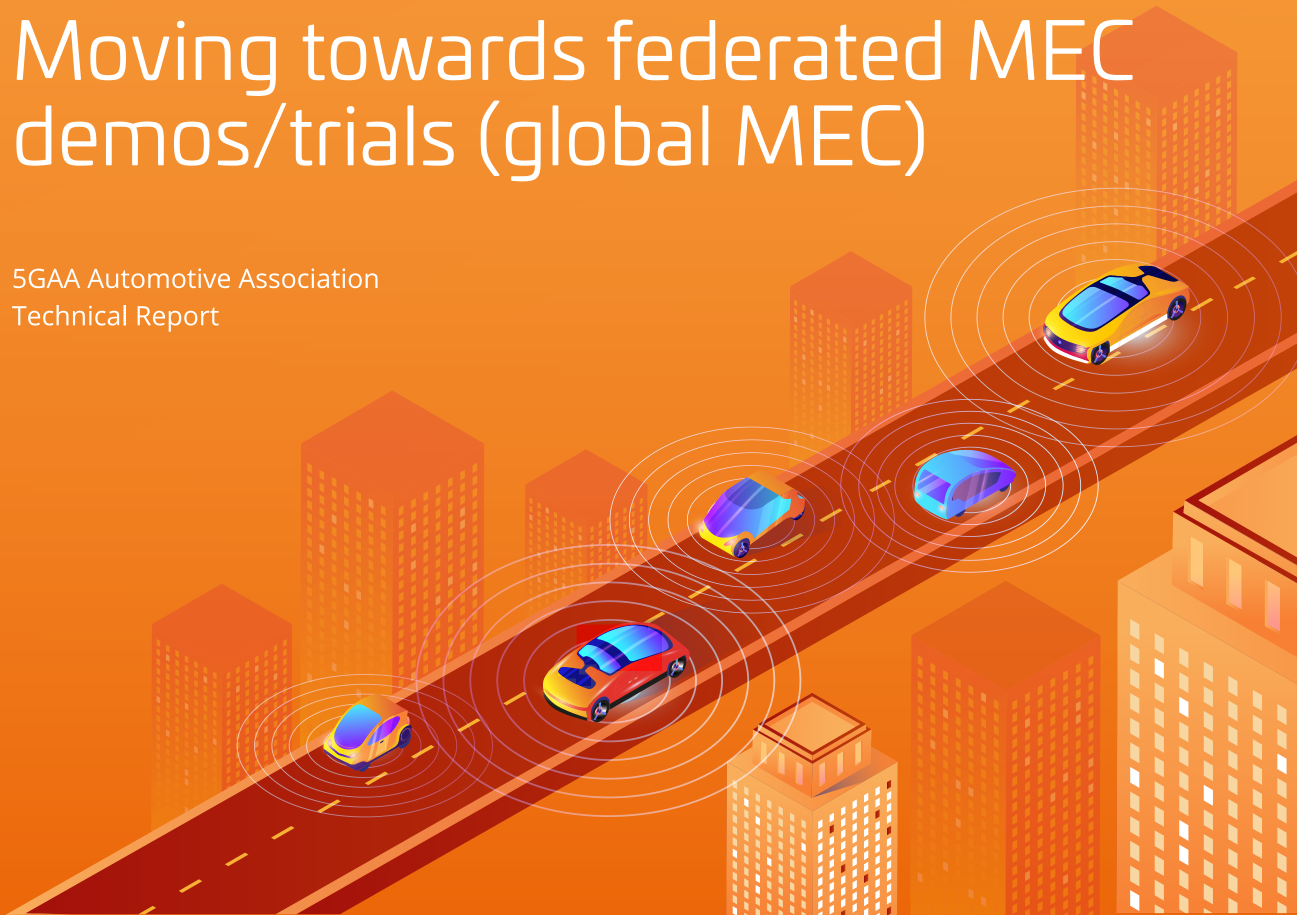
Cross Working Group Work Item gMEC4AUTO

Moving towards federated MEC demos/trials (global MEC)

5GAA Automotive Association
Technical Report



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Contents

Foreword

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The contents of the present document are subject to continuing work within the Working Groups (WG) and may change following formal WG approval. Should the WG modify the contents of the present document, it will be re-released by the WG with an identifying change of the consistent numbering that all WG meeting documents and files should follow (according to 5GAA Rules of Procedure):

x-nnzzzz

(1) This numbering system has six logical elements:
    (a) x: a single letter corresponding to the working group:
        where x =
        T (Use cases and Technical Requirements)
        A (System Architecture and Solution Development)
        P (Evaluation, Testbed and Pilots)
        S (Standards and Spectrum)
        B (Business Models and Go-To-Market Strategies)

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(2) No provision is made for the use of revision numbers. Documents which are a revision of a previous version should indicate the document number of that previous version

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Introduction

Edge computing is an important topic in vehicle-to-everything (V2X) use cases which for selected cases require ultimate latency and reliability as well as a large amount of data exchange across the vehicles in a specific region. The support of specific performance requirements is key for the realisation of those use cases and potentially not fulfilling such requirements may require closed-loop adaptation in the application in order to cope with the potential undesired effects, which may also include service unavailability or limited support of selected features. This Technical Report (TR) focuses on the Multi-access Edge Computing (MEC) live trials and related public demonstrations of selected Automotive Use cases in multi-MNO, multi-OEM and multi-vendor environments, performed in various regions of the world. It provides a technical overview of the trial implementations, describing the stakeholders involved, the system architecture (in multi-MNO environments), the main use cases implemented and related requirements, together with a brief analysis from the perspective of Mobile Operators, Road Authorities and car OEMs, with a first discussion on possible trial impacts. Moreover, the TR starts exploring technical, regulatory and business constraints around the deployment of multi-MNO MEC scenarios under different conditions and meeting auto OEM requirements.

1. Scope

This document is focusing on the MEC live trials and related public demonstrations of selected automotive use cases in multi-MNO multi-OEM environments, carried out in various regions of the world. The TR explores technical, regulatory and business constraints around deployment of multi-MNO MEC scenarios under different conditions and meeting auto OEM requirements.

2. References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or nonspecific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

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3. Abbreviations

For the purposes of the present document, the following abbreviations apply:

G3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
5GC	5G Core
AC	Application Client
AECC	Automotive Edge Computing Consortium
AF	Application Function
API	Application Programming Interface
CAPIF	Common API Framework
DN	Data Network
DNN	Data Network Name
EAS	Edge Application Servers
ECS	Edge Configuration Server
ECSP	Edge Computing Service Provider
EDN	Edge Data Network
EEC	Edge Enabler Client
EES	Edge Enabler Servers
eNB	evolved Node B
E2E	End-to-End
ETSI	European Telecommunications Standards Institute
ETSI ISG	ETSI Industry Specification Group
GLOSA	Green Light Optimised Speed Advisory
GSMA OPG	GSM Association Operator Platform Group
IQN	In-advance Quality of Service Notification
KPI	Key Performance Indicator
MAP	MapData
ME	Mobile Edge
MEC	Multi-access Edge Computing
MEO	Multi-access Edge Orchestrator
MEP	MEC Platform
MEAO	Mobile Edge Application Orchestrator
MEPM	MEC Platform Manager
ML	Machine Language
MNO	Mobile Network Operator
MSP	Mobility Service Provider
NAT GW	Network Address Translation GW
NEF	Network Exposure Function
NFV	Network Function Virtualisation
NG-RAN	Next Generation RAN
NMS	Network Management System
OEM	Original Equipment Manufacturer
PDU	Protocol Data Unit
PGW	PDN Gateway

PoP	Point-of-Presence
PSA	PDN Session Anchor
QoS	Quality of Service
RAN	Radio Access Network
RSU	Road Side Units
RTA	Road Traffic Authority
SDO	Standards Development Organisation
SPaT	Signal Phase and Timing
ToD	Tele-operated Driving
UE	User Equipment
VRU	Vulnerable Road User
WI	Work Item

4. Multi-operator MEC trials and demonstrations

4.1 Overview

The automotive domain is a critical area for the introduction of MEC infrastructure in 5G systems, since it can benefit from moving cloud computing capabilities and IT service environments to the edge of the network. However, it brings several challenges, especially the need for interoperable data exchange in multi-operator environments (Figure 4.1-1 below shows the heterogeneous nature of these systems in practical cases deploying MEC in multi-MNO, multi-OEM, multi-vendor environments).

This document describes the first known development of edge federation/roaming for selected vehicular use cases. This has been carried out through a set of multi-MNO MEC live trials by several international players, including network operators, neutral hosts, car manufacturers, infrastructure vendors and technology providers. These practical experiences may also have an important impact on standards, in particular 3GPP, ETSI MEC and GSMA's Operator Platform Group, or OPG, for enabling inter-working between operators and carmakers to provide global MEC support for automotive services. Trials and standards can energise the deployment of 5G and so advance the benefits of MEC for end users.

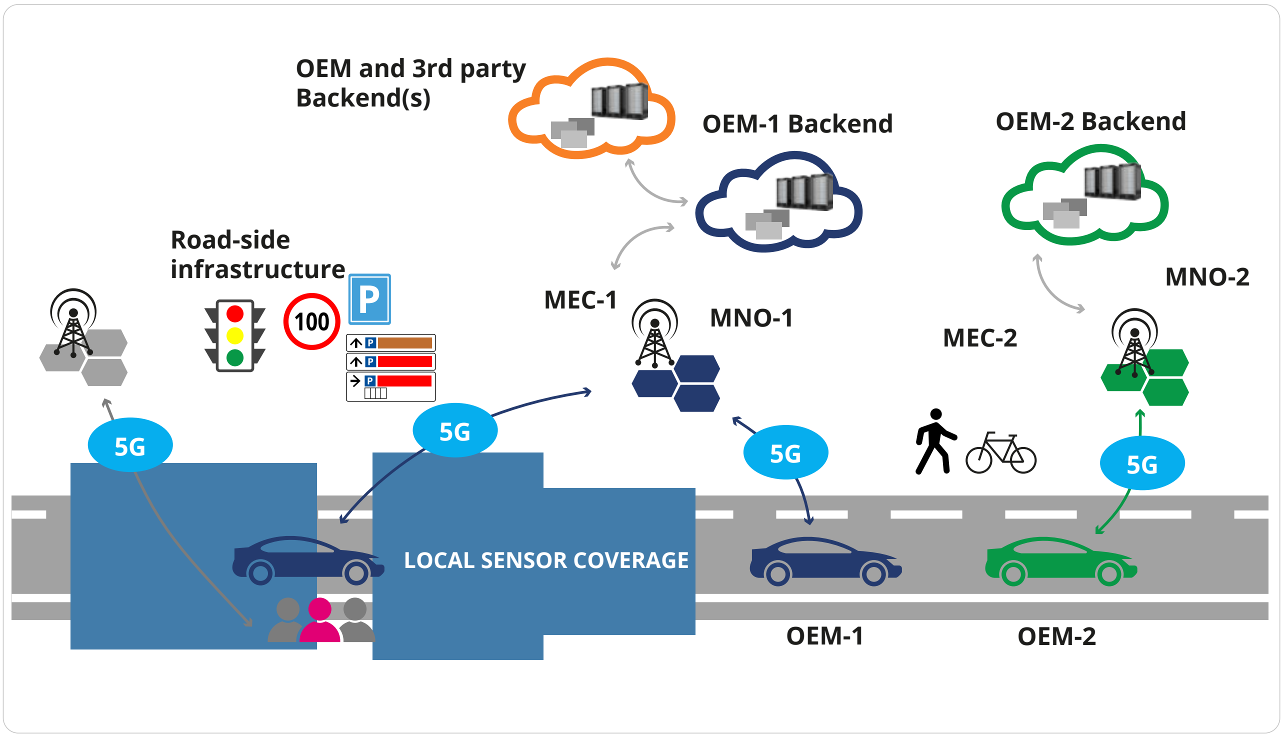

Figure 4.1-1: MEC in multi-MNO, multi-OEM, multi-vendor environments (5GAA MEC4AUTO report TR1 [2])

The present document is organised as follows. Section 5 describes the demonstration of MEC use cases and technical experience from various trials performed in different regions by multiple partners: in particular, two trials on vulnerable road user (VRU) use cases, respectively in Turin (Italy) and at Virginia Smart Road (Blacksburg, Virginia), and the Green Light Optimised Speed Advisory (GLOSA) use case trial in Frankfurt (Germany). Section 6 provides an overview of business considerations for MEC use cases, based on 5GAA WG5 methodology, including go-to-market considerations, technical and legal constraints, business, and liability aspects for the selected use cases. These issues may include challenges faced in public demos, as well as technical and business challenges. Moreover, in Section 7, some key performance indicator (KPI) measurements across multi-operator MEC networks are described, including lessons learned from the measured KPIs relevant to the selected use cases. Lastly, Section 8 concludes the document with some considerations on the technical results from these multi-MNO trials and from the business outcome.

5 Demonstrations of MEC use cases

5.1 Demo trial #1 on VRU (Turin, Italy)

In the previous activities of 5GAA, the work item MEC4AUTO has identified some selected use cases relevant for MEC, both from a technical and business perspective [25]. Starting from this analysis, a couple of demo trials were performed in Europe (EU) and North America (NA), where the partners considered this shortlist and first implemented some prioritised use cases (e.g. VRU in Table 5.1 below), while giving for a subsequent Phase 2 of the trials the possibility to consider also other use cases (e.g. IMA). The NA trial is described in detail in Section 5.2 of this document.

Use case	Description	Use of MEC	Comments
Vulnerable Road User (VRU)	Cooperative awareness-based approach: host vehicle (HV) and VRU send location and dynamics data (e.g. position, velocity, etc.) to its Machine Learning (ML)-enabled application counterpart in the edge cloud. This is also known as active VRU detection.	Location API, network API (vehicle/user mobility), Compute power (AI-based detection)	MEC is essential for analysing possible trajectories, predicting potential collisions using VRU and vehicles' awareness data, and alerting approaching vehicles.
	Infrastructure sensor-based approach: an app hosted in the local MEC platform uses the attached infrastructure-based sensors (e.g. surveillance cameras, wireless detection mechanisms) for monitoring and analysing VRU movements (e.g. at crossings). HV sends location and dynamics data (e.g. position, velocity, etc.) to its machine learning (ML)-enabled application counterpart in the edge cloud. This is also known as passive VRU detection.	Location API, network API (vehicle/user mobility), compute (AI-based detection)	MEC is essential for analysing possible trajectories, predicting potential collisions using infrastructure-based sensor inputs and vehicles' awareness data, and alerting approaching vehicles.

Table 5.1 – VRU use case selected for phase 1 of the MEC trials in EU and NA

The experimental trials, conducted in 5G live networks and involving multiple operators (using roaming scenario instead of neutral host in this first phase), were carried out in two locations: Turin (Italy) and the Virginia Smart Road (Blacksburg, Virginia, USA).

5.1.1 Introduction and stakeholders

The experimental trials conducted in Turin involved multiple operators (interacting in roaming scenarios), several vendors/solution providers, and a carmaker.

TIM acted as host and demo coordinator through its Innovation Lab competences and facilities, and also as a provider of 5G cellular connection, roaming features and MEC infrastructure.

Intel (trial lead) and Capgemini provided the common infrastructure which was instantiated on the hardware infrastructure provided by Cisco.

Telefonica and BT, acted as federated MNOs, while Stellantis acted as lead player for the automotive vertical segment and offered the vehicles for the demonstrations and the requirements of the services to be showcased.

Harman acted as MEC application developer/provider and V2X solution provider on the vehicle (OBU/smartphone). Capgemini also contributed as a MEC-based V2X solution provider.

5.1.2 System architecture (EU trial)

In the Turin experimental trials, TIM provided the 5G radio access to allow local connectivity with the devices and vehicles (from Stellantis) in the city, together with its own MEC infrastructure.

Federation between MNO MEC platforms was achieved allowing use cases where roaming subscribers from Telefonica and BT could access the application on the edge of the (TIM) visited network with the same level of performances as the local subscribers. The application endpoints, represented in the figure below by green/white textboxes, were made up of Client Apps running on the various vehicles (e.g. equipped with different SIM card subscriptions from local and roaming operators) and MEC Apps running at the edge of the hosting operator infrastructure.

