ENHANCEMENT OF AUTOMOTIVE USE CASES WITH 5G AND BEYOND

Deliverable D4.3

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6GSNS

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Deliverable

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SHORT ABSTRACT	This document explains the enhancement which is performed in the IDIADA network to improve network performance. The enhancement includes integrating MEC into IDIADA network, offering dynamic service orchestration and validate it with three use cases, and integrating network exposure API and accurate positioning tool.
KEY WORDS	Automotive, 5G, MEC, extreme edge, dynamic service orchestrator, localization, network exposure APIs, network KPIs
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Executive Summary

The objective of TARGET-X project is to accelerate the digitalization of four verticals (i.e., energy, construction, automotive, and manufacturing) by deploying large-scale trials testbeds. Work package 4 focuses on the automotive vertical and how the 5G network will enhance the experience in such vertical. In this context, this deliverable first reviews the 5G network deployment in IDIADA, the automotive trial site of the Target-X project, and introduces new features enhancing network functionalities to support the complex requirements of the automotive use cases.

Specifically, four features/functions deployed and integrated into initial IDIADA network. The first enhancement comprises providing edge processing by integrating a Mobile Edge Computing (MEC) server into IDIADA network. This integration helped in providing virtual environments to host applications' servers with low and controllable latency, which is critical KPI in automotive sector. A user-friendly user interface is also developed to facilitate the process of creating new virtual environment for non-expert people. The second enhancement includes the integration of a dynamic service orchestration that is able to dynamic offloading strategies for services across the compute continuum depending on network conditions and using networks and services metrics. As vehicles are constantly moving and experiences different network connection qualities, this feature becomes essential in automotive sector to find a proper trade-off between offloading computational processes to edge/cloud or keep them in vehicles if network connection into edge/cloud become unreliable. The third enhancement is the integration of a network exposure Application Programming Interface (API). Offering such API helps to provide an environment where third party applications and services can share information with mobile network to enhance its quality of experience. The fourth enhancement is introducing accurate positioning tool that improves vehicle location accuracy into the scale of decimetre.

Finally, an extensive network performance campaign was performed in IDIADA to assess network performance and evaluate the proposed enhancements for edge processing. As expected, the results show lower and more controllable latency when using the MEC.

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List of Acronyms and Abbreviations

3GPP	Third Generation Partnership Project
AEF	Action Enforcement Function
AMF	Access and Mobility Management Function
API	Application Programming Interface
API	Application programming interface
APN	Access Point Names
BSC	Base Station Controller
BW	Bandwidth
CA	Carrier Aggregation
CDF	cumulative distribution function
CN	Core Network
CPE	Customer Premise Equipment
DL	Down link
DMF	Decision Making Function
DSO	Dynamic Service Orchestrator
EPC	Evolved Packet Core
FSTP	Financial Support for Third Parties
GMLC	Gateway Mobile Location Centre
gNB	Next Generation Node B
GNSS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GUI	Graphical User Interface
HO	Handover
HWAC	Hardware Activation Codes
IaaS	Infrastructure as a Service
KPI	Key Performance Indicators
MBB	mobile broadband
MEC	Mobile Edge Computing
MEF	Metrics Exposure Function
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity

MOCN	Multi - Operator Core Network
MPN	Mobile Private Network
NEF	Network Exposure Function
NSA	Non Stand Alone
NWDAF	Network Data Analytics Function
OAM	Operation and Management
OMA	Open Mobile Alliance
PF	Prediction Function
QoD	Quality on Demand
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RNC	Radio Network Controller
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTK	Real-Time Kinematic
RTT	Round Trip Time
SA	Stand Alone
SDN	Software Defined Network
SINR	Signal-to-Interference-Plus-Noise
SNR	Signal to Noise Ratio
TAC	Track Area Code
TAC	Tracking Area Code
ToD	Tele-operated Driving
UE	User Equipment
UL	Uplink
UPF	User Plane Function
VLAN	Virtual Local Area Network
VM	Virtual Machine
WP	Work Package

1 Introduction

The TARGET-X project envisions accelerating the digital transformation of key verticals such as energy, construction, automotive, and manufacturing using large-scale trials in multiple testbeds. By demonstrating, validating, and evaluating the potential of 5G/6G in real environments, technologies such as real-time communication, localization, self-description, digital twinning, and sensor-network data fusion can be tested and evaluated. Work Package (WP) 4 of this project has the role of fulfil TARGET-X objectives in the automative sector. IDIADA connected vehicle Hub - CVH is the automative trial site that hosts use case development and deployment in WP4. Two prior deliverables in this WP described the initial network infrastructure in IDIADA network [1], and introduced use cases which are being developed and tested in the structure of TARGET-X project [2]. Three use cases were designed and deployed: Cooperative perception, digital twins, and predictive Quality of Service (QoS) for Tele-operated Driving (ToD). In the cooperative perception use case, the exchange of sensor information between vehicles and infrastructure, and among vehicles enable vehicles to increase their perception of the environment by enabling. The digital twin use case is used to evaluate the performance of cooperative perception techniques using simulation before performing costly real-life tests. In the predictive QoS for ToD, the remote driver will be notified about upcoming network performance degradation ahead of time providing remote drivers with a sufficient window of time to take the necessary actions that mitigate the impact of these changes.

This document, i.e. Deliverable D4.3, reports the efforts undertaken in task 4.3 of WP4 to enhance network connectivity, and therefore the performance of use cases. Such enhancements are performed through improving network connectivity quality, improving relevant metrics accuracy like position, facilitating the usage of deployed network by offering exposure APIs or GUI, and develop required tools. To fulfil this objective, the network infrastructure as described in Deliverable D4.1 [1] and the use cases introduced in D4.2 [2] were carefully reviewed to integrate new features to the existing 5G network.

The initial enhancement was the integration of a Mobile Edge Computing (MEC) server to reduce and control latency, a critical metric in the proposed use cases. The server has been integrated into IDIADA network and the process for creating Virtual Machines (VMs) has been automated and is elucidated in Section 3.1. By emerging new use cases in automotive sector that employ cellular networks for communication, running services in the MEC also offers high computation power, improved privacy and security and scalability.

The second feature is the integration of a simple dynamic orchestrator that can decide on moving applications/services from extreme edge (vehicle) to far edge (MEC) and perform the necessary actions to deploy them on the right platform. In the automotive sector, the connectivity quality is not reliable and uniform during the lifetime of applications and services, since the User Equipment (UE) is normally moving across the network coverage. Hence, the performance of the applications/services might degrade once the network connectivity is weak. Therefore, dynamic offloading use cases' services across the compute continuum (extreme Edge or UE to MEC or cloud) becomes necessary to maintain the required performance. Given the availability of various environments for service/application computation (i.e., field device, MEC, and cloud in proposed use cases), it is more efficient to dynamically switch the environment based on available resources and connectivity quality. Section 3.2 details the endeavours to dynamically orchestrate service and applications to optimize user satisfaction.

The third feature that was deployed in IDIADA testbed is the network exposure Application Programming Interface (API) in the context of teleoperated vehicle. Teleoperated vehicle is an automated vehicle which is supervised by remote driver and relies on the reliable network connection. Such a feature enables the network to expose some information about the status of the cells where the tele-operated vehicle is and will be moving. In this way, different types of warning will be sent to the remote driving centre to notify the remote driver about network performance degradation. This topic is covered in section 3.3.

An additional enhancement explored in this document is the improvement of localization accuracy that is required and essential for autonomous and Tele-operated Driving (ToD). This topic is illustrated in section 3.4.

Furthermore, a tool has been developed within the framework of this task to continuously monitor connectivity key performance indicators (KPIs) from the UE point of view. This tool, akin to a watchdog system, is invaluable for monitoring, troubleshooting, identifying root issues, and serving as a dataset generator for AI models. In addition, it will be used to trigger the dynamic orchestration explained in Section 3.2. This tool in addition to Qualcomm tool were used to evaluate the MEC footprints and provide a comparison of network performance when the application server resides either in the deployed MEC or cloud (8.8.8.8).

1.1 Relation to other activities

In addition to the primary focus of task 4.3 efforts, this document also details close collaboration between WP4 and both WP3 and the Financial Support for Third Parties (FSTP) project Impact-xG that joined the Target-X project through open calls. This collaboration is related to the service orchestration detailed in Section 3.2.

1.2 Document overview

Section 2 of this document provides a background of the infrastructure and highlights the motivations to consider enhancements in the infrastructure and deployment. Section 3 explores the enhancement features including the network and MEC orchestrator, the dynamic service orchestrator, the network exposure API, and the improved localization features. Section 4 evaluates how much the MEC processing can improve the network KPIs and therefore enhance use case experiences. Section 5 concludes the document.

2 Trial site 5G network: A deployment review

This section provides a background of 5G network deployment in IDIADA which is employed for the efforts in WP4 and are reported in deliverables D4.1 [1], and D4.2 [2]. Section 2.1 describes the current deployment in the IDIADA network, and section 2.2 highlights the enhancements that are proposed for the deployment in the structure of task 4.3.

2.1 Current deployment description

While traditional automotive test tracks are sufficient for standard vehicles, cooperative, connected, and automated vehicles demand new testing environments that can offer configurable and controlled networks, encompassing both physical and digital infrastructures to safely replicate test scenarios. Achieving specific challenging conditions often requires extensive travel, which can be resource-intensive, and in some regions, regulations prohibit certain tests on public roads. Additionally, commercial cellular networks lack the controlled conditions necessary for this type of testing, as their performance can vary based on user demand and operational factors.

To ensure reliable test results, it is essential to control network parameters like transmit power of gNB, active/inactive status of the gNB, toggle the aggregation mode, etc, and recreate specific scenarios. Moreover, commercial networks may not easily adopt the latest features needed for efficient and secure applications, as their implementation depends on the interests of mobile network operators. Furthermore, keeping sensitive data within a private network can also help address privacy concerns.

IDIADA offers a private network solution that encompasses a comprehensive 2G/3G/4G/5G network at its central facilities in Santa Oliva, Tarragona, all adhering to 3GPP standards. Due to regulatory restrictions, the radio frequency spectrum is reserved for telecommunications operators, leading to a Multi - Operator Core Network (MOCN) configuration, aligning IDIADA’s private network with Orange's commercial network.

The technical solution is a commercial-grade 3GPP network provided by Ericsson, owned and operated by Orange and IDIADA, as illustrated in Figure 1.

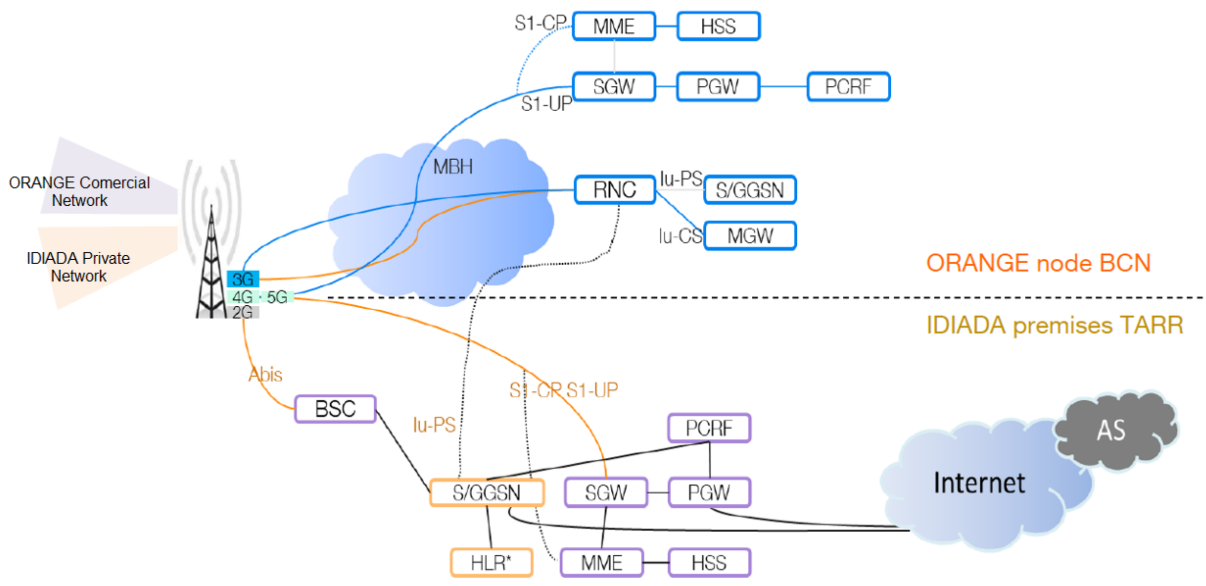


Figure 1: IDIADA's private network solution general outline.

The solution implemented at IDIADA's facilities features its own Core Network (CN) for 2G, 4G, and 5G, along with a shared CN for 3G. This network is dedicated solely to data transmission and does not support voice services.

The transport network connects base stations to the Base Base Station Controller (BSC), Radio Network Controller (RNC), and Evolved Packet Core (EPC) using IP over fibre optic links, which ensures high reliability, fast performance, and low latency. External application servers can connect directly to the internal network or via broadband, depending on the testing requirements.

The UEs connect through the Radio Access Network (RAN) via the air interface by employing various radio technologies. IDIADA's network comprises four base stations that support 2G, 3G, 4G, and 5G-NSA radio access technologies configured with the latest software and network features. The collaboration with Orange Spain allows IDIADA to use all common frequency bands, enabling the creation of specific network scenarios with adjustable coverage across these technologies and frequency bands. This partnership permits the use of commercial frequency bands for all radio access technologies.

Further details about the RAN components can be seen in Figure 2.

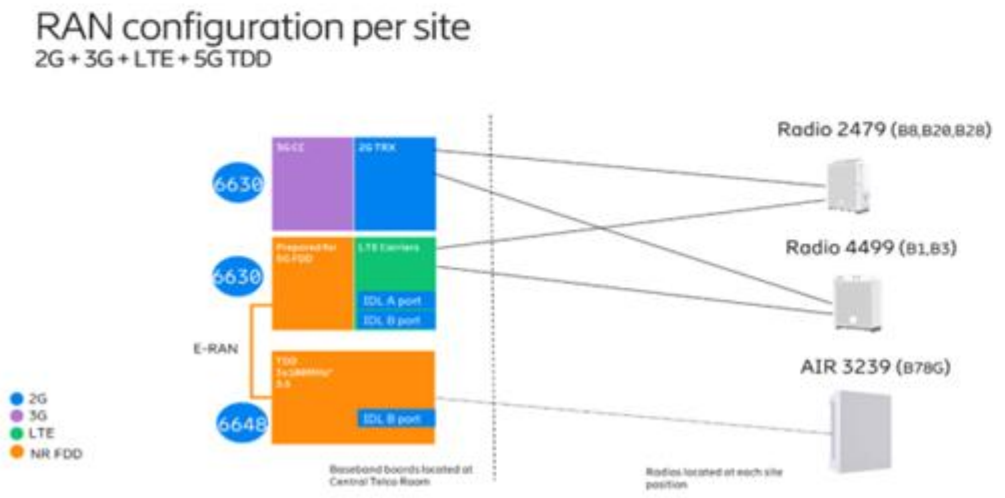


Figure 2: RAN Configuration.

IDIADA's private network radio solution is based on the same hardware and software elements as commercial networks. There are no specific nodes, Hardware Activation Codes (HWAC), or software tailored for a private network solution.

The network's bands and capacities are as follows:

- 2G: 1 TRX per sector. Band 1800 MHz (B3)
- 3G: 1 UMTS Carrier. Band 900 MHz (B8). Bandwidth (BW) 5MHz
- 4G: 1 LTE Carrier. Band 1800 MHz (B3). BW 20 MHz
  1 LTE Carrier. Band 2100 MHz (B1). BW 10 MHz
- 5G: 1 NR Carrier. Band 3500 MHz (N78). BW 60 MHz

The network is distributed across 4 nodes strategically positioned to cover the entire installation with maximum performance capabilities. Figure 3 illustrates the location of the 4 nodes with their 9 sectors and the coverage distribution they provide.

Figure 3: Cellular network coverage map.

IDIADA has its own SIM cards divided into different Access Point Names (APNs). Each APN is configured with specific routing conditions so that the APNs used internally by IDIADA can connect to IDIADA's own servers, while those used by clients do not have this capability. Each APN allows all

SIM cards within it to have visibility among themselves but not to see other APNs. This setup enables multiple clients on tracks to have direct visibility between their devices without interfering in tests with other clients. Additionally, all APNs have SIM cards with different QoS to conduct tests under different conditions.

The services offered over the network are varied and aim at enabling clients to also test under degraded network conditions:

- Handovers between different technologies.
- Emulation of low coverage areas by reducing power in the nodes.
- Disabling Carrier Aggregation (CA) and Multiple Input Multiple Output (MIMO) for testing under adverse network performance conditions.
- Adding fixed latencies to services.
- Stressing the network either by increasing the number of connected equipment and/or their bandwidth, or by reducing the bandwidth in 4G and 5G if the first option is not possible.

The services offered with the IDIADA cellular network include the possibility of configuring 4G+5G CA using only the two 4G carriers or disabling it completely to only have traffic with a single carrier. In addition, the MIMO configuration can be modified from the standard 4x4 to a 4x2 or 2x2 configuration. Modifying network characteristics enables a testing user to evaluate the performance of its systems in non-optimal situations. In parallel, power reductions can be applied to all radio technologies (together or separately) to emulate adverse coverage level conditions.

If a testing user wants to evaluate the performance of its systems and services when moving from one technology to another, Handover (HO) can be forced between the different Radio Access Technologies (RATs), so that it can move, for example, from being in a cell with 5G coverage to another with 4G. In this way, the user has the possibility to test mobility by making HO between cells of different technologies.

IDIADA network can be adapted to recreate different scenarios in which users can test their systems and services in a private and confidential environment, emulating features and issues of a public network.

2.2 Enhancement of the network deployment

The IDIADA 5G private network provides the essential features to test the use cases of the automotive vertical in TARGET-X and the open call projects. However, some additional features were identified to provide advanced services:

- The integration of a MEC in IDIADA network. The MEC allows the deployment of services as close as possible to the core network, leading to lower and more stable latency that is required by some of the use cases. The description of the deployed architecture can be found in Deliverable D4.1 [1] and section 3.1 of this document.
- Integration of a dynamic network orchestration that enables the provision and reservation of network resources for a given service in an automated way, which will lead to better use of the network resources and enhanced service performance. The network orchestrator was only deployed in Neutroon lab due to hardware limitations in IDIADA network (i.e, dynamic radio configuration is not allowed as it might affect public network) and is described in Section 3.1.

- Integration of a dynamic service orchestrator to enable the deployment of computation services either on the far edge (MEC) or the extreme edge (end user device in the vehicle). This is needed to evaluate the possibility of offloading some of the use cases' applications to the far edge, when network conditions allow it, to reduce energy consumption in the end users' devices that are connected to vehicle batteries or their own batteries. In addition, this will reduce the computational latency due to the higher computational power of the far edge. The dynamic service orchestrator will enable an automatized offloading of the applications to the far edge when the network conditions allow it and re-deployment these applications in the extreme edge when the network conditions are bad without loss of service continuity. The proposed service orchestrator and its implementation are described in Section 3.2.
- The integration of a network exposure API connected to the Operation and Management (OAM) dashboard of IDIADA and to an MQTT broker emulating the presence of a Network Data Analytics Function (NWDAF). This API will enable interaction between the network and the ToD application to warn the latter of bad network conditions before they occur. The deployment in TARGET-X shows that such solution (normally available in 5G SA network) can be also deployed through integrated APIs. Further details of the implementation and experimental results are described in Section 3.3.
- The use of 3GPP Global Navigation Satellite System (GNSS) Real-Time Kinematic (RTK) to enhance the accuracy of GNSS systems like GPS, GLONASS, Galileo, and BeiDou. 3GPP-GNSS-RTK can provide the decimeter-level accuracy that is required by some of the use cases such as ToD. Further details of the implementation and experimental results are described in Section 3.4.

