructure-based use cases.
- **Capacity**, the amount of data traffic that a network can manage simultaneously from all users in a specific area.
- **Reliable connectivity** is another prerequisite for Road CAM service provision and shall take into account **Quality of Service (QoS)** as a main indicator (like packet loss, bandwidth and latency). QoS should be predictable and meet performance requirements for smooth and reliable operation tailored to the use cases operational within the coverage area, e.g. remote operation or driving versus routing. Multiple stakeholders have demonstrated ways to ensure that CAM use cases can already be executed with regularity under predictable conditions. In addition, providing clear mechanisms to enable interoperability between MNOs will be crucial to ensure service continuity for remote driving and advanced CAM services.
- **Privacy and security** are critical because mobility-related data transmitted through cellular networks contains aspects governed by privacy regulations. Encryption and authentication throughout the networks must ensure trusted end-to-end connections. Information security and privacy have been key design principles within 5G. Deployment of 5G will, therefore, enhance security and protection of privacy also for technologies using 5G as a backbone.
- **Resilience** as the capability of the networks to tolerate and respond to external events, disasters, faults, misuse or attacks. Similar to the above, CAM services should be made aware of possible network degradation along the road network.
- **Scalability** as the capability of the networks to quickly scale up the deployment of services on the full road network and respond to the demand.
- **Seamless service continuity** across or between multi-vendor, multi-carrier inter-connections (i.e., node-to-node or network-to-network, including cross-border) is enabled by mobile network interoperability. This must happen when working under normal and stress conditions, and as per the applicable standards, requirements, and specifications. For example, a vehicle

driving across borders using dedicated 5G network functionality should be serviced under the same service requirements in the visiting network.

Additionally, **supporting non-3GPP radio technologies could enhance the deployment of other road transport-related use cases and technologies**. This can be supported either by using over-the-top IP-based services or by 5G's Non-3GPP Inter-Working Function (N3IWF), which is already being used for (regular consumer) WiFi connections and Non-Terrestrial Network integration. Both options allow leveraging the coverage, capacity, QoS, and security of 5G networks for the benefit of these dedicated services and technologies.

The 5GAA's technical report on **Road Operator Use Case Modelling and Analysis** [21], underpinned by a dialogue between industry and selected road operators in Europe, has found that initial Day-1 CAM use cases preferred by road operators today can be supported by mature 4G mobile networks. Recommended strategies for network providers to adapt coverage for increased capacity include network densification, network expansion, enhancing quality of service, increasing MEC deployment for CAM use, prioritising availability of real-time data for low -latency, IT interfaces between data exchange elements and network slicing. The examined Day-1 use cases were local hazard and traffic information, GLOSA, Probe Vehicle Data and Data Collection and Sharing for high definition (HD) Maps.

On later deployment stages, Day-2 use cases, as defined by C2C-CC, will enable cooperative perception capability by enabling vehicles to access real-time sensor data (e.g. about traffic and road condition) from other connected vehicles and infrastructures. While the Day-2 phase takes advantage of the presence of vehicles with enhanced sensing capabilities to deliver use cases adopting shared sensor data, the rising introduction of automated driving will pave the way to Day-3 use cases, which supports sharing of vehicle control intentions or decisions and even negotiation among traffic actors up to cooperative manoeuvring. **More advanced use cases (Day-2+)** will place much higher network demands on the infrastructure. Also, to amalgamate the 5G innovations into a coherent, flexible and efficient end-to-end ecosystem will be critical to provide these services.

A fully automated mobility will require a totally reliable and safe network infrastructure, which will have to combine all available technologies: sensors (in vehicles and on the ground), high accuracy timing, precise positioning, HD mapping, converged AI on devices, at the network near- or far-edge (including Multi-Access Edge Computing) and in the cloud, and, in particular, high-quality direct and network communications between all moving and fixed elements (vehicles, bikes, pedestrians, and road infrastructure). Functional redundancy and complementarity in the architecture will be necessary to be able to meet the demanding Key Performance Indicators of such full automation.

In **remote management operations**, the most demanding services may require uninterrupted coverage, high data throughput, real-time transmission of HD videos, very low latency, and high reliability of control commands to enable continuous video streaming and allow commands to be sent from the control centre to the assisted vehicle.

3.2 Logistics operations service requirements

Logistics operations will need capabilities for real-time tracking and control of logistics fleets to monitor car locations and optimize routes dynamically. Connectivity must allow a transparent process end-to-end that integrates all elements from producer to consumer, including the continued tracking of smart sensors and Internet of Things (IoT) devices. Strong encryption and safety protocols must ensure data security.

3.3 Digital Twins service requirements

The use of 5G in mobility digital twins demands specific service capabilities from 5G networks to ensure real-time accuracy, responsiveness, and scalability, including highly reliable, low-latency communication, enhanced mobile broadband and massive machine-type communication (mMTC) for connectivity, plus Multi-access Edge-Computing.

3.4 Connected Passenger service requirements

Connected Passenger Services comprise the same services used by consumers every day and everywhere over mobile networks, either directly or indirectly (via in-vehicle Wi-Fi): i.e., telephony, messaging, and internet-based services for multimedia communication, information, business communication/mobile office and entertainment purposes.

Connected Passenger Services can be served by 4G, 5G NSA and 5G SA networks, as they are covered by the capabilities needed for (enhanced) Mobile Broadband services provided by mobile networks. For the delivery of these services, throughput and latency need to be adequate for a satisfactory user experience. Minute-long interruptions, multiple reconnection attempts and network ping-pongs disrupting the service might have been an annoying, yet tolerable situation in the past; nevertheless, service continuity is becoming a commodity customer expectation and hence a service requirement.

3.5 Software-defined vehicle service requirements

The 5G requirements for Software-Defined Vehicles (SDVs) are driven by the need for high-performance, reliable, and secure connectivity to support a wide range of vehicle functionalities—from autonomous driving to infotainment and remote diagnostics. In this context, the focus of this chapter specifically refers to the interfaces between onboard vehicle systems and the external network, rather than the vehicle's internal architecture or system design.

For optimal performance of SDVs, ubiquitous connectivity and wide-area network coverage are crucial requirements. These should be combined with economically sustainable models for network usage in periods of excess capacity, which is key especially in scenarios that involve both high-throughput downlink traffic, such as Over-The-Air (OTA) updates, and uplink-intensive workloads like the transmission of sensor data for AI model training.

Additional requirements typically include highly-reliable low-latency communication, enhanced mobile broadband for high data rates, massive machine-type communication (mMTC), and network slicing for custom connectivity, among others.

4 Innovations needed to meet the service requirements

This section describes several innovative topics and features needed to meet the CAM service requirements.

Services for passengers and services for road CAM (safety and traffic efficiency) differ in terms of requirements and performance levels. Nevertheless, since they are normally confined to the same geographical area, certain building blocks are common to both.

It must be emphasized that when it comes to defining a roadmap for investment in 5G infrastructure and related technology, it becomes necessary to establish a compromise between the requirements of the use cases and the feasibility of the business case. For instance, designing a network for the most challenging use cases could result in cost that renders current and near-future services commercially infeasible; this needs to be considered in the identification of the necessary building blocks.

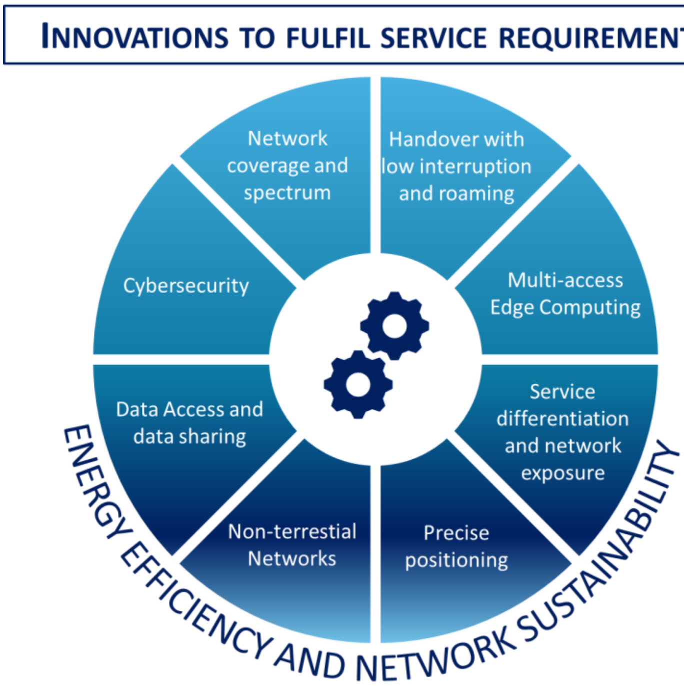

Figure 3: Innovations needed to meet the service requirements

4.1 Network coverage

The 5G network deployment planning must take into account the compromise between wide-area coverage and capacity in order to maximize its effectiveness across all potential services. Refarming of spectrum previously used by older network generation (2G, 3G and, over time also 4G) for 5G will enable a significantly higher spectral efficiency, meaning higher throughput capacity with the same spectrum depth. Successful 5G deployment is relying on spectrum access in low, mid and, in some cases, high spectrum bands. Studies by the GSMA on **low-band** [22], **mid-band** [23] and **high-band spectrum** [24] for 5G conclude the following:

- **Low-band spectrum is any spectrum lower than 1 GHz** on the spectrum chart. A low-band spectrum in a 5G world will allow communication service providers to provide comprehensive coverage. Still, the throughput of the 5G network will only be incrementally better than what is delivered with 4G networks due to relatively small maximum spectrum block sizes available in these bands.

