D2.1 – Specifications of the 5G-IANA architecture

Dissemination level:	Public (PU)
Work package:	WP2
Tasks:	T2.1, T2.2, T2.3, T2.4
Deliverable lead:	LINKS
Version:	V2.0
Submission date:	30/05/2022 and 21/10/2022
Due date:	31/05/2022
Partners:	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101016427

www.5g-iana.eu

Authors

Authors in alphabetical order		
Name	**Organisation**	**Email**
Alexis Aivaliotis	O7	aaivaliotis@oseven.io
Amr Rizk	UULM	amr.rizk@uni-due.de
Claudio Russo	BYL	claudio.russo@bylogix.it
Daniele Brevi	LINKS	daniele.brevi@linksfoundation.com
David Alemany	5COMM	david.alemany@fivecomm.eu
David Martín-Sacristán	5COMM	david.martin-sacristan@fivecomm.eu
Dimitris Klonidis	UBI	dklonidis@ubitech.eu
Edoardo Bonetto	LINKS	edoardo.bonetto@linksfoundation.com
Eirini Liotou	ICCS	eirini.liotou@iccs.gr
Fotis Foukalas	COGN	fotis@cogninn.com
Francesca Moscatelli	NXW	f.moscatelli@nextworks.it
Gabriele Scivoletto	NXW	g.scivoletto@nextworks.it
George Karagiannopoulos	HIT	g.karagiannopoulos@hit-innovations.com
Giada Landi	NXW	g.landi@nextworks.it
Giorgos Adamakis	COGN	giorgos@cogninn.com
Héctor Donat	5COMM	hector.donat@fivecomm.eu
Janez Sterle	ININ	janez.sterle@iinstitute.eu
Joerg Schaepperle	NOKIA	joerg.schaepperle@nokia-bell-labs.com
Konstantinos V. Katsaros	ICCS	k.katsaros@iccs.gr
Manuel Fuentes	5COMM	manuel.fuentes@fivecomm.eu
Marios Zinonos	HIT	m.zinonos@hit-innovations.com
Markus Wimmer	NOKIA	markus.wimmer@nokia.com
Matteo Andolfi	NXW	m.andolfi@nextworks.it
Nehal Baganal Krishna	UULM	Nehal.Baganal-Krishna@wiwinf.uni-due.de
Pasquale Marasco	BYL	pasquale.marasco@bylogix.it
Rudolf Susnik	ININ	rudolf.susnik@iinstitute.eu
Thanos Xirofotos	UBI	txirofotos@ubitech.eu
Theodoros Rokkas	INC	trokkas@incites.eu
Yann Garcia	FSCOM	yann.garcia@fscom.fr

Control sheet

Version history			
Version	**Date**	**Modified by**	**Summary of changes**
0.0	27/01/2022	LINKS	Draft Table of Contents
0.1	06/05/2022	NXW, UULM LINKS	Initial contributions to Sections 2, 3, 5, 6
0.2	09/05/2022	ICCS, NXW, INC	New contributions to Section 2
0.3	13/05/2022	UBI, UULM, NXW	New contributions to Section 4, 5, 7, 8
0.4	21/05/2022	HIT, 5COMM, BYL, UULM, COGN, O7, ININ, NOKIA, FSCOM	Contributions to Section 8
0.5	25/05/2022	NXW, LINKS, ICCS, UULM, UBI	Revisions and contributions to all sections
0.6	27/05/2022	NXW, LINKS, ICCS, UULM, UBI, INC, HIT	Additional revisions and contributions
1.0	30/05/2022	NXW, LINKS, ICCS, UULM, UBI	Final revisions
2.0	21/10/2022	NXW, LINKS, ICCS, UULM, UBI, 5COMM, BYL, HIT, COGN, O7, ININ	Major revision based on the recommendations from the interim project review

Peer review		
	Reviewer name	**Date**
Reviewer 1	Giada Landi (NXW)	20/05/2022
Reviewer 2	Francesca Moscatelli (NXW)	21/05/2022
Reviewer 3	K. Katsaros (ICCS)	24/05/2022
Reviewer 4	Dimitris Klonidis, Thanos Xirofotos (UBI)	15/10/2022

Legal disclaimer

The information and views set out in this deliverable are those of the author(s) and do not necessarily reflect the official opinion of the European Union. The information in this document is provided "as is", and no guarantee or warranty is given that the information is fit for any specific purpose. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein. The 5G-IANA Consortium members shall have no liability for damages of any kind including without limitation direct, special, indirect, or consequential damages that may result from the use of these materials subject to any liability which is mandatory due to applicable law.

TABLE OF CONTENTS

List of Figures

List of Tables

ABBREVIATIONS

Abbreviation	Definition
3GPP	3rd Generation Partnership Project
5G-IA	5G Infrastructure Association
5G-PPP	5G Infrastructure Public Private Partnership
ADAM	Adaptive Moment Optimization
ADAS	Advanced Driver-Assistance Systems
AF	Application Function
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AO	Application Orchestrator
AOEP	Automotive Open Experimentation Platform
API	Application Programming Interface
AR	Augmented Reality
AVR	Automotive VNFs Repository
B2B	Business-to-business
B2C	Business-to-consumer
B5G	Beyond 5G
BR	Business Requirement
CAF	Cloud-native Application Function
CAN	Controller Area Network
CCAM	Connected, Cooperative and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CL	Client
CNF	Cloud-native Network Function
CRUD	Create, Read, Update, and Delete
DML	Distributed Machine Learning
DoA	Description of Action
E2E	End-To-End

EAC	Edge and Cloud infrastructure segments
EC	European Commission
ECU	Electronic Control Unit
eMBB	enhanced Mobile Broadband
ETSI	European Telecommunications Standards Institute
FL	Federated Learning
GPU	Graphics Processing Unit
GVI	General Virtualized Infrastructure
HD	High Definition
HMI	Human-Machine Interface
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LCM	LifeCycle Management
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
mIoT	Massive IoT
ML	Machine Learning
MNO	Mobile Network Operator
NASK	NetApps "Starter-Kits"
NAT	NetApps Toolkit
NBI	North-Bound Interface
NEST	NEtwork Slice Type
NF	Network Function
NFV	Network Function Virtualization
NFVO	NFV Orchestrator

NOD	NetApp Orchestration and Development
NSD	Network Service Descriptor
OBU	On-Board Unit
ONAP	Open Network Automation Platform
OPEX	OPerating EXpenses
OS	Operating System
OSM	Open Source MANO
OVM	“On-Vehicle” MANO
PAF	Physical Application Function
PNF	Physical Network Function
PPDR	Public Protection & Disaster Relief
PU	Public
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RMSProp	Root Mean Square Propagation
RO	Resource Orchestrator
RSU	Road-Side Unit
RTT	Round Trip Time
SA	Stand Alone
SAP	Service Access Point
SBI	South-bound Interface
SD	Service Descriptor
SDK	Software Development Kit
SGD	Stochastic Gradient Descent
SLA	Service Level Agreement
SM	Slice Manager
SME	Small and Medium Enterprise
SR	System Requirement
SRF	System Requirements Functional

SRNF	System Requirements Non-functional
SW	Software
UE	User Equipment
UHD	Ultra High Definition
UR	User Requirement
URLLC	Ultra Reliable Low Latency Communications
VAF	Virtual Application Function
VL	Virtual Link
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	VNF Descriptor
VSB	Vertical Service Blueprint
VSD	Vertical Service Descriptor
WP	Work Package

Executive Summary

This deliverable has the objective to provide the outcomes of the activities performed in Work Package (WP) 2 “Specifications”. The activities included the design of the 5G-IANA Automotive Open Experimentation Platform (AOEP) and the requirements specification of each architecture layer. The specified 5G-IANA architecture capitalizes on the 5G prospect of being a unified multi-service platform by orchestrating Vertical Services based on virtualized network slices and a coordination of distributed edge-to-cloud deployment.

The 5G-IANA AOEP aims to provide an open and flexible experimentation platform to third-parties developers (e.g., SMEs) that want to develop new 5G-based services devoted to the Automotive vertical. The availability of an easy-to-use experimentation environment can facilitate the launch of new services creating new market opportunities. Moreover, 5G-IANA will actively address the configuration of the 5G network (e.g., network slicing, edge resources, etc.) with the objective of supporting in the best way the requirements of the new services. In this way, it will be also possible to verify if the current 5G implementation can adequately satisfy the highly demanding performance requirements of the Automotive services.

The two main layers of the AOEP architecture are the NetApp Orchestration and Development (NOD) layer and the Slice Management and Resource Orchestration layer. The first one offers the functionalities to design, model, and provision a Vertical Service/NetApp, while the Slice Management and Resource Orchestration layer is in charge of allocating and managing the 5G Network Slices and the compute resources of the 5G-IANA infrastructure. Other layers of the 5G-IANA AOEP are the Distributed Machine Learning (DML) Orchestration layer, which manages DML Vertical Services/NetApps, the Monitoring and Analytics layer, and the Distributed Data Collection layer.

The AOEP integrates the ability to manage and orchestrate Services/NetApps across an extended compute continuum and comprises of multiple interconnected and virtualized segments including centralized, edge and far-edge resources. In the latter case the integrated virtualized infrastructure segment includes resources constituted by Cooperative Intelligent Transport Systems (C-ITS) equipment, namely the On-Board Units (OBU) on the vehicles and by Road-Side Units (RSU).

This deliverable, apart from the requirements specification of each introduced layer, provides an overview of the 5G-IANA related State-of-the-Art solutions, and it introduces the advances brought by 5G-IANA. An overview of the requirements specified for the

use-cases, that will be demonstrated within the 5G-IANA project, is included as well in this deliverable as it supported the design of the AOEP.

1. INTRODUCTION

1.1. 5G-IANA concept and approach

5G-IANA aims at providing an open 5G experimentation platform, on top of which third party experimenters, i.e., Small and Medium Enterprises (SMEs) in the Automotive vertical sector will have the opportunity to develop, deploy and test their services. An Automotive Open Experimentation Platform (AOEP) will be specified, as the whole set of hardware and software resources that provides the computational and communication/transport infrastructure as well as the management and orchestration components, coupled with an enhanced Networked Application (NetApp) Toolkit tailored to the Automotive sector, for simplifying the design and onboarding of new NetApps. 5G-IANA will expose to experimenters secured and standardized Application Programming Interfaces (APIs) for facilitating all the different steps towards the production stage of a new service. 5G-IANA will target 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). 5G-IANA NetApp toolkit will be linked with a new Automotive Virtual Network Functions (VNFs) Repository including an extensive portfolio of ready to use and openly accessible Automotive-related VNFs and NetApp templates, that will become available for SMEs to use and develop new applications. Finally, 5G-IANA will develop a Distributed Machine Learning (DML) framework, that will provide functionalities for simplified management and orchestration of collections of Machine Learning (ML) service components and will allow ML-based applications to penetrate the Automotive world, due to its inherent privacy preserving nature. 5G-IANA will be demonstrated through seven Automotive-related use cases in 2 5G Stand Alone (SA) testbeds. Moving beyond technological challenges, and exploiting input from the demonstration activities, 5G-IANA will perform a multi-stakeholder cost-benefit analysis that will identify and validate market conditions for innovative, yet sustainable business models supporting a long-term roadmap towards the pan-European deployment of 5G as key advanced Automotive services enabler.

1.2. Purpose of the deliverable

The purpose of this deliverable is to report the architecture of the 5G-IANA AOEP and the requirements of the AOEP that have been specified for each layer of the AOEP.

1.3. Intended audience

The dissemination level of this deliverable is "public" (PU). It is primarily aimed to be the reference document to be used by the 5G-IANA Consortium Members during the development and integration phases of the 5G-IANA project. Furthermore, this deliverable is addressed to any interested reader (i.e., public dissemination level) who wants to be informed about the 5G-IANA AOEP architecture, and especially any third-parties who would be interesting in experimenting on this platform.

2. OVERVIEW OF THE 5G-IANA AUTOMOTIVE OPEN EXPERIMENTATION PLATFORM

This section introduces the main aspects of the 5G-IANA Automotive Open Experimentation Platform (AOEP). First, an overview of the actors, that constitute the 5G-IANA ecosystem, is provided in Section 2.1. The objectives of 5G-IANA are recapped in Section 2.2. The definitions of the AOEP building blocks are provided in Section 2.3. A high-level system design of the 5G-IANA AOEP architecture is provided in Section 2.4, while the methodology, which has been followed for the specification of the requirements, is presented in Section 2.5.

2.1. 5G-IANA ecosystem and technologies providers

This section provides an overview of the actors that are part of the 5G-IANA ecosystem. The term actor includes an entity that participates in the ecosystem and may provide or consume resources or services. A role is defined as a function within the business model of the ecosystem. Each actor may have one or several roles from the following ones:

- **Mobile Network Operators (MNO)**: they deploy and operate the telecommunication infrastructure that is required for connectivity (core and Radio Access Network - RAN). They own the physical equipment such as base stations, antennas, switches, etc.
- **Cloud Infrastructure Providers**: they provide all required storage, cloud computing and corresponding networking resources (CPUs, RAM, storage). These can be in a central (cloud location) or local location, edge servers.
- **Road Infrastructure operators**: they are responsible for the deployment, operation, and maintenance of the road infrastructure. They can also own and operate road-side facilities such as ICT equipment, cameras and sensors located in the road networks.
- **HW Vendors**: they provide all type of hardware to all interested parties, for example base stations, antennas, switches, routers, servers, network cards, sensors, cameras, CPUs, RAM, Road-Side Units (RSU), On-Board Units (OBU), entertainment systems, etc.
- **SW vendors**: they provide all the necessary software that is required by all other parties. For example, the firmware that is required for the hardware devices, all type of applications, software for the entertainment systems, etc.

- **Vehicle Manufacturers**: entities that are in charge of manufacturing all type of vehicles.
- **Regulatory Authorities**: it includes authorities at national and European level that are responsible for defining the legal framework. It includes authorities responsible for issues like privacy, telecommunications, and security.
- **Standardization Bodies**: includes national and international entities that define standards (these will be adopted by the telecom and automotive industries). Some examples are 3GPP, IEEE, ETSI, ITU, IETF.
- **Policy Makers**: it includes authorities at national and international level that are responsible for defining policies. It also includes governmental entities such as municipalities or city administrators.
- **R&D**: research centres and academic institutions that are responsible for the development and testing of upcoming technologies and applications.
- **Service Creators**: all type of service creation entities such as SMEs, and software developers.
- **Service Providers**: they are responsible for providing the service to end users (for example Intelligent Driving, HD maps, etc.).
- **Application and Network Functions Developers:** they develop the Application Functions (AFs) and Network Functions (NFs) that can be used as building blocks for creating NetApps[1].
- **Application and Network Functions Providers:** they are responsible for providing the AFs and NFs to be on-boarded trough the functionalities provided by the NetApp Toolkit platform component presented in Section 3.5.
- **NetApp Developers**: they are responsible for the development of NetApps.
- **NetApp Providers**: they are the ones that provide the NetApps either to end users or service creators/providers.
- **End Users**: includes all type of users that are the recipients of the services. They can be individual users (B2C) or business customers (B2B). Some examples are vehicle owners, drivers, passengers or pedestrians for end users and transport operators, traffic management, freight and logistics, or providers of public services.
- **Third-parties**: includes all the 5G-IANA AOEP's experimenters which are outside of the 5G-IANA consortium; the third-parties can include some of the categories

[1] The definitions for Application functions, Network Functions and NetApps are presented in Section 2.3.

already mentioned, such as the Service Creators, Application and Network Functions Developers, NetApp Developers.

Evidently, a certain stakeholder in the emerging ecosystem may well hold more than one of these roles. Characteristic examples include Service Creators, who may be a SW Vendor, a NetApp Provider can be a Service Provider, a NetApp Developer may be a SW Vendor. The identification and this fine-grained distinction between roles aim to highlight the focus areas and different specializations, not indicating necessarily the emergence of distinct stakeholders.

2.2. High-level objectives of the 5G-IANA AOEP architecture

In the context of 5G-IANA, an Automotive Open Experimentation Platform (AOEP) is specified as the whole set of hardware and software resources that includes the computation and communication/transport infrastructure as well as the management and orchestration components, coupled with an enhanced NetApp (Network Application) Toolkit tailored to the Automotive sector.

The main objectives of the AOEP platform are the following:

- To form an enhanced Automotive-related experimentation infrastructure (including the vehicles) where an AFs/NFs Repository will exist, along with the hosting of a number of NetApp Starter Kits, i.e., simple examples of different NetApps that third parties can use as baseline to develop their own NetApps or can include in Vertical Service chain to consume exposed services.
- To provide capabilities and functionalities for designing, validating, and benchmarking/experimenting Vertical Services and their components (i.e., NetApps and NFs/AFs) and thus, provide functionalities for easing the design and chaining of new Automotive-related services.
- To deploy and orchestrate Vertical Services from both the application and the networking point of view and to monitor and dynamically adapt them at run-time.
- To allow the implementation of services at the edge of the network (on OBUs and RSUs), reducing in this way the end-to-end application latency of services, but also further supporting privacy for sensitive application data. Especially, to implement/integrate a “lightweight” orchestration on top of OBUs/RSUs for offering a more flexible and scalable management of Vertical Services and constituent NetApps and AFs/NFs.
- To develop a DML framework as the means to allow ML-based applications to penetrate the Automotive world. The DML framework shall abstract and simplify

common application-agnostic DML operations e.g., Federated Learning iterative process.

- To deploy Automotive services with extremely low service creation time (instantiation and re-configuration).
- To be operator and segment agnostic, enabling cross-domain and cross-platform interoperability.
- Overall, to create an open accessible environment in which third party developers can experiment and test their applications with ease.
- In total, to create new business opportunities and boost market for start-ups and SMEs with Automotive NetApps.
- According to these objectives, the AOEP is designed as a multi-layered platform that extends from the end user (application) layer to the infrastructure layer and optimally combines context and network infrastructure aware functionalities for the deployment of advanced services represented as linked chains of virtualised functions (application, network, and communication functions).

2.3. Definitions of 5G-IANA AOEP

This subsection introduces the definition of the main building blocks of the 5G-IANA AOEP.

2.3.1. NetApp

In 5G-IANA a NetApp is defined as a virtualised composite network application that can be deployed over a 5G infrastructure and can use 5G services (e.g., connectivity, localization etc.). The NetApp components are referred to as functions. The NetApp concept extends the typical orchestration-oriented descriptors proposed in ETSI NFV (e.g., Virtual Network Function Descriptors – VNFDs and Network Service Descriptors - NSDs). Additional information that should facilitate the re-usage, customization, integration, and provisioning of NetApps in diverse environments that encompass Cloud, Edge and Far-Edge infrastructure is what defines them. A NetApp can be composed by one or multiple Application Functions (AFs) or Network Functions (NFs). The AFs correspond to the NetApp components that implements the application logic, while NFs implement functionalities of the NetApp related to networking and communication (e.g., ICT long-distance communication functionalities). AFs and NFs are deployed using cloud-native orchestration techniques, then we refer to them also as Cloud-native AFs (CAFs) and Cloud-native NFs (CNFs). Each function in a NetApp, or the entire NetApp, may be deployed either at the Central/Remote Cloud or at the Edge levels. Descriptors for both functions and NetApps should specify which level they will have to be deployed to, by either forcing a function to be deployed on a specific level, or allowing a function to exist in multiple levels and switching levels dynamically based on performance-related policies.

In order to facilitate the NetApp re-usage, the NetApp Package format used in 5G-IANA includes service-level information, e.g., the specification/documentation of supported interfaces, to enable the sharing of the NetApp and its composition with other NetApps. The composition of NetApps allows to build advanced Vertical Services, which result in distributed chain of multiple NetApps. In addition, each NetApp Package also includes the specification of main characteristics of the required 5G slice profile for proper operation of the NetApp. Finally, further information is provided in the NetApp Package, such as the test cases documentation, correlated with test scripts and collected results, the list of relevant metrics to be monitored and the list of Key Performance Indicators (KPIs) to assess the Vertical Service behaviour on a certain scenario (i.e., functional integration and overall performance). D5.1 provides an overview of service level KPIs defined in the frame of the 5G-IANA Use Cases and their mapping with 5G network related KPIs.

2.3.2. Application orchestration

The role of the orchestration process at the application level is to handle the deployment and real-time management of Vertical Services, while inherently providing elasticity and compliance with certain high-level service-related policies. This process essentially decouples the application layer management procedures from the network layer management, providing application awareness to the underlay slice creation and management and compatibility with any structured slice management and network orchestration solution. The overall concept is aligned to the way that modern complex vertical applications are designed over distributed architectures with edge processing capabilities. Such applications consist of a chain of AFs in the form of cloud-native components that can be managed independently, as far as their scaling aspect is concerned. Each AFs is bundled in an orchestration-friendly way, i.e., as a VM image, a container, or even a unikernel maintaining a backward compatibility with all three industry-leading approaches while offering important telco-interplay capabilities such as bi-directional interaction with a slice management system, resource-constrained slices, application profiling and policy enforcement. From the system design point of view, an Application Orchestrator (AO) should interface directly with the frontend user interface framework or equally a repository for the onboarding of the requested AFs, or linked NFs in the form of NetApps. In its southbound interface, it is connected to a slice management module for providing the application level requests that should satisfy the Vertical Service functional and operational requirements.

2.3.3. Virtualized infrastructure segment

The virtualized infrastructure segment represents the virtualized environment where the Vertical Services and constituent components (i.e., NetApps and AFs) run. Cloud, Edge, and Far-edge virtualized infrastructure segments are identified. The Far-edge infrastructure segment in the Automotive vertical, that is the focus of the 5G-IANA project, consists of the On-Board Units (OBU) on the vehicles and the Road-Side Units (RSU).

The OBUs provide the 5G connectivity through the Uu interface towards the edge segment. The RSUs are the devices providing connectivity from roadside sensors towards the edge and cloud segments. The RSUs make available computing capabilities at the roadside far-edge segment to process raw data if needed. A RSU can be connected to the edge server using either a 5G connection or, if available, a wired connection.

In both OBU and RSU cases, the far-edge infrastructure segment integrates all compute, storage, and network resources, locally present/interconnected at the OBU/RSU device level.

Further essential component related to the far-edge segments (i.e., OBU and RSU) is the MANO framework that is used in these segments. In the following of this document, the term "on-vehicle MANO" is used to distinguish this MANO framework from the one used at the central level of the AOEP, i.e., to orchestrate Edge and Central Cloud resources.

2.3.4. Slice Management and resource orchestration

The 5G-IANA AOEP leverages pre-established Network Slice Instances (NSIs), with different profiles, to support the operation of Vertical Services. At the Slice Management and resource orchestration layer, the available slices are catalogued in an inventory that offers procedures to add/update and remove the NSIs. When a request for the provisioning of a Vertical Service is issued, the platform validates the request against the available NSIs and related service profiles. In particular, the mapping of the desired service with one of the available NSIs is performed according to the high-level requirements that are specified at the NetApp Orchestration and Development (NOD) layer when designing the Vertical Service and performing its intent-based provisioning. The slice mapping procedure comprises: i) the translation of the high-level requirements

of the Vertical Service into the most appropriate 5G Network Slice profile (i.e., the Network Slice Type – NEST) associated with an already established NSI and ii) the coordination of the provisioning of compute resource quotas across the target virtualized infrastructure segments for running the Vertical Service components, i.e., NetApps and related AFs/NFs. The resource orchestration of compute resources is coordinated and executed according to the computing constraints related to the NetApp components of the Vertical Service (i.e., the needed amount of computational resources in terms of virtual CPUs, virtual RAM and virtual storage) and taking into account other parameters depending on the requested Vertical Service (e.g., the coverage area, specific host capabilities etc.).
In 5G-IANA, at least two pre-configured eMBB slices (radio and core network) will be provided, which will share the resources of one MEC-Server. QoS differentiation for data flows of a use case can be realized by either configuring the eMBB slices with different radio priorities, or by configuring QoS flows within an eMBB slice.

2.3.5. Distributed Machine Learning framework

The DML Orchestration layer hosts the functional components in charge of handling the selection of the most appropriate resources for supporting the operation of the desired DML Vertical Service. This functional component consists mainly of the DML orchestrator, which is integrated with the Slice Management and resource Orchestration to serve as DML-specific constraint provider for the vertical application provisioning. In essence, the DML orchestrator input acts as constraint for the arbitration, allocation, and provisioning of DML compute resources. This entails functionalities related to the monitoring of DML resources on Edge and the far-edge, the provisioning of DML applications and the delivery of trained DML models

2.3.6. Application Monitoring

The application monitoring refers to the platform capability to receive information from deployed and operational Vertical Services during runtime. This includes a number of service-related metrics, such as: CPU and memory usage, disk usage, TCP open sockets, container resources, number of read/write operations, etc. The application monitoring is defined by the application orchestrator mechanisms and allows specific monitoring parameters to be recorded. The process is typically combined with the internal (to application orchestrator) analytics engine, with forward and backward chaining inferences based on the collected metrics, providing rule-based analysis and management.

2.4. High-level system design of AOEP

The high-level system design of the AOEP is depicted in Figure 1, where the main functional building blocks of each layer are represented. The AOEP system design follows a layered approach where each layer hosts specific functionalities according to the identified stakeholders in the 5G-IANA ecosystem. In the rest of this Section, we briefly present the main building blocks along with the supported functionalities, while more details are reported in the subsequent Sections. A detailed system design of the AOEP is shown in Figure 21 that is introduced in Annex 1 – 5G-IANA AOEP Detailed System Design.

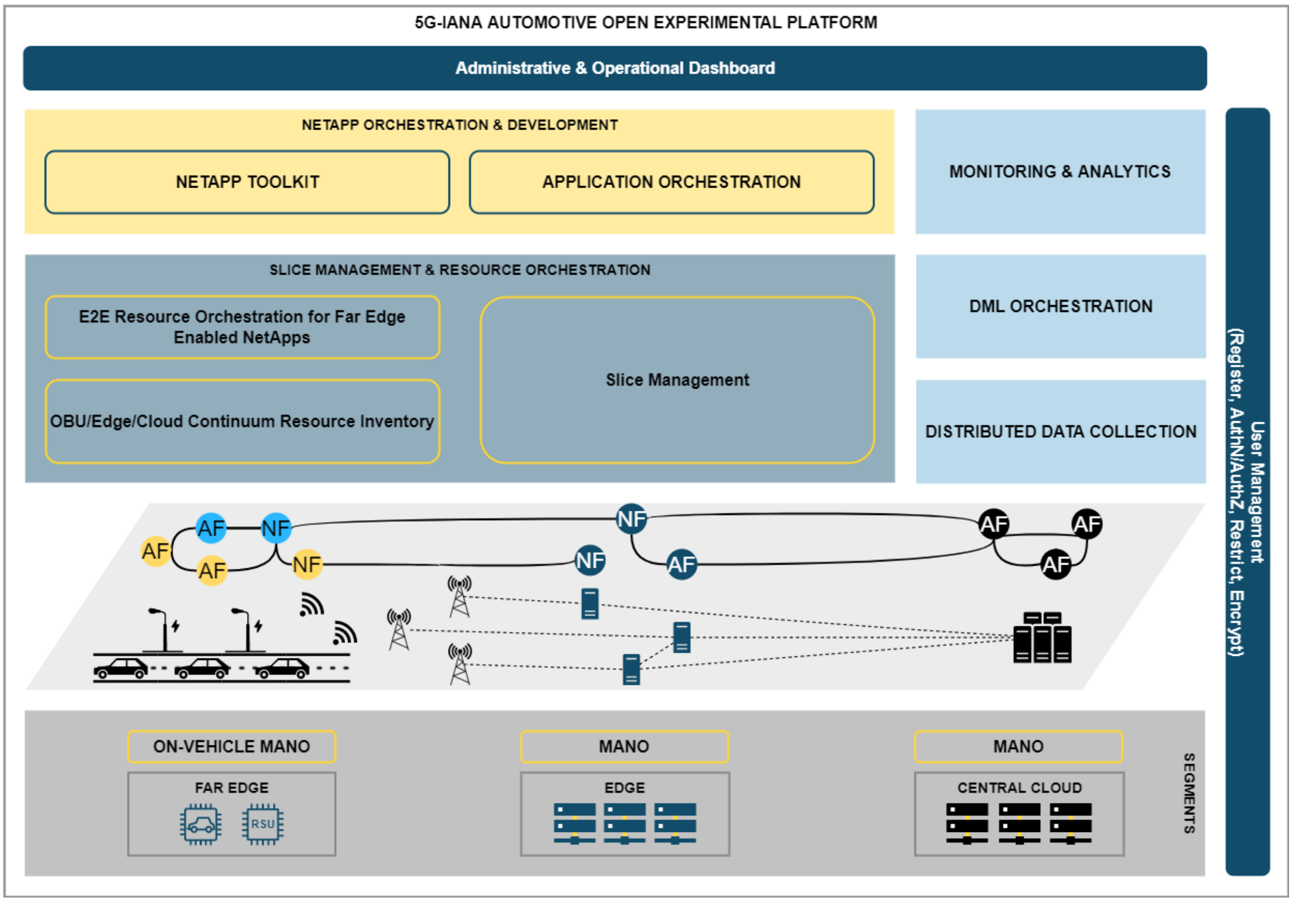

Figure 1: 5G-IANA Automotive Open Experimentation Platform System Design

2.4.1. NetApp Orchestration and Development

The NetApp Orchestration and Development (NOD) layer of the 5G-IANA AOEP represents the entry point to the overall system, for a subset of the identified stakeholders. In particular, the main actors that operate at this layer are the Service Provider, the Service Creator, the NetApp Provider, the NetApp Developer, and the AF/NF Provider; the specified functionalities supported by the NOD are tailored to fulfil the requirements expressed for such set of stakeholders. The NOD includes two main building blocks, namely the NetApp Toolkit and the Application Orchestrator that provide respectively the functionalities related to modelling/design and provisioning/orchestration phases of the Vertical Service lifecycle. Here below we summarize the list of functionalities supported by the NetApp Toolkit and the Application Orchestrator, while more details are reported respectively in Section 3 and 3.1.

