



Deliverable D3.2  
5G Edge Deployment Scenarios for CCAM Use Cases

Coordination of 5G edge and distributed cloud integration for  
European corridors and smart communities



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# 5G Edge Deployment Scenarios for CCAM Use Cases

## 1. Reading Guide deliverable 3.2

This deliverable aims to serve as a practical guide for stakeholders such as network operators, infrastructure providers, system integrators, and application developers engaged in planning or executing real-world deployments of 5G and MEC-based mobility services.

### Introduction

The emergence of 5G and Multi-access Edge Computing (MEC) technologies marks a pivotal advancement in modern communication infrastructure. These innovations enable transformative capabilities such as ultra-low latency, high bandwidth, and localized data processing. These features are crucial for supporting next-generation services, notably Cooperative, Connected, and Automated Mobility (CCAM). Within this framework, developing and evaluating deployment scenarios is vital to unlocking the full potential of 5G and MEC-enabled mobility use cases. Effective deployment strategies ensure that the technical advantages of 5G and MEC translate into practical, scalable, and sustainable real-world applications.

### 5GMEC4EU Work package 3.2

Work Package 3.2 (WP3.2) focuses on a comprehensive analysis of deployment scenarios for the mobility use cases identified in the broader project framework. Unlike Deliverable 3.1, which concentrated on defining and describing use cases, WP3.2 emphasizes the technical and operational deployment aspects. This includes detailed scenario definitions, data flow modeling, and identification of best practices aligned with the unique capabilities and constraints of 5G and MEC-enabled distributed cloud environments. The objective is to provide actionable insights that inform the design and implementation of robust deployment strategies.

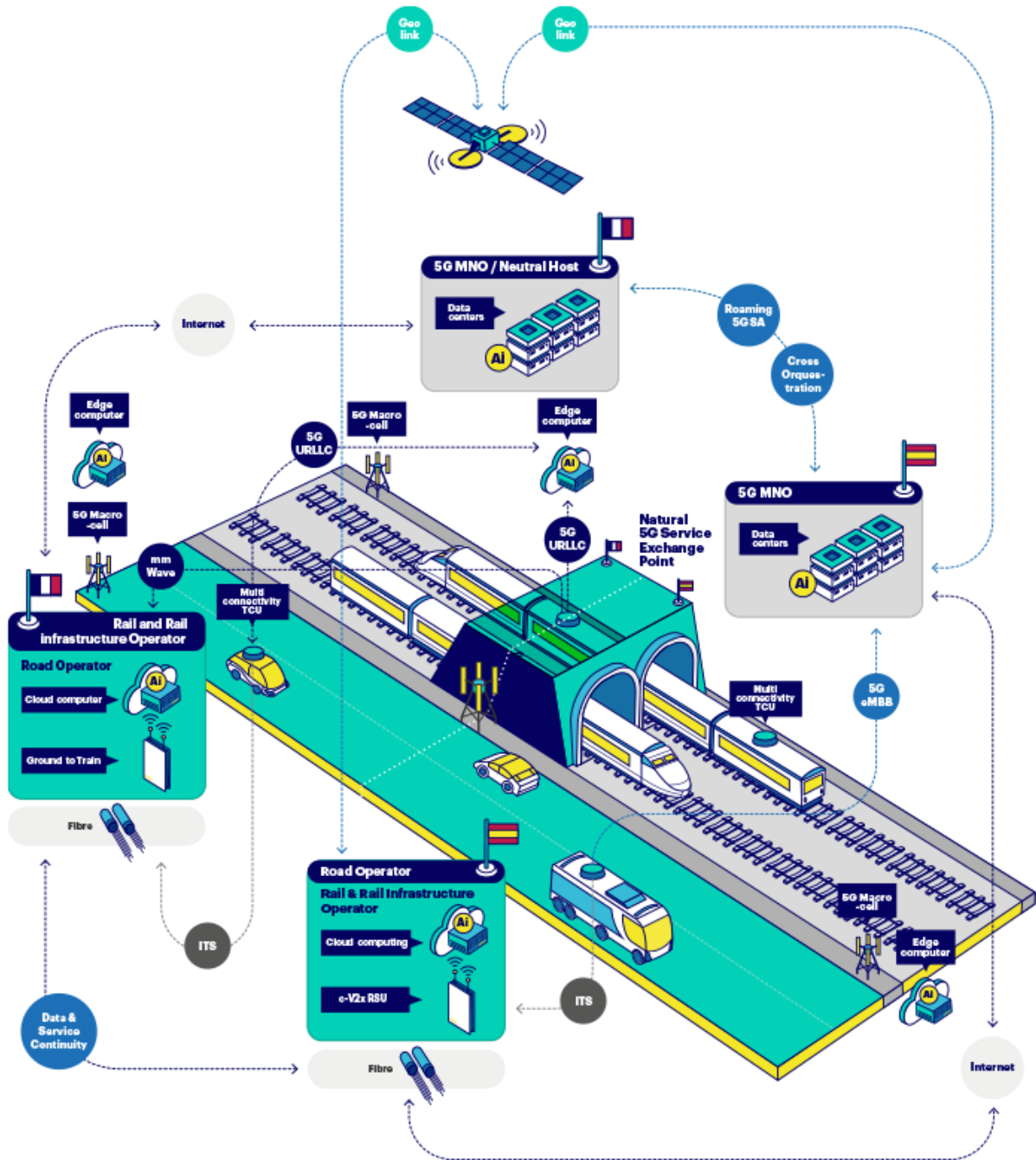
### Scope

By bridging the gap between high-level use case definitions and concrete implementation, WP3.2 enhances the overall deployment readiness of the scenarios identified. This supports faster time-to-market and improved service quality for end-users, while enabling more efficient network and infrastructure utilization by operators and service providers.

It is important to distinguish WP3.2 from related deliverables:

- Deliverable 3.1 focused on outlining the functional scope and objectives of the use cases. (See Annex 1 for a summary table).

- Deliverable 3.4 will focus on the real-world implementation and validation of the Emergency Vehicle Approaching (EVA) use case, relying heavily on deployment insights from WP3.2.
- Deliverable 3.3 is the effort to disseminate towards projects at selected events, fora and via the website of the results and experiences of the analysis of the use cases.



D3.2 5G Edge Deployment Scenarios for CCAM Use Cases

## 2. Executive Summary

*5G Edge deployment scenarios for Cooperative, Connected, and Automated Mobility (CCAM) use cases are essential for enabling advanced functionalities such as low-latency communication, predictive QoS, and seamless service continuity.*

This report explores how 5G and Multi-access Edge Computing (MEC) can be effectively deployed to support Cooperative, Connected, and Automated Mobility (CCAM) use cases. As mobility becomes more automated and data-driven, the timely processing and reliable transmission of information are critical to safety, efficiency, and user trust. The convergence of 5G and edge computing technologies enables ultra-low latency, localized data processing, and real-time decision-making at scale—essential capabilities for next-generation transport systems.

The analysis presented in this document bridges the gap between conceptual use cases (defined in prior deliverables) and their technical deployment. It provides a structured evaluation of technical and operational requirements, including latency thresholds, bandwidth needs, orchestration strategies, and edge infrastructure design. Deployment scenarios are outlined for distinct domains—cities, highways, and cross-border corridors—each with specific performance expectations and architectural implications.

### **Key findings highlight that:**

Urban deployments benefit from dense edge node placement and strong integration with public transport and vulnerable road user protection systems. Highway deployments prioritize reliable coverage, fast handover, and support for high-speed applications like safety related information and automated freight. Cross-border scenarios require seamless interoperability, regulatory harmonization, and advanced orchestration for uninterrupted service continuity.

The report emphasizes that MEC not only enhances performance but also enables new CCAM services—such as real-time hazard detection, intersection coordination, and dynamic fleet management. It also explores challenges around multi-operator roaming, session continuity, data security, and regulatory compliance.

### **Recommendations include:**

- Investing in scenario-based validation environments (e.g., living labs and corridors).
- Ensuring orchestration automation to manage network and compute resources dynamically.
- Supporting standardization and harmonization efforts for MEC federation and interoperability.
- Prioritizing collaborative models among stakeholders—including operators, technology providers, regulators, and municipalities.

Ultimately, this deliverable serves as a technical and strategic guide to ensure that 5G and edge computing are deployed in a way that meets the stringent demands of CCAM while delivering tangible benefits for citizens, transport systems, and industry.

In more detail:

**5G and Multi-access Edge Computing (MEC)** are foundational for the realization of Cooperative, Connected, and Automated Mobility (CCAM) in Europe.

**Deployment scenarios** are domain-specific (urban, highway, cross-border) and require integration of digital and physical infrastructure, advanced orchestration, and robust validation.

**Key recommendations:** Prioritize scenario-based validation, invest in living labs, ensure interoperability, and focus on seamless MEC integration for low-latency and reliable mobility services. Ongoing collaboration between industry, regulators, and research is vital for success.

**Network Requirements**, general deployment remarks:

- Latency: Ultra-Low Latency (<20 ms) critical for collision prevention (EVA, emergency brake light), tolerant for road condition reports (< 1 s). (Spikes are not a real issue, many messages will follow up)
- Throughput: Highest for HD map updates (50–100+ Mbps) and crowdsourced data, lowest for basic safety alerts (1–5 Mbps).
- Geofencing: Essential for Road work warnings, environmental zones, and location-specific alerts.
- Multi-Network Redundancy: Mandatory for mission-critical services like railway crossings.
- Reliability: Mission/safety-critical services (e.g. V2V Safety, GLOSA) require 99.999% uptime. Non-safety services (e.g., traffic flow data) tolerate 99.9%.
- Multi-operator roaming for cross-border continuity (handover within 1 sec).
- Predictive QoS: Ensures consistent performance by anticipating network conditions
- Cybersecurity: Protects sensitive V2X communications from cyber threats
- Edge computing for localized decision-making can benefit from technology like Local Break Out, 5G-Slicing and facilitates the growing convergence of AI, Edge Computing, and 5G networks.
- Also to consider Precise Positioning: Enhances safety-critical applications like collision avoidance.

See chapter 4 for an overview of latency, throughput and QoS for the main categories of use cases with some examples. (See Annex 1 and deliverable 3.1 of 5GMEC4EU for the long list of use cases)

### 3. Introduction and background

**CCAM leverages 5G and MEC to enable advanced, automated, and cooperative mobility services and aims to improve road safety, efficiency, and inclusivity through automation and connectivity.**

**5G/MEC provide the ultra-reliable, low-latency connectivity and edge processing needed for real-time vehicle communication and decision-making.**

**Objectives:**

- Identify and analyze viable deployment scenarios for 5G and MEC in CCAM.
- Assess MEC implications for latency, data processing, and cross-border continuity.
- Provide actionable recommendations for stakeholders.

**Scope:** Address scenarios based on scope-of-application, technical, operational, best practices and expected impact aspects.

Cooperative, Connected, and Automated Mobility (CCAM) marks a transformative evolution in the design and delivery of mobility services, aiming to create transportation systems that are safer, more efficient, and more inclusive. Central to this transformation are advanced digital technologies, most notably 5G connectivity and Multi-access Edge Computing (MEC), which together provide the ultra-reliable, low-latency communications and localized data processing capabilities essential for real-time vehicle cooperation, automation, and seamless integration with both digital and physical infrastructure.

CCAM's ambition is to enable vehicles, infrastructure, and road users to communicate and cooperate seamlessly, reducing accidents, optimizing traffic flows, and ensuring mobility is accessible to all segments of society. Achieving these goals relies on the technological advancements of 5G networks for real-time vehicle-to-everything (V2X) communication and instantaneous decision-making, complemented by MEC's ability to process data at the network edge, close to vehicles and infrastructure. This combination supports advanced use cases such as cooperative driving maneuvers, automated fleet management, and dynamic interaction with vulnerable road users.

The implementation of CCAM is inherently scenario-based, reflecting the diversity of operational contexts, technological requirements, and societal impacts across domains. Urban environments, for example, require solutions that prioritize interaction with vulnerable road users and integration with public transport, while highway scenarios focus on applications like hazardous location warnings, platooning and automated freight transport. Cross-border corridors introduce unique challenges related to interoperability, regulatory alignment, and uninterrupted service continuity as vehicles move between different national networks and infrastructure providers.