3 New features to improve use case experiences

Based on the first round of network experiences in IDAIDA testbed, which are reported in deliverables D4.1 and D4.2 [1] [2], and considering WP4 use cases requirements, deliverable 4.3 aims to offer features that help improving the performance of the use cases.

The proposed use cases in WP4 (both the main use cases initially introduced in the TARGET-X project proposal and the use cases deployed through open calls) require low latency. More importantly, these use cases and automotive use cases in general require a *controlled* end-to-end path between the connected vehicles and the application servers so that all the communication are under control. Therefore, providing MEC processing close to the 5G network became essential. Hence, the first improvement had been adding a MEC server into the network. Section 3.1 of this document explains the integration of a MEC into a 5G network. An initial version of the integration, which includes an orchestrator to facilitate and simplify the process of deploying virtual environment in MEC (VMs in this case), is deployed in IDIDADA testbed. In this instance, a user-friendly Graphical User Interface (GUI) is integrated. The GUI abstracts the computing platform configuration for non-expert people. As a result, the end user can simply define the requirements of the desired virtual environment, and the orchestrator takes care of all low-level actions like creating the virtual environment (i.e. VM in this case), assigning required computational resources and network configurations (e.g., IP addresses), etc. This deployment is introduced and explained in section 3.1.1.

An enhanced version of the MEC orchestrator that is introduced in 3.1.1 is also introduced in section 3.1.2. This extended version does not only provision the virtual environment but also orchestrate the 5G network elements by assigning required network resources to the new orchestrated VM. This enhanced version is developed and deployed in Neutroon lab only where a 5G SA network is deployed.

The second improvement, which is addressed in task 4.3, is a dynamic service orchestrator that can dynamically move some functions of the service from extreme edge (connected vehicle) to far edge (MEC) and vice versa to guarantee required user expectation and/or service requirement based on several parameters such as computing power, energy consumption, and network conditions. The dynamic service orchestrator functionality is explained in section 3.2.

The third improvement is related to the integration of a network exposure API that exposes network information in form of warning to the application, in particular for the Human Machine Interface (HMI) of the remote driver in the predictive Quality of Service (QoS) for ToD. The architecture and the functional testing of this API are provided in Section 3.3.

The fourth improvement is the introduction of the standardized solution by 3GPP using GNSS- Real-Time Kinematic (RTK) localization, which is described in Section 3.4.

3.1 Network orchestrator: 5G integrated MEC orchestration and automation

The network orchestrator is a software platform to initially configure the network and the MEC server, automate the process, optimize the deployment, and stay available for further optimization and adaptation [3] [4] [5]. It plays a critical role in ensuring seamless communication, resource allocation, and service delivery across complex 5G and MEC environments. A network orchestrator may provide one or more of the functions below [6] [7]:

- Automation: Automating tasks such as provisioning, configuration, and scaling of network resources based on the requirement or on user request.
- Service life cycle management: manage the service and application life cycle from deployment, management, monitoring and decommissioning.
- Resource allocation: dynamically allocate and optimize resources. If the orchestrator is a network orchestrator, the considered resources might be network resource blocks, bandwidth, slice, etc. If the orchestrator is a cloud environment orchestrator, resources refer to compute resource, storage, etc.
- Coordination: coordination between different functions, especially for virtualized network functions (VNFs), physical devices and MEC/cloud resources.
- Policy enforcement: ensures that network operations comply with predefined policies, such as security rules, quality of service (QoS), and compliance requirements.
- Monitoring and Analytics: Continuously monitors network performance and uses analytics to identify bottlenecks, predict failures, and optimize operations.

Task 4.3 considered developing a 5G network-wide orchestrator. From one side, it orchestrates the virtual environments in the MEC to host desired services and applications of TARGET-X project, referred hereinafter as Virtual Machine (VM) orchestrator. Furthermore, it orchestrates the 5G network equipment, which includes necessary configurations in Core and RAN functions, and map them to specific virtual environments, referred hereinafter as advanced network orchestrator. It provides dedicated network resources for data flow of specific services and applications. The first part, i.e. the VM orchestrator, is deployed in IDIADA network, whereas the complete network-wide orchestrator is deployed in Neutron's lab.

Figure 4 depicts a general architecture of the network-wide orchestrator for Mobile Private Network (MPN). Through a single GUI, this orchestrator addresses configuring, managing, and monitoring all elements in the 5G network including the RAN, the Core, and the MEC environment.

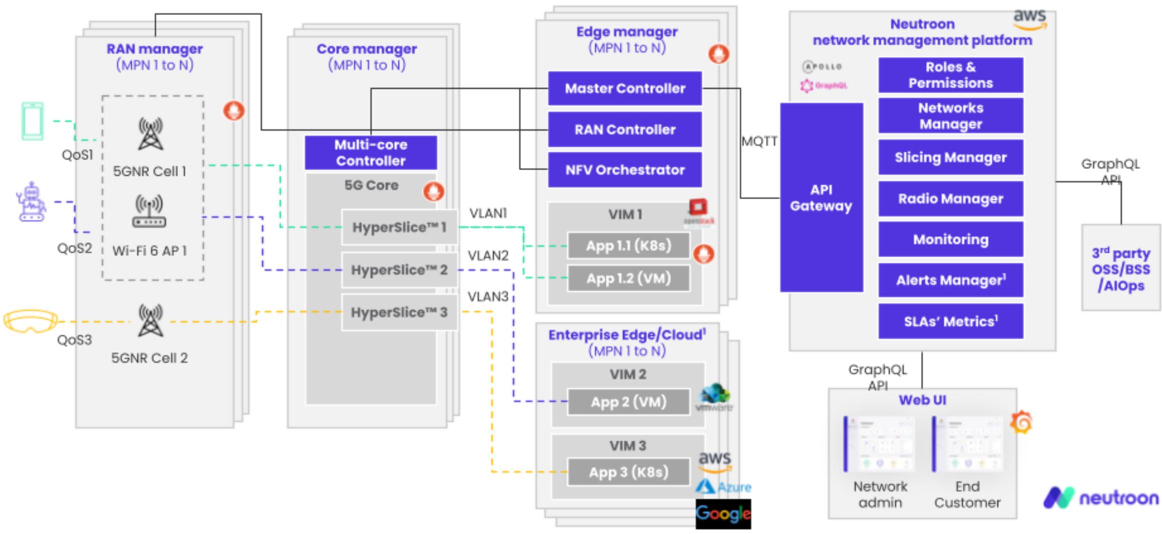


Figure 4: General architecture of the network-wide orchestrator.

The network-wide orchestrator is composed of 5 blocks: The Neutroon network management platform, the Web User Interface (UI), the edge manager, the core manager, and the RAN manager. The Neutroon network management platform is the placed in the cloud and host the orchestrator for the whole network. The communication to management platform either goes through GUI, or by using API calls. Thanks to the embedded GUI, a non-expert user can easily monitor, manage, and configure the whole network. Once an orchestration action is requested by the network management platform, a message will be sent to Neutroon agent which is running in the edge server. Then the local agent sends individual message to edge, core and RAN manager. Each agent is responsible of executing the received command downward its own management environment (i.e. MEC, core and RAN respectively). The main role of agents is adapting the received command to network element instances that are running in the network. For example, there are various 5G core brands with different configuration options. Therefore, the agent in the core manager is designed to be intelligent enough to identify the core brand and adapt received command from orchestrator to corresponding actions for that core. This scenario is the same for agents in edge and RAN manager boxes.

As it is mentioned, the user request might be deploying any kind of virtual environment, orchestrating network element, monitoring activities of network elements, etc. Based on the request of the user in the platform, various functions in edge manager, core manager and RAN manager boxes might be run to address the user request. If the request is to only deploy an instance of virtual environment like VM, K8s, etc, (the topic of section 3.1.1), the request is only sent to the edge manager. The latter will run relevant functions to automatically deployed desired virtual environment and assign relevant computational and network resources. If the request targets various elements not only in the edge but also functions in the Core and RAN (the topic of section 3.1.2), the relevant commands are sent simultaneously to edge, Core, and RAN manager where corresponding agents enforce desired configurations. All features for the end user are developed to be accessible either through GUI, or by exposing APIs. By using exposing APIs, the orchestrator will be able to respond to triggers generated by network functions, end-user applications, or third-party services.

3.1.1 VM orchestrator

Figure 5 shows the Dell EMC power-edge R450 [8] [9] that was provided to host the MEC server incorporating the different use cases' applications and services. The server offers 32 CPU cores and 64 GB of RAM. It hosts Ubuntu 22.04 server as the operating system.

The server offers a virtual environment for not only running TARGET-X main use cases, but also to host services and applications of the two open call projects. During two rounds of open calls, six projects in WP4 required MEC processing to host their application and services and benefited from the integrated MEC server.

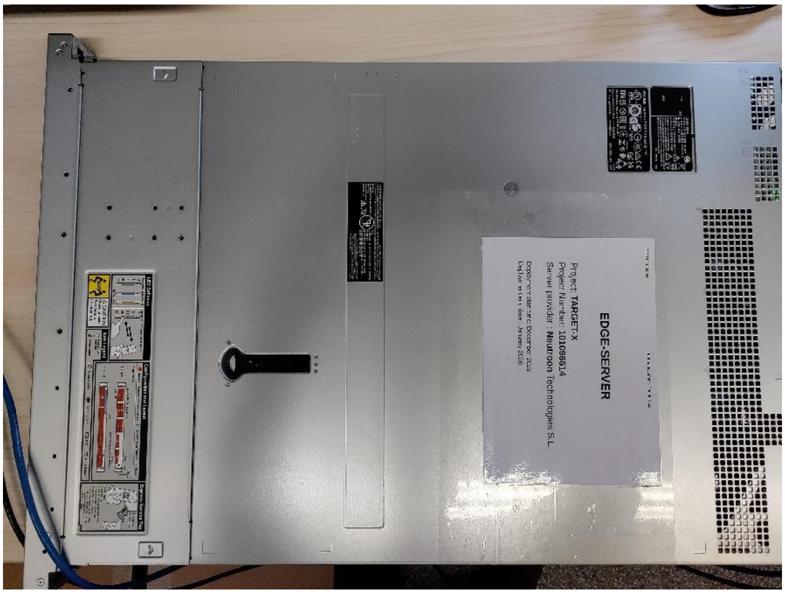


Figure 5: The MEC server integrated into IDIADA network.

The process of the VM deployment starts with a request from user including desired virtual environment type (i.e. virtual machine, container, etc.), required computational resources, and the network that the VM belongs to. The orchestrator automatically creates the VM, dedicates requested computational resources, and assigns network dependencies (e.g. IP, Gateway, DNS, Virtual Local Area Networks - VLAN, etc).

The MEC solution which has been deployed in IDIADA and integrated by Neutroon is based on OpenStack [10]. OpenStack, an open-source cloud computing platform, offers Infrastructure as a Service (IaaS) for deploying and managing scalable cloud environments. Its modular architecture includes several key components:

- **Nova**: The primary compute service, managing virtual machine (VM) and bare-metal server lifecycles, and providing APIs for instance creation, management, and scaling.
- **Neutron**: The networking service that handles virtualized networking, supporting features such as VLANs, VXLANs, and SDN integration, and providing advanced features like security groups, floating IPs, and load balancing.
- **Cinder**: The persistent block storage service for VMs and containers, ideal for applications requiring reliable storage.
- **Glance**: The service that manages virtual machine disk images, simplifying workload deployment.
- **Keystone**: The identity service ensuring secure authentication and authorization.
- **Heat**: The orchestration service using YAML templates to automate resource provisioning and management.
- **Horizon**: A web-based dashboard for user interaction and resource management.

OpenStack supports various application hosting models, including VMs (managed by Nova) and container orchestration (through integrations like Kubernetes and OpenStack Magnum), making it a versatile solution for organizations seeking scalable and future-ready cloud infrastructure. Figure 6 depicts the block diagram and relation between OpenStack services.

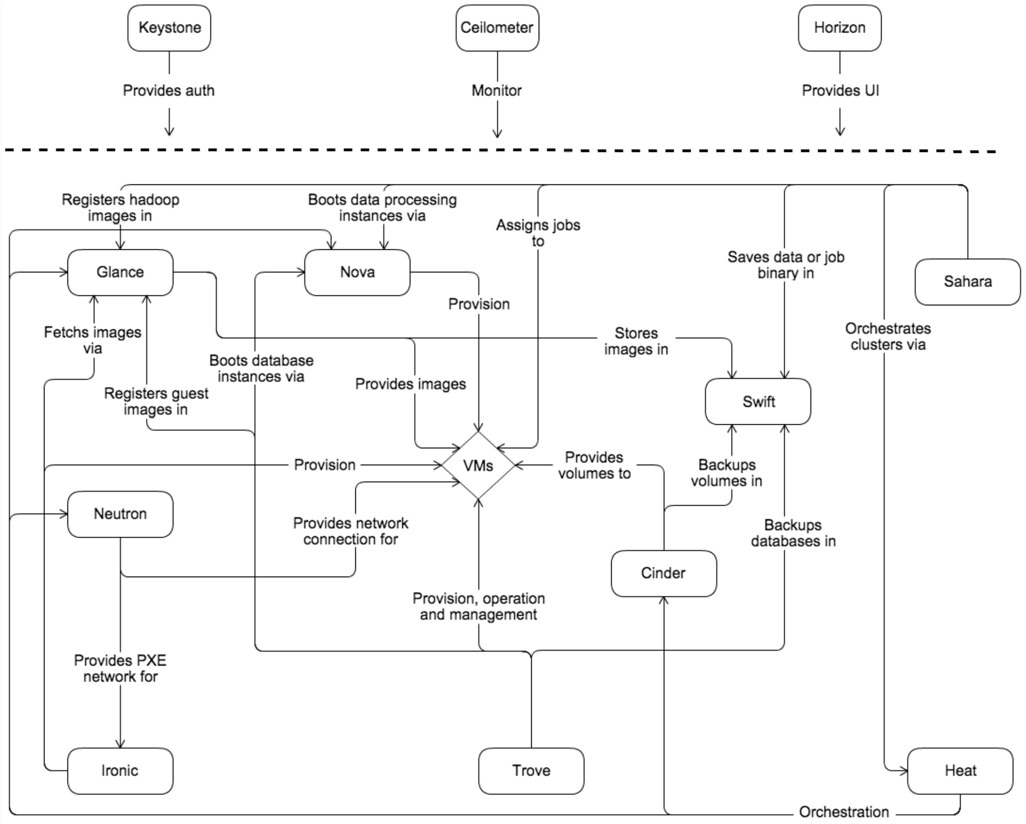


Figure 6: Block diagram and relationships among the OpenStack services [11].

The whole process of creating the VM is automated through a user-friendly GUI. Figure 7 shows the automated steps that abstracts the process of VM creation. Once the process is done through the steps depicted in Figure 7, the desired VM becomes accessible, and it appears as an active VM in the Neutroon's edge orchestrator dashboard. Figure 8 shows a screenshot of this dashboard.

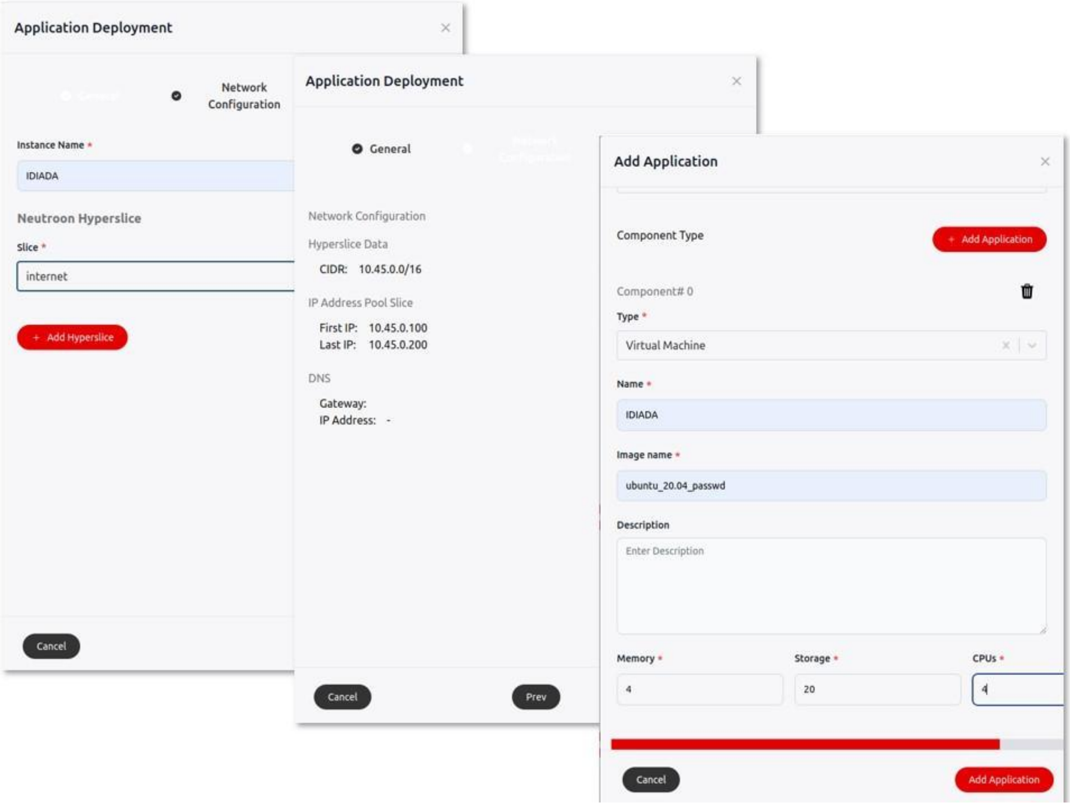


Figure 7: Automated steps to orchestrate a VM on the MEC server.

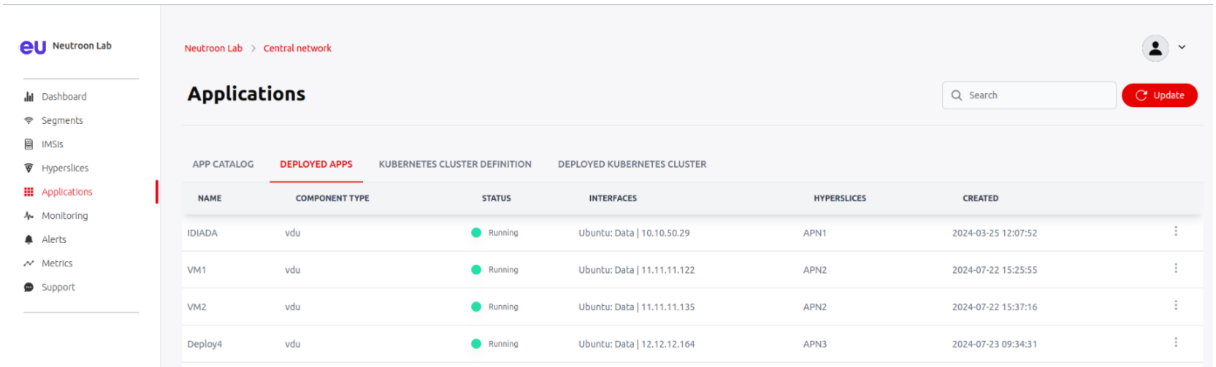


Figure 8: Neutroon's automated edge orchestrator dashboard.

3.1.2 Advanced network orchestrator

An advanced version of the network orchestrator is developed in Neutroon lab. It is an advanced version of the MEC orchestrator, which is introduced in section 3.1.1. It does not only orchestrate virtual environments and assign corresponding network setting but also includes orchestrating the 5G network functions where the user also can define and assign network QoS for specific VM as well. It means that this deployment can offer end-to-end traffic segregation from groups of various UEs toward different VMs.

