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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Core Network and Interoperability Testing (INT).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The purpose of the present document is to provide recommendations on methodologies for testing and validation of Network Application based services over 5G networks.

The present document is based on the work of the 5G-IANA project which aims to build an Automotive Open Experimental Platform (AOEP) to bring up the 5G potential of orchestrating Vertical Services based on virtualized network slices and coordinating distributed edge-to-cloud deployment for the Automotive sector.

The 5G-IANA AOEP provides Small and Medium Enterprises (SMEs) an opportunity to create, test, and deploy their services. This is achieved by providing a set of hardware and software resources (by the AOEP), as well as computational and communication/transport infrastructure, management, and orchestration components, and a Network Applications Toolkit tailored to the automotive sector but also universally applicable, simplifying the design and onboarding of new Network Applications.

There are additional active projects that currently work in the same field and develop and use methodologies for testing and validation to achieve their project results (as an example see Annex B summarizing the PoDIUM project). Therefore, it is planned to make the present technical report a living document that will see regular new versions reporting on the methodologies used in these projects. The objective is to arrive at a common methodology that can be globally applied and could be published as a technical specification in the future.

Introduction

In the context of the present document, a Network Application is defined as a virtual application that can be deployed in a 5G infrastructure and can use 5G services (e.g. connectivity, localization, etc.). The Network Application concept extends the typical orchestration-oriented descriptors proposed in ETSI NFV (e.g. Virtual Network Function Descriptors - VNFDs and Network Service Descriptors - NSDs) through the specification of additional information that should facilitate the Network Application re-usage, customization, integration, and provisioning. Indeed, a Network Application can be composed by one or multiple Application Functions (AFs) or Network Functions (NFs). On one hand, the AFs correspond to the Network Application components that implements the application logic, on the other hand, NFs implement those functionalities of the Network Application that are related to networking and communication (e.g. ICT long-/short- distance communication functionalities).

To facilitate the Network Application re-usage, a specified Network Application Package may include service-level information such as the specification/documentation of supported interfaces to enable the sharing of the Network Application and its composition with other Network Applications to build advanced Vertical Services, which result in a chain of multiple Network Applications. In addition, the Network Application Package may also include the specification of main characteristics of the required 5G slice profile for properly operating the Network Application. Finally, further information may be provided in the Network Application Package, such as the test cases documentation, correlated with test scripts, the list of relevant metrics to be monitored and the list of Key Performance Indicators (KPIs) to assess the Network Application behaviour on a certain scenario (i.e. functional integration and overall performance).

The present document describes concepts for the provision of common validation methodologies and techniques that may be used for the validation of Network Application functionalities based on the experiences gained within the 5G-IANA project within the Use Case (UC) and deployments of the project partners and the Automotive Open Experimental Platform (AOEP).

Future versions of the present technical report will report on the validation methodologies used in other projects with the aim of developing a globally applicable methodology that can in the long run be published in a technical specification.

1 Scope

The present document provides recommendations on methodologies for testing and validation of Network Application based services over 5G networks. The present document includes recommendations covering the aspects of a Network Application validation framework by providing definitions of 5G relevant KPIs for Network Applications, the application and network functions making up Network Applications, and the services composed of the Network Applications. Moreover, recommendations on the testing and validation environment, on involved processes, and, finally, on the design of the Network Applications and services under test. Such recommendations can be equally applicable to a wide range of Network Applications composed services, application cases and may also be applicable beyond 5G scenarios.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] 5G-PPP: "Service performance measurement methods over 5G experimental networks; White paper - ICT-19 performance KPIs", 2021.

[i.2] 5G-PPP Test, Measurement and KPIs Validation Working Group: "Whitepaper: Beyond 5G/6G KPIs and Target Values", 2022.

[i.3] 5GAA: "C-V2X Use Cases and Service Level Requirements Volume I", 2020.

[i.4] 5GAA: "C-V2X Use Cases Volume II: Examples and Service Level Requirements", 2020.

[i.5] ETSI TS 122 186 (V17.0.0): "5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 Release 17)".

[i.6] 5G-IANA deliverable D5.1: "Initial validation KPIs and metrics", 2022.

[i.7] 5G-IANA deliverable D5.2: "Validation methodology", 2023.

[i.8] 5G-PPP Test, Measurement and KPIs Validation Working Group: "KPIs Measurement Tools - From KPI definition to KPI validation enablement", 2023.

[i.9] Robot Framework Foundation: "Robot Framework open source automation framework".

[i.10] 5G-IANA deliverable D5.3: "Technical validation and demonstration of the UCs", 2024.

[i.11] IEEE 802.11™: "IEEE Standard for Information Technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

application function: implementation of the logic of the applications, e.g. a remote driving module application function, a hazardous driving behaviour detection function, etc.

atomic component: virtualizable function that is deployable in a container

network application: virtual application that can be deployed in a 5G infrastructure and can use 5G services and that implements and exposes a specific service

NOTE: A network application can be composed of one or multiple application and/or network functionalities.

network function: implementation of the communication between application functions that ensures connectivity with the 5G network, e.g. a sensor's data capturing function

3.2 Symbols

Void.

3.3 Abbreviations

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

3GPP	3rd Generation Partnership Project
5G-IANA	5G Intelligent Automotive Network Applications
5G-PPP	5G Infrastructure Public Private Partnership
AF	Application Function
AOEP	Automotive Open Experimental Platform
AR	Augmented Reality
CAF	Cloud-native AF
CCAM	Cooperative, Connected and Automated Mobility
CNF	Cloud-native NF
DML	Deep ML
E2E	End-to-End
EEO	Extreme Edge Orchestrator
IUT	Implementation Under Test
KPI	Key Performance Indicator
LSTM	Long Short-Term Memory
MANO	Management And Network Orchestration
ML	Machine Learning
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NF	Network Function
NL	Network Level
NSD	Network Service Descriptor
OBU	On-Board Unit
PAF	Physical AF
PDI	Physical and Digital Infrastructure
PNF	Physical NF
QoS	Quality of Service
RSU	Road Side Unit
RTK	Real Time Kinematic
RTT	Round-Trip Time
SL	Service Level
TC	Test Case

UC	Use Case
UE	User Equipment
VAF	Virtual AF
VM	Virtual Machine
VNF	Virtual NF
VNFD	Virtual NF Descriptor
VRU	Vulnerable Road Users

4 Introduction to Network Applications

4.1 What are Network Applications?

A Network Application is defined as a virtual application that can be deployed in a 5G infrastructure and can use 5G services (e.g. connectivity, localization etc.). The Network Application concept extends the typical orchestration-oriented descriptors proposed in ETSI NFV e.g. Virtual Network Function Descriptors (VNFDs) and Network Service Descriptors (NSDs) through the specification of additional information that can facilitate the Network Application re-usage, customization, integration, and provisioning.

To facilitate the Network Application re-usage, the Network Application Package specified in 5G-IANA includes service-level information such the specification/documentation of supported interfaces to enable the sharing of the Network Application and its composition with other Network Applications to build advanced Vertical Services, which result in a chain of multiple Network Applications. In addition, the Network Application Package also includes the specification of main characteristics of the required 5G slice profile for properly operating the Network Application. Finally, further information is provided in the Network Application Package, such as the test cases documentation, correlated with test scripts, the list of relevant metrics to be monitored and the list of Key Performance Indicators (KPIs) to assess the Network Application behaviour on a certain scenario (i.e. functional integration and overall performance).

4.2 Atomic elements of Network Applications

Network Applications are typically composed of one or multiple Application Functions (AFs) and/or Network Functions (NFs). These are the atomic elements of Network Applications.

AFs correspond to the Network Application components that implement the application logic; NFs implement those functionalities of the Network Application that are related to networking and communication (e.g. ICT long-/short-distance communication functionalities). AFs and NFs can be deployed applying different virtualization techniques:

- Virtual AFs (VAFs) and Virtual NFs (VNFs) are packaged for executing a Virtual Machine (VM)-based deployment,
- Cloud-native AFs (CAFs) and Cloud-native NFs (CNFs) are packaged for a container-based deployment and
- Physical AFs (PAFs) and Physical NFs (PNFs) are not dynamically orchestrated/deployed, these functions can be statically deployed on top of hardware or deployed as well in static VM or containers.

4.3 Aggregation of Network Applications into services

4.3.1 Introduction

The present clause describes the service chain design based on the aggregation of Network Applications. The service chains may be composed of several application and network functions, potentially provided by multiple partners, which can be organized in one or more Network Applications. The following clauses provide high level descriptions of the service chain associated to example deployable services, identifying the virtual functions (application or network oriented) that compose the end-to-end service, their interactions, their placement in the 5G infrastructure (i.e. at cloud or edge nodes, etc.), and their communication with the physical devices deployed for each service. For each application in the service chain, a brief description is provided. The examples are taken from the work of the 5G-IANA project which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101016427.

4.3.2 Example deployments of Network Applications

4.3.2.1 Example 1: Augmented Reality content delivery

V2X communication interfaces can be used to deliver Augmented Reality (AR) content to the UEs of end users which are located in a moving vehicle. The objective is to deliver the content to the users with ultra-low latency and also to manage the infrastructure resources in order to achieve optimal utilization rates. The solution focuses on AR content embedded on map applications for vehicular networks. Specifically, the end-users will have access to a navigation map interface which will provide information related to their current location. The key challenges in 5G-enabled Vehicular Networks are the high bit rate and the ultra-low latency requirements and also the deployment of an efficient caching methodology. Especially for AR applications, such requirements also pose a possible system bottleneck, and they have to be efficiently addressed.