Given this complexity, the objectives of this report are threefold:

- To identify and analyze viable deployment scenarios for 5G and MEC in CCAM, drawing on recent European research and large-scale demonstrations.

- To assess the implications of MEC for latency, data processing, and cross-border continuity, factors that underpin the reliability and safety of automated mobility services.
- To provide actionable recommendations for stakeholders, including policymakers, industry leaders, and technology providers, to accelerate the safe and inclusive deployment of CCAM solutions.

The scope of this report is firmly rooted in the European context, referencing leading initiatives and research from organizations such as 5GAA, EU projects, and the 5GMEC4EU partners. It covers a spectrum of deployment scenarios, from dense urban centers and high-speed highways to complex cross-border corridors and addresses not only technical and operational aspects but also broader societal and regulatory considerations critical for widespread acceptance and long-term success.

European projects provide comprehensive frameworks for scenario-based implementation, each with its own challenges and requirements. These initiatives make extensive use of living labs and large-scale demonstrations to test and validate CCAM solutions in realistic conditions, focusing on interoperability, integration of digital and physical infrastructure, and societal impact. Scenario-based safety assurance is essential for building trust in AI algorithms and the acceptance of automated driving.

By synthesizing insights from scenario-based validation, integration of digital and physical infrastructure, and lessons learned from real-world demonstrations, this report provides a comprehensive foundation for understanding and advancing the deployment of 5G edge and MEC technologies in support of next-generation CCAM use cases across Europe. Ultimately, the combination of 5G/MEC with scenario-based approaches and European collaboration positions CCAM to deliver safer, more efficient, and more inclusive mobility solutions for the future.

## 4. CCAM use case requirements:

*CCAM use cases cover a wide range of applications, from safety and automation to infotainment and fleet management. Each use case is governed by stringent service-level requirements (SLRs): ultra-reliable low-latency communication for safety-critical functions, high reliability for sensor data sharing, high throughput and data quality for AI-driven processing, and seamless handovers across Europe-wide coverage. Together, these requirements ensure mobility that is safe, efficient, and centered on user needs.*

*See **ANNEX 1** (based on deliverable 3.1) for an table overview of 5GMEC4EU description of usecases and sub-use cases.*

*The **5G Automotive Association (5GAA)** provides a comprehensive framework for defining and analyzing Cellular Vehicle-to-Everything use cases and their associated Service Level Requirements (SLRs). These use cases are central to enabling advanced CCAM functionalities, supporting both safety-critical and value-added mobility services across diverse driving environments.*

### Technical and operational requirements for the functional use case categories:

- **Safety Use Cases:**  
These are focused on preventing accidents and enhancing situational awareness through the real-time exchange of safety-critical data between vehicles and infrastructure. Typical examples include hazard warnings, intersection collision avoidance, and emergency electronic brake lights. The key requirement is ultra-reliable, low-latency communication to ensure that vehicles and road users can respond instantly to developing hazards.
- **Autonomous Driving Use Cases:**  
Applications such as cooperative adaptive cruise control, platooning, lane merging, and automated valet parking fall under this category. These use-cases depend on highly reliable and low-latency communication to coordinate complex vehicle maneuvers and support safe automation at higher SAE levels (4 and 5).
- **Infotainment and Convenience Use Cases:**  
These include services like video streaming for passengers and over-the-air software updates. While they require high data throughput and robust connectivity, their latency requirements are less stringent compared to safety or automation use cases.
- **Fleet and Traffic Management Use Cases:**  
Examples include dynamic routing, real-time fleet coordination, and demand-driven mobility services. These scenarios require seamless integration of V2X data with backend systems to optimize traffic flows and fleet operations.

## Service Level Requirements (SLRs)

Each CCAM use case is underpinned by specific Service Level Requirements, which define the technical performance necessary for safe and effective operation:

- **Quality of Information (QoI):**  
In general, independent of the communication channel, information exchanged must be timely, appropriate, reliable, accurate, complete, concise, and secure. For safety use cases, vehicles must receive precise and up-to-date information about nearby vehicles, road hazards, and traffic signals.
- **Latency:**  
The time from event occurrence to actuation, including both data processing and communication, must be minimized. For collision avoidance, end-to-end latency should be 100 ms or less to enable timely vehicle reactions. Ultra-low latency (<20 ms) is critical for immediate safety functions, while less urgent data (e.g., road condition reports) can tolerate up to 1 second.
- **Data Rate and Message Size:**  
Safety messages typically range from 300 to 1400 bytes, depending on the number of detected objects and event types. Throughput requirements are highest for applications like HD map updates (50–100+ Mbps) and lowest for basic safety alerts (1–5 Mbps).
- **Range:**  
Communication range requirements can extend up to 300 meters in highway scenarios to provide sufficient reaction time at high speeds.
- **Reliability:**  
Mission- and safety-critical services, such as V2V safety and Green Light Optimal Speed Advisory (GLOSA), require extremely high transmission reliability of the communication channel, often above 99.999% uptime. Non-safety services, like general traffic flow data, can operate with 99.9% reliability.
- **Security:**  
Ensuring data integrity and privacy is mandatory, especially for safety-critical and regulatory-compliant applications. Cybersecurity measures are essential to protect sensitive V2X communications from threats.

## Deployment Considerations

- **Geofencing:**  
Essential for location-specific alerts such as road work warnings and environmental zones.

- Multi-Network Redundancy:**  
 Mandatory for mission-critical services (e.g., railway crossings), ensuring service continuity even if one network fails.
- Multi-Operator Roaming:**  
 Required for cross-border mobility, enabling handover between operators within one second to maintain service continuity.
- Predictive QoS:**  
 Anticipates network conditions to ensure consistent performance for critical applications.
- Edge Computing:**  
 Edge computing for localized decision-making can benefit from technologies like Local Break Out, 5G-Slicing and facilitates the growing convergence of AI, Edge Computing, and 5G networks.
- Precise Positioning:**  
 Enhances safety-critical applications like collision avoidance by providing accurate vehicle location data.

## Network Requirements

The next table gives an overview of latency, throughput and QoS for the main categories of use cases with some examples. (See deliverable 3.1 for the long list of use cases).

Category	Use Case examples	Throughput	Latency in ms	Key QoS Requirements
<b>A. Probe Vehicle Data</b>	Probe vehicle data (crowdsourced telemetry)	50–100 Mbps	< 500	Scalability, data consistency
<b>B. Road Works Warning</b>	Road works warning (RWW)	5–20 Mbps	< 200	Geofenced alerts, multi-network redundancy
<b>C. Signage Applications</b>	In-vehicle signage	1–10 Mbps	< 100	Low jitter, moderate reliability
	Dynamic in-car speed limits	1-5 Mbps	< 100	Real-time updates, GPS accuracy
	Dynamic access control (environmental zones)	5–15 Mbps	< 100	Priority scheduling, authentication

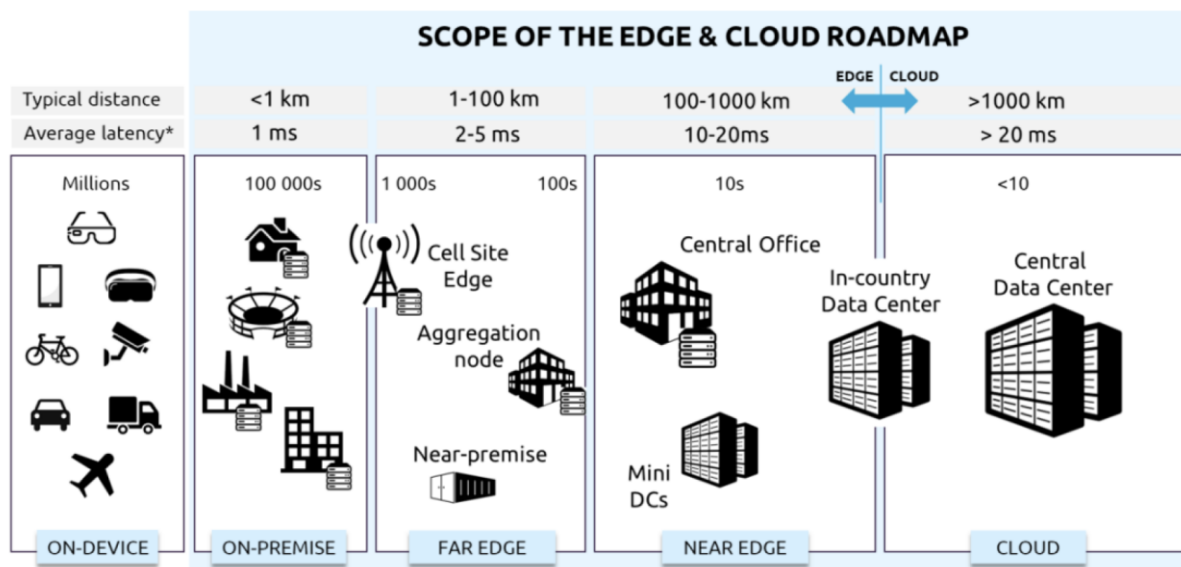
<b>D. Hazardous Location Notifications</b>	Emergency vehicle approaching (EVA)	1–10 Mbps	< 100	Ultra-low latency, 99.999% reliability
	Slow/stationary vehicles, end of traffic jam	1–5 Mbps	< 100	High availability, geolocation accuracy
	Temporarily slippery road	5–10 Mbps	< 200	Weather sensor integration
	Obstacle on the road	1–5 Mbps	< 200	Sensor fusion compatibility
	(Unprotected) Accident area	5–15 Mbps	< 100	Multi-modal alert delivery
	Alert wrong way driving	1-5 Mbps	< 50	Ultra-reliable, low-latency (URLLC)
	Reduced visibility	1-5 Mbps	< 200	Weather data integration
<b>E. Traffic Info &amp; Smart Routing</b>	Traffic jam warning	10–50 Mbps	< 500	Predictive analytics integration
	Traffic info and smart routing	10-50 Mbps	< 300	Real-time optimization, routing algorithms, predictive analytics
<b>F. Parking, Park &amp; Ride</b>	Dynamic parking allocation	1–10 Mbps	< 1 sec	Geolocation accuracy, moderate reliability
<b>G. Intersections</b>	Green light optimal speed advisory (GLOSA)	5–20 Mbps	< 50	Time synchronization, 99.999% uptime
	Traffic signal priority request designated vehicles	1-10 Mbps	< 50	Mission-critical prioritization
	Time to green (TTG)	5-10 Mbps	< 50	Accurate timing, low jitter
	Signal violation/intersection safety	10-50 Mbps	< 50	GPS tracking, V2X coordination/analytics support
	Public transport priority	1-10 Mbps	< 50	Mission-critical prioritization

<b>H. Traffic Management</b>	Shockwave damping	20–100 Mbps	< 100	V2V coordination, ultra-reliable
<b>I. Vulnerable Users</b>	VRU collision warning	1–5 Mbps	< 50	Mission-critical prioritization
<b>J. Logistics</b>	Freight info, corridor optimization	10–50 Mbps	< 300	Multi-operator handover, GPS tracking
<b>K. Level Crossing</b>	Railway crossing alerts	1–5 Mbps	< 50	Fail-safe redundancy
<b>L. Law Enforcement</b>	Signal violation detection	10–50 Mbps	< 50	GPS tracking, V2X coordination/analytics support
<b>M. Payment Services</b>	Real-time tolling transactions	5–10 Mbps	< 50	Encryption, zero packet loss
<b>N. Remote Services</b>	Teleoperation/remote diagnostics	10–50 Mbps	< 200	Ultra-reliable, low jitter
	HD map updates	50-100+ Mbps	<1sec	Throughput availability

*N.B.: \* Data aligns with 3GPP TS 22.186 (V2X) and C-Roads/NordicWay implementations Throughput and Latency values represent typical estimated needs based on 5G-CCAM application requirements and might change depending on specific implementations.\**

## 5. EDGE Definition and Concept

*Edge Computing is defined as the processing and storage of data as close as possible to where it is produced. It involves using Edge Nodes, which can be devices, servers, or sets of servers capable of processing data closer to the user. See [5GMEC4EU\\_FlyerEdgeComputingPrimer.pdf](#)*



Source: IPCEI SIS

### The Cloud-Edge-Continuum

The Continuum refers to the full range of locations where edge computing can take place, from the device itself to centralized cloud data centers. At one end, data is processed directly on devices like sensors or vehicles ("on-device"), providing instant responses for tasks that require ultra-low latency. Next, edge nodes can be placed within an organization's premises ("on-premises"), followed by "far edge" deployments close to data sources but outside the immediate premises. The "near edge" typically involves regional data centers or aggregation points, while the other end of the continuum is the "public cloud" or central data centers, where large-scale computing resources handle more complex or less time-sensitive processing. This flexible, layered approach allows organizations to optimize speed, security, cost and efficiency by choosing the most suitable location for each application's data processing.

