INTEGRATED PILOT SETUP

Deliverable D4.1

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Deliverable

INTEGRATED PILOT SETUP

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SHORT ABSTRACT	This deliverable describes the detailed testbed setup, including the 5G network and edge computing facilities, and a description of the use case scenarios and requirements.
KEYWORDS	Testbed, 5G, edge computing, use cases, KPI, automotive, system integration.
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Disclaimer

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. In particular, 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 presents three use cases showing what enhancement 5G network could bring to automotive vertical and describes IDIADA Connected Vehicle Hub (CVH) or IDIADA testbed that will be used to evaluate these use cases.

The document first describes, in detail, IDIADA CVH with its 5 pillars: 5G network, edge computing facilities, cloud platform, modems and routers, and vehicles and equipment. In addition, it presents the status of the deployed infrastructure, system integration, and the first 5G network proof test that showed that basic 5G connectivity features are well deployed.

Furthermore, the document presents three use cases and their scenarios. These use cases are cooperative perception, digital twins, and predictive quality of service for tele-operated driving. For each scenario, the requirements in terms of key performance indicators (e.g., latency, throughput, reliability) are introduced.

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
API	Application Programming Interface
APN	Access Point Name
AWS	Amazon Web Services
CAM	Cooperative Awareness Message
CAV	Connected and Autonomous Vehicle
CCAM	Cooperative, Connected, and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CVH	Connected Vehicle Hub
CWS	Collision Warning Service
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communication
GNSS	Global Navigation Satellite System
HDD	Hard Disk Drive
HMI	Human Machine Interface
IVS	In-Vehicle System
KPI	Key Performance Indicator
LDMS	Local Dynamic Map Service
NAT	Network Address Translation
NSA	Non-standalone
OEM	Original Equipment Manufacturers
PLMN	Public Land Mobile Network
QoS	Quality of Service
RAM	Random-Access Memory
RAT	Radio Access Technology
ToC	Tele-operation Centre
ToD	Tele-operated Driving
ToV	Tele-operated Vehicle
V2I-DSS	Vehicle to Infrastructure Data Sharing Service
V2N	Vehicle to Network
vCPE	Virtual Customer Premises Equipment

VLAN	Virtual Local Area Network
VPN	Virtual Private Network

1 Introduction

In the last decade, the automotive industry has witnessed a tremendous evolution towards automated and teleoperated vehicles that will have a huge impact on human life. However, this paradigm shift from human driven vehicle to autonomous vehicle generated several substantial challenges, especially in terms of human safety. This evolution was accompanied by tremendous advances in both communication and computing technologies that enabled safe and efficient autonomous driving. One technology supporting this is 5G/6G networks that can guarantee that all communications requirements in terms of latency, data rate, reliability, and availability can be fulfilled.

In this context, one of the objectives of the TARGET-X project is accelerating digital transformation by demonstrating and evaluating the potential of 5G/6G networks in realistic automotive environments. This deliverable will provide a detailed description of IDIADA testbed, denoted in this document by IDIADA Connected Vehicle Hub (CVH), that will be used to validate the end-to-end performance of automotive use cases in a realistic environment. The testbed includes 1) 5G non-standalone network, in addition to 2G/3G/4G networks (explained in section 2.1), 2) edge computing facilities (explained in section 2.2), 3) public Internet (public cloud) access (explained in section 2.3), 4) 5G modems and routers (explained in section 2.4), and 5) Teleoperated, connected, and autonomous vehicles (explained in section2.5). In addition, the document will describe how the edge computing facilities are integrated in the infrastructure to be able to deploy the server side of applications required by the use cases. The testbed will be used to evaluate the performance of three use cases that are briefly described in this document: Cooperative perception, digital twins, and predictive Quality of Service (QoS) for Tele-operated Driving (ToD).

Cooperative perception will allow vehicles to increase their perception of the environment by enabling the exchange of sensor information between vehicles and infrastructure, and among vehicles. This will support automated driving above level 2 (i.e., the vehicle can perform most or all driving tasks with or without human intervention possibilities) and is estimated to be deployed starting from 2026 [5GAA22-W]. In TARGET-X, we defined and will evaluate two cooperative perception scenarios that will be described in this document.