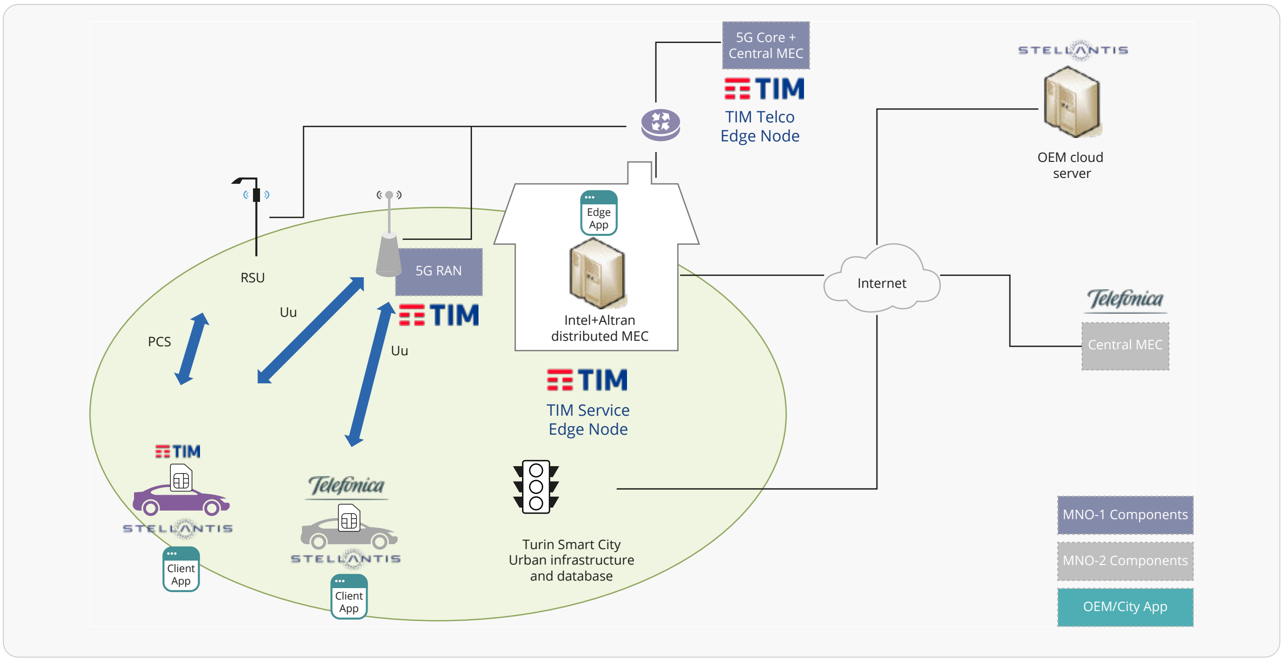

Figure 5.1.2-1: MEC in multi-MNO, multi-OEM, multi-vendor environments (5GAA MEC4AUTO report TR1 [2])

Capgemini's ENSCONCE MEC solution for multi-MNO, based on Intel® Smart Edge Open, was deployed in the following way: there were three inter-connected instances of the ENSCONCE MEC Solution. One instance of MEC was hosted in TIM infrastructure acting as the local edge implementation. This instance was processing the applications being used for the demo use cases. Two other instances were installed respectively in Telefonica (Spain) and BT (UK) in order to redirect outbound roaming subscribers to the TIM visited network where the closest edge was running.

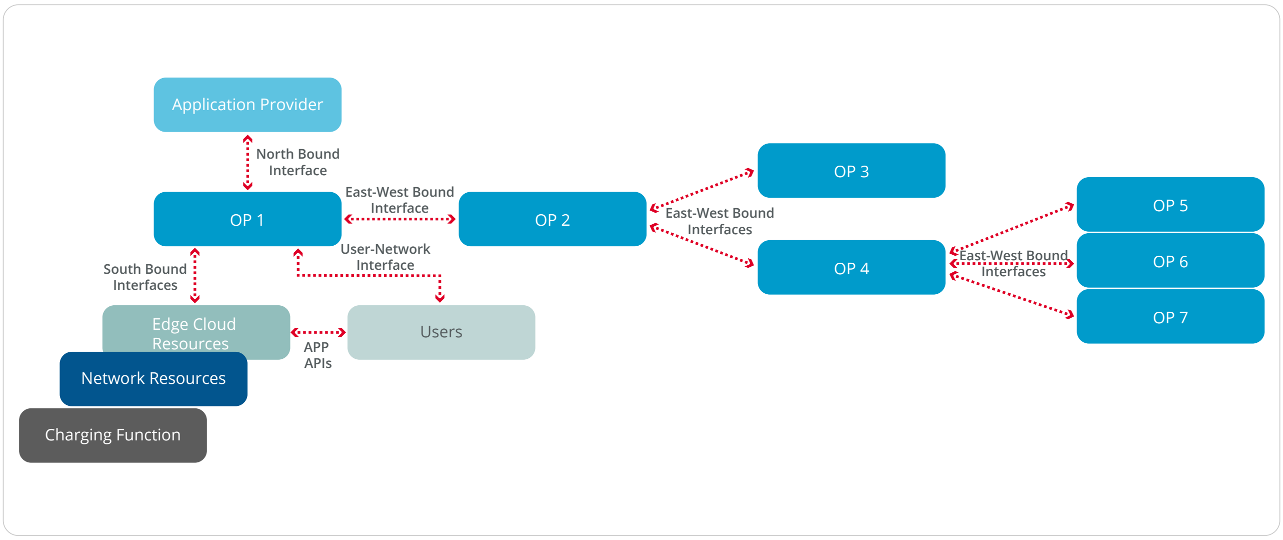

Figure 5.1.2-2: High-level architecture of the operator platform defined by GSMA OPG (source TEC Forum)[1]

The EWBI (East/West Bound Interface) shown in Fig.5.1.2-2 implemented the federation functionality for the multi-MNO scenario. This functionality enabled the three MEC instances to share application images and metadata between the partner MEC instances. The functionality also enabled authorisation and application connectivity of roaming clients to the corresponding application server instance available in the visited network. The MNOs hosted one ENSCONCE instance in each respective network and federated them to deliver a multi-domain edge capability. Additionally, the MNOs provided the inter-mobile-network level connectivity allowing local breakout to ensure user plane termination at the closest edge for home and roaming subscribers. More in detail, the network connectivity provided by the MNOs was realised by use of:

- The 5G User Plane Function (UPF) or Packet Gateway – User Plane (PGW-U), to create the breakout session. LTE APN-OI based on a roaming model was used throughout the demo to achieve local breakout, demonstrating the type of capabilities that will be natively available on the 5G Core Network (5GC) service and for session continuity inter-MNO optimisation.
- A secure interconnection for the multi-MNO MEC control plane exchange through EWBI, to implement the edge apps across use cases. This introduced a few models including (a) MNO extending their run-time applications to a serving MNO edge using a single developer (control plane) interface via a direct agreement, or (b) MNO interconnections potentially brokered by a third-party mediator.

The MNOs offered their preferred UPF solutions which were already integrated with their 5G core, and that have been further integrated with the MEC solution.

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[1] https://www.gsma.com/futurenetworks/telco-edge-cloud-forum/

From a deployment point of view, the specific implementation of this multi-MNO trial instance can be mapped into the interoperability scenarios described in Annex A of the present report. In fact, the multiple options captured in the architectural variants are classified based on the specific value assumed by the following attributes/dimensions (and depicted in the figure below, which describes:

1. **Presence of MEC application instance(s):** In the EU trial, the host operator TIM (MNO A below) provided not only the local RAN connection, but also the edge resources to host the MEC application instance. Hence, this scenario is corresponding to the case “1w” in Figure A.2.1-1, found in the Annex.
2. **Presence of MEC platform (s) to expose edge services:** The MEC platform used to host the MEC application instance was running on TIM premises (MNO A). Hence, this scenario is corresponding to the case “2w” in the Figure A.2.1-1.
3. **Network subscription of the end-user (vehicle (sub)system):** Two cars were involved in the EMEA trial, both located in Turin, and respectively with TIM and Telefonica subscriptions. The first one in home TIM network, and the second one in roaming. Hence, this scenario is corresponding to the case “3a-3a” (Vehicle1- MNO A SIM and Vehicle2- MNO B SIM and Roaming in MNO A network) in the Figure A.2.1-1.
4. **Available interconnection between MNOs:** the EU trial exploited a controlled IP connection to connect TIM local network in Turin (Italy) with the Telefonica premises in Spain (core network and MEC system connected via EWBI). Hence, this scenario is corresponding to the case “4b” in the Figure A.2.1-1.
5. **Roaming options:** the vehicle#2, equipped with a Telefonica subscription, was in network roaming with the local TIM network. Data connection was realised with local breakout (LBO). Hence, this scenario is corresponding to the case “5b” in the Figure A.2.1-1.

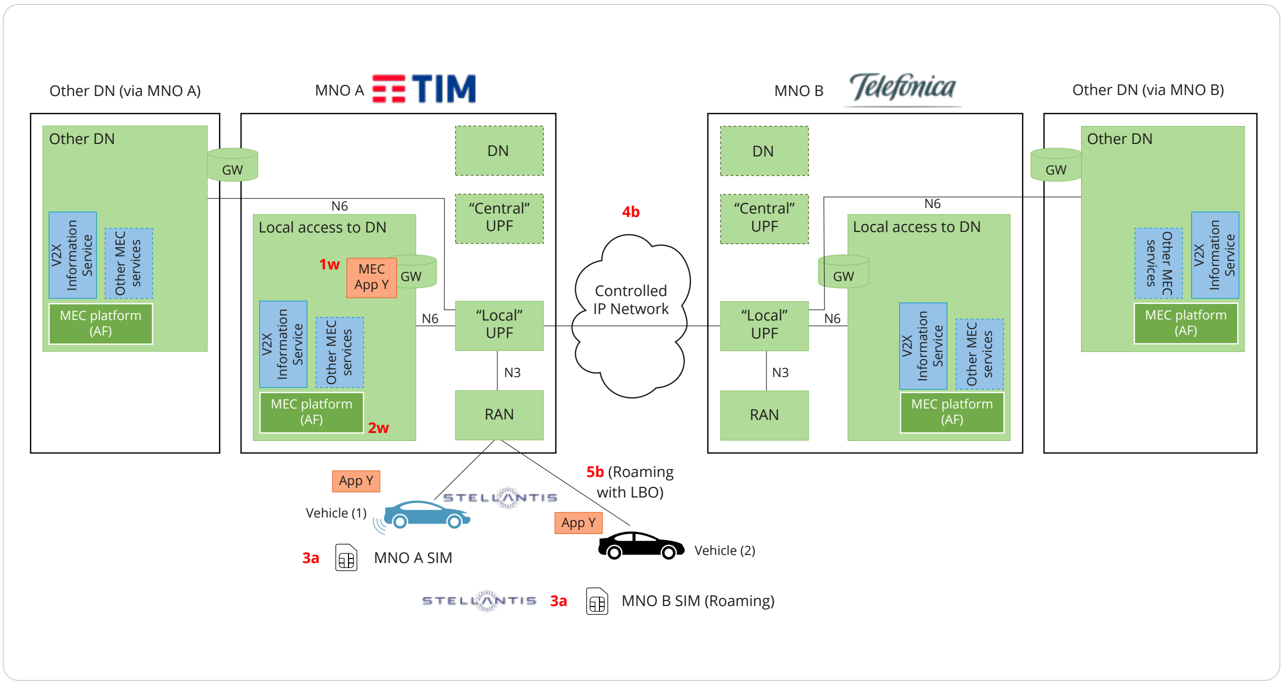


Figure 5.1.2-3: Mapping of the EU trial instance into the gMEC4AUTO architectural variants

5.1.3 Use cases and requirements

The EU region thus instantiated MEC systems in a multi-MNO environment, where the mobile operator, TIM, was providing the radio access, to allow local connectivity with the devices and Stellantis vehicles in Turin, together with its own MEC infrastructure. Federation between MNO MEC platforms was achieved allowing use cases where roaming subscribers can access the application on the edge of the visited network (in the EU example, Telefonica and BT customers could access their MEC application running on TIM infrastructure). The application endpoints, represented in the figure below by green/white textboxes, were constituted by Client Apps running on the various vehicles (e.g. equipped with different SIM card subscriptions) and MEC Apps running at the edge of the hosting operator infrastructure.

The same two use cases were selected for both the EU and NA regions: the solution based on passive VRU detection provided by Capgemini Engineering and the solution based on active VRU detection provided by Harman. In addition, IMA use case is still under evaluation for implementation in EU demo region, e.g. for a possible future Phase 2 of trials.

The data flow diagrams in the two section below describe in more details the two different solutions.

Solution based on passive VRU detection

The VRU scenario aims to alert the vehicles about pedestrians or other vulnerable road users in the vicinity. The passive variant of the VRU detection focusses on utilising the visual scene intelligence derived via machine learning from the traffic cameras installed along with the road infrastructure. This variant is suitable for non-connected pedestrians (i.e. pedestrians don't need to carry a V2X-enabled device to interact with the infrastructure in the use case).

The traffic cameras and the vehicles are connected to the MNO's connectivity infrastructure via a 5G mobile network.

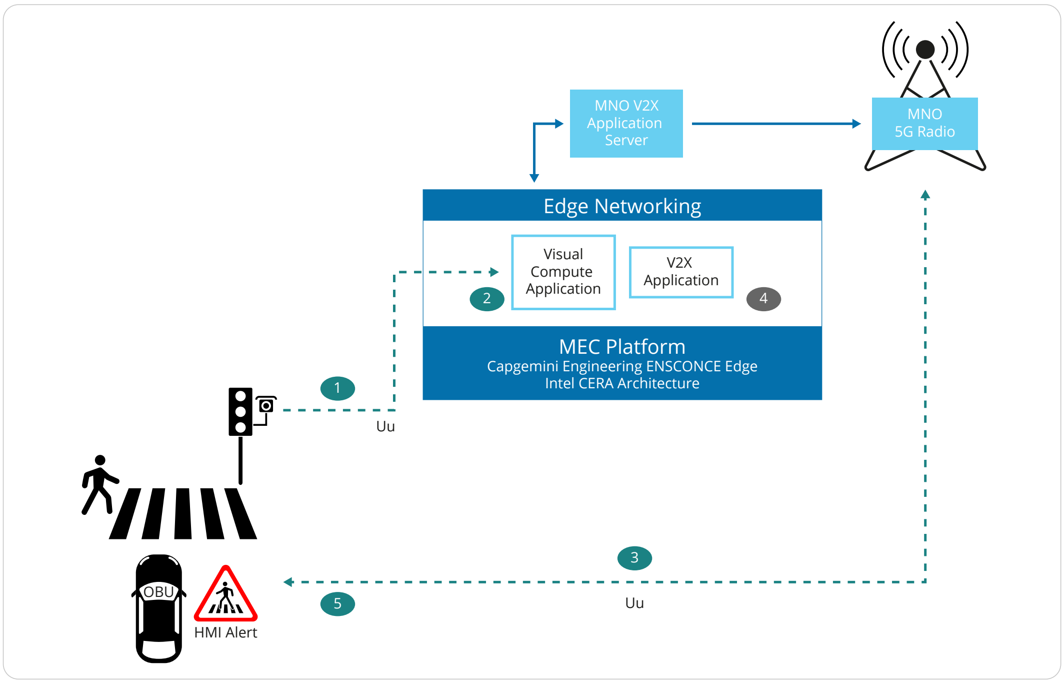


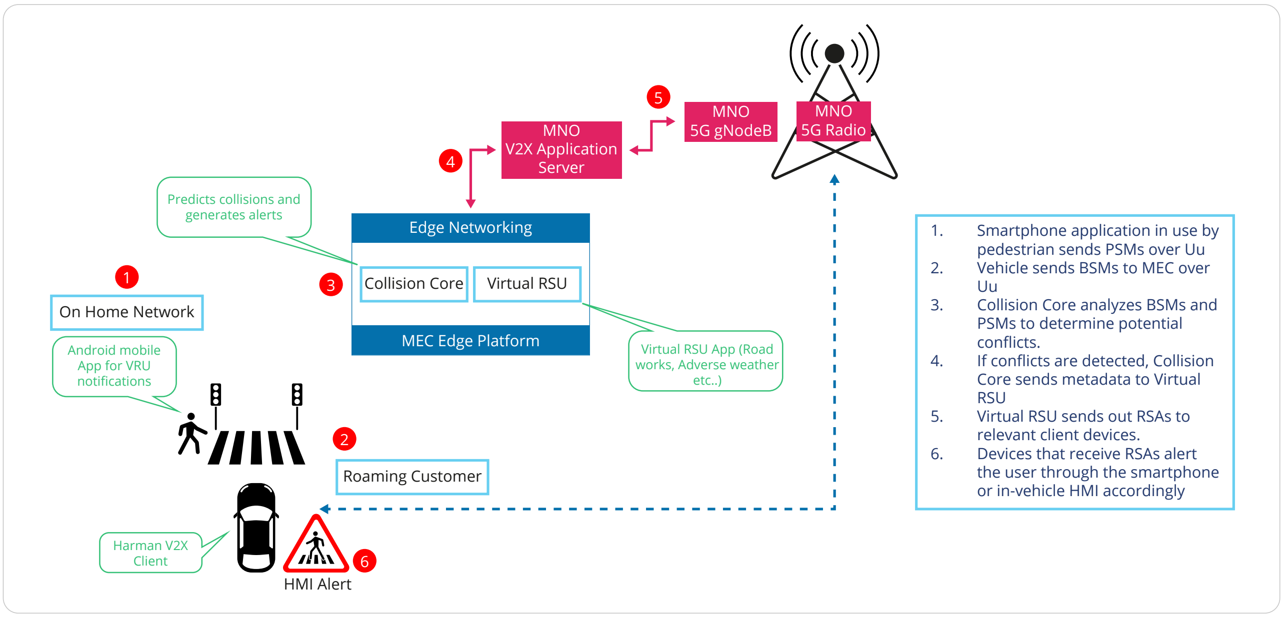
Figure 5.1.3-1: Solution based on passive VRU detection

The passive VRU detection scenario is realised via the following steps (see above Figure 5.1.3-1):

1. Collecting video stream information from the traffic camera(s) mounted on traffic lights, streaming video to edge node through 5G Uu interface;
2. The video stream is processed using AI and computer vision techniques to detect the VRUs, their location and direction of movement in real time;
3. Vehicles send BSM over Uu to the V2X application;
4. V2X application analyses the received pedestrian and vehicle information to ascertain probable collision scenario;
5. V2X application sends out a notification message to the vehicles based on the probability of collision, to enable them to take appropriate action and prevent a collision with the VRU.