### Key (technical) Benefits

1. Low to ultra-low latency responses for applications like autonomous vehicles and industrial automation
2. Data sovereignty ensures data is processed locally to meet regulatory requirements and enhance data security.
3. Lower connectivity costs
4. Bandwidth Optimization, reduced data transfer volumes across networks

5. Improved security and compliance
6. Ability to overcome unreliable connectivity

### Edge deployment scenarios can be summarized as follows:

- **Private Edge:** Organizations deploy edge data centers at key locations such as manufacturing plants or corporate headquarters. This setup gives companies direct control over their infrastructure, facilitating ultra-low latency, enhanced security, and compliance with data regulations.
- **Colocation and Hosting:** Businesses use services from third-party IT infrastructure providers who host the necessary hardware in their data centers. This model balances privacy and flexibility, as companies manage their own equipment while benefiting from the host provider's facilities and support.
- **Edge Cloud:** This scenario merges the scalability and on-demand flexibility of cloud computing with the low latency and security benefits of edge computing. Resources are virtualized and can be provisioned as needed, while compute and storage are located closer to end-users.

### Multi-access Edge Computing (MEC)

MEC refers to a specific edge deployment tightly integrated with connectivity service providers' networks. MEC provides access to the network operator's APIs, assures end-to-end Quality of Service (QoS), and is directly embedded within access networks such as 5G. The standardization of MEC is led by groups such as ETSI.

### Architecture Considerations:

Edge architectures must be tailored to the specific needs of diverse use cases, such as industrial IoT or autonomous vehicles. There is no universal edge architecture, and requirements for performance, latency, and security will vary. Ongoing standardization efforts by organizations like ETSI aim to address these differing needs and ensure interoperability. Specifically for the use of edge in CCAM deployments there needs to be a harmonization of architectures and interoperability of participating edge providers across roads and cities.

## 7. CCAM implications of Multi-access Edge Computing (MEC)

*MEC is a cornerstone of future CCAM: it delivers ultra-reliable low latency, local compute capacity, and uninterrupted service continuity across operators and borders. Achieving this vision requires not only technical foundations such as open standards, federated MEC, and orchestration, but also cross-industry cooperation and business agreements to ensure truly European-scale mobility.*

The integration of Multi-access Edge Computing (MEC) with 5G is pivotal for Cooperative, Connected, and Automated Mobility (CCAM). MEC brings compute and intelligence close to where data is generated, enabling safety, efficiency, and seamless mobility across borders.

### Key Benefits of MEC for CCAM

#### **Low latency for safety-critical services:**

By processing data at the network edge, MEC ensures end-to-end reaction times below 20 ms, supporting applications such as emergency braking, collision avoidance, and cooperative maneuvering.

#### **Localized intelligence and privacy:**

Keeping data local reduces backhaul congestion, enhances privacy, and enables real-time AI/ML inference directly at the roadside. This is essential for use cases such as cooperative perception or automated driving, where immediate data analysis is required.

#### **Session continuity across borders:**

CCAM requires seamless service continuity when vehicles move between cells, operators, and countries. This involves two complementary processes:

- *Radio handover* – transferring the UE's air-interface connection between base stations (and potentially across PLMNs).
- *Application-level handover* – transferring an active service session between MEC instances, which may belong to different operators.

Both must be harmonized to avoid service disruption—a prerequisite for mission-critical applications like lifesaving V2X warnings or cross-border automated driving.

### Pan-European MEC Requirements

To realize CCAM services at scale, MEC deployment must support a **pan-European ecosystem** with the following requirements:

- **Service continuity in multi-operator environments:** MEC federation mechanisms are needed to guarantee uninterrupted CCAM services across network operators and borders. 5GAA highlights APIs and architectural variants that enable such interoperability.

- **Interoperability and portability:** Applications must run seamlessly across MEC platforms, independent of vendor or operator, relying on open standards (ETSI MEC, 3GPP, GSMA) or commonly adopted industry practices.
- **Contextual awareness:** MEC should exploit local network and environmental data to optimize performance, e.g., location-specific traffic or safety conditions.
- **Business and policy frameworks:** Beyond technology, achieving federation requires agreements on how resources are shared and services federated among operators and stakeholders.

Challenges remain, including the absence of Local Breakout (LBO) in current roaming designs (where traffic may be unnecessarily routed via distant home networks), and the need for mechanisms to inform applications of the nearest MEC site and to enable seamless application handover for moving vehicles.

## Integration Points: Unlocking Real-Time Mobility

MEC is not a standalone feature but part of an integrated digital infrastructure that combines connectivity, compute, and orchestration. Key integration points include:

- **Data locality:** Ultra-low latency decisions enabled by edge processing, e.g. hazard alerts, intersection priority, or vulnerable road user warnings.
- **Session continuity:** Persistent service delivery during radio and application handovers, especially in cross-border scenarios.
- **Integration with digital infrastructure:** Real-time fusion of traffic management data, sensor feeds, and digital traffic regulations directly at the edge.

## Infrastructure Components: The Backbone of CCAM

Delivering these capabilities depends on a robust and scalable infrastructure:

- **Edge nodes (MEC servers):** Deployed at roadside units, intersections, and hubs. Scalable according to traffic demand or risk zones.
- **Connectivity stack:**
  - *5G Standalone (SA) with New Radio (NR):* Provides high bandwidth and sub-100 ms end-to-end latency, with 100+ Mbps for HD map updates.
  - *V2X interfaces:* Direct vehicle-to-vehicle, infrastructure, and pedestrian communication.
  - *Fiber backhaul:* High-capacity connectivity between edge nodes and the core network.
- **Orchestration platforms:** Automate dynamic resource allocation and ensure Quality of Service (QoS) for mission-critical applications, while supporting multi-operator and cross-border continuity.

## 8. Scope-of-application deployment scenarios: aspects, challenges & analysis

### Urban, Highway/Corridor and Cross-border Edge Deployment Scenarios

#### **Identified Deployment Models**

##### **Urban:**

*Dense edge node deployment for high data demand and complex interactions.  
Focus on integration with public transport and vulnerable road users.*

##### **Highway/Corridor:**

*Edge nodes at intervals for continuous coverage and low latency.  
Emphasis on high-speed cooperative maneuvers platooning and automated logistics.*

##### **Cross-border:**

*Interconnected MEC nodes for seamless handover between countries/operators.  
Address regulatory, technical, and operational challenges for seamless service continuity,  
roaming, and interoperability.*

#### Deployment model for Urban areas

The deployment of Connected, Cooperative, and Automated Mobility (CCAM) use cases in urban areas requires a scenario-based approach tailored to the unique challenges and opportunities of dense city environments. According to the 5GAA and recent European research, several key elements define the urban deployment model:

##### **1. Focus on Vulnerable Road Users and Public Transport Integration**

Urban CCAM deployments prioritize the interaction with vulnerable road users such as pedestrians and cyclists, as well as seamless integration with public transport systems. This focus addresses the complexity and diversity of urban mobility, ensuring safety and efficiency for all road users.

##### **2. Living Labs and Large-Scale Demonstrations**

Urban deployment models are validated through living labs and real-world demonstrations in cities like Tampere, Trikala, Turin, and Barcelona. These environments enable the testing of interoperability between automated and conventional vehicles, the integration of digital and physical infrastructure, and the real-time management of mixed traffic flows.

##### **3. Digital and Physical Infrastructure Integration**

Successful urban CCAM deployment requires the integration of digital infrastructure, such as real-time traffic data, V2X communication, and dynamic traffic management systems, with physical infrastructure like traffic signs, sensors, and charging stations. Projects like AUGMENTED CCAM and PoDIUM have demonstrated the importance of this dual integration for robust and scalable solutions.

#### **4. Scenario-Based Validation and Safety Assurance**

Urban deployments use scenario-based validation to develop, train, and virtually test CCAM systems in complex city situations. This includes generating diverse traffic scenarios, simulating unexpected events, and ensuring the robustness and safety of AI-driven mobility solutions. Scenario-based safety assurance builds trust in automated driving technologies among users and regulators.

#### **5. Use Case Examples**

Urban use cases include automated shuttles, dynamic fleet and traffic management, real-time hazard warnings, intersection safety, and advanced parking solutions. These use-cases are designed to enhance user acceptance, inclusivity, and the integration of shared and demand-driven mobility services.

#### **6. Societal and Policy Considerations**

Urban deployment models also address societal impacts, regulatory compliance, and inclusivity. Participatory platforms, simulations, and data analysis are used to evaluate public acceptance and inform policy development, ensuring that urban CCAM solutions are future-proof and widely supported

### **Deployment Model for Highway or Corridor Areas**

The deployment of CCAM (Connected, Cooperative, and Automated Mobility) use cases along highways and corridors is characterized by a scenario-based, large-scale approach that addresses the unique operational, technical, and regulatory challenges of these environments. Drawing from 5GAA publications and recent European research, the following key aspects define the deployment model for highways and corridors:

#### **1. Focus on Advanced Automation and Logistics**

Highway and corridor deployments prioritize use cases such as vehicle platooning, automated freight transport, and high-speed cooperative maneuvers. These scenarios require robust, long-range V2X (Vehicle-to-Everything) communication and the ability to coordinate both automated and conventional vehicles at high speeds.

#### **2. Integration of Digital and Physical Infrastructure**

Deployment models integrate digital infrastructure, such as real-time traffic rules, V2X communication, and dynamic fleet management, with physical infrastructure including road signs, sensors, and charging stations. This dual integration is crucial for supporting complex logistics operations and ensuring safety and efficiency along extended corridors.

#### **3. Living Labs and Cross-Border Demonstrations**

Implementation is validated in living labs and through large-scale demonstrations on real highway corridors, often spanning national borders (e.g., Netherlands–Norway corridor). These environments test interoperability, seamless handover between networks, and the

integration of physical and digital assets, with a focus on cross-border continuity and regulatory alignment.

#### 4. Scenario-Based Validation and Safety Assurance

Highway deployments use scenario-based validation to develop, train, and virtually test CCAM systems in realistic, high-speed traffic conditions. This includes generating a variety of traffic situations, such as unexpected obstacles or mixed traffic flows, to ensure the robustness and safety of automated driving systems under real-world conditions.

#### 5. Use Case-Specific Scenarios

- **Logistics:** Automated trucks navigating cross-border corridors, addressing challenges like customs, loading/unloading, and interaction with conventional traffic.
- **Fleet Management:** Dynamic coordination of vehicle fleets for efficient, shared, and demand-driven mobility.
- **Passenger Transport:** Automated shuttles and buses operating on highways, with emphasis on user acceptance and integration with broader mobility services.

#### 6. Network and Operational Requirements

Highway deployments demand ultra-reliable, low-latency connectivity, multi-network redundancy, and seamless handover between operators, especially in cross-border scenarios. Predictive QoS, edge computing, and robust cybersecurity are essential to maintain service continuity and safety at high speeds.

#### 7. Societal and Policy Considerations

Deployment models also evaluate societal impact, regulatory compliance, and inclusivity through simulations, participatory platforms, and large-scale data analysis. This ensures that solutions are future-proof and widely accepted by stakeholders and the public

### Deployment Model for Cross-Border Corridors

The deployment of CCAM (Connected, Cooperative, and Automated Mobility) use cases in cross-border corridors is among the most complex, requiring a robust and harmonized approach to ensure seamless, safe, and efficient mobility across national boundaries. According to 5GAA publications and recent European research, the cross-border deployment model is characterized by the following key elements:

#### 1. MEC Integration with Orchestration Architectures

Multi-access Edge Computing (MEC) systems are tightly integrated into orchestration architectures to manage data routing efficiently across borders. This integration enables real-time, localized processing of safety-critical data, which is essential for maintaining low latency and high reliability as vehicles transition between national networks.