Table 1: Mapping of NOD Functionalities

Component	Functionality	Description
NetApp Toolkit Application Orchestrator	NetApp Package Management	On-boarding, query, update and delete of NetApp Packages
	Vertical Service Composition and Customization	On-boarding/registration of Afs/NFs. Chaining of Afs/NFs with available NetApps into a Vertical Service design. NetApp packaging. Customization of Afs/NFs and Quality of Service (QoS) parameters
	Policy Management	Creation, modification, and deletion of optimization Policies associated to Vertical Services/NetApps
	NetApp "Starter-kit"	Catalogue of NetApp "Starter-kits" grouped per service category
	Vertical Service Deployment & Lifecycle Management	Deployment and Lifecycle related operations of the Vertical Service over the programmable resources allocated by the slice
	Slice Intent Handler (Creation, Processing, Modification)	Slice Intent mechanism for supporting CRUD operations over the allocated slices
Application Orchestrator NetApp Toolkit	Service Profiling	Provision of correlation diagrams over the collected Vertical Service specific metrics
	Policy Execution	Create, update, delete Vertical Service specific policies applied to deployed services
	Vertical Service Runtime Monitoring	Collection of various Vertical Service specific metrics
	NetApp Package Management	On-boarding, query, update and delete of NetApp Packages

	Vertical Service Composition and Customization	On-boarding/registration of AFs/NFs. Chaining of AFs/NFs with available NetApps into a Vertical Service design. NetApp packaging. Customization of AFs/NFs and Quality of Service (QoS) parameters

2.4.2. Slice Management and Resource Orchestration

The Slice Management and Resource Orchestration layer provides the functionalities for managing the available NSIs and validate Service Providers' requests for Vertical Services in terms of supported 5G service profiles. This layer also hosts the functional components responsible for the arbitration, allocation, and provisioning of compute resources across the 5G-IANA distributed compute infrastructure. In particular, this layer includes functionalities related to the subscription and continuous discovery of Far-edge resources (i.e., OBUs and RSUs), which according to their nature are not always "on-line" and available for executing services. Then, the Information & Localization service along with the resource orchestration services executed at the OBU/RSU and Edge hosts allow to collect relevant information about the status of such resource environment in order to be able to orchestrate AFs and NFs on top of it. Table 2 summarizes the functionalities available at this layer. More details are reported in Section 3.1.

Table 2: Mapping of Slice Management and Resource Orchestration Functionalities

Component	Functionality	Description
E2E Resource Orchestration for Far-edge Enabled NetApps	Tenant Management & Quota Reservation	Management of Tenant profiles and related SLA for quotas reservation. Coordination of the resource quotas provisioning at the target hosts
	Multi-segment Resource Arbitration	Arbitration of compute resources across available segments according to the received provisioning request and Tenant's SLA
Far-edge/Edge/Cloud Continuum Resource Inventory	Edge/Cloud Resource Inventory	Inventory of available Edge/Cloud compute resources
	Far-Edge Resource Inventory	Inventory of available Far-edge resources
	Far-Edge Resource Information Service	Collection of Far-edge resources related information (e.g., status,

		localization etc.). It leverages the Localization & Information Service provided by OBUs/RSUs and Edge nodes.
Slice Management	Vertical Application Intent to Network Slice QoS Mapping	Translation of Intent high-level QoS requirements and constraints into the most suitable 5G Service Profile (i.e., NEST)
	Network Slice Verification, Selection & Vertical Application Coordination	Mapping with the most suitable NEST according to the Intent translation. Verification of available NSIs matching the NEST QoS indicators. Coordination of compute resources provisioning
	Network Slice Management & Inventory	Inventory of available 5G Network Slice instances, including the possibility of adding/removing/updating NSIs
	Network Slice Template Management	On-boarding, query, update and delete of NEST templates

2.4.3. DML Orchestration

The DML Orchestration layer hosts the functional components in charge of handling the selection of the most appropriate resources for supporting the operation of the desired DML Vertical Service. The integration with the Slice Management and Resource Orchestration allows taking the DML orchestration input as constraint for the arbitration, allocation, and provisioning of DML compute resources across the 5G-IANA multi-segment compute infrastructure. The DML Orchestration layer includes functionalities related to the monitoring of DML resources on Edge and the Far-edge nodes and mapping DML applications to these as well as the final delivery of trained DML models. Table 3 summarizes the functionalities available at this layer. More details are reported in Section 5.

Table 3: DML Orchestration Functionalities

Component	Functionality	Description
DML Orchestrator	Mapping of DML application to DML resources	Selection of the most suitable DML resources on-top of RSU/OBU for a given DML application with a given set of DML requirements

	DML model delivery	Feedback of the final trained model to the NetApp Toolkit to update the corresponding NetApps

2.4.4. Monitoring and Analytics, Distributed Data Collection

Following the principles of the service mesh concept telemetry and analytics, functionalities are coupled with the applications orchestration, as a software management layer for controlling and monitoring internal, service-to-service traffic in microservices-based applications. It consists of a data and a control plane. Both monitoring and analytics are achieved for the data and control plane by a set of intelligent proxies deployed alongside the application software components supporting the provision of support/backing services (e.g., service discovery, load balancing, health checking). This enables traceability and logging, each software component's streams have to be captured by the execution environment, collated together with all other streams from the application, and routed to one or more final destinations for viewing and long-term archival and analysis. The collection of such monitoring data can be meaningful for introspecting application's behaviour over time and thus for profiling purposes. Traceability in terms of identification of faults and misbehaviours of software components has also to be supported. Table 4 summarizes these functionalities.

Table 4: Monitoring and Analytics, Distributed Data Collection Functionalities

Component	Functionality	Description
Monitoring & Analytics	Vertical Service Runtime Monitoring	Monitoring of Vertical Service-related metrics, according to specified monitoring parameters defined in policies
	Analytics	Rule-based management system with a forward and backward chaining inferences that relies on collected metrics
Distributed Data Collection	Vertical Service Data Collection	Collection of Vertical Service-specific metrics, i.e., provided by AFs to be consumed by the Vertical Service Runtime Monitoring
	Network Slice Data Collection	Collection of Network Slice specific metrics, i.e., provided by 5G services

	Infrastructure & Virtual Resources Data Collections	Collection of Infrastructure and Virtual Resources metrics, i.e., related to the overall virtual infrastructure usage or specific of virtual resources (e.g., of a container running a certain function)

2.4.5. AOEP Virtualized Infrastructure Segments

The functionalities of the 5G-IANA virtualized infrastructure segments are listed in Table 5. The virtualized infrastructure segments must ensure that NetApps and AFs can be effectively deployed on the segments and that communication services are provided. The virtualized infrastructure segments must report location and other useful information to the AOEP. Resource monitoring information are provided as well from the virtualized infrastructure segments to the AOEP. The OBU must provide interfaces related to the communication with Human-Machine Interface (HMI) for interacting with driver and/or passengers, and with the vehicle network for interacting with Electronic Control Unit (ECU) and Advanced Driver-Assistance Systems (ADAS) modules. More details are reported in Section 6.

Table 5: AOEP Virtualized Infrastructure Segments Functionalities

Component	Functionality	Description
General Virtualized Infrastructure Segment	Local Infrastructure Virtualization and Management	The virtualized infrastructure segment must be able to manage the virtualization of the local physical resources at the virtualized infrastructure segment
	Local Resource Registry	Inventory of the local resources at the virtualized infrastructure segment
	Local Resource Orchestration	Management and provision of local resources at the virtualized infrastructure segment
	Resource Monitoring Agent	The virtualized infrastructure segment must monitor and provide information about the status e.g., health, utilization, of its virtualized resources
	Package/Descriptor Management	The virtualized infrastructure segment must be able to locally manage the onboarding, the update, and

		the delete of a package/descriptor
	Local Service Orchestration	The virtualized infrastructure segment must be able to locally manage the provisioning, termination, and modification of services
	Information and Localization Service	The virtualized infrastructure segment must be able to provide information related to the position and capabilities to the AOEP
Far-edge segment	Network connectivity at OBU and RSU	OBU and RSU must provide the needed network interfaces for achieving network connectivity
	OBU interface with vehicle occupants	OBU should provide information and interact with the vehicle's occupants
	OBU interface with the vehicle network	OBU must be connected to the vehicle network to provide and receive information from the vehicle's ECU and/or ADAS

2.5. Methodology for specification of requirements

The requirements of the 5G-IANA AOEP have been specified starting from the uses cases, introduced in Section 8, that are demonstrated in 5G-IANA. In Section 8, the overview, the scenarios, and the related storylines, are introduced together with the functional requirements of the use cases. The analysis of this information and of the use cases' needs provided the basis for the elicitation of the 5G-IANA requirements.

The specification of the AOEP requirements have been also performed based on the 5G-IANA AOEP functionalities that are introduced in Section 2.4. These functionalities have been analysed to identify which requirements have to be specified to ensure that all of them can be guaranteed. The identification of the functionalities and the related elicitation of requirements was based on the Partners' expertise whose diverse backgrounds can ensure a complete view of the 5G-IANA AOEP. These steps were performed first as individual actions, then the results were integrated and refined during common brainstorming sessions.

The type of requirements, which have been considered in the context of 5G-IANA, are System Requirements (SR), User Requirements (UR), and Business Requirements (BR). The System Requirements include all those requirements that ensure that the 5G-IANA AOEP operates correctly providing all the needed functions. They can be distinguished

in System Requirements Functional (SRF), which identifies what the system does, and System Requirements Non-functional (SRNF), which describes how the system behaves from an operation point of view. The User Requirements correspond to the requirements that detail what a user of the AOEP needs to do with the system, and which actions the user must be able to do. The Business Requirements describe the business-related characteristics of the system considering the needs of the system stakeholders including the scope and the objectives of the system from a business point of view.
A priority level is associated with each requirement to classify the importance of having it satisfied during the implementation phase. Four levels of priority have been identified:

- **Must**: the requirement is mandatory to be satisfied.
- **Should**: the requirement is highly important to be met.
- **Could**: it is preferable that the requirement is satisfied, but it is not of fundamental importance.
- **Would**: the requirement is not strictly needed; it can be satisfied in a second moment.

The requirements of the 5G-IANA AOEP and of its main components are introduced in the following sections using as template Table 6.

Table 6: Template table for introducing the requirements of the AOEP and related components.

Identifier	Title	Priority	Description
...	...	...	...
SFR-OVM-2	Function local on-boarding	MUST	The OVM must provide a procedure for onboarding Functions descriptors and/or images to the local repository
...	...	...	...

The template table is made by the following columns:

- **Identifier**: a unique identifier that is made by the combination of i) the type of requirements, ii) the acronym of the AOEP component or segment to which the requirement is related (Table 7), and iii) an incremental integer number; for example, "SRF-RO-1" identifies the first functional system requirement of the Resource Orchestrator component or segment are introduced in.
- **Title**: a unique title of the requirements.
- **Priority**: one of the four priority levels that have been previously introduced.
- **Description**: a textual description of the requirement.

Table 7: Acronyms of AOEP components/segments used in the requirements' identifier.

Acronym	AOEP component/segment
AO	Application Orchestrator
AVR	Automotive VNFs Repository
DML	Distributed Machine Learning
EAC	Edge and Cloud infrastructure segments
GVI	General Virtualized Infrastructure
NASK	NetApps "Starter-Kits"
NAT	NetApps Toolkit
NOD	NetApp Orchestration and Development
OBU	OBU infrastructure segment
OVM	"On-Vehicle" MANO
RO	Resource Orchestrator
RSU	RSU infrastructure segment
SM	Slice Manager

3. SPECIFICATIONS OF THE 5G-IANA NETAPPS TOOLKIT

3.1. State-of-the-Art of NetApps solutions

In recent years, orchestration techniques have been evolved to cope with Vertical industries requirements, in particular, to accommodate heterogeneous services on top of generic 5G infrastructures while facilitating the provisioning procedure by means of Vertical-oriented information/data models and APIs. Indeed, during the 5G-PPP phase II, some research initiatives, e.g., 5G-TRANSFORMER, 5GTANGO etc., have started investigating mechanisms to capture Vertical requirements and map them into orchestration-oriented descriptors usually adopted to achieve the service deployment through an NFV MANO platform. With the advancement of 5G technologies, in particular, in correlation with the possibility of leveraging network slicing to improve resource sharing while providing the requested QoS, deployment scenarios have increased their complexity, further highlighting the need of exposing simplified information to Verticals to let them request the provisioning of services/applications in an autonomous way. To this end, in order to propose a comprehensive solution that captures the Vertical perspective, the design and specification of the 5G-IANA NetApp Toolkit leverages the work performed in past and currently active research activities. In particular, the proposed design exploits the background and outcomes from the following 5G-PPP Phase II and Phase III projects:

- **H2020 5G-PPP Phase II 5G-TRANSFORMER**: 5G-TRANSFORMER specified and implemented a data-model, i.e., Vertical Service Blueprint (VSB) and Vertical Service Descriptor (VSD), for the representation of Vertical Services that hides orchestration-oriented information in favour of service-oriented ones [5]. The VSB/VSD concept has been adopted and further evolved in following projects dealing with the provisioning and experimentation validation of Vertical Services, like 5G EVE [6], 5Growth [7] and VITAL-5G [8]. In 5G-IANA the VSB/VSD data-model, subsequently evolved in VITAL-5G, is considered as baseline for the specification and implementation of the service-oriented NetApp Template data-model.
- **H2020 5G-PPP Phase II MATILDA**: The main outcome of the MATILDA project [9], that is used in 5G-IANA, relates with the front-end design and functionalities for easing the composition of Vertical Services. The key interfacing functions for application parameter editing and graph composition are inherited within the implementation of the NetApp Toolkit. The user interface functionalities also expose the necessary fields to Vertical Service Providers for the composition and

customization of their services (either as single application functions/components or linked components in the form of NetApps.

- **H2020 5G-PPP Phase III VITAL-5G**: like 5G-IANA, VITAL-5G investigates mechanisms for facilitating the modelling of NetApps and their chaining into 5G-ready Vertical Services. VITAL-5G has already progressed in this direction with the specification of a solution for the modelling, management and cataloguing of NetApps. 5G-IANA leverages the specification and on-going implementation work performed in VITAL-5G for realizing the NetApp Catalogue component. The NetApps modelling from VITAL-5G is applicable to NetApps for general Vertical Services in 5G environments, but defining additional attributes specifically tailored to their target sector, i.e., the Transport and Logistic. This approach makes it suitable to be adopted in different Vertical contexts with specific customizations. In 5G-IANA the VITAL-5G solution will be extended and enhanced for NetApps targeting the automotive sector, to cope with the project-specific requirements and goals, e.g., the NetApp orchestration on-top of far-edge segments.

More details about planned and on-going extensions on top of the identified baseline components are reported in Section 3.5, where the NetApp Toolkit system design has been specified.

3.2. NetApp modelling

This section describes the NetApp concept in 5G-IANA, how NetApps are modelled and how they can be chained into Vertical Services. 5G-IANA aims at realizing the NetApp concept, whose goal is to ease the procedures for the Vertical Service design, lifecycle management (LCM) and testing on top of 5G infrastructures.

5G-IANA focuses on the experimentation of Vertical Services for the Automotive Industry. Vertical Services are the result of the composition of NetApps into end-to-end (E2E) service-chains that make use of 5G connectivity. In particular, within the E2E service-chain, each NetApp provides its own complete functionality and can operate as a stand-alone entity or cooperate and interact with other NetApps to deliver more complex Automotive Services and complement the set of available functionalities. Then, from a Service Provider perspective, it's of primary importance to ensure the availability of mechanisms that facilitate the composition of NetApps while abstracting the low-level orchestration details required to deploy the service on top of 5G infrastructures and handle its LCM.

A NetApp can be defined as a virtual network application that can be deployed in a 5G-enabled environment, leveraging the mobile connectivity, and eventually making usage of 5G services (e.g., localization). In 5G-IANA, NetApps build atop cloud orchestration concepts, where services are realized as the composition of one or multiple functions usually deployed in containers. Cloud-native techniques are today largely adopted in many industry context, indeed, as part of the NFV architecture evolution, also ETSI ISG NFV specifies in [10] requirements and procedures for handling cloud-native deployments in NFV environments, defining the concept of Cloud-native Network Function (CNF). The main objective behind the proposed NetApp modelling is to decouple the service-level information from the orchestration-oriented information (i.e., descriptors processed by orchestration platforms) that are needed to actually perform the NetApp deployment and operation. In particular, to simplify its reusage and integration, a NetApp extends such orchestration-oriented descriptors with Vertical-friendly information, mainly focused on:

- high-level QoS parameters that correspond to the main characteristics of the required 5G Slice Profile and available interfaces for service-chains composition,
- 5G Core services and/or external services (e.g., AI-driven) integrated with the NetApp for optimized orchestration decisions,
- available interfaces that can be used to integrate the NetApp in a more complex service-chain,
- test cases related scripts, target metrics and KPIs that enable the assessment of the NetApp from a functional and performance perspective.

Figure 2 represents a generic example of four different NetApps interconnected within a service-chain. In particular, NetApp A and NetApp B on the left side are deployed on top of Far-edge resources, i.e., OBUs and RSUs, then the 5G Core and Access network is not just used to let the UEs consume the desired services, but also to enable the interconnection between AFs and NFs belonging to different NetApps and located on both the UEs and Edge/Cloud sides. In addition, the picture highlights some of the concepts related to the modelling of a NetApp. Indeed, following an approach similar to the structure of an NFV Network Service (NFV-NS) [1], a NetApp can be considered as a set of AFs and NFs, respectively the blue and white boxes in Figure 2, which implement the NetApp logic and can be deployed as containers, i.e., CAFs and CNFs.

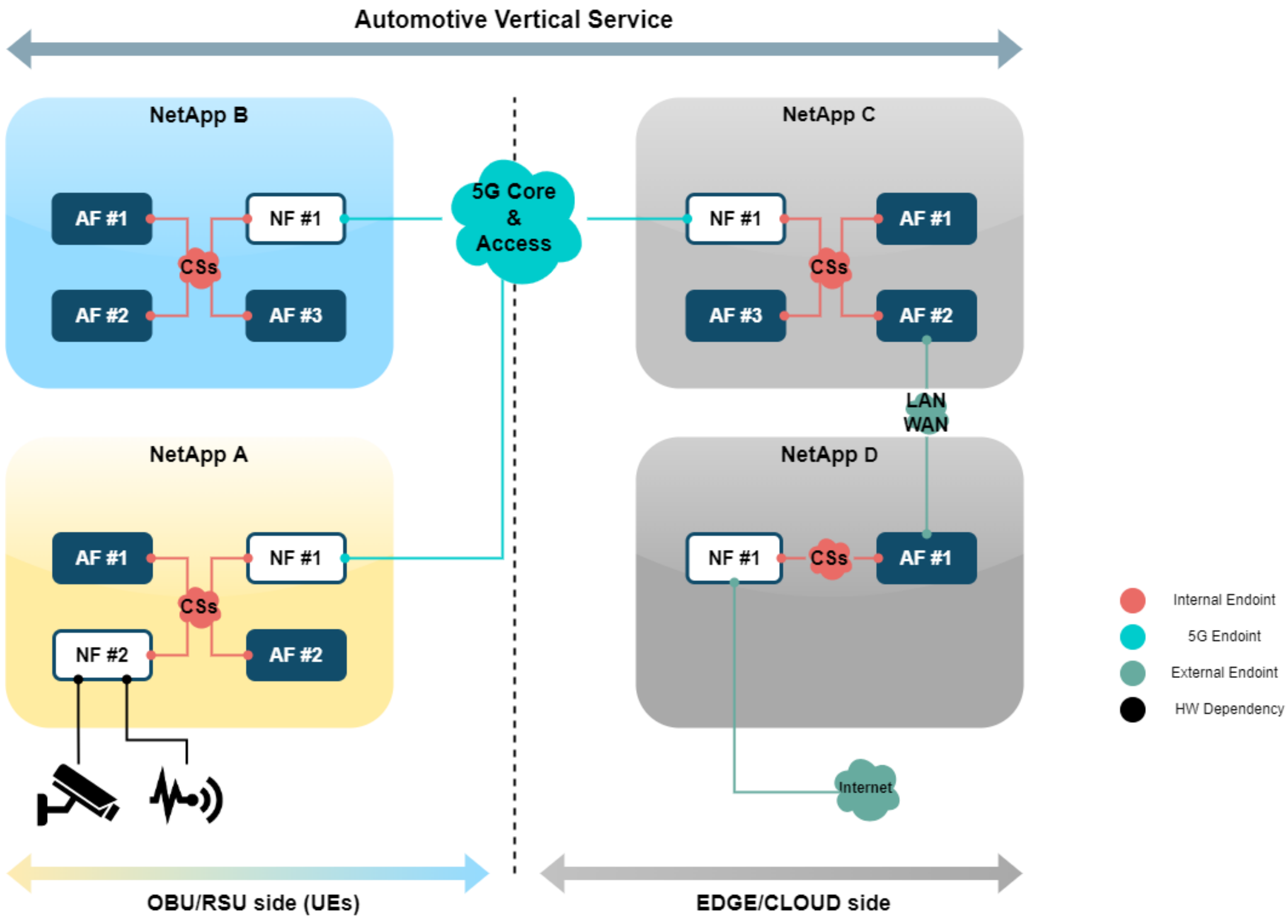

Figure 2: Example of interconnected NetApps

Within a specific NetApp, AFs/NFs interact with each other through a number of internal Connectivity Services (CSs) (in red in Figure 2) whose scope is similar to the internal Virtual Links (VLs) in an NFV-NS. Both AFs and NFs present one or more endpoints that enables different types of interactions:

- **Internal Endpoints**, represented in red in Figure 2, are used only for the interaction among AFs and/or NFs within the same NetApp.
- **5G Endpoints**, represented in light blue in Figure 2, are the ones interconnected with the 5G Core and Access network, then attached to the N6 interface of the 5G System. This type of endpoint is specified along with a set of information characterizing the needed mobile connectivity in terms of Network Slice QoS parameters. Such parameters are described in the form of a 5G Service Profile, which includes different QoS Indicators (e.g., uplink and downlink data rate, latency, jitter) depending on the Slice Service Type (SST) (i.e., eMBB, URLLC, mIoT). Other parameters can be also present, such as coverage area, radio access technology,

etc. Through this endpoint is also possible to consume services that could be potentially offered by the 5G network (e.g., analytics, localization of UEs etc.).

- **External Endpoints**, represented in green in Figure 2, are used to interact with elements external to the NetApp (e.g., AFs/NFs in a different NetApp, external services in the public internet, etc.). They can act as Service Access Points (SAPs), providing the access to the NetApp functionalities to the end users or to other services.
- **HW Dependencies**, represented in black in Figure 2, determine which AFs/NFs have a dependency on HW components, such as sensors, actuators, or other interconnected devices such as cameras or car's specific components. If an HW Dependency is associated to an AF/NF, then its functionalities are strictly dependent on the interaction with the target HW, whose integration is mandatory for the proper operation of the AF/NF. Then, HW Dependencies constitute the list of the compatible HW that the AF/NF can support and that should be integrated.

The described categorization of the endpoints, along with the service-oriented characteristics described at the beginning of this section, should facilitate an intuitive re-usage and/or customization of NetApps from Service Creators/Providers to build advanced Vertical Services. Indeed, the goal of the proposed modelling is to hide the actual complexity of the desired deployment in terms of network and compute resources and related configurations. Through this approach, the Service Creator/Provider does not need to be aware of the NetApp deployment characteristics and constraints, either of the required complex configuration and slicing of the 5G network.

3.2.1. NetApp Package Information Model

The described modelling is realized and made available to Service Creators/Providers through a catalogue of NetApp Packages, where each NetApp Package provides the following information:

- an abstract and service-oriented description of the NetApp formalized in a NetApp Template. The NetApp Template contains the metadata used to search, chain, customize and deploy the NetApp through the functionalities provided by the NetApp Toolkit and the 5G-IANA Orchestration Platform.
- a deployment/orchestration-oriented description that consists in the set of CAFs and/or CNFs descriptors/packages, to be deployed and interconnected to realize the E2E service-chain, along with the related 5G Service Profiles in the form of Network Slice Type Templates (NESTs). The set of CAF/CNF descriptors/packages

and the related Service Descriptors define how the NetApp components need to be instantiated, dimensioned, and interconnected over the virtual computing infrastructure. The NEST specifies how the 5G Network Slice should be configured to achieve the expected performances. These descriptors and the NEST are not directly exposed to the Service Creator/Provider but are used internally by the 5G-IANA orchestration components to drive the deployment of NetApps over the selected resources in the target 5G infrastructure.

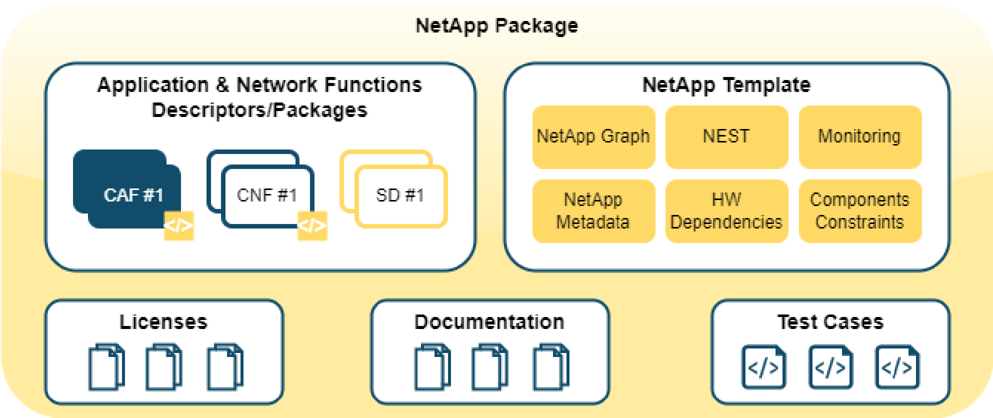

Figure 3: NetApp Package content

Figure 3 represents the NetApp Package content, which includes:

- the set of CAF Descriptors/Packages.
- the set of CNF Descriptors Packages.
- the list of Service Descriptors (SDs) including the target CAFs/CNFs.
- the licenses associated to single NetApp components (AFs/NFs) and to the overall NetApp.
- the NetApp documentation, which includes the NetApp SW description along with information to facilitate the NetApp integration (e.g., description of interfaces, protocols, messages, etc.).
- the NetApp Test Cases, which include the set of scripts, API collections to be executed for the run-time validation of the NetApp. In addition, also information about how functional and performance Test Cases should be executed are provided.
- the NetApp Template, which contains: 1) the metadata, 2) the NetApp high-level graphs (i.e., the list of AFs and NFs, related endpoints and CSs), 3) the NEST, 4) the monitoring parameters, 5) the list of HW Dependencies and constraints per AF/NF.

The details of the implemented NetApp Information Model are reported in Table 8. All the different elements of the information model are implemented, when they are labelled as “optional” it means that the specific element is not mandatory for the validation of the package, then if this element is not present, the package can be still on-boarded to the platform.

Table 8: NetApp Information Model

NetApp package element	Source	Notes
Software Images (Optional)	CAF/CNF Package	If the images are already on-boarded, they are referred in the CAF/CNF descriptor and not directly contained in the package. For this reason, the presence of images in the package is not mandatory for its validation
CAF/CNF Descriptors/Packages	Files in NetApp Package	The CAF/CNF Descriptor/Packages format is compliant with the selected cloud orchestration platform, i.e., Kubernetes
Service Descriptors	Files in NetApp Package	The Service Descriptor format is compliant with the selected cloud orchestration platform, i.e., Kubernetes
Software Licenses	License files in NetApp Package, Licensed element in NetApp Template	Licenses of the whole NetApp and related components
NetApp Metadata	NetApp Template	High-level characteristics of the NetApps that enable their categorization and usage
NetApp Graph	NetApp Template	AFs/NFs, Connectivity Services and Endpoints
5G Mobile Connectivity Requirements	NetApp Template	5G Service Profiles associated to 5G Endpoints (NEST)
Monitoring Information (Optional)	NetApp Template	List of infrastructure and application metrics that can be monitored. The monitoring information are not mandatory for the validation of the package
Documentation (Optional)	Additional files in NetApp Package	Software description Information to facilitate the NetApp integration (interfaces, protocols, messages, etc.)
Test Cases (Optional)	Additional files in NetApp Package	Test cases with validation information (scripts, APIs collections etc.)
Components Constraints (Optional)	NetApp Template, CAF/CNF Descriptor	Server-related requirements for the NetApp components (location constraints, specific compute requirements)

Hardware Dependencies (Optional)	NetApp Template	List of HW devices that must be installed to enable NetApp's functionalities

3.2.2. Vertical Service Categorization

In 5G-IANA different categories have been defined to catalogue Vertical Services and related NetApps according to their logic and their field of applicability. In particular, within the automotive specific context, four different categories have been identified to group the different types of services that can be offered:

1) Hazard Notification

The primary goal of Vertical Services in this category is the identification of hazards, exploiting data available from sensors and/or information from other vehicles, such as:

a) electronic emergency brake light detection,
b) adverse weather conditions detection,
c) road conditions detection, collision warning.

2) Vehicle Movement

Vertical Services in this category provide support for the driving of a vehicle, including:

a) suggestions to the autonomous driving module about the trajectories taking into account information from hazard notifications, collective perception, etc.,
b) perform cooperative manoeuvres coordination with other vehicles at tactical level functions (e.g., lane change, overtake, etc.),
c) Vertical Services providing remote driving functionalities.

3) Smart Traffic Planning

Vertical Services in this category identify the required modification to the infrastructure for avoiding accidents, traffic jams or for guaranteeing adequate parking facilities. Advanced features include:

a) smart route planning,
b) knowledge about vehicles' position, traffic conditions and traffic events to suggest alternatives.

4) Infotainment

Vertical Services in this category provide information or entertainment to the human driver and/or passengers, including:

a) traffic information services (e.g., Human Machine Interface - HMI, augmented reality HMI, etc.),
b) context-aware services (e.g., touristic and/or shopping local information according to personal interests).

In 5G-IANA, a set of NetApps to support the design and provisioning of Vertical Service in the aforementioned categories is delivered. The goal is to develop NetApps whose usage is not strictly limited to any category, but that can be integrated in different types of service chains and services. Although the project goal is to deliver NetApps for the Automotive industry (e.g., NetApps providing ITS long-distance communication functionalities), some NetApps can be potentially considered as **Vertical-agnostics** and adopted and integrated in services for different Vertical industries. Indeed, these NetApps can be easily customized to be adopted in various Industry scenarios, examples include monitoring functionalities but also generalized ML engines.

3.2.3. Vertical Service Design

According to the presented modelling, a NetApp can provide its own set of functionalities and operate also as a stand-alone entity. However, the overall goal is to enable a facilitated usage and chaining of different NetApps to deliver more complex Vertical Services. In 5G-IANA different NetApps are developed and integrated to build advanced Vertical Services belonging to the described five identified categories. The modularity behind the design of Vertical Services, allows and facilitates the re-usage of developed NetApps in different sectors. Indeed, the 5G-IANA architecture, along with the specified NetApp modelling and supported functionalities can be considered applicable to different Vertical context and not only to the Automotive one.