- **Mid-band spectrum (1 GHz - 6 GHz)** is essential in tackling coverage and capacity challenges. It's considered perfect for 5G, because it can offer a well-balanced compromise between capacity and coverage. The GSMA describes spectrum in the 3.3 GHz to 3.8 GHz range as ideal because many countries worldwide have already designated and allocated it for 5G.
- **High-band spectrum (mmWave, beyond 24 GHz)** offers the opportunity to provide high speed and capacity, but only with very limited coverage areas and niche lower-speed mobility services. Although it is not a requirement, this may become an option for future transport solutions in high-density traffic areas and transportation hubs in dense urban environments.

Currently, many 5G mid-band deployments in Europe rely on the 5G pioneer band n78, primarily 3.4 GHz to 3.8 GHz, with a focus on urban areas. At the same time, considering that the lower the frequency, the larger the inter-site distance (ISD) and thus the fewer cell towers are necessary to assure sufficient coverage, the shift to low-band deployments, such as 700 MHz, shall drastically improve coverage by simply upgrading existing sites with the relevant radio equipment. In addition, dynamic spectrum sharing and spectrum refarming (e.g. for n1, n3, n7 FDD bands) have already proven to be good catalysts in accelerating early 5G coverage while keeping capacity for legacy 4G LTE.

4.2 Spectrum for 5G cellular networks (IMT bands)

Once coverage is assured, capacity is the next challenge, which directly relates to spectrum availability. 5G will reach its full potential only if sufficient harmonised spectrum is made available to deliver the service in a timely way and with long term license duration. It will also be important to ensure that spectrum is assigned under fair and reasonable economic terms, so as not to hinder the spectrum holder's capability to invest in network infrastructure.

At the moment, it is expected that CAM services can be supported using the following frequency bands:

- Existing cellular mobile frequency bands (e.g. 800, 900, 1800, 2100 and 2600 MHz); these frequencies would be the result of a refarming from primarily 2G/3G, and 4G.
- 5G pioneer bands (e.g. 700MHz and 3400-3800 MHz)

5GAA investigated long-term **spectrum needs for use cases which involve network-based communications between road users through cellular mobile networks** in bands designated and licensed for use by mobile communication networks. Use cases considered tele-operated driving, high-definition map collection and sharing, obstructed view assist, infrastructure-assisted environmental perception, patient monitoring and in-vehicle entertainment.

The study concluded the following:

- **at least 50 MHz** of additional service-agnostic low-band (< 1 GHz) spectrum is needed **to provide advanced automotive V2N services in rural environments** by using cellular networks with affordable deployment costs, and
- **at least 500 MHz** of additional service-agnostic mid-band (1 to 7 GHz) spectrum is needed to provide **high-capacity, citywide advanced automotive V2N services**.

The term "additional" means availability of spectrum in addition to the bands that are currently identified for International Mobile Telecommunications (IMT) use by mobile communication networks.

It should be noted that the study is based on a long-term view and addresses the needs for the target use cases considering full market penetration of CAM-enabled vehicles. **This study is expressing a view by the industry, not a conclusion on spectrum availability and assignment, which is subject to validation and decision by the national spectrum management authorities**.

A deployment path to ensure capacity considers the following actions:

- **Refarming of existing spectrum** from 2G, 3G or 4G networks. 5G has higher spectral efficiency, meaning higher throughput per unit of radio spectrum. Nevertheless, additional spectrum and refarming are slow processes that need to be complemented by further measures.
- **Service differentiation will assure sufficient capacity** for most CAM services, especially given their slow uptake. Most capacity is still consumed by mobile broadband services from smart-phones and in-vehicle Wi-Fi (which has low adoption in Europe). Giving **mission-critical CAM services priority** over these Mobile Broadband services will virtually assure sufficient capacity for CAM services through Slicing and Quality on Demand (QoD).

4.3 Handover with low interruption and roaming

Handover is an essential feature in 5G (and earlier cellular systems) since it allows the mobile device to stay connected when moving from one network cell to another. Whereas handover ensures uninterrupted connectivity as users transition between network cells, roaming enables users to access services seamlessly when traveling outside their home network.

In Europe CAM services introduce the challenge to provide Inter-PLMN handovers at high- speeds and with no interruption, when crossing country borders. According to the outcomes explained in the **5G-PPP R&I 5G corridors projects White Paper** [25], crossing borders faces unacceptable service interruptions: today, cellular modems hang on to the network of the source country (including legacy 2G/3G or 4G) and will not search for a network in the target country until connection to the source network is lost. This can cause many seconds or even minutes with no or low-quality service. It needs to be addressed with specific roaming optimization techniques and their implementation. The establishment of cross-border test beds for 5G for CAM could significantly help developing a blue-print for large-scale deployment across all borders in Europe.

4.4 Multi-access Edge Computing (MEC)

Multi-access Edge Computing (MEC) brings computing and storage resources closer to the network edge and end users. Distributed MEC ecosystem is an important building block of “3C Network” (Connected, Collaborative Computing) and of high benefit for critical CCAM services as it provides access to the necessary compute resources at lowest possible latency, increases service reliability, security and overall quality of experience (QoE).

The main requirements of the automotive industry for a pan-European, cross-border utilization of services based on MEC cloud are the following:

- ✓ **Service Continuity Across Multiple Operators:** MEC service providers must ensure seamless service continuity in multi-operator scenarios. This is critical for applications like Vehicle-to-Everything (V2X), where vehicles may move across different MNO networks. MEC federation is a proposed solution to facilitate this interoperability by enabling cooperation between MEC systems from different operators.
- ✓ **Interoperability through standards or other means, like industry best-practice**: CAM service providers (and their application developers) must be sure that what they develop will run on any MEC platform and, where needed, will be interoperable with applications running on other MEC platforms within the same or other MNOs.
- ✓ **Low-Latency and Real-Time capabilities**: MEC must support low-latency communication and real-time data processing to meet the demands of automotive services, such as autonomous driving and connected vehicles. This involves leveraging edge computing resources at the network edge for faster response times.
- ✓ **Federation enablement:** the 5GAA emphasizes the need for federation enablement APIs to

support collaboration between different operators' edge platforms. This includes defining deployment options and architectural variants that allow seamless integration across MNOs.

- ✓ **Contextual awareness and localized service:** MEC applications should utilize real-time contextual information from local networks to optimize performance. This is particularly important for automotive use cases where location-specific data can enhance safety and efficiency.
- ✓ **Business agreements and partnerships:** beyond technical standards, achieving interoperability often requires business agreements between operators, service providers, and other stakeholders to define policies for resource sharing and federation operations.

To meet these requirements, multiple challenges have to be addressed. Some of the already known challenges include the lack of Local Breakout (LBO) for roaming scenarios in the MNOs network design. That would allow the data from the user device to be processed locally, instead of traversing to the MNO's mobile core in its own network possibly hundreds of miles away (known as Home Routing). Another important challenge is the ability to provide the location of the closest MEC site to the application and to enable seamless handover between MEC sites for moving objects (e.g. cars, buses, etc.).

While these and many other challenges are well known and are being addressed by standardisation organisations like ETSI MEC, 3GPP and GSMA, the implementation of these standards can take time, and may reveal further challenges. Close co-operation between mobile network operators, standardisation bodies and the industry is therefore essential in order to fulfil this task.

4.5 Service Differentiation and Network Exposure

Along with ongoing 5G network deployments in pioneer bands and in existing, refarmed IMT spectrum, **service differentiation is a key technique to manage capacity, being the second most important enabler after coverage**. Service differentiation has constantly evolved throughout the different cellular network generations. "Network Slicing", another evolution of service differentiation, was added with 5G, being mainly a 5G Core feature. Besides this strict meaning according to 3GPP 5G Core standards, Network Slicing also became a synonym for any means of service differentiation.

Key for service differentiation is the differentiated treatment in the radio network, as it is, usually, the communication bottleneck. QoS algorithms used to achieve that differentiation are not subject to standardization. Furthermore, many means exist to identify and filter different services. Network Slicing is one of them, but it can also be done by using different data network sessions identified through different Access Point Names (5G NSA) or Data Network Names (5G SA) or by filters matching IP addresses and ports. Given this huge space of different solutions, APIs like CAMARA Quality on Demand are essential to hide away the realization and provide broadly accepted means to request service differentiation for CAM services requiring that.

Whereas with LTE linking dynamic routing with Access Point Names (APNs) is complex because routing decisions are mostly static, in the case of 5G User Route Selection Policy (URSP) networks gain flexibility by dynamically selecting paths based on application needs, reducing dependency on static APN mappings.