## **2. Advanced Handover and Data Routing Solutions**

Cross-border mobility inherently introduces connectivity interruptions due to roaming mechanisms and differences in network operators. To address this, advanced solutions such as Localized Breakout (LBO) routing are deployed. LBO allows data to be processed and routed locally at the edge, minimizing latency during handover and ensuring that critical CCAM services remain uninterrupted as vehicles cross borders.

## **3. Inter-PLMN MEC Interconnection**

Seamless service continuity requires robust interconnection between Public Land Mobile Networks (PLMNs) on either side of the border. Standardized protocols and interfaces are essential to support efficient session continuity and handover, allowing vehicles to maintain ongoing data sessions and application states as they move between different network domains.

## **4. Synchronization of ITS Centers and Regulatory Compliance**

Intelligent Transport System (ITS) centers on both sides of the border must synchronize data flows, ensuring that traffic management, hazard notifications, and other CCAM services remain consistent and reliable. This synchronization must also respect local regulations regarding data sharing and privacy, requiring careful alignment of technical and legal frameworks.

## **5. Living Labs and Large-Scale Demonstrations**

Cross-border deployment models are validated through living labs and large-scale demonstrations along international corridors (e.g., Netherlands–Norway). These tests focus on interoperability, integration of digital and physical infrastructure, and the management of both automated and conventional traffic across borders.

## **6. Scenario-Based Validation**

Scenario-based approaches are used to develop, test, and validate cross-border CCAM systems. This includes generating diverse traffic situations, simulating unexpected events, and ensuring the robustness of systems under real-world cross-border conditions. Such validation is critical for building trust in automated mobility and ensuring regulatory acceptance

## 9. Operational deployment scenario aspects, challenges and analysis

### Use case analysis with and without Edge/MEC technology

*Edge/MEC technologies significantly enhance CCAM use cases by enabling real-time, area-wide data processing, lower latency, and improved detection of complex or hidden hazards. Without edge, systems rely on direct V2V communication and onboard sensors, which limits coverage, scalability, and reliability, especially in dense, urban, or complex traffic scenarios.*

Examples of practical scenarios for implementing CCAM safety use cases, comparing deployments with and without edge/MEC technologies. Each scenario highlights the use case, system functioning in both setups, and the key differences in performance, reliability, and scalability.

Use Case	With Edge/MEC Technologies	Without Edge/MEC Technologies	Key Differences
<b>Emergency Brake Warning</b>	Edge aggregates and broadcasts area-wide alerts, integrates infrastructure data	Direct V2V alerts within communication range only	<b>Edge offers broader, faster, and more reliable warnings, especially in dense/complex environments</b>
<b>Lane Change Warning</b>	Edge processes multi-vehicle and infrastructure data, predicts and warns about hidden risks	Vehicle sensors and V2V only, limited to line-of-sight	<b>Edge improves detection of complex/hidden hazards, increasing reliability and safety</b>
<b>Intersection Movement Assist</b>	Edge coordinates all vehicle and infrastructure data for real-time intersection management	Limited V2V and basic infrastructure communication	<b>Edge enables holistic, real-time coordination, reducing collision risk</b>
<b>VRU Alerts</b>	Edge fuses roadside and infrastructure data to detect and warn about hidden pedestrians/cyclists	Vehicle sensors and V2V only, cannot detect VRUs out of range or sight	<b>Edge greatly enhances detection and timely warning for VRUs, improving safety</b>

#### 1. Emergency Brake Warning

##### With Edge/MEC:

Edge servers aggregate braking event data from multiple vehicles in real time. When a vehicle brakes suddenly, the edge node instantly processes this information and broadcasts alerts to all nearby vehicles, including those not in direct line-of-sight. The edge can also integrate data from infrastructure sensors (e.g., traffic cameras, road weather stations) for higher situational awareness and accuracy.

### **Without Edge/MEC:**

Vehicles communicate directly via V2V (Vehicle-to-Vehicle) protocols. When one vehicle brakes hard, it transmits a warning to other vehicles within its direct communication range. There is no centralized processing or aggregation, so only vehicles close enough receive the alert.

### **Key Differences:**

Edge/MEC enables broader, faster, and more reliable dissemination of alerts, especially in complex or dense environments. V2V alone may miss some vehicles, especially those just out of range or blocked by obstacles and may experience higher latency or message loss in congested radio environments.

## **2. Lane Change Warning**

### **With Edge/MEC:**

Edge nodes receive and process data from multiple vehicles and roadside infrastructure (e.g., cameras, radar). The edge analyzes traffic flow, predicts lane change risks, and broadcasts warnings to affected vehicles with minimal latency. Non-line-of-sight hazards (e.g., vehicles in blind spots) are detected using aggregated sensor data.

### **Without Edge/MEC:**

Each vehicle relies on its own sensors and direct V2V communication to detect adjacent vehicles and potential lane change conflicts. Warnings are limited to what the vehicle can see or what is communicated by nearby vehicles.

### **Key Differences:**

Edge/MEC improves detection of complex situations and hidden risks, increasing reliability and safety. V2V alone is limited by each vehicle's sensor range and cannot account for hazards hidden from view.

## **3. Intersection Movement Assist**

### **With Edge/MEC:**

Edge servers aggregate real-time data from all vehicles approaching an intersection and from smart traffic lights. The edge coordinates vehicle movements, detects potential conflicts, and issues targeted warnings to prevent collisions. The system can optimize intersection flow and prioritize emergency vehicles.

### **Without Edge/MEC:**

Vehicles communicate with each other and, if available, with basic infrastructure (e.g., traffic lights that broadcast status). Coordination is limited, and not all vehicles or infrastructure may participate, leading to gaps in situational awareness.

### **Key Differences:**

Edge/MEC enables holistic, real-time intersection management, reducing collision risks and improving traffic flow. Without edge, coordination is fragmented and less reliable, especially in busy intersections.

## **4. Vulnerable Road User (VRU) Alerts**

### **With Edge/MEC:**

Edge nodes integrate data from roadside units, cameras, and sensors to detect pedestrians and cyclists, even those not visible to vehicle sensors. The edge processes and fuses this data, sending timely alerts to approaching vehicles to prevent VRU collisions.

**Without Edge/MEC:**

Vehicles rely solely on their own sensors and direct V2V communication. VRUs behind obstacles or outside the sensor range may not be detected, increasing the risk of missed alerts.

**Key Differences:**

Edge/MEC greatly enhances detection and timely warning for hidden or unpredictable VRUs, improving safety for pedestrians and cyclists. V2V-only systems are limited by the vehicle's own perception capabilities.

## Roaming and interoperability: Ensuring seamless service across operators and countries.

Ensuring seamless roaming and interoperability is essential for the successful deployment of CCAM services across different operators and countries. As vehicles travel across borders and move between network providers, uninterrupted service continuity must be maintained for safety-critical applications such as emergency alerts, intersection management, and vulnerable road user warnings. This requires robust technical solutions, including standardized interfaces, harmonized data formats, and multi-operator roaming agreements that enable quick and reliable handovers, ideally within one second, between networks. Interoperability also depends on consistent implementation of security, authentication, and quality-of-service mechanisms across all participating operators and jurisdictions. By prioritizing these aspects, CCAM deployments can deliver truly cross-border mobility experiences, ensuring that vehicles and infrastructure communicate effectively regardless of location or network provider, and supporting the broader goals of road safety, efficiency, and user trust throughout Europe.

## Security and privacy: Data protection and compliance with local/EU regulations.

Security and privacy are fundamental pillars in the deployment of CCAM services, especially given the sensitive nature of vehicle and user data and the stringent requirements set by local and EU regulations such as the General Data Protection Regulation (GDPR). Protecting data throughout its lifecycle, whether processed at the edge, in transit, or in the cloud, requires robust encryption, secure authentication, and strict access controls to prevent unauthorized access and ensure data integrity. Compliance also demands that personal data is processed lawfully, transparently, and for specified purposes only, with strong mechanisms for user consent and data minimization. In addition, CCAM systems must be designed to support data localization requirements and facilitate auditability for regulatory oversight. By embedding privacy-by-design principles and adopting industry best practices for cybersecurity, CCAM deployments can safeguard user trust, mitigate risks of data breaches, and ensure alignment with evolving legal frameworks across Europe.

## Integration with legacy systems: Gradual migration from 4G/LTE to 5G.

The gradual migration from 4G/LTE to 5G in CCAM environments requires careful integration with existing legacy systems to ensure service continuity and maximize investment in current infrastructure. Rather than a disruptive overhaul, this transition typically involves a phased approach where 4G/LTE networks continue to support foundational connectivity and basic CCAM services, while 5G is incrementally introduced to enable advanced features such as ultra-low latency, higher bandwidth, and edge computing capabilities. During this period, hybrid solutions are deployed, allowing vehicles and roadside units to operate seamlessly across both network generations. This ensures that critical safety and mobility applications remain operational regardless of the underlying connectivity, while new 5G-enabled services can be gradually rolled out and optimized. Over time, as 5G coverage expands and legacy systems are updated or replaced, the ecosystem can fully leverage the benefits of 5G, such as more reliable V2X communication, real-time analytics at the edge, and support for a greater density of connected devices. This stepwise migration not only protects existing investments but also provides flexibility for stakeholders to adapt to evolving standards and operational requirements across different regions and countries.

## 10. Technical deployment scenario aspects, challenges and analysis

### Edge Deployment Scenarios

- Private Edge: Deployed by industries at critical locations like plants or headquarters
- Colocation and Hosting: Utilizing services from IT infrastructure providers
- Edge Cloud: Combining cloud computing flexibility with edge computing benefits

### Multi-access Edge Computing (MEC)

MEC is a specific implementation of Edge Computing integrated with connectivity service providers' networks. It offers additional features like:

- Access to provider's network services via APIs
- Guaranteed end-to-end QoS
- Integration with service provider's access network (e.g., 5G)

### Architecture Considerations

There's no one-size-fits-all solution for Edge architecture. Different use cases and applications have varying requirements. Standardization efforts are ongoing for specific scenarios like Industrial IoT and autonomous driving, with bodies like ETSI developing MEC standards.

### Edge Computing for V2X Real-Time Data Processing

Multi-access Edge Computing (MEC) nodes play a critical role in processing data locally to reduce latency, particularly in scenarios involving roadside sensors and vehicle-to-everything (V2X) communication.

#### Data Flows

- V2V (vehicle-to-vehicle): Direct communication (sidelink/PC5) for cooperative maneuvers.
- V2I (vehicle-to-infrastructure): Roadside units and traffic management centers.
- V2N (vehicle-to-network): Cloud and edge services for navigation, updates, and analytics.

For instance, MEC nodes aggregate data from roadside units to extend the perception range of connected vehicles and validate sensor data from other vehicles.

In cross-border contexts, MEC systems are integrated into orchestration architectures to manage data routing efficiently. Cross-border mobility introduces connectivity interruptions due to roaming mechanisms, requiring advanced solutions like localized breakout (LBO) routing for efficient handover. Also, ITS centers on either side of a border must synchronize data flows while adhering to local regulations for data sharing.

## Latency SPIKES vs LATENCY requirements

*While low latency is generally crucial for Cooperative, Connected and Automated Mobility (CCAM) systems, the impact of occasional latency spikes may not be as critical as one might initially assume. This is primarily due to the repetitive nature of messaging in CCAM applications.*

In CCAM systems, vehicles and infrastructure components frequently exchange messages containing information about their status, position, and surroundings. These messages are typically sent at high frequencies, often multiple times per second.

This repetitive communication creates a form of redundancy that can help mitigate the effects of occasional latency spikes.

When a latency spike occurs, causing a delay in message delivery, the impact is minimized because:

1. Subsequent messages quickly follow: The next message in the sequence is likely to arrive shortly after the delayed one, providing updated information.
2. Interpolation and prediction: CCAM systems often employ algorithms that can interpolate or predict missing data points based on previous and subsequent messages, filling in gaps caused by delays.
3. Safety margins: CCAM applications are designed with safety buffers that account for potential communication delays or losses.
4. Multiple data sources: Many CCAM systems rely on sensor fusion, combining data from various sources. This redundancy helps maintain situational awareness even if one data stream experiences a delay.

However, it's important to note that while occasional latency spikes may be tolerable, consistent low latency remains crucial for real-time decision-making in critical scenarios, such as collision avoidance or emergency braking. The system's ability to handle latency spikes depends on the specific use case, the frequency of these spikes, and the overall system design.