Automotive Vertical Services result in E2E service-chains of NetApps and related CAFs/CNFs, which are deployed on top of a 5G infrastructure by leveraging the different functionalities offered by the 5G-IANA AOEP. NetApps and in particular the constituent CAFs/CNFs can be reused and composed across multiple Vertical Services, reducing the time needed to design new 5G-ready services and deploy them in the target environment. Then, a Vertical Service can be composed by multiple NetApps released by different vendors. In the same way, CAFs/CNFs can be offered by different providers and reused within multiple NetApps/Vertical Services.

The Vertical Service design and composition depend on the specific logic and requirements that the Vertical would like to implement and NetApps constitute already packaged and ready to use functionalities that can be flexibly chained into E2E services. A Vertical Service can be composed of multiple NetApps offering specific services and provided by different vendors. In some cases, the Service Provider may be interested in developing its own functionalities in the form of NetApps and/or proprietary AFs, but without focusing on other complementary functionalities that are chained and used as offered though the NetApp Catalogue. Then, the Service Provider develops the AFs/NFs he/she is interested in and on-board/register them through the NetApp Toolkit. Subsequently, the registered AFs/NFs are quickly composed with available NetApps, provided by third parties, into an E2E service-chain to be proposes to its customers. As a consequence, the design and composition of the Vertical Service is a responsibility of the Service Provider, who has to take into account the specific requirements of the NetApps he/she intends to use. Such requirements can be accessed and verified by consulting the documentation provided within the NetApp Package, where the information related to interfaces, protocols and messages are present. The NetApp Package contains also the information related to the target Key Performance Indicators (KPIs) to be verified and the description of the testing methodology for different applicable scenarios. Of course, the compatibility and applicability of NetApps within a Vertical Service depends on the exposed interfaces, which operates through the External and 5G Endpoints. Then the openness of such interfaces along with their documentation are fundamental enablers for achieving the NetApps chaining into Vertical Services. The implementation of the internal logic, instead, can be kept proprietary and fully hidden to Service Providers, who are allowed to see only the relevant set of information for the NetApp usage.

3.2.3.1.NetApp "Starter-kit"

5G-IANA provides a set of NetApp "Starter-kits" to be used to create Vertical Services belonging to the identified service categories. The idea behind the proposed "Starter-kit" concept is to further facilitate, from a Service Creator/Provider perspective, the creation of advanced Automotive Vertical Services. In the 5G-IANA Automotive specific context, in order to be able to fully exploit the usage of resources available in the 5G infrastructures, which includes also the possibility of orchestrating and running applications on top of Far-edge resources (i.e., OBUs and RSUs), the deployment of some specific services, in the form of AFs/NFs, may be required. For instance, for properly consuming and forwarding information on top of an OBU, some Intelligent Transport Systems (ITS) communication functions may be required. Since verticals usually do not have the knowledge to understand the specific purpose and usage of low-level functionalities, 5G-IANA offers a set of open-source NetApp "Starter-kits" that provide a baseline set of AFs/NFs to be deployed to support the service operation across different segments. The NetApp "Starter-kits" are designed and developed to support the roll-out of 5G-IANA and third-party UCs, taking into consideration the needs of different types of applications. Each "Starter-kit" is released in the form of ready-to-use NetApp Package, where all the relevant information for its usage in a specific context/scenario are also provided. Figure 4 depicts an example of NetApp "Starter-kits" for a manoeuvres' coordination service (i.e., the one developed in the context of Use Case 2) in the Vehicle Movement category. In particular, two different NetApp "Starter-kits" are highlighted in Figure 4: i) the first one, located on the left side, contains a set of NFs and AFs that can constitute the starting point for implementing part of a manoeuvres coordination service that runs on top of OBUs, ii) the second one, located on the right side, contains a NF that implements the service ITS communication on the Edge side along with the manoeuvres coordination service. The AFs highlighted in purple are the ones that potentially can be integrated/customized by experimenters and third parties that, e.g., would like to provide a specific logic/algorithm for the Manoeuvres Planning functionality. The endpoints/interfaces exposed by AFs/NFs in the NetApp "Starter-kits" will be documented in order to facilitate the Vertical Service chaining and easily understand the AFs/NFs compatibility with respect to the custom AFs that the experimenter/third-party would like to integrate.

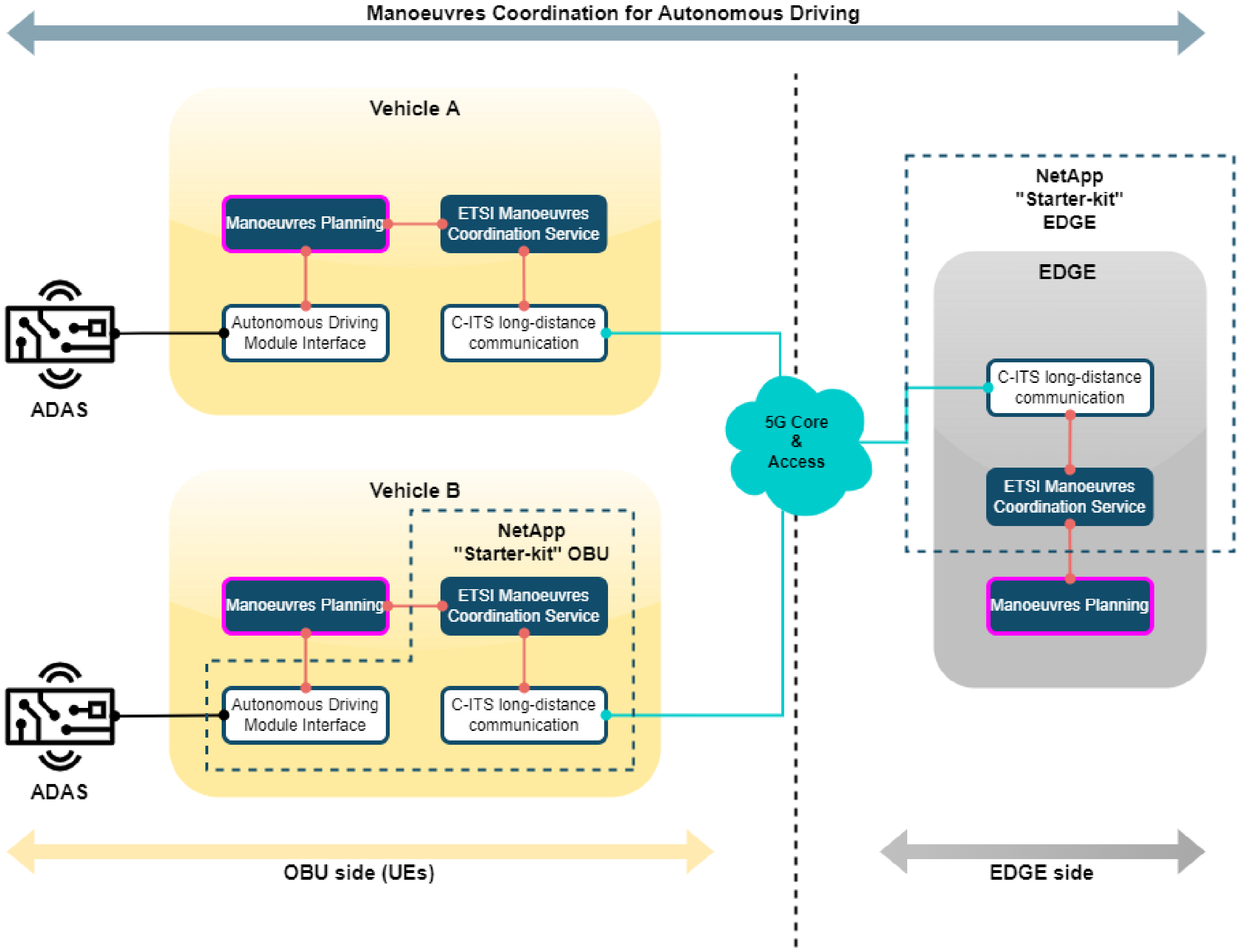

Figure 4: Manoeuvres Coordination for Autonomous Driving NetApp "Starter-Kits" Example

3.3. Specifications of the requirements

In Table 9 we report the list of specified functional requirements for the NetApp Toolkit (NAT), the Automotive VNFs Repository (AVR) and the NetApp "Starter-kit" (NASK). The reported requirements are considered as an input for the design and specification of the NetApp Toolkit component of the 5G-IANA AOEP.

Table 9: NetApp Toolkit Functional Requirements

Identifier	Title	Priority	Description
SFR-NAT-NOD-1	User registration	MUST	The NAT must provide the interface for user registration and profile creation
SFR-NAT-NOD-2	User authentication	MUST	The NAT must allow user authentication
SFR-NAT-NOD-3	User restrictions	MUST	The NAT must enable frontend access environment restrictions based on the user profile (vertical, developer, operator/administrator, etc.)
SFR-NAT-NOD-4	User encryption	SHOULD	The NAT must enable user information encryption
SFR-NAT-NOD-5	NetApp on-boarding	MUST	The NAT MUST provide a procedure for the on-boarding of NetApps
SFR-NAT-NOD-6	NetApp update	SHOULD	The NAT SHOULD provide a procedure for updating NetApps
SFR-NAT-NOD-7	NetApp delete	MUST	The NAT MUST provide a procedure for deleting NetApps
SFR-NAT-NOD-8	NetApp query	MUST	The NAT MUST provide a procedure for querying NetApps
SFR-NAT-NOD-9	Service graph composition	MUST	The NAT MUST provide a procedure for chaining AFs and NetApps into Vertical Services
SFR-NAT-NOD-10	Service graph modification	MUST	The NAT MUST provide a procedure for editing the Vertical Service graph
SFR-NAT-NOD-11	Service graph delete	MUST	The NAT MUST provide a procedure for deleting the Vertical Service graph
SFR-NAT-NOD-12	Service component customization	MUST	The NAT MUST provide a procedure for customizing AF parameters (e.g., minimum execution requirements, operational application constraints, components dependencies, HW dependencies, etc.)
SFR-NAT-NOD-13	Service customization	MUST	The NAT MUST provide a procedure for customizing the Vertical Service parameters (e.g., delay, jitter, location, bandwidth, etc.)
SFR-NAT-NOD-14	Service packaging	MUST	The NAT MUST provide a procedure for packaging the designed Service graph into a new NetApp Package

SFR-NAT-NOD-15	Policy creation	MUST	The NAT MUST provide a procedure for the creation of Service-related optimization policies
SFR-NAT-NOD-16	Policy update	MUST	The NAT SHOULD provide a procedure for updating a Service -related policy
SFR-NAT-NOD-17	NetApp "Starter-kit" catalogue	MUST	The NAT SHOULD provide a catalogue of NetApp "Starter-kit" organized per service categories (i.e., Vehicle Movement, Infotainment, Smart Traffic Planning, Hazard Notification)
SFR-NAT-NOD-18	Function on-boarding	MUST	The NAT MUST provide a procedure for on-boarding Function Descriptors and Packages (e.g., CAFs/CNFs) together with NetApp Packages
SFR-NAT-NOD-19	Function update	SHOULD	The NAT SHOULD provide a procedure for updating Function Descriptors and Packages (e.g., CAFs/CNFs) together with NetApp Packages
SFR-NAT-NOD-20	Function delete	MUST	The NAT MUST provide a procedure for deleting Function Descriptors and Packages (e.g., CAFs/CNFs) together with NetApp Packages
SFR-NAT-NOD-21	Function query	MUST	The NAT MUST provide a procedure for querying Function Descriptors and Packages (e.g., CAFs/CNFs) within a NetApp Package
SFR-NAT-NOD-22	Registry	MUST	The NAT MUST provide a centralized registry functionality to collect CAFs/CNFs images
SFR-NASK-1	NetApp "Starter-kit" content	MUST	The on-boarded NetApp "Starter-kit" MUST include a NetApp Template and the baseline AFs/NFs needed to run a category-specific (e.g., infotainment, vehicle movement etc.) service (e.g., communication functions that are mandatory to run services across OBUs/RSUs)
SFR-NASK-2	NetApp "Starter-kit" Additional content	MUST	The on-boarded NetApp "Starter-kit" MUST include the documentation and scripts needed to test and run the NetApp (e.g., guidelines, OpenAPI, testing collections)

3.4. Advances in 5G-IANA and fulfilment of 5G-IANA objectives

5G-IANA aims at advancing with respect to the analysed state-of-the-art and related baseline solutions by focusing on two important innovation aspects: the dynamic orchestration of DML NetApps and the orchestration of AFs/NFs on top of Far-edge resources, which in the Automotive-specific context consists of OBUs and RSUs. In particular, in the frame of the NetApp Toolkit, the project is investigating mechanisms to:

- Model NetApps in an abstract, Vertical and platform agnostic manner. This way NetApps can be easily chained and re-used for composing Vertical Services while the complexity of the deployment remains hidden to users with a limited expertise such as Service Providers. In addition, the proposed modelling aims at overcoming fragmentation in the way services are described while enabling a unified and automated NetApps provisioning on top of distributed compute resources, including Far-edge ones. Indeed, the adoption of a unified data-model exposed to the NetApp Toolkit users enables in a transparent manner distributed deployments across the different infrastructure segments without the need for the Service Creators/Providers of dealing with orchestration procedures executed at the different segments.
- Catalogue NetApps through a proper set of metadata in order to enable and facilitate their usage and chaining through proper information related to interfaces, used protocols, messages etc. The cataloguing aspect is important also to enable the on-demand selection of DML NetApps in charge of optimizing the operation of one or multiple NetApps in a Vertical Service. Indeed, it's fundamental being able of determining if an ML application, released in form of a NetApp, can be coupled, and provisioned with other NetApps. 5G-IANA aims at realizing a coherent cataloguing of NetApps, including ML-driven ones. The idea is to enable an intuitive selection of ML applications while composing a Vertical Service; moreover, using the NetApp Catalogue functionalities will be possible to update NetApps, e.g., updating trained models or creating new ones.

With respect to 5G-IANA declared objectives, the NetApp Toolkit solution described in the rest of this section contributes to their fulfilment as reported in Table 10.

Table 10: 5G-IANA NetApp Toolkit Objects Fulfilment

#	Objective	Item	Implementation
1	**Specify and provide an Automotive Open Experimentation Platform (AOEP)**	The 5G-IANA NetApps toolkit linked with a new Automotive VNFs Repository	The designed NetApp Toolkit includes the functionalities for the management of CAFs/CNFs as described in Section 3.5
		A DML framework, as part of the VNFs Repository	The NetApp data-model enables a proper cataloguing of heterogeneous NetApps to facilitate their usage and chaining in Vertical Services. The needed information is modelled for

			accommodating heterogeneous applications, including DML NetApps. See 3.2
2	**Specify and implement a repository environment for NetApps and VNFs to ease the design and chaining of new Automotive-related services – to be integrated with 5G-PPP open repositories**	5G-IANA will provide a set of VNFs (communication and baseline) and predefined NetApps ("starter-kit"/templates) that will make easier for new entrants and especially SMEs or start-ups to design and create their own 5G Automotive-relates application and services on top of existing services	The functionalities supported by the NetApp Toolkit enable an intuitive reusage of NetApps and related AFs/NFs. See Section 3.5 NetApp "starter-kits" will be developed within WP4. The scope of "starter-kits" is explained in Section 3.2.3.1
		5G-IANA will develop the Automotive VNFs Repository specifications in task T2.3. Based on these specifications, the Repository will be developed and integrated with 5G-PPP repositories, as part of WP4 tasks	The NetApp Catalogue includes a repository of CAFs/CNFs. Within WP4, identified AFs and NFs coming from other 5G-PPP repositories are packaged and made available for the 5G-IANA experimentation
6	**Improve service creation time (5G-PPP KPI)**	The 5G-IANA AOEP components are designed to deploy Automotive services with extremely low service creation time (instantiation and re-configuration)	The NetApp Toolkit makes available ready to use NetApps, properly catalogued for an intuitive re-usage. See Sections 3.2 and 3.5
		Services will be developed with NetApps and VNFs as part of the WP4 activities	WP4 will develop and package a set of NetApps according to the specified information model
7	**Create new business opportunities and boost market for start-ups and SMEs with Automotive NetApps**	5G-IANA solutions will make easier for new entrants to design and create their own application and services on top of existing Automotive services and application templates	The envisioned functionalities for the NetApp Toolkit are intended to facilitate the on-boarding of new NetApps and related AFs/NFs as well as the composition of new Vertical Services starting from available building blocks. See Section 3.5
		5G-IANA NetApps Toolkit and the developed Automotive VNFs Repository can be further leveraged by other developers to develop new businesses in the Automotive area	

9	**Ensure cross-domain and cross-platform interoperability and boost standardisation committees on NFV and Network orchestration**	5G-IANA focus on standardisation is to ensure interoperable deployment of NetApps beyond vendor-specific implementation and across multiple domains, through active participation of 5G-IANA standardisation experts in selected technical bodies and Working Groups	The data model and interfaces implemented at the NetApp Catalogue takes into consideration cloud-native orchestration techniques to provide a great degree of interoperability among different segment-specific platforms. This way the proposed framework allows to manage AFs/NFs descriptors and packages in a unified manner across different cloud-native platforms

3.5. NetApp Toolkit internal system design

The internal system design of the NetApp Toolkit is depicted in Figure 5, where the main functional building blocks and related functionalities are also represented. The NetApp Toolkit is the component of the 5G-IANA NetApp Orchestration and Development framework whose goal is to enable the on-boarding and update of NetApps Packages and related components from NetApps and AFs/NFs Providers as well as to facilitate the chaining and customization of 5G-ready Vertical Services from Vertical Service Providers. Then, the NetApp Toolkit is responsible for implementing and exposing the needed set of functionalities that are related to the design and modelling phases during the overall Vertical Service and NetApps lifecycle. In the rest of this section, we provide a more detailed description of each component, related functionalities and supported functional workflows.

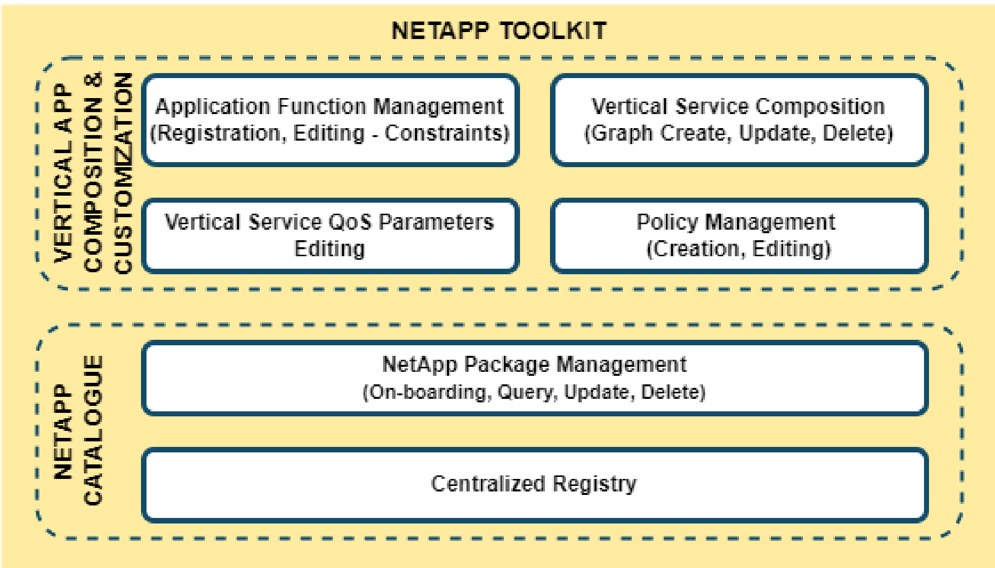

Figure 5: NetApp Toolkit Internal System Design

The following paragraphs describe the NetApp Toolkit main functionalities grouped per component and specific scope.

3.5.1. Vertical Service Composition and Customization

The Vertical Service Composition and Customization functional component of the NetApp Toolkit is responsible for providing a unique entry point to Service Providers for designing/composing new Vertical Services starting from available NetApps and related AFs/NFs. In particular, the following functionalities are supported:

- **Application and Network Function Management**: through this functionality, a facilitated and guided procedure is exposed to AF/NF Providers that would like to register/on-board new AFs/NFs. In particular, the procedure also supports the editing of AF/NF-specific constraints, e.g., computing and location constraints.
- **Service Composition**: this functionality is oriented to Vertical Service Providers that would like to create new service-chains starting from available building blocks, i.e., AFs/NFs and/or NetApps. The Vertical Service composition results into a directed acyclic graph that contains the desired NetApps and that can be also eventually modified/updated at a subsequent stage.
- **Service QoS Parameters Editing**: this functionality enables the customization of a Vertical Service from a service-logic point of view. Indeed, through this procedure is possible to provide a set of application-specific high-level QoS parameters that then are used to determine the most suitable deployment profile from a network/infrastructure point of view.
- **Policy Management**: this functionality allows to create, update, and delete optimization policies associated with a Vertical Service and its included NetApps. Through the definition of optimization policies is possible to exploit collected metrics from different data sources (e.g., service components, infrastructure, network etc.) as well as generated events to automate the run-time modification/optimization of the Vertical Service.

3.5.2. NetApp Catalogue

The NetApp Catalogue functional building block offers a set of functionalities related to management of NetApp Packages. In particular, the following functionalities are supported:

- **NetApp Package Management**: this functionality includes the support for NetApp Packages on-boarding, query, update and delete. The format and content of the NetApp Package correspond to the information model described in Section 3.2.1. According to the content of the package, internal procedures are also triggered to manage the CAF/CNF Packages/Descriptors and the related SDs.
- **Centralized Registry**: this functional component is used to manage the images of the on-boarded CAF/CNF Packages.

Table 11 provides details about the reused software baseline and the planned extensions with respect to each of the identified functional blocks of the NetApp Toolkit.

Table 11: Reused Software and Extensions

#	Functionalities	Origin	Foreseen Extensions	Responsible Partner
1	**Application and Network Function Management**	H2020 5G-PPP phase II MATILDA project	New APIs to support the management (registration, editing, parameterization) of application and network functions between the 5G-IANA front-end and the NetApp catalogue.	UBI
2	**Service Composition and Customization**	H2020 5G-PPP phase II MATILDA project	Graphical Extensions during the constitution of the NetApp with projection of information related to the edges involved (available/registered OBU/RSUs). In addition, exposure of the available NetApp Templates to the service creators and service providers during the composition of the NetApp. Planned Extension on the repositories and the data model regarding the Applications and Network Functions.	UBI
3	**Service QoS Parameters Editing**	H2020 5G-PPP phase II MATILDA project	Extensions are planned on the editing of the Service QoS definition with more parameters regarding the moving edges.	UBI

4	**Policy Management**	H2020 5G-PPP phase III 5G-INDUCE project	Small modifications to include automotive sector related polices	UBI
5	**NetApp Package Management**	H2020 5G-PPP phase III VITAL-5G project	The VITAL-5G NetApp Catalogue and the related NetApp information model is extended in 5G-IANA to: i) provide a more specific categorization of NetApps according to the defined service categories, ii) provide additional attributes mapped into the NetApp Template to describe automotive relate constraints and the location of the components images in the registry, iii) manage cloud service descriptors (e.g., Kubernetes Helm charts) and iv) integrate a CI/CD pipeline for the verification/packaging of NetApp Packages and their on-boarding to the platform.	NXW
6	**Centralized Registry**	Open-source software	An open-source registry to host CAF/CNF images integrated with the NetApp Catalogue	NXW

Figure 6 depicts a high-level sequence diagram that describes: i) the NetApp Package on-boarding and composition procedures performed by the NetApp Provider at the NetApp Catalogue and ii) the Vertical Service composition procedure executed by the Service Creator, which includes the specification of the QoS high-level parameters as well as the definition of the optimization policies.

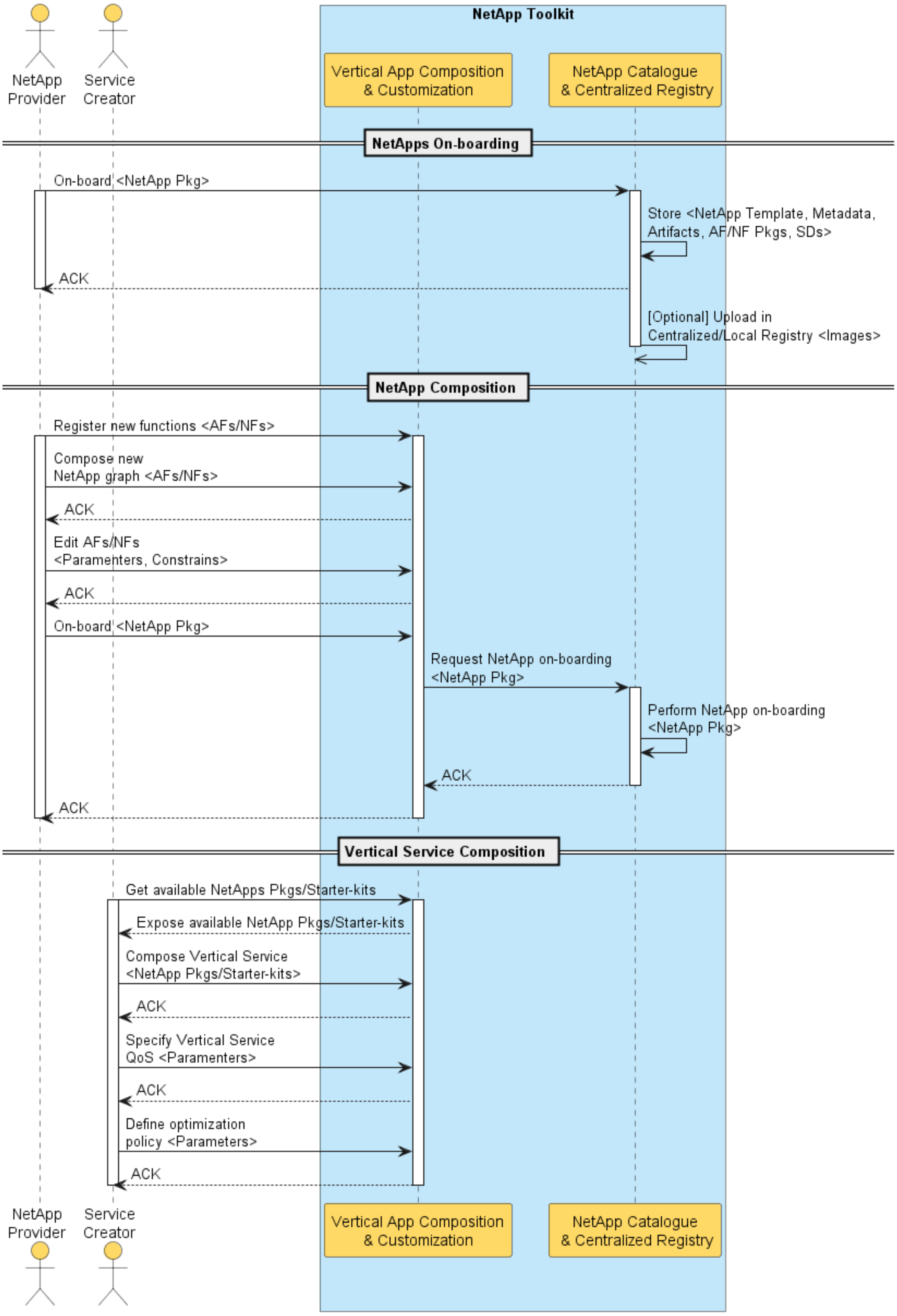

Figure 6: NetApp Toolkit high-level workflow

4. SPECIFICATIONS OF THE 5G-IANA ORCHESTRATION PLATFORM

4.1. State-of-the-Art of orchestration solutions

Orchestration embraces automation which is critical for the commercial survival of today's Service Providers, who face rising technology complexity, increased commercial pressures, and accelerated technology refresh cycles. According to the study in [11], automation has the ability to lower the cost of operations by a 60% while, at the same time, enabling the agility and innovation Service Providers need to enter and compete effectively in new markets. The global enterprise market is highly attractive for this kind of automation and its benefits and thus, seeks for new entries to compete and differentiate there. One other missing part is the capability of the Vertical Services to dynamically interact with this orchestration primitives the infrastructure exposes and provides. In that sense, a service orchestration, taking into account vertical needs, is a key factor for success in the enterprise market. The ability to orchestrate new services through the full-service life cycle of design, deployment, and operation is essential to reduce OPEX, achieving agility, reducing operational costs, and enabling new revenue generating services. However, as with the adoption of any new technology in complex legacy architecture, service providers should expect the operational overhead and complexity to increase in the short term before the long-term benefits can be realized. In consequence, the adoption of a unified programmability model and the definition of proper abstractions to constitute the creation of an open development environment that may be used by applications as well as network functions developer is something this project embraces and from previous work [9], [33].

This section describes projects and frameworks relevant with 5G-IANA while focusing on the orchestration and MANO aspects (MANO aspects are presented in Section 6.1.1) that have already been specified or developed. The purpose is to investigate if any of these frameworks can cover the requirements of the AOEP. This will elucidate the design and development of the 5G-IANA orchestration platform, by lowering the complexity of the design of the platform and indicate potential pitfalls in the design and implementation phase. The presented projects provide insights for the state-of-the-art projects that 5G-IANA leverages as baseline for the orchestration blocks to build some of the component atop of them. It also provides a summary of the state-of-the-art available MANO frameworks.

4.1.1. Relevant Projects

MATILDA-5G. Matilda-5G brings the architectural concept based on the "separation-of-concerns" concept, which allows individuals and vertical industries to orchestrate their applications and service through a Vertical Application Orchestrator. MATILDA follows a layered architectural design of four layers, (i) Applications Layer that covers the application components, the virtual network functions, and a set of network resources that attaches the network functions to achieve a complete network service package, (ii) Orchestration Layer that incorporates a set of intelligent mechanisms for optimal deployment, strategic placement, runtime policies enforcement, data mining and analysis and context awareness support for 5G end-to- end network service. This layer takes advantage of a high-level software module that contributes to network awareness and builds an intelligent and innovative orchestration service system; (iii) Network Functions and Resource Management Layer provides the resource management features and the lifecycle management of VNFs, this layer uses both PNFs and VNFs to deliver application -aware network slices; Finally, iv) Infrastructure Layer consists of user data traversing cloud computing and other resources such as Edge/fog computing, edge network, etc. 5G-IANA inherits the same approach following the "separation-of-concerns" between the application providers and the network services orchestration. 5G-IANA will also re-use and extend the software artefacts involved in orchestration loop as well as monitoring and the profiling Mechanism that had been developed in MATILDA-5G.