In the advanced network orchestrator, all manager boxes that are introduced in the Figure 4 are developed and deployed. In this case, the orchestrator placed in the network manager platform sends individual messages to edge manager, core manager, and RAN manager. Each manager box has its own agent to perform the actions requested by the orchestrator. The agent in the core manager adapts the received command to the relevant core instance running in the network and manipulates core functions accordingly. Same action is performed by the agent in the RAN manager box that enforces the required configurations into the RAN functions. These agents are also responsible to send metrics across the network to the network management platform to feed monitoring systems.

In the advanced network orchestrator, all elements from RAN toward the MEC server can be configured by the orchestrator to satisfy the requested requirements. Hence, end-to-end data flow from the UE, which consumes applications running in the MEC, toward the VM in the MEC benefits from guaranteed QoS. To guarantee the required QoS for specific groups of UEs, the orchestrator offers segregating data flows through dedicated Data Network Names (DNN) where it can assign proper slicing and 5QI to that DNN. Until this step, data flow arrives to UPF while it is segregated with respected to desired priority. The next step is to pass the received segregated data flow to the target VM in the MEC.

In this framework, the OpenStack edge orchestrator employs a virtualization strategy to segregate traffic from diverse UE groups targeting different network slicing. This is achieved by utilizing specific VMs within the OpenStack, each belonging to a distinct VLAN, ensuring traffic separation at the edge. However, this L2 approach at the edge contrasts with the L3 approach employed by the 5G network. Integrating these distinct methodologies (i.e. L2 and L3) necessitates adapting the edge's L2 methods to align with the 5G network's L3 approaches in both the core and RAN. To overcome this challenge and maintain segregated traffic from UEs, distinct DNNs should be utilized, followed by packet forwarding or routing within the core User Plane Function (UPF). This ensures that packets are relayed to the appropriate VLAN interface. Consequently, the RAN and the UPF of the Core, both situated on either side of the N3 interface, should ideally reside within the same VLAN. In scenarios with multiple VLAN configurations, the pertinent interfaces to RAN and UPF should be designated as "Trunk", with all VLANs incorporated as a property. The VLAN tag list should correspond with the VLAN numbers assigned to the VMs at the MEC.

Figure 9 provides a visual representation of the end-to-end data flow segregation architecture, spanning from the UE to the VM at the MEC. This architecture is designed to guarantee security and QoS satisfaction. The red rectangle within the gNB is the RAN interface toward the core, which are adapted to accommodate various VLANs.

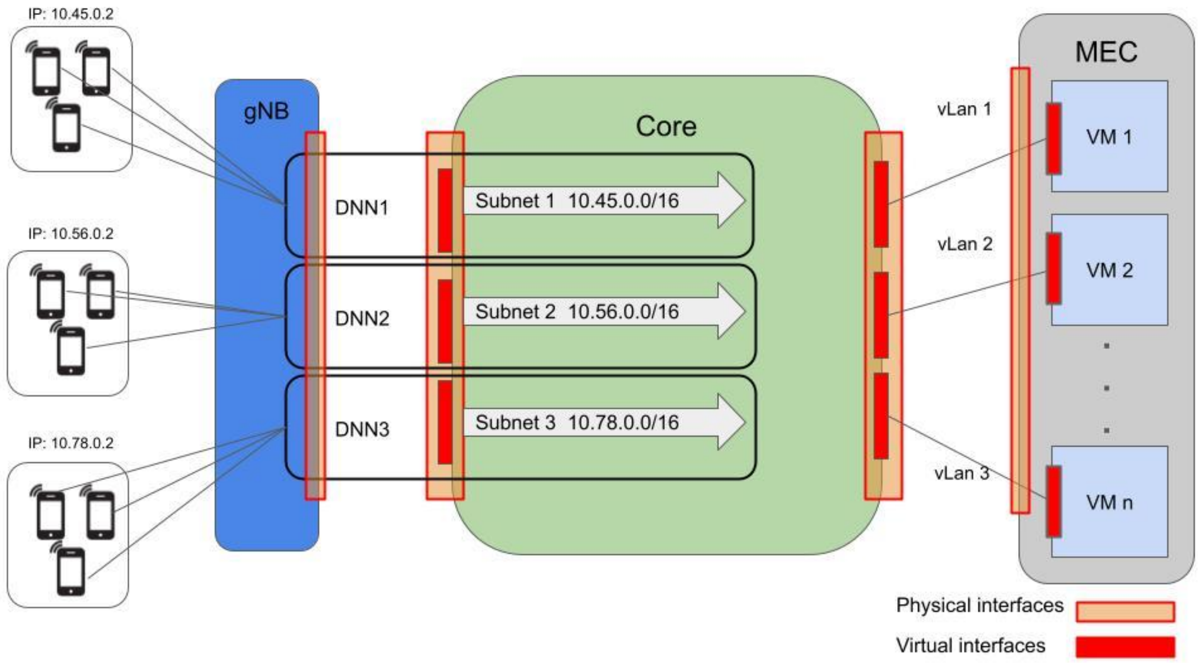


Figure 9: UE to MEC, End to End data flow segregation.

The UPF plays a pivotal role in managing and directing network traffic. It receives data flow from the RAN's N3 interface, which is a key point for user data transmission. This data arrives through various DNNs, which are essentially identifiers that distinguish different types of network services or connections. The Core UPF then segregates this incoming data directly into different subnets, ensuring that each type of traffic is kept separate and handled appropriately.

In addition to its traffic segregation capabilities, the UPF also has a L2 connection to the MEC server. This connection allows efficient segregation from UPF to VM using VLANs.

Now, the established dedicated connection from the UE toward the MEC server can be mapped to specific VM which is going to be created through edge orchestrator process.

3.2 Service orchestrator: Extreme-edge and edge dynamic orchestration

Section 3.1 introduced the network-wide orchestrator where we explained how the virtual environments are created and network connectivity is established. This section introduces Dynamic Service Orchestrator (DSO) which aims to introduce methods to dynamically orchestrate services and move them between the extreme edge (i.e. connected vehicle) and far edge (i.e. MEC) to satisfy use case requirements. There are various reasons to the need of moving/adapting the computation from the field device into the MEC [12]:

1. service and data proximity
2. latency
3. local vs. shared
4. data sovereignty, control, and privacy
5. data management practicality
6. data replication costs
7. statistical effects on resource utilization

8. statistical effects on profitability
9. statistical multiplexing effects on resource availability
10. resilience and security

While the end-to-end connection from the UE (or devices behind UE) are established to the relevant VM in the MEC, the dynamic service orchestrator dynamically changes the location of running some functions either in the field device or in the VM. This migration is based on evaluated connectivity KPIs to select the proper host for running services and applications.

Figure 10 depicts the general architecture of DSO that its functions can be running in the MEC environment or in the field device, based on the use case. The DSO includes three functions: The Decision-Making Function (DMF), the Action Enforcement Function (AEF), and the Metrics Exposure Function (MEF). The DMF and the AEF play the main roles of DSO by making decisions and enforcing new config of the deployment, respectively. These actions rely on the metrics, which are collected and stored by the MEF in the Prometheus database in real-time. The granularity is set to 5 seconds and it can be decreased to 1 second.

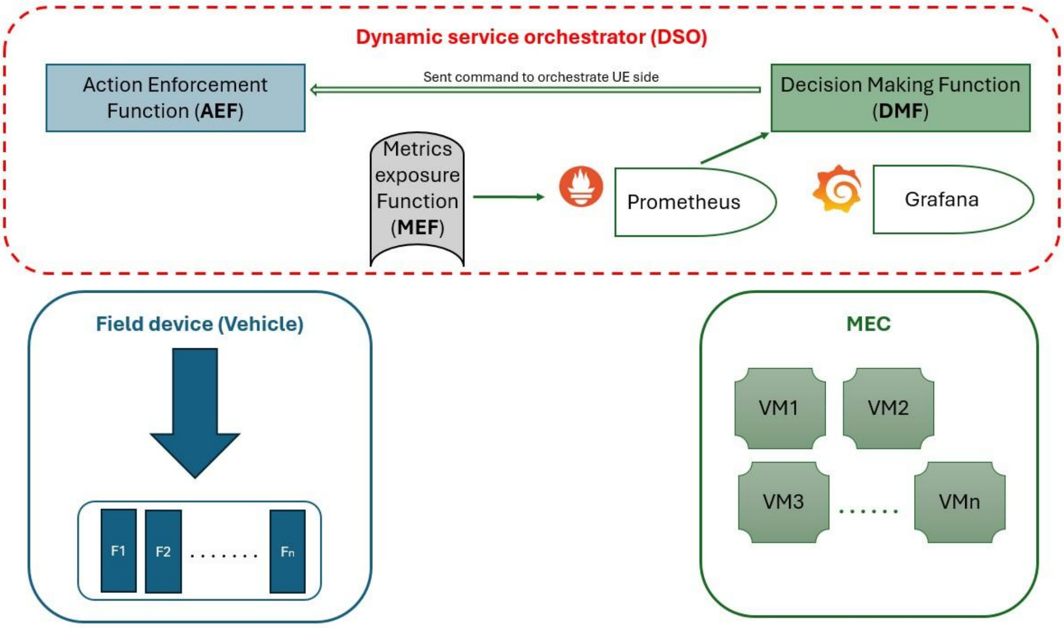


Figure 10: Dynamic service orchestrator, the general architecture.

The DMF is the logic that determines whether the service should run in the field device or on the MEC. This function is placed in a VM inside the MEC and makes this decision based on network connectivity KPI assessment. These metrics are collected by the MEF and stored in Prometheus in real time. Based on the use case and the deployment architecture, the MEF might be placed in the field device or on the MEC. That is why it is depicted between them. The decision-making mechanism in DMF is completely customizable and can rely on any KPI metric available in Prometheus database.

The DMF simply transforms the quality of the network to some qualificative levels (e.g. very good, good, enough, and weak). Once the decision is made by DMF, it sends the connectivity qualitative level to the AEF. The AEF is responsible for interpreting how to perform proper actions and change the orchestration of functions based on the new network connectivity status. The actions associated with AEF depend on the use case functionality, features, and functions. Hence, there should be a customized developed version of AEF for each specific use case.

The dynamic orchestration process starts with a subscription from the AEF to the DMF. Hence the DMF has the complete list of UEs which will receive notifications on network status changes/updates. The subscription ends either implicitly by the UE, or when the UE drops the connection with the network.

Three use cases have been discussed in WP4 to be deployed in the structure of DSO:

- The first use case is a watchdog system that monitors and inspects network KPIs from the UE point of view and stores them dynamically either in the field device inside the vehicle, or in the MEC, based on the network resource availability. This use case employed a tool to record desired KPIs that is developed for the TARGET-X project. This tool and the orchestrator mechanism are introduced and explained in section 3.2.1.
- The second use case is based on a collaboration between WP4 and WP3. The idea is to use the VILLAS, the software framework to monitor energy consumption and KPIs, in the automotive use cases [13]. VILLAS is developed in WP3 and is introduced in Deliverable D3.4 [14]. Section 3.2.2 of this document explains how this solution is integrated with the dynamic orchestration mechanism.
- The third use case is integrated in the Impact-XG project, which joined Target-X through the second open call. The use case offers a watchdog to monitor the vehicle environment conditions, including connectivity situation, for remote and supervised driving. Section 3.2.3 introduces this use case and explains how the dynamic orchestrator works.

Any of 14 metrics that are introduced in section 3.2.1 (Table 1) can be used as the trigger to fire the DO. For each considered metric, user can define four different thresholds. As the Proof of Concepts (PoCs), the Signal to Noise Ratio (SNR) is selected as the main KPI to validate the functionality of use case number 1 and 2 (section 3.2.1 and 3.2.2). The thresholds also can be defined by the user. Below thresholds are defined as the sample outputs of DMF:

- Very good: If the SNR is higher than 20
- Good: If the SNR is higher than 15 and lower than 20
- Enough: If the SNR is higher than 10 and lower than 15
- Weak: If the SNR is lower than 10

The DMF has the possibility to make the decision based on the very last value of reported basis metric or based on a statistical average during specific recent reports (e.g. last 3 minutes).

3.2.1 VISTA: A user experienced network KPI tool

VISTA stands for Visibility, Insights, Signal Telemetry, and Analytics and is the tool which developed by Neutroon in the framework of the TARGET-X project to provide a comprehensive "view" into the network's performance from the UE perspective, offering deep insights and analytics for monitoring, troubleshooting, and AI model training.

VISTA logs and reports user-experienced network KPIs and acts like a watchdog to log connectivity metrics from the user point of view, which can further be used for network monitoring, troubleshooting, auditing, etc. VISTA offers a real time dashboard for monitoring purposes while it can also feed analysis functions in the network (e.g. feed the DMF function in this specific use case). Collected network metrics over a long time can be used for troubleshooting, identifying root causes of network issues, as well as a rich dataset for AI-model training. The latter is out of scope of this document but as an example, the collected dataset can be used for an AI-model to predict the UE throughput and latency based on specific network KPIs.

The idea also includes designing and developing Customer Premise Equipment (CPE) registered in the network that does not only give connectivity service to features within (or behind it) but also to host VISTA to perform PoCs. Figure 11 shows an instance of the manufactured CPE that has embedded the VISTA tool. The CPE has a motherboard with Intel®Core™ i3-N305 CPU that we attached to a Quectel RM500Q-GL module [15] to offer 5G connectivity. The CPE runs Ubuntu 22.04, hence can easily host applications and services. The CPE also has two ethernet ports and an added WiFi 6 module (WiFi 6 AX200 NGW [16]) if the CPE supposed to act as router to provide connectivity for devices behind.

Figure 11: Developed CPE to host VISTA.

Vista collects 14 metrics listed in Table 1. The definition of these metrics is inspired by the 5G-PPP KPI measurement white paper [17]. Among the 5G connectivity metrics, there are also WiFi and Ethernet throughput KPIs in order to assess service requirements if they are running behind the CPE. In this case, the CPE acts as a gateway to offer 5G connectivity to devices which don't have a 5G module embedded.

Table 1: Metrics that VISTA can collect and monitor.

#	Name		Unit	Definition
1	SNR		dB	Signal to Noise Ratio
2	SINR		dB	Signal-to-Interference-Plus-Noise Ratio. Relation between the reference signal power received and the sum of the noise and interference power received.
3	RSRP		dBm	Reference Signal Received Power. Power received from the pilots sent by the base station.
4	RSRQ		dBm	Reference Signal Received Quality. Parameter that measures the quality of the radio communication channel.
5	Cell number			
6	TAC			Tracking Area Code
7	RTT to MEC		ms	Round Trip Time from the UE to MEC
8	RTT to Cloud		ms	Round Trip Time from the UE to cloud
9	User experience data rate DL	5G Module	Mbps	Current downlink throughput on 5G module interface
10		WiFi module	Mbps	Current downlink throughput on WiFi module interface
11		Ethernet	Mbps	Current downlink throughput on Ethernet module interface
12	User experience data rate UL	5G Module	Mbps	Current Uplink throughput on 5G module interface
13		WiFi module	Mbps	Current Uplink throughput on WiFi module interface
14		Ethernet	Mbps	Current Uplink throughput on Ethernet module interface

Figure 12 depicts the dynamic orchestrator architecture of the VISTA in the TARGET-X testbed, i.e. in the IDIADA network.

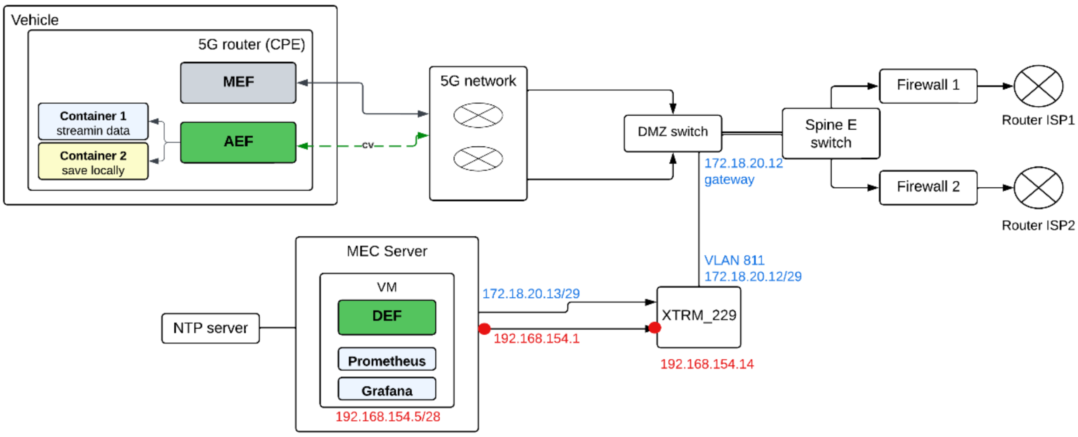


Figure 12: VISTA deployment architecture in the IDIADA test road network.

The VISTA is developed in a container. Container 1 streams raw KPI data toward the MEC to first be collected in Prometheus and then to be presented and reported in the Grafana dashboard on the MEC. The tool in container 2 does not stream KPI logs to network, instead stores them locally in the field device. The optimal situation is streaming KPI logs to MEC (the container 1) since from one side, logs are going to be collected centrally from various field devices and central management decisions become feasible, and from other side, field devices are very low capacity machines and typically are resource constraint to process and store large log data. Therefore, the main job of the AEF is switching between containers, starting one and stopping another. As aforementioned, this action is based on the command which comes from DMF.

We entitled container 1 as “Good container” and container 2 as “Limited container”. The AEF, which is a Python-based service running on Ubuntu, runs in the background and starts or stops containers once it receives signal from DMF. Figure 13 shows an example of AEF logs where the Good container had been running, and the AEF switches from the Good container to Limited container.

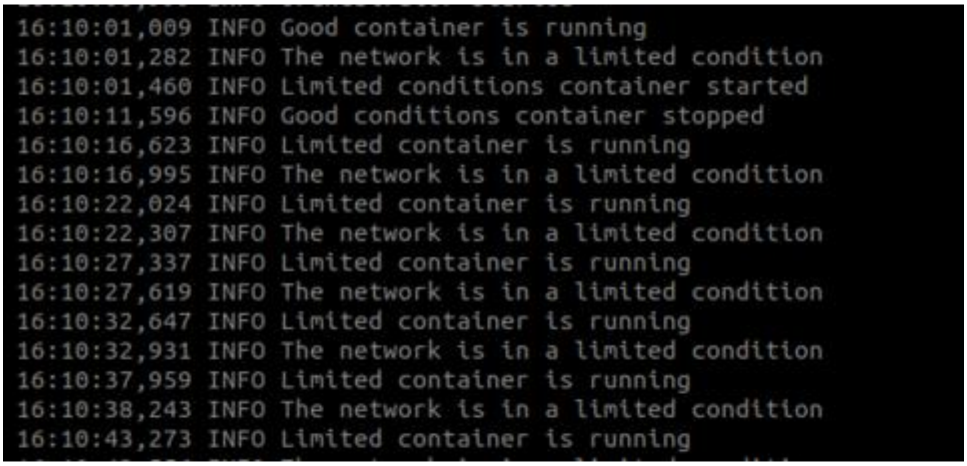


Figure 13: VISTA service log example.

Figure 13 reports the steps where the network was in Good condition and then, it turns to Limited conditions. So, the Limited conditions container was started first, and when it was completely started, the Good conditions container was stopped. The intention of this order is to be sure that no metrics are lost in the container switch.

Even though the orchestrator is always running in background, the communication period between DMF and AEF can be customized and actions are executed periodically in the predefined interval.

3.2.2 Remote power consumption monitoring tool

The VILLAS framework is an open-source software set with different components that allows to collect power consumption KPIs from the connected devices and provide further assessment [7]. This kind of framework is interesting for connected and autonomous electrical vehicles to monitor the energy consumption of certain functionalities.