Solution based on active VRU detection

In this variation of the use case (see Figure 5.1.3-2), the VRU is equipped with a device capable of broadcasting safety messages, a smartphone with an app to send PSM messages to the MEC application was used. The vehicle broadcasts BSM messages over Uu interface to the MEC application at 10Hz frequency.



1. Smartphone application in use by pedestrian sends PSMs over Uu
2. Vehicle sends BSMs to MEC over Uu
3. Collision Core analyzes BSMs and PSMs to determine potential conflicts.
4. If conflicts are detected, Collision Core sends metadata to Virtual RSU
5. Virtual RSU sends out RSAs to relevant client devices.
6. Devices that receive RSAs alert the user through the smartphone or in-vehicle HMI accordingly

Figure 5.1.3-2: Solution based on active VRU detection

The MEC application processes the PSMs and BSMs, analyses the trajectories of all the VRUs and vehicles in the location, predicts potential collisions, and alerts both the vehicles and the VRUs for taking necessary evasive actions. The HMI on the vehicle and the smartphone app of the VRU provides the audio, visual and tactile warning to alert the users.

5.1.3.1 The mobile operator perspective

The service experience realised in the trial was based on the local breakout feature. In fact, the potential of the edge cloud solutions is fully utilized when LBO solutions are implemented to manage the mobile traffic of the application clients. In the case of roaming users, this of course requires specific agreement between MNOs, and the adoption of specific technical solutions that in normal conditions are not implemented despite their existence in the technical standards.

5.1.3.2 The road authority perspective

The governance model currently adopted by Turin entrusts the management of the technological infrastructure of the urban road network to 5T, an "in-house" company owned by the City of Turin and Piedmont Region.

Being a private company and yet fully owned by public administrations, 5T's activity has a dual perspective. On the one hand, its business is linked to the achievement of the required levels of efficiency in the management of urban traffic, expressed for example in terms of:

- Fluid or well-flowing vehicular traffic (by means of traffic light control, info-mobility to users, etc.);
- Increased efficiency and commercial performance of public transport services (by means of traffic light priority, supply/demand analysis, etc.)

On the other hand, 5T participates in the implementation of official mobility policies, whether European, national or local, aimed at consolidating in the medium-long term the positive trends in road safety, efficiency and resilience of traffic management systems and, more generally, the economic and environmental sustainability of transportation.

At EU level, the usual term of reference is Directive 40/2010 which, although referring specifically to ITS, justifies the need for a European diffusion of ITS with both the growing levels of congestion in vehicular traffic and related energy consumption, and the environmental impact of transport and consequent social problems.

The Directive emphasises a number of essential features of ITS systems:

- The "cross-border" continuity of ITS solutions, based on reciprocal sharing of vehicular traffic data and operational resources between the different ITS operators, particularly those belonging to neighbour states;
- Consistency with the EU framework for trade in technological products and services (conformity, standardisation, responsibility, etc.);
- The interoperability of ITS, which is the intrinsic ability to exchange information between systems and processes of different subjects, whether industrial and institutional;
- The multi-modal vision of mobility and the need to collect and provide mobility users with real-time, accurate information between the different modes of transport and their connections.

Among the priority actions identified by the Directive, the following also stand out:

- The commitment of national and local authorities in the collection of data on respective road networks and traffic, to feed the production of digital maps;
- The harmonisation at EU level of a "universal minimum set" of traffic data to be made available "free of charge" to the road users.

Finally, the recently proposed amendments to Directive 40/2010 are adding a particular emphasis on collaborative ITS services (C-ITS), automated driving (CCAM) and Mobility-as-a-Service (MaaS) models, and consequently on V2X and B2B communication technologies.

Also at the EU level, a further boost to the redefinition of technological roadmaps comes from with the General Data Protection Regulation (GDPR, 2016). Vehicular communication technologies and personal mobility services seem to have become fully aware of the GDPR's specific implications only in recent years. The question of the legal basis justifying the treatment of personal transport data is still being discussed and contributes to the uncertainty associated with long-term investments in technological infrastructure. Indeed, some "worst-case" scenarios still foresee no scope for implementing future services enabled by the exchange of personal transport data (e.g. geolocation, profiling of transport habits, etc.). On the other hand, the requirements of "privacy-by-design" and information security have a strong impact on the options available when implementing road infrastructure.

In Italy, the Smart Road Decree of 2018 identifies a tool for possibly reducing road accidents and authorises its use in experimental traffic conditions, also linked to connected and automated guidance. The Decree has also outlined very clearly both the technological characteristics of smart roads, and the general horizon (2025-2030) for their implementation, starting from the technological adaptation of the existing national road network. Among the indications of the Decree about the technological equipment of a smart road are:

- High bit rate network on the roadside;
- Standardised V2X communication infrastructure;
- Wi-Fi access in service areas or parking lots;
- Traffic control capabilities;
- GDPR-compliant collection and storage of mobility data;
- Implementation of predictive traffic models for the timely scenario identification;
- Real-time monitoring of weather conditions;
- Info-mobility to road users to enable dynamic routing;
- Application of traffic management systems based on predefined scenarios;
- Availability of information on parking and refuelling/recharging services at least for professional users;
- Implementation of V2x-based C-ITS services at least for service vehicles used by the road operator.

It should be highlighted that all these legislative initiatives utilise the EU Galileo and EGNOS systems for satellite positioning in transport and between transport modes.

Lastly[2], Turin periodically releases its *Sustainable Urban Mobility Plan* (SUMP or PUMS in Italian), which in its 2021 edition also outlines local interventions planned for 2030, introducing explicitly the MaaS paradigm for mobility services, infrastructures for e-vehicles, and bikes.

In the above context of both legislative indications and operational needs, the infrastructure operator is led to increasingly adopt technologies and strategies enabling, for example:

- The extension of ITS services to as many users as possible, therefore considering a plurality of different mobility use cases, possibly involving all of the vehicle categories, preferring the multi-operator approach in mobile communications, while not forgetting the "not connected" users (at least in the short term), etc.;
- The reduction of roadworks (excavations, installation of roadside artifacts of various types, etc.);
- The reduction of physical hardware "on premise", in favour of a greater virtualisation level of computing resources and implementation by means of modern managed services, with a consequent decrease in related management costs (e.g. ICT man hours, spaces for server rooms, etc.);
- The use of standardised interfaces for the data exchange between systems and operators, given the need especially in the public domain, not to be bound over time to specific manufacturers and their proprietary technologies.

In Turin, since the indications of Directive 40/2010 and the Smart Road Decree, a series of initiatives were activated with the involvement of several local technical actors, both public (administrations, university, in-house companies) and private (automotive industry, applied research institutes, technology suppliers, etc.). The main one was the identification of a 35km urban circuit, the so-called Torino *Smart Road Circuit*, on which the circulation of experimental autonomous vehicles could be authorised. As a result, 5T has concentrated its technological infrastructure activities on that circuit, now including:

- Traffic-light control systems with the generation of forecasts able to be forwarded to vehicles;
- Roadside unit for vehicle-to-infrastructure (V2I) communications;
- Collection of traffic data in real time and publication in OpenData format (e. g. traffic, parking, ZTL, etc.);
- Collection of traffic events and communication to national service centres by means of DATEX2 protocol;
- Collection and publication of real-time data on local public transport (e.g. time-of-arrival at the stop);
- Real-time video streams of selected intersections or infrastructures;
- Parking sensors in hospital areas and peripheral based on internet of things (IoT) technologies;
- Infrastructure and traffic monitoring in urban tunnels along the circuit.

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[2] http://www.cittametropolitana.torino.it/cms/trasporti-mobilita-sostenibile/pums/pums-elaborati-di-piano

The *Torino Smart Road* initiative was finally enriched with working groups for sharing the different visions among local stakeholders of the "smart" mobility. The activity of these working groups resulted in several technological demonstrations also in collaboration with 5GAA (for example in November 2019 and December 2021).

5.1.3.3 The car OEM perspective

From the automotive perspective, edge computing solutions can contribute to the effective realisation of many V2X use cases of interest, especially when performance and system requirements are challenging, in terms of latency, quality of service (QoS) management and prediction, deployment flexibility, and access to local context-rich information. Together, MEC and 5G can support applications and use cases requiring a consistent network connection, rapid deployment, and low latency to reduce the amount of backhaul bandwidth required as well as operation costs. The two technologies can allow for the simultaneous use of a massive number of connected technologies without incurring network outages due to traffic bottlenecks.

The benefits of MEC can be illustrated with a compelling V2X safety application for VRUs. Two different solutions can be implemented to help in-vehicle drivers and pedestrians navigate safely locally as well as across borders with the same QoS and edge applications, whether on their mobile handset or on their vehicle on-board unit (OBU). Cellular 5G connection and the MEC platform allow the local system to quickly make decisions at the point where data is collected. For example, using on-site cameras and sensors to collect detailed data, that is beyond what a single vehicle can "see" using its on-board systems at the intersection, the MEC system can locally process and communicate safety risks to onsite pedestrians and approaching vehicles.

A critical requirement for efficient use of information provided by VRUs is the accuracy of the positioning information provided by these traffic participants. Additional means to use available information for better and reliable accuracy is crucial to allow real-world usage of information shared by VRUs. The VRUs making their presence/location known through their mobile devices (active solution), or detected by a camera and/or other sensors connected to the edge infrastructure (passive solution), along with vehicle's use of that information, will be an important element to improve traffic safety and avoid accidents.

If compared with a more traditional advanced driver assistance system (ADAS), the edge solutions can indeed cover all situations where the road user is not immediately visible to the vehicle driver and to the on-board sensors feeding the ADAS (camera) designed to cover the pedestrian protection function.

The benefits of the edge solutions are particularly relevant in cases where the pedestrian is not in line of sight with the vehicle as for example when a driver's view is blocked by an obstacle or in the case of a right turn while a pedestrian is approaching from the right.

In all these cases, the driver should be promptly alerted to the presence of a VRU. For the application to issue a valid warning, it will need to calculate the trajectories of a HV and VRU, know the geometry of the road and intersection, and determine the risk of collision in the time frame where their trajectories meet.

The edge solution therefore offers complementary information to the ADAS solution making it possible to offer an all-round safety coverage to the future autonomous vehicles.

In this scenario, cross-operator interoperability is essential for a successful implementation of automotive use cases.

In the automotive context, a roaming scenario between multi-operator (MNO) service locations is very common (several users, vehicles etc) and it means guaranteeing requested QoS in any ecosystem for automotive safety use cases. The federation among multiple MNOs and edge operators across countries and geographic borders can greatly facilitate the deployment of V2X use cases that can provide seamless and uninterrupted quality of service and- experience. In a multi-operator scenario, the end-to-end latency between the vehicles is limited by the location of “peering points” for data traffic between the mobile operators’ networks. These peering points are usually located centrally in the mobile operators’ networks. The end-to-end latency between the vehicles will thus be the same if MEC is deployed close to the vehicles or close to the peering points. To achieve the low latency described in this document, new local peering points between the mobile operators’ networks need to be deployed.

5.1.4 Impacts

The work done in the framework of this multi-MNO live trial can be relevant as an implementation of MEC technology in real cases of interest for automotive use cases, and in that context can potentially provide great insights and inputs for the introduction of standardised solutions to enable globally interoperable MEC deployments.

In particular, many operators and technology providers are heavily engaged in industrial fora (GSMA) and standards bodies (ETSI, 3GPP), to enable MEC federations by standardising the concept of the operator platform (OP) introduced the GSMA OPG, which is composed of over 40 of the world’s leading operators and more than 25 key ecosystem partners. The goal of standardised solutions is to ensure interoperability between the various systems, with global benefits for the MEC end-users. The concept of the OP is that “edge compute” from operators should be federated and “exposed” in the same fashion to create a multi-domain capability that could be presented to customers/developers. Moreover, the exploitation of the edge can be enhanced by utilising network resources (e.g. device location, user plane control, mobility, etc.).

The OP concept, architecture and core functionality are introduced in initial white papers [14][16] while in a second phase a Permanent Reference Document (PRD) [17] specified more in detail the technical requirements, functional blocks and interface characteristics. The OP architecture (see Figure 5.1.4-1 below) thus identifies several interfaces, and in particular the following:

North Bound Interface (NBI), which provides a simple and universal way for application providers to interact towards the edge computing platforms. It exposes the edge computing capability, integrated with the mobile operator’s existing capabilities and network services. A universal NBI ensures that application developers can “write once, deploy anywhere”, onto any operator.

East/West Bound Interface (EWBI), allowing operators to federate (cooperate) and developers/customers to deploy their loads across all federated domains. Moreover, the east/west integration enables scenarios such as national and international roaming where redirection mechanisms are in place to drive the end-user always towards the closest edge.

User Network Interface (UNI), which allows a client application (e.g. on a vehicle OBU, or a smartphone) to communicate with the edge computing platform to coordinate for scenarios such as the discovery of edge applications, mobility, measurements, etc.

South Bound Interface (SBI), which allows platform access to network and cloud operator resources in order to improve the workload and lifecycle management of applications and infrastructure. In particular, SBI-NR (network resources) allows for the OP solution to leverage network operator capabilities and integrate edge solutions with other enablers such as network slicing or device location with respect to the mobile network.

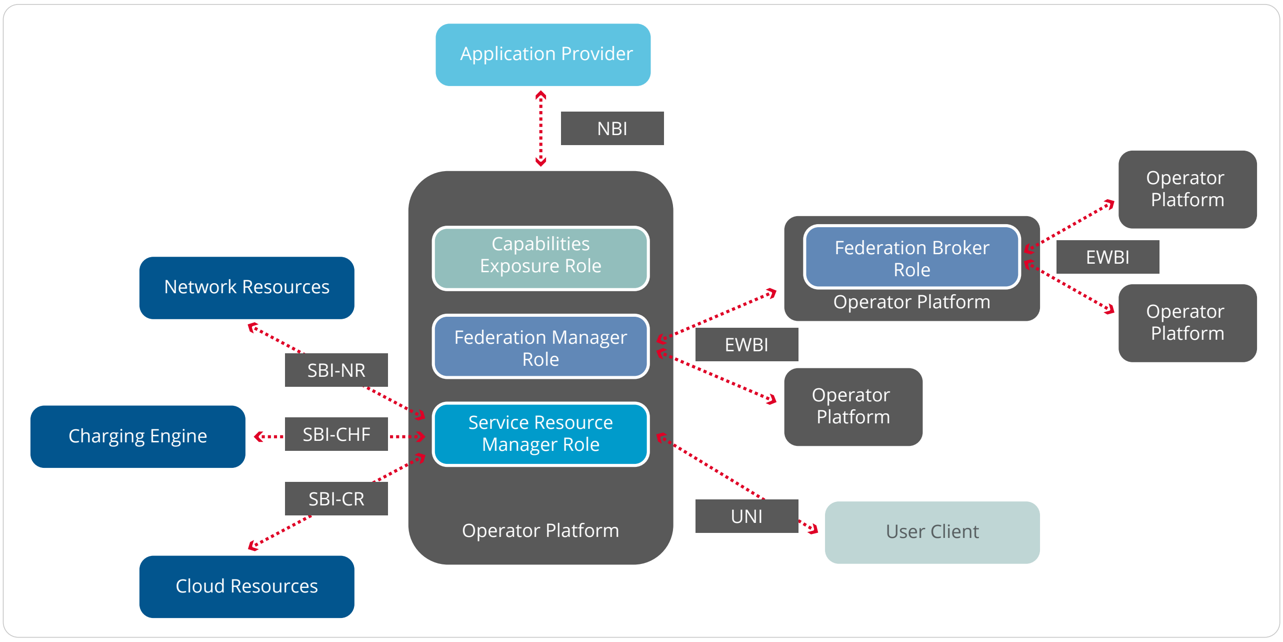


Figure 5.1.4-1 – Operator platform architecture, where different instances are communicating together through EWBI via federation manager roles (source GSMA [17])

The PRD also identified 3GPP and ETSI MEC as the best bodies to standardise the various interfaces and functionality to achieve the PRD requirements. These two bodies are collaborating with GSMA in order to avoid duplication of work and ensure that coherent standards are put in place, guaranteeing interoperability among all federating entities, and providing application portability for a global deployment of MEC services.