## 5G-SLICING i.r.t. CCAM and Edge

*5G network slicing is a key feature of 5G technology that allows for the creation of multiple virtual networks (slices) on a single physical network infrastructure. This concept enables network operators to tailor network resources and capabilities to meet the specific needs of different services, applications, or customers.*

*By leveraging 5G network slicing and edge computing, the automotive industry can create more reliable, efficient, and customizable CCAM solutions. This combination allows for the optimization of network resources, improved performance for critical applications, and the*

*flexibility to adapt to evolving requirements in the rapidly advancing field of connected and automated mobility.*

### **Benefits for CCAM (Cooperative, Connected and Automated Mobility)**

1. Customized performance: Network slices can be optimized for CCAM applications, ensuring low latency, high reliability, and sufficient bandwidth for critical communications between vehicles and infrastructure.
2. Guaranteed quality of service: Dedicated slices for CCAM can provide guaranteed performance levels, crucial for safety-critical applications like autonomous driving and real-time traffic management.
3. Flexibility: As CCAM requirements evolve, network slices can be dynamically adjusted to accommodate new use cases or changing demands without affecting other services.

### **Benefits for Edge Computing**

1. Enhanced resource allocation: Network slicing allows for efficient allocation of edge computing resources, ensuring that latency-sensitive CCAM applications have priority access to nearby edge nodes.
2. Improved security: Isolated network slices can enhance data privacy and security for edge computing applications, which is crucial for handling sensitive vehicle and infrastructure data.
3. Optimized data processing: By combining network slicing with edge computing, data can be processed closer to its source, reducing latency and improving real-time decision-making capabilities for CCAM applications.

### **Key Use Cases Benefiting from 5G Slicing and Edge Computing**

1. Real-time situational awareness and HD mapping: A dedicated slice can ensure low-latency transmission of high-definition map data and real-time traffic information to vehicles.
2. Software over-the-air (OTA) updates: A separate slice can be optimized for efficient distribution of software updates to large numbers of vehicles without impacting on critical safety communications.
3. Tele-operated driving: Ultra-low latency slices combined with edge computing can enable remote control of vehicles in emergency situations or for last-mile delivery services.
4. High-density platooning: Dedicated slices can guarantee the consistent, low-latency communication required for coordinating groups of closely spaced vehicles.

## Local Break Out and its role in Edge cloud

*In essence, LBO plays a crucial role in optimizing network architecture for the demands of modern cloud-based applications and edge computing scenarios, enhancing both performance and efficiency*

The main purpose of Local Break-Out (LBO) in edge computing is to reduce latency and network load by routing internet-bound traffic directly to the internet from local branches or remote offices, instead of sending it through a centralized data center. This approach offers several key benefits:

1. **Reduced latency:** By creating a shorter path between users and data networks, LBO significantly decreases end-to-end latency, resulting in faster response times and improved user experience.
2. **Network efficiency:** LBO offloads traffic from the core network, reducing strain on expensive core network functions and backbone infrastructure.
3. **Cost-effectiveness:** By bypassing the need to backhaul all internet traffic to a central data center, LBO enables more cost-effective connections, especially for cloud applications and SaaS services.
4. **Improved performance:** LBO allows for faster browsing experiences and better performance of latency-sensitive applications like video calling.
5. **Support for edge services:** LBO enables the provision of edge-based microservices and targeted, context-aware services to end users by selectively routing edge-service related packets to edge computing nodes.

## Impact of AI on Edge Network Infrastructure and CCAM Use Cases

*We note the growing convergence of AI, Edge Computing, and 5G networks, particularly in the context of Cooperative, Connected, and Automated Mobility (CCAM).*

*AI is not only influencing CCAM use cases but also shaping the requirements of Edge network infrastructure. The ability to perform AI inferencing at the edge, combined with the capabilities of 5G network slicing, is paving the way for innovative and efficient CCAM solutions. Edge networks provide the low-latency, secure, and scalable environment needed to fully leverage the power of AI in connected and automated mobility.*

### **1. AI Inferencing at the Edge:**

- **Real-time Data Analysis:** AI models, pre-trained, are applied for real-time data analytics closer to the data source (i.e., at the edge). This is vital for CCAM applications requiring immediate decisions, such as autonomous driving.
- **Low Latency:** By processing data at the edge, AI inferencing minimizes latency, which is critical for safety-related CCAM functions.

- **Bandwidth Optimization:** Processing data locally reduces the need to transmit large volumes of data to a central cloud, saving network resources.
- **Edge as a facilitator:** Edge networks help facilitate real-time data analysis and low latency which is a key aspect of AI.

## **2. Impact on CCAM Use Case examples:**

- **Real-Time Situational Awareness and HD Maps:** AI algorithms can process sensor data from vehicles and infrastructure to create real-time situational awareness, which includes generating and updating high-definition (HD) maps. This processed data can be efficiently delivered to vehicles via low-latency edge networks.
- **Tele-operated Driving:** AI can augment tele-operation by providing features such as object detection, path prediction, and driver assistance, even when human operators are remotely controlling vehicles. The edge infrastructure allows these algorithms to function with acceptable latency.
- **High-Density Platooning:** AI is essential for coordinating the movement of closely spaced vehicles in platoons. Edge computing enables the necessary real-time communication and processing for safe and efficient platooning.
- **Predictive Maintenance:** As noted in one of the documents, predictive maintenance can be done by edge networks using AI.

## **3. Edge Computing as an Enabler for AI:**

- **Low Latency Requirements:** Edge computing addresses the low-latency requirements of AI-powered applications, especially in time-sensitive CCAM scenarios.
- **Data Sovereignty:** Edge Computing addresses this need by keeping data local. This facilitates the use of AI while ensuring compliance.
- **Scalability and Cost-Effectiveness:** Edge infrastructure provides a scalable and cost-effective platform for deploying AI models across a large fleet of connected vehicles.
- **Customized Performance:** Network slices can be optimized for AI-driven CCAM applications, ensuring low latency, high reliability, and sufficient bandwidth.
- **Guaranteed Quality of Service (QoS):** Dedicated slices for CCAM can provide guaranteed performance levels, crucial for safety-critical AI applications.

## 11. Best Practices for Deployment

- **Scenario-based validation:** Use living labs and large-scale demonstrations (e.g., Tampere, Trikala, Turin, cross-border corridors) to test interoperability and safety.
- **Edge placement:** Align with traffic density and use case latency needs.
- **Orchestration:** Automate service management across MEC and 5G domains.
- **Collaboration:** Foster MNO cooperation, standardization, and regulatory alignment
- **Business and regulatory:** Develop shared infrastructure models, Address investment, data sharing, and liability.

Effective deployment of 5G Edge technologies for Cooperative, Connected, and Automated Mobility (CCAM) demands a holistic and multidisciplinary approach. Drawing on lessons from European living labs, large-scale demonstrations, and major corridor projects, including Tampere, Trikala, Turin, and cross-border trials, this section outlines best practices to ensure robust, scalable, and interoperable deployments.

### Previously

Previously, the focus was on establishing foundational elements such as interfaces, communication channels, signing mechanisms, standards, and data formats, with an emphasis on demonstrating societal benefits, building solutions from scratch, and conducting repeated pilots or proof-of-concepts, often resulting in significant spending and upfront costs. Today, the emphasis has shifted toward agility, scalability, and service-oriented architectures, prioritizing data quality and coverage, and balancing societal benefits with clear returns on investment. Rather than reinventing the wheel, there is a stronger drive to reuse and build upon existing solutions, deploy rapidly, and continuously improve, all while being mindful of opportunity costs and maximizing the value of investments.

### Scenario-Based Validation

Scenario-based validation is essential to replicate the diverse and dynamic conditions encountered in real-world CCAM environments. Living labs and large-scale demonstrations play a pivotal role by providing controlled, yet realistic testing grounds where interoperability, safety, and service continuity can be rigorously assessed.

Key practices include:

- Employing diverse traffic and environmental scenarios mimicking urban, highway, and cross-border conditions to evaluate system robustness.
- Leveraging collaborative trial environments such as those promoted by the 5G Strategic Deployment Agenda (5G SDA) and corridor initiatives like 5GSC and 5G-MOBIX, ensuring cross-stakeholder participation.

- Using these environments to validate automated handover mechanisms, edge orchestration functions, and multi-operator roaming at scale.

## Edge Node Placement

Strategic edge node placement is critical to meet the ultra-low latency and high reliability required by CCAM use cases. Optimal placement aligns closely with:

- Traffic density hotspots and high-risk zones such as intersections, urban centers, and critical highway segments.
- Use case-specific latency and throughput needs, for example, dense urban areas demand numerous nodes to serve vulnerable road users, while highway corridors require nodes spaced at intervals to maintain continuous coverage.
- Flexibility to scale or relocate edge resources based on evolving traffic patterns and deployment feedback from operational monitoring.

## Orchestration Automation

Automated orchestration across MEC and 5G network domains is a cornerstone for dynamic resource allocation and consistent Quality of Service (QoS) assurance. Best practices include:

- Utilizing advanced orchestration platforms capable of real-time monitoring and predictive QoS adjustment to prioritize mission-critical CCAM services.
- Enabling seamless cross-domain coordination, including multi-operator and cross-border scenarios, by adopting standards-compliant frameworks such as those defined by ETSI MEC and 3GPP.
- Supporting service continuity through automated session handover and application instance migration between MEC hosts, ensuring uninterrupted user experience.

## Collaborative Ecosystem Development

Cross-industry and cross-border collaboration is fundamental to overcoming technical and operational challenges. This entails:

- Fostering close cooperation among Mobile Network Operators (MNOs) to harmonize deployment strategies, share operational data, and coordinate infrastructure rollouts.
- Driving standardization efforts on interfaces, protocols, and APIs to enable seamless interoperability between competing vendors and multiple MEC platforms.
- Engaging regulatory bodies early to align policies on spectrum usage, data sovereignty, and cybersecurity, which are critical to broad adoption.

## Business and Regulatory Frameworks

Sustainable deployment requires clear business models and regulatory alignment:

- Developing shared infrastructure models that enable cost-efficient usage of edge resources and network assets among multiple operators and service providers.
- Establishing frameworks for investment sharing, risk management, and liability, especially considering the mission-critical nature of CCAM applications.
- Enforcing data sharing agreements that balance operational efficiency with privacy and security compliance, aligned with GDPR and relevant European directives.
- Encouraging innovation-friendly policies and incentives to accelerate deployment uptake and foster a competitive market for CCAM services.

By adhering to these best practices, stakeholders can ensure that the deployment of 5G Edge technologies for CCAM use cases is not only technically sound but also economically viable and socially acceptable, underpinning Europe's leadership in next-generation mobility solutions.

## 12. Expected Impact

- **Technical:** Improved reliability, scalability, and performance of CCAM services.
- **Operational:** Enhanced traffic management, reduced congestion, and increased safety.
- **Business:** New revenue streams for telecom and mobility providers.
- **Societal:** Increased user acceptance, inclusivity, and accessibility of automated mobility.

### Technical Impact

The deployment of 5G and MEC for CCAM is expected to significantly enhance the reliability, scalability, and overall performance of mobility services. By leveraging ultra-reliable, low-latency connectivity and localized edge processing, CCAM systems can support real-time vehicle communication and decision-making, even in complex urban and cross-border scenarios. This technical foundation enables robust integration of digital and physical infrastructure, as well as advanced AI-driven safety assurance and validation processes, leading to more resilient and adaptable mobility solutions.

### Operational Impact

Operationally, CCAM deployment will transform traffic management by enabling dynamic, data-driven control strategies that reduce congestion and improve road safety. Living labs and large-scale demonstrations across Europe have shown that integrating automated vehicles, conventional traffic, and vulnerable road users leads to more efficient traffic flows and better incident response. Scenario-based validation ensures that CCAM systems are rigorously tested in realistic environments, supporting safe interactions and seamless service continuity across domains such as urban centers, highways, and cross-border corridors.

### Business Impact

The evolution toward connected and automated mobility opens new revenue streams for telecom and mobility providers. The integration of 5G edge and MEC technologies allows for the development of innovative services, such as on-demand mobility, dynamic fleet management, and data-driven logistics. These advancements enable telecom operators and mobility companies to diversify their offerings and tap into emerging markets, including smart logistics, mobility-as-a-service, and advanced infotainment solutions.