The VILLAS solution relies on VILLASnodes, which are developed in containers (see Figure 14). The field device container includes the VILLASnode1 that receives analog energy KPIs as input and timestamps them. There is no limit for the input sample rate and it is configurable. Common sample rate setting is from some hundreds up to hundred kilo samples per second.

The second VILLASnode, i.e. VILLASnode2 in the diagram, hosts the Dynamic phasor conversion (DFT) algorithm to perform phasor estimation. The DFT converts thousands of samples received from the in-field VILLASnode1 into a few ones to be further reported in Grafana.

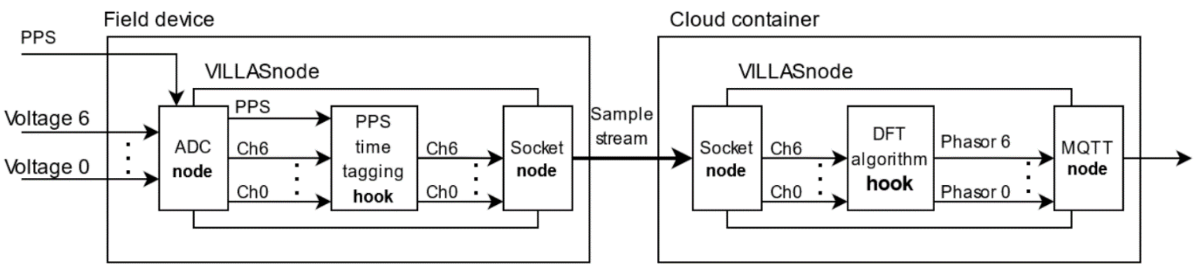


Figure 14: VILLAS framework.

The initial deployment in WP3 has been running VILLASnode1 in the field devices and VILLASnode2 in the MEC/cloud. This deployment is suitable while the field device location is fixed and there is reliable 5G connectivity available in order to reduce the computation in the field devices. However, in the automotive use cases in WP4, field devices are mobile, and the network connectivity quality is not uniform, and network resources might become limited. In this case, the dynamic service orchestrator mechanism comes to the picture to dynamically move the VILLASnode2 from the MEC into the field device (i.e. vehicles in WP4 use cases). The benefit of this action is that only few estimated samples are going to be sent instead of thousands of raw data, hence saving network resources while there are not enough network resources.

Figure 15 shows the dataflow and functions that are in action for this use case. The blue border functions are basic functions developed in the structure of WP3 and reported in deliverable D3.4. The red border and green function are the features added to the use case in the structure of task 4.3 to adapt it with automotive use cases.

The container 3 in Figure 15 initially was placed in the MEC server whereas in the framework of the DSO, it is considered to dynamically move it from MEC to the field device. The DMF assesses network KPIs and decides whether or not container 3 should stay running on the MEC or should be moved to the device inside the vehicle.

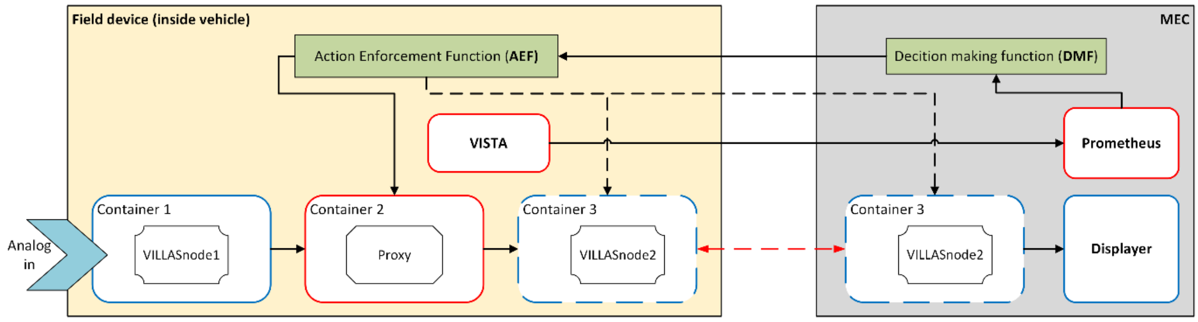


Figure 15: VILLASframework integration architecture into DSO

Once the decision is made by DFM, the relevant action is fired in the dynamic orchestrator function and this function makes relevant configurations in container 2 to either keep sending dataflow to the container3 instance in the MEC or redirect them to the instance running in the same device in the vehicle.

Next step is that Container3 sends received samples to the Displayer in the MEC. Displayer includes MQTT, Telegraf, InfluxDB internal steps until finally shows results in Grafana.

3.2.3 Remote environment monitoring tool for automated vehicles

The third DSO use case is based on the Impact-XG project [18]. The importance of this use case is to show how the TARGET-X trial site in IDIADA can effectively collaborate and integrate with cutting-edge automotive use cases. Impact-XG aims to explore and evaluate the capabilities of 5G mobile broadband (MBB) networks in supporting use cases requiring high-performance video streaming. The project is designed to assess the performance of mobile nodes, such as passenger vehicles commuting within city environments, under real-world conditions. Additionally, Impact-xG seeks to develop an advanced monitoring system using video to Tele-operated Driving (ToD). Figure 16 depicts the connection between different functions of the Impact-XG [18].

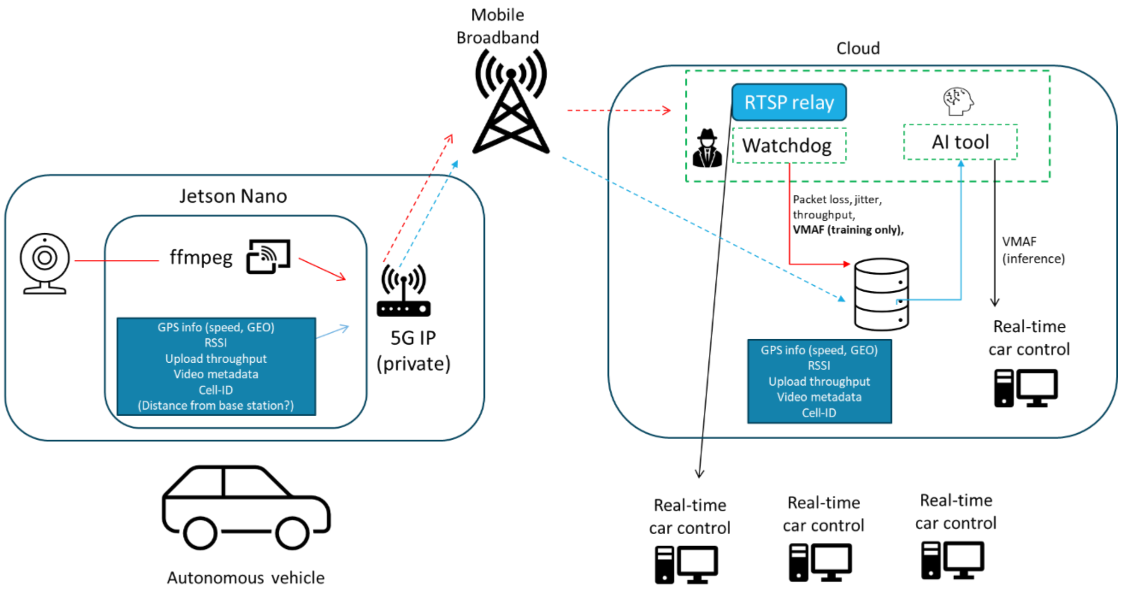


Figure 16: Impact-xG project action flow.

The left box in the Figure 16 represents modules in the vehicle and the right box includes modules in the MEC. In the vehicle, video that streams from camera be encoded by Jetson Nano and be sent through 5G network toward the MEC. The RTSP relays the video to the remote car control. The watchdog box in the MEC continuously collects service KPIs and assess them. The assessment is performed using the embedded AI tool.

The deployment and validation of the use case functionality is offered by the use case owner and is out of scope of this document. What is relevant to this document is how this use case collaborates and integrates into the DSO of the testbed. Figure 17 depicts the architecture of how the use case is integrated into the dynamic service orchestrator mechanism of the TARGET-X testbed.

Prometheus and the DMF are the same functions which are introduced in Figure 10. The MEF of Figure 10 also developed in the MEC in this use case. The MEF is adapted to stream loss rate and store it in Prometheus. An adapted AEF function is also necessary in the field device (the vehicle). The job of AEF is reorchestrating the camera configs and/or compression process to stream videos considering the current connectivity status.

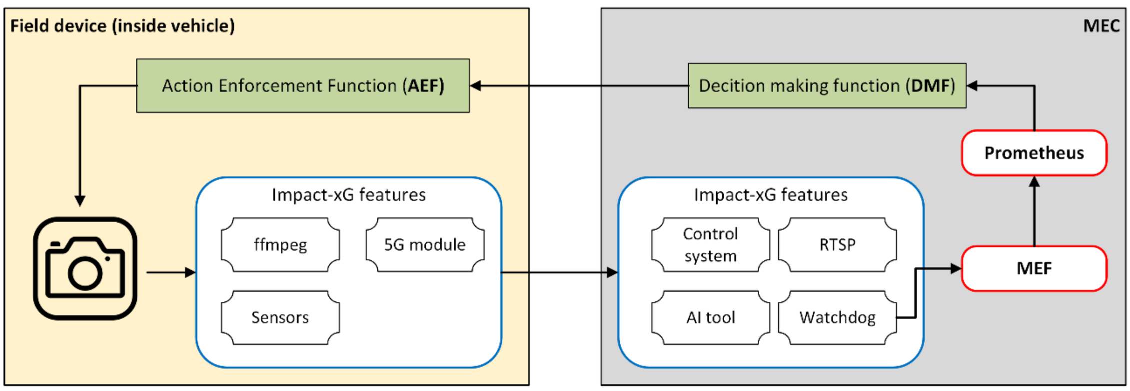


Figure 17: The architecture of integration the Impact-xG into the DSO

3.3 Network exposure API

3.3.1 Motivation

The interaction between the network and the application function in the context of 5G and 6G networks will enable to unlock the powerful potential of these network to provide the best performance to the application. In this context, network exposure APIs such as CAMARA [19] allow the network to expose some information to the application. Although the type and amount of information is still limited in such initiative – due to absence of need to more rich information in the deployed services – the needs of the automotive vertical will require the availability of network exposure APIs with richer information and more flexibility. The exposed information can come from the NWDAF that is a key function in 5G core network. However, in current network deployment the full potential of the NWDAF is not unlocked.

In the current deployment of the 5G network in IDIADA, the NWDAF is not deployed and therefore, i2cat has designed in TARGET-X a network exposure API emulating the presence of the NWDAF, exposure functions as Network Exposure Function (NEF), and exposure APIs such as CAMARA with richer information. The main idea of deploying this API is to show how the interaction between the network and applications can enhance the application performance in a simple and reliable way.

3.3.2 Solution description

The developed API was designed to serve the predictive QoS for Tele-operated driving use case and its architecture is shown in Figure 18.

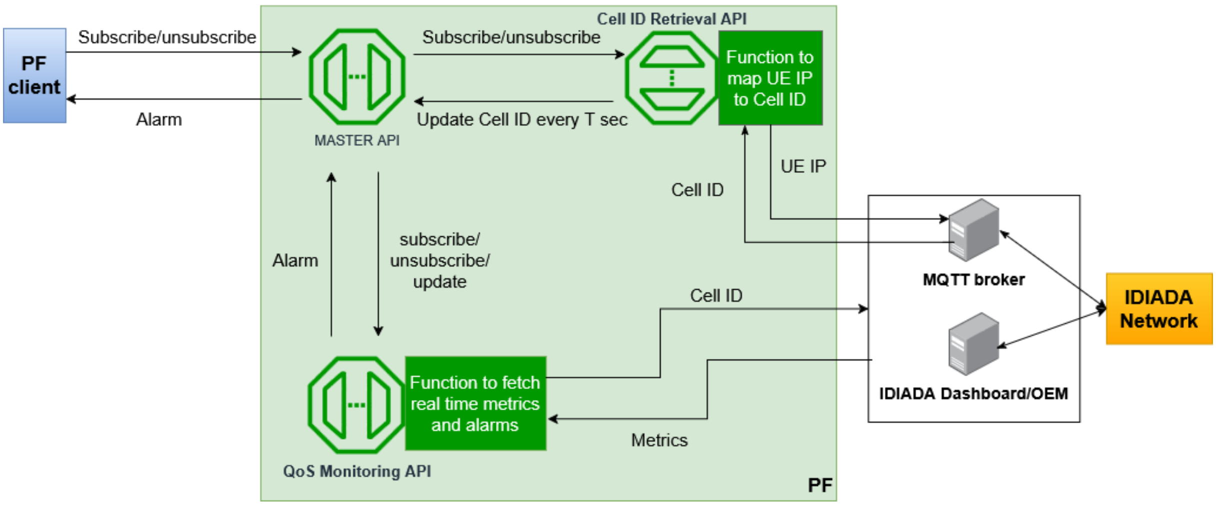


Figure 18: Exposure API for the predictive QoS application.

The proposed architecture was explained in Deliverable D4.2. The objective is to monitor the status of the cell to which the tele-operated vehicle is connected in addition to the cell ahead. When the network KPIs in these cells cross certain thresholds, an alarm will be generated and posted on the HMI of the remote driver. If the threshold is crossed in the cell of the tele-operated vehicle, a warning “low coverage” is shown if there is low coverage (low SINR or RSRP), or “cell congested” if one of the network KPIs (e.g., throughput, latency) crosses a certain threshold. In a similar way, if a threshold is crossed in the cell ahead, an alarm of “Next cell is low coverage” is shown if low coverage or “Next cell is congested" if one of the network KPIs is crossed. As shown in the figure above, the proposed architecture includes:

- The Prediction Function (PF) client can be part of the application or a third part application and has the responsibility of subscribing to and unsubscribing from the PF. The subscription will contain the IP address of the connected vehicle, the requested service, and the thresholds. This function will send an alarm to the HMI that will post an alarm of bad conditions.
- The PF that emulates the presence of NWDAF and enhanced exposure APIs. It includes:
    - MASTER API: Based on the request inside the subscription, the MASTER API will decide about the process and the APIs (i.e., transformation functions) to be called. In our case, it will call two APIs: the cell ID retrieval API and the QoS monitoring API.
    - Cell ID retrieval API: It is responsible for tracking the cell ID to which the tele-operated vehicle is connected to. The cell ID will be updated each *T* seconds as the vehicle will be moving and cell will change. In order to have real time update and since we don't have the NWDAF, we developed an MQTT broker that gets the cell ID of the connected vehicle and expose it to this API.
    - Monitoring API: It is responsible of monitoring the network metrics (e.g., signal level, latency, throughput, cell status) of the current cell to which the tele-operated vehicle is connected and the cell ahead. In case one of the metrics does not satisfy the requirements, the API will generate an alarm and send it to the MASTER API. The cell IDs will be provided by the MASTER API, which is updated through the cell ID retrieval API. These metrics are cell status and network KPIs. The cell status is obtained from IDIADA dashboard that shows information fetched from the O&M with a frequency of 15 minutes. This metric shows the current KPIs and granularities that we can obtain from current deployments. The network KPIs are fetched from the MQTT broker that collect network KPIs, such as latency, throughput, SINR, and RSRP from the tele-operated vehicle and a connected vehicle that is connected to the cell ahead. In case a full NWDAF is deployed, we can directly fetch these KPIs as the cell IDs will be provided.

3.3.3 Functional testing

In order to test the functionality of the proposed API, we designed a lab testbed with two UEs: one representing the tele-operated vehicle and the second the connected vehicle. To emulate the case of low coverage we remove the antennae of the corresponding UE, and to emulate the case of congestion we change the threshold of certain KPIs so that the threshold will be crossed in normal situation.

Table 2: Results of the lab test for the exposure API.

Test number	Description	Hardware conf	Expected result	Results
1	Put all thresholds to Limit	**All antennae clear**	No warning	Success
2	All thresholds to Limit except Latency to Best	**All antennae clear**	Next cell is congested	Success
3	All thresholds to Limit except throughput to Best	**All antennae clear**	Next cell is congested	Success
4	All thresholds to Limit except jitter to Best	**All antennae clear**	Next cell is congested	Success
5	All thresholds to Limit except rsrp to Best	**All antennae clear**	Next cell is low coverage	Success
6	All thresholds to Limit except SINR to Best	**All antennae clear**	Next cell is low coverage	Success
7	All thresholds to Best	**All antennae clear**	Next cell is low coverage	Success
8	All thresholds to Limit	**All antennae clear**	No warning	Success
9	All thresholds to Best	**All antennae clear**	Low coverage/Next cell is low coverage	Success
10	All thresholds to Limit except SINR to current	**Antenna ToV removed**	Low coverage	Success
11	All thresholds to Limit except SINR to current	**All antennae clear**	No warning	Success
12	All thresholds to Limit except SINR to current	**Antenna CV removed**	Next cell is low coverage	Success

The results are depicted in Table 2. As can be seen, all the tests were successful. The terms best, limit, and current for the thresholds are defined in Table 3. The values “Limit” provide thresholds that cannot be crossed in normal conditions and will not generate any warning. The values “Best” provide thresholds that can be always crossed in normal conditions and therefore should generate a warning. The values “current” are thresholds that will be used in the predictive QoS for tele-operated driving use case.

Table 3: Level of the thresholds used in the test of the exposure API.

Thresholds	Current	Limit	Best
latency	100	100000	0
throughput	15	0	10000
jitter	40	100000	0
rsrp	-105	-200	0
SINR	5	-100	100

3.4 Accurate positioning tool

The use of Global Navigation Satellite Systems (GNSS) revolutionized the way to determine precise positions worldwide. However, standard GNSS positioning is often limited to meter-level accuracy, which is insufficient for applications that require higher precision, such as automated driving and indirect tele-operated driving, where waypoints need to be followed precisely. With the introduction of Real-Time Kinematic (RTK) positioning the GNSS positioning data can be improved enabling decimeter-level precision. RTK is a technique to improve the accuracy of GNSS data by utilizing a network of ground-based reference stations that provide correction data. In the Third Generation Partnership Project (3GPP) Release 15, transmission of RTK information through cellular telecommunication technologies was standardized [20]. The Secure User Plane Location (SUPL) standardized by the Open Mobile Alliance (OMA) is used for that.

RTK information is typically valid for areas of a few kilometres and changes in timescales of few seconds. According to the 3GPP-standardized procedures and architecture [21], it can be delivered over-the-top with now special cellular network features available besides the modem being capable of extracting network identifiers like the Tracking Area Code (TAC) or the Cell ID. When integrated with the Core network, the Mobility Management Entity (MME) in 5G NSA or Access and Mobility

Management Function (AMF) in 5G SA provide this information to the location server. The end-device does not need to extract and send it. This reduces uplink data volume and, in many jurisdictions, means that user consent is required for collecting privacy-relevant information. The third variant broadcasts RTK correction data relevant for a given area within RAN System Information Blocks (SIB). The RTK correction data can be encrypted, so only users subscribed to the service will get the keys to decrypt it. This procedure is also standardized by 3GPP [21].

In Figure 19, a simplified 3GPP-GNSS-RTK architecture is described to illustrate how the RTK data is broadcasted through the 5G network from the Internet to a 5G connected car.