Differentiated services enable Service Level Agreements (SLA), but providers offering those need to first gather experience on how reliably a certain service promise can be delivered in the area where it is promised. Otherwise, the financial risk of paying severe contractual penalties due to violating the SLA is high. Furthermore, service differentiation can be done not only to promote high SLA but also low SLAs with better prices. Massive Over-the-Air (MOTA) updates could benefit from free resources in the network with an overall traffic limitation.

4.6 Technologies for precise positioning

CAM services are mostly outdoor services, needing to rely on Global Navigation Satellite Systems (GNSS) complemented by vehicular inertial sensors. Using radio-based positioning from cellular towers cannot provide the precision of GNSS. It can still be used to detect GNSS spoofing, if the position obtained by GNSS does not match with cell tower identifiers sensed in the area.

Many CAM use cases need more precise position than GNSS can provide. For that, GNSS Real Time Kinematic (GNSS-RTK) is used to correct the GNSS position towards a range of decimetre-accuracy. Without RTK, only few meters of accuracy can be reached. Various solutions exist to obtain RTK information from the Internet, and cellular networks can provide the necessary Internet connectivity. Still, 3GPP has specified the LTE Positioning Protocol (LPP) -also specified for 5G NR- as a position-solution-provider-neutral protocol to obtain RTK information. This can be done over-the-top, without any network-integration, as done by other RTK data providers. When integrated with the Core network, a rough but sufficiently precise location of the vehicle can be required to assure the right RTK information is sent to the vehicle without requiring the vehicle to reveal its precise position. Same RTK information is valid for several kilometres and for many seconds or minutes. A further optional improvement allows to broadcast the RTK information by cells, where each cell only broadcasts information valid for the area it serves.

The MNO provides the RTK service, allowing it to easily provide information from different RTK providers (that could vary in cost and quality) and/or to use different providers for different locations, e.g. to always choose the one having highest-quality information for a given geographic area. Change of RTK provider does not require software or hardware changes in the vehicle, as LPP is always used.

4.7 Non-Terrestrial Networks (NTN)

In cases of coverage limitations, upcoming 5G NTN could complement 5G Terrestrial Networks (TN) to provide coverage in gap areas. In particular, **satellite connectivity could complement terrestrial solutions in white spots, in case of outages and, but to a very limited degree, in case of terrestrial network congestion**. 3GPP has progressed in the recent years on this topic to the point where seamless integration between TN and NTN with a full alignment on 3GPP standards appears achievable. In September 2024, 5GAA published a set of requirements and an **NTN use case roadmap** [26].

4.8 Data access and Data Sharing

Modern vehicles are digitally connected IoT and AI devices. They are equipped with sensors that continuously collect data on the mechanical and electronical functioning, as well as the location of the vehicle and the road condition. These data could, under certain conditions, be communicated in real time from the car to a variety of stakeholders, from the public sector to service providers, thus opening opportunities to improve the efficiency of existing services and to offer new services. For instance, the Extended Vehicle Concept as standardised in the context of ISO is being deployed by vehicle manufacturers to ensure data exchange in a safe and secure manner. Examples of already implemented platforms and standards focussing on data sharing for and from vehicles include **ADASIS** [27], **SENSORIS** [28], and **DFRS** [29].

Sharing data from road authorities' roadside equipment to road users offers significant advantages, particularly when leveraging 5G networks. The high-speed, low-latency capabilities of 5G enable real-time traffic information dissemination, allowing drivers to make informed decisions and optimize routes, reducing congestion and travel times. This data sharing improves safety by providing instant alerts about potential hazards or incidents ahead. The enhanced connectivity of 5G networks facilitates better traffic flow management and more accurate forecasting, improving overall transportation network efficiency. 5G's increased bandwidth and reliability support the development and improvement of advanced mobility services, including sophisticated navigation apps and connected vehicle technologies. Data sharing of these kinds of data is implemented through **NAPCORE** [30] and **dEMDS** [31], supported by the standards provided by **DATEX-II** [32] + **TN-ITS** [33].

5GAA has published **a holistic, cross-stakeholder approach to data access and sharing** [34]**,** outlining a **cross-stakeholder, data-driven framework for modernizing road traffic operations using 5G, digital twins, and federated data exchange to enable safer, greener, and smarter mobility**.

4.9 Cybersecurity

End-to-end cybersecurity aspects are essential to ensure secure CAM services. They need to go beyond the currently defined security specifications for V2X direct communications to encompass the full cellular network context, respectively 5G-based communications, as well as distributed edge cloud and back-end cloud systems. In this context, the European Union Agency for Cybersecurity (ENISA) has published a set of **recommendations for the security of CAM** [35]. The aim of this section is to provide a high-level overview of the cybersecurity challenges in the CAM sector and to highlight both the concerned CAM actors and associated recommendations.

In the European Union, the new regulation on cybersecurity is mandatory for all new vehicle types from July 2022 and for all new vehicles produced from July 2024. Moreover, the UNECE Regulation and related ISO standards apply to all CAM stakeholders who must ensure that their products and services conform to cybersecurity goals.

Connected services may be attacked by cyber-attackers and create cyber fraud, data breach and privacy incidents, as well as software overrides resulting in dangerous situations and accidents when part of the vehicle to everything (V2X) network is attacked, thereby threatening the drivers, road users and companies.

The whole ecosystem involved in the CAM lifecycle must cope with key challenges that add complexity to responding and managing CAM cybersecurity risks. Today, connected vehicles, connected environment and connected infrastructure should be designed with new capabilities and features that have the potential to provide increased safety, better vehicle performance, competitive digital products and services, more comfort, environmental friendliness, as well as convenience for its end-users.

There are many stakeholders engaged in CAM service development and operation that need to consider cybersecurity aspects. From that regard, it will be required **to develop a holistic three-tier cybersecurity model encompassing the vehicular/roadside systems, the V2X direct and mobile network communications domain including backbone communications, the cloud and edge cloud-based distributed and centralised computing domains**. Along with cybersecurity, GDPR and ePrivacy aspects will need to be addressed appropriately.

The NIS 2 Directive and the Cyber Resilience Act (CRA) are also providing recommendations on Intelligent Transport Systems that need to be taken into consideration.

4.10 Energy efficiency and network sustainability

The evolution from 4G to 5G has been marked by a shift from physical network infrastructure to a more virtualized network environment. Software-defined networking (SDN) and network functions virtualization (NFV) have emerged as key technologies, enabling a level of flexibility, scalability, and efficiency in network management and operations previously unattainable with hardware-reliant 4G networks.

The major energy consumer element in the current mobile networks is the RAN with an energy consumption of 73% of the network’s total energy consumption, and then is the core network as the second energy consumer with 13% of the total consumption.

The development of Edge capacities (local catching), which exploits the use of localized storage at edge sites to reduce traffic load on backhaul links, is also a way to increase energy efficiency thanks to the reduction of transmissions of the same content from/to centralized instances of the 5GC's user plane.

This evolution has also many impacts on energy consumption that could be taken into consideration for deployment. The following are **key aspects to improve network sustainability**:

- Regarding **energy consumption** shift from 4G to 5G with the network virtualisation, it is **recommended to use 5G SA solutions instead of 5G NSA**.
- It is **needed to measure the energy consumption of each network element**.
- The **use of edge capacities** (local catching) **is recommended** to decrease traffic load.
- The selection of **virtualisation technologies (virtual machines, bare-metal, containers) must be the most appropriate** for the specific service deployment.
- Providing a real time metering of the energy consumption of each component from the end-user device to the service platform is also recommended, for energy consumption awareness.
- Recommendations by regulation bodies and technical experts regarding infrastructure sharing shall be considered.
- **Looking to the huge share of RAN with regards to energy consumption (73%), it is recommended to carefully look to the implementation of this element**.

Apart from the networking aspects, there is a need to consider also the data aspects which are also a huge energy consumer. **CAM services will obviously contribute to the boom in data traffic (i.e. 400 million connected vehicles in the EU with terabytes of data generated by sensors).** In order to limit this data boom, **CAM applications should count on an optimal framework that avoids data duplications in several centres**.

Nevertheless, 5G-enabled CAM services can deliver greater overall energy savings—mainly through optimized traffic management and eco-friendly driving patterns. To fully understand their impact, real-time measurement of these energy savings is essential.

5G and the **TM Forum's Autonomous Networks (AN) initiative** [36] work together to enable intelligent, self-managing networks. While 5G provides the high-speed, low-latency foundation, the AN framework guides networks through five levels of automation—from manual to fully autonomous. This synergy supports real-time, secure, and adaptive vehicle-to-everything (V2X) communication, enabling predictive maintenance, dynamic network slicing, and improved road safety in smart mobility ecosystems.

5 Regulatory aspects

The deployment of the global connected car market will be driven in part by positive regional regulatory action in Europe. This chapter suggests recommendations for a supportive public policy context and a regulation framework that can be a more favourable environment to encourage private investments.