5G-INDUCE. 5G-INDUCE targets the development of an open, ETSI NFV compatible, 5G orchestration platform for the deployment of advanced 5G NetApps. The project focuses on the Industry 4.0 vertical sector and the platform's unique features provide the capability to the NetApp developers to define and modify the application requirements, while the underlay intelligent OSS can expose the network capabilities to the end users on the application level without revealing any infrastructure related information. This process enables an application-oriented network management and optimization approach that is in line with the operator's role as manager of its own facilities, while it offers the development framework environment to any developer and service provider through which tailor-made applications can be designed and deployed, for the benefit of vertical industries and without any indirect dependency through a cloud provider. 5G-IANA will inherit and extend the South-Bound API which is responsible for the communication and the formulation of vertical requirements into a resource (slice intent) template intent with the underlying network orchestrator.

Int5Gent. Int5Gent project targets the development of a complete 5G system platform for the validation of advanced 5G services and Internet of Things solutions. Int5Gent's role of the Orchestration Framework is to enable the dynamic provisioning and Lifecycle Management (LCM) of Vertical Services across distributed and multi-technology E2E 5G Network Slices. 5G-IANA will exploit and enhance the mechanisms for mapping vertical high-level requirements to 5G Network Slices and compute quotas over the various programmable infrastructures.

4.2. Specifications of the requirements

The following table provides the list of functional requirements for the orchestration framework. This includes:

a) **AO-NOD**: the Application Orchestrator part of the NetApp Orchestration and Development framework, which is responsible for the formalisation of the Vertical Service deployment request towards the provisioning of the Network Slice and the deployment of the NetApps and their reconfiguration during runtime and according to the established policy criteria, the end user dynamic requests and the monitoring information from the network.

b) **SM**: the Slice Manager, which undertakes the procedure for translating the Vertical Service intent-based request into 5G performance requirements, selecting the most appropriate NEST and verifying the availability of a suitable NSI. The SM also coordinates the compute resource quota provisioning, termination and modification depending on specific Vertical Service policies.

c) **RO**: the Resource Orchestrator, which is responsible for the multi-segment resource arbitration and orchestration, including: i) Far-edge resources information management, ii) Tenant quota management, iii) Edge/Cloud/Far-edge resource management and allocation.

Table 12: Orchestration framework functional requirements (Application Orchestrator – Slice Manager – Resource Orchestrator)

Identifier	Title	Priority	Description
SFR-AO-NOD-1	Slice intent creation	MUST	The AO must translate all the Vertical Service graph constraints and requirements into a slice intent, formalising the descriptor for requesting the necessary programmable resources
SFR-AO-NOD-2	Slice reception	MUST	The AO must provide a procedure for processing the allocated resources information provided by the Slice Manager in a specific format
SFR-AO-NOD-3	Vertical Service deployment management	MUST	The AO must enable the deployment of Vertical Services over programmable infrastructure

SFR-AO-NOD-4	Vertical Service lifecycle management	MUST	The AO must enable the proper execution of (vertical sector driven) Vertical Services over a programmable infrastructure, maintaining operational state and communication info for all the deployed components
SFR-AO-NOD-5	Vertical Service status monitoring	MUST	The AO must monitor the operational status of the deployed Application Functions
SFR-AO-NOD-6	Vertical Service metrics monitoring	MUST	The AO must monitor Application Functions' specific metrics (e.g., CPUs, RAM)
SFR-AO-NOD-7a	Visualisation - metrics list	MUST	The AO should allow end users to visualize the list of metrics
SFR-AO-NOD-7b	Visualisation - metrics select	SHOULD	The AO should allow end users to select the metrics to be visualised
SFR-AO-NOD-7c	Visualisation - metrics remove	MUST	The AO must allow end users to remove metrics from the visualisation
SFR-AO-NOD-7d	Visualisation - metrics display	SHOULD	The AO should display to end users the list of metrics for visualisation
SFR-AO-NOD-8	Policy inference	MUST	The AO must allow the triggering of optimization actions in response to the monitoring of Vertical Service metrics (e.g., adapting deployed components when certain monitored metrics are exceeding thresholds defined through the policies)
SFR-AO-NOD-9	Analytics	COULD	The AO could provide the main optimization actions as result of corelations among monitored metrics
SFR-AO-NOD-10	Slice Manager registration	MUST	The AO must provide a functionality for the registration of the Slice Manager in terms of connection details
SFR-SM-1	Network Slice Intent-based translation	MUST	The SM must provide a procedure for translating the intent-based provisioning request into 5G performance requirements (Service Profile - NEST) and the amount of computational resources needed for running the Vertical Service logic
SFR-SM-2	5G System Network Slice selection	MUST	The SM must provide a procedure for the selection of a 5G System Network Slice instance based on the translated Service Profile
SFR-SM-3	Network Slice templates on-boarding	MUST	The SM must provide a catalogue functionality for on-boarding Network Slice templates according to the supported models i.e., GSMA NEST and 3GPP NRM)
SFR-SM-4	Network Slice templates query	MUST	The SM must provide a catalogue functionality for querying Network Slice templates

SFR-SM-5	Network Slice templates deletion	MUST	The SM must provide a catalogue functionality for deleting Network Slice templates
SFR-SM-6	Network Slices template update	SHOULD	The SM should provide a catalogue functionality for updating Network Slice templates according to the supported models (i.e., GSMA NEST and 3GPP NRM)
SFR-SM-7	Network Slice instances management	MUST	The SM must provide functionalities that allows to maintain an inventory of available Network Slice instances to be selected
SFR-RO-1a	Host information on-boarding	MUST	The RO must provide an inventory functionality for on-boarding host information
SFR-RO-1b	Host information delete	MUST	The RO must provide an inventory functionality for deleting site information
SFR-RO-1c	Host information query	MUST	The RO must provide an inventory functionality for querying site information
SFR-RO-1d	Host information update	MUST	The RO must provide an inventory functionality for updating site information
SFR-RO-2	Tenant SLAs Management	MUST	The RO must provide a set of functionalities for the creation and modification of Tenants SLAs (maximum available resource quotas)
SFR-RO-3	Multi-segment resource arbitration	MUST	The RO must provide a functionality for arbitrating and coordinating the provisioning of compute resource quotas across different segments (e.g., OBUs/RSUs, Edge, Cloud)
SFR-RO-4	Far-Edge resource subscription	MUST	The RO must provide a functionality for the subscription of OBUs and RSUs to enable the provisioning of desired services
SFR-RO-5	Far-edge/Edge/Cloud resource management	MUST	The RO must provide functionalities for maintaining and inventory of available resources in Far-edge, Edge, and Cloud segments
SFR-RO-6	Far-edge resource discovery	MUST	The RO must provide a functionality for the continuous discovery and updating of information related to subscribed OBUs and RSUs
SFR-RO-7	External multi-segment resource allocation support	MUST	The RO must support the interaction with the DML Orchestrator for enabling a tailored resource allocation for DML NetApps

4.3. Advances in 5G-IANA and fulfilment of 5G-IANA objectives

The orchestration part of the platform constitutes the core of the Vertical Service management logic in 5G-IANA. The role of the framework is to act as the enabler for linking advanced end user applications in the automotive sector, with the required supporting network functions over a programmable and adaptive infrastructure that allows innovative services with strict mobility requirements to be delivered over diverse environments and be easily reusable and re-deployable in different locations.

In order to achieve this, 5G-IANA adopts a deployment and orchestration process that is logically split in the three main parts of the Application Orchestrator (AO), Slice Manager (SM) and Resource Orchestrator (RO), presented in the overall system architecture design in Section 2.4. It is noted that in this architecture, the AO part is logically allocated at the application layer of the platform, as part of the NOD framework, while the SM and RO are parts of the network management layer. However, from the orchestration point of view the combination of the three orchestration parts constitutes the key advancement of 5G-IANA AOEP in delivering application aware deployment and management of services on top of 5G infrastructures. For this reason, the design of the AO-SM-RO follows a consolidated design approach, considering in parallel the interfacing of the NetApp Toolkit (presented in Section 3) with AO and SM at the northbound and the interfacing of RO with the virtualised infrastructure segments (Far-edge, Edge and Cloud) (presented in Section 6) at the southbound.

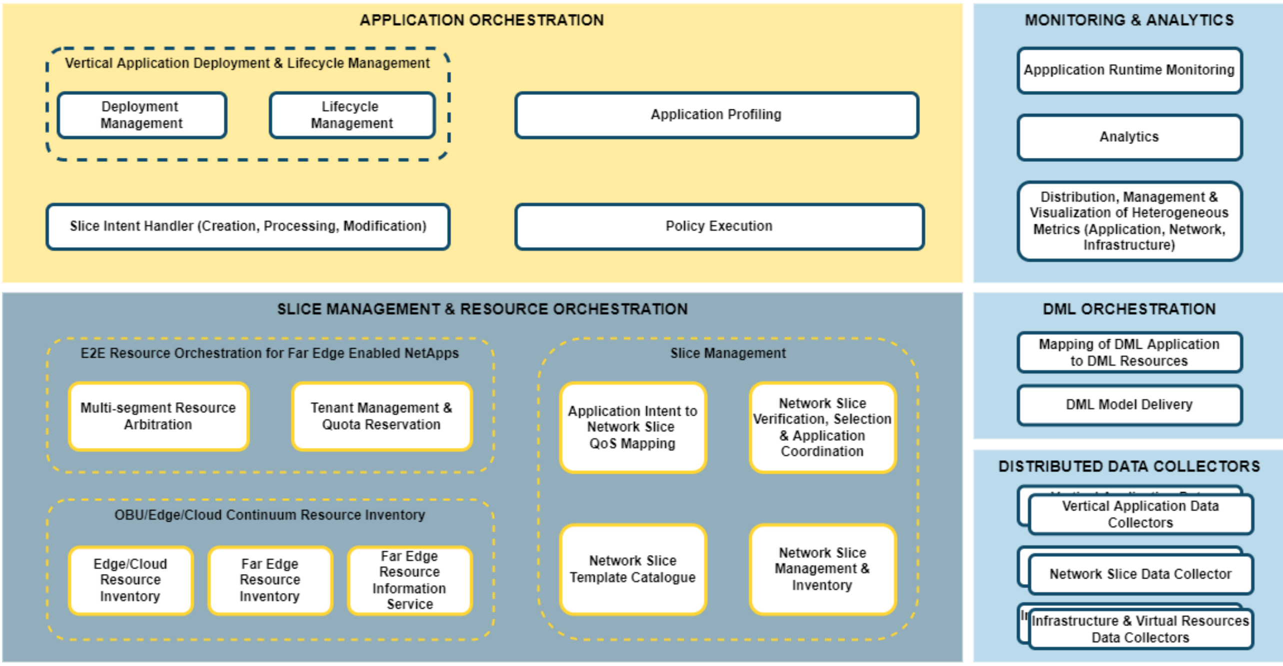

Figure 7: 5G-IANA Orchestration Framework System Design

In the next paragraphs the key advancements for each part of the orchestration mechanism are discussed also considering the specified requirements. Figure 7 shows the detailed Orchestration Framework system design with respect to the overview architecture presented in Section 2.
In order to fulfil the objectives of the project, the orchestration framework is built by re-using several components from other projects. Table 13 lays out the reused components, based on Figure 7, providing their origin and the extensions foreseen to be added in the course of the project. These extensions lead to the advancements shown in the following subsections.

Table 13: Reused Software and Extensions

#	Functionalities	Origin	Foreseen Extensions	Responsible Partner
1	**Vertical Application Deployment and Lifecycle Management**	H2020 5G-PPP phase II MATILDA	Fully compatible with the resources of Kubernetes environment and some lightweight variations of it.	UBI
2	**Slice Intent Handler**	H2020 5G-PPP phase III Int5Gent project	The component collects and formulates the user specified requirements into a template, In addition, regulates the communication between SM and Vertical Application Deployment Manager (AO) . Planned extensions are for the validation of the Slice intent and the slice before the deployment takes place. Notifications upon successful slice allocation or failure and the reason for failing	UBI

3	**Application Profiling**	Maestro® (Commercial Product by UBI)	Profiling microservice will extend to provide correlation and analysis on OBU/RSU related metrics	UBI
4	**Policy Execution**	H2020 5G-PPP phase II MATILDA	Policies extension on the OBU/RSU related application metrics	UBI
5	**SM – Application Intent to Slice QoS Mapping**	H2020 5G-PPP phase III Int5Gent project	This component maps the intent QoS parameters into a suitable NEST. Planned extensions relate to the enhancement of the mapping mechanism to support additional QoS parameters	NXW
6	**SM – Network Slice Verification, Selection & Application Coordination**	H2020 5G-PPP phase III Int5Gent project	This component coordinates the selection of the NSI and the provisioning of the compute quotas. Planned extensions relate to the implementation of a verification mechanism to assess the presence of a suitable running NSI that matches the selected NEST	NXW
7	**SM – Network Slice Management & Inventory**	H2020 5G-PPP phase III Int5Gent project	This component is an inventory of available NSIs. Planned extensions relate to the implementation of a RESTful interface to enable the management of NSIs by the Network Operator.	NXW
8	**SM – Network Slice Template Catalogue**	H2020 5G-PPP phase III Int5Gent project	This component catalogues the available Network Slice Templates (i.e., NEST [2] and 3GPP-based [3] ones). The component can be	NXW

			eventually extended to update the implemented data models according to the evolution of the related standard specification	
9	**RO – Multi-segment Resource Arbitration**	This component/service is developed from scratch in 5G-IANA	-	NXW
10	**RO – Tenant Management & Quota Reservation**	H2020 5G-PPP phase III Int5Gent project	This component is responsible for managing tenant's SLAs perform the allocation of compute resource quotas across multiple Kubernetes clusters. Planned extensions relate to the modelling of tenants' SLAs and profiles to accommodate constraints related to the usage of Far-edge resources (i.e., OBUs, RSUs)	NXW
11	**RO – Far-Edge/Edge/Cloud Resource Inventories**	These components/services are developed from scratch in 5G-IANA	-	NXW
12	**RO – Far-edge Resource Information Service**	This component/service is developed from scratch in 5G-IANA	-	NXW

With respect to 5G-IANA declared objectives, the orchestration platform described in the rest of this section contributes to their fulfilment as reported in Table 14.

Table 14: 5G-IANA NetApp Toolkit Objects Fulfilment

#	Objective	Item	Implementation

1	**Specify and provide an Automotive Open Experimentation Platform (AOEP)**	The Orchestration Platform will include The NetApp Orchestration and Development framework (NOD) the Slice Manager (SM) and the Resource Orchestrator (RO)	The design of the Orchestration Platform includes the method to integrate these three elements (NOD, SM, RO). Section 4.3
2	**Specify and implement a repository environment for NetApps and VNFs to ease the design and chaining of new Automotive-related services – to be integrated with 5G-PPP open repositories**	5G-IANA provides the interface with the NetApp toolkit for the onboarding of NetApp and VNF as well as the storage of the created NetApp graphs	An API leveraging a common data model describing all parameters for NetApp deployment and the chaining information among AFs/NFs Section 4.3.1
4	**Provide accurate localization and low latency mission-critical applications.**	5G-IANA utilises the NOD framework to provision strict application requirements and the SM/RO to deploy them over the infrastructure	Implementation considers the parameters of delay, service type profile and priority for the deployment of services and also the runtime management of critical decisions
6	**Improve service creation time (5G-PPP KPI)**	The design of the different orchestration blocks as well as the interfaces are optimized to lower the service creation time. In addition, improvements on the runtime service reconfiguration times are considered.	Measuring of overall service creation time (from end user request to NetApp service establishment) in the order of few minutes (<5min). Reconfiguration on NetApp resource scale level in the order of 40-60 sec (both depending on NetApp complexity)
7	**Create new business opportunities and boost market for start-ups and SMEs with Automotive NetApps**	5G-IANA Orchestration Platform with the User-friendly GUI of the NetApp toolkit and the adoption of the state-of-the-art orchestration primitives for the NetApp deployments.	Implementation of modular design approach enabling clear roles for service providers operators and NetApp developers with respect to the overall platform

4.3.1. Application Orchestrator advancements

The introduction of the Application Orchestrator adds the logical separation between the application and network/resource orchestration layers. The key idea is to keep the application-oriented functionality detached from the underlay management solution, thus allowing the definition and management (i.e., orchestration) of the application related processes to be handled separately from the network related processes. The key advancement is the introduction of application or equally context-aware features, in the way that applications are handled over 5G network infrastructures, which complies to the latest standardisation trends on Network Slice templates (i.e., GSMA GST/NEST model) and potentially other APIs (as for example the TMF open API).

A number of more specific advances is listed below and constitute the implementation innovations that are developed for the AO part of the orchestrator and its interface with SM:

Application deployment and runtime (lifecycle) management: The two main functions supported by the Application orchestrator can be logically split in the Deployment Management and Lifecycle Management parts (see Figure 7). The Deployment Manager interfaces directly with the NetApp Toolkit and triggered by the requests for an initial deployment of Vertical Services. Its roles then include first the passing of the request (i.e., Vertical Service graph, operating requirements, polices and dependences) to the Slice Intent Handler which in turn creates the slice creation intent according to a specified template format that is passed to the SM. The second and main role of the Deployment Manager is triggered after the slice management process is completed and the targeted slice is returned to the AO (i.e., as a set of interfaces identified for the deployment of components able to meet the requested parameters). Once the slice is established the Deployment Manager provides the appropriate commands for the deployment of NetApp images at the designated nodes, the interconnection among them according to the NetApp graph and the initiation of the NetApp function following the designated (by the graph) sequence of actions. Next the Lifecycle Manager takes over for the duration that the NetApp is active. Monitoring plays here an important role since it provides the metrics for the management decisions. The metrics are analysed by the policy execution engine, which considers the policy requirements and if the application follows the respective requirements. The metrics are also analysed through the application profiling engine to gain insights on the application behaviour and status. Based on the monitored data, the Lifecycle Manager may initiate reconfiguration requests which in turn are triggered either directly by the end user as application or policy adaptation demands, or automatically by the orchestrator if certain policy thresholds are passed.

Automated application orchestration processes: The initial designs of the Application Orchestrator considered end user driven requests and policy related configuration requests. The 5G-IANA design provides an additional reconfiguration degree that considers the automated triggering of events through intelligent monitoring and analytics processes enabled by the DML framework discussed in Section 5. The concept examined for development includes the gathering of network status information as well as user, device and application related information (e.g. traffic conditions, registered end users/vehicles at specific edge node) with the goal to provide predictions on important parameters that may potentially affect the performance of applications (e.g. as traffic increases at a specific junction then CPU and memory for given application at the designated node must be increased to efficiently support the application). Such predictions will be provided at first stage as recommendations to the Lifecycle Manager, but the option to include them in automated processes will be examined too.

Functional end user frontend for NetApp onboarding: The 5G-IANA orchestrator design is detached from the frontend processes of NetApp registration and design. This allows advance frontend frameworks to be developed and seamlessly attached to the orchestrator service which is implemented as the functional backend; in 5G-IANA the NOD NetApp toolkit is the front-end framework. A specific model is defined as a REST interface for establishing this communication, while the model can be adaptable in terms of declared parameters. Such frontend frameworks can be open to end users for defining the declared parameters as well as monitoring values and policies. In principle they can be expanded with supporting programmability tools that for example provide a translation of high-level user defined parameters into the required parameters or the prediction of NetApp components required to be attached in order to meet certain performance/policy metrics.

Modular architecture to enable new features: A final important feature to be mentioned is the modular design approach adopted for the orchestration functions. The approach enables the easy introduction of future updates or modifications concerning important decision modules as for example the runtime analytics engine (which can be further enhanced with ML features) or the link of the profiling engine with advance application specific dashboard mechanisms. Moreover, the Application Orchestrator part of the overall orchestration platform can interface over any detached programmable infrastructure acting as a stand-alone service orchestration mechanism in isolated environments, as for example over private edge infrastructures with SDN enabled programmability at the transport layer.

4.3.2. Slice manager advancements

The SM block of the orchestrator is responsible for mapping the QoS parameters specified within the intent produced by the AO with the most suitable available 5G NSI (i.e., taking into account the available configuration of the radio and 5G Core network segments). In addition, the SM complements the provisioning of the 5G connectivity by coordinating the allocation of compute resource quotas for running the different

NetApps across the different segments. It is typically offered as unified slicing and resource orchestration solution and therefore it is represented in a single architectural layer in Figure 7. The SM functionalities are included in the block of modules located at the right part of the Slice Management and Resource Orchestration layer in the same figure. The key advancements offered by the SM in combination with the Application Orchestrator in its NBI and the RO at the South-bound Interface (SBI) are described in the following paragraphs:

Application Intent to Network Slice QoS Mapping: the intent-based requests provided by the Application Orchestrator are first authenticated and validated and then forwarded to the Application Intent to Network Slice QoS Mapping module. This module implements the logic to map the Vertical Service high-level requirements specified through the intent-based request into the most appropriate NEST [13] for the subsequent mapping with an available 5G System configuration. In principle, each Vertical Service request is translated into a proper NEST (or set of NESTs). This mapping procedure is essential in order to check the availability of the core and access network and the related configured NSIs and their characteristics. An additional key feature of this module is that it determines the amount of resources needed for the deployment of the Vertical Service and its constituent NetApps.

Network Slice Verification, Selection & Vertical Application Coordination: Following the mapping process and according to the selected NEST, the coordination module takes care of the verifying the availability of a suitable NSI among the already existing ones established by the Network Operator. Then, the component coordinates the Vertical Service quota provisioning across the target hosts in the different network segments. The management and allocation of compute resources in the distributed hosts is performed by the RO, whose role and functionalities are described in Section 4.3.3.

Network Slice Template Catalogue: This functional component implements a catalogue of Network Slice templates. In particular, the component implements two standard-compliant data models: i) the GSMA NEST and the ii) 3GPP-based Network Slice Template (NST). The translation of the QoS parameters in the intent-based request is performed against the NEST templates available in this catalogue.

Network Slice Management and Inventory: The SM implements also functionalities for the management of NSIs by the Network Operator. The provided inventory lists all the available NSIs configured by the Network Operator and the related characteristics in terms of Slice Profile. In addition, the inventory offers an API that allows to create/update/delete the available NSIs.

4.3.3. Resource Orchestrator advancements

The RO is the functional block of the 5G-IANA orchestration framework that is responsible for the management and allocation of compute resources distributed across different segments in the 5G-IANA infrastructure. Indeed, the RO provides a set of functionalities that target the orchestration of compute resources located in OBU, RSU, Edge and Central Cloud segments. The major challenge posed for the RO is the implementation of an efficient set of procedures that enable the usage of OBUs and RSUs as orchestration-enabled hosts. Indeed, while the usage of fixed Edge and Central Cloud resources can be easily addressed and eventually optimized through the usage of almost static inventories and nodes can be easily accessed within the Network Operator network, the same approach cannot be fully applied for resources on the UE side, considering their discontinuous availability, their mobility, and the necessity of having the management traffic flowing through the 5G mobile network. The RO solution proposed in 5G-IANA is realized through the implementation of a set of functionalities to enable the continuum resource discovery and control. The orchestration of Far-edge resources is an important topic currently investigated in beyond-5g research initiatives and 5G-IANA plans to contribute to this direction through the prototyping of the RO and its validation through the Use Cases and third-parties' experimentation. The main functionalities provided by the RO are the following:

E2E Resource Orchestration for Far-Edge Enabled NetApps: The SM coordinates the provisioning of the compute resources for running the Vertical Service by triggering the RO. The RO takes care of the E2E resource allocation across Cloud, Edge, and Far-edge resources. First of all, the provisioning of the needed resources is executed according to Service Level Agreements stipulated with the authorized Tenants, whose information are managed and maintained. The RO includes an inventory of the registered hosts for each segment, in addition the most relevant information in terms of access information and capabilities are stored. Indeed, especially for what concerns Far-edge segments, a subscription functionality is provided to register them to the system. Moreover, the multi-segment arbitration of resources can be also performed by relying on external algorithms/services. Indeed, in case of ML NetApps, in 5G-IANA the selection of the hosts and the consequent allocation of compute resources is performed by the DML Orchestrator, which determines the most suitable placement for probes and ML agents depending also on the specific capabilities of the nodes, data-set availability and the expected trajectory/location in case of OBUs.

Far-Edge/Edge/Cloud Continuum Resource Inventory: For each registered host, an inventory of available resources is also provided. In particular, a continuum discovery is applied for Far-edge resources, in order to keep the inventory updated with respect to the availability of OBU and RSU nodes. Indeed, especially OBUs may be not always reachable in a given coverage area. The continuum resource checking for OBUs and RSUs is executed by relying on the mechanisms offered by Kubernetes, i.e., the selected orchestration platform to be used on top of the different hosts across the infrastructure segments, and the Information and Localization service that is offered by these hosts, then information about capabilities and expected trajectories are collected periodically at the RO that updates its inventory accordingly.

Figure 8 depicts a high-level sequence diagram reporting the initialization workflow for the Slice Management and Resource Orchestration components. Part of the initialization consists in the creation of information related to available Slice Profiles (NEST) and running Network Slice Instances that can be selected for supporting the provisioning of an incoming Vertical Service. Also, information related to the affiliated hosts in the different segments and related available resources are created as part of the AOEP initialization. Concerning the Far-edge resources, once the corresponding hosts are registered, their availability is assessed every time a provisioning request is issued.

Figure 9 depicts a high-level sequence diagram describing the Vertical Service provisioning procedure across the different layers and components of the AOEP Orchestration framework. In particular, the sequence diagram highlights the role of each orchestration layer, where: i) the Application Orchestration layer is responsible for formalizing the provisioning request and performing the LCM of NetApps, ii) the Slice Management and Resource Orchestration layer is responsible for the NEST selection and the coordination of compute resources provisioning across the target hosts in the different infrastructure segments and iii) the MANO platforms at the Far-edge, Edge and Cloud segments are in charge of the AFs/NFs local LCM.

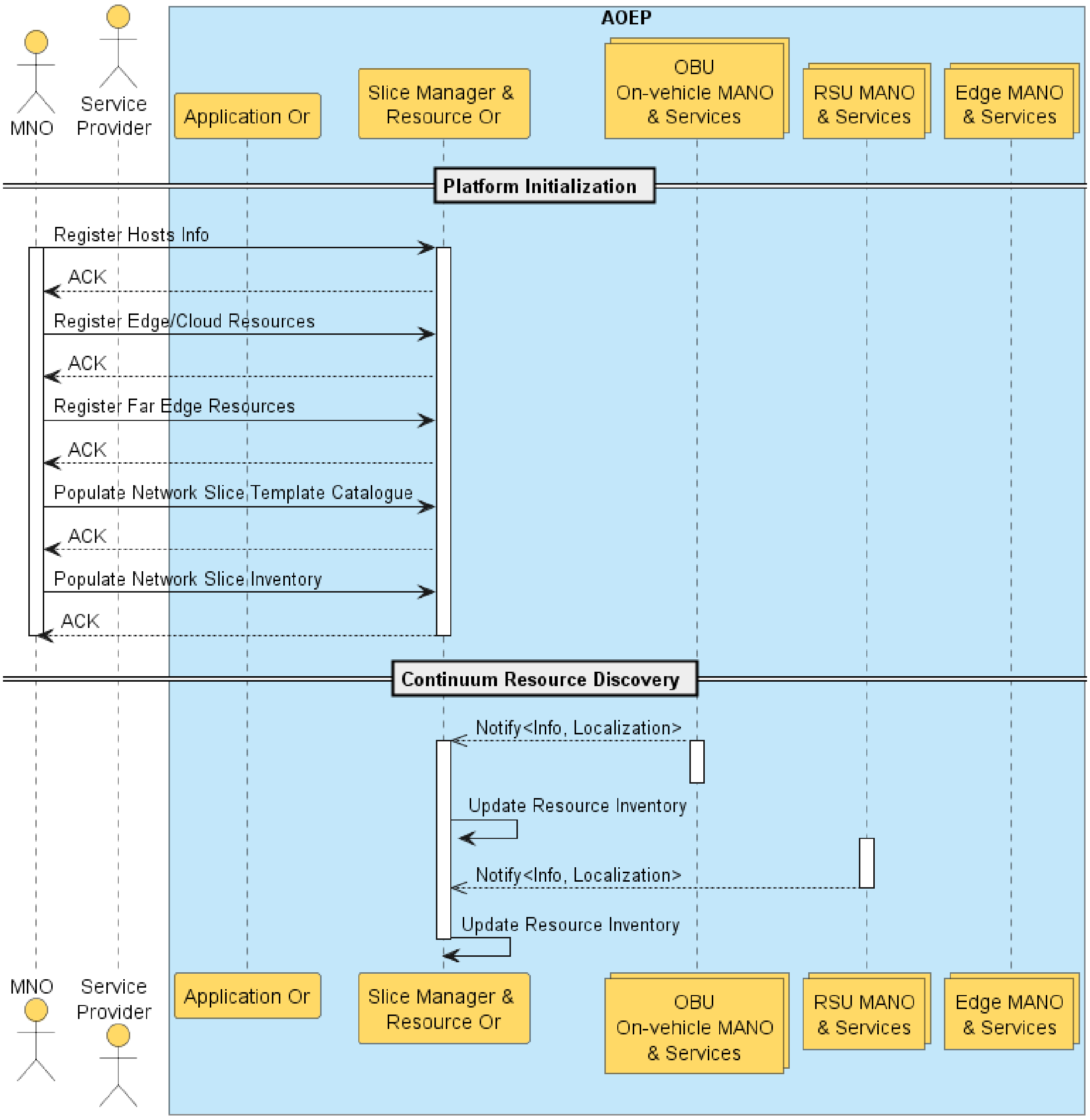

Figure 8: Slice Management and Resource Orchestration high-level initialization workflow

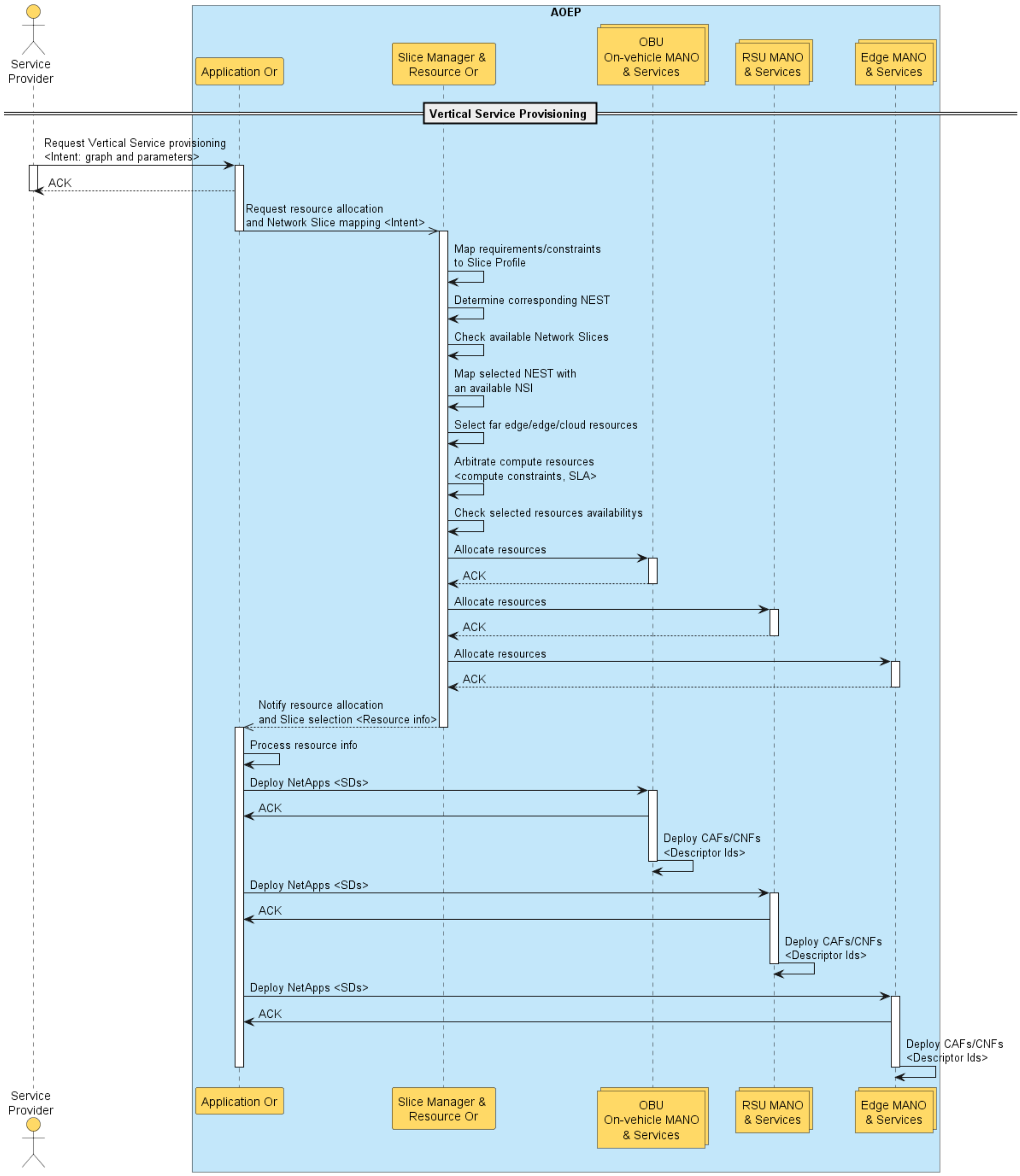

Figure 9: AOEP Orchestration framework high-level provisioning workflow

5. SPECIFICATIONS OF THE DISTRIBUTED ML FRAMEWORK

This section introduces the requirements of the Distributed Machine Learning (DML) framework, which is deployed within the AOEP infrastructure. After reviewing the state of the art of DML solutions, this section introduces the specifications of the requirements for the DML Orchestrator, as well as the advances provided by the DML framework in 5G-IANA.