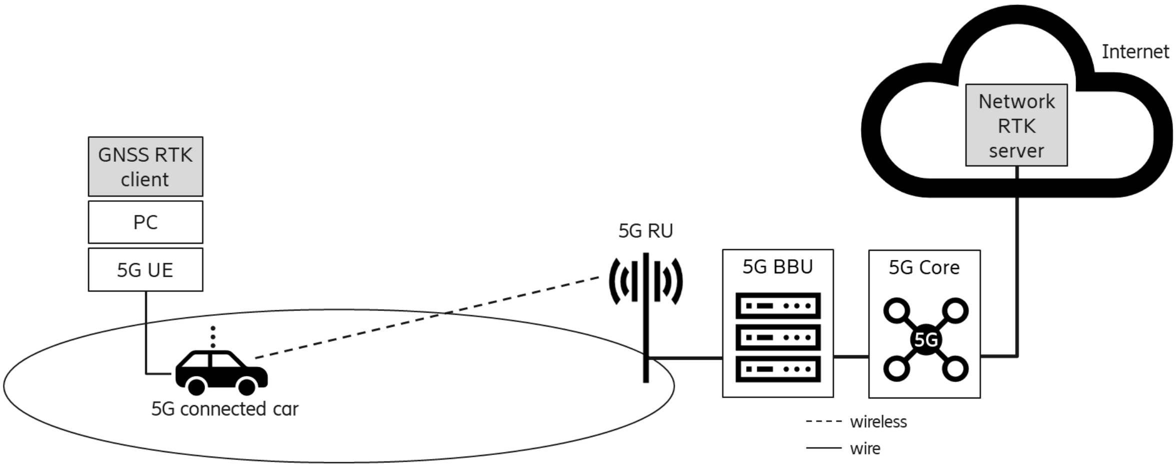


Figure 19: Simplified 3GPP-GNSS-RTK system architecture and experimental setup.

In Target-X we showed how GNSS-RTK correction data was provided to the vehicle. The location exposure API, described in the next section, was used to test and verify that worked as expected.

3.4.1 Location exposure API

The 3GPP Gateway Mobile Location Centre (GMLC) is providing location information access to clients and applications, typically via a 3GPP NEF or an API gateway, but can be accessed directly when within a secure environment. GMLC provides location information combined with detailed uncertainty estimates on demand or as a periodic subscription. It can provide a network-based location information (subject to a reliable location request) or forward a device-reported location information.

Within Target-X we used an GMLC prototype deployed in Sweden, accessible also from IDIADA. It is a prototype of Ericsson's commercial Ericsson Network Location product. It provided GNSS RTK correction information to end-devices and received device-reported information.

Figure 20: Horizontal Accuracy over Location Retrieved from GMLC

For our trials we store the location information, incl. reported accuracy, in a database. Figure 20 shows an example plot from horizontal accuracy information obtained during testing in IDIADA. This shows that location exposure and also providing GNSS-RTK correction data to the testbed in IDIADA, and also the 5G Industry Campus Europe, works as expected.

4 MEC server footprints

This section aims to evaluate connectivity KPIs when the MEC server is present in the network, hence having a benchmark for network KPIs. The intention is to first validate the MEC connectivity to host use case application, as well as evaluating the improvement which the MEC computing adds to network KPIs.

Section 4.1 reports comparison network KPIs from UE toward MEC and cloud, which are evaluated using a network KPI measurement tool developed by Neutroon in the project, VISTA. This is the same tool that was introduced in Section 3.2.1. Section 4.2 gives a very deep network quality assessment, evaluated using the Qualcomm tool to confirm that the end-to-end connectivity to MEC can satisfy use cases requirements.

IDIADA network offers 40Mhz bandwidth in 4G and 60Mhz bandwidth in 5G. The TDD pattern is configured to have 75% downlink and 25% uplink (i.e. 3D:1U).

4.1 MEC communication assessment

This section first shows how the VISTA tool can effectively report user experienced network KPI in real time and provides a benchmark for end-to-end UE connectivity through 4G and 5G.

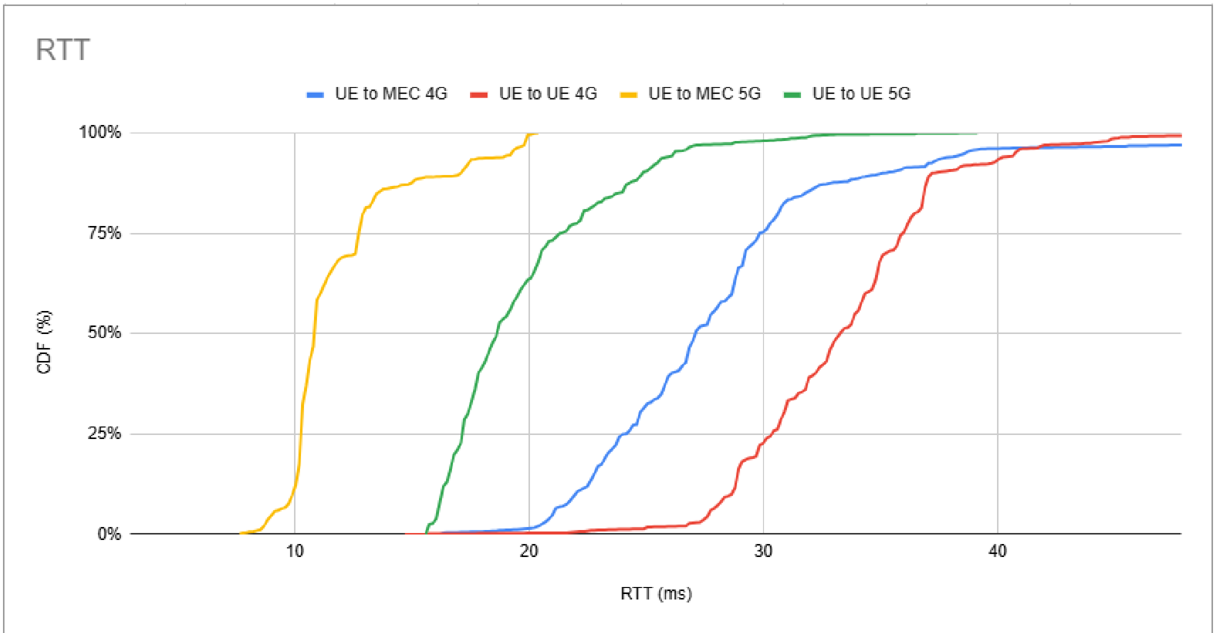
Figure 21 shows the Grafana dashboard for the VISTA tool. It reports all metrics that are listed in table 1 in real time.

Figure 21: VISTA GRAFANA dashboard

To assess network connectivity, we used two commercial 5G UEs, i.e. Teltonica RUTX 50 [22] (CPE) and Nokia XR20 [23] (phone) to register to the IDIADA network. Figure 22 shows the locations where we performed evaluations. The blue point in the figure locates the office that was used as fixed location to evaluate both 4G and 5G network KPIs. To this end, we enforced the mentioned UEs to register to only 4G or 5G to be able to also compare KPIs between different generations.

Figure 22: IDIADA map and the locations where to perform network assessment test.

Figure 23 shows the CDF of the RTT when the UE is connected to the network through 4G and 5G respectively. The RTT is measured from the UE to the MEC (i.e. ping initiated from the UE toward the MEC), as well as UE-to-UE when the CPE and phone are both sides of the connection (Teltonica CPE and Nokia XR20 [22] [23]). The figures clearly show how 5G network improves RTT not only for the absolute average, but also to offer a reliable connection with very low standard deviation.

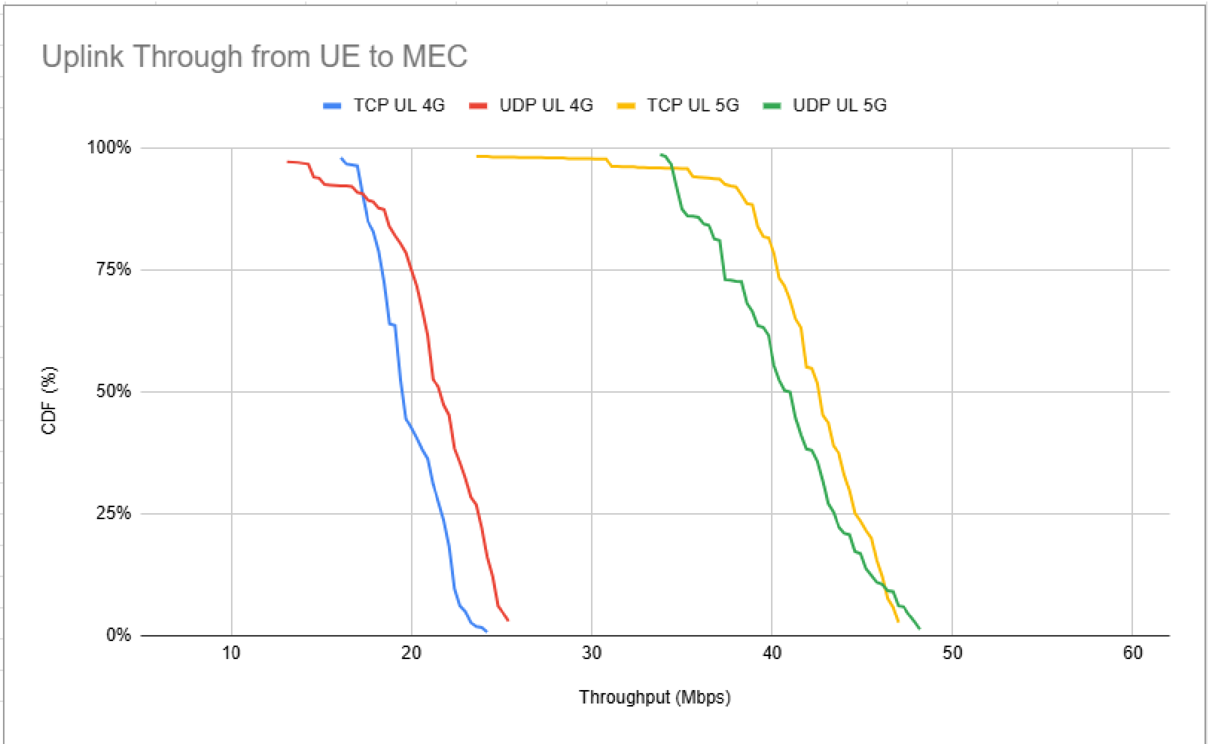


Tт -	Count	Min	Avg	Median	Max	95%	Std
UE to MEC 4G	300	16.2	29.6	27.1	174.0	38.6	15.8
UE to UE 4G	300	21.6	33.5	33.3	64.8	40.8	4.5
UE to MEC 5G	300	8.2	11.9	10.8	20.4	19.2	2.7
UE to UE 5G	300	15.6	19.7	18.6	39.2	26.3	3.5

Figure 23: Round trip time through 4G and 5G.

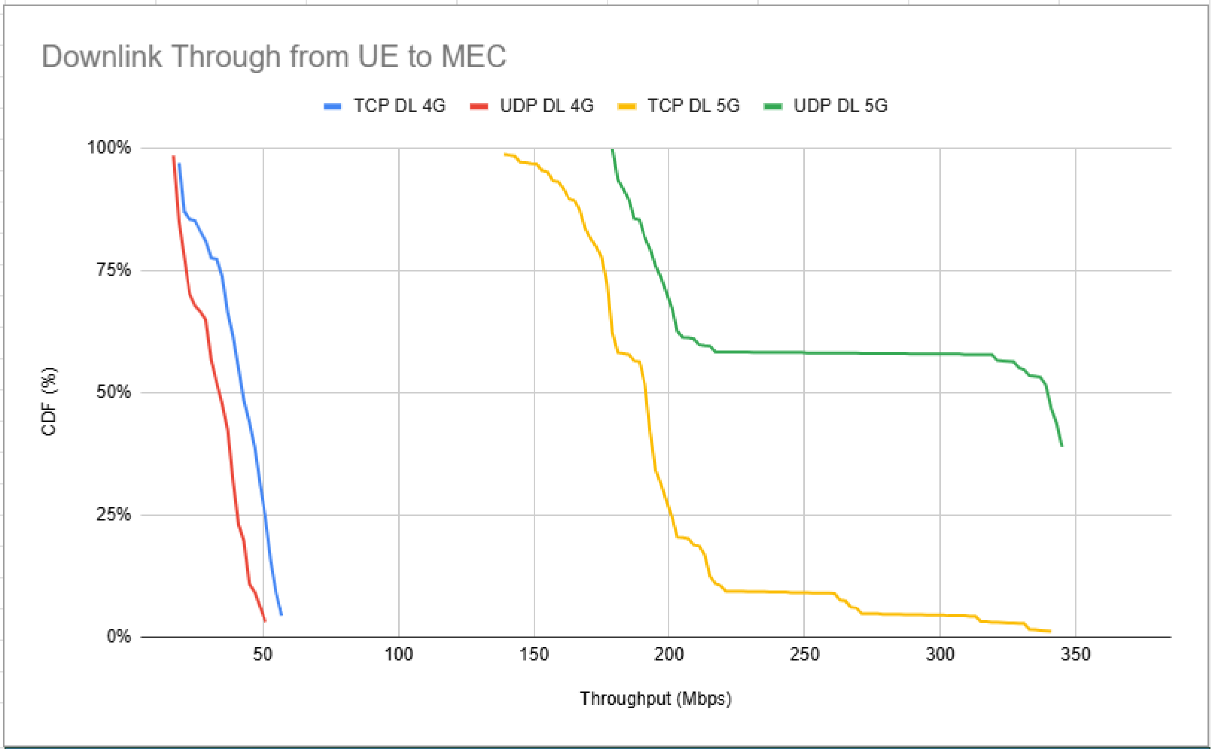
In general, 5G network offers lower RTT with average of 11.8 ms and 19.7 ms for UE-to-MEC and UE-to UE connection respectively. The RTT experienced in 4G network is almost 3 times more than 5G where the average RTT for UE-to-MEC is 29.5 ms and UE-to-UE is 33.38 ms. If there is a way to guarantee of the 5G coverage across the road, it is possible to estimate a deterministic RTT from UE to application server in the VM below 20 ms. However, if handover between different generation is inevitable, the use case should be prepared to experience RTT even around 40 ms.

In Figure 24 and Figure 25 throughput performance is shown, when the UE is connected to the network through 4G and 5G respectively. The uplink and downlink throughput are evaluated for TCP and UDP protocols, through 4G and 5G network respectively. These figures show that DL capacity of the 5G network is almost 7 times (UL capacity almost 2 times) more than 4G network. The average network capacity in DL channel is 55.7 Mbps and 343 Mbps for 4G and 5G network respectively. The capacity in UL channel is 24.9 Mbps and 47.6 Mbps for 4G and 5G network respectively. Figure 24 shows the CDF of the different throughput is 4G and 5G networks.



Tт -	Count	Min	Avg	Median	Max	95%	Std
TCP UL 4G	300	15.9	19.9	19.5	24.3	17.1	2.00
UDP UL 4G	300	12.9	21.3	21.5	25.5	14.6	2.97
TCP UL 5G	300	23.4	42.1	42.6	47.0	35.3	3.97
UDP UL 5G	300	33.7	40.7	41.0	48.3	34.5	3.93

Figure 24: Unlink throughput from UE to VM inside MEC when using 4G and 5G networks.

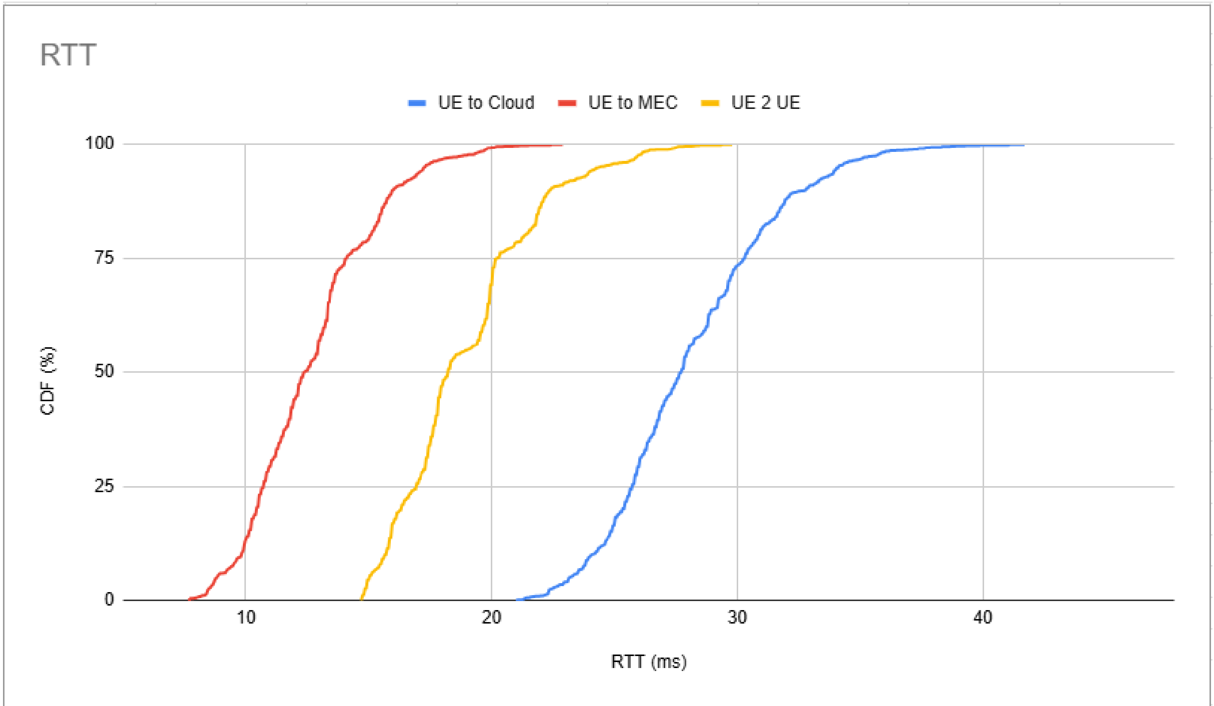


Tт	Count	Min	Avg	Median	Max	95%	Std
TCP DL 4G	300	18.4	40.2	41.5	58.5	20	12.1
UDP DL 4G	300	15.8	31.9	31.8	52.9	18	11.1
TCP DL 5G	300	138.0	233.0	233.0	385.0	155	88.6
UDP DL 5G	300	179.0	288.8	341.0	345.0	180	72.0

Figure 25:Downlink throughput from UE to VM inside MEC when using 4G and 5G networks.

The next evaluation is when we drove on the high-speed road (with the speed of 150 km/h), which is highlighted with a red line in Figure 22. In this test, we did not force UEs to connect to a specific cellular generation and let them use the proper one while driving around and jumping from one cell to another. In the first round, we evaluated the RTT from the UE to cloud, UE to MEC and from one UE to another registered UE in the network.

Figure 26 show the results taking from measurement for almost 40 seconds, which is the duration of the trip. Figure 26 confirms that running applications in the VM inside the MEC always offers better RTT and in 95% of the time the RTT is less than 17.3 ms. The end-to-end RTT from one UE to another UE that are both connected to 5G network is still better than RTT to cloud, which is less than 24.4 ms in 95% of the time. The average RTT to cloud is 28.11ms while it is 12.70 ms to MEC. hence, the MEC offers 2.2 times better RTT.



Tт -	Count	Min	Avg	Median	Max	95%	Std
UE to Cloud	1200	21.0	28.1	27.7	41.7	34.2	3.4
UE to MEC	1200	7.6	12.7	12.6	22.9	17.3	2.6
UE to UE	1200	14.5	19.1	18.5	31.8	24.4	2.9

Figure 26 : CDF Round trip time in the high speed road.