Digital twinning in the automotive vertical allows the creation of virtual replicas of the vehicle, road environment, and/or network used to connect the vehicles. In the case of automotive vertical in TARGET-X, digital twinning is used to evaluate the performance of cooperative perception techniques using simulation before performing real life tests [WHT22]. In this document, we describe the digital twins that allow the simulation of the cooperative perception use cases also presented herein.

Predictive QoS techniques allow the prediction of changes in QoS provided by the communication network and early notification to vehicles affected by these changes. This will provide vehicles or humans teleoperating vehicles with a sufficient window of time to take the necessary actions that mitigate the impact of these changes [KMP+21]. In this document, we describe briefly the predictive QoS for ToD use case that will be tested in the project.

These use cases will be briefly described in this deliverable together with their technical requirements in terms of Key Performance Indicators (KPIs) that will allow us to evaluate the performance of the developed techniques and deployed infrastructure.

1.1 Document structure

The document is structured as follows. In section 2, we will describe the testbed setup in terms of 5G network, vehicles and equipment, modems and routers, and the integration of edge computing facilities in the testbed. In section 3, we provide a brief description of the three use cases that will be developed and tested during the project's lifetime. In addition, we describe in this section the KPIs that will be used to evaluate their performance. In section 4, we present a summary of the main topics discussed in this deliverable.

2 Automotive testbed setup

With the aim of replicating many possible network conditions that a vehicle might encounter on the road, the ability to cover test tracks with the full range of access technologies that enable the development and deployment of V2X applications is an important requirement from a network design perspective. This includes Dedicated Short-Range Communication (DSRC) devices compliant with IEEE 1609 and ITS G5 standards, as well as a cellular network spanning all generations from 2G to 5G.

For this reason, the TARGET-X automotive vertical will test the use cases developed by project partners and third parties in the test site (IDIADA Connected Vehicle-Hub – CVH) in Santa Oliva (near Barcelona), Spain (see Figure 1). The testbed is located on the IDIADA proving ground. It consists of a 5G network (See Section 2.12.2), an Edge computing facility (See Section 2.2), a hyperscaler public cloud computing platform (See Section 2.3), modems and routers (See Section 2.4), and vehicles and equipment (See Section 2.5).

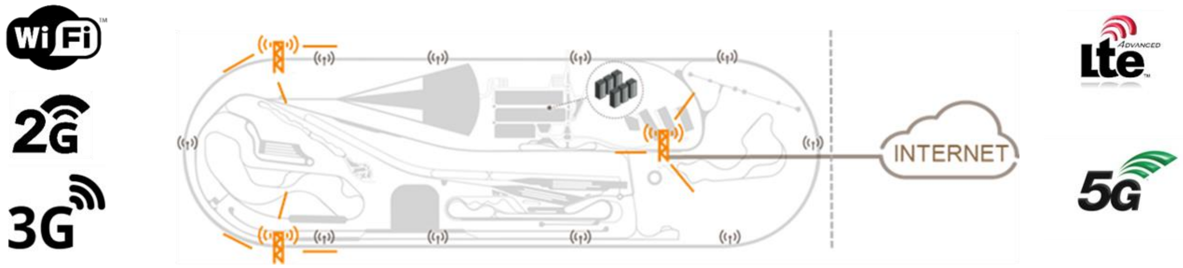

Figure 1. IDIADA Connected Vehicle Hub - Technologies.

The proving ground covers an area of 370 hectares and comprises 14 multi-purpose test tracks with a unique, exclusive, and controlled environment capable of reproducing worldwide network configurations and conditions to develop and validate connected vehicle solutions from 2G to 5G Non-Stand Alone (NSA). Full coverage of the proving ground is provided by 4 multi-standard radio base stations (see Figure 2), which complement the DSRC infrastructure by jointly building a complete connectivity test platform.