These are the most important **telecommunication aspects**:

- **Road coverage / incentivize network expansion**: for CAM services, ideally the market dynamics would provide an automatic business incentive for telecom providers to realize full road coverage of 5G for CAM. Setting clear guidelines and targets for network coverage, capacity, and quality of service will support deployment.
- **Road coverage obligations:** within spectrum auctions, road coverage obligations are an option to achieve the same goal as the previous point. On national level, Germany for example provides clear obligations on network demands along the roads, whilst in France the MNOs and the national regulator agreed on common Key Performance Indicators (KPIs) for network coverage of roads. Another example are the Netherlands, who established KPIs as coverage obligation in the procurement rules for spectrum action for 5G.
- **Cross-border coordination issues:** MNOs are expected to discuss cross-border coordination issues on a bilateral, or multilateral basis and additionally in respective industry forums. The involvement of policy makers and/or administrations in these discussions can, if required, be a useful complement. It is recommended that all mobile operators agree to synchronise their networks.
- **Harmonized TDD operations:** with respect to the Radio Access Network, it is important to make sure that harmonised TDD operations are harmonized at national, international and cross-border areas.
- **Infrastructure sharing / re-use of road infrastructure:** national regulators can support road coverage by clarifying infrastructure sharing options, reduce the cost and increase the speed of deployment of very high-capacity networks, notably by removing unnecessary administrative hurdles.
- **Spectrum:** the deployment of 5G for CAM throughout Europe, i.e., cross-border, would benefit from greater consideration in the requirements for pioneer bands, spectrum refarming, temporary licences, and spectrum for NTN as complementary coverage solution. Public authorities should prepare and implement spectrum assignments -if not already done- alongside the funding that has been and should continue to be made available for network deployment, pre-deployment and research & innovation.
- **Cross-border / CAM Roaming**: though cross-border network reselection is already technically feasible, the incentives are still lacking to get it implemented in networks in the absence of a tangible business case for MNOs. Ways should be analysed to facilitate and incentivise a minimum coverage rate in cross-border areas.
- **The implementation of the Gigabit Infrastructure Act (GIA)** as of November 12, 2025, **will facilitate cross-border deployment of high-speed networks by harmonizing and streamlining permitting processes, encouraging infrastructure sharing, and mandating fibre-ready features in new and renovated buildings across EU Member States.** These new provisions will be particularly relevant for the NHP cooperation model (described in chapter 6.2), and will support 5G for CAM infrastructure deployment across borders throughout Europe.

- **Lawful intercept with respect to CAM:** while they have been defined for voice and data, it is unclear how lawful intercept requirements are translated towards CAM services.
- **Deployment of passenger services via public APNs** requires alignment with KYC rules, telecom regulations, data privacy laws, and security standards. OEMs must navigate MNO licensing, permanent roaming policies, and lawful interception obligations while ensuring a secure, compliant, and consumer-friendly experience.

These are the most relevant **road infrastructure aspects**:

- **Service coverage:** although state-of-the-art mobile network coverage on all roads and seamless handovers are critical enablers, other innovations are required to ensure that services are delivered to the end-customers and the vehicles. Service providers should work towards their availability throughout Europe and should use data from the relevant road operators provided through the national access points to realise a scalable digital data exchange among stakeholders.
- **Cross-border continuity:** as with network service continuity, these traffic rules should be continuous, preventing any gaps or omissions when crossing a border. This is particularly relevant when a switch towards a different data/service source is necessary.
- **Data disclosure and sharing:** it is critical that traffic information and rules maintained by public road managers are made available in real time and in a machine-readable format to relevant service providers and guidance. The regulatory aspects of sharing data (e.g. through neutral platforms between road authorities and road users) are now primarily governed by the European Data Act[2], the Open Data Directive[3], the General Data Protection Regulation[4] (GDPR) and the ITS Directive[5]. Road authorities and road operators make their data available in a timely, fair, and non-discriminatory manner, while adhering to data protection principles. Initiatives like NAPCORE, DATEX, TN-ITS, and many more are working towards facilitating this convergence.

The following are the most relevant **automotive-related aspects**:

- To **strengthen the semiconductor market** to ensure the availability of chips, components and equipment.
- **Regulation of CCAM services should set essential requirements** in a technology agnostic manner and embed a flexible mechanism to upgrade requirements when evolving technology requires it.
- **For telecom, the concept of lawful intercept exists, nonetheless for highly automated vehicles it is currently unclear** if specific message sets, protocols, and measures need to be

[2] Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data

[3] Directive (EU) 2019/1024 of the European Parliament and of the Council of 20 June 2019 on open data and the re-use of public sector information (recast)

[4] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data

[5] Directive (EU) 2023/2661 of the European Parliament and of the Council of 22 November 2023 amending Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport

defined and standardized on international level to allow for lawful interception by enforcement authorities. This issue should be explored.

- Regarding the increase in software and updates of vehicles, alongside the Virtual Vehicle Concept, a **common European understanding of whether the system is safe and secure enough is necessary**. This aspect is currently covered by UN R144 and UN R156.

In terms of the **safety and cybersecurity**, there is a noticeable gap for (functional) security in the form of trusted perception from off-vehicle sources (GNSS, HD Maps, etc.). Moreover, there is uncertainty in how to handle non-compliance. Given the relation to safety and economic prosperity of both communication and transportation, it is critical to prevent systemic failures through intended and unintended breaches of security and functionality. How to handle non-compliance (e.g. lack of service continuity, safer response to cyberattacks, etc.) also needs to be clarified.

6 Cooperation models

The coordination between different stakeholders on the various communication infrastructure levels will help to leverage the strengths of the different players to identify viable business models and enable a sustainable deployment of 5G for CAM.

In its white paper on **Cooperation Models enabling deployment and use of 5G infrastructures for CAM in Europe** [37], 5GAA identified several cooperation models, which explain the roles and responsibilities of each stakeholder, including the relationship between the different categories of actors. The paper explains the role and contractual relations among the three major industries involved in the connected automotive environment ecosystem: vehicle manufacturers (OEMs), road operators (ROs) and communication service providers (CSP), which include mobile network operators (MNOs) and neutral host infrastructure providers (NHPs). A NHP invests in telecommunications infrastructure, such as cell towers, fibre-optic networks, and leases this infrastructure to multiple service providers (CSPs) on a shared-tenant basis. Other Services Providers (SPs: location-based data, Mobility as a Service (Maas) etc.) are also having an increasingly important role in the ecosystem.

A new series of publications extended that first White Paper to provide a **holistic cross-stakeholder approach for road traffic operation in a digital age** [38], including architecture, solution blueprint, and use case implementation examples, as well as business perspectives on deployments.

The following diagram presents the most prominent cooperation models for cost reduction through infrastructure investment and commercial agreements.

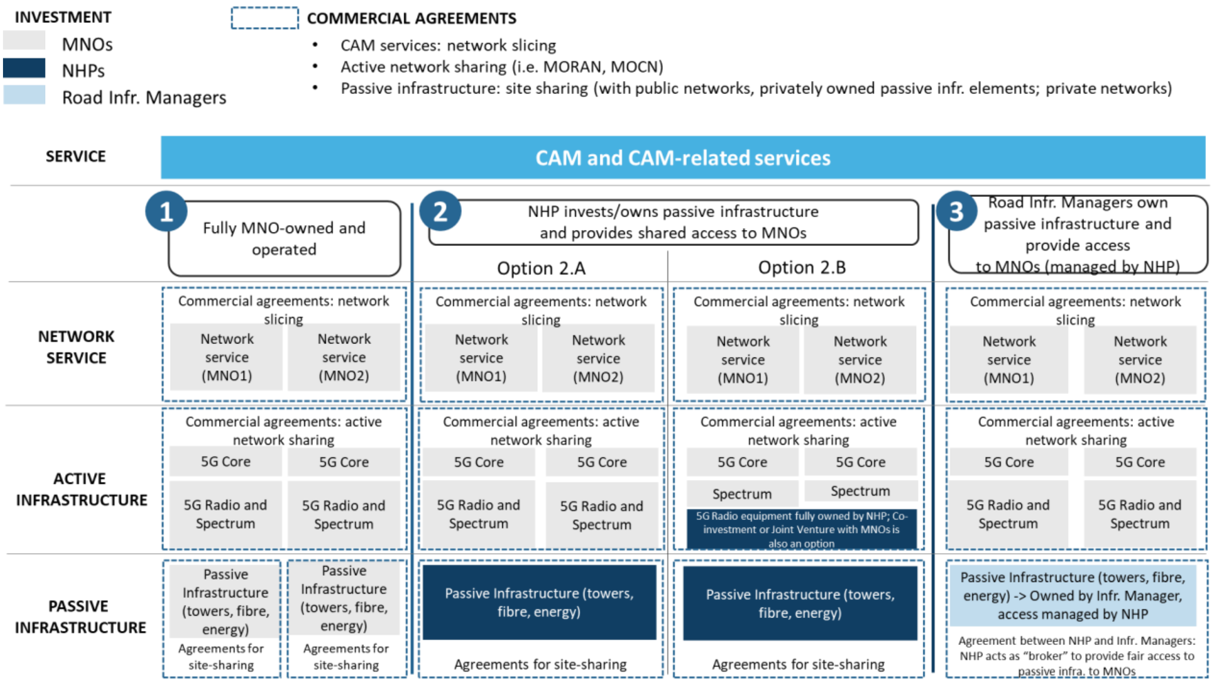

Figure 4: 5G Deployment cooperation models

Beyond traditional MNO-led approaches, innovative models involving shared infrastructure and public-private coordination are gaining ground. This report outlines four key 5G deployment models—MNO Fully Invested, Neutral Host, Shared Active Network, and the Public Entity / Road Infrastructure Manager model. These models, explained in the subsequent chapters, are not mutually exclusive and are potentially more beneficial in combination.