In the view of this collaboration model, the OPG requirements are the first step to identify the OP architecture composing a MEC federation, where a high-level mapping with the various Standards Development Organisations (SDO) is being defined starting from the PRD document (Refer Annex A in [17]). The subsequent work from SDOs, complemented by an implementation from open-source communities (OSCs), will produce a set of specifications that can be used by GSMA to verify the product compliance with said OP requirements, in the view of certifying them to interoperate within a MEC federation.

ETSI MEC

As a first step starting from these OPG requirements, ETSI Industry Specification Group (ISG) released a Group Report on MEC 035 to enable inter-MEC system deployment and MEC-cloud system coordination [18]. This report led to the creation of a further work item that produced the MEC Phase 3 normative standard GS MEC 040 on MEC federation enablement APIs (ref. [19]). Furthermore, ETSI ISG MEC Phase 3 work considers all the needed enhancements in the published Phase 2 specifications, to support the MEC federation, also in collaboration with 3GPP and OSCs. In particular, ETSI published an updated MEC architecture in GS MEC 003 [1], introducing a reference variant for MEC federation, to enable inter-MEC system communication. This allows different stakeholders collaborate for joint business purposes, and "federate" their edge computing resources, by offering/exposing their MEC service capabilities, not only for mutual consumption, but also offering those to application developers and end customers (e.g. vertical market segments).

3GPP

With the EDGEAPP work item, 3GPP SA6 has specified the application layer architecture [20], procedures and information flows necessary for enabling edge applications. This EDGEAPP architecture enables users to deploy applications with stringent QoS requirements at the edge to reduce latencies and improve user experience. In a more recent effort, 3GPP SA6 is working on enhancing EDGEAPP, where the harmonisation with ETSI MEC is in scope for Rel.18 ([21]), as an effort to avoid duplication of work and ensure coherence among standards. In the context of MEC federation, SA6 is primarily involved (together with other 3GPP groups SA5 and SA2) in identifying the impact of OPG requirements for the future standardisation work, starting from the current level of support in 3GPP specifications. The aim also in this perspective is to align with ETSI MEC to provide a comprehensive set of standards that would support the MEC federation as required by OPG. Recent activities in 3GPP SA6 (captured in the TR 23.700-98) are also related to the identification of key issues and solutions to study architectural and procedural enhancements for improving the Rel-17 architecture in order to enable edge applications and support emerging industry requirements. The study bases the enhancements on the work done in 3GPP TS 23.558 [20] and takes into consideration other related work carried out within and outside 3GPP, i.e. ETSI MEC [23] and GSMA OP [24].

CNCF project CAMARA

A complementary effort to standards bodies is offered by the open source project CAMARA, established under the Cloud Native Computing Foundation (CNCF) [22] with the aim of ensuring that the requirements published by OPG are aligned with the standards published by the SDOs, and with the API specifications of CNCF.

In particular, CAMARA (https://github.com/camaraproject) is in charge of defining the Service APIs, which enable the network operators to make their network capabilities available for consumption by end-customers (e.g. application developers, vertical market segments, 3rd parties, etc.). This is a complementary effort to standardisation from ETSI and 3GPP, aiming at ensuring that 4G/5G network capabilities are exposed through APIs to provide benefits for end-customers, by hiding telco complexity behind APIs and making them available across the networks and countries.

5.2 Demo trial #2 at Virginia Smart Road (Blacksburg, Virginia, USA)

At a high level, the trial demonstrates connected car 5G edge services in a roaming scenario for active and passive VRU detection use cases, identical to the demo trial #1 described in Section 5.1 of this document. This objective translates into three primary themes:

1. Inter-MNO networking: how a vehicle, which has radio access to MNO A, uses a MEC application operated by MNO B without losing the benefits of low latency.
2. Global operational availability: how an OEM as the MEC application developer can be sure, especially on a global basis, that a MEC application works in the same way if it is operated by MNO A, or if it is operated by MNO B.
3. Roaming services: how the two operators seamlessly transfer the V2X service from one operator to the other as the car OEM moves from one geographical area to another in a roaming scenario; typically involving two operators and an in-vehicle driver crossing a border.

5.2.1 Introduction and stakeholders

The 5GAA NA trial was deployed using CSP infrastructure services at the network edge of Verizon and Telus using AWS Wavelength (WL) where a vRSU was built using cloud native technologies and partner solutions on Intel architecture. A MEC node was deployed at the network edge of Verizon that functioned as a vRSU to demonstrate active and passive VRU 5G edge service to pedestrians and in-vehicle drivers.

American Towers, Capgemini, Harman, Intel, Stellantis, Telus, Verizon and Virginia Tech Transportation Institute (VTTI) collaborated to build a VRU 5G edge service using the MEC concept.

5.2.2 System architecture (NA)

The high-level diagram below shows the deployment architecture for the 5GAA NA trial. Two MEC platforms were built to host vRSUs in Canada and US using AWS regions and WL within the network of the two MNOs. It operated as follows:

1. The roadside infrastructure involves 5G cameras connected to the Verizon 5G network.
2. The connected pedestrian has a Telus SIM card in his/her mobile phone and hosts the Harman active VRU App
3. The in-vehicle driver is also a Telus subscriber and has a Harman OBU in the Stellantis car receiving V2X notifications for the active VRU use case.
4. Both the in-vehicle driver and the connected pedestrian who are Telus subscribers are in a roaming scenario travelling from Canada to US and connected to the 5G Verizon network because of the roaming agreement between the two MNOs.
5. The two MEC platforms – Telus and Verizon – are in a MEC federation and communicate over EWBI to ensure seamless transfer of VRU service from Telus to Verizon, and its availability and continuity for the roaming subscribers.

6. The Capgemini ENSCONCE platform offers MEC federation over EWBI and was based on Intel Smart Edge Open on IA.
7. The Capgemini vRSU Passive VRU service is owned by Telus, while the Harman Active VRU service is owned by Verizon in the diagram to service their respective subscribers and geographies.
8. In a roaming scenario, the Capgemini VRU edge service is transferred to Verizon MEC platform after a successful handshake to serve the Telus subscribers in US with the same QoS.

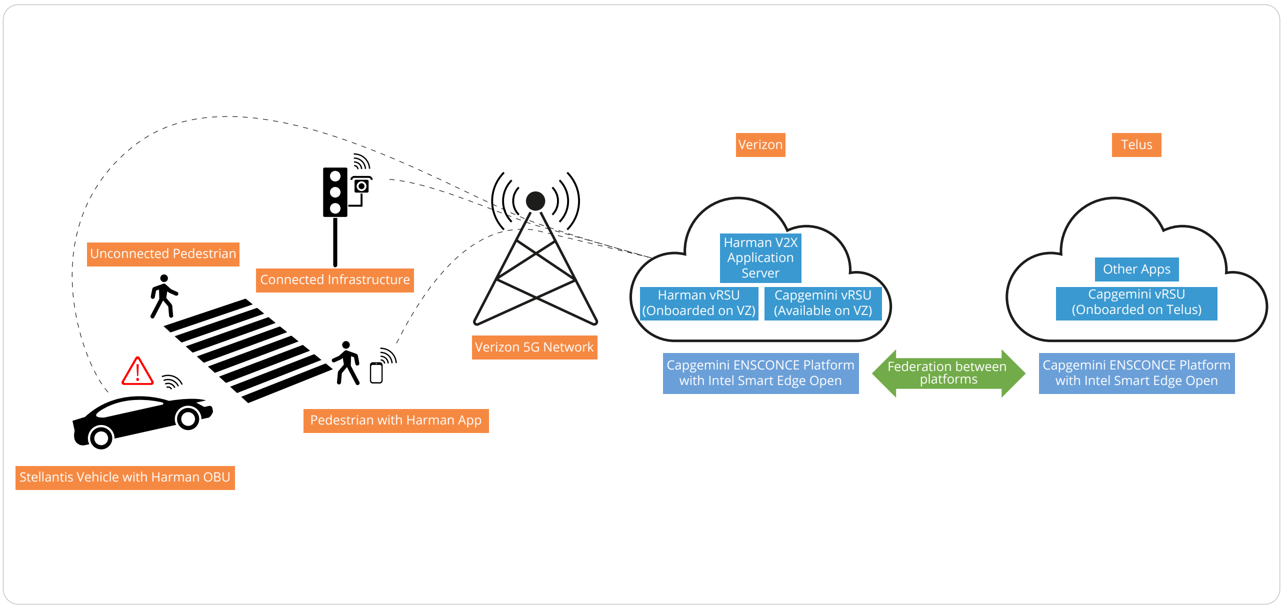


Figure 5.2.2-1: 5GAA NA trial: high-level architecture

The diagram below shows the Verizon MEC platform. The Telus MEC platform has a slightly different stack because the serving apps need to be deployed as near as possible from the demo location.

1. The MEC Platform is a converged edge solution where IT, OT and CT workloads interplay to deliver a 5G VRU service.
2. The 5G Cameras stream data to the MEC platform.
3. The OT apps – Harman and Capgemini V2X apps – implement the active and passive VRU detection business logic and send V2X notifications over 5G Uu interface to the pedestrian and in-vehicle drivers.
4. The IT apps, such as Capgemini’s federated MEC ENSCONCE solution, help in orchestration, availability and continuity of the service.
5. The CT workloads, such as the UPF or PGW of 5G or 4G core network, provide the edge breakout through a network slice offered for connected car services; LBO roaming or home routed traffic roaming.
6. All workloads connect to the cloud for deferred processing, analytics, and optimising the service or building new connected car services.

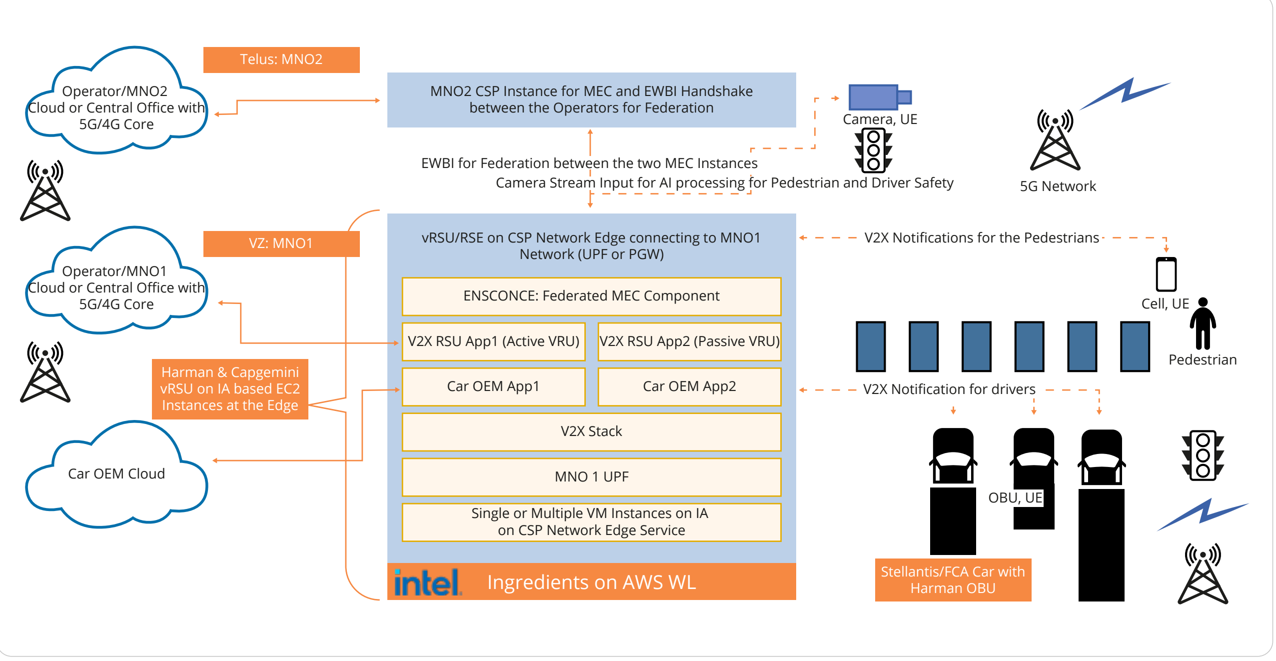


Figure 5.2.2-2: 5GAA NA trial: high-level MEC architecture for vRSU

From a deployment point of view, the specific implementation of this multi-MNO trial instance can be mapped onto interoperability scenarios described in Annex A. In fact, the multiple options captured in the architectural variants are classified based on the specific value assumed by the following attributes/dimensions, and depicted in Figure 5.2.2-3.

1. **Presence of MEC application instance(s):** In the NA trial, the host operator Verizon (MNO A below) provided not only the local RAN connection, but also the edge resources to host the MEC application instance. Hence, this scenario is corresponding to the case "1w" in Figure A.2.1-1 (see Annex).
2. **Presence of MEC platform (s) to expose edge services:** The MEC platform used to host the MEC application instance was running on Verizon premises (MNO A). Hence, this scenario is corresponding to the case "2w" in Figure A.2.1-1.
3. **Network subscription of the end-user (vehicle (sub)system):** Two cars were involved in the NA trial, both located in Virginia, and respectively with Verizon and Telus subscriptions. The first one in home Verizon network, and the second one in roaming. Hence, this scenario is corresponding to the case "3a-3a" (Vehicle1- MNO A SIM and Vehicle2- MNO B SIM) in Figure A.2.1-1.
4. **Available interconnection between MNOs:** The NA trial exploited a controlled IP connection to connect Verizon local network in Virginia (USA) with the Telus premises in Canada (core network and MEC system connected via EWBI). Hence, this scenario is corresponding to the case "4b" in Figure A.2.1-1.
5. **Roaming options:** the vehicle#2, equipped with a Telus subscription, was in network roaming with the local Verizon network. Data connection was realised with Home Routed roaming. Hence, this scenario is corresponding to the case "5a" in Figure A.2.1-1.

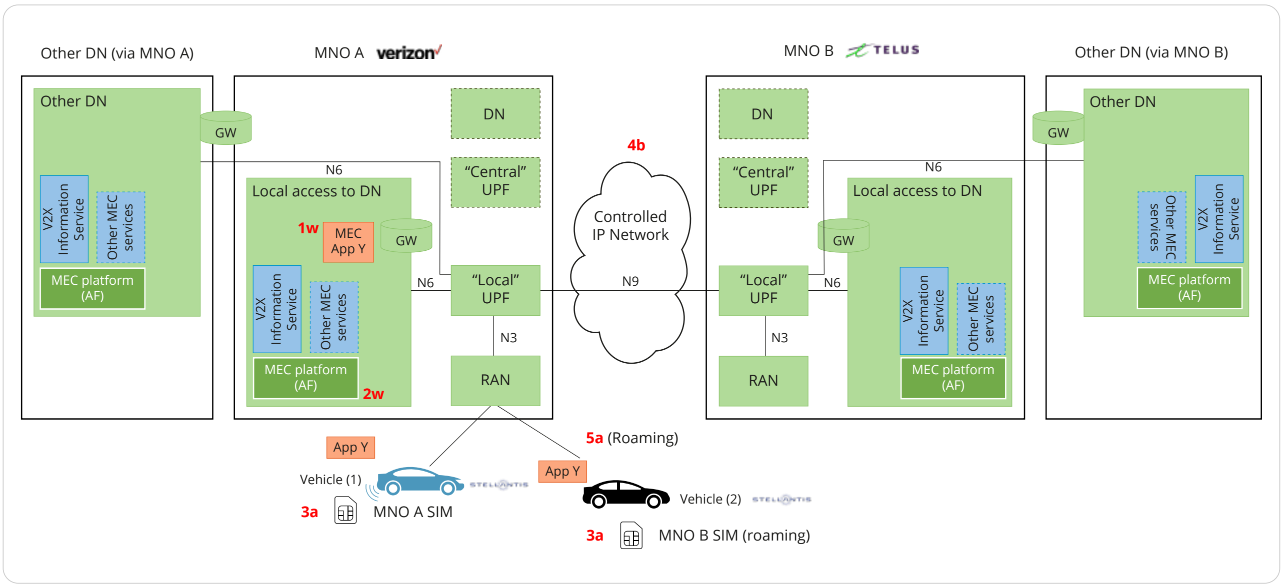


Figure 5.2.2-3: Mapping of the NA trial instance into the gMEC4AUTO architectural variants

5.2.3 Use cases and requirements

The following two use cases were demonstrated in 5GAA NA trial:

Passive VRU detection use case detects the presence of unconnected pedestrian (i.e. pedestrians do not need to carry a V2X-enabled device to interact with the infrastructure to realise the use case) at an intersection and sends alerts to nearby vehicles. The traffic cameras and the vehicles are connected to the MNO's connectivity infrastructure via a mobile network.