### Societal Impact

From a societal perspective, the widespread adoption of CCAM is poised to increase user acceptance, inclusivity, and accessibility of automated mobility services. By focusing on scenario-based approaches that address the needs of various user groups, including vulnerable road users and public transport passengers, CCAM ensures that mobility solutions are safe, equitable, and widely accepted. Participatory platforms, simulations, and real-world demonstrations contribute to building public trust and fostering a regulatory environment that supports inclusive and future-proof mobility systems

## 13. Annexes:

### Annex 1. Overview of CCAM Use Cases (Recap of 3.1)

The following categories as described in 3.1 illustrate the breadth of applications:

Category	Key Functions & Examples
<b>Probe Vehicle Data (A)</b>	Traffic data collection, event detection, reporting vehicles in distress
<b>Road Works Warning (B)</b>	Alerts for lane closures, operator vehicles, winter maintenance, automated vehicle warnings
<b>Signage Applications (C)</b>	In-vehicle dynamic speed limits, toll station information, enhanced driver orientation
<b>Hazardous Location Notifications (D)</b>	Alerts for slippery roads, obstacles, accidents, reduced visibility, emergency braking
<b>Traffic Information &amp; Smart Routing (E)</b>	Real-time traffic updates, rerouting, smart points of interest, travel time estimation
<b>Parking, Park &amp; Ride, Multimodality (F)</b>	Parking availability, public transport schedules, modal transfer advice, car-sharing
<b>Intersections (G)</b>	Green Light Optimal Speed Advisory (GLOSA), intersection violation warnings, in-vehicle signage at merges
<b>Traffic Management (H)</b>	Dynamic lane management, traffic bans, variable speed limits, non-autonomous zone notifications
<b>Vulnerable Users (I)</b>	Pedestrian warnings, road worker alerts, protection for users at public transport stops
<b>Logistics (J)</b>	Estimated time of arrival, dock reservations, optimal truck routing, terminal guidance
<b>Level Crossing (K)</b>	Warnings for malfunctioning/closing level crossings, detection of vehicles in critical areas
<b>Law Enforcement (L)</b>	Identification of vehicles of interest, law enforcement vehicle status, automated driving system monitoring
<b>Payment Services (M)</b>	Toll station or parking payment services
<b>Remote Services (N)</b>	Remote maintenance and monitoring

Overview of subcategories of use cases.

Code	Name
A1	Traffic data collection
A2	Probe vehicle data on detected events
A3	Probe vehicle data on manually declared events
A4	Detection of a vehicle in distress in a critical area
B1a	Alert closure of part of a lane, whole lane or several lanes
B1b	Alert planned closure of a road or a carriageway
B1c	Alert planned road works - mobile
B2a	Alert operator vehicle approaching
B2b	Alert operator vehicle in intervention
B2c	Alert operator vehicle in patrol
B2d	Alert end of queue by a road operator vehicle
B3a	Winter maintenance - salting in process
B3b	Winter maintenance - snow removal in process
B3c	Winter maintenance - alert vehicle moving
B4	Dangerous vehicle approaching a road works: warning to the dangerous vehicle
B5	Dangerous vehicle approaching a road works: warning to workers
B6	Road works warning for automated vehicles
B7	In-vehicle signage (embedded mobile VMS)
C2	In-vehicle dynamic speed limit information
C3	In-vehicle signage (embedded VMS)
C4	Toll station approaching: orientation of drivers
C5	Toll station approaching: event information
C6	Toll station approaching: orientation of automated vehicles
C7	Toll station approaching: enhanced orientation of drivers
D1	Alert temporary slippery road
D2a	Alert animal on the road
D2b	Alert people on the road
D3	Alert obstacle on the road
D4	Alert stationary vehicle / breakdown
D5	Alert accident area
D6	Alert reduced visibility
D7	Alert wrong way driving
D8	Alert unmanaged blockage of a road
D9a	Alert temporary mountain pass route closure
D9b	Alert approaching a closed mountain pass route
D10	Alert emergency brake
D11	Alert end of queue
D12	Emergency vehicle approaching
D13	Longitudinal collision risk warning
D14	Alert slow vehicle
E1	Traffic information about snow on the road
E2	Rerouting
E3	Smart routing
E4	Smart POI
E5	Travel time of heavy goods vehicle
E6	Alert extreme weather conditions
F1	Information on parking lots location, availability and services
F2	Parking lots location and availability: break time indication

F3	Information about the schedule of the next public transport after parking at the station
F4	Information about the schedule of the next public transport when approaching a station
F5	Modal transfer advice
F6	Reservation of a parking space released by a user
F7	Information about a parking space released by a user
F8	Car-sharing service between two specific stations
G1	Green Light Optimal Speed Advisory (GLOSA)
G2	Traffic signal priority request by designated vehicles
G3	Intersection violation: warning to the violator vehicle
G4	Intersection violation: warning to approaching vehicles
G5	In-vehicle signage at a merge for vehicles on the entry slip road
G6	In-vehicle signage at a merge for vehicles on the main road
H1	Permanent traffic ban to specific vehicles
H2	Dynamic traffic ban to specific vehicles
H3	Dynamic lane management - reserved lane (I2V2I)
H4	Dynamic lane management - reserved lane (I2V)
H5	Dynamic lane assignment
H6	HGV overtaking ban
H7	Variable speed limit for automated vehicles
H8	Vehicle entering a non-autonomous zone
I1	Pedestrian at signalized intersection: warning to vehicles
I2	Pedestrian at signalized intersection: warning to pedestrian
I3	Road workers in the field
I4	Pedestrian out of intersections and out of pedestrian crossings: warning to vehicles
I5	Vulnerable user at a public transport stop
J1	Estimated Time of Arrival (ETA) for terminal operators
J2	Dock reservation
J3	Assigning a slot to a given vehicle for cross-channel traffic
J4	Information on the site's access conditions
J5	Optimal route advice for trucks
J6	Guide the truck in the port (terminal or truck parking)
K1	Level crossing out of order
K2	Level crossing approaching
K3	Level crossing in process of closing
K4	Detection of a vehicle in distress in a critical area
L1	Identification of vehicles reported by law enforcement agencies
L2	Stationary law enforcement vehicle
L3	Automated driving system status
L4	Location of vehicle particularly sought after by law enforcement agencies
M1	Payment service at a toll station
M2	Payment service for parking
N1	Remote maintenance
N2	

## The Challenge for Road Authorities

European Road Authorities (RAs) face a perfect storm: **Aging infrastructure** demands increasing maintenance despite limited resources, while **budget constraints** make operational efficiency more critical than ever. At the same time, the **need for digitalization** is growing, with a rising demand for data-driven decision-making. **Workforce shortages** add further pressure, as recruiting and retaining

technical expertise has become increasingly difficult. In parallel, preparations are underway for the integration of connected and automated vehicles (**CCAM**) into daily operations.

*Yet one of the most valuable resources, **real-time vehicle-generated data**, remains largely inaccessible to them. OEM real-time data streams are rarely available, which limits the ability to manage operations proactively and increases reliance on external service providers.*

## The Value of Real-Time Vehicle Data

Real-time data provides significant benefits across multiple areas. It enables **faster incident detection**, reducing response times and improving safety. **Predictive maintenance** becomes possible, allowing early warnings to prevent costly failures. **Traffic flow** can be optimized through dynamic signal control and routing, while **sustainability** goals are supported by reducing congestion, emissions, and fuel consumption. In addition, real-time data enhances **equity and accessibility** by delivering better information services to all road users.

### Key Insights

**OEM real-time vehicle data** can close current information gaps, reduce reliance on costly new roadside infrastructure, and improve safety, maintenance efficiency, and sustainability outcomes.

**Communications** (5G, Edge and Cloud) provide ultra-low latency, data exchanges vital for safety-critical events (e.g., traffic light priority, safety, hazard warnings, V2X) and enable system-wide coordination, cross-border integration, and large-scale real-time data dissemination.

**AI, advanced analytics and edge computing** empowers to act instantly on live data while cloud systems host historical and predictive intelligence.

**Governance dimensions** legal compliance, ethical considerations, trust frameworks, and inclusivity are essential for public legitimacy, interoperability, and long-term resilience.

## Use Cases, Methods and Technologies

In red Vehicle data sharing related contributions to the use cases for road authorities

High-Level Use Case	Manual / Traditional Methods	Modern Methods and Technologies (Short-/Long-Range Comms, Sensors, AI, Cloud Platforms, etc.)
<b>Road Condition Monitoring</b>	Visual inspection	Pavement & weather sensors, roadside V2I, <b>V2X comms</b> , cloud analytics
<b>Traffic Flow Management</b>	Manual counts, roadside surveys	Inductive loops, <b>probe vehicle data</b> , <b>CCAM</b> , 4G/5G cloud analytics, adaptive control algorithms
<b>Incident Detection &amp; Response</b>	Patrols, phone reports	Roadside sensors, cameras, automated systems, <b>OEM telematics</b> , <b>cloud alerts</b> , connected roadside units

<b>Weather &amp; Hazard Detection</b>	Weather stations	<b>Vehicle sensors</b> , IoT/weather networks, cloud analytics & data fusion
<b>Maintenance Planning &amp; Asset Management</b>	Spreadsheets, manual audits	IoT asset sensors, structural health monitoring, predictive maintenance analytics, cloud diagnostics dashboards
<b>Traffic Signal Optimization (e.g., GLOSA)</b>	Fixed cycles	Intelligent Traffic Light Controllers, <b>CCAM comms</b> , edge computing, cloud coordination
<b>Dynamic Route Guidance &amp; Travel Info</b>	Static signs, radio	<b>Probe data</b> , <b>Mobile in car apps</b> , APIs, predictive congestion/traffic models
<b>Automated / Emergency Vehicle Prioritization</b>	Manual override	Priority detectors, <b>vehicle tags</b> , <b>CCAM</b> , cloud/cellular coordination
<b>Hazard &amp; Safety Alerting</b>	Public signs, radio	Cellular/DSRC <b>push hazard alerts</b> , Roadside Variable Message Signs
<b>Truck Platooning &amp; Cooperative Driving</b>	None	<b>V2V, V2I</b> , AI-based coordination, 4G/5G edge integration
<b>Smart Parking &amp; Urban Access</b>	Paper permits, patrols	On-site sensors, IoT, cloud aggregation, payment/reservation apps
<b>EV Charging Monitoring</b>	Manual checks	IoT smart chargers, on-site meters, cloud energy mgmt platforms, pricing optimization

## Annex 2. Summary of the 5G Strategic Deployment Agenda for Connected, Cooperative and Automated Mobility(5G SDA for CCAM)

*Developed in 2025 by the GUIDE Coordination and Support Action with input provided by the 6G SNS JU Strategic Working Group on 5G for CAM Deployment and states in summary:*

Road CAM (Cooperative, Connected, and Automated Mobility) services leverage advanced connectivity technologies to significantly enhance traffic efficiency and safety in road transport. Their deployment is already delivering tangible benefits to travelers, including real-time traffic updates, improved navigation, and in-vehicle notifications about congestion, safety hazards, and environmental zones. These features empower drivers to make better route choices and maintain heightened situational awareness.

Widely implemented systems, such as Automated Crash Notification (ANC/e-Call), mandatory in all new EU cars since 2018, have become foundational to road safety. Newer services, like traffic light priority for emergency vehicles and Green Light Optimal Speed Advisory (GLOSA), are increasingly available, further boosting efficiency and convenience for road users.

#### The Role of 5G in Road CAM Services

The promoters of the 5G Strategic Deployment Agenda (SDA) recognize 5G as a decisive enabler for the next generation of Road CAM services, including:

- **Highly Automated Driving Functionalities:**  
Current Road CAM services largely target traditional vehicles and focus on Day-1 (Awareness) services. These basic safety services support the exchange of status information about local hazards, traffic conditions, and map updates.
- **Day-2 (Sensing) Services:**  
As SAE Level 3 (L3) vehicles become more common, connectivity will support Day-2 services, enabling vehicles to share sensor data and provide richer information about detected objects and traffic. This will further enhance safety compared to Day-1 services.
- **Day 3+ (Cooperative) Services:**  
In later deployment phases, Level 3 and Level 4 automated vehicles will support Day 3+ services, such as coordinated planning and execution of cooperative maneuvers with other vehicles and infrastructure.