6.1 Contribution by MNO in a full 5G network (along the roads)

This deployment model, depicted in Figure 4 as option 1, consists of the full investment by the MNO in its own 5G network infrastructure. In this scenario, MNOs use their own network, as communication bridge between vehicles and connected road infrastructure, to deliver a broad range of CAM services.

This approach offers to MNOs maximum control and flexibility for innovation and service quality, with the potential to provide unique services, while it is facing several challenges related to high CAPEX/OPEX, and difficulties to manage coordination and cooperation complexities.

6.2 Investment by single NHP in passive infrastructure

Depicted as option 2, a Neutral Host Provider (NHP) invests in telecommunications infrastructure, such as cell towers, real estate and fibre-optic networks, and leases this infrastructure to multiple communication service providers (CSPs) on a shared-tenant basis.

A neutral host infrastructure is a shared platform, potentially capable of supporting ITS services in addition to all MNOs and IoT smart city technologies. This allows operators to focus on service delivery and infrastructure companies to focus on real-estate development and capital investment.

By shifting investment from an upfront, CAPEX-heavy model, where MNOs shoulder all deployment costs, to a neutral host model, where NHP shared infrastructure helps to spread costs across multiple parties, the CAPEX burden is converted to an easier to manage more efficient OPEX. Additionally, the NHPs responsibility is also to apply for relevant building and environmental permits for the construction of the passive infrastructure, as well as, for taking over landlord management and ground lease costs (for the rooftop or land under the tower site).

As already indicated in chapter 5, the following options shall be explored to remove bureaucratic hurdles and accelerate deployment:

- **Gigabit Infrastructure Act[6] (GIA) & permit acceleration:** The bureaucratic variability in costs and processes involved with obtaining relevant permits in different Member States (and on a more granular, local, i.e., regional and municipal level) creates a lot of inefficiency, cost, and delay in the deployment of new networks (esp. passive infrastructure). The GIA provides considerable improvements from that perspective that will need to be translated into national frameworks.
- Moreover, a **tacit approval mechanism for permit granting** as the default solution across Member States would contribute to speeding up network deployments.

In addition to covering the passive infrastructure layer (as shown in option 2.A), the role of the NHP can cover as well the last-mile 5G active equipment, enabling, therefore, further synergies (5G active synergies) and supporting with upfront CAPEX investments (as shown in option 2.B).

Market developments of the last 10 years evidenced that separation of the infrastructure investment value chain is efficient. In fact, the NHP approach is very established nowadays. These options can offer additional advantages to the ecosystem partners:

a. MNOs investment capabilities are limited and **CAPEX for active equipment can be saved** and taken on by the NHP to offer Network as service out of one hand in combining passive and

[6] Regulation (EU) 2024/1309 of the European Parliament and of the Council of 29 April 2024 on measures to reduce the cost of deploying gigabit electronic communications networks, amending Regulation (EU) 2015/2120 and repealing Directive 2014/61/EU (Gigabit Infrastructure Act)

active neutral host services. MNO expenditures would shift more to OPEX potentially also increasing participation incentives.

b. **A further reduction of contractual complexity**. To be precise one would need to draw an additional dashed rectangle encompassing the sections active and passive infrastructure. Hosting & access granting to the passive infrastructure and the operator of the active equipment would be subject to a contract. This contractual level can be economised if the passive and active is offered jointly by the NHP which offers a holistic network as a service.

c. **Future proofness relating to site upgrades**. Modification and upgrades to the active network equipment due to higher MNO demands or potential future third party uses can be undertaken by the NHP itself. All necessary data of both the passive and active equipment (physical space, static proofness, available Electromagnetic field (EMF) budget below limits, sufficient power capacity, etc.) all are available to the NHP without having to inquire with multiple external parties. 2B solution network as a service out of one hand enables the NHP to quickly assess colocation potential and feasibility of site upgrades.

6.3 Investment by Road Infrastructure Managers in passive infrastructure

Road infrastructure upgrades are required to integrate the necessary technologies to deploy most Vehicle-to-Infrastructure (V2I) or Vehicle-to-Network-to-Infrastructure (V2N2I) services, regardless of whether cellular networks or Roadside Units (RSUs) are ultimately used. In the case of regions with outdated infrastructures, the following cooperation aspects could be explored:

- **Road Infrastructure Managers granting access to key passive infrastructure:** For roadside deployment, the introduction of new 5G equipment will require the installation of additional cell towers and edge data centres, meaning significant CAPEX investments. As mentioned in section 6.1, deployment can be greatly facilitated, if road operators grant CSPs access to key passive infrastructure (land, fibre, electricity), since these are main costs drivers. Based on new legislation of the GIA, access to road infrastructures is mandated to be at fair and reasonable conditions. Favourable access conditions by ROs not only speed up deployment processes, but also increase the economic viability of entire CAM frameworks and use cases.
- The role of a broker is currently explored in some countries, and typically assumed by NHPs, to deal with the unknown complexities arising from this model. The broker explores the feasibility of the technical integration and use of Road infrastructure and can ensure access to the road operator’s infrastructure under the same conditions to all mobile network operators, while minimising the burden on the road operator.

This model, shown as option 3, promotes infrastructure reuse, reduces civil engineering costs, lowers public disruption, it requires, however, strong public-private coordination and regulatory frameworks.

Coordination between NHPs and Road Infrastructure Managers is an option that shall be explored due to its potential to build network capacity, especially along transport corridors, thanks to the access to Infrastructure Assets, an optimized site planning and permissions, and cost efficiency (reduced CAPEX for MNOs, and OPEX reduction through co-maintenance models). A close alignment has also the benefit to ensure that 5G deployments fulfil the requirements of traffic management services, where Road Operators are a central stakeholder for the rollout.

6.4 Commercial Agreements

Cooperation can also happen via commercial agreements between industry and public authorities to deliver mobile network coverage and capacity.

6.4.1 Site sharing of base stations

Different options of site sharing can be distinguished: one option is the usage of public infrastructure by private MNOs or NHPs (making sure to communicate the societal benefits of the services that this approach will enable); a second option is the sharing of (privately owned) mast sites between MNOs.

While lowering deployment costs and boosting public-private alignment to achieve digital and mobility goals, it needs to be considered that the use of public-owned assets brings challenges related to governance and coordination, harmonization and transparency and maintenance responsibility.

This approach can succeed in municipal and utility-owned infrastructure, enabling cities to support universal coverage and smart services, and in greenfield infrastructure projects, where inclusion of 5G-ready passive assets can be mandated by policy.

Sharing of infrastructure owned by private companies (e.g., private road operators) is also an option, however that is done based on commercial terms between the involved parties and, in practice it makes more sense for the Road operators to cooperate with an NHP, as an intermediate actor (see 6.3), to optimise the site sharing on the limited space available on the road furniture for telecom equipment.

6.4.2 Active Network Sharing

A pro-network sharing approach can offer benefits, where it preserves national network-based competition (between the sharing parties, and between the sharing parties and other network operators). Network competition is driven principally by capacity in areas of high traffic (urban and suburban areas) and coverage in areas of low traffic (rural areas).

MNOs should be able to engage into active network sharing (such as radio equipment on joint network sites) under the appropriate legal framework that ensures that competition criteria are respected, by considering guarantees in terms of capacity for commercial differentiation. Different options of active sharing reported in **GSMA's 5G network co-construction and sharing guide** [39], such as Multi-Operator Radio Access Network (MORAN) or Multi-Operator Core Network(MOCN) are already used by MNOs across Europe, especially in less densely populated areas, such as rural areas, less frequented roads, etc.

MNOs jointly deploying and operating shared active components—such as base stations and antennas—while maintaining separate spectrum licenses and core networks achieves a balance between cost-sharing with service differentiation.

Although it requires governance coordination, needs to comply with competition rules, and potentially limits the degree of service differentiation, network-sharing approaches allow cost-efficiency, maintain moderate MNO control and are suitable for scenarios such as rural areas with low ROI for full build-outs, transportation corridors where coordinated deployment reduces cost and disruption and government-supported universal service coverage zones.

6.4.3 Network slicing

Mobile networks are inherently multi-service, meaning network capacity is shared among various services, which can cause the quality of a given service to be affected by other services as demand fluctuates. Network slicing addresses this by allowing MNOs to partition and reserve portions of the network capacity for specific services, ensuring guaranteed Quality of Service (QoS). Each slice operates in isolation, enhancing performance and security, so critical services remain unaffected by other traffic, such as entertainment. ROs, for instance, can collaborate with MNOs through commercial agreements, including SLAs with QoS guarantees, to create dedicated slices tailored to their service-level requirements.