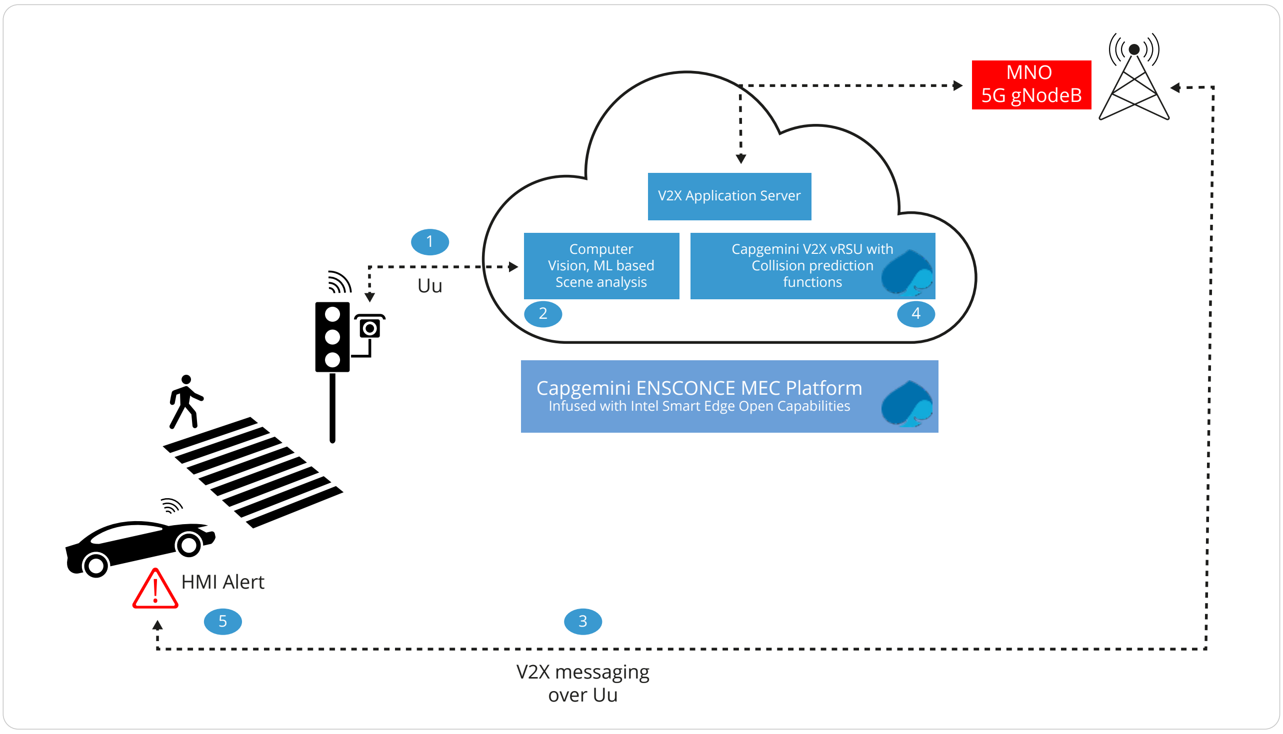


Figure 5.2.3-1: 5GAA NA trial: passive VRU detection use case

1. Camera mounted on traffic intersection streams video to edge node through 5G Uu interface.
2. The video stream is processed using machine learning and computer vision techniques to analyse the traffic scene.
3. Vehicles send BSM over Uu to the V2X application.
4. V2X application analyses the received pedestrian and vehicle information to ascertain probable collision scenario.
5. V2X application sends out a TIM message to the vehicles based on the probability of collision,

Active VRU detection use case detects the presence of a connected pedestrian at an intersection and sends alerts to nearby vehicles.

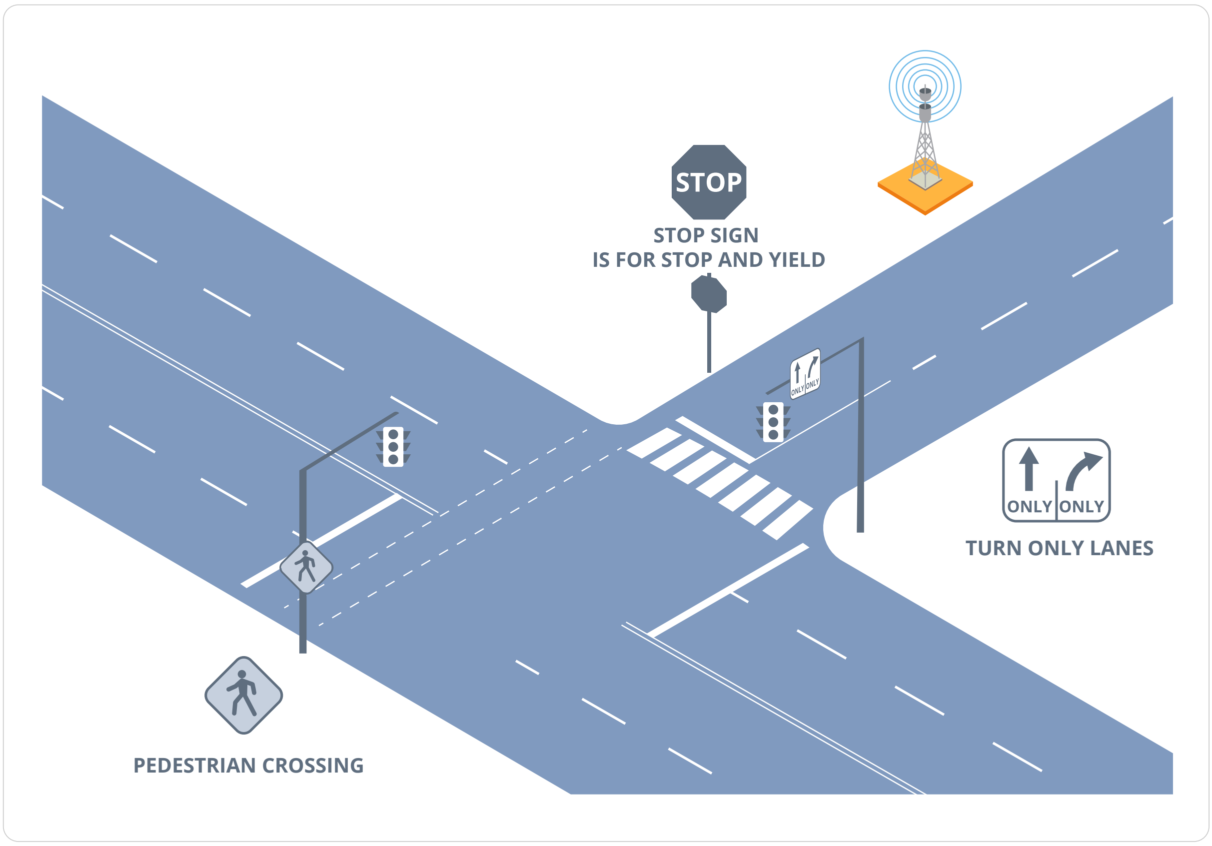


Figure 5.2.3-2: 5GAA AMR trial: active VRU use case

1. VRU is predicted to step onto the road or crosswalk in an intersection using video feeds from traffic camera and hyper precision location with RTK.
2. MECWAVE processes the data and locally makes decision about likely collision based on the trajectory. A MECWAVE is a virtualised infrastructure and connects V2X and non-V2X participants. MECWAVE acts as a collision core that predicts potential safety threats.
3. Awareness notifications are sent to the VRU and vehicles on the path to slow down.

5.2.3.1 The mobile operator perspective

The practical realisation of this multi-operator MEC live trial helped to explore the interconnection between different MNO infrastructures, as a meaningful example of EWBI implementation between MEC systems, as seen in Figure 4.2.3.1-1. MNOs engaged in this trial provided the inter-mobile-network level connectivity using 3GPP home routed data traffic for roaming.

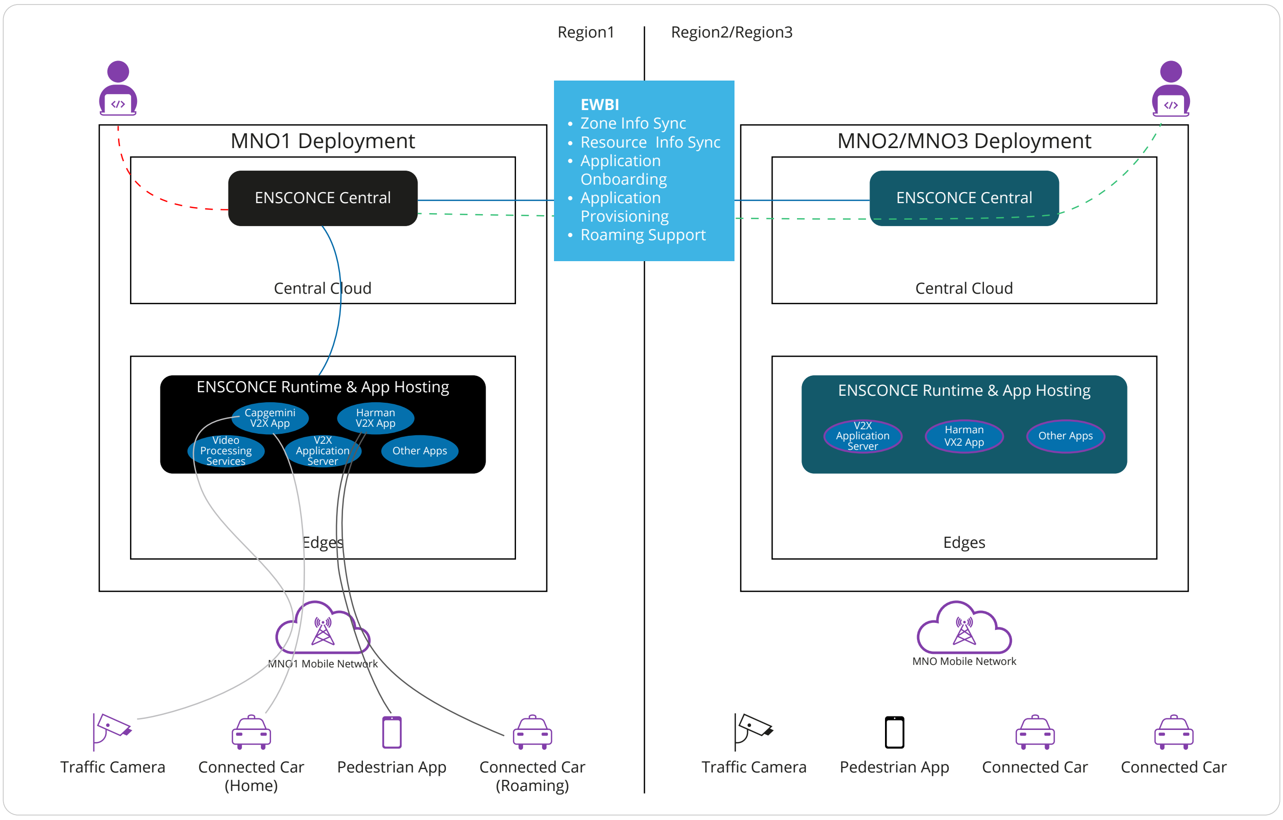


Figure 5.2.3.1-1: Overview of the ENSCONCE platform with EWBI interconnection between MEC systems across different regions

Despite of the complexity of the present multi-MNO and multi-region MEC trial, due to the number of partners and related technical implementation of all components, this work permitted all stakeholders involved to learn from practice how a MEC federation can be realised in 5G live networks.

Traditionally, telco operators are used to working with their vendors and service providers almost in isolation, and communication with partner operators is limited to enabling basic services such as roaming using available options for architecture and service design. However, the MEC has opened up a huge space for more players (e.g. hyper-scalers, system integrators, gaming industry etc.) collaborating more closely than ever to develop new services and solutions. Telco operators need these services to be developed in a cohesive fashion that complements the overall technology roadmap and aligns with the emergence of functions/components (e.g. NEF in 5G) on relevant technology roadmaps.

5.2.3.2 The road authority perspective

The Virginia Smart Roads are state-of-the-art, closed test-bed research facilities managed by VTTI in cooperation with the Virginia Department of Transportation (VDOT).

In partnership with VDOT, VTTI performs research, operates and manages the smart roads – a suite of test tracks that enable advanced-vehicle testing in an interconnected and comprehensive cross-section of roadways: including highway, surface, rural, and unimproved. With more than six miles of paved roadbed, these research facilities feature weather-making, lighting capabilities, advanced sensors, traffic intersections, and varying pavement types, enabling VTTI to conduct vehicle evaluations and driver safety testing for its partners in a secure location. Collectively, the Virginia Smart Roads – which include a highly modular and reconfigurable surface street environment – are an ideal facility for advanced-vehicle testing. Smart Roads play a critical role in the overall success of VTTI and its research mission: to save lives, time, and money, and protect the environment. The Virginia Smart Roads is an FAA-approved testing facility for unmanned aerial systems.

American Tower – as a neutral host provider in collaboration with VTTI/VDOT, Intel, Verizon and ecosystem partners including but not limited to Capgemini and Harman – is working to create a permanent testbed that can not only prove the advanced safety but also add sensor fusion use cases, such as the VRU pedestrian crossing, to showcase the value of MEC4AUTO use cases. The goal is to expand the VRU use case for pedestrian crossing, but also to figure out how to deploy large-scale C-V2X from an architecture and shared digital infrastructure point of view, but also to establish the business model and commercial feasibility. The goal is to expand on the lessons learned from the roaming scenario for MEC4AUTO VRU use case and study neutral hosting as an enabler of seamless CV2X applications from various MNOs and OEMs, and to make the whole approach simpler and more economical.

5.2.3.3 The car OEM perspective

Refer to Section 5.1.3.3.

5.2.4 Impacts

As described in Section 5.1.4, this MEC trial instance in North America is also a practical experiment to find suitable standardisation paths (in a wider sense, thus including not only ETSI and 3GPP but also GSMA OPG), and open-source contributions (e.g. CNCF project CAMARA).