A combination of direct (vehicle-to-vehicle) and network-based (vehicle-to-network) communications will be used to meet the requirements for these services.

- **Integration of New Vehicle Types:**  
Beyond traditional vehicles, new forms of mobility, such as shuttles and e-scooters, are emerging, offering greater flexibility and user choice. Connectivity will allow these vehicles to be safely integrated into the broader CAM ecosystem.

#### Remote Management Operations

Teleoperation, alongside human and automated driving, enables remote control of vehicles in unforeseen situations. Levels of support include:

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

These remote management systems will require 5G capabilities for priority service provisioning, ultra-low latency, and high data transmission capacity.

### Smart Traffic Management

The integration of 5G, Artificial Intelligence (AI), and cloud computing is transforming traffic management and control systems. Key benefits include:

- Near-instant communication
- Real-time, high-volume data analysis
- Massive device connectivity
- Segmented networks for differentiated services
- Real-time traffic analysis and response

### Logistics Services

As 5G networks expand, logistics operations will advance through:

- Automated and connected vehicle fleets communicating with control centers, traffic systems, and other vehicles
- Real-time diagnostics, monitoring, and predictive maintenance
- Large data transfers enabling real-time management and data-driven decision-making
- Automated transport operations within and between hubs, improving efficiency, safety, and tracking while reducing costs and environmental impact
- Seamless multimodal transport requiring interoperability between systems, locations, vehicles, and transport modes, with optimal network load balancing

### Digital Twins for Mobility

The deployment of 5G, advanced computing, AI, and sensor networks has accelerated the use of digital twins in mobility. Digital twins, together with AI models, enable:

- Traffic pattern prediction and informed decision-making
- Predictive road maintenance based on vehicle sensor data (where contracts with road operators exist)
- Eco-friendly transport through optimized routing and EV charging infrastructure

### Connected Passenger Services

Connectivity is now a critical factor in customer vehicle choice. OEMs are expected to bundle connectivity-enabled features tailored to specific regions and customer segments.

Connected passenger services, supported by local (in-vehicle), edge, and cloud computing, include:

- **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, smart home/office integration, advertising, gaming, videoconferencing, e-commerce/app-stores
- **Expansion to 2-wheelers:** Many connected services are expected to grow rapidly for motorbikes and scooters

Integrating 5G in vehicles today improves coverage and throughput, enabling OEMs to leverage new network functionalities such as edge computing, network slicing, regional breakout, precise positioning, and multi-connectivity management. These technologies support seamless user experiences and efficient software/AI updates.

#### Software-Defined Vehicles (SDVs)

Software-Defined Vehicles (SDVs) are transforming the automotive industry by shifting control from hardware to software, enabling:

- Continuous updates and flexible customization
- Seamless integration with cloud services
- Enhanced performance, autonomy, and real-time adaptability via AI and advanced connectivity

As OEMs scale up 5G adoption, SDVs are increasingly connected to cloud and edge resources, unlocking new revenue streams (data-driven services, subscriptions, OTA updates) and enabling agile service delivery. This evolution is underpinned by cloud-based service models (IaaS, PaaS, SaaS, NaaS), which support seamless, scalable user experiences and new business opportunities. Connectivity is thus a critical enabler for SDV architectures, supporting continuous integration, real-time data exchange, and orchestration across distributed computing environments.

#### Associated Vertical Services

The deployment of 5G along European roads enables innovations across multiple industry verticals, including:

- **Rail and Other Transport Modes:** Enhanced connectivity supports multimodal coordination, real-time data sharing, and improved safety and efficiency across cars, public transit, bikes, and pedestrians.
- **Road Infrastructure and Operations:** 5G connectivity benefits construction and maintenance by enabling safer, more efficient, and productive work environments, including autonomous machinery and robotic inspections.
- **Cybersecurity:** 5G supports real-time anomaly detection and threat simulation, localized threat response, and secure, isolated network environments via network slicing.
- **Other Sectors:** 5G also supports smart farming, smart warehouses, and other services along transportation networks.

## Annex 3. An overview of EU Implementation of Edge Computing

*The European Union is actively promoting the development and deployment of edge computing technologies to achieve its digital transformation goals. The focus is on creating a robust, secure, and interoperable edge infrastructure across Europe, with various initiatives and projects contributing to this vision.*

### Key Aspects of the EU's Edge Strategy:

1. **Strategic Importance:** The EU recognizes edge computing as a critical enabler for various sectors, including manufacturing, automotive, healthcare, and energy. It supports data sovereignty, reduces latency, optimizes bandwidth usage, and enhances security.
2. **Funding and Support:** The EU provides funding through programs like the Connecting Europe Facility (CEF) Digital to support the rollout of 5G systems and the integration of edge computing facilities along transportation routes and within local communities. Initiatives like the "5GMEC4EU" Coordination and Support Action foster community exchange on integrated 5G edge infrastructure.
3. **Standardization and Interoperability:** The EU promotes standardization and interoperability to ensure that edge solutions from different providers can work together seamlessly. Bodies like ETSI (European Telecommunications Standards Institute) are developing standards for edge computing, particularly in the context of Multi-access Edge Computing (MEC).

### Specific Initiatives and Projects:

1. **Simple Edge Discovery – CAMARA Project:**
  - The CAMARA project, driven by the Linux Foundation, seeks to create a unified, open, and global API solution.
  - In the context of edge computing, CAMARA aims to simplify the discovery and utilization of edge resources through standardized APIs. This enables developers to easily access and integrate edge capabilities into their applications, fostering innovation and interoperability.
  - This API standardization is very important for interoperability.
2. **API Usage Map**
  - Related to the CAMARA project, the API Usage Map is meant to illustrate the number of APIs being developed across the EU with open-source code.

### 3. Edge Observatory for the Digital Decade:

- The Edge Observatory monitors the deployment of edge nodes across Europe.
- This observatory aims to track the progress of edge infrastructure development, identify gaps, and inform policy decisions.
- It also provides valuable insights into the benefits of edge computing, such as reduced latency, improved security, and optimized bandwidth usage.

#### Challenges and Future Directions:

Despite the progress, challenges remain in the EU's edge computing implementation:

- **Fragmentation:** The edge computing landscape is still fragmented, with varying levels of maturity across providers.
- **Security:** Ensuring the security of edge infrastructure and data is a critical concern.
- **Interoperability:** Achieving seamless interoperability between different edge solutions requires further standardization efforts.

LINKS [Simple Edge Discovery – Camara Project](#) and [Edge Observatory for the Digital Decade – Monitoring the Deployment of Edge Nodes | Shaping Europe’s digital future](#), for the world [Api Usage Map](#)

## Annex 4. Summary of ETSI MEC architecture white paper

Published June 2025: [ETSI-WP-68-MEC-app-dev-guidelinestracking.pdf](#).

### ETSI WP68: MEC Application Development Guidelines - Summary

This white paper clarifies how developers can effectively access and consume APIs in the Telco edge computing ecosystem, reconciling contributions from **ETSI standards**, **open-source CAMARA APIs**, **GSMA's Open Gateway**, and **TM Forum** operate-APIs [ACM Digital Library+10ETSI+10LinkedIn+10](#).

### Key Objectives

- Map roles across the API lifecycle, from definition (e.g. CAMARA, ETSI standard-setting) to implementation (operators, vendors) to consumption (application developers, vertical industries) [ETSI](#).
- Clarify interoperability and alignment between various API frameworks and how developers should approach API design and integration in MEC applications [ETSILinkedIn](#).

### Core Sections

1. **Developer Perspectives**  
Differentiates between API-definition contributors, API implementers, and API consumers, with guidance tailored to each role [ETSI](#).
2. **Standards and API Alignment**  
Describes the ETSI MEC service APIs (e.g. location, radio network, V2X APIs) and how they interoperate with open-source CAMARA definitions and TM Forum adoption mechanisms [GTI+3ETSI+3LinkedIn+3](#).
3. **Use Cases**  
Showcases real-world edge application scenarios (e.g. smart traffic, remote diagnostics, edge-AI) to illustrate practical API consumption models.
4. **Developer Guidelines**  
Provides pragmatic recommendations on API exposure, versioning, abstraction layers, sandbox testing (e.g. MEC Sandbox evolving into Edge Native Connector via STF-678), and API safety/interoperability best practices [LinkedIn+1ETSI+1ETSI+1LinkedIn+1](#).
5. **Outlook & Collaboration Opportunities**  
Highlights future collaboration among ETSI, CAMARA, TM Forum, GSMA and other forums to streamline API experiences and support Telco Edge Cloud evolution [GSMA+4ETSI+4LinkedIn+4](#).

## Why It Matters

The document helps developers navigate a fragmented API ecosystem by:

- Presenting a unified approach toward consuming both ETSI-defined and open-source APIs.
- Emphasizing real-world tooling (e.g. sandbox environments, testing frameworks).
- Supporting alignment among standards bodies (ETSI, GSMA, TM Forum, CAMARA) to bolster interoperability.

## Annex 5. Handover on Service Level with Interchange

### 1. Introduction

This chapter examines **service-level handover** in ETSI MEC, focusing on how services and application instances are maintained or seamlessly migrated when users or devices move across MEC hosts. We reference the ETSI GS MEC 003 (latest version) architecture, including MEC platform, orchestrator, host, and federator roles, and relevant reference points (Mm1–Mm5, Mp1–Mp3).

### 2. ServiceLevel Handover in MEC

Service-level handover enables **application continuity and user experience preservation** as UEs traverse edge coverage zones. In **intrahost mobility**, the MEC platform maintains traffic routing without moving the application instance. In **interhost mobility**, the target MEC host must replicate the application instance, and for stateful services, import the UE/application context, before switching traffic.

Applications are classified as:

- **Stateless:** no context transfer needed; new instance can immediately serve the UE ([iTech Standards](#)).
- **Stateful:** require context/session state transfer to ensure seamless continuation.

### 3. ETSI MEC Architecture Components

#### MEC Platform (MEP)

Provides service discovery, session-state relocation, DNS/traffic rules, and persistent storage via reference point **Mp1**

#### MEC Orchestrator (MEO)

Manages application lifecycle, resource coordination, and federated activities (Mm1–Mm5):

- **Mm1:** Trigger app instantiation/termination via OSS ([studylib.net](#)).
- **Mm2–Mm3:** Manage platform config and app lifecycle (rules, policies).
- **Mm4:** Interfaces with VManager for VNF, resource orchestration.
- **Mm5:** Ensures app relocation support, including platform config, state migration, and lifecycle events.

#### MEC Host (MEH)

Runs the MEP, hosts applications, and connects to local virtual infrastructure.

#### MEC Federator / Broker

Coordinates **inter-MEC handovers** across disparate administrative domains, supporting

service registration, discovery, and context exchange, outlined in ETSI GS MEC 003 ([portal.etsi.org](http://portal.etsi.org), [studylib.net](http://studylib.net)).

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## 4. ReferencePoint Overview

### RefPoint Role

- Mp1** Service registration/discovery, sessionstate relocation, DNS/traffic configuration
  - Mp2** Dataplane control for traffic routing
  - Mp3** Control-plane communication between MEC platforms
  - Mm1** MEO ↔ OSS (application instantiation/termination)
  - Mm2** OSS ↔ MEPM (configuration, fault/performance management)
  - Mm3** MEO ↔ MEPM (app lifecycle, service tracking)
  - Mm4** MEO ↔ VIManager (resource provisioning, image management)
  - Mm5** MEPM ↔ MEP (platform config, app relocation support)
- 

## 5. Handover Process & Mechanisms

### 5.1 Detection & Triggering

Handover begins when either:

- Network signals UE mobility to the MEC system; or
  - MEC or orchestrator detects suboptimal service conditions.
- Triggers are communicated via **Mm5** and **Mp3**.

### 5.2 Service Discovery & Registration

For inter-host handover, the target MEP must discover the existing service. This uses **Mp3** (platform-to-platform communication) and may involve federator mediation. The target MEP then registers a new application instance and subscribes to service state via **Mp1**.

### 5.3 Context & State Transfer

For stateful services:

1. MEPM initiates state transfer to the target host via Mm5-triggered orchestration.
2. The source application pushes context (session, user data) to the target.
3. Confirmation reaches the orchestrator, which updates policies, routes, and DNS entries.