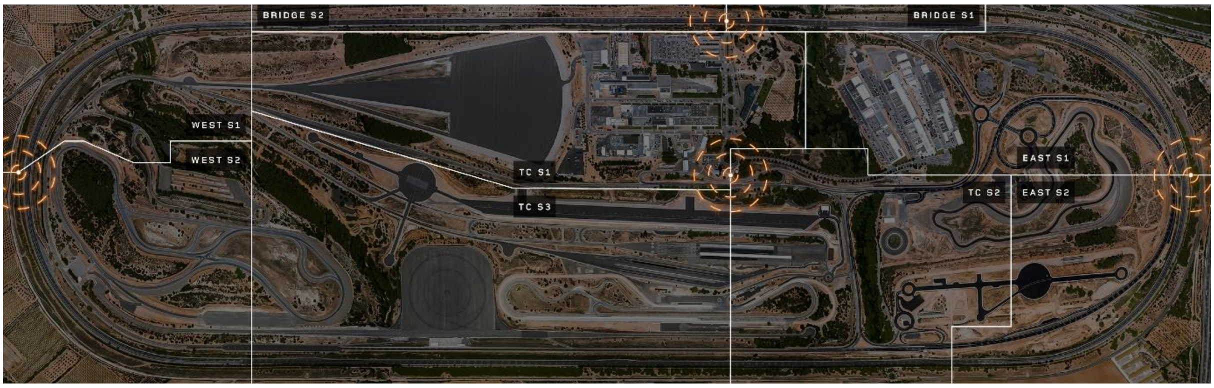

Figure 2. IDIADA Connected Vehicle Hub - Antennas Sites.

2.1 5G network

One of the main objectives of the test tracks on the proving ground is to replicate conditions and situations that may occur on the roads of different countries. These capabilities are also reflected in the available mobile communication technologies, as the proving ground is part of a commercial network and offers the possibility to realize services with different situations that could occur in everyday road use. Examples of such services and scenarios are presented in Table 1.

Table 1. Example of services and scenarios offered by IDIADA CVH.

TYPE OF SERVICE	**BASIC**	All technologies are enabled (2G, 3G, 4G, and 5G NSA) with carrier aggregation for LTE (4G) and NR (5G), MIMO (4x4 → 4G and 8x2 → 5G) and 300 Mbps throughput with 18 ms latency on average.
	Predefined	Intra-site handovers, Inter-site handovers, and Inter-RAT handovers.
		4G and 5G carrier aggregation with which tests are performed by combining two 4G carriers (1800 MHz and 2100 MHz) or 4G and 5G carriers.
		Variable signal conditions to allow testing under different radio channel quality conditions.
		MIMO test whereby, by changing some features, we are able to test different MIMO configurations (2x2, 2x4, 4x4).
		IMS voice test whereby customers can test standard IMS voice calls through IDIADA-Orange commercial SIMs.
	Customized	If basic and predefined approaches do not fit with client's requirements, we will analyse and provide, if possible, a tailored solution. This service allows clients to describe the test they wish to perform. When this happens, the connected vehicle team must study if changes are possible and finally confirm the decision to proving ground department. **Each case must be studied to determine whether it is possible to implement the changes on all tacks.**

To meet the test requirements, the test site has an operational network supporting mobile generations from 2G to 5G NSA, with bandwidths similar to those found in public networks.

The 4 base stations consist of a total of 9 sectors (see Figure 2) with the following technologies:

- 2G in 1800 MHz (Bandwidth = 0.2 MHz per sector)
- 3G at 900 MHz (Bandwidth = 5 MHz)
- 4G in 1800 MHz (Bandwidth = 20 MHz) and 2100 MHz (Bandwidth = 10 MHz)
- 5G NSA at 3500 MHz (Bandwidth = 60 MHz)

A dedicated Public Land Mobile Network (PLMN) ID is assigned to testbed users, allowing data to and from the vehicles to be efficiently routed to the on-premises infrastructure and platforms for third party hardware and software testing. This is possible thanks to the fact that the 5G NSA core is a dedicated core located in the IDIADA premises.

As a connection method, SIM cards from the IDIADA network will be available with different network configurations. Such configurations are divided into cards with RAT limitation (e.g., only 5G connectivity) and cards with throughput limitation (e.g., 150 Mbps limits). Moreover, there are different Access Point Names (APNs) to the network that will be used to distribute the network resources according to the various open call applicants throughout the design and development of the challenges identified in WP7. The list of APNs will be provided in deliverable D4.2 [TAR24-D42].