5.3 Demo trial #3 on collision warnings and GLOSA (Frankfurt, Germany)

1. Introduction and stakeholders

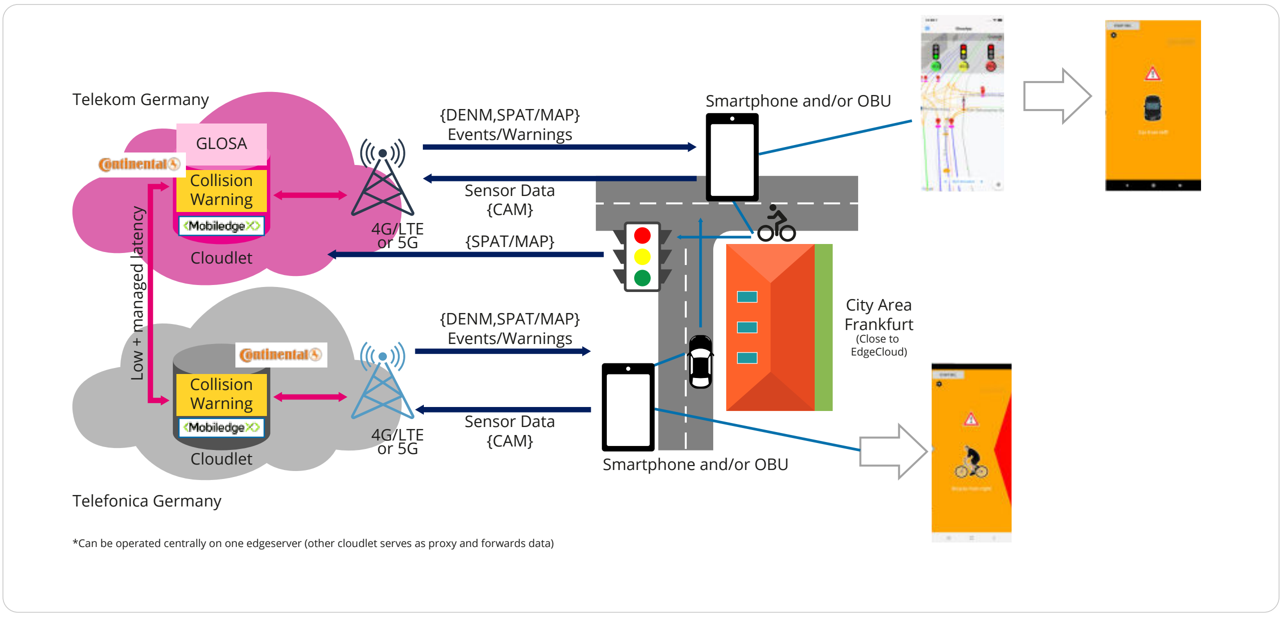
Deutsche Telekom is jointly working with partners Continental, BMW and Fraunhofer FOKUS on VRU use cases. It interconnects passenger vehicles and elements of the traffic infrastructure such as traffic lights in the City of Hamburg – with VRUs (pedestrians, cyclists and scooter drivers), so that they can optimise their movement and reach their destination safely and comfortably. It provides collision risk warning services to improve the safety of VRUs in particular.

All services are based on the ETSI standardisation for Cooperative Intelligent Transport Systems (C-ITS). The VRU awareness basic services have been standardised by ETSI in November 2020 (ETSI TS 103 300-1/2/3) [1], which are used to demonstrate a subset of the use cases defined by ETSI. The main focus are bicycles, e-bikes and e-scooters with speed limited to 25km/h. The selected VRU uses cases are selected on the basis of the following:

- High safety risks to these user groups.
- Strong interest of road operators and authorities to support these kinds of mobility modes.
- Power consumption of applications are not critical because power is available at the UE; so it is not a limiting factor as described in 5GAA's VRU report [27].

2. System architecture

Figure 5.3.2-1 shows the principle architectural setup of the trial. The C-ITS rationale behind the ITS use cases is based on the requirement, several UEs at the same location are using the same ITS-application/service, but they are subscribed and attached to different RANs.



*Can be operated centrally on one edgeserver (other cloudlet serves as proxy and forwards data)

Figure 5.3.2-1: Data flows in collision warning use case and TTG/GLOSA

Following MEC applications are operated:

A GLOSA service/application is operated on a MEC in operator network A. The GLOSA application receives information continuously (10Hz) from different traffic controllers in the city, Signal Phase and Timing (SPaT) and topography MapData (MAP) and receives CAM messages from customers who are subscribed to the service, and provides Time to Green (TTG) information to the subscribers.

(a) A collision warning service/application ("Digital Guardian Angel") is operated on a MEC in operator network A, but also operated on a MEC in operator network B. The service receives CAM messages from customers who are subscribed to the service, and provides collision warning information to them.

(b) A message broker function provides received information from ITS stations to the various applications/services on the MECs.; customers subscribed to multiple services, such as TTG and Digital Guardian Angel.

(c) Further MEC platform services are used for configuration, monitoring, and other operational purposes. The MEC platform runs on general purpose hardware. Application workloads are managed within Kubernetes. Device applications are able to leverage several APIs/SDKs, also providing GPU capacities. Openstack and VMWare are providing Infrastructure-as-a-Service (IaaS) support. The MECs were deployed near the PGW over a 4G network, and near UPF via 5G network, but not directly installed in co-location with the eNB's/gNB's (see Figure 5.3.2-2).

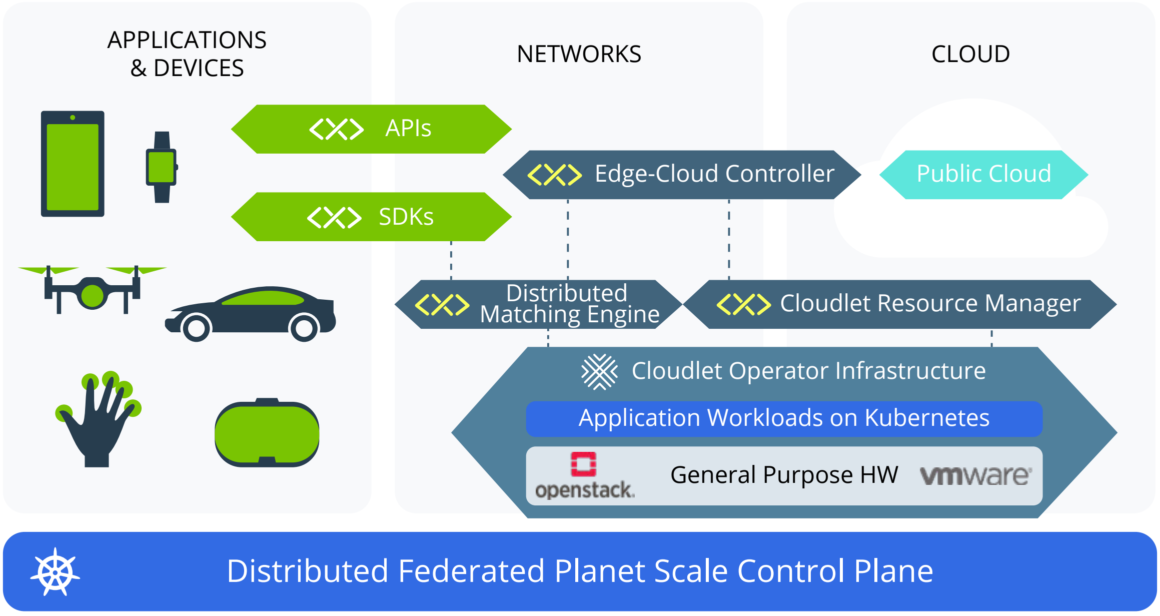


Figure 5.3.2-2: Infrastructure-as-a-Service and Platform-as-a-Service (PaaS) setup

The following ITS stations are involved:

(a) An application on an OBU installed on a bicycle, integrated into the head unit of a vehicle, or a smartphone app downloaded on a consumer device is used by a customer. The application produces CAM messages, either continuously or if the cyclist is located within a defined area. Definition criteria for the area could be availability of traffic light forecast data (TTG), categorisation of an area as an accident hotspot, or other criteria set by the service operator, in cooperation with the road operator/road authority. The OBU or consumer device receives GLOSA information from the GLOSA service, and DENM collision warnings from Digital Guardian Angel service, in the event collision probability exceeds a defined threshold.

(b) RSU, attached to the traffic light controller, which transmits the SPaT/MAP massages and relevant TTG information to the edge cloud via fixed line. Fixed line as well as mobile connection can be used for data transmission.

From a deployment point of view, the specific implementation of this multi-MNO trial instance can be mapped into the interoperability scenarios described in Annex A of the report. The multiple options captured in the architectural variants are classified based on the specific value assumed by the following attributes/dimensions, and depicted in Figure 5.2.3-3.

1. **Presence of MEC application instance(s):** Two host operators, Telekom Germany and Telefonica Germany provided local RAN connection and edge resources to host the MEC Application instances. Hence, this scenario is corresponding to the case “1e” in Figure A.2.1-1 (see Annex). As one application (GLOSA/TTG) was operated on Telekom Germany MEC only, this scenario reflects case “1a”.
2. **Presence of MEC platform(s) to expose edge services:** The MEC platform used to host the MEC application instance was running on both MNO premises (MNO A, and MNO-B). Hence, this scenario is corresponding to the case “2e” in Figure A.2.1-1.
3. **Network subscription of the end-user (vehicle (sub)system):** Two ITS stations were involved in the Germany trial, both located in Germany/Frankfurt, and respectively with Telekom Germany and Telefonica Germany subscriptions. Each ITS station was attached to the radio access network subscribed to. Hence, this scenario is corresponding to the case “3a-3a” (Vehicle1- MNO A SIM and Vehicle2- MNO B SIM) in Figure A.2.1-1
4. **Available interconnection between MNOs:** MNOs MEC facilities are interconnected via IPX-link, a managed IP network between operators used for various MNO purposes. IP connection can be managed properly, so that latencies between the MECs are always kept within the required limits, as mean values but also the jitter. Hence, this scenario is corresponding to the case “4b” in Figure A.2.1-1.
5. **Roaming options:** No roaming options were considered, so all UEs involved in the tests were in home network condition. Hence, this scenario is not relevant to the dimension 5 of Annex A.

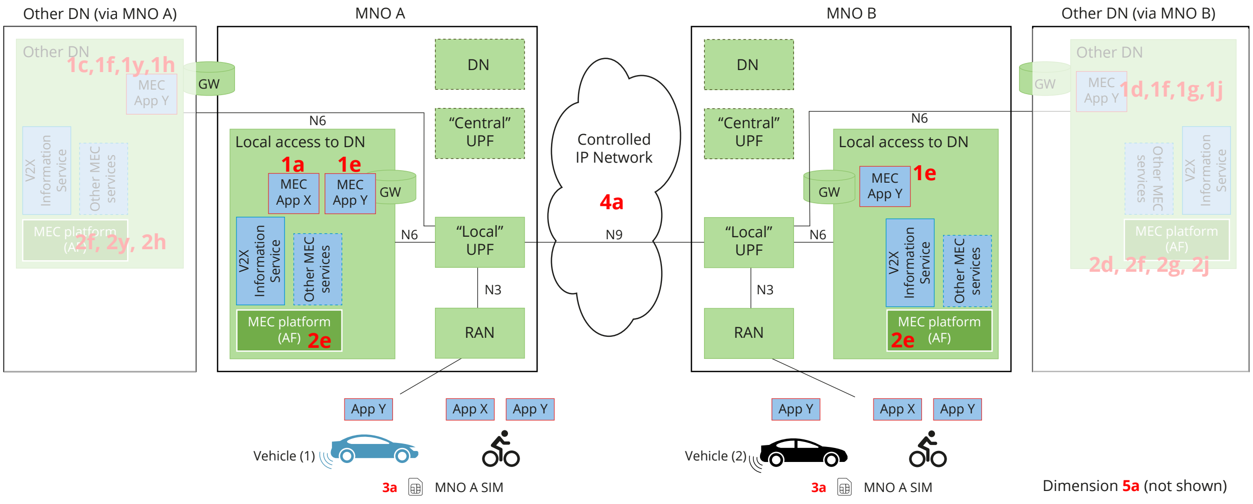


Figure 5.3.2-3: Mapping of the Germany trial instance into the gMEC4AUTO architectural variants

The following UEs are involved:

(d) Smartphone app or application on OBU (i.e. bicycle): The app produces CAM messages, receives GLOSA information, and DENM collision warnings if a collision probability exceeds a defined threshold.

(e) Smartphone app or application on OBU installed in a car: The app produces CAM messages, receives GLOSA information, and DENM collision warnings if a collision probability exceeds a defined threshold.

(f) RSU, attached to the traffic light controller, transmits the SPaT/MAP massages and relevant TTG information to an edge cloud. Fixed line as well as mobile connection are used for the data transmission.

Cloud applications/services

Cloud applications are only used for configuring, monitoring, and other operational purposes, e.g. some of the traffic light information is only available at a central gateway of the traffic management centre. Therefore, the GLOSA service operated on the edge is able to receive raw data from various data sources, also with different data characteristics.

All three use case scenarios are relevant for low latency and high availability; therefore, all applications are operated on a MEC. The MEC is closely attached to the MNO network in the relevant region, but not directly installed in co-location with the eNBs.

5.3.3 Use cases and requirements

Traffic light assistant

The Green Light Optimised Speed Advisory systems have been shown to be able to reduce both CO_2 emissions and fuel consumption [2] by giving drivers speed recommendations when approaching a traffic light. Beside optimisation of physical traffic infrastructure, the optimisation of traffic efficiency of VRUs on the bike is primarily related to controlled intersections. The European ETSI ITS Standards [3] is using the Signal Phase and Timing (SPAT) and MAP topology information of the intersection messages [4],[5] for data exchange at traffic lights. A GLOSA service was developed with the aim to provide "traffic light assistant" for bicycle, e-bikes and e-scooter drivers. The focus is on vulnerable road users using a smartphone application but the same message can also by presented on the vehicle manufacturer's display. The SPaT/MAP messages are transmitted from the traffic light controller via the cellular network technologies such as LTE and 5GNR to Deutsche Telekom's OpenEdgeX server. The GLOSA app provides the end user with real-time information (TTG) about the traffic light phases and gives speed recommendations to the subscribed users. The end user sees the next traffic light and a countdown to the next green or red phase on the display. In addition, anonymised movement profiles of VRU groups (e.g. cyclists) will be transmitted to the traffic management centre, which can then decide to prioritise specific modes of traffic. This helps to make urban mobility more relaxed, more efficient and with less emissions.

With respect to multi-operator MEC scenarios, it is obvious that a customer should get access to TTG/GLOSA services irrespective of the radio access network he/she is subscribed to. With respect to latency requirements, the use case is not requiring latencies below 500msec. So, one could envisage operating a GLOSA service also in the cloud, avoiding multi-operator MEC challenges. But in combination with other ITS use cases, such as collision avoidance (see below), the CAM messages are used for multiple purposes. Therefore, the MEC also provides the benefits of co-locating latency sensitive use cases with more latency-relaxed scenarios (TTG/GLOSA).

Collision risk warning

Continental is developing a collision warning service (the previously mentioned Digital Guardian Angel) at hotspots with a significant risk of accidents. Endangered and vulnerable road users, especially cyclists, have a high risk of being seriously injured at intersections by vehicles turning left or right, especially trucks. A collision warning service, operated on a MEC, is able to configure accident hotspots in geographically limited areas, e.g. 50m around an intersection. A collision warning client application, e.g. deployed on the user's smartphone or integrated into vehicle telematics control units (TCU) or head units (HU) of the car, sends CAMs specified according to the ETSI ITS standard to the backend, which contains information about the position, classification, accuracy and dimensions of the road situation and user. The backend then evaluates the resulting trajectories and calculates possible future collisions with VRUs. Road users potentially affected by a collision are warned by the backend via DENM, which contain the future collision point, a collision probability and the current position of the user as well as the type and position of the collision partner. This information can be processed and visualised by applications (e.g. smartphone/smartwatch). Geographical distribution and possible communication with low latency is supported by MEC over 5G or LTE. The aim of Continental is to increase the safety of all VRUs through the use of networked collision warnings. For this purpose, an open interface for the integration of a large number of device classes (ECUs, smartphones, OBUs) is offered by Continental.

Digital St. Andrew's cross/level crossing

The GLOSA app will show also the status of level crossings. Analogous to the traffic light systems, the digital St. Andrew's cross will use of the ETSI and ISO standardised SPaT/MAP message. The main difference is that the forecast of the opening and closing of the barrier has to come from a separate source. The European Train Control System (ETCS) will provide the position and heading of the train in real time. As ETCS was not available for the tests and demonstration the forecast data will be based on the RIS (travellers information system) of Deutsche Bahn.

5.3.3.1 The mobile operator perspective

MNO radio access network (RAN) roles

As the client applications are running on clients, normally attached to different MNO RANs with their respective MNO subscriptions, MEC-operated applications thus need to be accessible from different MNO RANs – i.e. each deployed in both MNOs networks (see Figure 5.3.2-1).

MEC infrastructure

The MEC infrastructure can be either used as a hosting environment for the application as such, but also as a relay/routing mechanism which is able to route the application traffic to the application host on the respective MEC. So, either an application is operated on both MECs, or only on one MEC, whereas the second MEC simply acts as a routing server.
In the above described setup, both MNOs operated a MEC including MEC platform (see Figure 5.3.2-1).

MNO interconnection

MNO MEC facilities are interconnected via IPX-link, a managed IP network between operators used for various MNO purposes. IP connection was managed with specific latency measures, so-called Low Latency Low Loss Scalable (L4S) throughput technology[3], so that latencies between the MECs are always kept within the required limits as mean values but also the jitter.

MEC application/services

According to the use cases described in Section 5.3.3, two applications are operated on the MEC: one application cluster for TTG/GLOSA in combination with St. Andrew's cross prediction, and one application for collision warning.