We used the 8.8.8.8 as the cloud destination. The traceroute from the UE to cloud and MEC destinations are shown in Figure 27 and **Error! Reference source not found.** Figure 28 respectively.

```
root@Teltonika-RUTX50:~# traceroute 8.8.8.8
traceroute to 8.8.8.8 (8.8.8.8), 30 hops max, 46 byte packets
 1  10.11.20.18 (10.11.20.18)  21.303 ms  11.636 ms  28.188 ms
 2  10.11.20.17 (10.11.20.17)  16.209 ms  13.215 ms  13.398 ms
 3  172.18.20.12 (172.18.20.12)  14.575 ms  17.894 ms  12.988 ms
 4  129.153.14.62.static.jazztel.es (62.14.153.129)  14.626 ms  16.356 ms  14.745 ms
 5  125.41.14.62.static.jazztel.es (62.14.41.125)  15.828 ms  21.054 ms  16.343 ms
 6  *  *  *
 7  *  *  *
 8  10.34.35.153 (10.34.35.153)  27.254 ms  24.252 ms  24.453 ms
 9  74.125.32.200 (74.125.32.200)  27.670 ms  72.14.195.234 (72.14.195.234)  23.910 ms  74.125.119.112 (74.125.119.112)  27.235 ms
10  108.170.225.251 (108.170.225.251)  23.236 ms  108.170.252.213 (108.170.252.213)  24.107 ms  108.170.225.251 (108.170.225.251)
24.132 ms
11  142.250.46.167 (142.250.46.167)  23.792 ms  142.251.54.155 (142.251.54.155)  23.604 ms  142.250.239.27 (142.250.239.27)  28.344
 ms
12  dns.google (8.8.8.8)  23.007 ms  27.173 ms  29.215 ms
root@Teltonika-RUTX50:~#
```

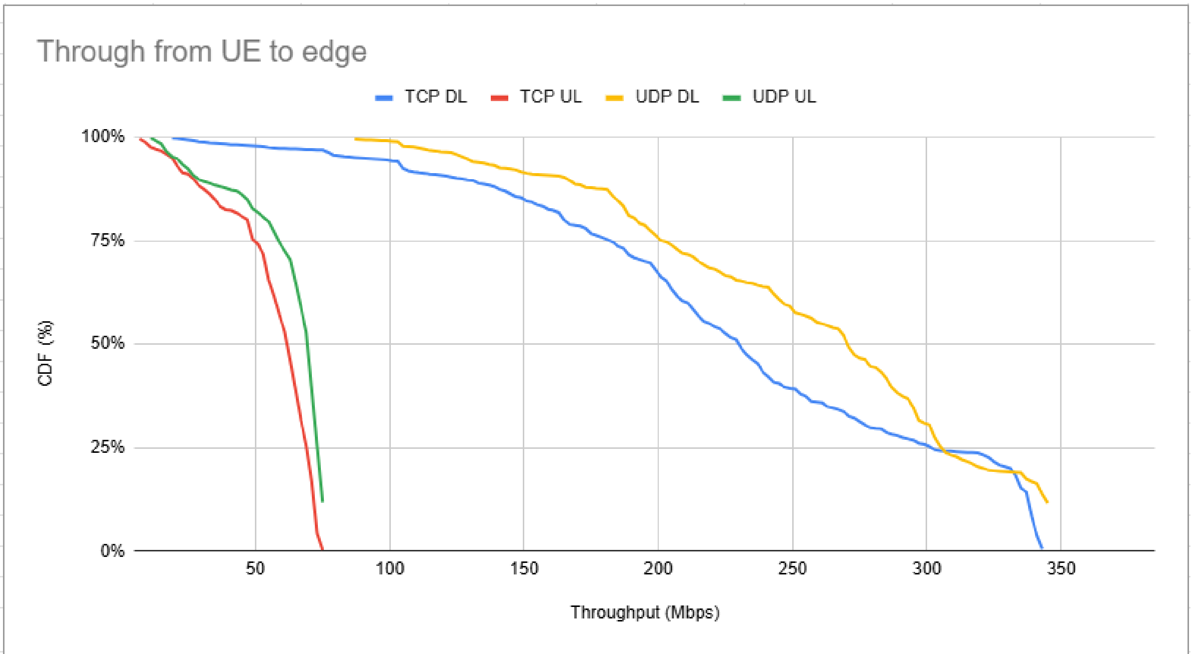
Figure 27: traceroute from UE to the cloud destination.

```
root@Teltonika-RUTX50:~# traceroute 192.168.154.4
traceroute to 192.168.154.4 (192.168.154.4), 30 hops max, 46 byte packets
 1  10.11.20.18 (10.11.20.18)  16.436 ms  10.473 ms  21.207 ms
 2  10.11.20.17 (10.11.20.17)  14.433 ms  16.600 ms  7.816 ms
 3  172.18.20.12 (172.18.20.12)  16.336 ms  17.889 ms  17.427 ms
 4  192.168.154.4 (192.168.154.4)  10.094 ms  10.056 ms  10.420 ms
```

Figure 28: traceroute from UE to VM in MEC.

The first two hops in Figure 27 and Figure 28 are the UE gateway and core IP addresses in the Erricson network. The third hope, which has the IP 172.18.20.12, is IDIADA firewall. In the E2E connectivity from UE to MEC, the fourth hop is the VM (Figure 28) while there are another 10 hopes to reach to mentioned cloud it address (Figure 27). In Figure 27, hop 4 and 5 are internet provider IP address and the location is in Madrid. We don't have more info about the location of hopes 6,7 and 8. From hop number 9 until 12, which is the destination, all IPs are located in United States. This explains the reason of high latency to reach to the cloud IP address.

In the next test round, we evaluated the throughput from the UE to the MEC in the mobile scenario. We used iperf3 tool to evaluate TCP and UDP throughput. Figure 29 shows the results for downlink and uplink for TCP and UDP protocols.



Tr	Count	Min	Avg	Median	Max	95%	Std
TCP DL	300	17.1	231.1	230.0	343.0	38.6	80.6
TCP UL	300	6.9	56.1	61.7	76.8	40.8	17.3
UDP DL	300	85.4	256.5	270.0	345.0	19.2	68.5
UDP UL	300	9.9	62.1	69.6	76.7	26.3	17.1

Figure 29 throughput in the high speed road.

Even though the absolute values for DL channels are higher, the standard deviation for the UL channel is lower. In 87% of the time, network offers 50 Mbps, which is enough for the use cases under discussion in WP4.

4.2 Qualcomm MEC/cloud communication assessments/comparison

While the section 4.1 introduced the tool dashboard for real time monitoring purposes, as well as to comparing the network connectivity KPIs through 4G and 5G, this section provides a very deep insight into the network connectivity considering various test configuration where it also engaged results with the UE location in the Target-X test road trial site. Qualcomm used three tools for perform evaluations that are mentioned in this section.

1. Test Devices: Qualcomm MTP (Mobile Test Platform) devices were used to collect detailed network measurements.

2. PCTel RF Scanner: A PCTel scanner capable of monitoring cellular technologies from 2G to 5G, covering both low Sub-6 and high mmW bands, was employed to collect radio frequency data.
3. Logging Software: QXDM was used for the test devices, while SeeHawk software was utilized for processing scanner data.

A sample of these devices are shown in the Figure 30.

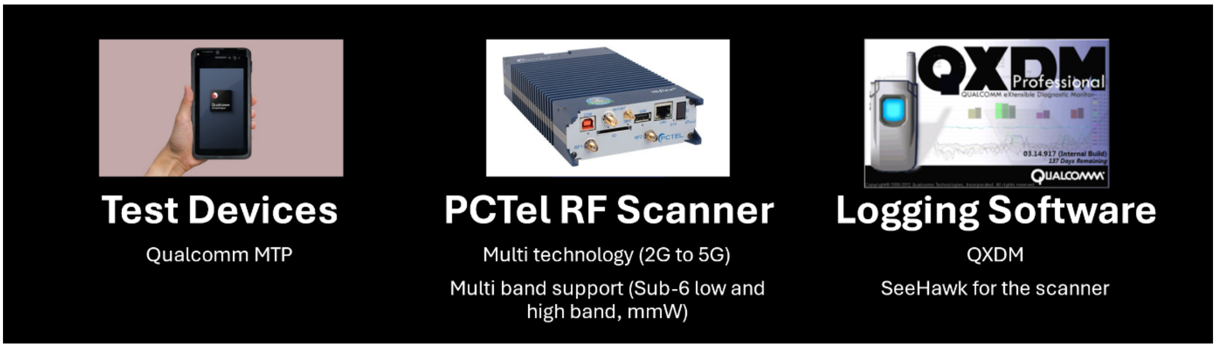


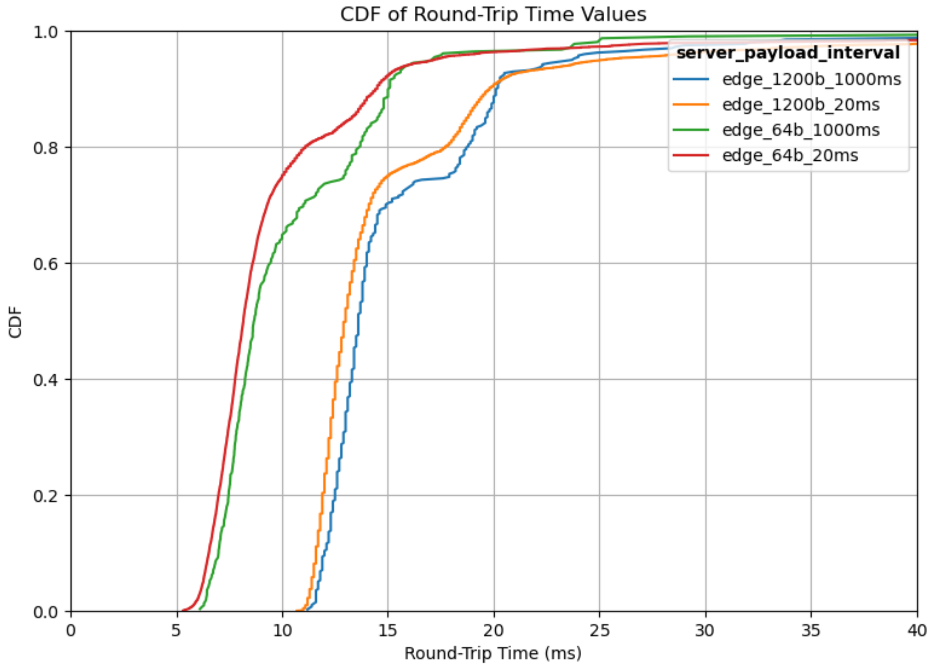
Figure 30: Qualcomm test setup and equipment

4.2.1 KPI Assessment Towards MEC Compute

This section provides the results obtained by doing measurements toward the MEC. It should be noted that a similar study was conducted in Deliverable D4.2 for the cloud case [2]. A comparison between the two cases will be provided in Section 4.2.2.

4.2.1.1 High-Speed Lap RTT Results

The latency towards MEC compute along the High-Speed Lap at IDIADA was evaluated under various payload sizes (64B and 1200B) and ping intervals (20 ms and 1000 ms). As shown in Figure 31, the lowest measured RTT was 5.31 ms for 64B with a 20ms ping interval, while the median was 8.17 ms. Payload size proved to have a significant impact, with RTT for 64B payload being approximately 5ms lower compared to 1200B, due to RLC segmentation. Additionally, the 20 ms ping interval consistently achieved about 0.5 ms lower RTT compared to the 1000 ms interval.



	Count	Min	Avg	Median	95%-tile	Max	Std
edge_1200b_1000ms	397	11.20	15.77	13.60	23.72	84.50	6.96
edge_1200b_20ms	5537	10.70	16.24	13.00	25.30	321.00	15.39
edge_64b_1000ms	307	6.12	10.62	8.69	17.07	60.80	5.73
edge_64b_20ms	5690	5.31	10.49	8.17	17.20	258.00	10.82

Figure 31: CDF of Round-Trip Time (RTT) Distribution Towards MEC Compute (64B and 1200B Payloads).

Figure 32 illustrates the RTT distribution along the route for the 64b_1000ms scenario, where 63.8% of samples were below 10 ms, 96.4% below 20 ms, and only 1% above 30 ms, indicating consistently low latency. In contrast, Figure 33 shows that for the 1200b_1000ms scenario, there were no samples below 10ms, and 87.4% of samples were between 10 and 20ms, with 2.5% above 30 ms, demonstrating a clear degradation due to larger payload sizes. The visible difference between the heat maps (64B being mostly green and 1200B mostly yellow) emphasizes the importance of payload size optimization.

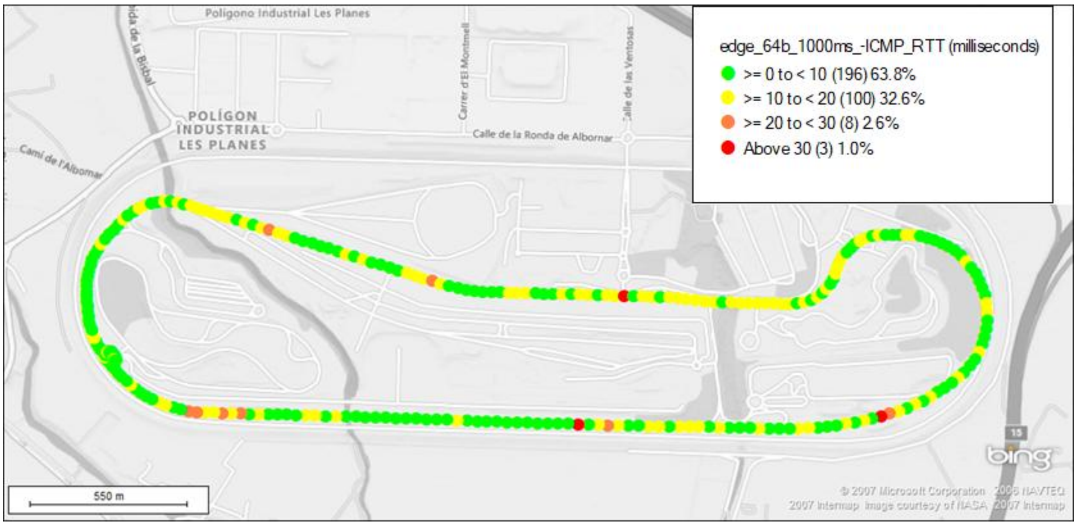


Figure 32: RTT Heat Map Along High-Speed Lap for MEC Compute (64B_1000ms Scenario).

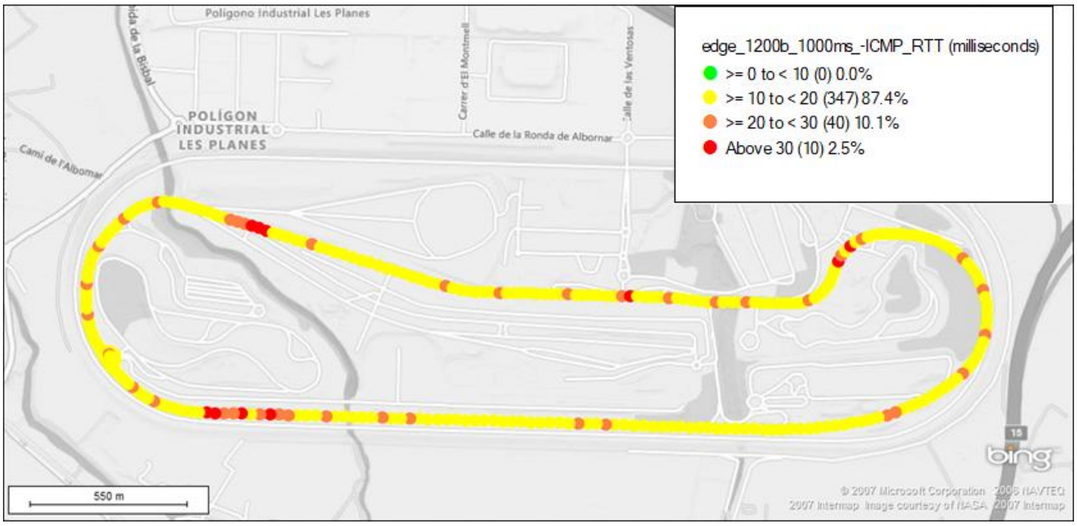


Figure 33: RTT Heat Map Along High-Speed Lap for MEC Compute (1200B_1000ms Scenario).

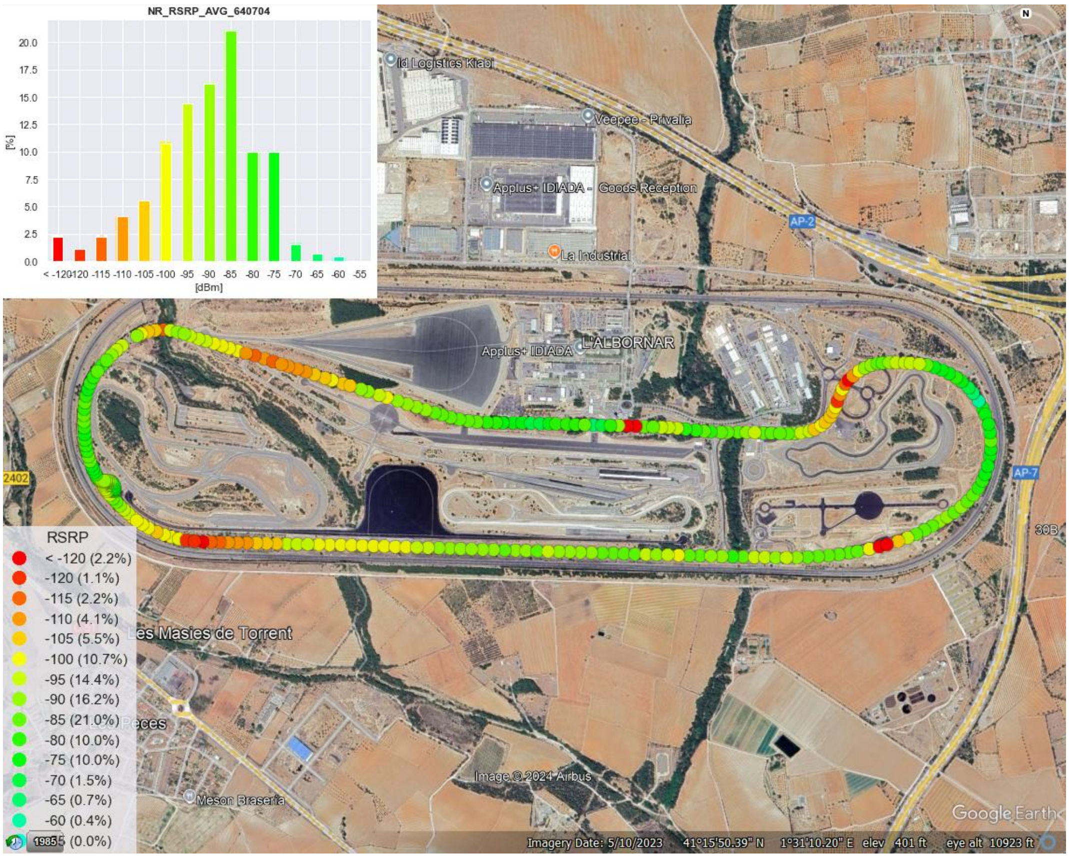


Figure 34: NR-n78 SS-RSRP Heat Map Along High-Speed Lap.

Comparing the RTT heat maps (Figure 32 and Figure 33) with the NR-n78 SS-RSRP heat map (Figure 34) reveals a strong correlation between areas with increased RTT and challenging RF conditions, particularly where SS-RSRP values dropped below -100 dBm. This finding is further corroborated by Figure 35, where the scatter plot shows that most RTT outliers occurred in poor RF conditions. This emphasizes the critical role of maintaining adequate signal strength for optimal latency.