2.2 Edge computing facility

The edge computing facility will provide the environment where third-party and WP4 applications will run and benefit from 5G network connectivity. The purpose of considering 5G edge computing is to process use case data with lowest possible end-to-end latency. Placing this process point in the same premises where the cellular network is located adds the feature of controlled end-to-end path for the services with reduced end-to-end latency, which is mandatory for many automotive use cases. In this section, a deep description of the edge server and relevant info about how to deploy it is provided.

2.2.1 Description

The 5G edge server is a bare metal server, currently running Ubuntu 22.04 as the operating system with Open Stack [OPS] as virtual infrastructure manager. The features of this server are explained below:

- This server offers virtual machines (VM) that can host the server side of applications of the use cases. VMs also can be considered as middleware to facilitate communication with clouds. This last functionality is important for use cases (especially in environment having legacy network technologies) that do not have the right to directly communicate with the cloud. In this case, their server side can be placed in a VM in the edge side where the data flow can be redirected to a destination in the cloud. In some other use cases, data flow comes from multiple end points in the 5G network and traffic should be first locally aggregated before sending them to a cloud location. In this case, the edge server will play the aggregation role.
- Based on the requirements of the application that is hosted in the VM, the latter can rely on a subset of physical resources (Virtual Customer Premises Equipment – vCPE, Random-Access Memory – RAM, Hard Disk Drive – HDD, and networking resources) of the total available in the server. OpenStack is responsible of guaranteeing the availability of resources for the VM and their proper deployment.
- The server can offer virtual switching. Hence VMs can communicate among each other. It can be considered as having multiple applications communicating and contributing for specific outcome.
- The edge server can adapt VMs to communicate with customized network settings. Hence, whatever is needed in terms of network customization like, Virtual Local Area Network (VLAN) tagging, subnet assignment, bridging, Network Address Translation (NATing), tunnelling, Virtual Private Networks (VPNs), packet forwarding, special encryption method, customized routing, special encapsulation or re-capsulation, protocol change, and so on, will be possible through this edge infrastructure.

The hardware resources provided with this server are:

- 16 CPU cores (which can be virtually extended to 32),
- 32-64 GB of RAM,
- 1-2 TB of hard disk space.

These physical resources will be distributed between the VMs that will be created according to the specific use cases' requirements and challenges.

The VM created will be shared with the third-party applicants with access to its resources. The guest operating system running on the VM can be customized, but further support is limited to Linux based systems only. The remote access method can be either through SSH or remote desktop, based on the security policies which IDIADA has in place.

2.2.2 Limitation

The hardware resources offered by the edge server are limited to the physical resources mentioned in the previous section. For this reason, it is necessary to properly planning the access to the edge resources by third parties, to avoid resource competition. Moreover, additional networking rules can be a limitation if special requirements from third-party services are needed.

2.3 Hyperscaler public cloud platform

The hyperscaler public cloud platform allows the deployment of backend services accessible through the Internet. The path between the mobile user and the service located in the cloud is longer than the path towards the service located in the Edge, which implies higher latency and, in some cases, lower throughput. However, the public cloud offers good scalability and flexibility, and complements the edge, in case the latter does not have enough resources to serve the application. A combination of Edge services for low latency features/services and public cloud for no latency-critical services is usually recommended.

2.3.1 Description

The hyperscaler public cloud provider selected for this project will be Amazon Web Services (AWS), which offers a powerful suite of services and tools to deploy platforms compatible with the project objectives. Unlike the Edge services, which use VMs, the applications to be deployed on AWS will run as docker containers, managed by an orchestrator based on Kubernetes. The containers' main features are:

- High scalability to easily adapt to higher demanding conditions, which guarantees certain levels of service availability and performance.
- Interconnection between the services of the platform is guaranteed, as they are part of the same domain/cluster. Also, AWS offers flexible networking capabilities to connect the cloud to IDIADA premises through Amazon Virtual Private cloud [AMA23], in order to reach the 5G network and, therefore, reach the road users bidirectionally.

A set of container-based services will be deployed, with the same functionalities as the edge computing facility and access method through SSH or remote desktop, based on the security policies which IDIADA has in place.

2.3.2 Limitation

In terms of limitations in the AWS tool, there are currently no limiting events. In terms of risks, IDIADA considers that they may exist when creating additional connection rules specific to the project. As the IDIADA cloud will not be able to create connections for third-party services, the solutions set up in WP7 with the open calls will have to be deployed only on the Edge (see section 2.2).