A promising opportunity exists in relation to Connected Passenger services, where a major issue relates to the business capability of those services: connectivity has a relevant cost, OEMs look for a separation between the telematics traffic and the driver/passenger digital life. Current solutions are based on Dual SIM Dual Active (DSDA), which is an expensive onboard solution. Slicing with a third-party billing system could lead to a single Subscriber Identity Module (SIM) with flow for different MNOs (the telematics and the driver/passenger one) providing a mutually beneficial approach

5G network slicing can also play a crucial role in improving OTA services for Software-Defined Vehicles, helping OEMs deliver more efficient, reliable, and secure software updates to vehicles thanks to prioritizing Critical Software Updates, to tailor connectivity for different update types. Thanks to network slicing, OEMs can create a slice to provide connectivity to the vehicle, which can continue downloading OTA updates seamlessly while in motion, enhancing the customer experience and ensuring that updates are applied without delay.

Slicing can allow a global OTA update at large scale, by allocating resources based on demand and ensuring adequate bandwidth and low latency, even during periods of high traffic, avoiding network congestion.

7 Deployment options

This section describes tentative deployment scenarios for the Road CAM services and Connected Passenger services, defining the criteria that scenarios must meet and identifying generic innovations to be used. The section concludes with a list of 5G corridors that are addressing Road CAM and/or Passenger Connectivity services.

For complete conclusions in this chapter, it is necessary to study the input from the ongoing 5G corridor deployments which are underway, partially due to the first wave of CEF2 Digital Cross-Border-Corridor projects, but also the extensive experiences from the current 5G rollout driven by European MNOs based on 100% private investment, which aims at providing and enhancing existing mobile network coverage based on 4G (LTE), 5G Non-Standalone (5G NSA, with a 4G core network, Evolved Packet Core) and 5G Standalone (5G SA, with a 5G core) along major road transport arteria. Each project has different regional characteristics, therefore different challenges e.g. due to a different regulatory framework.

7.1 Principles and criteria for deployment

The criteria and prerequisites for deployment are:

- Harmonised coverage across Member State and more broadly, Europe: achieving consistency in obligations and standards across EU Member States and further European countries remains a priority to support seamless connectivity for 5G CAM deployment.
- Ecosystem consolidation: a more unified ecosystem is necessary, including initiatives that foster collaboration among diverse stakeholders. Platforms that bring together transport and telecom sectors, like the CCAM Partnership, are essential for drawing synergies between the transport ecosystem and CEF Digital objectives.
- The extent to which the objectives of future road transport communication requirements are fulfilled in terms of:
    - The 5G vision for Road transport.
    - Fulfilment of service requirements.
    - Innovations required.
- The possibility to develop and establish the regulatory environment required for deployment.
- The possibility to develop an adequate cooperation model between stakeholders. Stakeholder engagement is key since agreements must be reached among all key actors including Communication Services Providers (Mobile Network Operators, Neutral Host Infrastructure Providers), Road Operators, OEMs and other Final User service providers.
- The extent to which the Cross-border co-operation is possible between MNOs on each side of the border (for example along TEN-T corridors).
- The possibility to engage in synergetic infrastructure deployment (e.g. Towers hosting several MNOs, other RO related equipment, etc.) to significantly reduce the overall investments and therefore enable sustainable business models for all the stakeholders.
- Synergies across Road CAM / Connected passenger services, between CAM and CAM-related services (such as construction and emergency services) and between different modes of transport.
- Vehicle OEMs need to timely specify, perform the cost-benefit analysis and plan the integration of 5G SA capabilities in the digital communication and computing architecture of their vehicles (typically in new models or as part of a major facelift) as increasingly complex services will require the use of 5G modules and to ensure long-term support of connected vehicles throughout their lifecycle.

Embedding 5G-compatible hardware now will ensure that vehicles sold in the near future are ready for evolving 5G services and standards and capable to integrate seamlessly with emerging mobility ecosystems. OEMs will be able to define premium and differentiated services using 5G like high-speed OTA updates, immersive infotainment, HD mapping, and remote diagnostics, and create subscription-based revenue streams. In manufacturing and logistics, 5G modems can improve tracking, diagnostics, and predictive maintenance for fleets and supply chain. In addition, vehicles equipped with 5G-compatible User Equipment will benefit from services using frequencies refarmed from 2G, 3G and over time, also from 4G, as this is an important part of 5G deployment strategy.

- The setup of operations, which support the most important service requirements of CAM services in designated areas (e.g. rural, low-density lines).
- The definition of realistic timelines for deployment, compliant with the planning of CEF2 or other funding frameworks.

7.2 Deployment of Road CAM services

7.2.1 5G network deployment as a fundamental enabler

The deployment of the 5G infrastructure for CAM and related services follows an incremental path where several phases are observable:

- **Past and ongoing:** full coverage of the European road network based on 4G (including the option of 5G NSA) provides a sustainable baseline for connected vehicles with 4G capabilities. Network deployment will enable service evolution and also guarantee the continued operation of “legacy” 4G-connected vehicles co-existing in mixed traffic.
- **Short/mid-term 2025-2028:** for the deployment of a full-fledged 5G System, i.e. 5G SA, along road transport infrastructures, MNOs and contributing NHPs should follow an approach that aims to provide continuous coverage along transport corridors, including 5G SA roaming across borders and, wherever feasible, enabling seamless service continuity or at least accelerated and deterministic network reselection based on 3GPP handover mechanisms across borders.
- **Long term / towards 2030:** 5G SA enhanced capability sets with support of mission-critical services across Europe will be needed to fulfil the requirements of advanced CAM services. As the fleet of 5G-enabled vehicles is growing, and so will 5G network utilisation as well, MNOs and contributing NHPs will have to consider increasing 5G network capacity by refarming the spectrum, including network densification, as data traffic will be shifting from previous network generations.

While the provision of a 5G baseline coverage is being realised in low-band spectrum, primarily the “5G pioneer band” 700 MHz or other lower bands from 800 MHz to 2.6 GHz based on refarming, the provision of higher capacity will be primarily provided in the “5G pioneer capacity band” 3.3-3.8 GHz (n78).

The most favourable cooperation models shall be considered, based on, but not limited to the common practice today, i.e., the cooperation between MNOs and TowerCos; as over time higher density network deployments along road transport infrastructures will require radio access towers, masts and poles being set up close to the road infrastructure, additional cooperation with road operators and road authorities will be required, with the potential to share and leverage existing ducts, fibre and power infrastructure along road corridors where available.

Depending on the respective national rollout obligations for road transport corridors, which are not necessarily tied to a specific network generation, i.e., to 4G or 5G, network sharing beyond passive infrastructures between MNOs could be considered as favourable, allowing for cost savings and potentially accelerated network rollout. This includes sharing / neutral host models involving tower companies. In case of public co-financing models, open access to the co-financed infrastructure (passive or active) is mandated.

7.2.2 Timeline for 5G deployment to support CAM services

Three main deployment phases for 5G are proposed to enable the introduction and support of CAM services for Road transport:

- Today, the following **Road CAM basic services can be already supported by LTE and 5G NSA**:
  - Real-time Traffic Information and Safety-Related Traffic Information.
  - Hazard information collection and sharing.
  - Data collection for HD Maps and distribution of updates.
  - Limited tele-operated driving in confined areas.
  - Automated vehicle parking and marshalling.
- **Midterm / 2026 and beyond, Road CAM advanced services** can be supported by 5G SA:
  - Remote operations in more complex environments, such as public roads.
  - High-Definition Sensor Sharing to support cooperative perception.
  - Complex interactions between vehicles and VRUs via mobile phones.
  - Intersection safety.
  - Vulnerable Road User (VRU) Collective Awareness.
  - Cooperative adaptive cruise control.
- **Long-term / 2030 and beyond**, **advanced traffic management services** are expected to be available and supported by 5G:
  - Cooperative manoeuvres.
  - Dynamic Cooperative Traffic Flow.
  - Dynamic Intersection Management.

With respect to passenger connectivity services and SDVs, many car OEMs have already implemented or are actively rolling out onboard app store services, depending on the specific car model. These services typically include over-the-air (OTA) updates, app ecosystems, cloud-based services, and in-car entertainment—features that are increasingly becoming standard in Software-Defined Vehicles (SDVs). The trajectory of onboard connectivity services across OEMs clearly reflects a shift toward a fully integrated digital ecosystem, where vehicles are evolving from simple transportation tools into smart, connected platforms.

By 2030, we can expect to see cars with services that are continuously updated, highly personalized, and capable of supporting highly assisted and automated driving functionalities via cloud-driven, AI-powered services.