## 5.4 Traffic Rerouting & Cutover

Once context sync completes:

- MEP updates traffic rules via Mp1 to steer traffic to the target.
- Data plane routing is reconfigured through Mp2.
- Network paths (e.g. 5G N4/N6 tunnels) are redirected accordingly.

## 5.5 Deregistration & Cleanup

Upon stable operation at the target:

- The source MEP releases resources, deregisters service availability.
- If federated, the federator coordinates de-registration at upstream registries.

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## 6. Session Persistence & Policy Consistency

- **Policy sync:** MEPM ensures policies (QoS, access control) replicate from source to target.
- **Authentication/Authorization:** User/device credentials remain valid across hosts.
- **Timing & TTL:** Session timeouts and retries are managed to avoid service interruption.

## 7. Challenges & Solutions

- **Detection latency:** Reduced via integration with radio and core network feeds (Mm3/Mp3).
- **State synchronization:** Solution: incremental state-transfer or mirrored datastore. Stateless designs simplified.
- **Traffic gaps:** Elastic policies and fast rerouting minimize packet loss.
- **Federation complexities:** Use standardized inter-domain protocols as described in ETSI GS MEC 003.
- **Security:** Encrypted state transfer, federator vetting, and trust anchoring.

## 8. Summary

Servicelevel handover in ETSI MEC ensures smooth service continuity across edge hosts by orchestrated coordination among MEP, MEPM, MEO, and federator components. The Mm and Mp reference points support lifecycle triggers, state migration, policy synchronization, and traffic management. Stateless designs simplify handover, but stateful services can be supported through careful context-transfer and standardized inter-MEC coordination. These capabilities are fundamental to robust edge deployments in 5G/IoT environments.



## Annex 6. 5GAA Summary of the 5GAA publication: Mobile Edge Computing Use Cases, Initial Test Specifications and Evaluation Methodology Review , July 2025

[mobile-edge-computing-use-cases-initial-test-specifications-and-evaluation-methodology-review.pdf](#)

Connected Cooperative Automated Mobility (CCAM) deployment through Mobile Edge Computing (MEC) is extensively addressed in the 2025 5GAA technical review, which details use cases, evaluation criteria, methodologies, and business dimensions central to future automotive solutions.

### MEC as an Enabler for CCAM

Mobile Edge Computing is positioned as a **key foundation for CCAM** applications that demand ultra-low latency, high reliability, and robust data processing. MEC's proximity to the end-user (vehicle) allows for efficient **local processing of large datasets**—integral to real-time decision-making and automation. By shifting computation from the central cloud to the edge, critical CCAM functions such as safety, navigation, and sensor fusion can operate more reliably, even in multi-stakeholder, multi-OEM environments.

CCAM deployments benefit from MEC in several direct ways:

- **Reduced latency:** MEC minimizes the round-trip time for data exchanges, crucial for dynamic on-road coordination and safety maneuvers.
- **Bandwidth optimization:** Applications process and filter data locally, greatly reducing burdens on backhaul networks.
- **Interoperability:** Standardized and open APIs, as recommended by ETSI and 3GPP, enable interoperable vehicular applications across different OEMs and mobile networks.
- **Scalability and context awareness:** MEC nodes can scale to serve dense urban environments and adapt to local traffic, weather, and regulatory conditions—a requirement for robust CCAM deployments.

### Key CCAM Use Cases Leveraging MEC

The report analyzes six foundational CCAM use cases supported by MEC:

- **See-Through Vehicle:** Real-time video sharing enables drivers to view obstructed traffic scenarios (e.g., overtaking) via low-latency MEC servers, enhancing safety and context awareness.

- **In-Vehicle Entertainment (IVE):** MEC supports seamless streaming, gaming, and context-based content delivery even in mobility, optimizing user experience and network utilization.
- **Intersection Movement Assist (IMA):** Vehicles approaching intersections receive real-time risk alerts facilitated by MEC's local aggregation and dissemination of multi-source traffic data.
- **Vulnerable Road User (VRU) Detection:** MEC enables sensor fusion and AI processing to identify and warn about pedestrians and cyclists, including those without connected devices, emphasizing local privacy and real-time scalability.
- **Vehicle Platooning:** MEC coordinates high-density multi-vehicle platoons with real-time status, control, and adaptation to road and traffic conditions.
- **Automated Valet Parking (AVP):** MEC hosts and executes motion control logic for automated parking services, ensuring reliability, availability, and compliance with ultra-low latency requirements.

Each of these CCAM scenarios requires advanced MEC APIs (e.g., Location API, V2X API, Radio Network Information API) for seamless interoperability, robust security, and privacy protections.

### CCAM Deployment Architecture and Evaluation

Deployment architectures discussed in the report highlight various routing options:

- **Onboard Processing:** Functions are handled within the vehicle—ideal for minimal network reliance but with constraints on scalability and computational power.
- **MEC Processing:** Edge nodes (typically located regionally or even at cell sites) provide local computations, striking a balance between latency and capacity.
- **Central Cloud Processing:** Functions handled at distant data centers maximize scalability but introduce latency and potential reliability issues—less optimal for many CCAM tasks.

Performance analysis relies on **comparing CCAM deployment across these architectures**, focusing on KPIs such as end-to-end latency, reliability, service availability, compute efficiency, security, and privacy. The methodology recommends weighting criteria based on use case demands, facilitating clear trade-off evaluations for OEMs and service providers.

### Evaluation Methodology and Criteria for CCAM

The framework proposes a systematic evaluation of deployment choices using key criteria:

- **CPU/GPU demand (vehicle vs edge/cloud)**
- **Data rate and bandwidth requirements**
- **Latency and reliability metrics**
- **Scalability and orchestration**

- **Multi-data source support, interoperability**
- **Energy efficiency (critical for battery electric and autonomous vehicles)**
- **Privacy and security adherence to regional laws (GDPR, etc.)**

Deployment decisions, particularly for CCAM, must align with service level requirements (SLRs), balancing operational costs with tangible benefits of edge versus onboard or cloud processing.

### **Business and Value Chain Implications**

The document details the **business roles and revenue models** implicit in CCAM deployment via MEC:

- MNOs and edge cloud providers monetize CCAM services by partnering with OEMs, municipalities, and ISVs.
- Road operators and public agencies leverage MEC-powered CCAM to improve safety, urban mobility, and gain regulatory or funding advantages.
- OEMs and vehicle owners benefit from advanced, value-added features, potentially facilitated through subscription models or integration with existing app ecosystems.

### **CCAM Deployment Challenges and Recommendations**

Implementation challenges include orchestration across diverse MEC environments, maintenance of interoperability, upholding security and privacy, and managing energy and compute trade-offs. The report recommends open standards, robust certification methods, and continued cross-industry collaboration (5GAA, ETSI, AECC, 3GPP) to address these issues and accelerate widespread CCAM deployment.

## References and Resources

- **5GAA:**

- White papers on C-V2X use cases, SLRs, and deployment models.  
[5GAA Publications](#)
- [5GAA-2025-SLRs] C-V2X Use Cases and Service Level Requirements (2025).  
<https://5gaa.org/publications/c-v2x-slrs-2025>
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- [5GAA-2025-Roadmap] Visionary Roadmap for C-V2X (2025).  
<https://5gaa.org/publications/c-v2x-roadmap>
- [5GAA-2024-Deploy] Deployment Guidance for 5G Edge (2024).  
<https://5gaa.org/publications/deployment-guide-2024>

- **ETSI:**

- ETSI GS MEC 003: MEC architecture, reference points ([studylib.net](#))
- ETSI GR MEC 018: Service continuity and stateful/stateless classification ([iTeh Standards](#))
- ETSI White Paper No. 24: 4G/5G MEC mobility support ([Scribd](#))

- **5G PPP/5G-MOBIX/5GCroCo/5G-CARMEN, AUGMENTED CCAM, PoDIUM:**

- Reports on cross-border trials, deployment challenges, test results for digital/physical infrastructure integration, and best practices.

[5G-MOBIX](#)

[5GCroCo](#)

[5G-CARMEN](#)

- **5GMEC4EU:**

- Implementation frameworks and orchestration insights.  
[5GMEC4EU](#)
- 5GMEC4EU *Coordination of 5G edge and distributed cloud integration for European corridors and smart communities* [D3.1 Analysis-Use-Cases-5G-CCAM final.pdf](#)
- Case studies on digital infrastructure and orchestration.  
[Monotch](#)
- **ERTRAC/ROAD CCAM Roadmap:**
  - Strategic guidance on deployment scenarios and societal impact.  
[ERTRAC/ROAD CCAM Roadmap](#)
- **AUGMENTED CCAM, PoDIUM:**
- **Road authorities**
  - CEDR National Road Authority guidance on trustworthy digital infrastructure and data use. <https://www.cedr.eu/docs/view/671a140149ef1-en>
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## Abbreviations

3GPP	<i>3rd Generation Partnership Project</i>
4G	<i>4th Generation Wireless Systems</i>
5G	<i>5th Generation Wireless Systems</i>
5G SA / 5G NSA	<i>5G standalone / 5G non-standalone</i>
5GAA	<i>5G Automotive Association</i>
5G-PPP	<i>5G Public Private Partnership</i>
ACEA	<i>European Automobile Manufacturers' Association</i>
ADAS	<i>Advanced Driver Assistance Systems</i>
AI/ML	<i>Artificial Intelligence / Machine Learning</i>
API	<i>Application Programming Interface</i>
CAGR	<i>Compound Annual Growth Rate</i>
CAM	<i>Connected and Automated Mobility, or in the context of ITS-G5 Cooperative Awareness Message</i>
CCAM	<i>Connected, Cooperative and Automated Mobility</i>
CAPEX	<i>Capital expenditure</i>
CEF	<i>Connecting Europe Facility</i>
C-ITS	<i>(Cooperative) Intelligent Transport Systems</i>
CSA	<i>Coordination and Support Action</i>
CSP	<i>Communication Service Providers</i>
C-V2X	<i>Cellular-Vehicle.to.Everything</i>
EC	<i>European Commission</i>
EEA	<i>European Economic Area</i>
EPC	<i>Evolved Packet Core (4G)</i>
ERTRAC	<i>European Road Transport Research Advisory Council</i>
EV	<i>Electric Vehicle</i>
GDPR	<i>General Data Protection Regulation</i>
GLOSA	<i>Green Light Optimal Speed Advice</i>
GNSS RTK	<i>Global Navigation Satellite System Real-Time Kinematic</i>
GSMA	<i>Global System for Mobile Communications Association</i>

<i>GSM-R</i>	<i>Global System for Mobile Communications-Railway</i>
<i>IoT</i>	<i>Internet of Things</i>
<i>ISA</i>	<i>Intelligent speed assistance</i>
<i>ISO</i>	<i>International Organization for Standardization</i>
<i>ITS</i>	<i>Intelligent Transport Systems</i>
<i>KPI</i>	<i>Key Performance Indicator</i>
<i>LTE</i>	<i>Long Term Evolution (4G)</i>
<i>MBB</i>	<i>Multi Broad Band</i>
<i>MEC</i>	<i>Multi-access Edge Computing (formerly known as Mobile Edge Computing)</i>
<i>MNO</i>	<i>Mobile Network Operator</i>
<i>NESTs</i>	<i>Network Slice Templates</i>
<i>NHP</i>	<i>Neutral Host infrastructure Provider</i>
<i>NTN</i>	<i>Non-Terrestrial Networks</i>
<i>OEM</i>	<i>Original Equipment Manufacturer (car manufacturer)</i>
<i>OPEX</i>	<i>Operational expenditures</i>
<i>PLMN</i>	<i>Public Land Mobile Network</i>
<i>QoS</i>	<i>Quality of Service</i>
<i>RO</i>	<i>Road Operator</i>
<i>RoD</i>	<i>Remote Driving</i>
<i>RRF</i>	<i>Recover and Resilience Facility</i>
<i>RSU</i>	<i>Roadside Unit</i>
<i>SAE</i>	<i>Society of Automotive Engineers</i>
<i>SDA</i>	<i>Strategic Deployment Agenda</i>
<i>SNS JU</i>	<i>Smart Networks and Services Joint Undertaking</i>
<i>STEM</i>	<i>Science, Technology, Engineering and Mathematics</i>
<i>TDD</i>	<i>Time Division Duplex</i>
<i>TN-ITS</i>	<i>Transport Network – Intelligent Transport Systems</i>