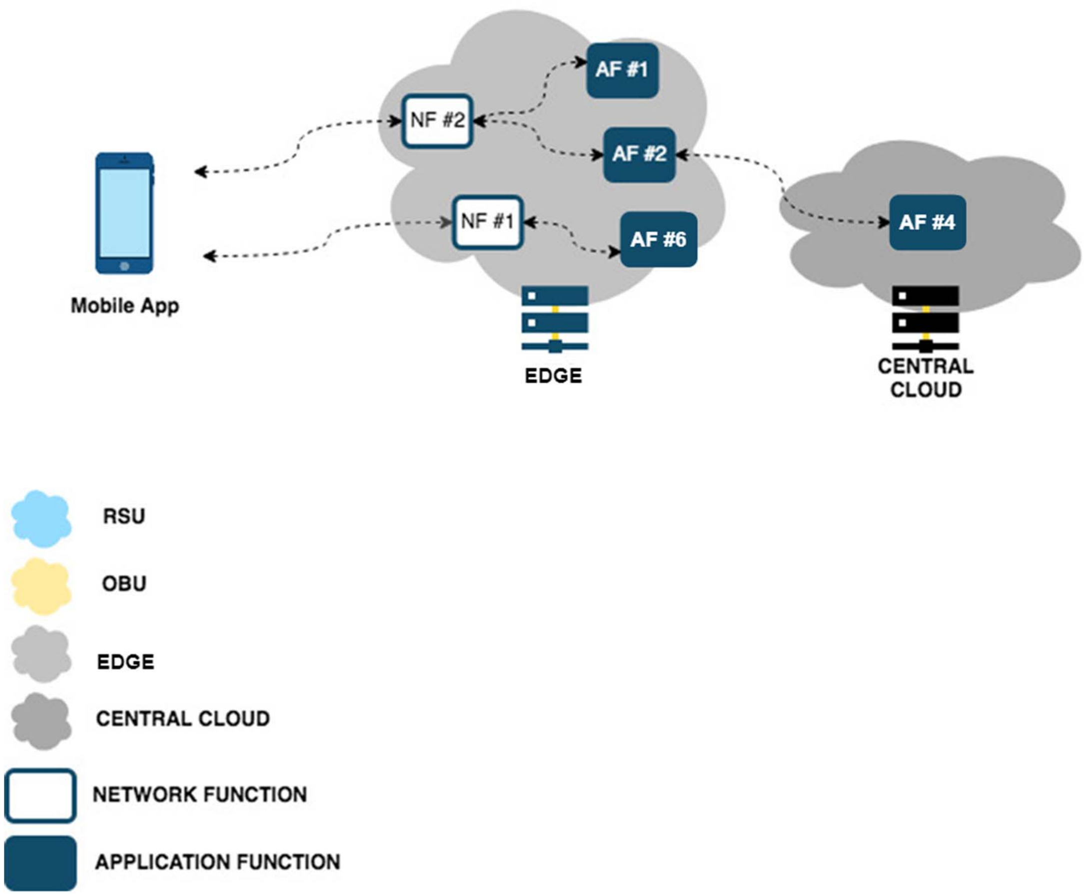

Figure 1: Service Chain design for AR content delivery

Table 1 lists the AFs and NFs deployed for the AR content delivery service and briefly describes their functionality.

Table 1: AFs and NFs deployed for AR content delivery

Item	Name	Description
AF #1	Virtualized cache - vCache	This AF is the cache on the Edge Server.
AF #2	AR content repository	Storage for AR content such as 3D objects.
AF #4	Load balancer	Load balancing between cloud and edge.
AF #6	Network monitoring	Network monitoring for KPIs.
NF #1	Long-distance data communication	This VNF is in charge to transmit and to receive data for other VNFs for long-distance 5G communication channel to specific edge/cloud services.
NF #2	AR media access function	This AF provides the access to the AR content.

4.3.2.2 Example 2: Real-time risk assessment

Real-time risk assessment provides live feedback to drivers about road segments along the vehicle's route with high frequency of risk related events (e.g. speeding, harsh accelerations, harsh braking), to inform the users in advance to adjust their driving behaviour and mitigate the risk of a road accident. Using V2X communication interfaces allows retrieving network accumulated information about road segments with high frequency of risk related driving events. The information is delivered in real-time and on demand to the drivers via the in-vehicle communication system, by multiple ways, such as pinpointing on a map the location of the places with high risk/low "safety score" and advising to reduce speed when necessary. To further improve feedback quality, current weather conditions may also be taken into account, i.e. in case of severe weather conditions the driver receives more intense notifications.

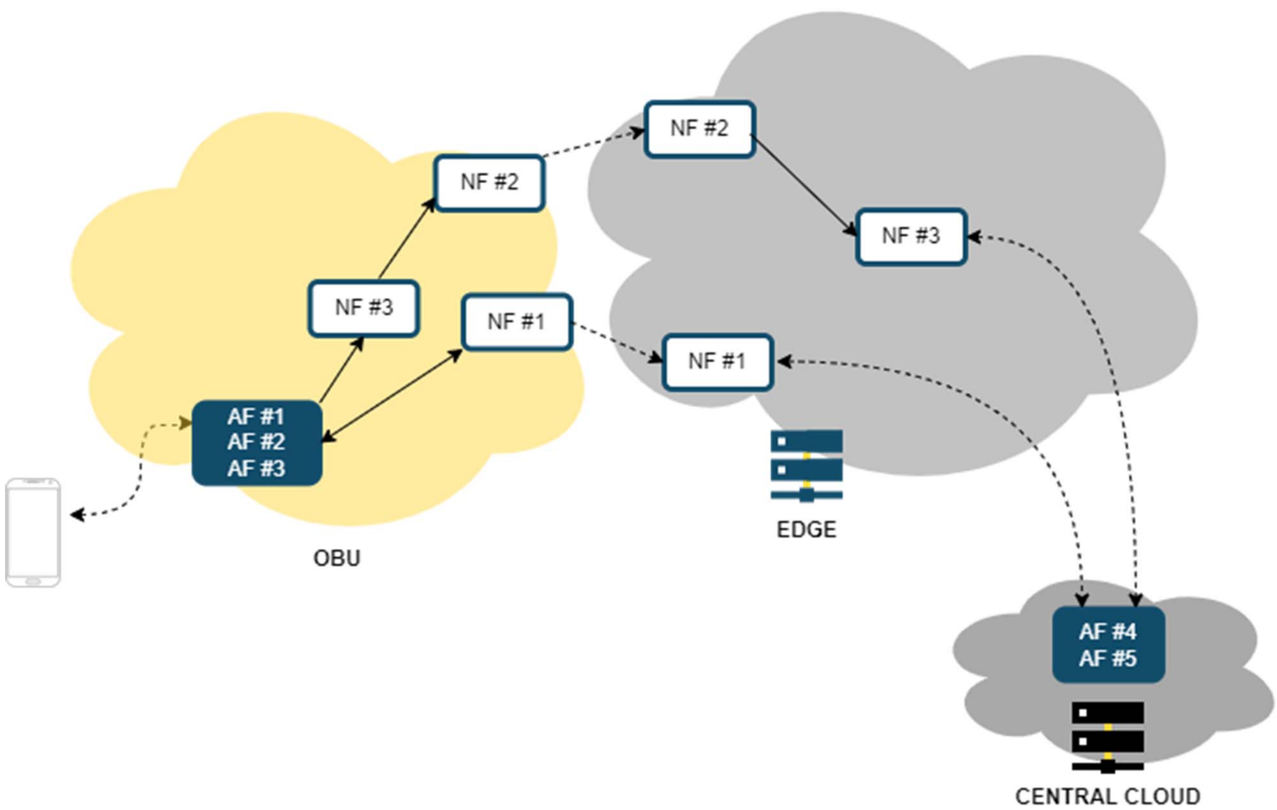

Figure 2: Service Chain design for real-time risk assessment

Table 2 lists the AFs and NFs deployed for the AR content delivery service and briefly describes their functionality.

Table 2: AFs and NFs deployed for real-time risk assessment

Item	Name	Description
AF #1	Position and time service	Implements the position and time service in order to provide accurate information about the vehicle's position and time to other VNFs. The localization service is based on Real Time Kinematic (RTK).
AF #2	Hazardous event receiver and display	Receives and displays a warning notification on hazardous events on the road.
AF #3	Hazardous driving behaviour detection	Detects hazardous events during driving: harsh braking, harsh acceleration, speeding, and mobile use.
AF #4	Elastic search service	Implements a dedicated stack for monitored data management, analysis, and storage and for processing applications' data and logs' events.
AF #5	Log reporting service	Retrieves the information to insert in the log and it sends the log to the proper cloud logging service through the Long-distance data communication VNF. The log details are defined by the NetApp implementing the log service on the vehicle, which is also in charge to trigger the sending of the log.
NF #1	Long distance data communication	Transmits and receives data for other VNFs for long-distance communication channel to specific edge/cloud services.
NF #2	C-ITS messages long-distance communication	Transmits and receive C-ITS messages for long-distance communication channel interacting with a Message Broker located on Edge Server.
NF #3	ETSI decentralized environmental notification service	Generates Decentralized Notification Messaged that are sent to NF #1 and NF #2 for the transmission of alerts.

4.3.2.3 Example 3: Network status monitoring

This example provides an overview of the status of network components or virtual network functions and draws conclusions and predictions with respect to the performance of the monitored components. It utilizes V2X communications to deliver predictions of the network quality to a central computation entity at the MEC server. This Network Application has the goal to minimize the data collection effort through utilizing a distributed Machine Learning (ML) approach i.e. instead of collecting large amounts of network monitoring data to be centrally analysed, the ML analysis/prediction model is distributed on the VNFs located at the external nodes located in the road infrastructure and the vehicles. The goal of the ML model is to learn data traffic patterns for data traffic prediction, to learn network condition models to provide QoS predictions, and to learn to distinguish between normal and abnormal network behaviours to detect and predict faults.

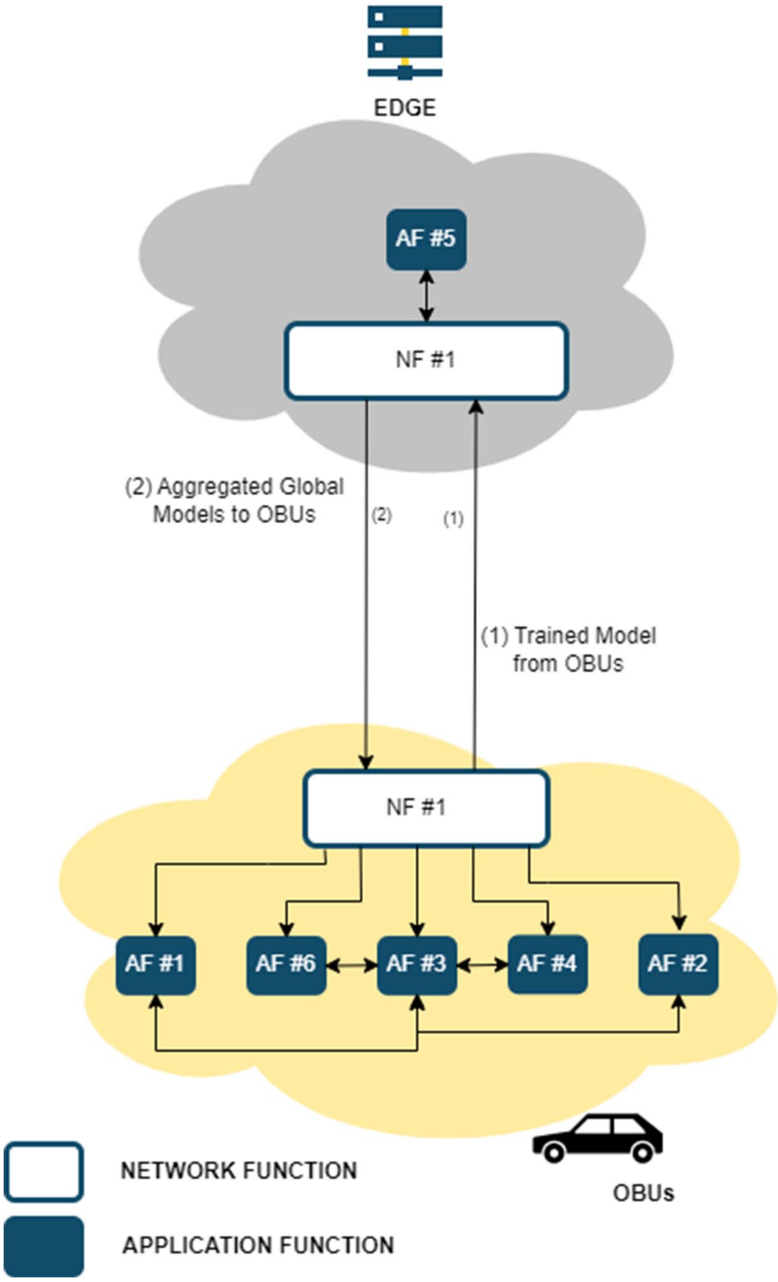

Figure 3: Service Chain design for network status monitoring

Table 3 lists the AFs and NFs deployed for the network status monitoring service and briefly describes their functionality.