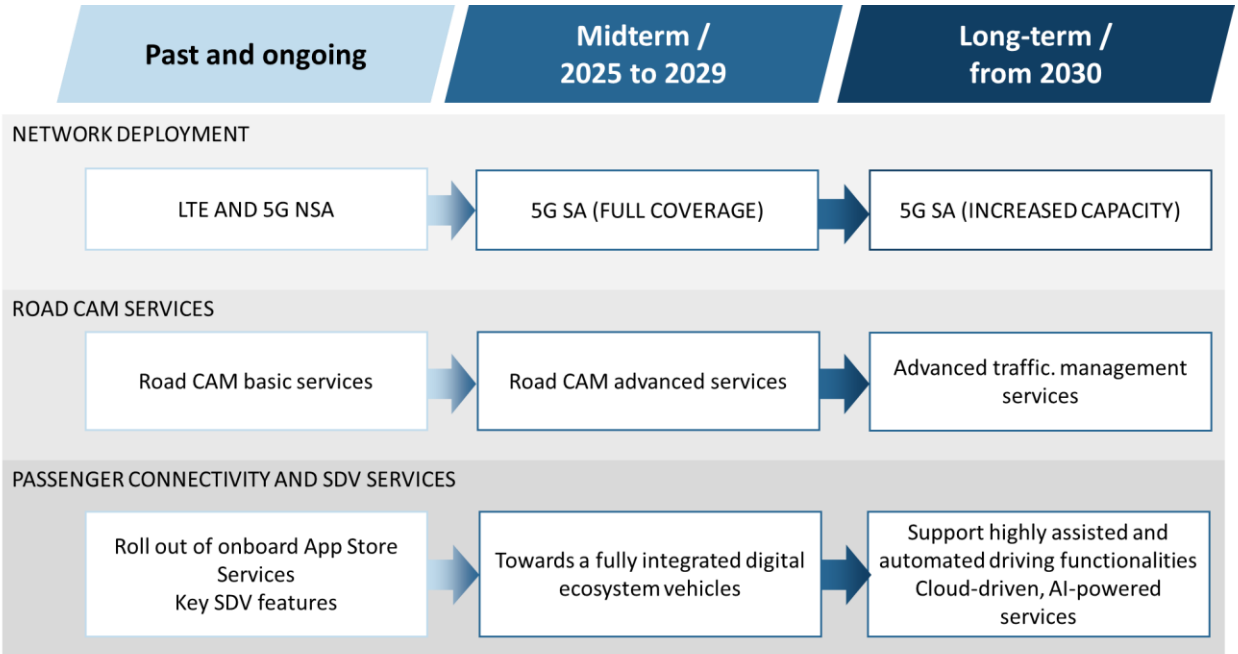

Figure 5: Deployment roadmap of 5G network and supported Road CAM services

7.3 Optimization of deployment costs

Mobile Network Operators and other stakeholders need to make a number of considerations on several fronts -network investment and operation-. Many of these considerations are highlighted in GSMA's report **Realising 5Gs full potential: Setting policies for success** [40]. They will be key to optimize the total cost of network deployment:

- **Selection of suitable cooperation models:** the most favourable cooperation models for network sharing shall be considered depending on the respective national characteristics and rollout obligations for road transport corridors, which are not necessarily tied to a specific network generation, i.e., to 4G or 5G.
- **ROI-driven deployment strategies:** operators must establish a clear understanding of the return on investment (ROI) for each individual network initiative involving technology deployment. This includes adopting decision-making frameworks that prioritize network rollouts based on the ROI potential of the 5G use cases they are intended to support.
- **Leverage Network Virtualization:** adopt network virtualization allows to create more cost-effective and flexible network architectures. This not only lowers operational costs but also supports innovations like network slicing.
- **Enable automation and intelligence:** the configuration, management, and operation of mobile networks are highly complex, but there is significant potential for automation to simplify these tasks. In the near term, programmable, rules-based automation can deliver substantial cost savings by streamlining network processes. Looking further ahead, machine learning and artificial intelligence will enable network components to learn from data, leading to more efficient optimisation and supporting the development of self-organising networks.
- **Optimize backhaul with wireless alternatives:** a common assumption in small cell deployment is that fibre connectivity must be extended to every individual pole. However, alternative network architectures using wireless backhaul—such as point-to-point or mesh networking topologies—offer more flexible options. In these models, only select poles require fibre connections, while most of the small cells can be wirelessly backhauled to these fibre-fed nodes. This approach could significantly reduce deployment costs and infrastructure requirements, improving the overall business case. Additionally, it opens the possibility of

leveraging existing urban infrastructure, such as streetlights or traffic signal poles, to create a denser, more cost-effective small cell network without the need for extensive fibre trenching.

7.4 Ongoing 5G corridors deployment projects and initiatives

Projects under the **CEF2 Digital programme** are driving the development of 5G infrastructure for CAM services. These projects focus on deploying both active and passive infrastructure across European transport corridors, with several waves of implementation running from 2023 to 2027. The aim is to enhance mobile network coverage along major European transport routes using 4G LTE, 5G NSA, and 5G SA technologies. Each project faces unique challenges due to differing regional regulatory frameworks. The following are the key projects:

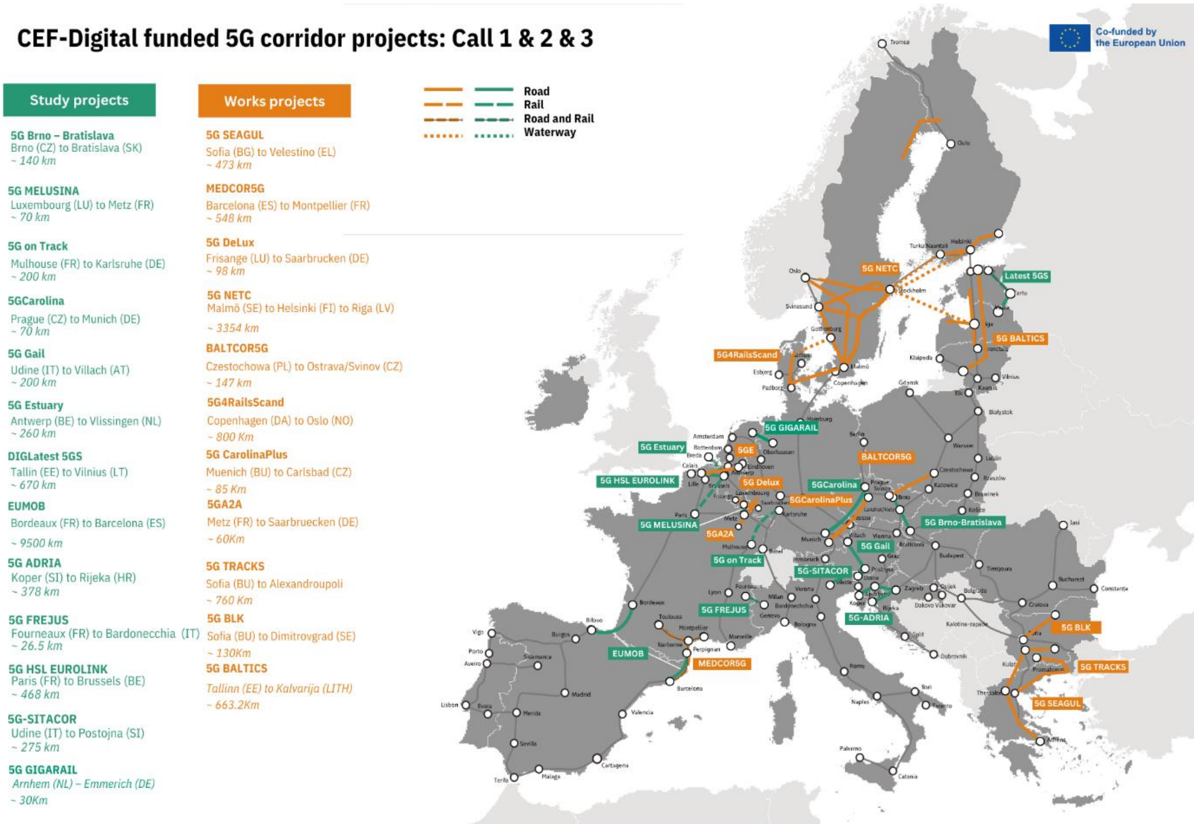

Figure 6: CEF2 Digital 5G Corridors map (source: GUIDE project)

- **5G NETC** focuses on improving service continuity for transport and logistics along Northern European highways and railways. It covers Scandinavian-Mediterranean TEN-T and North Sea-Baltic corridors with dedicated 5G infrastructure.
- **5G SEAGUL** deploys 5G RAN infrastructure to support CAM services along the Bulgaria-Greece border. Its objective is to ensure seamless interconnection, roaming, and handover for connected vehicles through real-life trials using advanced SA 5G networks.
- **5G DELUX** develops seamless handovers between mobile operators across Luxembourg and Germany, ensuring no loss of connectivity. It focuses on creating a blueprint for harmonized European handover solutions.
- **MEDCOR5G** establishes 5G coverage along the Mediterranean corridor in underserved regions of France and Spain. It deploys infrastructure over 548 km, benefiting MNOs, transport operators, and OEMs by addressing connectivity gaps.
- **5G BALKANS** aims to deliver uninterrupted 5G connectivity along the Sofia-Dimitrovgrad route, with a focus on dark fibre and gigabit infrastructure. It addresses capacity needs for automated mobility through optimized radio network deployments.