2.4 Modems and Routers

The modems and routers used in this project have two objectives:

- Send and receive data as required by the applications described in section 3.
- Collect network/modem/cloud metrics to better understand measured application-level KPIs.

Two modems/routers have been identified: Quectel RM500Q-GL 5G modem and Teltonika RUTX50 5G router. The selected modems/routers support both 5G NSA and SA technologies.

- The Quectel RM500Q-GL modem (See Figure 3) is a 5G modem that supports several radio bands including N78 band that will be used in the TARGET-X project. It can provide data rates up to 2.5 Gbps in downlink and 900 Mbps in uplink as mentioned in the data sheet [QUE]. 4x4 and 2x2 MIMO configurations are enabled by this modem. The modem is connected to a laptop through which other network elements can be connected.

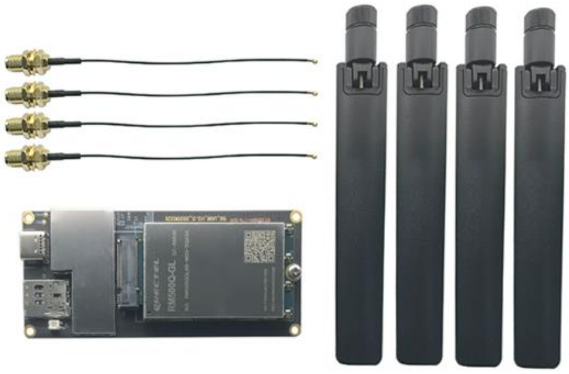

Figure 3. Quectel RM500Q-GL modem.

- The Teltonika RUTX50 5G router (see Figure 4), is a modern router designed to work in the automotive sector, as it has many adapters for various types of vehicle compartments. It has a kit consisting of 4 cellular antennas, 2 Wi-Fi antennas and 1 Global Navigation Satellite System (GNSS) antenna. It supports both 5G NR SA and NSA bands (e.g., N38, N40, N41, N41, N77, N78), 4G bands (LTE-FDD: B1, B3, B5, B7, B8, B20, B28 and LTE-TDD: B38, B40, B41, B42, B43) [TEL22].

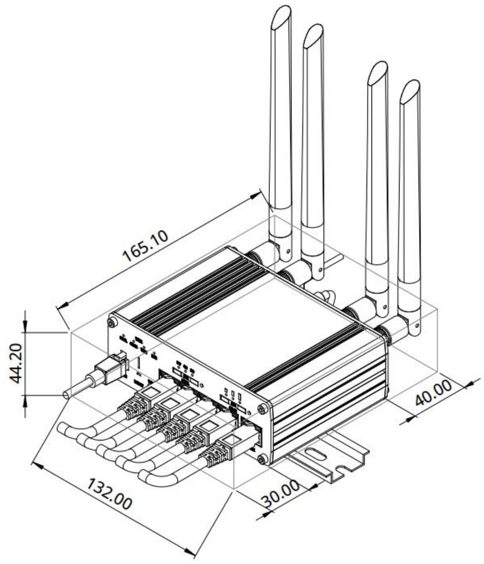

Figure 4. Teltonika RUTX50 5G router

2.5 Vehicles and Equipment

For the different tests that will be carried out during the project, IDIADA will provide two vehicles to perform the different use cases. The first one will be a connected vehicle, called CAVRide, with the capability to recreate Collective Perception Message (CPM) messages. The CAVRide has been used for other European projects such as C-Mobile [CMO] and has the following architecture depicted in Figure 5.