Table 3: AFs and NFs deployed for network status monitoring

Item	Name	Description
AF #1	Position and time service	The VNF collects the information about the current location of the worker nodes (far-edge devices) to facilitate the generation of spatio-temporal latency maps.
AF #2	QoS prediction	An LSTM prediction model is trained (locally) on each worker node, then all local models are aggregated to a global model at the edge server (DML Aggregation Node) and the updated global model is sent back to the worker nodes for further training. After several repetitions (training rounds), when the global model has converged, it is sent to the worker nodes for inference i.e. for QoS prediction.

Item	Name	Description
AF #3	ML pre-processing	The VNF gets the collected data from Network Monitoring function and prepares the data to be fed into ML training node.
AF #4	ML node-training agent	The VNF trains the model using a locally collected data set. This model is sent to the aggregation VNF. After the aggregation, the VNF receives a new globally trained model for further training.
AF #5	DML aggregation node	The VNF receives the locally trained ML models from all the worker nodes (from the far-edge devices) and aggregates them.
AF #6	Network monitoring	The VNF monitors the network behaviour passively and actively at the far-edge device. It sniffs the application packets received by the edge/cloud services and calculates network-based metrics (such as data rate and latency).
NF #1	Long distance data communication	This VNF is in charge to transmit and to receive data for other VNFs for long-distance 5G communication channel to specific edge/cloud services.

5 Testing Network Applications step 1 - Definition of KPIs

5.1 Introduction

The present clause describes different KPI categories applicable in the validation of Network Applications and is based on existing work on KPIs, namely the 5G-PPP whitepaper 'Service performance measurement methods over 5G experimental networks' [i.1] and for the project related application of KPIs 5G-PPP whitepaper 'Beyond 5G/6G KPIs and Target Values' [i.2]. Additionally, work from the 5GAA ([i.3] and [i.4]) and from 3GPP [i.5] has been considered.

Furthermore, an approach to defining a meaningful set of KPIs for a service comprised of one or several Network Applications is described based on the work done in the 5G-IANA project and described in deliverable D5.1 'Initial validation KPIs and metrics' [i.6].

5.2 KPI categories

5.2.1 Network Level KPIs

Network level KPIs provide information on the baseline performance requirements from the 5G network, in order for applications to operate optimally. Core KPIs are generic and always applicable. It should be noted that some of the generic KPI definitions can be used as a basis for both the definition of 5G network KPIs and service level KPIs where both KPI definitions need to specify between which reference points they are measured.

Below a set of common definitions for 5G Network level KPIs followed by a number of relevant generic Network level KPIs is listed.

- **Performance KPIs** are defined as a quantity used for measuring performance (e.g. latency, data rate, packet loss rate, etc.).
- **Performance requirements** define a range or a target value for a KPI which is required for a service to work properly (e.g. latency < 20 ms). KPIs' measurement can be based on threshold values defined for each KPI; minimal, maximal, and nominal value where an acceptable KPI value should be close to its nominal value and should not be less than its minimal threshold value or exceeding its maximal threshold value.
- **Reference points** define a network interface or a node or a protocol layer used as a measurement point. 5G network KPIs definitions need to specify at which reference points they are measured. It should be noted that 5G network and service level performance KPIs will differ in the reference points. Below a set of typical network level KPIs have been considered.

- **5G Latency** is the time duration between the transmission of a message from a point A in a transmitter and the successful reception of the message at a point B in a receiver.
- **Round-Trip Time (RTT)** is defined as the time duration between the transmission of a message from a network node and the successful reception of the response message by the same point i.e. the time duration between the transmission of a message from a point A in a first network node and the successful reception of the message at a point B in a second network node plus the server response time at point B plus the time duration between the transmission of a response message from the point B in the second network node and the successful reception of the message at the point A in the first network node.
- **UL (DL) user data rate** is defined as the amount of user data transmitted by the UE (edge server) and received from the IP layer in the edge server (UE) divided by the total time between reception of the first packet and the reception of the last packet.
- **Maximum user data rate** is defined as the user data rate with only one user active in the system, full transmit buffer and favourable radio channel conditions.
- **UL (DL) packet loss rate** is defined as the one minus the number of packets received from the IP layer in the edge server (UE) divided by the number of packets passed for transmission to the edge server (UE) to the IP layer in the UE (edge server).
- **Reliability** is defined as the one minus packets loss rate.

5.2.2 Service Level KPI

Service Level KPIs provide information on the baseline performance expectations of a deployed service. These KPIs target specific Vertical Services from a business perspective i.e. each set concerns a service focused on a specific industry or group of customers with specialized needs (e.g. automotive, entertainment, etc).

The following service level KPIs may be considered:

- **E2E Latency** is the maximum accepted latency across the entire service chain (of a UC).
- **E2E Reliability** is defined as the percentage of correctly received packets over the total packets transmitted in the complete service chain.
- **Service Availability** is the percentage of time that an application is accessible and usable within a predefined QoS level e.g. the fraction of time a software component is functional (up) or the fraction of requests that are serviced correctly.
- **Application Jitter** is the statistical variation of the end-to-end latency for the communications across the entire service chain of the vertical service.
- **Quality of Experience (QoE)** is defined as the overall acceptability of an application or service, as perceived subjectively by the end-user.
- **Prediction Accuracy** in classification tasks is a measure of how well an algorithm correctly identifies or excludes a condition i.e. the proportion of correct predictions among the total number of cases examined.

5.2.3 Business Level KPIs

Business level KPIs provide information used to quantify the business-related opportunities and value propositions for vertical industries and third-party users occurring by each UC related Network Application/Service. Same as SL KPIs, each KPI concerns a service focused on a specific industry or group of customers with specialized needs.

The description of business level KPIs is out of scope of the present document.

5.3 Practical approach towards KPI definition

5.3.1 Concept

An approach to defining a meaningful set of KPIs is to provide an initial set of KPIs and metrics for evaluation and analysis for a given set of existing services defined by one or several Network Applications with the vision and objective of making the so defined KPIs generally available to third-party developers and experimenters wishing to use the existing Network Applications or their atomic components (AF and NF) for the development and evaluation of new services and Network Applications.

A top-down approach may be chosen i.e. defining first the service related KPIs including initial information on where and how to observe/measure/monitor them. This approach is preferred to a bottom-up approach of collecting generic KPIs from literature/past work and leads to a relevant, useful, and re-useable set of KPIs.

Following the service-based KPI-definition-exercise, a KPI clustering can been made to derive a generic KPI pool that can be advertised to third parties as an incentive to develop individual services based on a set of existing Network Applications, Afs and NFs and to use the defined KPIs for their evaluation.

5.3.2 KPI template

It is advisable to create a template to describe the main characteristics of the KPIs. As a minimum set of information, the following fields are considered necessary:

- Unique identifier allowing for exact identification/referencing of the KPI
- Description of the objective of the KPI
- Context of the application of the KPI
- Observation points i.e. where to observe the behaviour targeted by the KPI
- Measurement methodology i.e. how to observe the behaviour targeted by the KPI
- Evaluation methodology i.e. criteria defining whether a KPI is met or not
- Comments for additional information, if necessary

Table 4 acts as example for a KPI template.

Table 4: KPI table template

KPI title	**Unique identifier for each KPI** **Example: KPI_xx_yyy_##**
Description	High-level description of KPI
Context	Associate the KPI with a particular service/platform/Network Application.
Where to observe/measure/monitor	Point(s) of observation (e.g. reference points) to obtain a KPI "value".
How to observe/measure/monitor	A high-level description of the measurement methodology, including (where applicable): • Detailed definition of KPI e.g. what timestamps to use for latency, which packets to consider for throughput, etc. • Key (functional) requirements for the measurements e.g. endpoint synchronization, background, traffic generation (if any), etc.
How to evaluate	Definition of comparison approach i.e. what values the measured KPI data points are compared against. This can include Target Values or results retrieved by identified alternative setups/experiments.
Comments	If any.

5.3.3 KPI examples

5.3.3.1 Introduction

To further illustrate the KPI development approach, a few example KPIs defined in the 5G-IANA project are shown in the following tables. A complete set of the KPIs can be observed in the 5G-IANA deliverable D5.1 'Initial validation KPIs and metrics' [i.6]. Information on the particularities of the 5G-IANA platform, the Automotive Open Experimental Platform (AOEP), are provided for further explanation in Annex A of the present document.

5.3.3.2 Example Network Level KPI for the Network Application platform

The Service Creation Time KPI indicates the time that is consumed by the end user of the 5G-IANA platform to create the desired Vertical Service chain to be deployed. In particular, the evaluation of this KPI concerns the performances of the Network Application Toolkit component of the platform and how its exposed functionalities facilitate the process of creating a new Vertical Service chain.

Table 5: Service Level KPI - Service Creation Time

Service Creation Time	KPI_SL_AOEP_01
Description	Time consumed by the end user of the platform to create a new Vertical Service chain through the functionalities provided by the Network Application Toolkit.
Context	All UCs.
Where to observe/measure/monitor	This KPI can be measured by processing relevant events reported by the Network Application Toolkit logging system.
How to observe/measure/monitor	This KPI is measured by automating the collection and processing of relevant events from the Network Application Toolkit log file. In particular the evaluation takes into consideration the time interval from the instant when the creation of a new Vertical Service chain is started from the user up to the instant when all the related packages and descriptors are fully available on the platform, and this is notified to the user. It should be noted that the time required by the user to interact with the platform has an impact on this KPI; for this reason, the KPI will be measured as an average of the time taken to execute the whole procedure involving users with different levels of expertise. These users will be classified in three categories (beginners, medium-expertise, experts) and the test will be repeated involving the same number of users from each category.
How to evaluate	The evaluation is performed taking into consideration the 5G-PPP [i.1] KPIs evaluation reports. Currently the Service Creation & Activation Time is expected to be no more than 90 minutes, including on-boarding of relevant templates and packages/descriptors, provisioning, and configuration procedures. The Service Creation Time in 5G-IANA corresponds to the Service Creation & Activation Time Phase I (i.e. Onboarding), therefore, the targeted maximum value is set to 60 minutes.