- **BALTCOR5G** builds 5G and C-V2X infrastructure along Baltic-Adriatic road corridors between Poland and the Czech Republic, developing innovative business models in regions with market failure.
- **5GA2A** (Autobahn-to-Autoroute 5G corridor), aims to deploy a 5G highway corridor connecting the cities of Metz (France) and Saarbrücken (Germany). The goal is to provide uninterrupted and high-speed coverage for cross-border travellers, while enabling the testing of CCAM use cases. Different cooperation models will be implemented: infrastructure will be deployed with option 2A (as in Figure 4) in the French part of the corridor, while in the German part of the corridor the deployment is based on the 2B option. Common to both options is that the passive infrastructure is owned and operated by the NHP.
- **5G-BALTICS** (Uninterrupted 5G coverage along Via Baltica) aims to deploy 5G infrastructure for the transport corridor to reach uninterrupted coverage that meets service requirements for CAM, Intelligent Transport Systems (ITS), and also for multi-service/multi-application 5G services along the European transport corridor via-BALTICA. Special focus activities will be undertaken for uninterrupted coverage at several border crossings.
- **5GCarolinaPlus (**5G corridors between Bavaria and Czechia) aims to leverage the historic trade and business ties between Germany and Czechia to foster renewed cross-border collaboration while addressing the transformation needs of the Carlsbad and Tachov regions. By deploying advanced 5G infrastructure, the project will deliver uninterrupted CCAM services across 85 km of cross-border corridors and 9 border crossings.
- **Projects resulting from CEF Digital Call 4 will be announced on the HaDEA website.**

Optimal deployment strategies should be derived by studying best practices and lessons from these projects. Private investment-driven rollout activities by MNOs should also be analysed for replication opportunities. This coordinated approach aims to bridge connectivity gaps, ensure seamless cross-border coverage, and establish Europe-wide standards for 5G-based CAM services.

Looking to the output of the survey conducted on Call 1 and Call 2 projects in 2024 regarding the deployment phase, the key lessons learned are the following:

1. Most of the projects are planning to deploy Mast/Pylons/Towers, some of them will also deploy ducts, dark fibre, equipment shelters, and power supply.
2. Works projects will deploy a number of active components, all of them will install 5G radio station, antennas, but also network controllers, routers, switch, storage capabilities, computing capabilities, Exchange and edge/MEC node.
3. Mobiles, Cameras, Sensors, On Board Units are the key devices used, Computer and Road-Side Units are also commonly used in developed use cases.
4. No works projects are planning to use Satellite connectivity at this stage.
5. All solutions are envisaged by Works projects to deploy the 5G networks, but an upgrade of an existing 3G, 4G Network scenario is the most common solution envisaged.
6. All Works projects are foreseeing deployment problems in all type of dimension, but Regulation got the highest score, it is mainly addressing the administrative procedures to build new towers and to get frequencies.
7. Most of the projects are planning to share their passive infrastructure at the end of the project.
8. Most of the projects are building a Business Plan and a Cost Benefit Analysis but they are not ready to share it.
9. A number of projects got problem to make agreement with MNOs, MNOs are key players to

deploy such service, they need to be involved at the beginning of the project.

10. Good cooperation among partners is key for a success, National administrations, Verticals, Academics, MNOs and TowerCos are mandatory in the consortium in order to avoid problems.

These difficulties and good practices need to be well addressed by projects as early as possible in order to avoid further deployment problems.

7.4.1 Cooperation example between MNOs and ROs to improve mobile network coverage

A promising cooperation initiative is happening in Germany between MNOs and road operators, with an overall objective to improve mobile network coverage, as demanded by the Federal Network Agency.

The collaboration between the MNOs and Autobahn has achieved initial success on the A1 in Saarland and consists of the joint effort to identify sites for equipment and planning for works. The cooperation benefits from an amendment to the Federal Highway Act passed in 2020, which allows the construction of mobile network masts in the previous “no-build zone” of 40 meters to the right and left of the motorway. Accordingly, the federally owned areas of Autobahn GmbH can now be used more intensively for mobile network expansion. New masts can be built on embankments, rest areas or construction yards. This not only speeds up the search for and selection of new mobile network site locations, but also greatly simplifies the process.

8 Conclusion and outlook: deployment of 5G for CAM on EU Road Transport Networks

5G deployments in municipalities – where the majority of people live and work - are progressing and as a by-product, it will provide 5G coverage to the municipal road networks. **5G corridor deployment projects as supported by the CEF Digital Framework will help unlocking the deployment of 5G not only along European road transport corridors, but also on the wider motorway, national road and lower-order road network** both in the EU, the EEA and further neighbouring European countries. It is clear that the vast majority of investment into 5G networks will come from private funds. **Enhanced cooperation models between actors**, including sharing of infrastructure assets and moving from sharing of passive assets to active network assets without jeopardising competition will help to achieve economically viable network coverage and capacity along all sections and layers of the road transport network. As the road transport network itself is a critical infrastructure, and these physical infrastructures are requiring digital services based on connectivity and computing capabilities to serve modern and efficient transport, **the provision of enablers of digital services needs to rapidly evolve and adopt state-of-the art technology, which is the 5G System (5GS) and is based on the 5G Standalone version of the specifications**. It is also the foundation of the further evolution with 5G Advanced and eventually 6G, which will build upon 5G, but not replacing it.

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Abbreviations

3GPP	3rd Generation Partnership Project
4G	4th Generation Wireless Systems
5G	5th Generation Wireless Systems
5G SA / 5G NSA	5G standalone / 5G non-standalone
5GAA	5G Automotive Association
5G-PPP	5G Public Private Partnership
5GS	5G System
6G	6th Generation Wireless Systems
ADAS	Advanced Driver Assistance Systems
AI/ML	Artificial Intelligence / Machine Learning
API	Application Programming Interface
APN	Access Point Name
C2C-CC	Car-to-Car Communication Consortium
CAGR	Compound Annual Growth Rate
CAM	Connected and Automated Mobility
CAPEX	Capital expenditure
CCAM	Connected, Cooperative and Automated Mobility
CEF	Connecting Europe Facility
CEPT/ECC	European Conference of Postal and Telecommunications Administrations - Electronic Communications Committee
C-ITS	(Cooperative) Intelligent Transport Systems
CSA	Coordination and Support Action
CSP	Communication Service Providers
C-V2X	Cellular-Vehicle-to-Everything
DEP	Digital Europe Programme
DSDA	Dual SIM Dual Active
EC	European Commission
EEA	European Economic Area
EMF	Electromagnetic field
EPC	Evolved Packet Core (4G)
ERTRAC	European Road Transport Research Advisory Council
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
FDD	Frequency Division Duplexing
GCF	Global Certification Forum
GDPR	General Data Protection Regulation
GIA	Gigabit Infrastructure Act
GLOSA	Green Light Optimal Speed Advice
GNSS	Global Navigation Satellite System
GSMA	Global System for Mobile Communications Association
GSM-R	Global System for Mobile Communications-Railway
HD Maps	High-definition Maps
IaaS/MaaS/NaaS	Infrastructure as a Service / Mobility as a Service / Network as a Service

IoT	Internet of Things
IP	Internet Protocol
ISA	Intelligent speed assistance
ISD	Inter-site distance
ISO	International Organization for Standardization
ITS / C-ITS	Intelligent Transport Systems / Cooperative Intelligent Transport Systems
KPI	Key Performance Indicator
KYC	Know Your Customer
LBO	Local Breakout
LTE	Long Term Evolution (4G)
MBB	Multi Broad Band
MEC	Multi-access Edge Computing (formerly known as Mobile Edge Computing)
mMTC	Massive machine-type communication
MNO	Mobile Network Operator
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator Radio Access Network
MOTA	Massive Over-the-Air
NAD	Network Access Device
NESTs	Network Slice Templates
NHP	Neutral Host infrastructure Provider
NRA	National Regulatory Authority
NTN	Non-Terrestrial Networks
OBU	On-Board Unit
OEM	Original Equipment Manufacturer (car manufacturer)
OPEX	Operational expenditure
OTA	Over-the-Air
PaaS / SaaS	Platform as a Service/ Software as a Service
PLMN	Public Land Mobile Network
QoE	Quality of Experience
QoS	Quality of Service
RO	Road Operator
RoI	Return on Investment
RSU	Roadside Unit
RTK	Real-Time Kinematic
SAE	Society of Automotive Engineers
SDA	Strategic Deployment Agenda
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SME	Small and medium-sized enterprises
SNS JU	Smart Networks and Services Joint Undertaking
STEM	Science, Technology, Engineering and Mathematics
TCU	Telematics Control Unit
TDD	Time Division Duplex
TEN-T	Trans-European Transport Network

TN	Terrestrial Network
TN-ITS	Transport Network – Intelligent Transport Systems
ToD	Teleoperated Driving
UE	User Equipment
URSP	User Route Selection Policy
V2P / V2V / V2I / V2N / V2N2I / V2X	Vehicle-to-Pedestrian/ Vehicle-to-vehicle/ Vehicle-to-Infrastructure / Vehicle-to-Network / Vehicle-to-Network-to-Infrastructure / Vehicle-to-Everything
VRU	Vulnerable Road User