5.1. State-of-the-Art of distributed ML solutions

The availability of continuous streams of data paired with considerably improved statistical analysis has been playing a crucial role in developing ML techniques to accelerate computing applications. State-of-the-art Machine Learning solutions are based on training neural networks using large volumes of data to produce non-hard-wired algorithms tailored toward supervised tasks such as classification and regression, unsupervised tasks such as clustering, and tasks of continuous online improvement in reinforcement learning. The availability of large datasets is the main driver behind the success of Machine Learning algorithms. Another driver is the availability of processing hardware (e.g., GPUs) to train large datasets. In terms of the automotive verticals, we observe a need to train and execute Machine Learning models without centrally gathering the raw data. This is mainly due to a combination of the required overall training time, high bandwidth requirement to transmit raw data to a central location and data privacy concerns. To this end 5G-IANA takes a distributed learning approach.

The distributed ML approach [14] allows an ML model to be dispatched to distributed data source locations to be locally trained. Federated Learning (FL) has already been considered as a promising approach in the context of 5G networks, with proposed application areas including mobile content popularity, as well as a generic support technology for 5G Core's Network data analytic function [15]. The rationale behind that is a horizontal scaling of training while aiming at the accuracy of a centralized training. In the best case, the required training time scales down linearly with the number of DML nodes (here, OBUs and RSUs). In addition, the training is assumed to be more robust with respect to node failures as the contribution of single nodes, e.g., one OBU, to the overall model is only fractional. The resulting updated ML models are subsequently aggregated (averaged) at a central function, i.e., the trained model parameters are transferred instead of the raw data, delivering a new updated global model ready for subsequent dispatching cycles. This dispenses with the high bandwidth and storage requirements for the collection of raw data from the OBUs and RSUs as well as the privacy concern.

The components of the DML process described above can be broken down into two parts: (i) the distributed training algorithms and (ii) the orchestration and communication framework tying the nodes. The first component concerning the distributed training algorithms revolves around variations of the stochastic gradient descent (SGD) algorithm, which can be directly related to the state-of-the-art ML optimizers ADAM (Adaptive Moment Optimization) and RMSProp (Root Mean Square Propagation). Distributed versions of SGD build the iteration loop mentioned above, i.e., model distribution, training, and collection, around synchronous and asynchronous forms. Synchronous SGD couples the OBUs (nodes) in the network as iterations require all possibly heterogeneous nodes to finish before proceeding to the aggregation phase. This leads to challenges including slow computing OBUs and waiting for synchronization, which affect the model convergence speed and hence the DML task completion duration. Asynchronous SGD dispenses with the synchronization at the expense of stale gradients, i.e., merging old updates from slow computing OBUs and, hence, a gap in the model quality. Note that, the lack of synchronization in SGD essentially lets training nodes communicate gradients at will. This leads to an SGD convergence rate that is reciprocal to the square root of the number of participating nodes. The second component comprising the orchestration and communication framework of the DML is based notable on the selection of nodes e.g., OBUs/UEs, to form a (typically) star topology with the model aggregation set in the centre node (Edg [16]. In the presence of a potentially large set of candidate nodes, the selection process becomes important in achieving the desired training efficiency as expressed in terms of e.g., the consumption of computational and communication resources, the achieved accuracy, the speed of model convergence, i.e., the training time 2. Driving this selection process then requires key monitoring information regarding the overall node, resource and data level availability, as well as regarding the possibly heterogeneous OBU environment. Such parameters correspond to the actual properties of the distributed / federated learning framework, i.e., data quality/availability being heterogeneous and the heterogeneous training devices (OBUs, RSUs) and network conditions [17], which are obviously affected by the mobile nature of the nodes i.e., OBUs, and in turn have an impact on the efficiency of the training process e.g., selecting currently loaded OBUs is expected to delay the training convergence.

This is clearly seen in a 5G mobile scenario where different vehicle OBUs observe qualitatively different data (e.g., network conditions) as well as the fact that the OBUs

[2] D5.1 identifies specific KPIs aimed to capture the efficiency of the DML training process.

themselves are composed of heterogeneous hardware that might not be permanently available for DML tasks. Concretely, the phenomena related to these concerns are denoted by client drift and non-adaptivity, i.e., local models on the OBUs move away from a globally optimal model due to the reasons mentioned above. Further challenges of the state-of-the-art DML relate to the trade-off of model consistency and training performance. In Federated Learning, parameter consistency can vary from synchronous configurations (consistent) over stale-synchronous, asynchronous up to ensemble learning configurations. Implementations show that for few tens of nodes synchronous architectures can be used while for more training nodes asynchronous and stale-synchronous parallelism are more effective. There are various FL ecosystems such Tensorflow Federated [18], LEAF [19] and Fedscale [20] but none of them are able to bridge the gap between federated learning research practices and real-world use case requirements namely, scalability, heterogeneous client environment, transitions from simulation to real devices and flexibility and orchestration.

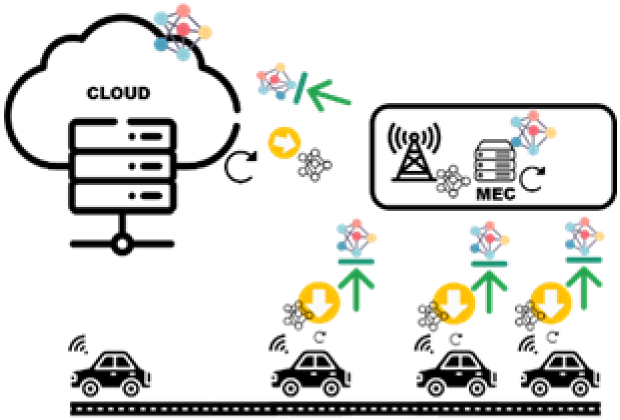

Figure 10: Federated Machine Learning for automotive verticals involving model training, aggregation, and transfer (using Edge server and OBUs)

The overall framework is depicted in Figure 10. The figure shows the aggregation node sending an initial version of the model parameters (weights and biases) of a global central server's Machine Learning model to all the device nodes running on Edge server or vehicles where these nodes execute the model, specifically, stochastic gradient descend, multiple times. After local training on the available data, each node will have its own version of the model. The weights and biases of the models of each node are sent back to the central server to evolve into a highly efficient global model. This aggregation is performed as model averaging through federated forms of server-side optimizers such as federated adaptive moment estimation (Federated ADAM) [21] or simple federated averaging (FedAvg) [14].

5.2. Specifications of the requirements

In the following table, we report the specified functional requirements for the DML framework. These requirements act as input to the design of the DML components that are part of the 5G-IANA AOEP.

Table 15: DML Functional Requirements

Identifier	Title	Priority	Description
SFR-DML-1	Application Server Interface	MUST	DML must be able to provide an API for Application Server for interaction
SFR-DML-2	DML Application Translator	MUST	DML Framework must be able to translate the request provided by the Application Server into defined parameters
SFR-DML-3	OBU/RSU System information access	MUST	OBUs/RSUs must be able to access their internal system information which has to be exposed to DML
SFR-DML-4	OBU/RSU HW information	SHOULD	DML should be able to get information regarding the HW characteristics of an OBU
SFR-DML-5	OBU/RSU Resource Availability/Utilization Information	SHOULD	DML should be able to get information regarding the availability or utilization of OBU compute/network/storage resources
SFR-DML-6	OBU Battery information	SHOULD	DML Framework should be able to collect information regarding the current energy availability of OBU devices
SFR-DML-7	OBU Data Volume Availability	SHOULD	DML Framework should be able to collect information regarding the current availability of training data volumes on OBU devices. The availability should be determined subject to a configurable volume threshold
SFR-DML-8	OBU Data Feature Availability	SHOULD	DML Framework should be able to collect information regarding the current availability of training data features on OBU devices. The availability should be determined in an application agnostic manner (e.g., Bloom filters)
SFR-DML-9	OBU Availability Estimation	WOULD	DML Framework would be able to produce an estimation of the expected availability of an OBU device in the imminent time window

SFR-DML-10	OBU Meta-data exposure	MUST	DML framework must be able to deliver OBU meta-data information to an application component (model aggregator CAF) e.g., location, availability, etc.
SFR-DML-11	OBU Selection / filtering	MUST	DML framework must be able to identify (filter) OBUs subject to criteria set by the service provider. Selection can be periodic, event-based, one-off
SFR-DML-12	Dynamic Policy-based orchestration	MUST	DML framework must be able to support dynamic orchestration subject to policies defined by service providers. This can follow an event-condition-action approach. Orchestration refers here to LCM actions
SFR-DML-13	DML - Application Orchestration	SHOULD	DML Framework should be able to forward the queries from Application Server to Application Orchestrator
SFR-DML-14	DML orchestration primitives	SHOULD	DML framework should support a set of ML pipeline orchestration primitives and its translation and decomposition to individual actions.
SFR-DML-15	ML Topology selection	SHOULD	DML framework should be able to suggest a placement for the distributed ML task, subject to resource availability and ML constraints e.g., use a single or multiple (synced) aggregators, hierarchical vs flat FL.
SFR-DML-16	DML-Edge communication	SHOULD	DML Framework should be able to receive responses/results from Edge server.
SFR-DML-17	Geo-fencing ML support	SHOULD	DML framework should be able to automatically either re-configure or re-deploy FL model VNFs subject to the spatio-temporal context.
SFR-DML-18	UE Resource Visibility	MUST	Far-edge resources must be visible and controllable to/by the RO i.e., part of the NFVI.

5.3. Advances in 5G-IANA and fulfilment of 5G-IANA objectives

In 5G-IANA, the DML architecture and the corresponding ML pipeline support provide a framework over which the automotive Vertical Services can run their DML models/tasks. This DML framework, will allow distributed ML-based applications to penetrate the automotive world, due to its inherent privacy preserving nature. As elaborated in the following, the role of the DML orchestrator (DMLO) is to facilitate ML model training and deployment/testing/inference (thereafter) on top of the 5G-IANA platform. This is realized in translating traditional ML pipelines to specific instances of NetApp service chains (see Figure 11), which can dynamically adapt to surrounding conditions during service provisioning (see next).

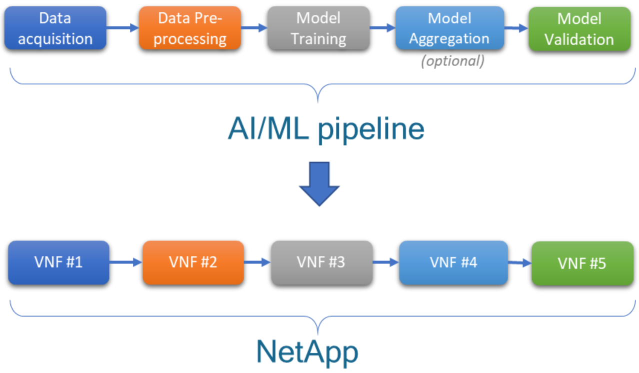

Figure 11: ML pipeline mapping to a NetApp service chain

The instantiation of the ML pipelines can take various forms, in terms of training scheme and topology. In the most notable example Federated Learning schemes and star-topologies (as previously discussed) can be supported by the DMLO, practically translating to placement decisions and life-cycle management operations driven by the discussed node selection functionality and the corresponding monitoring of essential parameters affecting training efficiency. However other options will also be available e.g. Centralized Learning, etc. that will allow the user to define his preferable method/policy in regards to the ML training procedure. Figure 12 below illustrates a simplified example of the above example options.

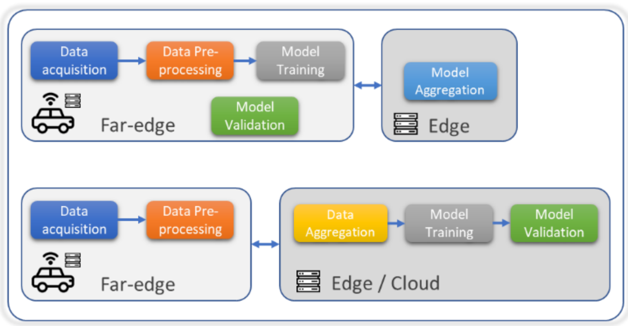

Figure 12: ML pipeline instantiation examples: (top) fully distributed, FL-based deployment; (bottom) semi-distributed / centralized (hybrid) deployment

It is important at this point to highlight, that the role of the DMLO is not to provide service/application specific functionality, but to only provide application-agnostic support to services focusing on ML training, in a manner orthogonal to the nature of the specific training task at hand. As such, 3rd party experimenters will still be able to steer the training process, from within their applications, subject to the specificities of their training task e.g., select training nodes with valuable contribution to the training convergence. To this end, the DMLO functionality is exposed through a runtime REST API to the Parameter Server / Aggregation Node that is directly developed by the vertical service provider to capture the specificities of the training task at hand e.g., Predictive QoS, Predictive Maintenance, Mobility/Trajectory Prediction, etc. To facilitate the usage of this API, the 5G-IANA Platform will prepare and make available a series of AFs already integrating this API within popular frameworks. For instance, in the case of federated learning, Model Aggregator and Training Node AFs will be developed using the FLOWER3 framework; 5G-IANA DMLO client selection functionality will then be integrated with FLOWER node/client management. This will allow 3rd parties to port their ML functionality (ML model, libraries and application specific management logic) to the well-known environment of FLOWER, without having to develop functionality to interface the DMLO.

With respect to 5G-IANA declared objectives the DML framework described in the rest of this section contributes to their fulfilment as reported in Table 16.

Table 16: 5G-IANA DML Framework Objects Fulfilment

#	Objective	Item	Implementation
1	**Specify and provide an Automotive Open Experimentation Platform (AOEP)**	A DML framework, as part of the VNFs Repository	The NetApp data-model enables a proper cataloguing of ML NetApps to facilitate their usage and chaining in Vertical Services. This is carried out in conjunction with the DML Orchestrator functional block of the AOEP system architecture
4	**Provide accurate localization and low latency mission-critical applications**	The DML framework will allow QoS prediction and consequent application/resource management for mission critical scenarios	WP4 will develop and package a DML NetApp to collect network state information and provide spatio-temporal QoS predictions

Based on the review of the state of the art above, the 5G-IANA project aims to achieve the above objectives given in Table 16 along two major directions. The first direction concerns the lack of an integrated system design for DML in 5G. State-of-the-art

[3] https://flower.dev/

application layer frameworks lack, for example, the visibility of mobile resources that is required for orchestration of DML in mobile networks, especially for automotive applications. The second direction concerns the optimization of distributed training with federated concepts for 5G automotive applications. Limitations of the state of the art include here the assumptions of data and node availability, the homogeneous network and device conditions and the spatio-temporal homogeneity of data.

The design obtained for the DML framework consists of the following functional pillars:

- DML resource monitoring mechanisms at discrete resource and data/application levels
- 5G-specific DML model distribution, training, and collection
- DML decision making mechanisms that are tightly coupled with the AOEP orchestration

The first pillar builds on a rigorous assessment and verification of underlying assumptions for example with respect to the overall resource and data availability in a distributed and inherently non-uniform environment. This is based on the requirements that reflect monitoring-enabled mobile DML resources as well as available data for training. The second pillar does not just aggregate ML training gradients (which usually assumes balanced OBU data) but builds on aggregating the model parameters themselves with a corresponding equalization/ normalization in face of intermittent availability of nodes in a mobile network. Corresponding functional requirements from above summarize the corresponding primitives such as appropriate OBU selection and appropriate application-specific data management before training. Specifically, as the OBU local datasets may well be non-independent and identically distributed and unbalanced, since some OBUs might use certain services (based on their location, requirements and tasks) more than other OBUs, 5G-IANA will provide support[4] for DML algorithms beyond distributed averaging such as Federated Averaging (FedAvg) [14], FedProx [22] or FedOpt [21]. To balance heterogeneous data and heterogeneous devices random subsets of suitable training nodes (OBUs) can be selected for the individual DML tasks in combination with asynchronous Stochastic Gradient Descent optimization at the aggregation on the Edge. The architecture to be used has a global logic for client selection, configuration and strategy abstraction, and local logic to handle model training. This division of logic enables the framework to offer scalability over device and data heterogeneity, as well as data privacy. The third functional pillar is resembled in the

[4] This will have the form of a configurable parameter of the FLOWER AFs.

tight integration of the DML in the AOEP architecture. This can be seen in the integration within the sequence diagram for onboarding and DML virtual application provisioning in Figure 13. While DML NetApps are onboarded in a standard fashion, as specified in Section 3, the continuum resource discovery in Figure 13 shows the integration of the DML-specific resource discovery continuum with the DML orchestrator functional block of the AOEP system architecture. Also, the DML application provisioning is tightly integrated with the DML orchestrator as seen in the resource mapping guidance in Figure 13. Finally, DML training proceeds as described above in this section and the final aggregated model is serviced back to Service Provider. This entails that the DML service is exposed at OTT which allows for flexibility. The specific operational flow is depicted in Figure 14. Here, the Model Aggregator (MA) (Edge) and client (CL) (OBU) can be seen after one iteration as depicted in Figure 13: (1) MA aggregates the local models; (2) MA dispatches current aggregate model of selected CLs; (3) CLs perform local ML model training according to the constraints (data availability, HW availability); (4) CLs that finish local training deliver trained models to MA; (5) MA aggregates the model asynchronously. Note that the initial DML client (OBU) selection by the DML orchestrator is performed based on: Node Availability, Connectivity, Battery Resources, Resource Availability, Node Location, Data Availability, Data Volume and Data Features. These selection criteria reflect the required knowledge to perform distributed machine learning tasks for automotive applications over a 5G mobile network as it is required to control data quality and device heterogeneity. An instantiation of the DML framework appears in UC6 where the focus lies on an application-layer network status monitoring. The output of the DML in UC6 will be available for all UCs such as for video streaming in UC3. In general any third party application could combine its functionality with the output of the DML.

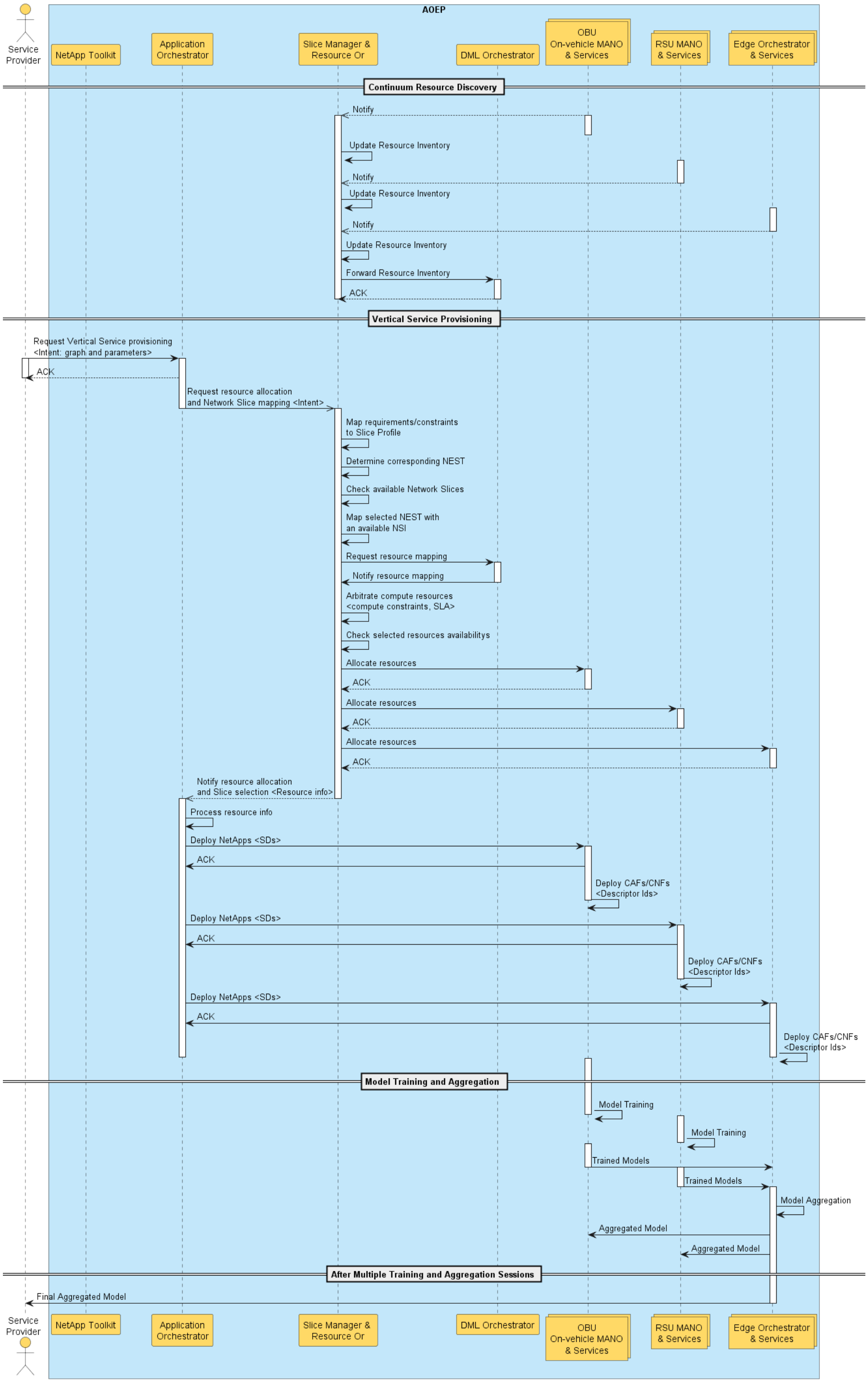

Figure 13: Sequence Diagram excerpts for the DML application provisioning and operation

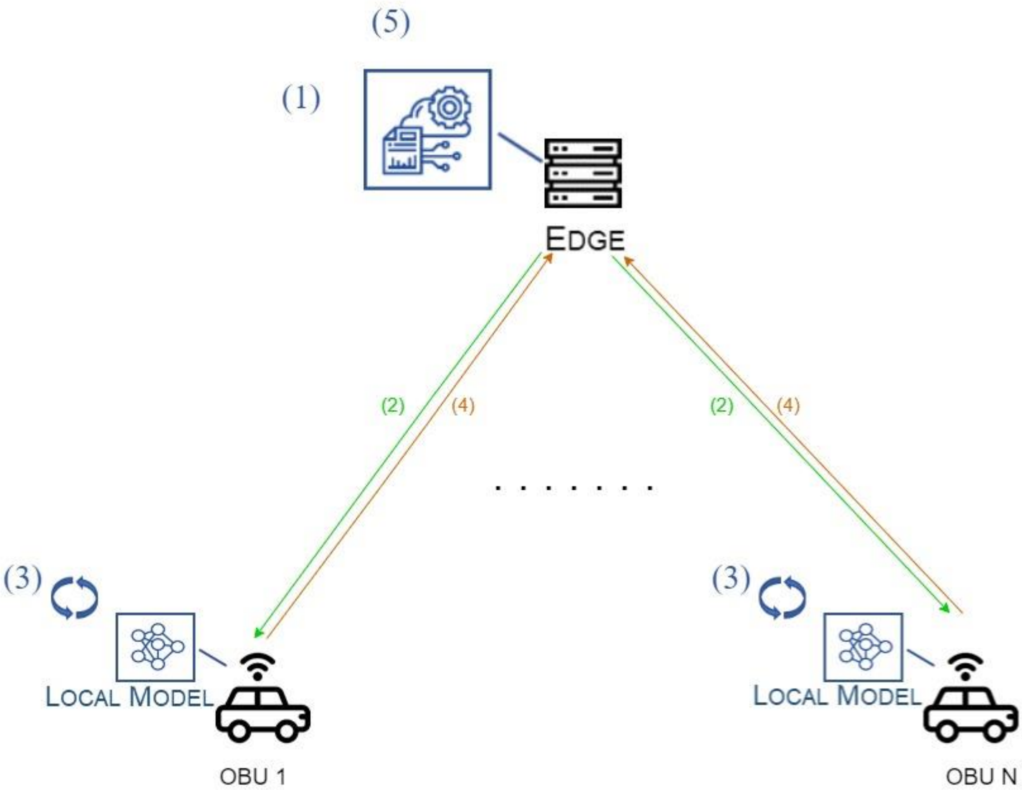

Figure 14: Operational Flow of a DML NetApp including (1) client (OBU) selection; (2) model dispatch; (3) local training; (4) model delivery; (5) model aggregation

6. SPECIFICATIONS THE AOEP VIRTUALIZED INFRASTRUCTURE SEGMENTS

This section introduces the requirements of the AOEP virtualized infrastructure segments. It is organized as follows. In Section 6.1, the state-of-the-art of virtualization solutions for automotive infrastructure segments is introduced as well for the state-of-the-art of MANO solutions that is provided in Section 6.1.1. The requirements of the AOEP virtualized infrastructure segments are provided in Section 6.2. The analysis of the advances that 5G-IANA introduces and a discussion on the fulfilment of 5G-IANA objectives are introduced in Section 6.3. The modules of the 5G-IANA AOEP on the virtualized infrastructure segments are illustrated in Section 6.4.

6.1. State-of-the-Art of virtualization solutions in automotive infrastructure segments

Virtualization approaches are not yet available in commercial OBUs and RSUs. This outcome has been reached after having analysed the products' characteristics of the major players in the CCAM arena. The OBU and RSU are provided with ITS communication stack software, but no specific virtualisation and orchestration features are mentioned.

Based also on 5G-IANA Partners' experience, commercial OBUs and RSUs are statically equipped with an ITS communication stack software. APIs are provided to interact with the ITS communication stack, and, in some cases, third-party software applications can be hosted on the OBUs or developed using the available Software Development Kit (SDK). The flexibility of current commercial solutions is then limited. This represents a critical issue when software updates of the ITS communication stack are required, and it makes it difficult to third parties to experiment and deploy new CCAM applications on commercial devices.

The survey of research projects and scientific papers highlights instead that the virtualization topic on OBU or RSU has been already considered in the research community. In [25] different virtualization technologies have been evaluated for improving the safety and security of vehicular ECUs. A similar approach, which focused on OBU virtualization, was also introduced in [26]. In both studies, container virtualization was not considered in the analysis.

The use of containers can constitute a more efficient virtualization solution since it is lightweight with respect to a solution based on VMs. A container-based approach was considered in [27]. The solution introduced was considered a self-standing environment where an internal orchestration is performed. No interaction with a central orchestrator was devised.

Other scientific works instead focused on a more centralized approach for the virtualization of OBU applications. One approach was to virtualize the entire OBU and have a virtual OBU at the edge server that is a replica of the real OBU [28], [29]. This approach can offload the OBU from the processing, but it requires a continuous exchange of information between the real OBU and the virtual OBU. This prevents the real OBU to be self-sufficient when the mobile connection is absent. A similar approach has been proposed in [30]. In this case, it is not considered to have a complete virtualized copy of the real OBU, but only specific services in form of docker containers are migrated to the Edge server.

The most similar approach to the one proposed by 5G-IANA was introduced by the 5GinFIRE project [31]. In this project, several vertical industries were targeted and, among them, also the automotive one. Indeed, the 5GinFIRE project made available the IT-Av Automotive Environment[5] where third-party developers can test their application on real OBU and RSU hardware by deploying them as Virtual Network Functions using virtual machines. A docker based deployment has been also added as new functionality to the 5GinFIRE platform[6]. The 5G-IANA extends the approach of the 5GinFIRE project by considering the orchestration of Far-edge virtualized infrastructure segments (i.e., OBU and RSU). The "on-vehicle MANO" is introduced in 5G-IANA to this extent. It is indeed in charge to manage the functions on a virtualized infrastructure segment by interacting with the central orchestrator. Further aspect, that 5G-IANA aims to target, is to ease the experimentation and the development of CCAM applications. The virtualized infrastructure segments are already provided with a set of functions that offer basic services (e.g., ITS communication stack) upon which advanced functions can be built by third parties experimenters. These basic services are provided within the NetApp "starter-kit" as detailed in Section 3.2.3.1.