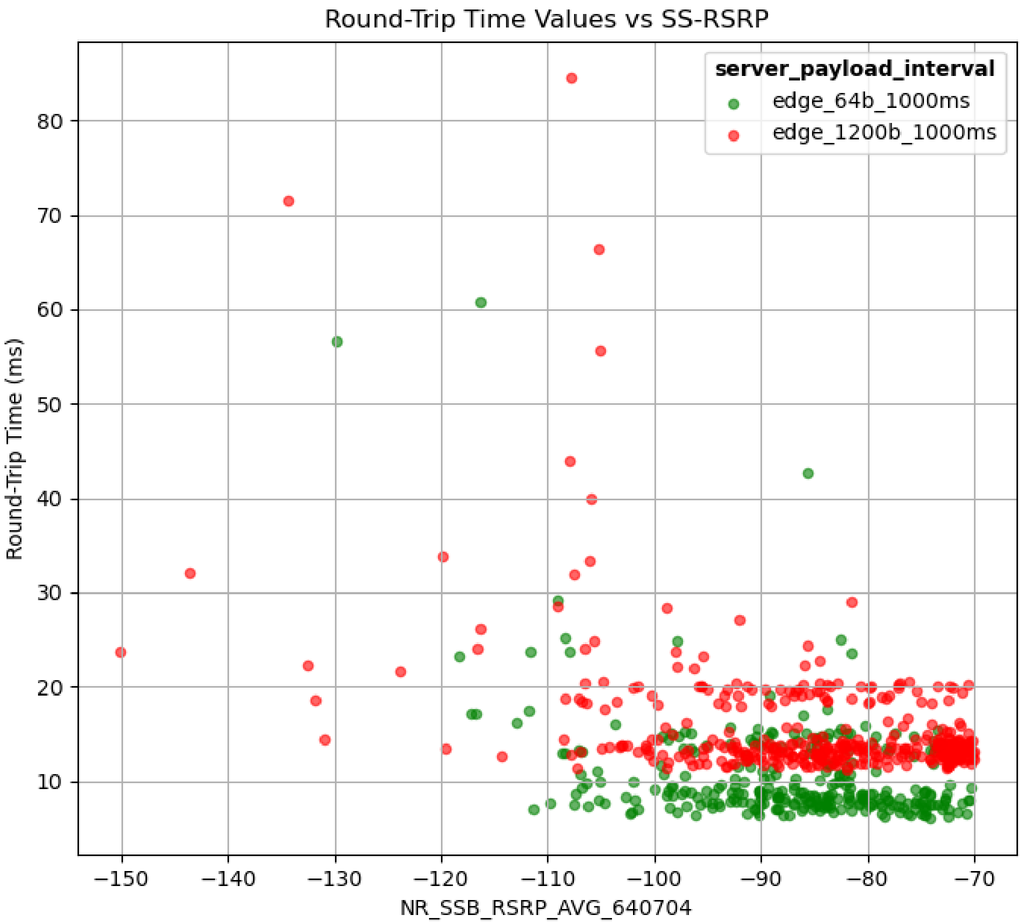
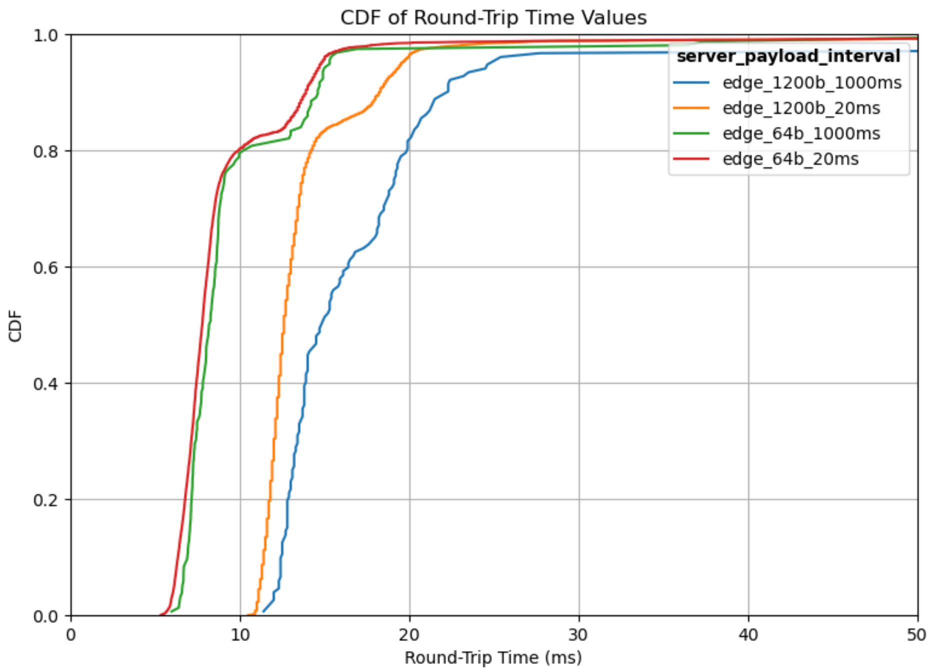


Figure 35: Scatter Plot of RTT vs SS-RSRP (64B_1000ms and 1200B_1000ms)

4.2.1.2 ToV UC Lap RTT Results

A similar evaluation was conducted on the TOV UC Lap, which is a smaller test track at IDIADA where the predictive QoS for ToD use case will be evaluated. As shown in Figure 36, the lowest measured RTT was 5.33 ms for 64B with a 20ms ping interval, while the median was 7.78 ms. The 64B payload consistently outperformed the 1200B payload by approximately 5ms, confirming the findings from the High-Speed Lap. The 20ms ping interval achieved 0.4-2.2 ms lower RTT compared to the 1000ms interval.



	Count	Min	Avg	Median	95%-tile	Max	Std
edge_1200b_1000ms	152	11.40	18.54	14.85	24.78	136.00	14.61
edge_1200b_20ms	4489	10.50	14.21	12.60	19.56	209.00	8.73
edge_64b_1000ms	156	5.97	10.04	8.22	15.30	73.70	7.29
edge_64b_20ms	5308	5.33	9.48	7.78	14.80	219.00	9.19

Figure 36: CDF of Round-Trip Time (RTT) Distribution Towards MEC Compute (64B and 1200B Payloads)

Figure 37 highlights that for the 64B_1000ms scenario, 79.5% of samples were below 10 ms, and 97.4% were below 20 ms, indicating stable low-latency performance.

Figure 37: RTT Heat Map Along TOV UC Lap for MEC Compute (64B_1000ms Scenario)

In the 1200B_1000ms scenario (Figure 38), the heat map shows no samples below 10ms, with 81.6% between 10 and 20ms and 3.3% above 30ms, again demonstrating the impact of larger payload sizes.

Figure 38: RTT Heat Map Along TOV UC Lap for MEC Compute (1200B_1000ms Scenario)

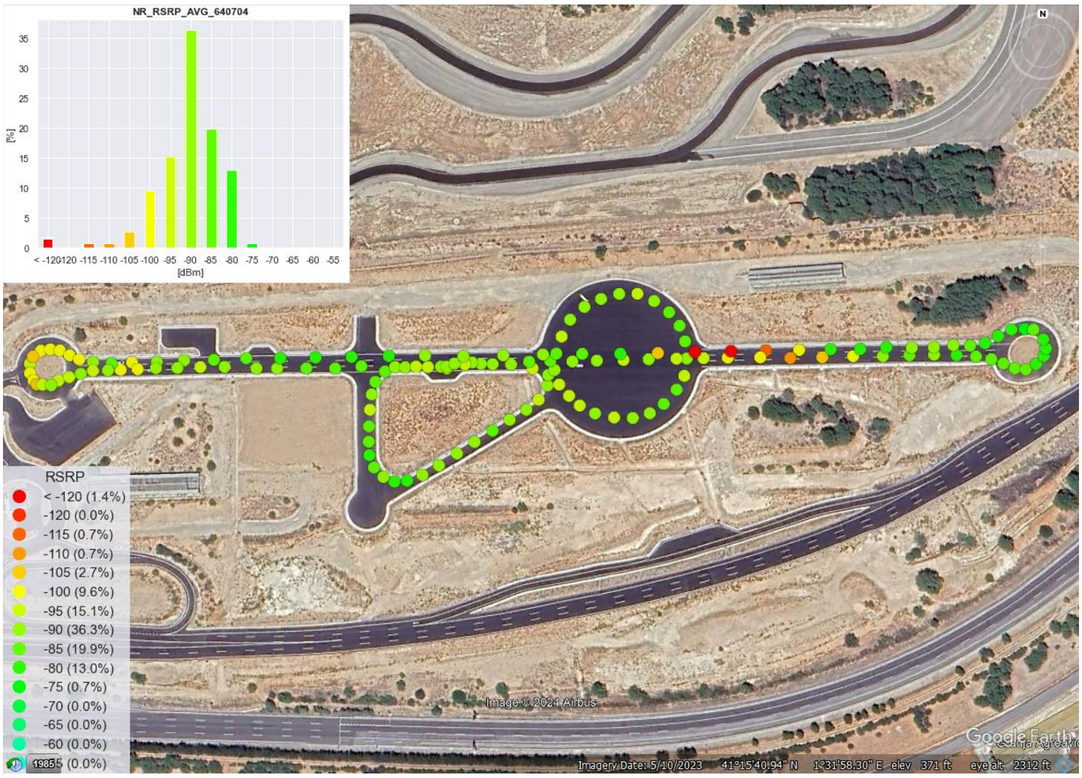


Figure 39: NR-n78 SS-RSRP Heat Map Along TOV UC Lap>

The NR-n78 SS-RSRP heat map (Figure 39) for this track also reveals a strong correlation between degraded RTT and poor RF conditions, although the RF environment on this track appeared more stable than the High-Speed Lap.

4.2.1.3 TOV UC Lap DL/UL Throughput Results

This section evaluates downlink (DL) and uplink (UL) throughput performance towards MEC compute along the TOV UC Lap (using iPerf3 UDP). The results confirm that the network consistently delivers high throughput across the track, with no areas experiencing significant degradation. The heat maps further demonstrate that the MEC compute platform and transport network are not limiting peak DL/UL Throughput.

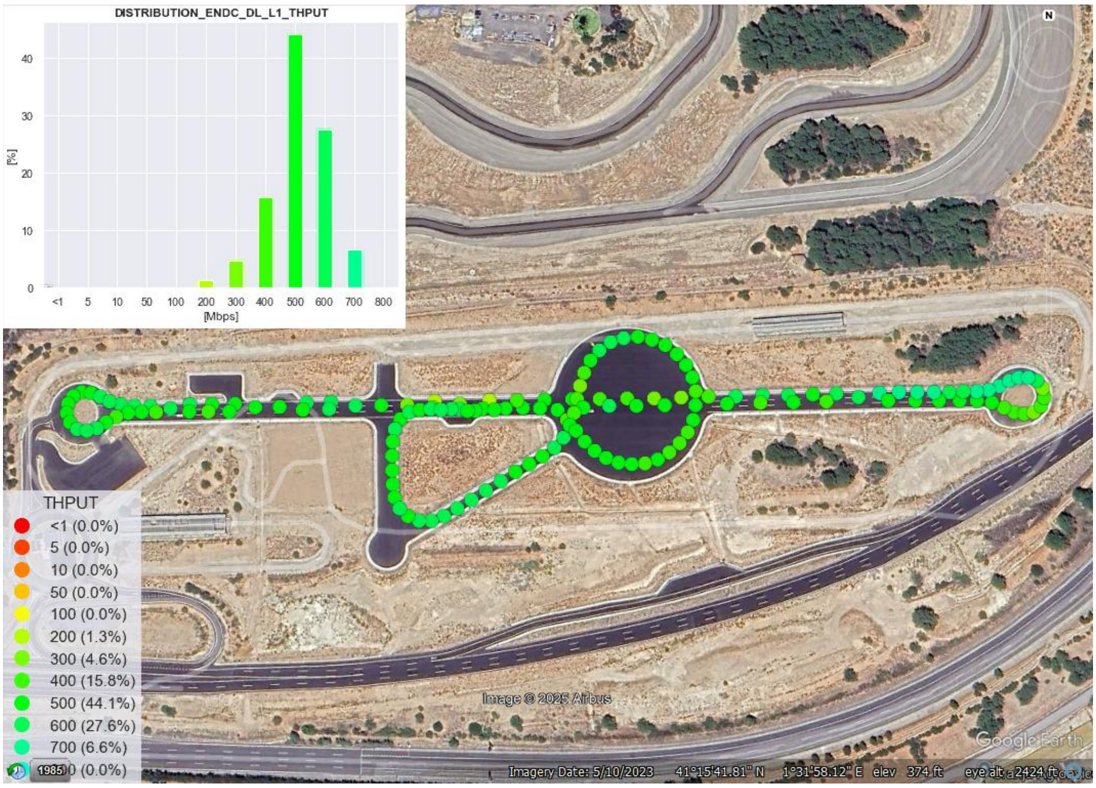


Figure 40: EN-DC DL L1 Throughput Heat Map.

Figure 40 shows that DL throughput remained above 200 Mbps at all times, with a significant portion of the track supporting 500 Mbps and beyond. The peak recorded DL throughput reached 675 Mbps, with full utilization of available NR resources (162 PRBs, 100% scheduling rate). This confirms that the MEC compute infrastructure does not impose any performance limitations.

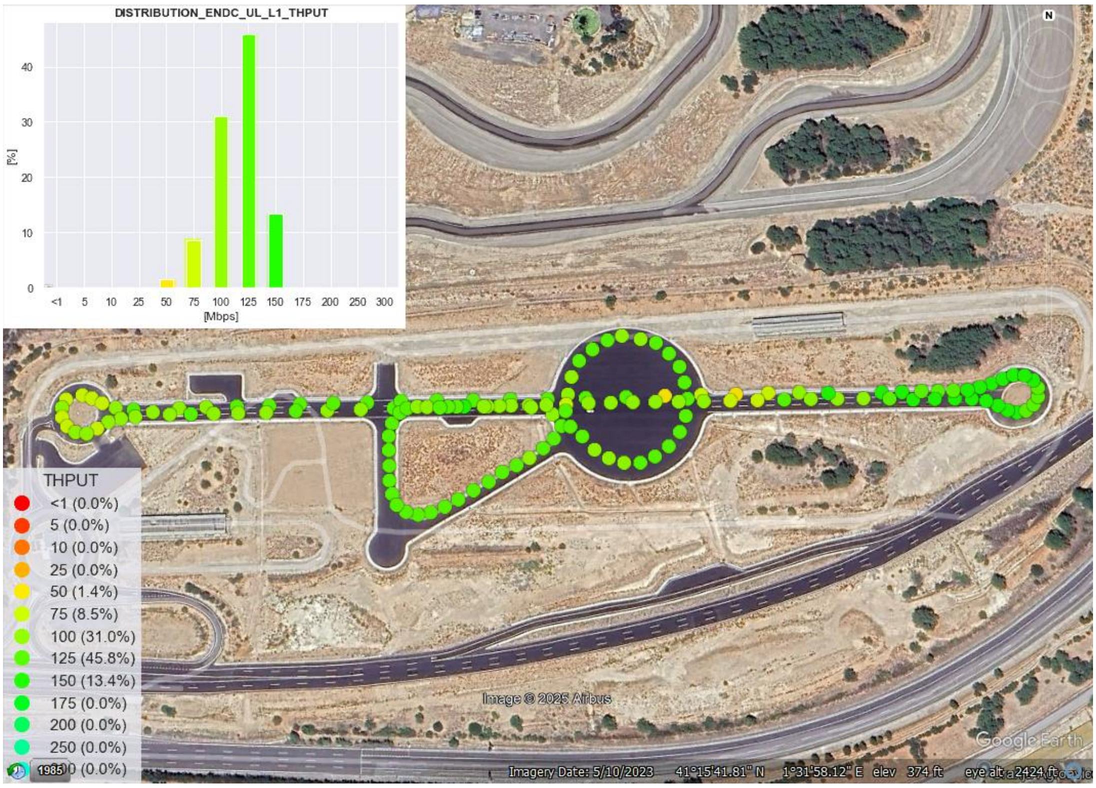


Figure 41: EN-DC UL L1 Throughput Heat Map

Similarly, Figure 41 indicates stable UL performance across the entire track, with no samples falling below 50 Mbps. The majority of the track supported 100 Mbps or higher, with a peak UL throughput of 133 Mbps. As in the DL case, MEC compute platform is not limiting peak UL performance.

These findings highlight the efficiency of the MEC compute deployment, ensuring that data-intensive applications can fully leverage the available 5G-NR capacity.

4.2.1.4 Conclusions

1. The RTT towards MEC compute was consistently low, with the majority of samples below 20 ms in both test tracks, highlighting the advantages of MEC computing for latency-sensitive applications.
2. Payload size significantly impacted RTT, with 64B consistently outperforming 1200B due to RLC segmentation.
3. Ping interval had a smaller but measurable effect on RTT, with lower intervals yielding slightly better latency. This results cannot be easily generalized as the difference is small and could be caused by statistical uncertainty of the measurement setup.
4. RF conditions were a critical factor affecting RTT, particularly when SS-RSRP dropped below -100 dBm. Optimizations in RF planning and network design can help mitigate these issues.
5. MEC compute does not limit data performance, with UE achieving peak rates of 675 Mbps (DL) and 133 Mbps (UL) under full NR and LTE resource utilization.

4.2.2 Comparison Between Cloud and MEC Compute

In this analysis, the term *cloud* refers to measurements taken towards external servers hosted outside the mobile network.

For RTT evaluation, the reference server was Google's public DNS (8.8.8.8), a commonly used and globally distributed service. The tests were conducted along the High-Speed Lap at IDIADA, covering different payload sizes (64B and 1200B) and varying ping intervals (20ms and 1000ms).

For throughput measurements, a dedicated *iPerf* instance was deployed in the AWS cloud, specifically in the Frankfurt region. The measurements were performed using UDP traffic, allowing an evaluation of maximum achievable throughput without flow control constraints. This setup enabled uplink and downlink performance comparisons between *MEC* and *cloud* solutions.

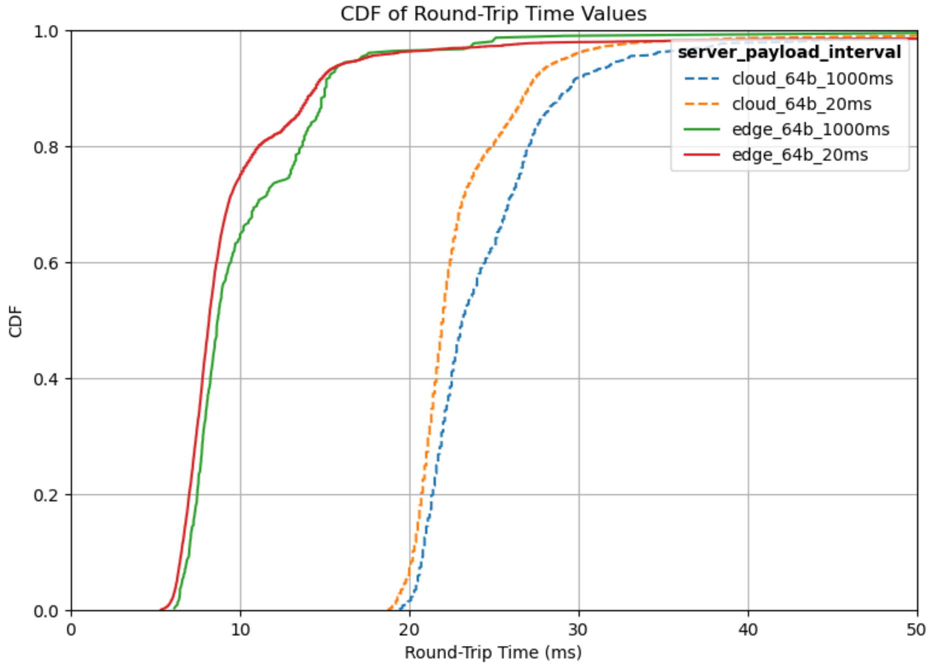
The primary objective was to assess the impact of MEC computing on latency and throughput relative to a traditional cloud-based approach, providing insights into its advantages for vehicular connectivity applications.