As for the first test in the dual operator environment, only collision warning application was deployed in two instances, each on both MEC sites.

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[3] https://www.telekom.com/en/company/details/5g-low-latency-feature-for-time-critical-applications-639090

5.3.3.2 The road authority perspective

Road operators and authorities are already deploying Infrastructure to Network to Vehicle (I2N2V) services, see e.g. Talking Traffic programme in the Netherlands, or MobiliData programme in Flanders/Belgium. The strength of such solutions is the very quick and high penetration rate of the services, because nearly every road user has access to a mobile network.

The distribution of information from the traffic infrastructure, such as traffic lights TTG, is provided to road users on publicly available cloud interfaces. In principle, every road user can get access to it. Latency below 1sec is not a critical requirement, because the dynamics of the traffic lights is in the range of seconds. But if the TTG/GLOSA service were to be combined with a latency critical service such as collision avoidance, operation of the service must fulfil latency requirements. Therefore, operation on a MEC provides one solution to fulfil the latency requirements properly.

With a MEC-operated collision avoidance service, the multi-operator requirement is vital to make sure the service can be accessed by road users, regardless of their transport mode (car drivers, cyclists, etc.), and regardless of their subscriptions to a certain MNO.

5.3.3.3 The car OEM perspective

As long as car OEMs are receiving information from traffic infrastructure, such as TTG/GLOSA service, a multi-operator network approach is not needed. Car OEMs present the service offered by the service provider to the driver.

But if the data provided by the car is used for other services consumed in the vehicle, such as collision warning, car OEMs expect that data provided by cars and other road users is transmitted via different radio access networks available at a certain location. Therefore, if an application is operated on a MEC it needs to be accessed via different radio access networks.

The German trial demonstrated the principles of multi-MNO MEC operation and gave evidence on the accessibility of MEC applications via different radio access networks, without losing the latency benefits of MEC operation.

5.3.4 Impacts

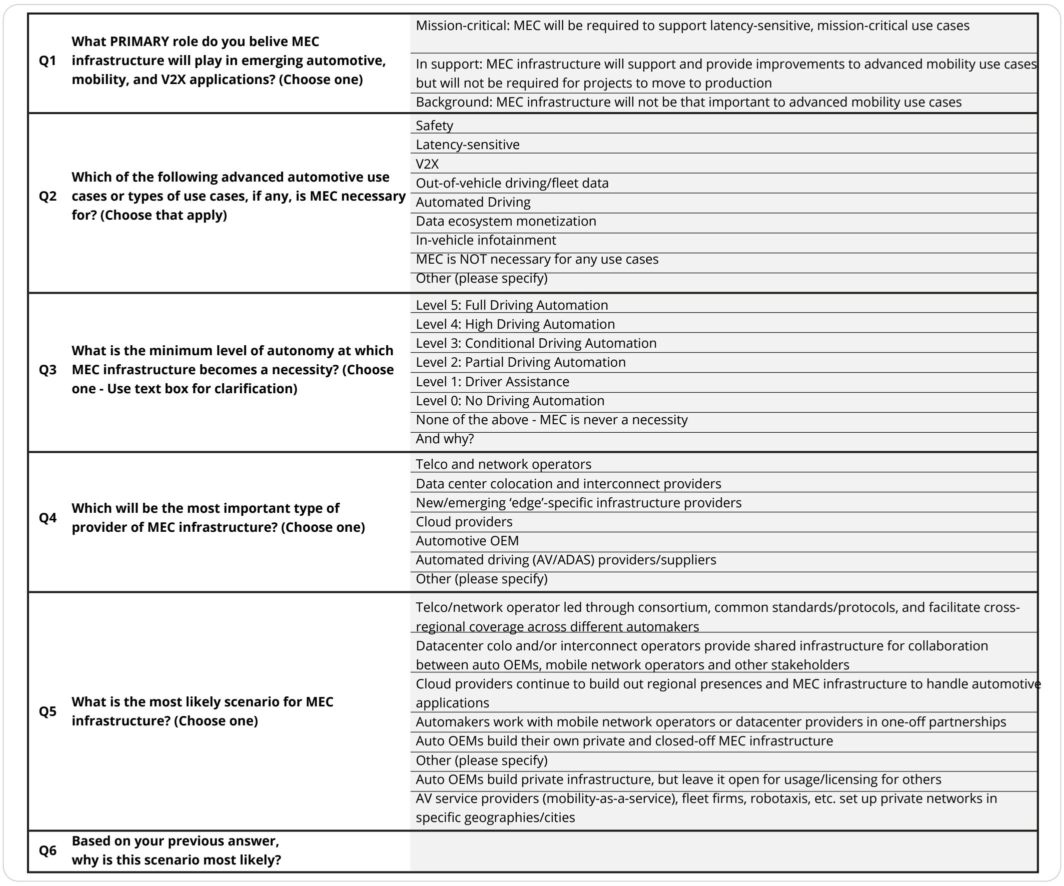
The German trial will lead to further industrial standardisation, especially in GSMA OPG, and open-source contributions, e.g. CNCF project CAMARA.

6 Business considerations for MEC use cases

6.1 Stakeholder overview

In November 2022, the gMEC4AUTO WI distributed a MEC survey to the WG1, WG5 and gMEC4AUTO WI colleagues to collect feedback from experts and stakeholders about the foreseen role and necessity of MEC in the automotive, mobility and V2X environment, together with some highlight on the expected MEC infrastructure provider ecosystem.

The five MEC survey questions, together with the answer choices are listed in the table below.



Q1	**What PRIMARY role do you belive MEC infrastructure will play in emerging automotive, mobility, and V2X applications? (Choose one)**	Mission-critical: MEC will be required to support latency-sensitive, mission-critical use cases
		In support: MEC infrastructure will support and provide improvements to advanced mobility use cases but will not be required for projects to move to production
		Background: MEC infrastructure will not be that important to advanced mobility use cases
Q2	**Which of the following advanced automotive use cases or types of use cases, if any, is MEC necessary for? (Choose that apply)**	Safety
		Latency-sensitive
		V2X
		Out-of-vehicle driving/fleet data
		Automated Driving
		Data ecosystem monetization
		In-vehicle infotainment
		MEC is NOT necessary for any use cases
		Other (please specify)
Q3	**What is the minimum level of autonomy at which MEC infrastructure becomes a necessity? (Choose one - Use text box for clarification)**	Level 5: Full Driving Automation
		Level 4: High Driving Automation
		Level 3: Conditional Driving Automation
		Level 2: Partial Driving Automation
		Level 1: Driver Assistance
		Level 0: No Driving Automation
		None of the above - MEC is never a necessity
		And why?
Q4	**Which will be the most important type of provider of MEC infrastructure? (Choose one)**	Telco and network operators
		Data center colocation and interconnect providers
		New/emerging 'edge'-specific infrastructure providers
		Cloud providers
		Automotive OEM
		Automated driving (AV/ADAS) providers/suppliers
		Other (please specify)
Q5	**What is the most likely scenario for MEC infrastructure? (Choose one)**	Telco/network operator led through consortium, common standards/protocols, and facilitate cross-regional coverage across different automakers
		Datacenter colo and/or interconnect operators provide shared infrastructure for collaboration between auto OEMs, mobile network operators and other stakeholders
		Cloud providers continue to build out regional presences and MEC infrastructure to handle automotive applications
		Automakers work with mobile network operators or datacenter providers in one-off partnerships
		Auto OEMs build their own private and closed-off MEC infrastructure
		Other (please specify)
		Auto OEMs build private infrastructure, but leave it open for usage/licensing for others
		AV service providers (mobility-as-a-service), fleet firms, robotaxis, etc. set up private networks in specific geographies/cities
Q6	**Based on your previous answer, why is this scenario most likely?**	

Table 6.1 – MEC Survey questions

Among the MEC survey, principal findings were:

- **Q1 – What primary role do you believe MEC infrastructure will play in emerging automotive, mobility, and V2X applications?** MEC infrastructure is critical for emerging automotive, mobility and V2X applications. The majority of respondents said MEC will be "required" to support mission-critical, latency-sensitive mobility applications. Nobody answered that MEC infrastructure will play a background role, meaning that MEC will be either critical or in support of advanced mobility use cases.

- **Q2 – Which of the following advanced automotive use cases or types of use cases, if any, is MEC necessary for?** The three top use cases categories selected by the survey respondents were: safety, latency sensitive, and V2X. Other use cases specified by the respondents focused on road infrastructure (like e-tolling), smart mobility (traffic efficiency: prioritisation, parking, etc.; improving intersection/road segment efficiency), smart city, and infrastructure-assisted environmental perception.

All comments provided in boxes under each corresponding question are provided anonymously.

> *"MEC is necessary for mission critical use cases. By mission critical we mean that the "mission", e.g. running a bus route or parking a vehicle cannot be executed when the ICT system fails. The primary aim here is to create end-to-end accountability. This is not possible if the communication service is provided by one provider, but the computing service (cloud) is provided by another. There must be at least one service provider with overall responsibility. In rare cases this may be required in order to [more easily] get a safety-related system certified. In most cases it is done for purely economic reasons. For example, the operator of autonomous level 4 or 5 vehicles must ensure remote "technical supervision". If this fails, the vehicle must be brought into a safe state (usually means standstill after a short time). Should an ICT failure be the cause, appropriate compensation for the case will be agreed in the service level agreement with the ICT service provider. Only MEC, i.e. full responsibility for the entire system end-to-end, allows such service level agreements to be concluded with a manageable risk. The "edge" does not necessarily have to be "close" for this, but can also be many kilometres away, provided the quality of service on the data lines is guaranteed. Conversely, it must also be emphasised that geographical proximity does not automatically mean guaranteed quality of service on data lines."*

- **Q3 – What is the minimum level of autonomy at which MEC infrastructure becomes a necessity?** High-performance MEC infrastructure becomes more important as autonomous driving levels increase.

A minority of respondents saw no role at all for MEC while the great majority of them said MEC was necessary to support at least level 2 autonomy (partial driving automation) or above; a need growing with the level of autonomy driving. Respondents' additional comments provided insight about the reasons MEC was considered a necessity. Higher autonomous driving levels (>2/3) require extended perception of the environment beyond vehicles sensors, enabled by MEC. A latency-sensitive use case is still taken into consideration when the upper levels of autonomous driving ask for low latency requirements that cannot be met without MEC. The respondents comments relate latency sensitivity to tele-operated driving (infrastructure assisted driving), traffic jam pilots, or robot-taxi use cases, and in general to improve safety with augmented information from other vehicles/infrastructure (MEC). On the other hand, lower ADAS level (0-3) can be met by the vehicle only, and there is a corresponding need for regulation to make upper ADAS levels and MEC a reality. Lastly, some comments pointed out that MEC might be used even for applications not related to ADAS or AD, e.g. for infotainment applications.

"We think MEC becomes really necessary when the use cases [are] mission critical (not necessary to be associated with certain level of automation), i.e. service level agreement (SLA) of both connectivity and computation is essential for performing the use cases. MEC enables SLAs; no MEC, no end-to-end control –too risky to offer an SLA for something not under your control – MEC simplifies contracting, as you just need one service provider, not two (one for connectivity, the other for computation/hosting). For example remote supervision or operation of vehicles etc. will depend on mission-critical and rapid responses from a system of actors. To enable this predictably, it is necessary to have a communication as well as decision (computation) path that can be guaranteed."

"From level 2 there is a need to perform functions (e.g. object detection and tracking, path planning, sensor fusion) with high computational requirements in vehicles. Offloading some of those functions to the edge or using the edge to enhance performance will improve safety, save battery and reduce costs. As published in previous 5GAA documents (MEC4AUTO) advanced driving assistance such as "see-through for passing" or "HD sensor sharing" require MEC infrastructure for mass deployment. It is of course possible to deploy L2 or L2+ automation without MEC infrastructure, but this is not economically convenient. In more general terms, other use cases such as IVE do require MEC infrastructure but that is not related with SAE levels of automation."

- **Q4 – Which will be the most important type of provider of MEC infrastructure?** Mobile operators will likely be the most important MEC providers. In a nod to their critical role in delivering 5G services, one in two respondents said telco/network operators would be the primary provider of MEC infrastructure. Beyond that, the rest of the respondents chose data centre providers (also known as neutral hosts), emerging edge-specific providers, and cloud providers.
- **Q5 – What is the most likely scenario for MEC infrastructure?** In line with the answers to the previous question, half of the respondents believe the most likely scenario for MEC infrastructure will be a collaboration led by mobile network operators. The key driver favouring this approach is the ability of such a group to build common standards and protocols that facilitate cross-regional coverage of different automakers. Some responses also suggested that another likely scenario foreseen for MEC infrastructure will be edge data centre owners partnering with cloud providers to set up edge infrastructure.
- **Q6 – Why is this scenario most likely?**
    - Role of telco/MNO

"There are multiple options for delivering edge cloud services, however it is only the telcos that are in a realistic position to couple the edge cloud service with a comprehensive, wide-area, and international wireless connectivity network. This puts the telcos in a position where they have a unique asset (connectivity) that is not easily replicated (like cloud/compute is). This fact rules out some of the options above that do not put the telco in the pole position. The telcos will also prefer to offer one solution that can address all possible future verticals – for example railway, airspace, public safety, immersive interaction, etc. – not just the automobile sector. This leads to the conclusion that telcos will be in a lead position and that they will target a solution that can be re-used across verticals."

"The telco operators are better positioned to provide the MEC infra availability to auto OEMs, fleet owners and city/road operators."

"To really reduce latency MEC should be provided inside the infrastructure of Telco operators, other solutions would be suboptimal in terms of latency"

"MEC still relies on the network, which can only be provided by the Network Operators."

"It's most likely that MNOs will own the MEC infrastructure and orchestrate its use among their different customers"

"We consider "provider" in the sense of "contracting party" and answer it based on "service provider" not "infrastructure provider". We consider telco and network operators as main provider. Through subcontracting, there can be a multitude of further parties involved providing hardware, connectivity, data center services, … but the overall responsibility is with the service provider, which in our opinion is most likely a "telco and network provider"."

> Role of edge data centres and clouds

“Cloud providers already offering edge computing solutions.”

“...ensure ... seamless connectivity across Hyperscalers for regional computations (MEC) and global clouds, preferably with standardisation across Hyperscalers.”

“MEC works on a global scale only in conjunction with regional breakout. Such solutions are rather complex and most likely not all telco operators will build their own infrastructure. They might use existing interconnect operators to do this job in an “as a service” model.”

“Edge data centre owners have the real estate necessary to enable MEC most effectively to deliver MEC SLAs.”

“...the MEC scenarios for automotive are natively involving multiple MNOs, and some neutral hosts can be likely a player that can facilitate this joint business among MNOs (and also with smart cities, RO, RTAs).”

> Role of collaboration/federation

“Economy of scale brought by standard APIs, procedures and modules as well as distributed multi-party business models are key to global adoption.”

“Easy to collaborate among all involved parties.”

“Road operators, telco infrastructure providers, network operators, and cloud (edge) service providers need to work collaboratively to build the shared/neutral roadside infrastructure with on-premises and central office MEC capability. They need to work closely with auto OEMs to adopt the technology. The shared infrastructure is key for the ubiquitous adoption.”

“Auto OEMs seem to be not willing to share infrastructure and data with others.”

“MNO and OEM seek support from DOTs and build MEC infrastructure that can support various types for AVs and other applications.”

The main take away from the survey is that MEC is necessary to support mission-critical, latency-sensitive mobility applications related to safety, latency and V2X. In general, any use case, where on-board (car) sensor and computing are not enough to address safety of the driver, passengers and VRU, MEC plays a critical role. MEC could provide the computing off-load, and low latency communication exchange between the parties to allow the V2X, in situations where communication with the road infrastructure, and any other party is required for situational awareness,

MEC provides a simple solution for all use cases that cannot be accommodated by the on-board sensor and computing. This also relates to the level of autonomous driving. ADAS could work without external computing and information data at the lower levels, but for higher levels ADAS requires external information to be processed by the MEC and provided in a timely way to the car.

Telco/network operators, according to 5GAA subject matter experts, would be the primary provider of MEC together with data centre providers and edge-specific providers. It is not easy to define a clear demarcation point between data centre and edge providers, as some data centre companies also provide edge services. That said, another approach to developing the MEC infrastructure could be data centre owners partnering with cloud providers to set up edge infrastructure.