6.1.1. MANO Solutions

Nowadays, the base unit of execution has the traction to shrink in order to downgrade the execution footprint, VMs, containers, unikernels and serverless functions. The orchestration primitives could be applied to all of them. It is important to take into consideration, that the orchestration over the edges (OBU/RSU) poses a lot of challenges regarding the volatility, the scalability, and the heterogeneity of the edges due to the

[5]https://5ginfire.eu/it-av-automotive-testbed/
[6]https://5ginfire.eu/adocker/

inherent continues-changing nature. Below are presented the study on the various open-source orchestration toolsets we examine.

Kubernetes[7] is an open-source container orchestration system for automating application deployment, service discovery, and scaling/load balancing/traffic distribution. For edge-based environments, Kubernetes can be useful for orchestrating and scheduling resources from cloud to edge data centre workloads, and also to manage and deploy edge devices together with cloud configurations. It also provides policies that can be narrowed down for specific channels or edge nodes based on particular configuration requirements, thus enabling high availability and low-latency application access from different edge/far-edge devices. Kubernetes acts as a PaaS diverting a bit from the following orchestration solutions. This means that you can build on top of Kubernetes and either leverage or develop new or existing features. Consequently, supporting Kubernetes is a must have for orchestrators that act as "wrappers" and build on top of container orchestrators.

Juju[8], developed by Canonical, is a framework that can be used to model, manage and scale services in the cloud. It contains some interaction tools such as a command line and a graphical user interface and is a solid solution that can reduce the workload for deployment and configuration. Thus, through these tools a DevOps user can easily embed a service or a web of services on top of multiple IaaS providers (e.g., OpenStack). The service metamodel of Juju is addressed as "charm" and contains a set of elements that are required in order, for a specific service to be composable and orchestratable. The service graph metamodel is addressed as "bundle" and it is a web of charms. Anybody can deploy a predefined charm or a bundle and use them. Both of them are described by some YAML files, and someone can moderate them with some commands called "hooks". In JUJU documentation, a strict list of commands per charm is provided, so that anybody can use them to configure it. However, the Juju platform was not built to address more specific network quality of service requirements and constraints.

Open Network Automation Platform (ONAP)[9] is an open-source project hosted by Linux Foundation2, officially launched in 2017, as an open-source platform enabling telco networks to move to become more and more autonomous. ONAP is the platform capable to provide real time, policy-driven service orchestration and automation, enabling telco operators and application developers to instantiate and configure network functions. ONAP is the platform addressing also future 5G challenges, covering multi-site and multi-

[7] https://kubernetes.io/
[8] https://juju.is/
[9] https://www.onap.org/

vendor automation capabilities, service, and resources deployment, providing cloud network elements and services instantiation in a dynamic, real time and closed-loop for several major telco activities as design, deployment, and operating services, within two main ONAP framework, Design-time, and Run-time. ONAP provides flexibility in automation platform for services management, vendor agnostic, able for policy-driven service design and analytics, providing orchestration and service configuration. ONAP is compatible with Kubernetes and Openstack which makes it a very attractive and promising solution to be adopted by the project, although the complexity and the technical depth to use makes it cumbersome.

Cloudify[10] is an open-source cloud orchestration framework. It enables the modelling of applications and services and automation of their entire life cycle, including deployment on any cloud or data centre environment. In addition, it offers monitoring of all aspects of a deployed application, detecting issues and failure, manually or automatically remediating such issues, and performing ongoing maintenance tasks. Cloudify's platform consists of a core engine responsible for the lifecycle management of applications and network services, and a set of plugins providing integration points for all needed components from cloud infrastructure automation (Compute, Storage, Network) to logging and monitoring. One extra feature of Cloudify in comparison with the others is that it uses blueprints for the modelling stage of the applications. Cloudify has been developed to describe any application or network service in a generic, intuitive, human-readable modelling language based on TOSCA standard. This concept where the end-users can port or compose their NetApps at ease is one of the objectives the 5G-IANA platform seeks. Given also the compatibility of Cloudify with Kubernetes this solution is very prominent. However, cloudify comes in two versions community and premium and while the latter provides all the functionalities its code is closed.

Open Source MANO (OSM)[11] is an ETSI-hosted open source project and community aiming to develop an open-source NFV Management and Orchestration (MANO) software stack for deploying network services, aligned with ETSI NFV information models. It constitutes a layered approach to create composite services of growing complexity and offers a production-quality MANO stack that meets operators' requirements for commercial NFV deployments. It is capable of consuming openly published information models, available to everyone, suitable for a broad ecosystem of virtual network functions (VNF) vendors, operationally significant and VIM-independent. Currently, Release NINE further evolved Kubernetes integration, making OSM installation

[10] https://cloudify.co/
[11] https://osm.etsi.org/

on Kubernetes the default, deploying VCA (Juju) on the same Kubernetes cluster as the rest of OSM, adding support for the Helm 3 package format, as well as the capability to operate distributed applications in multiple Edge locations through distributed proxy charms. OSM is aligned with ETSI NFV standards for what concerns the implemented VNF and Network Service Packages structures (ETSI GS NFV SOL004 [2] and SOL007 [32]), VNF Descriptors, PNF Descriptors and Network Service Descriptors data-models (ETSI GS NFV SOL006 [1] with augmentations mostly related to the management of CNFs) and the NBI for descriptors and packages management as well as for Network Services LCM (ETSI GS NFV SOL005 [4]). While heavily and actively developed OSM for the time is not supporting distributed resources orchestration and has limited federation capabilities (through the Or-Or reference point).

6.2. Specifications of the requirements

This subsection introduces the requirements of the following segments/components are provided:

- **General Virtualized Infrastructure (GVI)**: requirements that can apply to any of the AOEP virtualized infrastructure segments.
- **"On-Vehicle" MANO (OVM)**: requirements that are related to the MANO framework that is used on the Far-edge virtualized infrastructure segments (i.e., OBU, RSU).
- **On-Board Unit (OBU)**: requirements that are specific to the OBU virtualized infrastructure segment.
- **Road-Side Unit (RSU)**: requirements that are specific to the RSU virtualized infrastructure segment.
- **Edge and Cloud (EAC)**: requirements that are specific to the edge and cloud virtualized infrastructure segments.

6.2.1. General Virtualized Infrastructure framework

Requirements, that are related to any virtualized infrastructure segment, are reported in Table 17. The virtualized infrastructure segments must support the containerization and they must provide a communication channel to the network. Information about the use of virtualized resources (e.g., processing, memory, storage) should be provided from each infrastructure segment to the AOEP. The virtualized resources should be dimensioned to the average need of the NetApps to be deployed on each virtualized infrastructure segment (i.e., the OBU segment should guarantee enough resources for deploying NetApps that typically are executed on the OBU).

Table 17: Requirements of the General Virtualized Infrastructure framework.

Identifier	Title	Priorit	Description
SFR-GVI-1	OS-level virtualization technology in the infrastructure segment	MUST	The virtualized infrastructure segment must support OS-level virtualization technology for enabling containerization
SFR-GVI-2	OS-level virtualization support to GPU in the infrastructure segment	SHOU LD	The virtualized infrastructure segment should have OS-level virtualization supporting GPU abstraction
SFR-GVI-3	Resource status information of the virtualized infrastructure segment	SHOU LD	The virtualized infrastructure segment should be able to collect and provide information about the status of processing, memory, and storage of virtualized resources
SFR-GVI-4	Network communication	MUST	The virtualized infrastructure segment must guarantee to have a network communication channel
SRNF-GVI-1	Hardware resources in the virtualized infrastructure segment	SHOU LD	The virtualized infrastructure segment should be based on hardware providing sufficient processing, memory, and storage capabilities for supporting the instantiation of NetApps

6.2.2. "On-Vehicle" MANO

The requirements of the OVM component are provided in Table 18. The selection of the MANO framework to be used must consider that the OBU and RSU segments are characterized by constrained resources. Thus, a lightweight orchestration framework based on containers must be selected. The OVM must guarantee proper lifecycle management and orchestration of containers and it must provide the required procedures for Functions and Services management. It must also implement the needed interaction with the other AOEP components according to what is expected by the general design of the AOEP.

Table 18: Specifications of the requirements for the OVM.

Identifier	Title	Priorit	Description
SFR-OVM-1	Lightweight orchestration of containers	MUST	A lightweight orchestration based on containers (e.g., Kubernetes) must be available in the virtualized infrastructure segment. The lightweight orchestration must be able to support the lifecycle management and the

			orchestration of containers. The container orchestration system must be lightweight to allow its use also with the constrained resources of the OBU and RSU segments.
SFR-OVM-2	Function local on-boarding	MUST	The OVM must provide a procedure for onboarding Functions descriptors and/or images to the local registry
SFR-OVM-3	Service local provisioning	MUST	The OVM must provide a procedure for requesting/performing the provisioning of Service composed of different Functions
SFR-OVM-4	Service local termination	MUST	The OVM must provide a procedure for requesting/performing the termination of a Service composed of different Functions
SFR-OVM-5	Service local modification	SHOULD	The OVM should provide a procedure for requesting/performing the run-time modification of a Service composed of different Functions (e.g., scale-out/-in, reconfiguration)
SFR-OVM-6	Interaction with NOD and RO	MUST	The virtualized infrastructure segment must implement the required interaction with NOD and RO as foreseen in the general AOEP architecture
SFR-OVM-7	Interaction with the Automotive VNFs repository	MUST	The virtualized infrastructure segment must implement the required interaction with the Automotive VNFs Repository as foreseen in the general AOEP architecture

6.2.3. On-Board Unit infrastructure segment

The OBU requirements are introduced in Table 19. The OBU must guarantee the availability of a 5G Uu communication channel. The OBU segment must ensure the availability of accurate position and time information. OBU must also be connected to the vehicle network for being able to communicate with other vehicle modules. The connection with mobile devices or HMI for interacting with vehicle occupants could also be needed. OBU should also provide the physical interfaces to on-vehicle sensors and potentially process them on board the vehicle.

Table 19: Specifications of the requirements for the OBU infrastructure segment.

Identifier	Title	Priority	Description
SFR-OBU-1	5G connectivity in the OBU	MUST	The OBU must have a 5G Uu network interface
SFR-OBU-2	GNSS receiver at the OBU	MUST	The OBU must be connected to a GNSS receiver for having available position and time information
SFR-OBU-3	Wi-Fi connection between the	COULD	The OBU could have a Wi-Fi interface for connecting with a mobile device for

	mobile device and OBU		visualization and interactions with vehicle occupants
SFR-OBU-4	Bluetooth connection between the mobile device and OBU	COULD	The OBU could have a Bluetooth interface for connecting with a mobile device for visualization and interactions with vehicle occupants
SFR-OBU-5	Ethernet connection to vehicle network in OBU	MUST	The OBU must have an Ethernet interface for connecting with the vehicle network
SFR-OBU-6	CAN-bus connection to vehicle network in OBU	MUST	The OBU must have a CAN-bus interface for connecting with the vehicle network
SFR-OBU-7	Support for sensors' data collection in the OBU	COULD	The OBU could have a large availability of physical interfaces for connecting sensors
SRNF-OBU-1	Support to sensors' data processing in the OBU	COULD	The OBU could have services for processing sensors' data according to the available hardware resources

6.2.4. Road-Side Unit infrastructure segment

Table 20 introduces the requirements of the RSU infrastructure segment. A network connection between the RSU and the Edge server must be guaranteed using either a 5G Uu connection or a wired broadband connection. The RSU must provide the proper physical interfaces to collect data from locally connected sensors. The RSU could also provide the computing resources for processing process the sensors' data for providing the outcomes of the processing to the needed edge/cloud endpoints.

Table 20: Specifications of the requirements for the RSU infrastructure segment.

Identifier	Title	Priority	Description
SFR-RSU-1	Connectivity between RSU and Edge server	MUST	The RSU must have network connectivity to the Edge server
SFR-RSU-2	Support for sensors' data collection in the RSU	MUST	The RSU must have a large availability of physical interfaces for connecting sensors
SRNF-RSU-1	Support to sensors' data processing in the RSU	COULD	The RSU could have computing resources for processing sensors' data

6.2.5. Edge and Cloud infrastructure segments

The edge and cloud infrastructure segment requirements are provided in Table 21. These segments must satisfy the general virtualized infrastructure requirements that have been introduced in Section 6.2.1. Furthermore, the MANO on Edge and Cloud segments have to orchestrate containers, supporting their lifecycle management, and to manage the local services that are composed of different Functions. Besides these requirements, the edge and cloud segment must guarantee the availability of sufficient computing resources for processing sensors data from network-connected sensors that are located in the far-edge segment. Indeed, OBU and RSU cannot ensure the availability of resources for processing raw sensors data, while Edge and Cloud segments must ensure this availability.

Table 21: Specifications of the requirements for the Edge and Cloud infrastructure segments.

Identifier	Title	Priority	Description
SFR-EAC-1	Orchestration of containers	MUST	An orchestration based on containers (e.g., Kubernetes) must be available in the edge and cloud virtualized infrastructure segment. The orchestration must be able to support the lifecycle management and the orchestration of containers.
SFR-EAC-2	Service local provisioning	MUST	The MANO on Edge and Cloud segments must provide a procedure for requesting/performing the provisioning of Service composed of different Functions
SFR-EAC-3	Service local termination	MUST	The MANO on Edge and Cloud segments must provide a procedure for requesting/performing the termination of a Service composed of different Functions
SFR-EAC-4	Service local modification	SHOULD	The MANO on Edge and Cloud segments should provide a procedure for requesting/performing the run-time modification of a Service composed of different Functions (e.g., scale-out/-in, reconfiguration)
SFR-EAC-5	Interaction with NOD and RO	MUST	The virtualized infrastructure segment must implement the required interaction with NOD and RO as foreseen in the general AOEP architecture
SRNF-EAC-1	Support to sensors' data processing	MUST	The edge and cloud segments must have available computing resources for processing sensors' data

6.3. Advances in 5G-IANA and fulfilment of 5G-IANA objectives

The 5G-IANA project aims to achieve following advances for what concerns the virtualized infrastructure segments:

- A lightweight virtualization solution based on containers is targeted for the Far-edge infrastructure segment, in the specific for the OBU and RSU, to guarantee a better support also for hardware with constrained resources. The container-based solution can be more advantageous with respect to a virtual machine-based one due to the reduced size of containers, their faster start up time, and the possibility to directly access hardware resources such as graphic cards.
- A flexible and dynamic deployment of services wants to be ensured on the virtualized infrastructure segments. The on-vehicle MANO oversees these aspects, and it is assisted by the central AOEP orchestrator to this purpose.
- The virtualization and on-vehicle MANO approaches to be developed in the 5G-IANA project aim to contribute to the on-going standardization in ETSI ISG MEC in Far-edge context (i.e., mobile terminals, terminals with constrained resources); the main target is to identify applicability issues of ETSI MEC solution in Far-edge virtualized infrastructure segments (i.e., OBU, RSU) and to propose solutions for filling the identified gaps.

In Table 22, the contributions of the AOEP virtualized infrastructure segments to fulfil the 5G-IANA objectives are introduced.

Table 22: Contributions to the fulfilment of 5G-IANA objectives by the AOEP virtualized infrastructure segments.

#	Objective	Item	Implementation
1	**Specify and provide an Automotive Open Experimentation Platform (AOEP)**	The virtualized infrastructure segments: Far-edge, Edge, Cloud resources	The virtualized infrastructure segments are specified as part of the AOEP contributing to the achievement of this objective
4	**Provide accurate localization and low latency mission-critical applications.**	Beyond GNSS and RTK, multisensory positioning and Position and Time VNFs will deliver increased positioning accuracy	The system function requirements of the OBU infrastructure segment foresees the need of having GNSS receiver for having accurate position information

7	**Create new business opportunities and boost market for start-ups and SMEs with Automotive NetApps**	5G-IANA solutions will make easier for new entrants to design and create their own application and services on top of existing Automotive services and application templates.	This objective can be achieved thanks to the flexibility and openness that the specification of the virtualized infrastructure segments aims to pursue
9	**Ensure cross-domain and cross-platform interoperability and boost standardisation committees on NFV and Network orchestration.**	5G-IANA focus on standardisation is to ensure interoperable deployment of NetApps beyond vendor-specific implementation and across multiple segments, through active participation of 5G-IANA standardisation experts in selected Technical bodies and Working Groups	The specification of the virtualized infrastructure segments considers standardization aspects, when possible, to ensure cross-platform interoperability

6.4. Virtualized infrastructure segments internal system design

This section introduces the internal system design of the virtualized infrastructure segments. Figure 15 illustrates the internal system design of the far-edge, the edge, and the cloud virtualized infrastructure segments. In the following of this section, the modules of the virtualized infrastructure segments are introduced. A description of each module and the related functionalities are described.

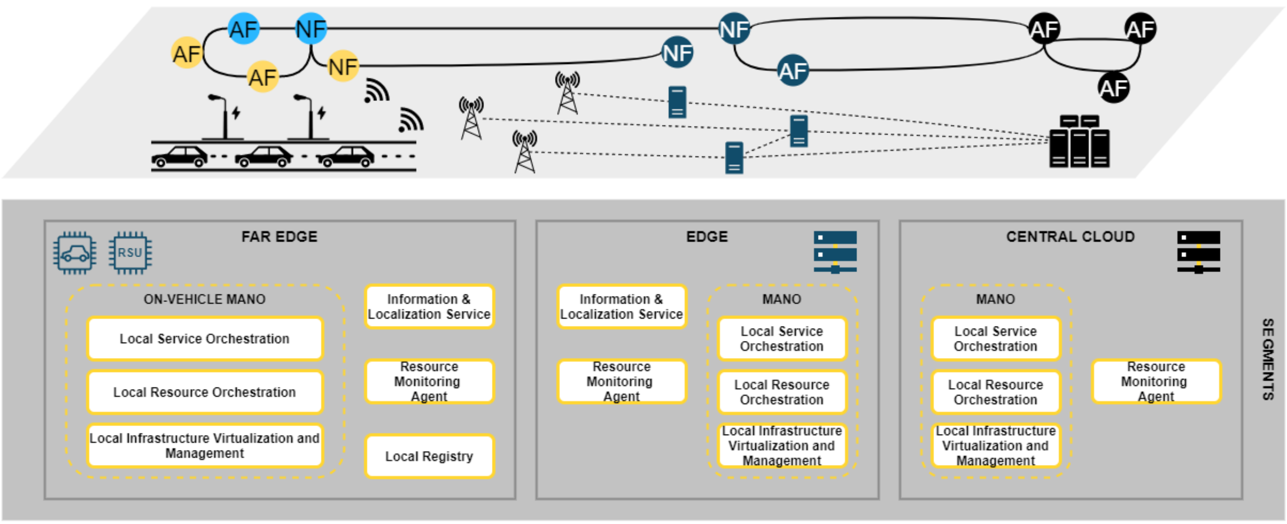

Figure 15: NetApp Toolkit Internal System Design

6.4.1. On-vehicle MANO and Edge and Cloud MANO

The main component on each virtualized infrastructure segment is the MANO. On the far-edge segment we refer to it as on-vehicle MANO to better highlight the constrained environment in which the MANO must operate.

The OVM and the Edge and Cloud MANO have to perform the virtualization and the related management of the physical resources (Local Infrastructure Virtualization and Management), to locally manage the provisioning, termination, and modification of services (Local Service Orchestration), and to manage and provision the local resource orchestration (Local Resource Orchestration)

The OVM has also to keep track of the available local resources (Local Registry) and to locally manage the CAFs/CNFs images. These functionalities on Edge and Cloud segment will be centrally provided by the NetApp Toolkit, thus the MANO on the Edge and Cloud does not need to implement them. This choice is performed to make the far-edge device independent from the rest of the infrastructure. Indeed, far-edge devices may not always have the connectivity to the 5G-IANA AOEP. In this way, they can continue to operate without any service disruptions.

The state-of-the-art research on MANO solutions, that is introduced in Section 6.1.1, highlights that the best solution to cope with the challenges posed by the diversity of orchestrating far-edge, edge, and cloud resources is **Kubernetes**. The best choice is to leverage on bare metal Kubernetes deployments. Some of the main reasons are:

- Its lightweight nature (in term of needed resources). There are couple of Kubernetes distributions that are optimized to be even less resource-intensive like Rancher's K3s [12], Kata[13] , KubeVirt [14] , EVE). This characteristic well suits the far-edge virtualization infrastructure segment where resources will be constrained.
- Fast onboarding of network functions to production environments. Tools like Helm [15], Nephio [16] provide common automation templates that materially simplify the onboarding and the deployment abstracting infrastructure specificities.
- It is market dominant, which provides very-well documentation on the technical aspects and also big community support for troubleshooting it.
- It uses the "declarative paradigm" also known as "configuration-as-data" which is a methodology for configuration management that rigorously enforces well-structured declarative configurations and separates those configurations from the

[12] https://rancher.com/docs/k3s/latest/en/
[13] https://katacontainers.io/
[14] https://kubevirt.io/
[15] https://helm.sh/
[16] https://nephio.org/

code that operates on them. This makes the configurations amenable to manipulation by well tested, reusable code, and enables robust, semantically aware merges of edits made by humans, bulk editing tools, and automations," they wrote.

While container-based PaaS solutions like Kubernetes seems a flexible asset, it is possible during the implementation phase to face PaaS limitations [33] (limited control over the resources is likely to happen). In that case the project will turn to a MANO framework and specially OSM. As written above, OSM provides full access to the code and according to this study [34] it has been proven more robust, mature and has better overall scaling performance

6.4.2. Information and localization service

The "Information and localization service" aims to provide to the AOEP information about the capability of the virtualized infrastructure segment (far-edge and edge) to the AOEP. The module, that implement this service, is developed from scratch in 5G-IANA.

The information can include resource details, such as the availability of a GPU, and the amount of available memory and computing resources on the device. Furthermore, this service provides the current position of the far-edge devices. This feature is extremely important in the specific for the OBUs as they can move over time.

The knowledge about the capabilities of the devices and of the position of far-edge devices is useful for the deployment of orchestration policies that consider this information. It is then possible to orchestrate the deployment of NetApps only to devices that provides some specific characteristics (e.g., the availability of a GPU). Similarly, the NetApps deployment can be performed based on the localization of the far-edge devices. For example, a NetApp can be deployed on OBUs that are in a given geographical area.

The position information is provided by the far-edge segments to the edge server that is responsible for that geographic area. The edge server aggregates all the information received and it forwards it to the AOEP.

The position information at the edge server is also exploited to provide the position of far-edge devices to the AFs that are running on the edge server. The position of the UEs should be indeed known by the network and this information should be provided at the edge server using the Location API as defined by the ETSI GS MEC 013 V2.2.1 [35]. However, current network deployment does not provide the UE position. For this reason, a NF providing the position information is made available in the context of the 5G-IANA project. The NF, that runs at the edge server, can exploit the information collected by the

“Information and localization service” and it provides to the AFs the position information using the same APIs that are introduced in ETSI GS MEC 013.

6.4.3. Resource monitoring agent

This module is intended to monitor and collect information in run-time about the use of virtualized resources (i.e., memory, computing, and storage resources) in the devices belonging to each virtualized infrastructure segment. The module, that implement this service, is developed from scratch in 5G-IANA.

This information is reported to the AOEP that considers it when performing the orchestration of NetApp. For example, a NetApp is not deployed on a specific device if the virtualized resources, that are at that given time available, cannot satisfy the requirements of the NetApp.

The resource monitoring has to be performed on far-edge, edge, and cloud segments. The information from the far-edge devices is aggregated at the edge server level that then forwards the aggregated data to the AOEP.

7. INTERFACES OF THE AUTOMOTIVE OPEN EXPERIMENTATION PLATFORM

The complete overview of the 5G-IANA AOEP in terms of functional building blocks and interfaces among them is reported in Figure 16 and Figure 17. In particular, Figure 17 provides a more detailed overview about the interaction among the identified software building blocks that implement the functional components represented in Figure 16 .

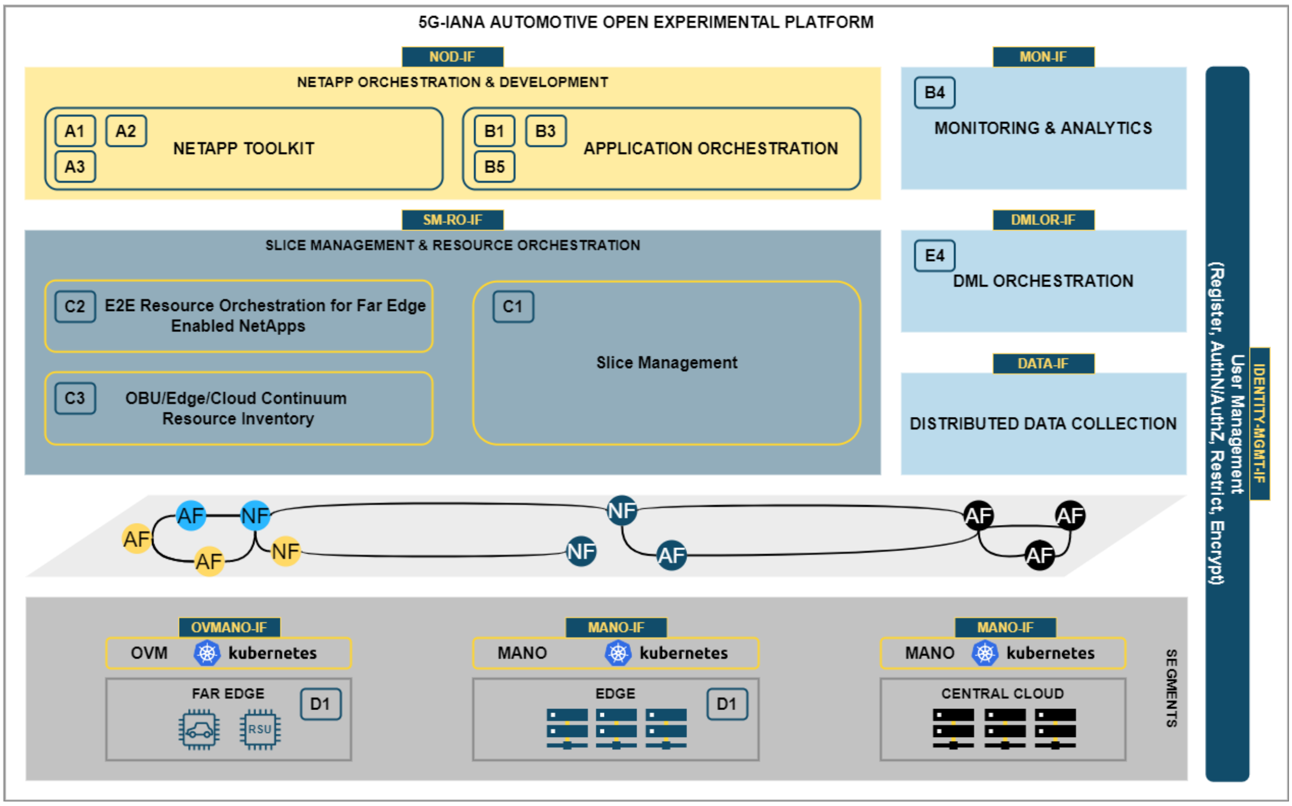

Figure 16: 5G-IANA AOEP Interfaces

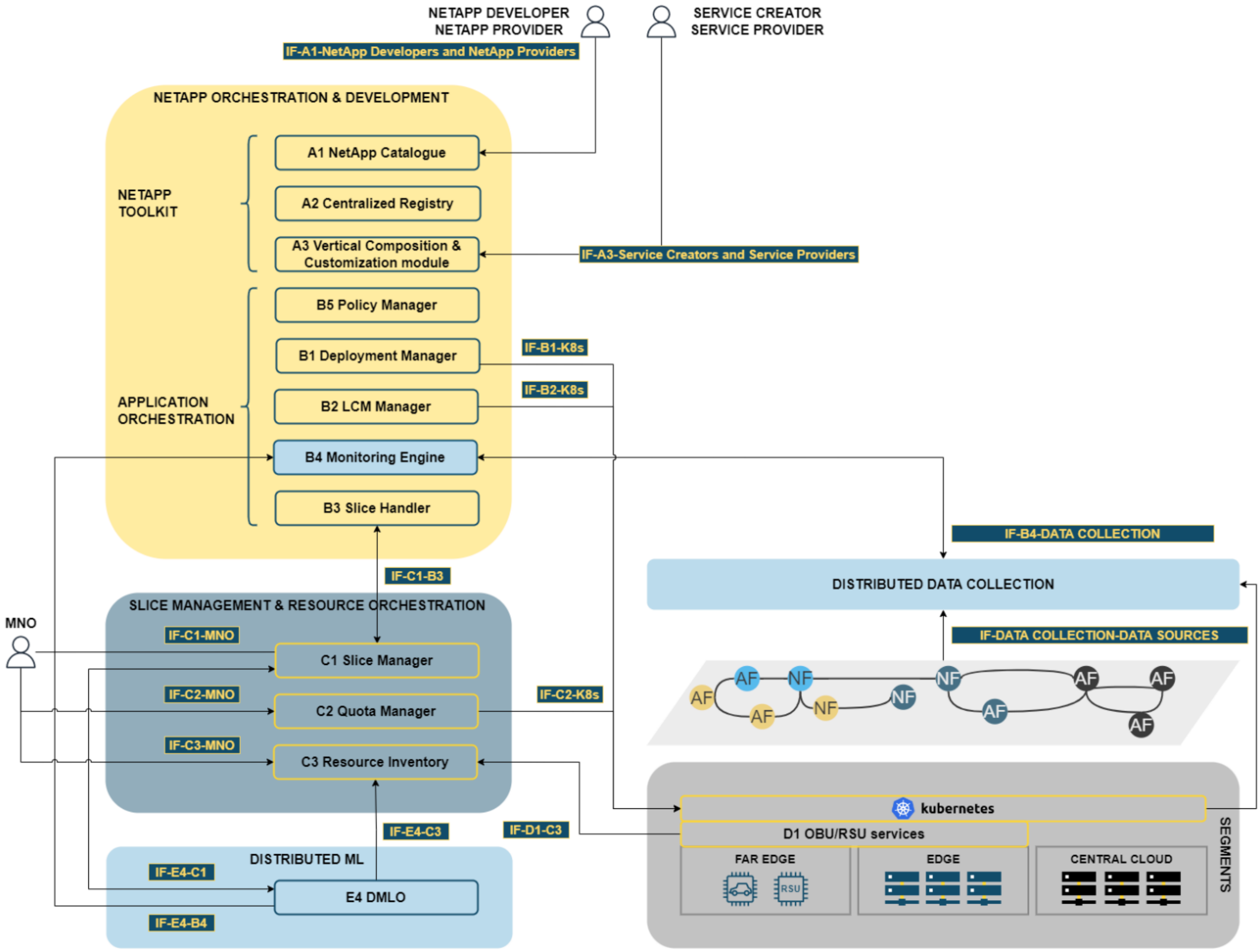

Figure 17: Software components and interfaces of the Automotive Open Experimental Platform

Table 23 described the AOEP interfaces that are exposed by the main component depicted in Figure 16 . The table provides the mapping with the actual software interfaces implemented by the identified software building blocks (as specified in D5.1 [36] workplan for scheduling the integration steps), the mapping with supported functionalities, the list of expected consumers, the software/standard baseline for the implementation (if any) and planned extensions.