5.3.3.3 Example Service Level KPI for a specific service

The E2E Latency KPI in Table 6 relates to a 5G-IANA use case providing a virtual tour, where virtual reality users will be joining a tour in a virtual environment of a double decker bus and will be represented in the Virtual Reality space with their avatars. Users will be able to receive to their Head Mounted Display the video of the tour surroundings streamed by a high resolution 360º camera mounted to a vehicle taking the real tour.

Table 6: Service Level KPI - E2E Latency

E2E Latency	KPI_SL_UC3_01
Description	The duration required to send data between two points of the service chain.
Context	In UC3 a maximum latency of 200 ms is required to maintain the communication between the users, who via their avatars will be able to gesture, speak and listen to one another.
Where to observe/measure/monitor	This KPI will be calculated by performing measurements between the Far Edge PC and the VR application server, and between the VR user application and the VR server components of the UC.
How to observe/measure/monitor	By measuring duration from when data is offered from the camera and responsible AFs/NFs until it is processed, rendered, and displayed to the VR headset of the user.
How to evaluate	UC3 requires UL video latency ≤ 200 ms.

5.3.3.4 Example Network Level KPI for a specific service

The 5G Round Trip Time (RTT) KPI in Table 7 is essential to the 5G-IANA use case implementing the integration, demonstration, and validation of advanced remote driving functionalities in the open and enhanced experimentation platform developed in the 5G-IANA project. The aim is to use a vehicle connected through 5G, which is controlled remotely via a teleoperation platform. The vehicle is equipped with both a front and a rear camera to transmit the video to the edge of the 5G network. The 5G enabled vehicle is equipped with an On-Board Unit (OBU) and connected to the edge of the network, both sending information based on its on-board sensors and video (constant feed). At the edge, an AI/ML algorithm will be processed and added on top of the video, providing information about the different elements located while driving on the road, such as pedestrians, cars, or traffic signals. An additional warning feature will be included by the use of sensors and lidars located in the vehicle, which permit to measure the distance to obstacles and to provide the driver additional information and/or stopping when a potential accident is about to happen.

Table 7: Network Level KPI - 5G RTT

5G RTT	KPI_NL_UC1_01
Description	5G Round Trip Time (RTT) between User Equipment (UE) and Edge Server.
Context	This KPI is required to guarantee a real-time experience when driving the vehicle, which is key to avoid delayed reactions and potential accidents.
Where to observe/measure/monitor	The RTT is determined between UE and Edge Server.
How to observe/measure/monitor	The RTT between UE and Edge Server is measured using PING. The measurement is started at the UE side.
How to evaluate	Average RTT ≤ 20 ms.
Comments	The use case can be executed safely if the average RTT does not exceed 20 ms.

5.3.4 KPI clustering

Service level KPIs target service performance i.e. the evaluation of the overall behaviour of a high layer service. This evaluation is based on the performance requirements of the relevant KPIs that is measured during the deployment and demonstration of services based on Network Applications, taking also into account network performance results.

In order to investigate the interrelationship between Service and Network Level KPIs, a methodology is proposed by the 5GPP Test, Measurement and KPI validation working group in the 'Whitepaper: Beyond 5G/6G KPIs and Target Values' [i.2]. This methodology urges for the mapping of the proposed KPI as an analysis tool to investigate possible aggregation/correlation between different KPI levels.

A methodology is proposed to adapt the large number of Service Level KPIs proposed due to the diverse needs of implemented services. Before mapping the service KPIs to the Network Level KPIs, they are clustered into categories based on a methodology proposed in 5G-PPP 'Service performance measurement methods over 5G experimental networks; White paper - ICT-19 performance KPIs' [i.1]. Then each cluster is mapped to the Network Level KPIs as depicted in Figure 4.

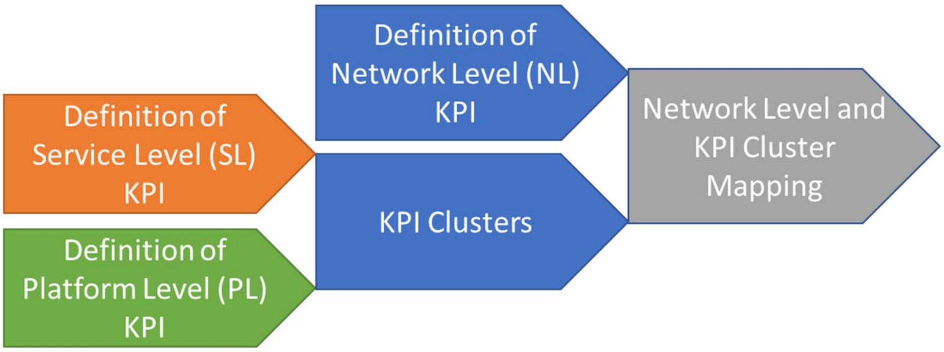

Figure 4: Procedure of mapping Service Level KPIs to Network Level KPIs

The aim of the methodology proposed is to provide a starting point for third party experimenters, by preparing a pool of KPIs that they can consider for the validation of their Network Applications. Once the KPIs of interest are identified by the external experimenter, they can look up the relevant entries in the KPI sections of the 5G-IANA UCs and discover details on the pertinent interfaces, the rationale between the KPI requirements set by each UC, etc.

The Service level KPIs of the 5G IANA UCs belong to the following five clusters defined in [i.1]:

- Latency Related: "Latency" is usually defined as the contribution of a network unit to the time from when the source sends a packet to when the destination receives it. A network unit can be a network segment or processing node. On the basis of this definition, the "Latency KPIs" category includes all KPIs that refer to latency or to latency components (contribution) of various segments/ functions/ components, at various planes.

- Packet Loss Related: The "Packet Loss" KPIs category refers to KPIs used to evaluate the packet transmission success rate of a system to transmit a defined amount of traffic within a predetermined time.

- Service Availability and Reliability Related: This KPI family cover KPIs related to service availability and reliability. Service is intentionally not defined in a specific manner, so it can cover different entities that relate to different domains.

- Capacity Related: The "Capacity" KPIs category refers to metrics that are used to evaluate the amount of network resources provided to end-users. This category includes KPIs evaluating the bandwidth resources provided per user (i.e. user data rate), the bandwidth resources provided per area surface or node (i.e. node capacity, area traffic density, etc.), and the number of connections/devices that can be served per area; as being multiple metrics of the network resources capability.

- Compute Related: This KPI cluster involves all KPIs that measurements of computing resources or computational tasks or service level KPIs that evaluate the efficiency of algorithms. This category reflects the importance of computing elements, and the fact that the use of computing resources is determinant in 5G and beyond 5G implementation, usage, and performance.

6 Testing Network Applications step 2 - Definition of validation methodology and test cases

6.1 Introduction

The main objective of the present clause is to provide a common validation methodology and technique that may be used not only within the service deployments of the 5G-IANA project partners but also in general by third party experimenters wanting to test services based on the use of Network Applications and their atomic elements. The idea is to present a comprehensive set of test cases for the existing Network Applications and services as deployed in 5G-IANA UCs as a toolbox for future Network Application validations.

Similar to the work performed for the definition of the KPIs and metrics in clause 5, a top-down approach was chosen i.e. defining first the UC related Test Case (TC) descriptions. Each TC covers functional aspects leading to Pass or Fail verdicts based on the tested behaviour and also the validation of the defined KPIs.

In view of the platform testing phase within the 5G-IANA project, which will validate software modules in a test environment and evaluate their suitability for integration into the final Automotive Open Experimental Platform (AOEP), a Test Automation framework approach is introduced describing concepts for the automatic execution of one or several test suites, one per Network Application or vertical service. It is important to note that the Network Application tests suites will be an integral part of the Network Application package, and that the test automation framework execution is triggered by a composer to validate the onboarding of Network Applications into the Network Application catalogue.

NOTE: Further information on the specifics of the 5G-IANA have been move to Annex A of the present document to keep description of the evaluation methodology generic.

6.2 Validation methodology

6.2.1 General concepts

In general, a validation methodology for Network Application based service implementations needs to provide open interfaces to monitor and operate these services for the enabling of automated testing. Therefore, it is necessary to prepare and deploy a testing framework to automate and homogenize the service validation with the objective of making the framework globally available to external users of a deployed validation platform.

In the 5G-IANA project, this task includes also the definition of a methodology to automate and homogenize testing and validation steps. The ultimate goal is to describe a common validation methodology and technique that may be used not only within the UC deployments of the 5G-IANA project partners but also by third party experimenters wanting to use the 5G-IANA platform for experimentation purposes where different proprietary services and challenges may be evaluated. The following descriptions are giving the concept developed within the 5G-IANA consortium. During the work on the Network Application validation and demonstration activities, the described concept is elaborated and tested against the AOEP and the UC deployments with the objective of defining a complete test automation framework.

A test automation framework is usually used to execute tests on a software. It builds on the following assumptions:

- The tests are part of the software development;
- User actions (if any) are simulated programmatically.

A test automation framework provides different categories of tests:

- Regression tests
- Integration tests
- Interface conformance tests
- Security tests

The benefits of automation testing include increased testing efficiency, faster feedback on the quality of the software, and the ability to run tests repeatedly without the risk of human error. It can also save time and money by reducing the need for manual testing, particularly in the case of repetitive or time-consuming tests.

6.2.2 Test automation framework

A test suite is a collection of test cases that are designed to cover the different categories of tests as introduced in clause 6.2.1. It is usually executed in the testing execution environment of an experimental platform that needs to provide the capabilities to execute one or more test suites. 5G-PPP document 'KPIs Measurement Tools - From KPI definition to KPI validation enablement' [i.8] describes how a test suite and its configuration can be integrated into a Network Application package.

It is the responsibility of a Network Application or the vertical service developers to provide the tests suites, based on the capabilities of the chosen test automation framework. It is also the responsibility of the Network Application or the vertical service developers to set up the test execution environment to execute properly the test suites.

6.2.3 Methodology to develop a test suite

The Network Application to be tested is either a single instance or a service composed of several Network Applications but tested in total and is representing the Implementation Under Test (IUT). The methodology is as follows:

1) Identify the set of Network Applications used to build the IUT.

2) Update the test automation framework configuration template file to embed the test suites to be executed (one for each Network Application category).

3) Trigger the test automation framework to execute the test suites.

4) Analyse the test automation framework reports to check the test case execution results.

5) Repeat the process until a successful execution of all test suites is achieved.