4.2.2.1 64 Byte Payload Comparison

Latency assessment with a 64B payload at IDIADA's High-Speed Lap highlights the significant advantage of MEC compute over cloud servers. As shown in Figure 43, the lowest measured RTT for edge_64b_20ms was 5.31 ms, with a median of 8.17 ms. This consistently outperformed the cloud server setup by a margin of approximately 13 ms, which aligns with expectations due to the MEC's proximity to the user. Figure 27 proves this outperformance, considering that hop number 3 in the figure is the IDIADA firewall and the travel time from hop 4 to hop 12 is reported between 9.28 ms and 16.24 ms. In order to cross-check the mentioned outperformance, Figure 42 shows a RTT from a VM inside the MEC that is connected the same IDIADA firewall (i.e. hop 3 in Figure 27) toward the same Cloud destination. The average RTT is 14.59 ms that proves the estimation.

```
neutroon@uc1:~$ ping 8.8.8.8
PING 8.8.8.8 (8.8.8.8) 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=116 time=15.0 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=116 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=3 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=4 ttl=116 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=5 ttl=116 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=6 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=7 ttl=116 time=14.7 ms
64 bytes from 8.8.8.8: icmp_seq=8 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=9 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=10 ttl=116 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=11 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=12 ttl=116 time=14.6 ms
64 bytes from 8.8.8.8: icmp_seq=13 ttl=116 time=14.5 ms
64 bytes from 8.8.8.8: icmp_seq=14 ttl=116 time=14.6 ms
^C
--- 8.8.8.8 ping statistics ---
14 packets transmitted, 14 received, 0% packet loss, time 13023ms
rtt min/avg/max/mdev = 14.482/14.599/14.956/0.110 ms
neutroon@uc1:~$
```

Figure 42: RTT from VM inside MEC to Cloud.



	Count	Min	Avg	Median	95%-tile	Max	Std
cloud_64b_1000ms	764	19.40	25.68	23.20	32.88	298.00	14.16
cloud_64b_20ms	6972	18.70	23.56	22.00	29.10	201.00	8.77
edge_64b_1000ms	307	6.12	10.62	8.69	17.07	60.80	5.73
edge_64b_20ms	5690	5.31	10.49	8.17	17.20	258.00	10.82

Figure 43: CDF of Round-Trip Time (RTT) Distribution for MEC and Cloud Compute (64B Payload)

The ping interval of 20 ms yielded around 0.8 ms lower RTT compared to the 1000 ms interval, demonstrating a modest impact from increased ping frequency.

Figure 44 reveals that in the edge_64b_1000ms scenario, 63.8% of RTT samples were below 10 ms, and 96.4% of samples were below 20ms, indicating a highly stable low-latency performance.

Figure 44: RTT Heat Map Along High-Speed Lap for MEC Compute (64B_1000ms Scenario).

In contrast, Figure 45 for cloud_64b_1000ms shows no samples below 10 ms, only 1.3% between 10 and 20ms, and a staggering 98.7% above 20 ms, with 11.1% exceeding 30 ms.

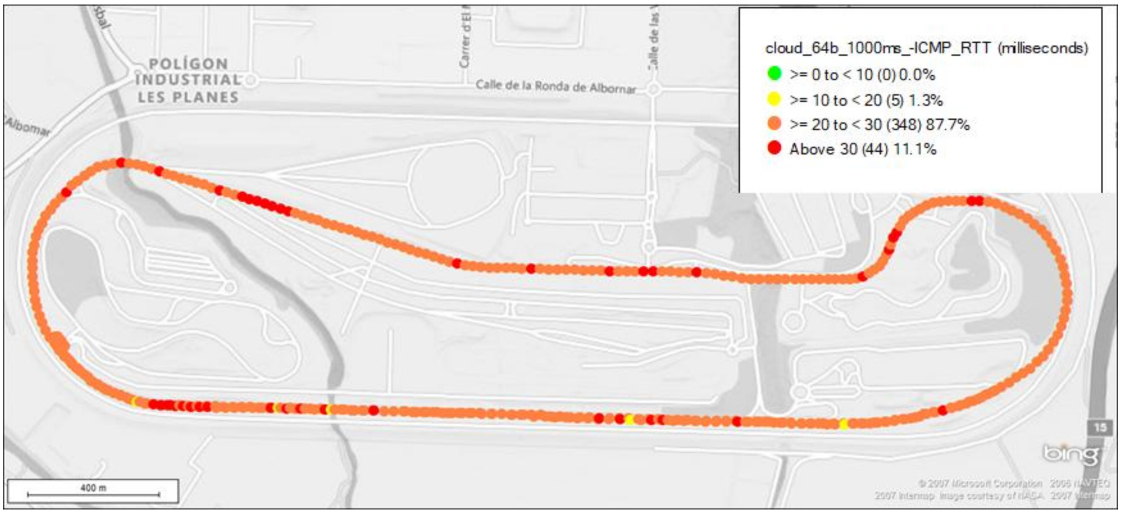
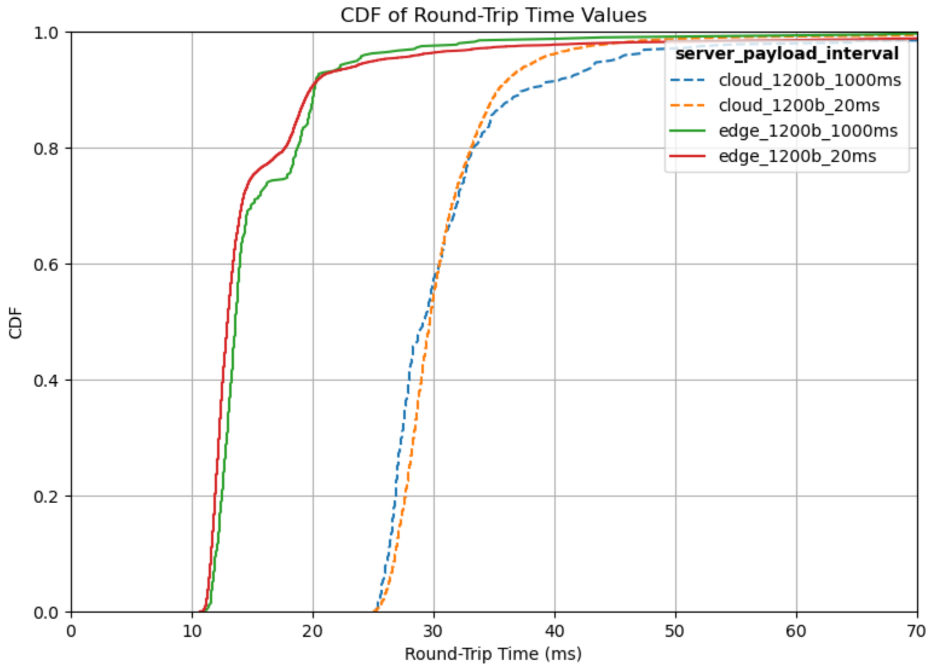


Figure 45: RTT Heat Map Along High-Speed Lap for Cloud Compute (64B_1000ms Scenario)>

Both the CDF Figure and heat maps highlight that MEC compute consistently provides significantly lower latency at all points along the High-Speed Lap compared to cloud servers for a 64B payload, making it an ideal solution for latency-sensitive applications.

4.2.2.2 1200 Byte Payload Comparison

The latency evaluation with a 1200B payload produced similar insights, with an even greater performance disparity between MEC and cloud compute. Figure 46 shows that the lowest measured RTT for edge_1200b_20ms was 10.7 ms, with a median of 13 ms, approximately 14 ms lower than the cloud setup.



	Count	Min	Avg	Median	95%-tile	Max	Std
cloud_1200b_1000ms	319	25.20	33.97	29.20	44.67	656.00	37.41
cloud_1200b_20ms	5937	25.00	31.13	29.70	38.60	217.00	7.65
edge_1200b_1000ms	397	11.20	15.77	13.60	23.72	84.50	6.96
edge_1200b_20ms	5537	10.70	16.24	13.00	25.30	321.00	15.39

Figure 46: CDF of Round-Trip Time (RTT) Distribution for MEC and Cloud Compute (1200B Payload)

Reducing the ping interval to 20 ms resulted in a 0.5 ms RTT improvement compared to 1000 ms, suggesting a diminishing benefit with larger payload sizes. As the ping interval did not have a consistent impact and the difference between the different intervals were under 1 ms, these results cannot be generalized and should be considered with cautious.

As illustrated in Figure 47, the edge_1200b_1000ms scenario exhibited 87.4% of RTT samples below 20ms, and only 2.5% above 30ms, indicating robust low-latency performance despite the larger payload size.

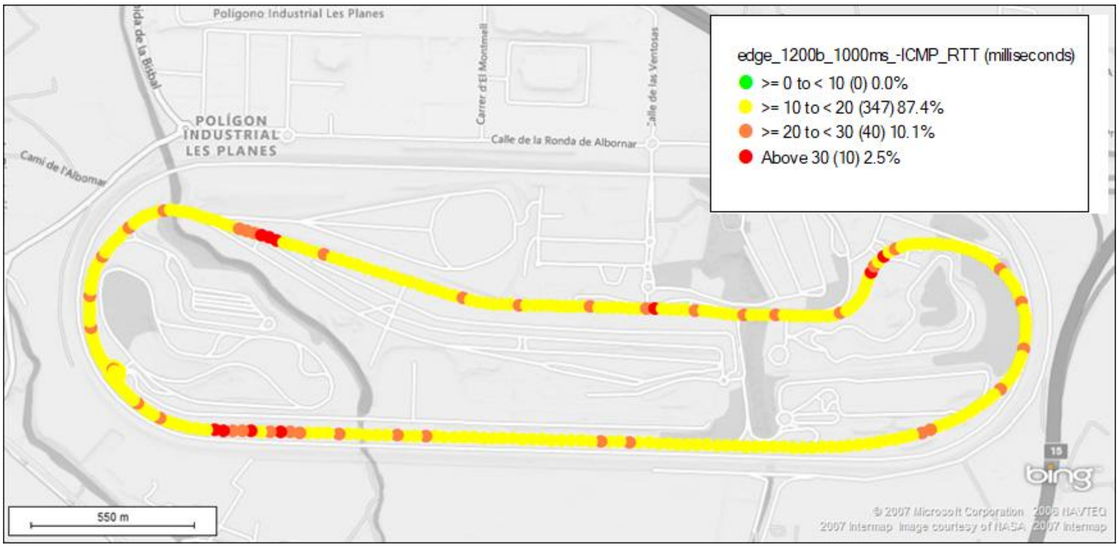


Figure 47: RTT Heat Map Along High-Speed Lap for MEC Compute (1200B_1000ms Scenario)

Conversely, Figure 48 for the cloud_1200b_1000ms scenario revealed no samples below 20 ms, with 55.6% between 20 and 30 ms and a concerning 44.4% above 30ms.

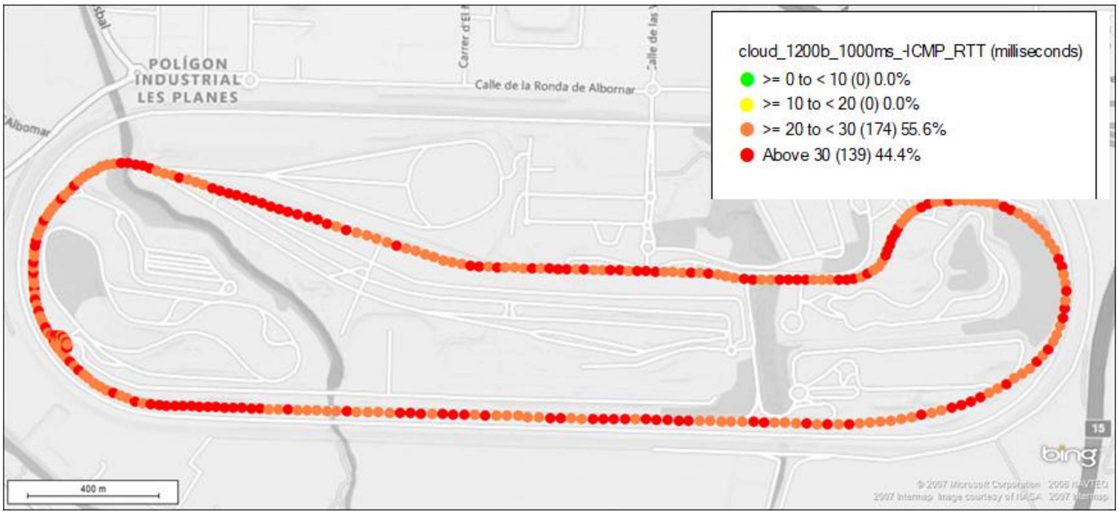


Figure 48: RTT Heat Map Along High-Speed Lap for Cloud Compute (1200B_1000ms Scenario)

Both the CDF and heat maps clearly demonstrate that MEC compute maintains consistently lower latency for larger payloads, further underscoring the limitations of relying solely on cloud servers for demanding applications.

4.2.2.3 EN-DC DL/UL L1 Throughput Comparison

This section examines downlink (DL) and uplink (UL) throughput performance for MEC compute and cloud-based solutions. Throughput trends are analysed across varying SS-RSRP levels to assess potential performance differences. The comparison provides insight into whether MEC computing influences data throughput or if performance remains consistent between both solutions.

Figure 49 presents two curves—green (MEC) and red (cloud)—that are closely aligned and cross each other across the SS-RSRP range of -110 to -70 dBm. This indicates that there is no noticeable difference in DL throughput performance between MEC and cloud solutions. This figure reports the L1 throughput performance.

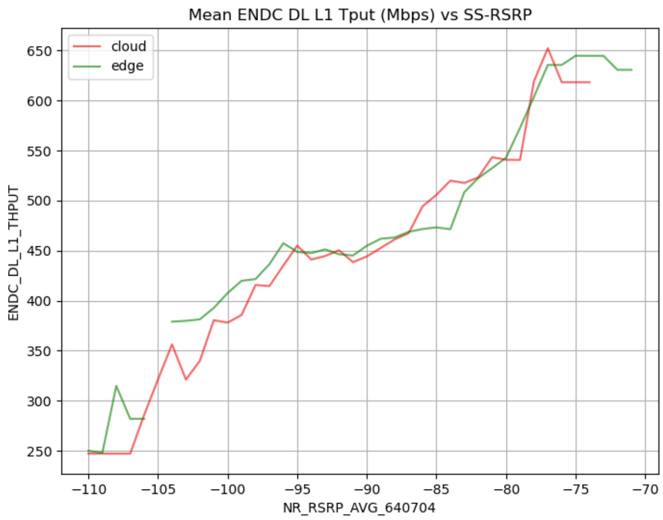


Figure 49: Mean EN-DC DL L1 Throughput vs SS-RSRP.

Figure 50 shows the green (MEC) curve consistently 20-40 Mbps above the red (cloud) curve across the SS-RSRP range of -110 to -70 dBm. This difference is attributed to varying LTE network load during the tests, where the LTE PCell allocated more PRBs on average during the MEC test compared to the cloud test. The observed UL throughput (L1) difference is a result of LTE resource availability rather than the server type.

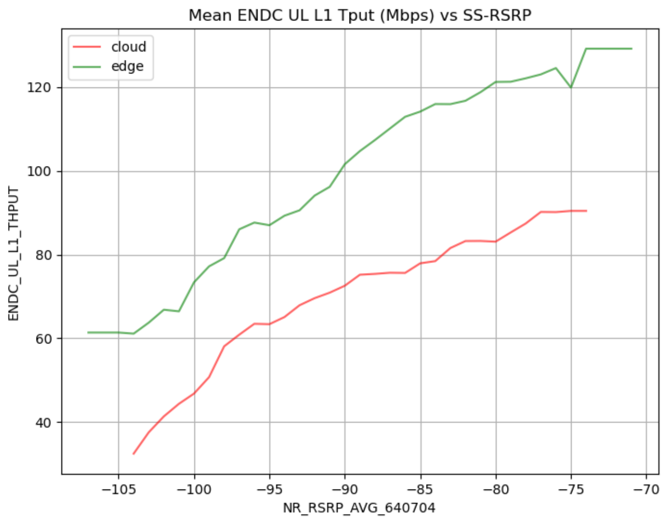


Figure 50: Mean EN-DC UL L1 Throughput vs SS-RSRP

4.2.2.4 Conclusions

- MEC compute significantly reduces RTT for both 64B and 1200B payload sizes compared to cloud servers. The observed gains of 13 ms for 64B and 14 ms for 1200B highlight the value of proximity-based compute solutions. Although it cannot be generalized to other scenarios, MEC compute consistently provides superior latency performance at every point along the High-Speed Lap, making it a critical enabler for real-time, latency-sensitive applications. This is due in part to the fact that the location of the cloud server is in USA. We also did some latency tests to other machines in Spain and the results were very diversified with some having low latency and other with high latency. This shows also the uncontrolled latency towards the cloud.
- Downlink throughput remains similar for both MEC and cloud solutions across the entire SS-RSRP range, indicating no performance advantage for MEC compute in the downlink direction. The observed uplink throughput is consistently higher when using MEC compute, with a noticeable gain of 20–40 Mbps over the cloud solution. This difference is attributed to varying LTE network load during the tests, where the LTE PCell allocated more PRBs on average during the MEC test compared to the cloud test. The observed UL throughput difference is a result of LTE resource availability rather than the server type.

5 Conclusions

This document presented advanced features proposed within WP4 of the TARGET-X project, designed to enhance defined use case functionalities in the automotive sector.

While initial use case deployments relied on cloud-based server-side application execution, this deliverable introduces the integration of a MEC server into the trial network to improve application latency (especially in terms of controllable and explainable latency), a critical KPI for the automotive sector, particularly for tele-operated vehicles. Measurement results indicate that running applications on the MEC reduces end-to-end RTT by approximately 10 ms. Although the decreased value cannot be generalized to other scenarios, the presence of a MEC will always provide a controllable and more stable (in some cases much lower) latency than the cloud.

The deployment of new virtual environments, specifically VMs, to host applications is streamlined through a user-friendly Graphical User Interface (GUI), facilitating VM deployment with specified computational resources and orchestrating network dependencies for users without specialized expertise.

Integrating the MEC server into the IDIADA network, the automotive trial site for the TARGET-X project, enables the offloading of application computation functions from field devices (vehicles) to the virtual environment on the MEC server. This architecture offers benefits such as increased computational resource utilization in the MEC, reduced vehicle energy consumption (particularly important for electric vehicles), centralized decision-making for some use cases as the cooperative perception use case, etc. However, challenges arise, especially in the automotive sector, due to the mobility of UE, i.e., vehicles, across network coverage and potential variations in network connectivity quality. Connectivity degradation during vehicle movement may impact application functionality, which relies on connectivity to the MEC. Therefore, this deliverable proposes dynamic service orchestration, initially deploying applications on the MEC for its inherent benefits, while continuously monitoring connectivity quality and migrating computation functions to the extreme edge (vehicles) when connectivity becomes unreliable. Three use cases are presented as PoC to validate the dynamic service orchestrator functionality.

A third advanced feature addressed in this deliverable is the development of a framework that monitor the network performance can be monitored upon subscription from an application such tele-operated driving. The framework also generates warnings when network performance is expected to be insufficient within the route chosen by tele-operated vehicle. The interaction between the network and the application is done through a network exposure API with extended features to what Quality on Demand API of the CAMARA API can provide. The primary objective of this API deployment is to demonstrate how the interaction between the network and applications can enhance application performance efficiently and reliably. It should be noted that the API was integrated in a 5G NSA network and can be easily adapted to 5G SA networks or to any other scenarios.

Given the importance of location accuracy in the automotive sector, especially for automated vehicles, this document also introduces an advanced positioning system employing Real-Time Kinematic (RTK) to achieve decimeter-level positioning accuracy. Additionally, it initiates a discussion on exposed positioning APIs and their facilitation of application functionalities.

Finally, VISTA, a watchdog monitoring tool, is developed within WP4 to monitor network KPIs from the user perspective. The outputs from VISTA are utilized in the dynamic service orchestration.

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