Table 23: 5G-IANA AOEP Exposed Interfaces

Interface	Component specific interface	Functionality	Consumer	Baseline/Standard	Extensions
IDENTITY-		Users Management	All users	Usage of external Identity	NA

MGMT-IF				Servers (e.g., Keycloak) is under evaluation	
NOD-IF	[IF-A1-NetApp Developer and NetApp Provider]	NetApp Management	NetApp Developer NetApp Provider	VITAL-5G NetApp Catalogue	Customizations related to the cataloguing of NetApps into service categories
	[IF-A3-Service Creators and Service Providers]	Vertical Service Composition and Customization	Service Provider Service Creator	MATILDA MAESTRO	Extensions to support the proposed NetApp information model
	[IF-A3-Service Creators and Service Providers]	Policy Management	Service Provider Service Creator	MATILDA MAESTRO	Application Policies based on 5G-IANA optimization workflows
	[IF-A1-NetApp Developer and NetApp Provider]	AF/NF Management	AF/NF Provider AF/NF Developer NetApp Developer NetApp Provider	VITAL-5G NetApp Catalogue	Support for CAFs/CNFs
	[IF-A3-Service Creators and Service Providers]	Vertical Service Deployment & Lifecycle Management	Service Provider	MATILDA MAESTRO	Extensions to support the proposed NetApp information model
SM-RO-IF	[IF-C1-MNO]	Network Slice Management & Inventory (Creation, Modification, Deletion)	MNO	5G-COMPLETE Network Slice Management Function 3GPP TS28.531 Rel.17 3GPP TS28.541 Rel.17	Extensions to support additional Service Profile's parameters and eventual updates according to latest 3GPP specifications
	[IF-C1-MNO]	Network Slice Template Management	MNO	5G-COMPLETE Network Slice Management Function NBI	Extensions to support additional Service Profile's parameters and eventual

				3GPP TS28.531 Rel.17 3GPP TS28.541 Rel.17 GSMA GST v7	updates according to latest 3GPP specifications
	[IF-C1-B3]	Application Intent to Network Slice QoS Mapping	NOD	Int5Gent Application-aware Network Slice Manager	Extensions to support automotive QoS parameters and location constraints in the intent-based request
	[IF-C2-MNO]	Tenant Management	MNO	NA	NA
	[IF-C3-MNO]	Far-edge, Edge, and Cloud Resource Inventory	MNO	NA	NA
	[IF-E4-C3]	Far-edge Resource Inventory & Information Service	MNO DML Orchestrator	NA	NA
DMLOR-IF	[IF-E4-C1]	Ad-hoc Resource Allocation for ML NetApps	RO	NA	NA
MANO-IF	K8s interface	Edge/Cloud Orchestration	NOD	Kubernetes	NA
	[IF-B4-Data Collection]	Data Collection (Infrastructure and Virtual Resources)	Distributed Data Collection	Kubernetes-compatible monitoring tools are currently under investigation	NA
OVMANO-IF	K8s interface	Far Edge Orchestration	NOD	Kubernetes	NA
	[IF-D1-C3]	Information and Location Service	NOD RO	NA	NA
	[IF-B4-Data Collection]	Data Collection (Infrastructure and	Distributed Data Collection	Kubernetes-compatible monitoring tools are	NA

		Virtual Resources)		currently under investigation	
MON-IF	[IF-E4-B4]	Data Consumption	DML Orchestrator	MATILDA MAESTRO Monitoring	Customizations according to infrastructure and application metrics to be supported for the different NetApps/Vertical Services

Each interface exposes a set of functionalities, and all are laid out in Table 23. For each of these interfaces, an open and reusable documentation will be provided. Since the majority of the functionality is exposed via RESTful APIs, the OpenAPI specification will be used to describe the technical details of each piece of functionality. The API specifications will be open and shared among the consortium in order to enable interoperability between components, and ensure the ease of integration. If the need to include specifications that fall outside the scope of OpenAPI arises, then the consortium will move to create a superset of OpenAPI, and any equivalent specification involved, in order make the sharing of APIs easier. Further details will be provided following the platform development and integration activities in WP3 and the related deliverables.

8. USE CASES

This section provides a high-level insight of the seven use cases within the 5G-IANA project. Each use case subsections provide specifications of the business models, the goals to be achieved, the partners involved in the tasks, the identified stakeholders and one or more scenarios to show and demonstrate the purpose of each use case.

Furthermore, each use case subsection provides an overview of Use Case “Functional requirements” that have been specified to support the design of the 5G-IANA AOEP. The other requirements category, named “Performance requirements” is provided in [36].

8.1. Use case 1 – Remote driving

8.1.1. Overview

UC1 is about 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.

In a first phase, the vehicle will be equipped with both a front and a rear camera to transmit the video to the edge of the 5G network. The vehicle to be used in this UC is an automated guided vehicle (AGV) with an “Ackerman” configuration, that is, the rear wheels provide traction force to the car, while the front wheels are adjustable and guide it. The 5G enabled vehicle will be connected to the edge of the network, 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 lidar located in the vehicle, which permit to measure the distance to obstacles and provides the driver additional information and/or stopping when a potential accident is about to happen.

The second phase will additionally include a series of advanced features that aim to push 5G to the next level. This includes the integration of two additional video feeds (right and left side) into a 3D environment. It will be processed from the four video cameras installed in this phase (front, left, back, right) and shown to the end user in a 360 environment by using VR glasses. Apart from that, the warning service will be enhanced by implementing a 3D tracking algorithm that will use both the data from the AI detection algorithm and lidar.

The business model of UC1-RMD is based on adding extra functionalities to current vehicles so that the remote-control service is available, apart from traditional user-manual driving. Based on the prototype developed, a specific business model based on three axes will be created, namely the provision of the technological solution from the sale of patents to OEMs, the production as tier 1 of the specific communication units or the provision of the service in collaboration with OEMs.

UC1-RMD aims to provide greater comfort to people when performing certain types of activities that do not require human presence, such as taking the car from one place to another, picking up another person or delivering objects. This NetApp can cause a great impact on the transport industry, since it can be adapted to large vehicles to transport material to sites in dangerous areas, transport dangerous substances, transport goods to places that are far away. Automotive industries enabling such a NetApp would safeguard the safety of the driver, thus saving resources, and in the case of long journeys they would not need to stop the vehicle for the driver to rest, but would simply be taken over by another operator, thus improving their service times.

Involved partners and their roles

Partner	Role
Fivecomm	NetApp developer and integrator AGV provider
Nokia	Infrastructure provider
Vicomtech	NetApp developer: Contribution and support on object detection and warning service VNFs
Fscom	Validation and testing of integration and deployment of VNFs
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.1.1.1. Scenario 1

Industrial control: The first scenario aims at having the possibility of control an AGV located on a manufacturing company via 5G connection. This will allow to avoid accidents between people and vehicles due to the controller will be placed out of the operation zone. Moreover, for a properly navigation, the AGV will provide the controller a video from the front camera equipped on the AGV. The network should be able to offer the necessary capacity and network speed to work with low latency.

8.1.1.2. Scenario 2

Automated-remote driving handover: In the event that an automated vehicle is not capable to handle a certain operation, remote driving can switch to remote mode involving a human operator to solve the situation. This could happen through providing additional information to the vehicle, enabling it to correctly perceive its situation. It can also include temporarily taking over control to resolve the situation or proposition of a new route.

8.1.1.3. Scenario 3

Transport in long journeys: The third scenario is related mainly in material transport but is also useful for other use cases. In case of long journeys, drivers would not need to stop the vehicle to rest. The remote driving control would take over from one driver to another, thus improving their service.

8.1.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Manufacturing companies	Material transport vehicles	Avoid possible accidents between vehicles and people and the accidents regarding with the material carried by this vehicle
Automotive industries	Vehicle manufacturers	The remote driving service can be part of a new service provided by the automotive industries as a new functionality

8.1.3. Storyline scenarios

8.1.3.1. Scenario 1

Industrial control: on a manufacturing company, it is necessary to transport material from one side to other to continue with the production chain. The remote driving functionality allows to control an AGV for that propose, controlling it from a control panel situated on the factory, out of the production zone, where the operator is provided by a video from the front camera and back camera equipped on the AGV. Moreover, if there are more than one AGV, the same controller could control all of it from the same control panel, being more comfortable to manage it. Using 5G connection, with a low latency, avoids accidents regarding the reaction time of the AGV and the capability of control it from anywhere.

8.1.3.2. *Scenario 2*

Automated-remote driving handover: a vehicle is working autonomously on a defined route. Due to some obstacles, the vehicle is not able to handle the situation, and does not know how to redefine the route. In this case, there are a control centre that can control the vehicle remotely, so, for that type of situations, the human control would drive the vehicle to the way again taking in consideration the situation of the road, being provided by videos both the front camera and back camera.

8.1.3.3. *Scenario 3*

Transport in long journeys: a transport company must transport material from across Europe. The truck driver cannot drive more than 9 hours per day, so the cost associated to the transport increases. Using remote driving, the truck control would switch from the present driver to another one located remotely, allowing the truck to reach its destination sooner and in thus reducing costs.

8.1.4. Functional requirements

Table 24: use case 1 - functional requirements

Requirement / Functionality	Description
Remote Driving	In UC1 the vehicle shall be able to be controlled remotely from any remote location
Front Camera	In UC1 the Automated Guided Vehicle (AGV) is set with a front cam that allows the user to see the road. It comes with distance indicators that inform the driver about the distance between the AGV and potential obstacles
Back Camera	In UC1 the AGV is set with a back camera that allows the user to see the road that is left behind. It is also useful when driving backwards
Edge Server	In UC1 an edge platform is needed at the 5G network to access the NetApp containers in near real time
OBU	In UC1an OBU is required in the vehicle to access some of the network functions in near real time
Controller	In UC1 a controller or any external peripheral is needed to move the vehicle and provide orders
User Interface	In UC1 the user interacts with the vehicle via an intuitive interface where all necessary functions are integrated. Both camera video feeds, battery status, vehicle speed, and warning indicators shall be added
Collision Sensor	In UC1 a sensor is set in the vehicle to warn the user in case a potential collision. A warning signal is sent when an object is below the minimum distance set

8.2. Use case 2: Manoeuvres coordination for autonomous driving

8.2.1. Overview

The use case aims to showcase a manoeuvre coordination service, available thanks to the 5G-IANA infrastructure, capable of lowering the risk of collision in complex junction scenarios by describing suitable paths and priorities for connected, eventually automated, vehicles directed by a shared coordination system. It facilitates AVs and human driven cars interaction at gatherings, complex intersections, and clogged traffic. The use case will include autonomous and traditional cars together with Virtual Vehicles that can be put in at will to recreate realistic traffic conditions. Virtual simulated vehicles, fully integrated into the AOEP, will also serve as a powerful tool to facilitate experimentation throughout the 5G-IANA platform ecosystem.

Involved partners and their roles

Partner	Role
BYLOGIX	Autonomous vehicle provider. Use case owner. Responsible for NetApp, planning, and scenarios. Develops on-vehicle HMI and integration software. Develops VNFs
NOKIA	Testbed and 5G Network provider
5Comm	Develops on-vehicle integration software. Develops VNFs
LINKS	OBU provider with 5G connectivity
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.2.1.1. Scenario 1

Simple colliding Manoeuvre Coordination. The scenario is aimed to show how both driven and driverless vehicles can benefit from a subscribed manoeuvre coordination service in complex or hazardous manoeuvre conditions. A great benefit is also perceived in the -expected to be long- transition period from all-driven cars to all-autonomous vehicles in terms of great help to human drivers confronting with fully autonomous vehicles and for facilitating the deployment of fully connected vehicles on roads shared with connected human-driven cars.

8.2.1.2. Scenario 2

Trafficked junction Manoeuvre Coordination: The scenario shows how connected and autonomous vehicles benefits from a centralised manoeuvre control service in situations where uncommon and unpredicted conditions, greatly depending on the surroundings, rises the complexity of the manoeuvres and pull-up the urgency. The situation adds to the first scenario a heavier traffic at the junction. This is to mimic very common real-life traffic scenarios that see crowded traffic in complex, clogged junctions, more and more frequently, custom vehicles with increasing automation and autonomy.

8.2.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Vehicle user	Receive, use the service	Relieved attention in complex situations. Maximise his/her safety in hazardous scenarios
Car makers	Onboard the service	Appealing services offer.
Vertical Application providers	Design and develop services	Easy access to a new market. Standardised approach in the development of high-end applications of the future. Broad, cloud native, high-tech development stack.
Insurance companies	Sell insurances	Tailor insurances based on the user subscription to safety services. Enrich their offer with subscription levels to Vertical Apps
Network Operators	Provide infrastructural connectivity and service hosting	New appealing network enablers for telecoms
Public sector, municipalities	Supervise public areas	Increase public safety for equipped areas. Ease the urban traffic control

8.2.3. Storyline scenarios

An autonomous vehicle and a human driven car, both connected with 5G to the 5G-IANA AOEP service and registered to a Manoeuvre Coordination Service, are approaching a supervised crossroad intersection with opposite directions. They are informed by the Manoeuvre Coordination Service of other vehicles' presence on the spot and of their suggested directions. That is a risky situation for the human as the automated actions of autonomous vehicles are unpredictable and no visible behavioural information can be perceived by intuition to help the driver decide how to act. A very complicate task for the autonomous vehicle too: many moving cars and a converging paths situation can easily drive the piloting platform out of its ODD.

8.2.3.1. *Scenario 1*

Simple colliding Manoeuvre Coordination: The autonomous vehicle and the human driven car are approaching the same intersection with opposite verses and their will to steer produces criss-crossing paths. As they are both subscribed to the Manoeuvre Coordination Service the autonomous vehicle path is superseded by the manoeuvring instructions while the driver on the regular car is instructed on how to behave traversing the crossroad. Both vehicles will safely exit the crossing.

8.2.3.2. *Scenario 2*

Trafficked junction Manoeuvre Coordination: Replay of the first scenario but now the autonomous vehicle and the human driven car are surrounded by other cars (they both see many other cars and their direction as signalled by the Manoeuvre Coordination Service) stuck in traffic. They must slow down and stop several times while they are neatly coordinated to exit the crossing.

8.2.1. Functional requirements

Table 25: use case 2 - functional requirements

Requirement / Functionality	Description
Manoeuvre Coordination	The UC2 NetApp must implement the functionality of manoeuvre planning
Election of the Manoeuvre Coordinator	A coordinator of the manoeuvre planning is elected among any more than one vehicle and the edge server (whenever reachable and available)
OBU	In UC2 the OBU is required to exchange manoeuvre coordination messages with the other vehicles and the edge server
ADAS Interface	The OBU and the ADAS module of the vehicle must exchange the information related to manoeuvre planning through a dedicated interface
User Interface	The UC2 NetApp must provide information about the manoeuvres suitable to show instructions and alerts to available HMIs on the vehicles
Edge server	In UC2 an edge server is needed to implement a centralized manoeuvre planning
Location Information	In UC2, location information of the vehicle must be available to decide if decentralized or centralized manoeuvre planning should be performed

8.3. Use case 3: Virtual bus tour

8.3.1. Overview

Use Case 3 (UC3-VBT) corresponds to a virtual tour, where virtual reality users will be joining a tour guide in a virtual environment of a double decker bus and will be represented in the VR space with their avatars. Users will be able to receive to their HMD (Head Mounted Display) the video of the tour surroundings streamed by a high resolution 360o camera mounted to a vehicle taking the real tour, along with GPS-driven landmark indicators providing information about the attractions. The users, via their avatars will be able to gesture, speak and listen to one another, from their dedicated virtual bus seats, which will be determined during their entry.

Involved partners and their roles

Partner	Role
HIT	Use case owner, NetApp provider responsible for planning, scenario, developer of Video Slicer VNF, will provide 360° camera, VR headsets, Edge PC, servers required
NOKIA	Testbed/5G Network provider
5Comm	Vehicle provider
LINKS	OBU provider with 5G connectivity
NXW	Load Balancer AF provider – (Use of this AF is under discussion)
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.3.1.1. Scenario 1

UC3-VBT will provide a standalone service that allows the user to participate in an immersive experience of a guided tour in a place of touristic interest, enabled by 5G. This will be showcased in a single scenario where two end-users will join the scenario operator, who will have the role of a live tour operator though a Virtual Reality Environment. Users will be able to receive to their HMD (Head Mounted Display) the video of the tour surroundings streamed by a high resolution 360o camera mounted to the bus/vehicle taking the real tour. Additionally, GPS-driven landmark indicators will be providing information about the attractions. The users, via their avatars will be able to gesture, speak and listen to one another.

8.3.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Tourism Industry Companies	Companies from this sector already have the	Company can provide a new service in the form of

	experience in providing guided tours and can integrate UC3 as another of their provided services	Virtual Tours creating a new stream of revenue. Virtual tours can either be part of a separate deal or can be used in order to advertise the touristic destination
Municipalities / City Councils	Municipalities / City Councils are commonly responsible for the management of Touristic points of interest and can use the service developed in UC3	A VR guided tour can be a part of larger campaign aimed to increase the number of visitors in a city
Other administrators of properties of touristic Interest or Exhibition Areas	Administrators of properties that occupy a large area such as places of touristic interests e.g., archaeological sites or natural parks and administrators of Exhibition Areas can use the service developed in UC3 to promote said property or Exhibits	A VR guided tour can be provided as service creating a new stream of revenue or as advertising aimed to increase the number of visitors to the point of interest
News Agencies and Professional recording agencies	News Agencies and Professional recording agencies can utilize the developed feature in "live coverage" of news or events	Agencies that provide live coverage of the event or of any news footage, will be able to benefit from high quality 360 live stream with high QoS

8.3.3. Storyline scenarios

8.3.3.1. Scenario 1

Giannis and Eleni are two friends living in different houses in the city Athens. Giannis is under quarantine due to COVID-19 infection. Eleni searches the internet for some form of entertainment that she can safely share with her ill friend and discovers a service concerning a guided tour in the city of Ulm via Virtual Reality. She books participation for two persons and receives instructions on how to connect via an e-mail.

At the time of the tour, both Giannis and Eleni are ready to join the tour from the comfort of their respective home. After choosing a customized avatar, they join the VR tour space.

There they meet Johan who is their guide tour: After a brief introduction, the tour starts: A vehicle driving around the city of Ulm provides 360o video for various Touristic points of Interest. Apart from the information provided verbally by Johan, Giannis and Eleni can also access GPS-driven landmark indicators providing additional information about the attractions. The vehicle drives through various areas with different coverage: Apart from optimizing the video stream, local servers, caches and adaptive techniques are used in order to maintain a high QoS for 4k 360video stream and provide a seamless experience to the people participating in the tour. The tour finishes and Giannis is already feeling better.

8.3.4. Functional requirements

Table 26: use case 3 - functional requirements

Requirement / Functionality	Description
Bus Positional Information	The UC3 will provide to the users' landmark indicators and touristic information about the surrounding attractions. To be able to do so the position of the bus at any given time must be available
Resource Monitoring	The UC3 NetApp should monitor and report the resources usage of the service (e.g., networking, computing, and storage)
OBU	In UC3 the OBU, connected to vehicle's CAN bus, should provide various data related to the particular vehicle, e.g., speed, acceleration, location etc.
Edge Server	In UC3 an edge platform is needed to support the execution of VR functions
Multi-user Support	The UC3 NetApp must provide a multi-user experience. Each user is able to communicate with the rest of the users in real time
Virtual Tour Guide	The UC3 NetApp must provide a multi-user experience where a tour guide is present and will guide the users through their experience. The tour guide will have an appropriate avatar, as well as assisting actions. These actions will be present only for this specific role
Virtual Presence	In UC3 each user will have a virtual presence, which will be able to respond to his movements using the VR equipment. The avatar will be able to place in different spots in the bus
Audio Communication	In UC3 each user can talk with the rest of the users
Gesture Communication	In UC3 each user can use gestures to communicate with the rest of the users
Spatialized Audio	In UC3 each user can talk with the rest of the users. Moreover, the voice should be spatialized, meaning that the position of the transmitted voice should match the position of the user avatar, relative to a static point on the bus
Privacy Masking Module	In UC3 a Privacy Masking module is required so the data transmitted complies with local and European privacy and protection, e.g., covering faces of bystanders and licence plates

8.4. Use case 4: AR content delivery for vehicular networks

8.4.1. Overview

UC4-ACOV Intelligent NetApp aims at providing "high-quality AR content streaming" taking advantage of the future web AR applications, the MEC and 5G connectivity. For a UE entering a 5G network, the Intelligent NetApp will provide information in the form of "high-quality" virtual 3D objects embedded on the user's (Google) 3D map on his mobile device (e.g., iPhone/iPad). This is an excellent example of convergence of edge computing, the ARCore Geospatial API and 5G networking that will give users the ability to interact with content, digital character displays, virtual experiences and outdoor navigation. Instead of using cloud, we will leverage MEC server so that the experience is rendered on powerful, edge-based GPUs and then streamed to any mobile device. Augmenting and offloading the processing from the mobile device provides the best user experience.

Thus, the NetApp will use a combination of edge computing and AR technology to offload the computing power needed to display high-quality 3D objects, rendered by unreal engine, and stream them down to AR-enabled devices. The 3D-objects streaming will be provided to the 3D navigation environment similar to Live View by using ARCore Geospatial API and MEC server. This is challenging for AR applications so that to support marker-less AR streaming content with the help of MEC elements in order to minimize the battery consumption of the mobile device. Apart from that and in case of using an on-board unit, where the battery issue is not considered anymore, the 3D objects streaming is useful in case of real-time collaborative experience with other users and through a unique 3d object descriptor.

Such AR streaming application will take into account different settings of the UE such as location, context, speed and throughput. A significant aspect of the Intelligent NetApp is that it will exploit AI at the MEC server (i.e., edge AI) existence and capabilities, bringing the services of the application closer to the user. It that manner, we will satisfy the need for QoE (Quality of Experience), delivering a high-quality AR content including virtual 3D objects in low latency, as well as maximizing the availability and reliability of the functions. The Intelligent NetApp will also take into consideration the coverage of the offered network in Ulm combined with the user's speed so it will adjust to the system requirements. Mobile users can enter 3D and AR experiences in seconds for future navigation support. The location of the user will play an important role as he/she could be moving with high speed at a highway or it could be in a dense urban environment. High mobility affects the throughput and consequently the experience of the user. Thus, considering the conditions of the mobile device connectivity, the application is going to provide AR content embedded on Google maps that will interact with the users in order to navigate him efficiently. On the other hand, AR content could be sent that will indicate places of interest such as gas stations, food places or requested places well known in the specific location.

The ultimate objective of the proposed system is to provide AR streaming services to 5G mobile users with high visual quality and low latency over a 5G mobile network. However, this task remains challenging because mobile devices have limited computing power for AR processing and network resources. Such applications would be more feasible if computing and storage resources of the mobile edge over 5G networks are effectively employed. UC4 will support navigation through outdoor localization enabled by AR content as a sort of an infotainment. Such navigation will be provided for both users within and outside the car in a sort of long and short coverage application scenario. We aim to support the transition of traditional two-dimensional direction instructions to world-fixed three-dimensional instructions that blend into the outside environment. A future research direction for autonomous vehicles would be to combine navigation tasks with passenger experiences and gamification. For example, we can use AR to playfully make the driver aware of situational warnings, a concept which could be translated to navigation and routing.

The development of an AR streaming NetApp, plays a significant role, as part of the evolving telecommunication systems. Not only in the automotive industry, but generally, Extended Reality (XR) will create new paths towards interactive smart applications. More specifically, automotive industry shall take advantage of modern car infrastructures to provide a more interactive, safe and interesting driving experience. Machine learning algorithms are able to predict the needs of a user, according to his/her choices and consequently, there is the opportunity to involve more than one player in the development of the application. On the other hand, advanced computer vision can provide a more efficient navigation applications for future mobility. As a user moves for example in a city in or out the car, a mobile user could interactively be informed, through a Map application, about near places of interest or of importance. In this manner, the enterprising sector can benefit from such applications by helping small and big businesses being promoted in such an interactive way. On the other hand, the public sector might have the chance to inform the drivers for specific services from security to tourism. The specified NetApp can be used for future navigation support.

Part of future infotainment in vehicular communications is the overall navigation experience. Intelligent NetApps should be developed to enable drivers to improve route planning, to estimated time of arrivals, to be notified about events happening nearby and have also a great experience of the surrounding environment. Combined with the previous, within an interactive way, a smart application can help users have a better control of his/her driving behaviour, for example providing information about his/her speed, warning the user about his/her safety. In addition, predicting algorithms shall be able to provide useful content before the user asks for it. Moreover, through advanced AR tools, our NetApp will enable one user to place a 3D AR object in the physical environment and another user to see the same object at the same place at a later time. For example, it will create virtual signs that help users find their way around train stations, offices and other common visiting places.

Involved partners and their roles

Partner	Role
Cogninn	Intelligent NetApp development and testing
Nokia	5G network infrastructure provision
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.4.1.1. Scenario 1

Urban Roaming: A user is moving inside a dense urban environment connected to the local 5G network. The mobile user is inside or outside in a vehicle with his mobile device such as iPhone or iPad that is capable of Google maps displaying with smartphone-like system requirements (RAM, media display, CPU). The user moves with a low speed of less than 30 km/h. Different markers can be selected as data about the environment and the conditions while information about the location of the user is provided to the edge in collaboration with the cloud. The application is deployed at the edge of the network, while it proactively caches data according to the user's interests. The combination of low mobility and good network coverage helps the applications create and deliver AR content with 3D object integration as well to the mobile user device with high data rates and low latency with a considerable refresh rate and resolution.

8.4.1.2. Scenario 2

I am the Highway: A vehicle connected to a 5G network is travelling in a city with a speed of more than 50km/h. The user has initiated the NetApp which is deployed at the edge of the network. The device that is used is capable of supporting AR applications. The various VNFs offer data in a sort of 3D objects to the NetApp about navigation conditions. Mobility of the vehicle affects significantly the data rate as the 5G mobile network throughput capacity may change at different locations, while the latency will remain at sufficient levels if there is no demand for a higher data rate as long as the vehicle is in-coverage of a mobile network. Thus, in this scenario, the NetApp monitors the capability of the 5G mobile network infrastructure and prepares content concerning the improvement of the user navigation experience, which is delivered with low latency and can be in adjusted in data volume.

8.4.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Cogninn	NetApp developer	To distribute a future 5G commercialized service
Nokia	Infrastructure provider	To test 5G networking equipment and associated services
Businesses	Advertisement	Businesses could be advertised in an interactive way, while a user is navigating
Public Sector	Information provider	Public Sector services could inform the drivers about important events including road safety
Car companies	NetApp providers	Car companies can benefit by providing the Intelligent NetApp navigation service
Driver	NetApp user	A driver can be informed about places of interest and safety instructions while navigating

8.4.3. Storyline scenarios

8.4.3.1. Scenario 1

Urban Roaming: A traveller for a meeting has arrived to Ulm while he is connected to the local 5G networks. As he is roaming in the city centre, he is looking for navigation information and the ACOV is initialized. His speed is a pedestrian like speed or taking a slow public transport like a bus, and the status of the connectivity is at satisfactory levels. As the user is new in town, they are interested to find the places of significance, thus the ACOV will take that into consideration. At the beginning of his navigation, he moves inside the city centre of Ulm. The application creates, beforehand, the appropriate content and caches it at the MEC server and/or at his smartphone. Such content includes places that are nearby like business offices, hotel and cafes and when the user approaches the specific places, AR is rendered and is displayed on his Google's map application. The content is renewed at specific time slots, so they have the chance to discover new places. As the time has passed, the user decides that is it time for lunch and not anymore in a car. The ACOV takes this into consideration and it prepares content that indicates nearby places, where restaurants and cafeterias are located. During his navigation within the city, the AR application informs the users about the surrounding areas and offers general navigation related information.

8.4.3.2. Scenario 2

I am the Highway: The same user takes a taxi to reach the meeting point and thus, he is navigating the city within a speed limit. When the user is moving along the city roads, his speed is approximately 50 Km/h. The ACOV is monitoring the wireless conditions and offers information to other functions. The radio capability monitoring function suggests that the data rates should be lower than usual. The application is adjusting to the conditions and starts to predict what type and size of content is suitable for this situation. At some point, the information about nearby gas stations is displayed, as the user frequently requests such information. In addition, the application renders AR content that will indicate the user about weather conditions or even about the traffic in the coming kms to estimate the arrival time. Due to lower 5G radio network throughput rates the NetApp must be able to predict what the user will need and download it to proactively to the smartphone. Also, the predicted content requests should be in reduced in volume so that the desired QoE is applied.

8.4.4. Functional requirements

Table 27: use case 4 - functional requirements

Requirement / Functionality	Description
Data Collection	In UC4 the data must be collected from the environment for the content creation
Data Aggregation	In UC4 the data must be translated and stored to hierarchical structures according to a taxonomy plan
User-specific Request	In UC4, for a better user experience, the NetApp should be able to take user's requests into account
OBU / Edge server	In UC4, the OBU / Edge server must support AR content rendering which will be embedded on the UE map
AR Runtime	In UC4, the display of content should have sufficient refresh rates and FPS
Caching	In UC4, the usage of caches must enable the prefetching of media before the user needs

8.5. Use case 5: Parking circulation & high-risk driving hotspot detection

8.5.1. Overview

Use Case 5 (UC5) aims to develop a feature that will be integrated in the 5G-IANA platform, which will detect aggressive and distracted driving (hazardous events), and transmit warning notifications on road risk-level to other vehicles. UC5 leader, OSeven, has a long experience in the development of telematics and driving behaviour assessment products, having developed an innovative smartphone application, which rates a driver's driving behaviour, in terms of safety and eco, according to specific metrics (e.g., speeding, harsh breaks/accelerations, distraction/mobile use).