6.2.4 Deployment example - The 5G-IANA Test automation framework

6.2.4.1 Architecture of the 5G-IANA Test automation framework

The 5G-IANA test automation framework is based on the open source automation framework for test automation and robotic process automation ROBOT [i.9]. This is a test automation framework characterized by:

- Open source (Apache License 2.0);
- Python-based framework;
- Extensible keyword-driven test automation framework;
- Supporting wide range of test automation libraries and tools (e.g. Selenium, etc.).

A test suite contains:

- One configuration file containing all the required parameters to execute the test suite;
- One or more 'robot' files containing the test cases descriptions. These test cases are based on the interface provided by the Network Application;
- One or more python files providing any specific extensions for the Robot framework required to execute the test suite.

The example in Figure 5 of a ROBOT Framework test case is included to illustrate the points above. It is extracted from the ETSI MEC Test Conformance API project. The 5G-IANA test automation framework is developed as a Network Application in itself. Consequently, the complete 5G-IANA test environment is designed to be dockerized and embedded into a Kubernetes pod. A 5G-IANA test automation cluster is dedicated for Network Application and vertical service testing before to be deployed.

```
*** Settings ***

Documentation
...    A test suite for validating Radio Node Location Lookup (RLOCLOOK) operations.

Resource    ../../../pics.txt
Resource    ../../../GenericKeywords.robot
Resource    environment/variables.txt
Library     REST    ${SCHEMA}://${HOST}:${PORT}    ssl_verify=false
Library     OperatingSystem

Default Tags    TC_MEC_SRV_RLOCLOOK


*** Test Cases ***

TC_MEC_MEC013_SRV_RLOCLOOK_001_OK
    [Documentation]
    ...    Check that the IUT responds with the list of radio nodes currently associated with the MEC host and the location of each radio node
    ...    when queried by a MEC Application
    ...
    ...    Reference    ETSI GS MEC 013 V2.1.1, clause 7.3.7
    ...    OpenAPI    https://forge.etsi.org/gitlab/mec/gs013-location-api/blob/master/LocationAPI.yaml#/definitions/AccessPointList

    [Tags]    PIC_MEC_PLAT    PIC_SERVICES    INCLUDE_UNDEFINED_SCHEMAS
    Get the access points list        ${ZONE_ID}
    Check HTTP Response Status Code Is    200
    Check HTTP Response Body Json Schema Is    AccessPointList
    Should Be Equal As Strings    ${response['body']['accessPointList']['zoneId']}    ${ZONE_ID}


TC_MEC_MEC013_SRV_RLOCLOOK_001_NF
    [Documentation]
    ...    Check that the IUT responds with an error when
    ...    a request for an unknown URI is sent by a MEC Application
    ...
    ...    Reference    ETSI GS MEC 013 V2.1.1, clause 7.3.7

    [Tags]    PIC_MEC_PLAT    PIC_SERVICES
    Get the access points list        ${NON_EXISTENT_ZONE_ID}
    Check HTTP Response Status Code Is    404


*** Keywords ***
Get the access points list
    [Arguments]    ${zoneId}
    Set Headers    {"Accept":"application/json"}
    Set Headers    {"Authorization":"${TOKEN}"}
    Get    ${apiRoot}/${apiName}/${apiVersion}/queries/zones/${zoneId}/accessPoints
    ${output}=    Output    response
    Set Suite Variable    ${response}    ${output}
```

Figure 5: ROBOT framework example

6.2.4.2 5G-IANA Test automation framework workflow

The 5G-IANA test automation framework is triggered by the DevOps pipeline after the Network Application or the vertical service docker image was built and published into the registry and deployed to the 5G-IANA test environment. Figure 6 describes the procedures to trigger the 5G-IANA Test automation framework:

1) After publishing the Network Application into the registry, the DevOps pipeline triggers the execution of the 5G-IANA test automation framework;

2) The 5G-IANA test automation framework builds the list of all the tests suites to execute. If the Network Application has some dependencies to another Network Application, the 5G-IANA Test automation framework will execute the tests suite of each of these Network Applications; it should be checked whether all Network Applications are available in the catalogue;

3) If the test suites' executions are successful, the DevOps pipeline validates the whole process. If not, the DevOps pipeline process fails.

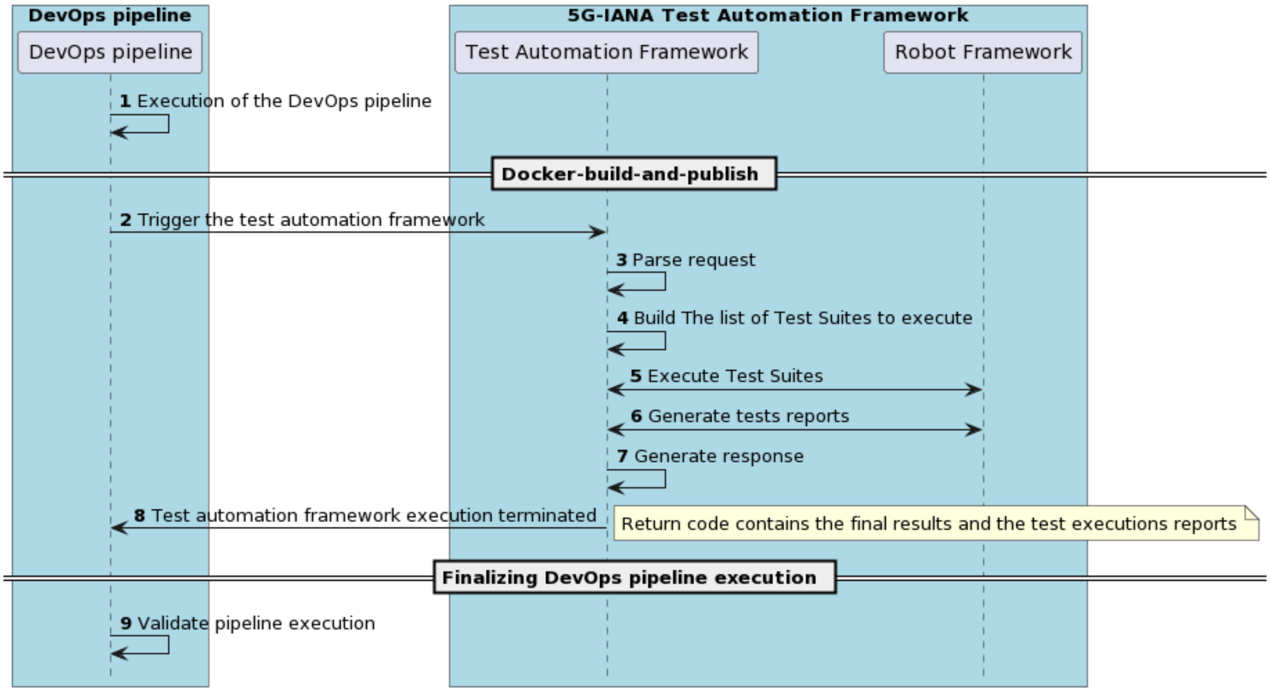

Figure 6: 5G-IANA Test automation framework synopsis

6.3 Test cases

6.3.1 Concept

The atomic elements of a test suite are the Test Cases (TCs). For the development of test suites for the evaluation of Network Applications TCs need to be chosen with a globalist view so that they cannot only serve within the Network Application deployment within a single service, but can also be reutilized by the service developers that may want to use the same test environment for the implementation, deployment and evaluation of proprietary services based on existing Network Applications and their components i.e. AFs and NFs.

In the example of the 5G-IANA project, two types of TCs are available:

- Functional tests leading to a Pass/Fail test verdict based on the observed test behaviour;
- KPI tests validating measured values e.g. Round-Trip Time Latency against the defined KPIs.

6.3.2 TC template

It is advisable to create a template to consistently describe the TC test sequence and all necessary information for its execution. As a minimum set of information, the following fields are considered necessary:

- Unique identifier allowing for exact identification/referencing of the TC
- High-level summary of the objective of the TC
- Context of the application of the TC
- KPI, identifier for KPI related tests
- Test objective i.e. testing goal and expected behaviour
- Pre-condition that are necessary for the TC execution
- Target result, needed to determine test verdict

- Test procedure, describing the TC execution steps
- Collecting data describing which information to collect and how
- Test verdict giving the criteria for determination of the test result

Table 8 acts as example for a TC template.

Table 8: TC table template

Test Case ID	**Unique identifier for each TC Example: TC_xx_yyy_##**
Summary	Short high-level description of test purpose.
Context	Either "UCx" (with x = 1 .. 7) or "AOEP" for platform tests.
KPI	KPI reference or "n/a" for functional tests.
Test objective	High level description of the test environment, the testing goal, and the expected behaviour.
Pre-conditions	Specific set of requirements, conditions or criteria that have to be met before the test can be executed in the targeted technical testing context.
Targeted result	Measurable result of the test for determination of the test verdict.
Test procedure	A step-by-step description of the actions taken to achieve the test result.
Collecting data	Description of the test data collection for the result determination.
Test verdict	For functional tests in the format: • Result condition 1: PASS • Result condition 2: FAIL For KPI evaluation, a description of the comparison between KPI and measured value(s).

6.3.3 TC examples

6.3.3.1 Introduction

To further illustrate the TC development approach, a few example TCs defined in the 5G-IANA project are shown in the following tables. A complete set of the KPIs can be observed in the 5G-IANA deliverable D5.2 'Validation methodology' [i.7].

6.3.3.2 Example functional TC

Functional tests evaluate the integration of the different components that form a UC in an incremental manner. Up to five different steps need to be validated. A first test case is checking the connectivity to the 5G network. Once the connection is up, the edge is pinged from the UC components to check visibility in all end points. The next steps are to check that the edge receives information from components deployed in a UC.

Table 9: Functional TC - Edge Connectivity Test

Test Case ID	**TC_FT_UC1_02**
Summary	OBU to Edge Connectivity
Context	UC1
KPI	n/a
Test objective	Check if the Edge and the ports used for each data flow are open and reachable.
Pre-conditions	OBU is powered on, 5G network is working properly and required ports are accessible. Visibility between OBU and edge server.
Targeted result	The OBU and Edge are reachable and can exchange data through the specific ports used.
Test procedure	1) Connect to the OBU/Edge via console/terminal. 2) Generate ICMP request from OBU/Edge to Edge/OBU. 3) Check if ICMP response is successfully received. 4) Use Netcat command for each port between OBU and Edge. 5) Check if Netcat command response is successfully received.
Collecting data	Check for PING and Netcat in console.
Test verdict	PING and Netcat commands responses successful: PASS. PING and Netcat commands are not successful: FAIL.

6.3.3.3 Example KPI TC

The KPI TCs are chosen for evaluation of target performances of the 5G network which is expected to enable Network Applications to e.g. stream video without interruptions (i.e. network and service level KPIs). Additionally, KPIs under test may focus on VPN performance and service deployment and scale-out times to demonstrate specific capabilities of the AOEP platform.