This is in line with the ecosystem-based and collaborative approach foreseen in the answers to Question 5. Multiple actors, MNOs, MTDC or Multi-Tenant Data Centres (aka neutral hosts), edge and cloud providers should enable MEC platforms on a convenience/coverage basis. This distributed and collaborative approach also helps in fulfilling the latency sensitive requirements, where the closest available MEC infrastructure operator will serve the user, but it requires the support of MEC federation, as demonstrated in this Technical Report and largely discussed and agreed in this WI, as well by external standards definitions organisations, such as ETSI. At the same time, some of the comments highlight the primary importance of MNOs as the only actor that can provide the radio network, and an end-to-end SLA (if they provide the edge as well).

The respondents are looking to validate the definition of a MEC federation approach, led by MNOs, where the different parts of the user/car to cloud/OEM continuum: MNOs, edges, DCs, clouds, OEMs; collaborate and share infrastructure on a convenience/coverage basis.

6.2 Go-to-market constraints

This federated multi-OEM-MNO-edge-cloud approach can favour the go-to-market process, lowering the investment requested by each single operator and provider.

But some constraints emerged from the answers and comments:

1. **SLA:** Who will provide end-to-end SLA on the services? Are end-to-end SLAs requested or mandatory?
2. **Legal/liability:** In terms of liability for the safety side based on MEC + network, who will be responsible in case MEC-based safety services fails?
3. **Contracts:** Is a single contract which covers all the aspects of the access network, MEC services, cloud services required by the market/OEMs? Who will be the main contractor?

6.3 Summary

With the on-demand, as-a-service infrastructure model, which clouds and some MTDC/edge providers support, we clearly see the benefit of a federated-on-demand commercial model, where not only technical capabilities and performance could be achieved, but also an on-demand, consumption-based (PAYG) cost model can be pursued.

MNOs have a central role, leading the collaboration between the different providers of MEC infrastructure.

Operators can start working with these types of solutions for various regions, whether they are looking at a full GTM, or simply running an innovation lab, small deployments, and trials.

7 KPI measurements across multi-operator MEC networks

7.1 Europe, Middle East and Africa (EMEA)

Table 7.1-1: Observations from the passive VRU scenario tests

Test descriptions	**Observations**	**Warning distance (based on notification in HMI app, visual estimate approach)**
Scenario 1: Vehicle is moving 5-10km/h towards the intersection, and stops. After several seconds, the vehicle moves back to the starting point. **Pedestrian is visible to the car from the beginning of his/her movement.**	• VRU YELLOW warning generated in both directions • VRU RED warning generated only at the intersection • Sporadic cases of RED alert false positive, moving the vehicle back to the starting point • RED alert with a delay between 1-5 seconds before the car stops and the pedestrian moves safely to the other side of the street • 5G mobile network RTT on the transport layer is between 9-18ms	2-8m
Scenario 2: Vehicle is moving 5-10km/h towards the intersection, and stops at the intersection. After some seconds, the vehicle moves back to the starting point. **Pedestrian is initially walking behind a wall, becomes visible to the car only when he/she approaches the crossing.**	• VRU YELLOW warning generated in both directions • VRU RED warning generated only at the intersection • Sporadic cases of RED alert false positive, moving the vehicle back to the starting point • RED alert arrives with a delay between 1-5 seconds before the car stops and the pedestrian moves safely to the other side of the street • 5G mobile network RTT on the transport layer is between 9-18ms	2-8m

Table 7.1-2: Observations from the active VRU scenario tests

Test descriptions	**Observations**	**Warning distance (based on notification in HMI app, visual estimate approach)**
Scenario 1: Vehicle is moving 5-10km/h towards the intersection, and stops. After several seconds, the vehicle moves back to the starting point. **Pedestrian is visible to the car from the beginning of his/her movement.**	• VRU YELLOW warning generated in both directions • VRU RED warning generated only at the intersection • Sporadic cases of RED alert false positives, moving the vehicle back to the starting point • At the car/pedestrian potential collision site, RED alert arrives with a delay of under 1 second; the car stops and the pedestrian moves safely to the other side of the street • 5G mobile network RTT on the transport layer is between 9-18ms • GPS position of the Car sometime is not precise, tracking the car indoor or within garden perimeter (the test was done with the smartphone's GPS)	2-8m
Scenario 2: Vehicle is moving 5-10km/h towards the intersection, and stops. After several seconds, the vehicle moves back to the starting point. **Pedestrian is initially walking behind a wall, becomes visible to the car only when he/she approaches the crossing.**	• VRU YELLOW warning generated in both directions • VRU RED warning generated only at the intersection • Sporadic cases of RED alert false positives, moving the vehicle back to the starting point • RED alert arrives with a delay of under 1 second; the car stops and the pedestrian moves safely to the other side of the street • 5G mobile network RTT on the transport layer is between 9-18ms • GPS position of the Car sometime is not precise, tracking the car indoor or within garden perimeter (the test was done with the smartphone's GPS)	2-8m

Note: the vehicle speeds were limited in the EMEA tests due to restricted runway available at the test venue/campus.

7.2 North America (NA)

Table 7.2-1: Observations from the passive VRU scenario tests

Test descriptions	Observations	Warning distance (based on notification in app)
Scenario 1: Vehicle was moving at 25mph towards the intersection and back. Warning to be generated between 28m (2.5s TTC) to 45m (4s TTC).	• VRU warning generated in both directions • No false warning generated	26-30m
Scenario 1: Vehicle was moving at 30mph towards the intersection and back. Warning to be generated between 34m (2.5s TTC) to 54m (4s TTC).	• VRU warning generated in both directions • No false warning generated	28-34m
Scenario 1: Vehicle is moving at 40mph towards the intersection and back. (Iteration 2-3 rounds) Warning to be generated between 45m (2.5s TTC) to 72m (4s TTC).	• VRU warning generated in both directions • No false warning generated	28-34m

Table 7.2-2: Observations from the active VRU scenario tests

Test descriptions	Observations	Warning distance (based on notification in app)
Scenario 1: Vehicle was moving at 25mph towards the intersection and back. Warning to be generated between 28m (2.5s TTC) to 45m (4s TTC).	• VRU warning generated • No false warning generated	20-28m
Scenario 1: Vehicle was moving at 30mph towards the intersection and back. Warning to be generated between 34m (2.5s TTC) to 54m (4s TTC).	• VRU warning generated • No false warning generated	28-34m
Scenario 1: Vehicle was moving at 40mph towards the intersection and back. (Iteration 2-3 rounds) Warning to be generated between 45m (2.5s TTC) to 72m (4s TTC).	• VRU warning generated • No false warning generated • Should have noticed a bit ahead	28-34m

7.3 Collision warnings and GLOSA (Frankfurt, Germany)

Table 7.3-1: Observations from the collision warning scenario tests

Test descriptions	**Observations**	**Warning distance (based on notification in app)**
Scenario 1: Vehicle was moving at 10km/h towards the intersection. Cyclist is moving at 10 km/h towards the intersection, hidden by an obstacle, several iterations. Warning to be generated between 12m (4s TTC) to 6m (2s TTC) to the vehicle, as well as to the cyclist.	• VRU warnings generated • No false warning generated	6-12m
Scenario 2: Vehicle was moving at 10km/h towards the intersection, several iterations. Pedestrian is moving at 4 km/h towards the intersection, hidden by an obstacle. Warning to be generated to the vehicle between 12m (4s TTC) to 6m (2s TTC), warning to be generated to the pedestrian between 4m (4s TTC) to 2m (2s TTC).	• VRU warning generated • No false warning generated	6-12m (vehicle) 2-4m (pedestrian)
Scenario 3: Vehicle was moving at 20km/h towards the intersection, several iterations. Cyclist is moving at 10 km/h towards the intersection, several iterations hidden by an obstacle, several iterations not hidden by an obstacle, several iterations reducing the speed of the cyclist. Warning to be generated to the vehicle between 15m (3s TTC) to 10m (2s TTC), warning to be generated to the cyclist between 9m (3s TTC) to 6m (2s TTC).	• VRU warning generated • No false warning generated • Need to be optimised, not to warn too early	10-15m (vehicle) 6-9m (cyclist)

8 Conclusions

This document focused on the MEC live trials and related public demonstrations of selected automotive use cases in multi-MNO, multi-OEM and multi-vendor environments, instantiated in various regions of the world. The TR explored technical, regulatory and business constraints around deployment of multi-MNO MEC scenarios under different conditions and meeting auto OEM requirements.

In particular, the following highlights from the MEC trials can be mentioned:

- The MEC trial instantiated in EU (Turin, Italy) was led by TIM, providing the 5G radio access to allow local connectivity with the devices and vehicles (from Stellantis) in the city, together with its own MEC infrastructure. Federation between MNO MEC platforms was achieved allowing use cases where roaming subscribers from Telefonica and BT could access the application on the edge of the (TIM) visited network with the same performance level as the local subscribers. This EU MEC trial instance was a practical experiment that could influence standardisation (in a wider sense, thus including not only ETSI and 3GPP but also GSMA OPG), and open-source contributions (e.g. CNCF project CAMARA).
- The 5GAA AMR trial was deployed using CSP infrastructure services at the network edge of Verizon and Telus using AWS Wavelength (WL) where a vRSU was built using cloud native technologies and partner solutions on Intel architecture. The North American MEC trial instance was a practical experiment which also influences standardisation and open-source contributions.
- The German trial, as a collaboration between DT, Continental, BMW and Fraunhofer FOKUS, provided collision risk warning services for VRU safety. For the future, it is expected to lead to further industrial standardisation, especially in GSMA OPG, and open-source contributions (e.g. CAMARA).

Moreover, based on an internal MEC survey (outlined in Section 6) we can summarise the following insights as preliminary considerations for MEC deployments:

- In general, there is a clear industry consensus on the benefits of federated MEC systems, where different business models could be further investigated in 5GAA.
- There is also some consensus on the central role of operators and service providers going forward, possibly in collaboration with the different MEC infrastructure technology providers (including data centre, neutral hosts, etc.).

The above considerations should be considered as preliminary, and 5GAA plans to further elaborate and align the business aspects and roadmap on MEC in multi-MNO, multi-OEM and multi-vendor environments.

Annex A: MEC system interoperability scenarios

A.1 Objectives

This document discusses the different MEC interoperability scenarios, focused on MEC from a UE perspective (service and network aspects) as well as from an inter-MNO (network aspects) and inter-OEM perspective of MEC systems.

The scenarios reflect the current and future eco-system as we known of today and may be expended in the future.

By identifying the different MEC interoperability scenarios, the future work needs to be done so that MEC can be leveraged under different deployments / architecture scenarios is revealed.

The ownership (and management) of the MEC platform has not been discussed in detail.

A.2 MEC interoperability scenarios

A.2.1 MEC system interoperability scenarios

The following figure captures the different MEC interoperability scenarios, identified in [2] (published in 2021). For updates to MEC interoperability scenarios, please refer to [26].

For the sake of simplicity, some of the scenarios in the figure are only implied, with the detail provided in the supporting table and in the following text.

An important clarification on the table is that it covers only the owner's physical resources and not the "logical" owner of the resources, which in many cases could be different and thus supports a different business case.

As an example, the MEC platform resides at/in MNO A, which may host the auto OEM as the logical owner of the MEC platform. The table does not reflect this valid business use case.

Another example would be that at/in the MEC platform, MNO A actually hosts two different OEMs, each managing its own MEC platform.

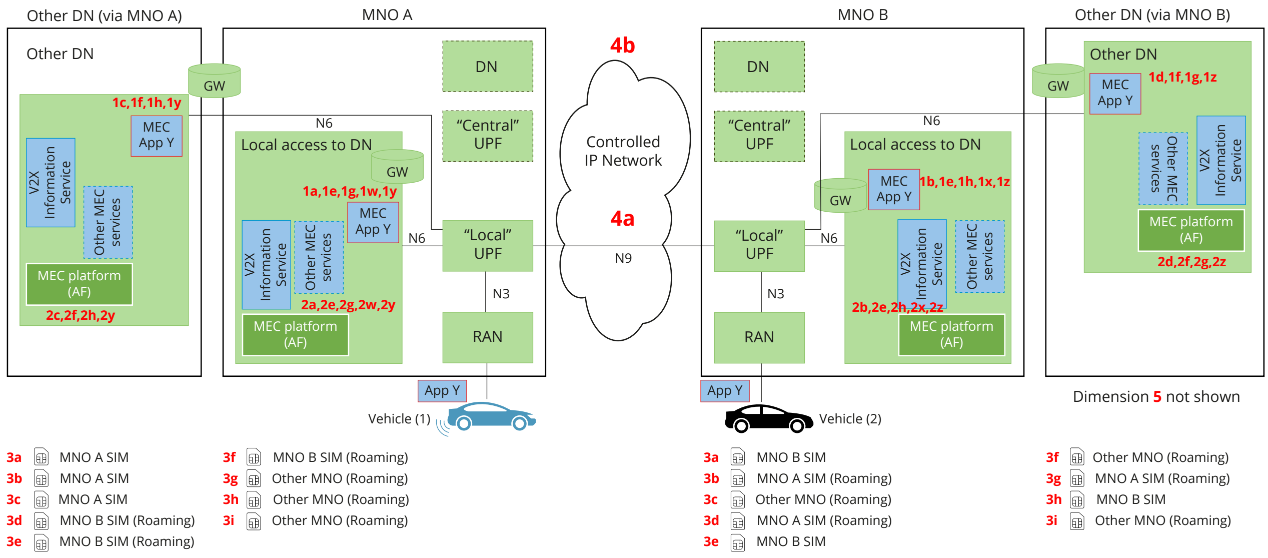


Figure A.2.1-1: Different inter-operability scenarios for MEC system – simplified view

Dimension	Attribute	Values											
		(*)	**(*)**	**(*)**	**(*)**	**(**)**	**(**)**	**(**)**	**(**)**	**(***)**	**(***)**	**(***)**	**(***)**
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**w**	**x**	**y**	**z**
1	Presence of **MEC Application instance(s)**	MEC App A in MNOA	MEC App B in MNOB	MEC App A in other DN (via MNOA)	MEC App B in other DN (via MNOB)	MEC App A in MNOA	MEC App A in other DN (via MNOA)	MEC App A in MNOA	MEC App A in other DN (via MNOA)	MEC App A in MNOA	MEC App A hosted in MNO B	MEC App A in MNOA	MEC App A hosted in other DN via MNO B
						MEC App B in MNOB	MEC App B in other DN (via MNOB)	MEC App B in other DN (via MNOB)	MEC App B in MNOB	MEC App B hosted in MNO A	MEC App B in MNOB	MEC App B hosted in other DN via MNO A	MEC App B in MNOB
2	Presence of **MEC Platform(s) to expose edge services,** like predictions	MNO A	None	Other DN	None	MNO A	Other DN Shared Data Center (Other DN)	MNO A	Other DN	MNO A	MNO B (MNO A uses MEC platform in MNO B)	MNO A	MNO B (MNO A uses MEC platform in other DN via MNO B)
		None	MNO B	None	Other DN	MNO B	Other DN	Other DN	MNO B	MNO A (MNO B uses MEC platform in MNO A)	MNO B	MNO A (MNO B uses MEC platform in other DN via MNO A)	MNO B

NOTE1: for all scenarios the assumption is MEC App instance 1 is owned by MNOA and MEC App instance 2 is owned by MNOB. For the sake of simplicity, we call them MEC AppA and MEC AppB

NOTE2: for all scenarios the assumption is that Vehicle 1 is connected to MNO A and Vehicle 2 to MNO B, and each Vehicle has a Client App running on the car

(*) these are cases of a single MEC App instance communicating with two Client Apps running on the two vehicles

(**) these are cases of two MEC App instances communicating with two Client Apps running on the two vehicles

(***) these are cases of edge resource sharing

Table A.2.1-1: Dimensions 1 and 2 of Figure A.2.1-1

			a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
3	**Subscription** of end-user (vehicle (sub) system) according to SIM (instead of Global SIM)	Vehicle 1	MNO A	MNO A	MNO A	MNO B (roaming)	MNO B (roaming)	MNO B (roaming)	Other MNO (roaming)	Other MNO (roaming)	Other MNO (roaming)
		Vehicle 2	MNO B	MNO A (roaming)	Other MNO (roaming)	MNO A (roaming)	MNO B	Other MNO (roaming)	MNO A (roaming)	MNO B	Other MNO (roaming)

Table A.2.1-2: Dimension 3 of Figure A.2.1-1

		a	**b**
4	Available **interconnection** between MNOs	N9	Controlled IP network
5	When in **Roaming**	Home routed	LBO

Table A.2.1-3: Dimensions 4 and 5 of Figure A.2.1-1

Contents

5GAA is a multi-industry association to develop, test and promote communications solutions, initiate their standardisation and accelerate their commercial availability and global market penetration to address societal need. For more information such as a complete mission statement and a list of members please see https://5gaa.org

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