The two kinds of risky behaviour the UC5 novel feature aims to detect are:

- Aggressive driving: harsh braking, harsh acceleration, speeding, crashes.
- Distracted driving: mobile use.

UC5 will use two different sources of data: i) the driver's mobile phone, which will provide data from the smartphone sensors (e.g., gyroscope, compass, accelerometer), and ii) an OBU installed on the vehicle, which will provide GPS and position data.

OSeven will develop an ML model to be trained on the edge, for the assessment of road risk level, that will be combined with real-time notifications. This ML model will assign a risk level along roads based on aggregated data over a specified model training period. In addition, UC5 will employ real-time hazardous events detection, in order to inform drivers on the increase of risk levels on the road they are driving on.

The developed feature will inform drivers in advance regarding risky and distracted driving in the road network, while also improving driving driver information, increasing their awareness and "decreasing" their reaction time. It will provide this information on a many-to-many integrated approach, detecting hazardous events from many vehicles and notifying many vehicles in real-time. In addition, it will assist drivers in enhancing their visibility in low visibility cases, such as fog, and low lighting conditions.

The developed feature will allow OSeven to enrich its solution (which at the moment is based on a post-trip assessment) with real time components, creating new revenue streams and targeting new customer segments. Specifically, the developed feature will be targeted to a variety of stakeholders: insurance companies, public authorities, fleet management companies, rental and leasing companies. The identified stakeholders can profit from UC5 either by directly implementing the feature or by integrating it in their telematics offerings and will enable them to decrease insurance claims (insurance companies), the risk of road accidents (public authorities), and the damage done to

vehicles through the reduction of accidents (fleet management, renting and leasing companies), while at the same time they increase user engagement.
UC5 will have a significant financial impact for OSeven and the above-mentioned stakeholders, as well as a significant societal and environmental impact. In fact, drivers utilising the UC5 feature will display a safer driving behaviour, as they will be alerted for potential risks, but at the same time this procedure will enhance driving awareness and training as a whole. This will decrease the number of road accidents, by avoiding crashes due to hazardous driving behaviour or low visibility conditions, and will also increase the overall road safety in the deployed area. It is worth noting that driving behaviour is a contributory factor in >90% of road accident, thus the training of the drivers and the improvement of driving behaviour can result on a 30% average decrease, of the road accidents and the related injuries/casualties, as this is illustrated by actual telematics data. Furthermore, it is a well-known fact that safe driving is also eco driving (safe driving may lead to a decrease in fuel consumption up to 30%). Therefore, the specific feature is expected to decrease significantly fuel consumption and CO_2 emissions, which is a critical factor, especially in the light of the ongoing energy crisis.

Involved partners and their roles

Partner	Role
OSeven	Lead
ICCS	Support OSeven in the development of the NetApp
NOKIA	Provision of the testbed for the experiments
5COMM	Provision of the vehicle for the experiments
LINKS & NXW	Provision of expertise and insight regarding the use and deployment of AFs/NFs
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.5.1.1. Scenario 1

We got your back: The concept of this scenario is called "We got your back". The driver uses the 5G network to receive automated push notifications on their smartphone, when entering a high-risk road network (risk level assessed by the ML model), and also receiving further notifications when the NetApp detects hazardous events that may be performed by various vehicles/drivers (aggressive or distracted driving) and updates the risk-level of the road. The driver then adjusts their driving behaviour (e.g., slows down) in order to avoid an accident.

8.5.1.2. Scenario 2

Eyes in the front of my car: The concept of this scenario is called "Eyes in the front of my car". The driver uses the 5G network to receive aggressive driving (speeding, harsh braking, harsh acceleration) notifications on their smartphone, which can be even more useful when driving in low visibility conditions, such as low lighting, fog, steep curves in junctions. The NetApp informs the driver in real-time on the detection of hazardous driving behaviour, so they can be more cautious in the road they are on, or the road they are going to enter through the junction, in order to avoid an accident.

8.5.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Insurance providers	Integration of the features in associated telematics products, and decrease of insurance costs (by decreasing risks involved)	Insurance providers could offer risk detection features to decrease improve driving behaviour, decrease insurance claims and cost, increase profitability. Further expected benefits include societal (e.g., decrease of road accidents, casualties, injuries) and eco (decrease of fuel consumption and CO2 emissions) benefits
Public authorities	Use the developed features in "smart-city" projects	Public authorities pushing for transition of areas in "smart-areas", can utilise the real-time risk detection feature to decrease the number of accidents on the road, increase the overall road safety and map the driving risk along road sections in order to optimize the budget utilization for the road network maintenance and improvements. Further expected benefits include societal (e.g., decrease of road accidents, casualties, injuries) and eco (decrease of fuel consumption and CO2 emissions) benefits
Fleet management companies	Use feature in in-house or external telematics apps	Fleet management companies will improve the road safety of their fleet drivers, decrease the risk of road accidents for their fleets (and consequently decrease their insurance cost), and they will also decrease their maintenance and vehicle financing cost. Further expected benefits include

		societal (e.g., decrease of road accidents, casualties, injuries) and eco (decrease of fuel consumption and CO2 emissions) benefits
Leasing, rental and Automotive companies	Integrate UC5 feature in telematics offerings	Leasing, rental and Automotive companies will decrease the risk of road accidents for their fleets (and consequently decrease their insurance cost) and they will also decrease their maintenance and vehicle financing cost. Further expected benefits include societal (e.g., decrease of road accidents, casualties, injuries) and eco (decrease of fuel consumption and CO2 emissions) benefits

8.5.3. Storyline scenarios

8.5.3.1. Scenario 1

We got your back: Carl has to take a highway when driving to his new job. He has the UC5 NetApp installed on his phone, and when he enters the highway on his first day to work, he receives a notification that he has entered a medium-risk road. Ahead of him, vehicles brake aggressively, while he also sees many vehicles overtaking him by accelerating and speeding, thus triggering a real-time notification that there are hazardous driving events taking place and that the risk level of the road has increased. He driver more cautiously and slows down. About a minute after he received the increased risk alert, he spots a car that has crashed, most probably with deadly consequences for the driver and the passengers. Carl himself, being aware of the increased risk level of the road, has driven sensibly and arrived at his work safely.

8.5.3.2. Scenario 2

Eyes in the front of my car: Nick enjoys driving to the mountains for hiking expeditions on the weekends. After an enjoyable such weekend in autumn, when driving back to his hometown, he encounters fog on the road. He slows down, but feels uncomfortable as he has low visibility and immediately turns on his UC5 NetApp. While driving, he receives a notification on his phone that there are hazardous driving events taking place in front of him along the road. He reduces his speed even more, and witnesses a car that has crashed on a tree and blocked part of the road, causing mild congestion. As the road is not wet, or damaged, he concludes that the driver in front of him must have been speeding.

8.5.4. Functional requirements

Table 28: use case 5 - functional requirements

Requirement / Functionality	Description
Initiate Button	In UC5, a “Searching for parking” button in the app to initiate the parking circulation process (communication to the Edge server) must be present
Termination Button	In UC5, a "Parking found" button to indicate that the user has parked, and the process terminates (communication to EDGE server) must be present
Push Risk Alerts	In UC5, the NetApp must send push notification about risk events to user
Risk Visualization	In UC5, the NetApp must display risky segments on the map

8.6. Use case 6: Network status monitoring

8.6.1. Overview

This NetApp 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 network communications to deliver predictions of the network quality to a central computation entity at the MEC server. This NetApp has the goal to minimize the data collection effort through utilizing a distributed Machine Learning 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 RSUs and the vehicle OBUs. The goal of the ML model is (1) to learn data traffic patterns for data traffic prediction, (2) to learn network condition models to provide QoS predictions, and (3) to learn to distinguish between normal and abnormal network behaviours to detect and predict faults.

The goal of UC6-NSTAT is to provide a network monitoring service that can be used to increase the efficiency of other NetApps through providing distributed predictions of QoS and in general of network conditions at various locations. The resulting spatio-temporal QOS map with predictions can be leveraged by other NetApps to decide for example on the grade of cooperate manoeuvring for autonomously driving vehicles.

5G enables new applications such as autonomous driving and cooperative manoeuvres. Distributed and predictive Network Monitoring supports 5G based applications to make efficient use of their data and resources. The result of this use case will support the deployment of new types of 5G mobile services such as autonomous driving. Also, it will demonstrate the potentials of Distributed ML schemes in 5G-PPP verticals like the Automotive one where the network may be volatile across time and space and where privacy concerns is of outmost importance.

Involved partners and their roles

Partner	Role
UULM	UC6 owner and leader of DML activities. NetApp provider
NOKIA	Testbed owners and will supervise the deployment of the UC6 in its 5G testbed.
FSCOM	Will contribute in the DML related VNFs (T4.2) development
ICCS	Will contribute in the DML related VNFs (T4.2) development
NXW	Will contribute in the DML related VNFs (T4.2) development
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment

8.6.1.1. Scenario

5G QoS Prediction: The aim of this scenario is to provide the current and predicted network status to autonomous driving vehicles. This will allow vehicles to have a prediction of some network-level Quality of Service metrics that e.g., allow taking local decisions such as switching to full autonomous mode or turning of some unnecessary communication in case a degradation of the communication quality is expected. In case an improvement is expected, the autonomous vehicle can again get back to cooperative driving mode or start transmitting additional informative but not necessary messages to other vehicles. Mechanisms such as advanced network probing, federated learning and time-series prediction are used to guarantee QoS prediction accuracy.

8.6.2. Involved stakeholders

Stakeholder	Role	Expected benefit
OEM Applications	Will provide the ML model for monitoring and prediction	Can use the developed Architecture in 5G-IANA to train their Network Prediction model
Users	Will run the ML prediction models for training and later for inference.	Vehicles (users) will obtain QoS prediction models and make use of the benefits of network prediction as demonstrated by UC6.

8.6.3. Storyline scenarios

8.6.3.1. Scenario1

Federated Learning of Trajectory Models: Consider an autonomous driverless vehicle being driven in the lanes of Ulm. The vehicle gets the input (such information feed from RSU, GPS Coordinates and trajectory of neighbouring vehicles) from their respective source location over the 5G network. Based on the timely reception of these inputs the driverless vehicle is able to make its precise decisions on the chosen trajectory. A network prediction model is being trained on every working node (driverless vehicles) in a Federated Learning fashion. This model present in every vehicle predicts the future behaviour of the network allowing the vehicle to decide if it will receive the input (such feed from RSU, GPS Coordinates and trajectory of neighbouring vehicles) in a timely manner. If there is an insufficient network connectivity predicted, then the vehicle will choose to perform different set of trajectory operations or e.g., completely give the control to humans rather than deciding without timely input.

8.6.4. Functional requirements

Table 29: use case 6 - functional requirements

Requirement / Functionality	Description
Location Information	In UC6, location information must be available to functions running on the OBU, for the appropriate tagging of ML/FL training data
QoS Data Access	In UC6, data to be used for ML Predictive QoS i.e., training data, must be available to a function. This data stems from active measurement / monitoring data
Traffic Condition Access	In UC6, awareness of vehicle trajectory and current traffic status (especially for smart traffic planning) could possibly augment the contextual information of input data
OBU	In UC6, OBUs/RSUs should have a communication module to interact. The communication module is required for CCAM and DML
Internal Information Access	In UC6, OBUs/RSUs should have access to their internal system information to save training data

8.7. Use case 7: Situational awareness in cross border road tunnel accidents

8.7.1. Overview

Use case 7 (UC 7) aims to develop and integrate necessary components (e.g., VNFs, RSU, OBUs, sensors and cameras, 5G SA network, 5G MEC) to provide situational awareness for first responders. In case of an accident in a road tunnel, situational awareness systems enable first responders to understand the exact location of the incident, number of involved vehicles and people and other critical situational information, such as temperature, smoke, and CO level status in the tunnel.

RSU and sensors connected to it, as well as OBUs, will provide environmental data sensed in a tunnel, including real-time video-stream. VNFs deployed in RSU and OBUs will take care of initial processing of collected data and will provide data transmission to the MEC where monitoring VNF will collect them.

One of the most important benefits expected to be achieved by using orchestrated 5G network is cross-border collaboration of first responders without a need to use UEs dedicated to each single administrative domain as is usual practice today (e.g., each of the two bordering countries having its own communication system). All components forming the solution will be generic and therefore applicable to any 5G network providing required conditions (e.g., eMBB network slice, latency requirements, etc.). To enable cross-border data sharing, the two networks will need to be connected in a proper way (e.g., VPN), as well, certain security rules will need to be established in order to prevent any data privacy or similar issues while transferring data cross border.

Involved partners and their roles

Partner	Role
ININ	Lead, providing of certain VNFs
TS	Providing domestic testbed (Ljubljana, limited to lab environment only)
NOKIA	Providing cross-border testbed (Ulm)
LINKS	Providing of RSU, OBU and certain AFs/NFs
NXW & UBI	Providing expertise regarding orchestration and AFs/NFs deployment
BYL	Providing test vehicle in Ulm testbed

8.7.1.1. Scenario 1

Normal traffic conditions in the tunnel: While there are normal traffic conditions in the tunnel, sensors and cameras are collecting requested environmental parameters which are further sent to MEC where they are analysed and stored according to the data privacy policy. As long as no emergency is detected, certain data are displayed on the dashboard in a traffic control monitoring centre only, while no data is forwarded to the notification centre of first responders.

8.7.1.2. Scenario 2

Emergency situation in the tunnel: Whenever a critical situation occurs in a tunnel and traffic control monitoring centre staff triggers accident alarm, alarm notification and relevant data, including video stream from the inside of the tunnel, are forwarded to the first responder's notification centre (SOS). As well, alarm notification and relevant data are also forwarded to the other tunnel administrative entity's monitoring and notification centre. Based on the exact location of the accident, authorized first responder unit takes intervention leading role and starts intervening also by the help of data available through situational awareness system.

8.7.2. Involved stakeholders

Stakeholder	Role	Expected benefit
Road tunnel operator	Uses the system and manages road tunnel traffic according to the situation (e.g., restricts/manages traffic volume through the tunnel, diverts traffic, sets speed limit, etc.), maintains RSUs and sensors	Improved road tunnel safety, faster response in terms of traffic management, faster response of first responders (less damage expected)
PPDR network operator	Provides network connectivity, provides MEC infrastructure, operates and maintain network	New services and revenue
Situational awareness service provider	Operates and maintain the service	New services and revenue
Vehicle manufacturers and OBU providers	Provides OBUs installed in vehicles potentially involved in the traffic accident	Improved specific OBU functionalities resulting in more safety vehicles
Authorized local firefighter units, paramedics, and local Civil Protection authority (depends of the organization of the PPDR	Provides rescue services in case of emergency (firefighting, rescuing, evacuation, triaging, etc.)	Safer and more efficient rescuing, faster response, improved collaboration between rescue units

system in a particular administrative domain)		
National PPDR administration	Provides additional rescue forces in case of escalated emergency, analyses rescue interventions and data collected in order to improve intervention tactics and operational processes	Improved reporting from the field, improved planning, ability to improve intervention tactics and operational processes, ability to propose safety standards improvements
Society	Participants in road traffic, people living close to the tunnel	Improved safety, reduced damage costs, more saved lives

8.7.3. Storyline scenarios

8.7.3.1. Scenario 1

Normal traffic conditions in the tunnel: While there are normal traffic conditions in the tunnel, data collected (including video stream) in the tunnel are presented to the tunnel monitoring centre staff but are not forwarded to the first responder's notification centre. Multiple sensors connected to the RSU are collecting various data (e.g., smoke level, CO level, visibility, temperature, humidity, etc.) and camera connected to the RSU is surveying the tunnel. All data, including video stream, are sent to the MEC where data are collected, analysed and displayed on dashboards of the traffic monitoring centre. As well, traffic monitoring centre staff watch video stream(s) to make sure everything is under control. Based on the data collected, several measures can be taken regarding traffic control, e.g., modifying speed limit for the vehicles driving through the tunnel, turning on additional warnings/prohibitions on smart traffic signs, increasing/decreasing tunnel's air ventilation fans speed, etc. Situational awareness system does not provide the above-mentioned functionalities, while it is possible for the tunnel monitoring centre staff to act manually according to the data displayed in the dashboards.

Figure 18: Smart traffic signs at the entrance into the tunnel.

8.7.3.2. Scenario 2

Emergency situation in the tunnel: A traffic accident in the tunnel is detected and alarm notification is triggered and forwarded to the first responder's notification centre. Along with the alarm notification, other relevant data and video stream surveying the accident location is forwarded as well. Based on the data available, first responders' incident commander orders intervention to start. All data available are now forwarded to the incident commander's UE as well. When leaving the first responders' station building, the system may also start collecting certain data related to the first responders' unit (e.g., location of vehicles, speed, vehicle diagnostics) in order to complement data related to the incident, thus improving situational awareness data available to the incident commander. Situational awareness data are of great importance for the intervention planning from its very beginning, through the rescue phase until its completion. In the beginning, incident commander can decide how many rescuers, what kind of vehicles and how many vehicles should be dispatched and also whether additional units are required (e.g., cross-border units). During the rescue phase, the incident commander can observe how the rescuing is progressing, what operations should follow at certain time, and whether additional forces should be activated. Based on the situation, the incident commander also instructs tunnel monitoring centre operator to commit certain action, e.g., stop the traffic through the tunnel, stop or increase air circulation in the tunnel. However, there are also other activities of the standard operational procedure that need to be executed by the tunnel operator and first responders. When the intervention is over, data stored can be later of great importance for the intervention analysis.

Figure 19: Situation at the tunnel entrance in case of an incident.

Figure 20: Road tunnel traffic accident and first responders right after emergency is over.

8.7.4. Functional requirements

Table 30: use case 7 - functional requirements

Requirement / Functionality	Description
Situational Awareness in Cross-border Road Tunnel Accidents	In UC7, data from the accident's hot zone must be provided to PPDR users to improve PPDR units' efficiency when dealing with tunnel accidents
Multi-scenario Applicability	In UC7, the NetApp should be flexible, adaptable, and scalable for other use cases within the same vertical, or for use cases within other verticals
Vendor Agnostic Solution	In UC7, the technical implementation must not be vendor-specific to be easily deployed over different infrastructures
Real-time Video Streaming	In UC7, PPDR users must be capable of accessing live video from the area of accident
Real-time Data Collection	In UC7, PPDR users must be capable of accessing real-time environmental data provided by sensors installed in the tunnel
System Compatibility	In UC7, all system components used must be compatible among them (cross-administrative domain cooperation, heterogenous UEs and sensors, heterogenous OBUs)

9. CONCLUSION

The architecture of the 5G-IANA AOEP has been specified in this document. The AOEP has the objective to promote the development of new Automotive vertical related services that can be enabled thanks to the performances and features offered by 5G mobile networks. The specification of the AOEP has been founded on the collection of generic requirements, but also on the specific needs of the seven Use Cases foreseen during the proposal phase.

To achieve this purpose the AOEP integrates the NetApps Toolkit which offers the functionality to easily create and manage NetApps. Furthermore, the 5G-IANA project offers a set of NetApp Starter-kits that the end-users can exploit to take full advantage of the 5G new capabilities, and of already available baseline and network functions that the 5G-IANA project makes available.

The management and exploitation of the 5G infrastructure, that includes the 5G Network Slices management and the compute resource allocation of the 5G-IANA infrastructure, is performed by the Slice Management and Resource Orchestration layer. End-users can also experiment Distributed Machine Learning (DML) services thanks to the DML Orchestration layer that is part of the AOEP. Further layers of AOEP are the Monitoring and Analytics layer, and the Distributed Data Collection layer that are mainly used for applications profiling and traceability of faults and misbehaviours.

The AOEP is made for operating on several virtualized infrastructure segments to better suit the different contexts in which the Automotive vertical services can run. In the details, the specifications of the AOEP take this into account by targeting to operate on Far-edge (i.e., OBU, RSU), Edge and Cloud virtualized infrastructure segment. The specifications of the AOEP take into account the different characteristics that are intrinsic to each of these segments.

REFERENCES

1. ETSI GS NFV, ETSI GS NFV SOL006 Protocols and Data Models; NFV descriptors based on YANG specification; v3.5.1, 2021.
2. ETSI GS NFV, ETSI GS NFV SOL004 Protocols and Data Models; VNF Package ad PNFD Archive specification; v3.5.1, 2021.
3. ETSI GS MEC, ETSI GS MEC 010-02, MEC Management Part 2: Application lifecycle, rules and requirements management; v3.5.1, 2021.
4. ETSI GS NFV, ETSI GS NFV-SOL 005 Network Functions Virtualisation (NFV) Release 3; Protocols and Data Models; RESTful protocols specification for the Os-Ma-nfvo Reference Point; v3.6.1, 2022.
5. 5G-TRANSFORMER, «D3.3 Final design and implementation,» 2019.
6. 5G-EVE, "D4.6 Final version of the experimentation portal", 2021.
7. 5GROWTH, «D2.4 Final implementation of 5G End-to-End Service Platform,» 2021.
8. VITAL-5G, "D1.2 System Specifications and Architecture", 2021
9. MATILDA, https://www.matilda-5g.eu/, (accessed May 18, 2022).
10. ETSI GR NFV-IFA 029, "NFV Release 3, Arcitecture; Report on the Enhancements of the NFV architecture towards "Cloud-native" and "PaaS"", 2019.
11. M. Liyanage et al., "A survey on Zero touch network and Service Management (ZSM) for 5G and beyond networks," Journal of Network and Computer Applications, vol. 203, p. 103362, Jul. 2022, doi: 10.1016/j.jnca.2022.103362.
12. P. Trakadas et al., "Comparison of Management and Orchestration Solutions for the 5G Era," Journal of Sensor and Actuator Networks, vol. 9, no. 1, p. 4, Jan. 2020, doi: 10.3390/jsan9010004.
13. GSMA, «GSMA NG.116 Generic Network Slice Template v5.0,» 2021. [Online]. Available: https://www.gsma.com/newsroom/resources/ng-116-generic-network-slice-template-v5-0/.
14. B. McMahan, E. Moore, D. Ramage, S. Hampson et B. A. y. Arcas, «Communication-Efficient Learning of Deep Networks from Decentralized Data,» Proceedings of the 20th International Conference on Artificial Intelligence and Statistics, 2017.
15. S. N. e. al., «Federated learning for wireless communications: Motivation, opportunities and challenges,» IEEE Communications Magazine, vol. 58, no. 6, pp. 46-51, 2020.
16. T. N. e. al, «Client selection for federated learning with heterogeneous resources in mobile edge,» chez IEEE ICC, 2019.
17. D. Y. e. al, «Federated Learning in Vehicular Edge Computing: A Selective Model Aggregation Approach,» IEEE Access, 2020.
18. M. Abadi, P. Barham, J. Chen, Z. Chen, A. Davis, J. Dean, M. Devin, S. Ghemawat, G. Irving, M. Isard, M. Kudlur, J. Levenberg, R. Monga, S. Moore, D. G. Murray, B. Steiner et e. al., «TensorFlow: A System for Large-Scale Machine Learning,» chez 12th USENIX Symposium on Operating Systems Design and Implementation (OSDI 16), 2016.

19. S. Caldas, S. M. K. Duddu, P. Wu, T. Li, J. Konečný, H. B. McMahan, V. Smith et A. Talwalkar, «LEAF: A Benchmark for Federated Settings,» chez Workshop on Federated Learning for Data Privacy and Confidentiality, 2019.
20. F. Lai, Y. Dai, X. Zhu, H. V. Madhyastha et M. Chowdhury, «FedScale: Benchmarking model and system performance of federated learning,» chez Proceedings of the First Workshop on Systems Challenges in Reliable and Secure Federated Learning, 2021.
21. S. Reddi, Z. Charles, M. Zaheer, Z. Garrett, K. Rush, J. Konečný, S. Kumar et H. B. McMahan, «Adaptive Federated Optimization,» chez International Conference on Learning Representations, 2021.
22. T. Li, A. K. Sahu, M. Zaheer, M. Sanjabi, A. Talwalkar et V. Smith, «Federated Optimization in Heterogeneous Networks,» chez Proceedings of Machine Learning and Systems, 2020.
23. D. J. Beutel, T. Topal, A. Mathur, X. Qiu, T. Parcollet et N. D. Lane, «Flower: A Friendly Federated Learning Research Framework,» arxiv, 2020.
24. E. Bisong, Kubeflow and Kubeflow Pipelines, Berkeley, CA: Apress, 2019.
25. Pelzl, J., Wolf, M., & Wollinger, T. (2008). Virtualization technologies for cars: Solutions to increase safety and security of vehicular ECUs. Automot. Saf. Secur, 2008, 164-173.
26. Zhu, M., Cao, J., Cai, Z., He, Z., & Xu, M. (2016). Providing flexible services for heterogeneous vehicles: An NFV-based approach. IEEE network, 30(3), 64-71.
27. Morabito, R., Petrolo, R., Loscrì, V., Mitton, N., Ruggeri, G., & Molinaro, A. (2017, May). Lightweight virtualization as enabling technology for future smart cars. In 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM) (pp. 1238-1245). IEEE.
28. Santa, J., Fernández, P. J., Ortiz, J., Sanchez-Iborra, R., & Skarmeta, A. F. (2019). SURROGATES: Virtual OBUs to foster 5G vehicular services. Electronics, 8(2), 117.
29. Muhammad, A., Saqib, M., & Song, W. C. (2021, May). Sensor Virtualization and Data Orchestration in Internet of Vehicles (IoV). In 2021 IFIP/IEEE International Symposium on Integrated Network Management (IM) (pp. 998-1003). IEEE.
30. Campolo, C., Iera, A., Molinaro, A., & Ruggeri, G. (2019, April). MEC support for 5G-V2X use cases through docker containers. In 2019 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 1-6). IEEE.
31. Silva, A. P., Tranoris, C., Denazis, S., Sargento, S., Pereira, J., Luís, M., ... & Simeonidou, D. (2019). 5GinFIRE: An end-to-end open5G vertical network function ecosystem. Ad Hoc Networks, 93, 101895.
32. ETSI GS NFV, ETSI GS NFV SOL007 Protocols and Data Models; Network Service Descriptor File Structure Specification; v3.5.1, 2021.
33. P. , Z. A. , F. E. , X. Gouvas, "Separation of concerns among application and network services orchestration in a 5G ecosystem.," 2018.
34. R. Dua, A. R. Raja, and D. Kakadia, "Virtualization vs Containerization to Support PaaS," in 2014 IEEE International Conference on Cloud Engineering, Mar. 2014, pp. 610–614. doi: 10.1109/IC2E.2014.41.
35. ETSI GS MEC, ETSI GS MEC 013 Multi-access Edge Computing (MEC); Location API; V2.2.1 (2022-01).
36. 5G-IANA "D5.1 – Initial validation KPIs and metrics", 5G-IANA, 2022.

ANNEXES

Annex 1 – 5G-IANA AOEP Detailed System Design

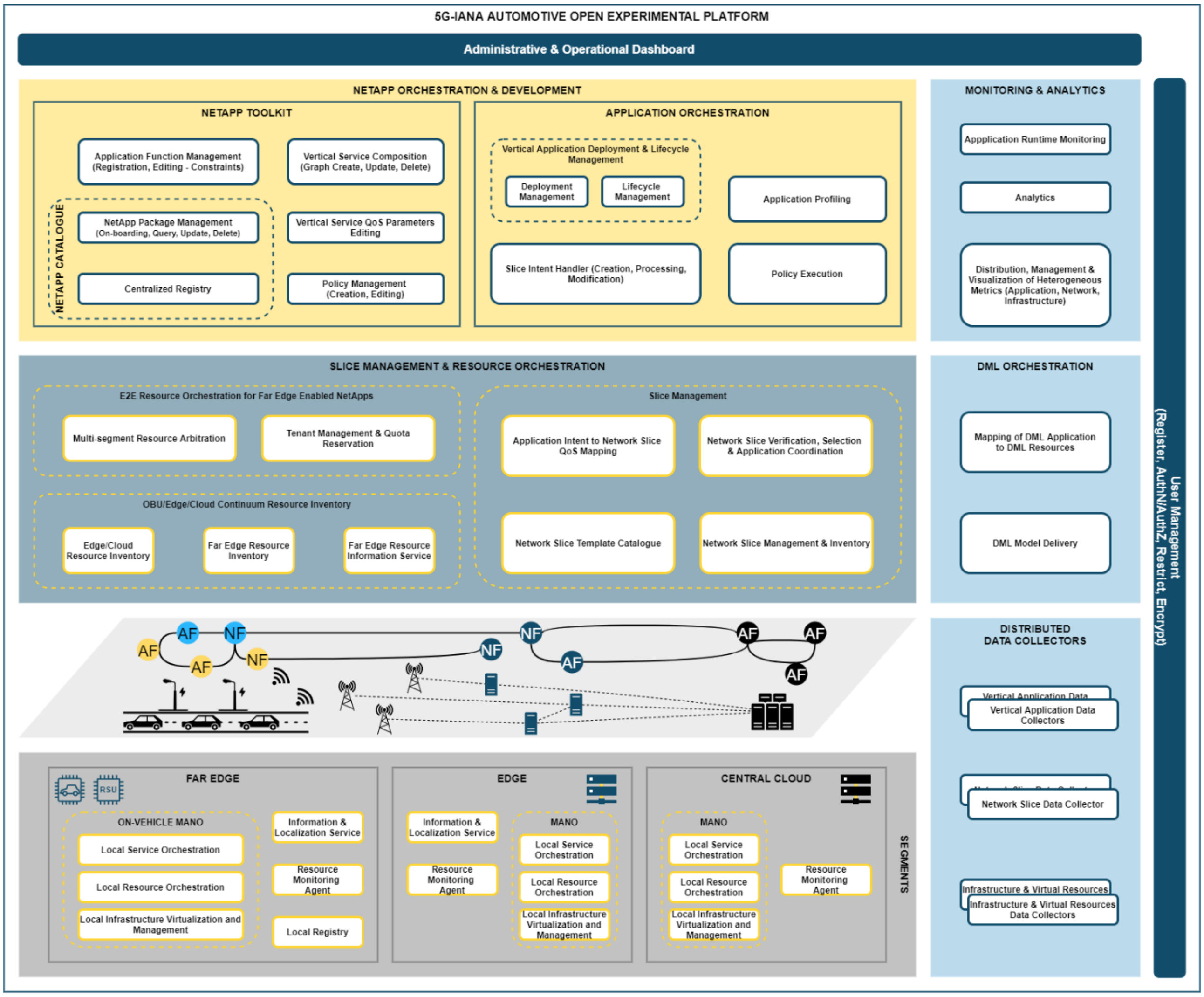

Figure 21: 5G-IANA AOEP Detailed System Design