Table 10: KPI TC - E2E Reliability

Test Case ID	TC_KPI_UC3_03
Summary	E2E Reliability
Context	UC3
KPI	KPI_NL_UC3_03
Test objective	Measure and calculate the probability of successfully delivered packets from the Far Edge PC to the edge server within a target latency threshold i.e. the packets are not either erroneous, lost, or arrive too late. UC3 requires near-real time response rates to match the avatars responses with the virtual tour 360º video stream, and to achieve an engaging and responsive experience: Packet error rate causes dropped packets which can result in lagging of the video stream.
Pre-conditions	5G network is operational, and an Edge PC is connected via the 5G network to the local edge server. The OBU will handle the connection.
Targeted result	Reliability ≥ 99,99 % (packet error rate < 10^{-4}) within a latency threshold of 20 ms.
Test procedure	1) Check that the Edge PC is properly connected to the 5G network (IP connectivity established). 2) Run Wireshark tool.
Collecting data	Wireshark logs.
Test verdict	Compare results gained through the test to targeted results value.

6.3.3.4 Example AOEP TC

The AOEP Platform is composed of a set of components which provide unique capabilities and functionalities to compose and deploy Vertical Services for the automotive sector. AOEP testing focuses primarily on validating software modules using a test environment and assessing their suitability for incorporation into the final experimental testbed. This includes features and functions relating to the time required for service deployment, the use of operational resources, the time required for reconfiguration, as well as some quality measurements relating to the use of the platform and the onboarding procedure.

Table 11: AOEP TC - Reliability

Test Case ID	TC_KPI_AOEP_01
Summary	The reliability is measured using cycles of uninterrupted working intervals (uptime), followed by a repair period after a failure has occurred (downtime).
Context	AOEP
KPI	Reliability
Test objective	To check if the AOEP platform is stable.
Pre-conditions	The AOEP is deployed on the target testbed.
Targeted result	The AOEP is stable, and the value measured as MTBF = total operational time / Number of failures is higher than the KPI value.
Test procedure	1) The platform is deployed and is up and running on the target testbed. 2) The platform is used by the users. 3) Log data are collected to be evaluated.
Collecting data	Retrieves specific logs inside each component. The test will be repeated several times with increasing usage time. The exact number of test runs and the applicable usage times will be determined during the active validation phase.
Test verdict	If the Reliability of the platform is higher than the KPI value: PASS. If the Reliability of the platform is lower than the KPI value: FAIL.

7 Testing Network Applications step 3 - Test execution

7.1 Introduction

The present clause reports on test execution and validation methodology used in the 5G-IANA project but strives to establish common procedures that may be used by future activities in the field Network Application implementation and deployment. The applied test execution methodology is explained by reporting on the results of the extended technical validation of the 5G-IANA Use cases, Automotive Open Experimental Platform (AOEP) and of the Extreme Edge Orchestrator (EEO) that was carried out in the two 5G testbeds of 5G-IANA, in NOKIA, Ulm Germany and in Telecom Slovenia, Ljubljana Slovenia across two validation cycles.

7.2 AOEP validation

7.2.1 General

The validation of the AOEP Platform is a critical phase that focuses on ensuring its robustness and effectiveness for deploying Vertical Services in the automotive sector. This process stretched over two development and integration cycles, ultimately leading to a stable platform ready for testing. The validation phase incorporated both KPI validation and user feedback collection to enhance platform functionality and streamline user interactions. Testing targeted the validation of software modules within a controlled test environment, allowing for thorough assessments of their integration into NOKIA and Telecom Slovenia's experimental testbed. This comprehensive approach scrutinizes various operational aspects, such as the efficiency of service deployment, the allocation and utilization of operational resources, and the time needed for system reconfiguration. Additionally, quality measurements related to user experiences and the onboarding process were also measured. Throughout this validation process, meticulous data collection and measurement were employed using loggers and probes to gather data, along with tools for simulating the onboarding process to minimize human error deviations. This thorough methodology is designed to ascertain whether the defined KPIs have been achieved, thus providing actionable insights into the platform's performance and guiding future improvements.

In the case of the 5G-IANA deployed AOEP, the reliability and availability KPIs were evaluated first. The validation took into account a five month period in which the AOEP was active. Afterwards, testing service deployment and provisioning KPI was performed. In the following, the methodology used is described. This methodology can be adapted for any Network Application deployment platform.

7.2.2 Reliability

Reliability is seen as a function of availability, meaning that while a component may be available, it does not necessarily ensure reliability. Reliability refers to the level of confidence in a system's ability to remain functional over time, whether it is an application or a distributed service. A highly reliable system can operate independently for extended periods before experiencing issues or needing human intervention.

To measure the reliability first, the total number of hours that the system did run (3 648 hours) and the downtime (3,5 hours) are determined. In the 5 month activity timeslot, two service interruptions for failures/upgrades occurred. Consequently, the Mean Time Between Failure (MTBF) is given by the Total Uptime divided by the number of failures. So, 3 648 / 2 = 1 842 hours. The MTTR (Mean Time To Repair) measures the average time it takes to repair a system after a failure and is calculated by dividing the total downtime with the number of failures which gives 1,75 hours. The reliability can then be calculated with MTBF and MTTR with the formula: Reliability = MTBF / (MTBF + MTTR). In the case of the 5G-IANA AOEP, the result is: 1 842 / (1 842 + 1,75) = 0,999077 which in percentage is 99,9 %. The test verdict for the reliability is then determined by comparing the results with the value defined as threshold for the reliability KPI.

7.2.3 Availability

A component is only considered to deliver high quality if it exhibits both strong availability and reliability. The availability of any platform is calculated by dividing the Uptime by the total time the system was running.

In the 5G-IANA example, the Availability KPI for the AOEP was evaluated with the metrics of a total time period of 3 648 hours and an aggregated downtime of about 3,5 hours. The availability of the system was measured using the uptime tool available on the Linux system. The tool provided essential information about how long the system has been running and about the current load. Taking the measurement of availability by the formula of (Uptime / Total time) × 100 results in a 99,94 of availability and 0,1 % downtime over a five month period.

7.2.4 Service deployment and provisioning time

In addition, KPIs had been developed to assess the usability, simplicity, and effectiveness of the AOEP for vertical service developers. A validation framework needs to collect and analyse logs from each platform component to verify if a KPI is met. The evaluation of these KPIs can be influenced by various unpredictable factors, such as user expertise, which can affect the time needed to interact with the platform. To avoid this unpredictability in the 5G-IANA example, tools have been implemented to automatically onboard and deploy application images from GitLab and to ensure precise timing measurements, eliminating the variability introduced by manual user interactions.

Using this methodology, the following KPIs were evaluated:

- Service Creation Time

  Measures the duration it takes for an AOEP end-user to create a required vertical service chain.

- Service Provisioning Time

  Covers all steps of the provisioning of a service e.g. selection of Network Application, parameterization of the Network Application, deployment including allocation of 5G resources, etc.

- Service Modification Time

  Covers the duration of the complete process for modification of a deployed Network Application including the service re-provisioning.

- Service Termination Time.

  Measures the duration of the complete process for deleting a deployed Network Application.

7.3 EEO validation

The core functionality of the Extreme-Edge Orchestrator (EEO) lies in its ability to provision resources in real time for extreme-edge devices (On-Board Units - OBUs) and manage the lifecycle of the VNFs (containers) running on these devices. In the context of the 5G-IANA project, one Use Case (UC6) serves as an enabler to demonstrate this functionality, as it involves a distributed AI/ML training process (Federated Learning - FL), which allocates resource-intensive AI/ML tasks across (mobile) extreme-edge devices. The EEO is responsible for orchestrating the FL process, monitoring devices capable of participating (based on various user-defined criteria such as resource availability, device characteristics, device mobility, etc.), and selecting these devices (client selection) through the interfaces provided by the 5G-IANA platform.

The validation and evaluation process for the EEO was conducted during the project's development in the following testing steps:

- A series of functional and unit tests to verify the internal operations of the EEO.
- Communication/interface tests over the 5G-IANA platform with other components, such as Resource Inventory, Prometheus Monitoring System, UC6's Aggregation Node VNF, and Policy Executor.
- Two live demonstrations in conjunction with UC6.
- A set of dedicated in-lab test scenarios.

For further details of the EEO validation, see clauses 3.4 and 4.6 of 5G-IANA D5.3 'Technical validation and demonstration of the UCs' [i.10].

7.4 UC validation

All seven UCs of the 5G-IANA project have been comprehensively tested evaluating all relevant KPIs defined in 5G-IANA D5.1 'Initial validation KPIs and metrics' [i.6], implementing and executing the test cases defined in 5G-IANA D5.2 'Validation methodology' [i.7].

The exact methodology used per UC is proprietary to the services and behaviours in each UC and are therefore not documented in detail in the present document.

The complete description of the individual test methods applied, and test results achieved can be found in clause 4 of 5G-IANA D5.3 'Technical validation and demonstration of the UCs' [i.10].

Annex A: The 5G-IANA project - Overview

A.1 5G-IANA, the project

The 5G-IANA project (see https://www.5g-iana.eu/) aims at providing an open 5G experimentation platform, on top of which third-party experimenters, i.e. SMEs in the Automotive vertical sector will have the opportunity to develop, deploy and test their services. The provided Automotive Open Experimentation Platform (AOEP) is a set of hardware and software resources that provides the computational and communication/transport infrastructure. This is coupled with management and orchestration components, as well as an enhanced network application Toolkit tailored to the Automotive sector, for simplifying the design and onboarding of new network applications. 5G-IANA exposes to experimenters Application Programming Interfaces (APIs) for facilitating all the different steps towards the production stage of a new service. The platform supports different virtualization technologies integrating different Management and Orchestration (MANO) frameworks for enabling the deployment of end-to-end network services across different segments (vehicles, road infrastructure, Multi-access Edge Computing (MEC) nodes and cloud resources). The 5G-IANA network application toolkit is linked with an Automotive Networks/Application Functions Repository including an extensive portfolio of ready-to-use and openly accessible Automotive-related functions and network application templates, which are available for SMEs to use and develop new applications. Overall, 5G-IANA aspires to encourage third parties to test novel software or hardware or use cases by exploiting the platform capabilities.

The project was funded under the H2020-ICT-41-2020 call (Grant Agreement No. 101016427) in the framework of the HORIZON2020 work programme of the European Union and ran from June 2021 to November 2024. The 5G-IANA consortium consists of 16 partner including 8 SMEs distributed as shown in Figure A.1:

Figure A.1: 5G-IANA project partner distribution

A.2 5G-IANA, the AOEP

The 5G-IANA Automotive Open Experimentation Platform (AOEP) is specifically conceived for simplifying and automating the management of network applications onto programmable infrastructures, and particularly 5G. At a glance, the proposed platform aims to mostly hide the complexity of programmable infrastructure and 5G environment to service developers and providers, and to make the development, deployment and operation of 5G-ready applications similar to the well-known corresponding processes applied to cloud-native applications in cloud computing environments.

Figure A.2 shows the 5G-IANA conceptual architecture at a high-level view, and highlights the two-layered Orchestration stack: the Network Application Orchestration and Development (layer 1), the Slice Management & Multi-Domain Orchestration, the virtualized infrastructure segments (layer 2) along with the cross layer supported functionalities: The Distributed AI/ML framework (cross-layer), the Monitoring & Analytics, and the Distributed Data Collection (cross-layer).

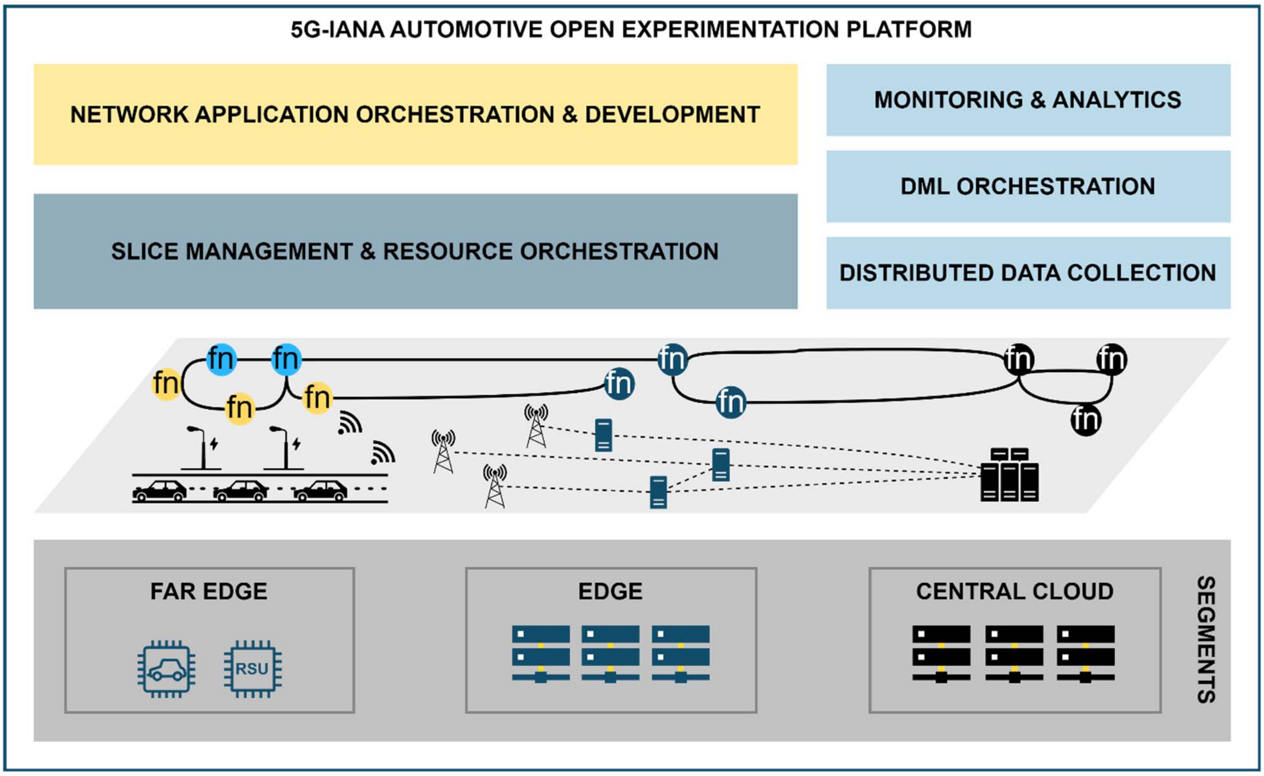

Figure A.2: 5G-IANA Orchestration Layers abstraction

The separation of the 5G-IANA orchestration platform functionalities between the two aforementioned layers serves the need to operate between the following two different administrative domains: the Application Domain (in yellow) and the Infrastructure Domain (in blue). The distinction of layers targets the different "work-burden" that has to be achieved and managed. This way, the tools of the orchestration are targeting two lifecycles and specifically those: a) of the application and b) of the programmable infrastructure and network services. In this sense, the 5G-IANA Platform is comprised of a set of orchestration tools with each set devoted to its specific (applicative or network) administrative domain. Each administrative domain is mainly targeted for a specific stakeholder's needs: for the Application Domain the stakeholders are network applications developers of various automotive vertical industries, while for the Infrastructure Domain the stakeholders are programmable infrastructure owners including 5G network operators. Specifically, the Slice Management & Resource Orchestration Layer handles communication with various edges including the on-vehicle MANO. Given that the OBUs and Road Side Units (RSUs) are part of the programmable resources, the specific work described is undertaken by the Slice Management & Resource Orchestration Layer.

The 5G-IANA's network application Toolkit enables developers to create brand-new network applications and vertical automotive services which can exploit 5G services with specific requirements and functionalities, and which can be deployed over a 5G infrastructure. The goal of the Toolkit is to make it easier to chain together and customize 5G-ready vertical services with the help of functionalities provided by the Vertical App Composition & Customization as well as by the network application catalogue. This enables the on-boarding and updating of network applications Packages and related components from software providers.

The Toolkit communicates from one side with the Application Orchestrator which manages the deployment requests. On the other side, the network application Toolkit exposes its services directly to the network application and Vertical service developers providing features to:

- register Application and Network Functions (AFs/NFs) as atomic components;
- compose network applications and vertical services in a graphical, intuitive, and simple way;
- onboard network applications and vertical services for future use.

A.3 5G-IANA, the Starter-kits

5G-IANA has created network application "Starter-kits" specifically designed to aid in the development of advanced Automotive Vertical Services. These kits are intended to support the creation of Vertical Services within identified service categories by providing a baseline set of AFs/NFs (atomic components) for deployment. By utilizing these kits, service creators and providers can better leverage the resources available through the 5G infrastructure, including the ability to orchestrate and run applications on Far-edge resources like OBUs and RSUs. As each Vertical has unique needs and requirements, 5G-IANA offers a variety of such open-source network application "Starter-kits," each designed to support the roll-out of 5G-IANA and third-party UCs. These kits are available as ready-to-use network application packages that contain all the relevant information necessary for their usage in specific contexts/scenarios.

In addition to facilitating the development of advanced Automotive Vertical Services, the network application "Starter-kits" also aim to provide Verticals with the necessary knowledge to understand the specific purpose and usage of low-level functionalities. This is particularly important as the deployment of certain AFs/NFs may be required to consume and forward information on top of an OBU, such as Intelligent Transport Systems communication functions.

For example, Figure A.3 provides an illustration of network application "Starter-kits" for a manoeuvres' coordination service, highlighting two different kits, each designed to aid in the implementation of specific functionalities. The AFs highlighted in purple in, Figure A.3 are customizable and can be integrated by experimenters and third parties looking to provide a specific logic/algorithm for the Manoeuvres Planning functionality.

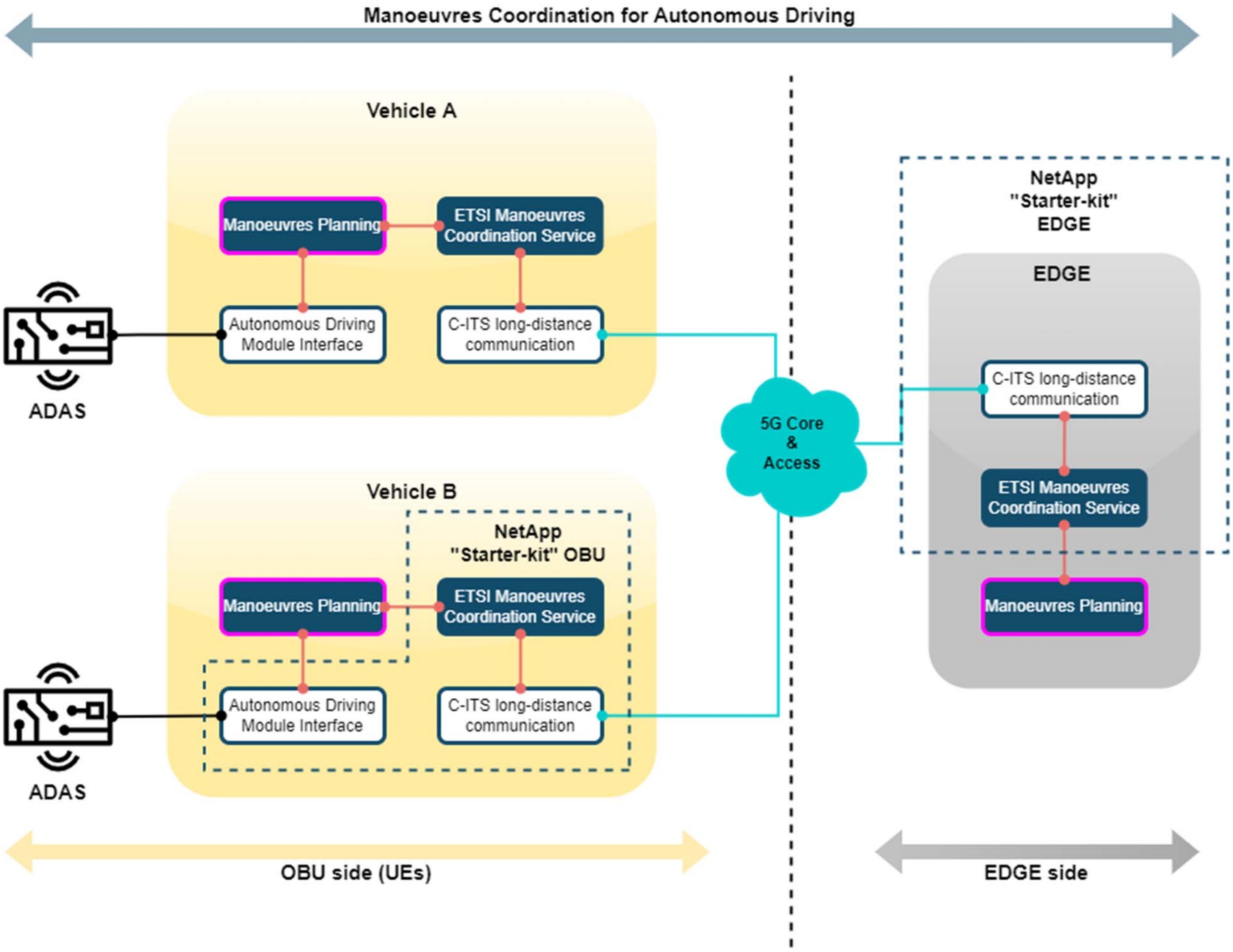

Figure A.3: Manoeuvres Coordination for Autonomous Driving network application "Starter-Kits" Example

Overall, the integration of network application "Starter-kits" aims to streamline the development of advanced Automotive Vertical Services and enhance the utilization of resources available through the 5G infrastructure.

Annex B: The PoDIUM project - Overview

B.1 PoDIUM, the project

Cooperative, Connected and Automated Mobility (CCAM) is seen as a key to enhancing the availability of mobility services for everyone. The implementation of systems for road traffic, especially for cooperative behaviour, relies on seamless communication among the road users themselves (vehicle-to-vehicle) and also between each of them and the infrastructure part of the system (vehicle-to-infrastructure), jointly named vehicle-to-anything communication. Overall, such a CCAM system requires advanced Physical and Digital Infrastructure (PDI), where the physical part comprises of classical road infrastructure like traffic signs or traffic lights as well as, e.g. communication networks and computation capabilities, not forgetting the vehicles themselves. Examples for the digital part are digital maps together with digitally processable descriptions of the traffic rules as well as the data collected, processed, and communicated by the road users and the infrastructure.

The PoDIUM project (see https://podium-project.eu/), which is funded by the EU within its Horizon Europe program, addresses the need of such PDI enhancements by developing and realizing five CCAM use cases in three living labs in Germany, Italy and Spain.

PoDIUM aims at increasing traffic efficiency and, thus, reducing the carbon footprint of road traffic. PoDIUM will pursue tangible impact to the respective domains by providing input to respective standardization bodies from real-world experience with such a CCAM system, and the methodologies for evaluating and testing the communication aspects of the networks used.

The project was funded under the HORIZON-CL5-2021-D6-01-03B call (Grant Agreement No. 101069547) in the framework of the HORIZON EUROPE work programme of the European Union and runs from June 2022 to May 2025. The PoDIUM consortium consists of 26 partners from 8 countries distributed as shown in Figure B.1:

Figure B.1: PoDIUM project partner distribution

B.2 PoDIUM, the PDI architecture

The PoDIUM consortium has developed a generic PDI architecture that allows the realization of new CCAM UCs, ensuring interoperability between the different deployments. A bottom-up approach to derive the architecture was chosen, by first deriving the following sub-views of the overall architecture:

- Communication view;
- Functional view;
- Data flow and storage view;
- Information Technology (IT) environment view;
- Software integrity and data truthfulness view.

Each of the views allows respective experts to easily understand the design and needs of this architecture for their field and to derive an implementation for a specific UC. Due to the common architecture, the implementations remain interoperable, e.g. with respect to data interfaces using CCAM related messages.

From the detailed views, an overall high-level view, as shown in Figure B.2, was derived to highlight the main contributions that PoDIUM will provide on a technical level across all LLs and UCs.

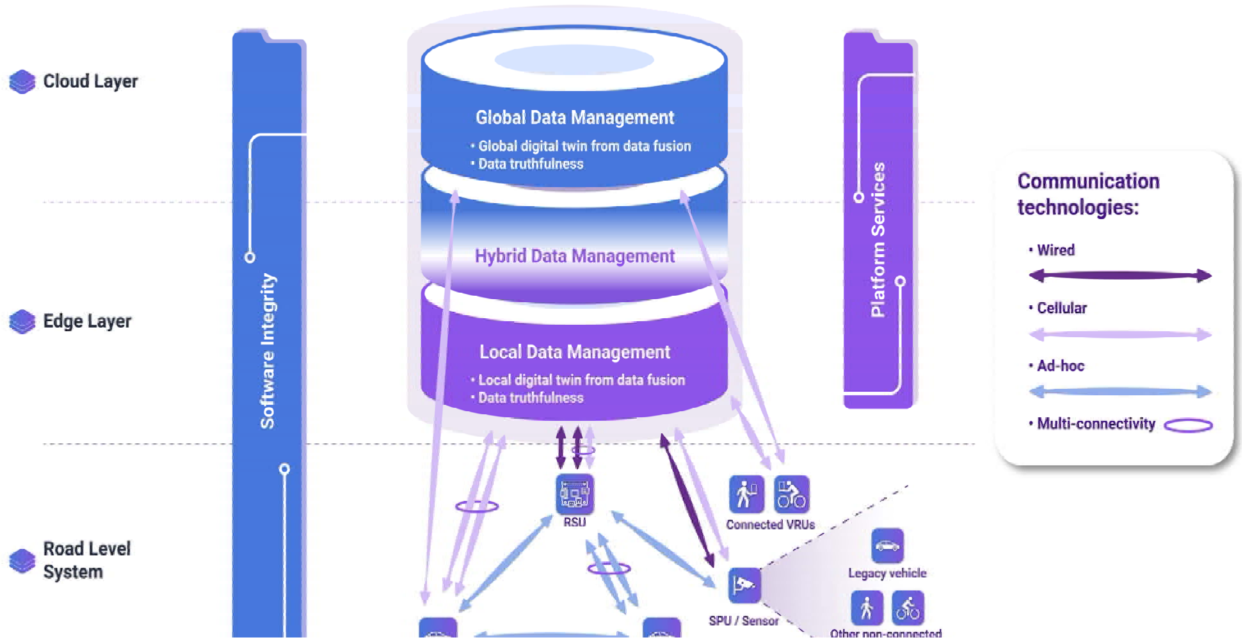

Figure B.2: High-level overview of the PoDIUM architecture

All types of road users are considered and supported, namely legacy (non-connected) vehicles and other non-connected road users; connected Vulnerable Road Users (VRUs) with a cellular User Equipment (UE); Connected conventional Vehicles, connected Emergency Vehicles and Connected Automated Vehicles with an On-Board Unit.

The platform services are either hosted on a MEC server or on the central cloud, determined mainly by their latency requirements. To ensure the integrity of the software and exchanged CCAM data, a trusted computing approach is developed on Trusted Platform Modules. Many services depend on a digital twin, which fuses incoming information from different sources (e.g. CCAM related messages and infrastructure sensor data) into an enhanced environmental model. Thus, the reliability of the digital twin data and, in consequence, of its sources is crucial. To reinforce this aspect, the PoDIUM architecture includes trust building and data truthfulness evaluation of data sources.

B.3 PoDIUM, the communication view

Communication technologies available for CCAM can be characterized in terms of communication range, reliability, latency, capacity, and costs. A basic classification is on cellular and ad-hoc ones.

Cellular network communication, also called mobile network communication, provides extended coverage through the deployed network infrastructure, and can be further classified into LTE and 5G cm-Wave is wireless communication in frequency bands between 450 MHz and 6 GHz, and 5G mm-Wave in frequency bands between 24,25 GHz and 52,60 GHz.

Ad-hoc wireless network communication enables end-user devices to communicate without relying on cellular network infrastructure, wireless access points or any other traditional network infrastructure equipment. ITS-G5 is an amendment to the IEEE 802.11 [i.11] WLAN standards to add wireless access in vehicular environments, for a vehicular communication system. Sidelink refers to direct communication between UEs without the data going through the network, based on the 3GPP standards LTE and 5G. The Sidelink interface does not necessarily require assistance from a mobile network and provides restricted (local) coverage with moderate to low throughput rates combined with very low latency.

PoDIUM further deploys and studies the Multi-Connectivity and Hybrid Communication types.

- In hybrid communications, all messages are transmitted simultaneously across all available communication technologies, ensuring that each message and data packet is duplicated for delivery via every communication interface. This approach creates a high level of redundancy, without considering the criticality of individual messages or data packets. Hybrid communication is enabled by routing functions built into every entity utilizing this capability.

- Multi-connectivity enables communication devices to intelligently manage and schedule messages and data packets across multiple available communication technologies. By selecting the optimal transmission technology or combination of technologies at the time of data transmission, multi-connectivity enhances the reliability, availability, and redundancy of the PDI system, and can also improve latency. The scheduler defines the criteria for selecting an interface, which can be adjusted dynamically as needed.

These aspects are comprehensively addressed within the PoDIUM project and are summarized as illustrated in Figure B.3. This communication framework provides an abstract representation of the PoDIUM communication architecture, meeting the diverse requirements of various use cases. As a standards-compliant, unified platform, it promotes efficient communication, data exchange, and collaboration among the different entities within each PoDIUM use case.

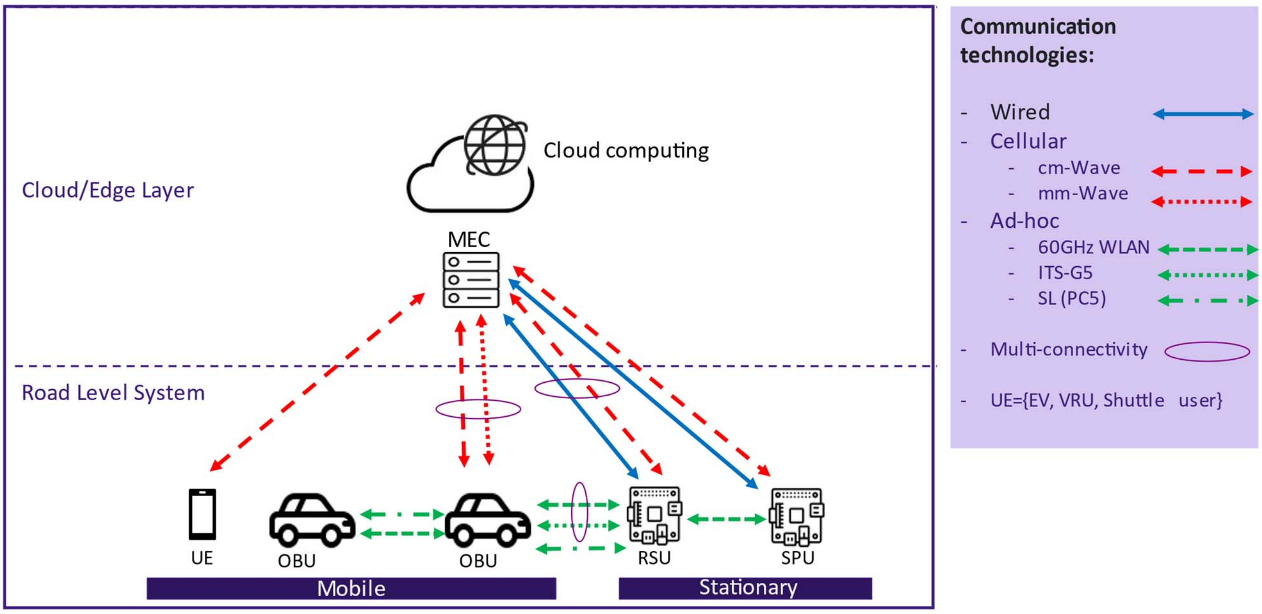

Figure B.3: High-level communication view of the PoDIUM system

History

Document history		
V1.1.1	January 2025	Publication