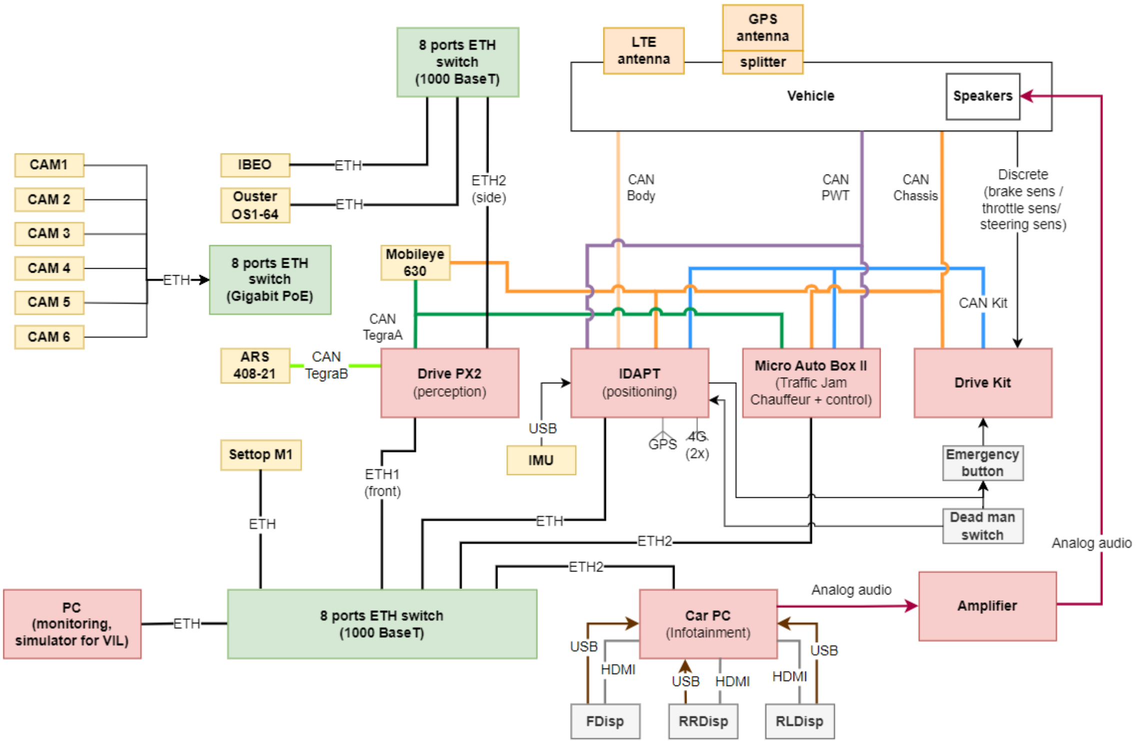

Figure 5. CAVRide Architecture.

The CAVRide components are listed below:

- NetGear GS108 Ethernet Switch
- Delta Components Automotive Ethernet Gigabit PoE Switch
- CAM 1-6: Basler ace 2 GigE – a2A1920-51gcBAS
- IBEO: Ibeo LUX (2010) (Laser Scanner – Frontal LIDAR)
- Ouster OS1-64 (Mid-Range High-Resolution Imaging Lidar – Rear LIDAR)
- ARS 408-21 (Long Range Radar Sensor)
- Mobileye 630 (ADAS system camera)
- NVIDIA Drive PX2 (Perception – Autonomous Car Development Platform)
- IDAPT (IDIADA ADAS Platform Tool)
- Laptop/HMI

This vehicle will be used to obtain information from the vehicle sensors (e.g., cameras, LIDARs, radar sensors, etc.) and thus be able to create what the infrastructure needs in the different use cases. In addition, during the course of the project, tele-operated actions will be taken to assess whether a remote driving service can be realised and perfected. The remote driving service is being developed internally at IDIADA and the vehicle is not yet at remotely control commercialisation stage. Regarding the components of the CAVRide, they are currently organized as shown in Figure 5 above but may undergo some changes and updates. In any case, the components necessary to be able to fulfil the project objectives will not be modified.

Another instrumented vehicle with the ability of connecting to the IDIADA private network will be used. It is equipped with the following:

- 5G router
- External mobile antenna(s)
- GNSS antenna
- Laptop/HMI

2.6 System integration

As mentioned in section 2.1, the 5G network is already deployed and fully functional. A first measurement campaign was performed by the TARGET-X team using Quectel modems and 5G enabled smartphones. The connection to the network was straightforward without any problems.

The network architecture to integrate the edge server into the commercial 5G network has been designed by the IDIADA IT team as well as the different project partners. The aim of this architecture is to allow 1) 5G enabled equipment to communicate with the edge (purple link in Figure 6), 2) the edge to have internet connection for software update (yellow link in Figure 6), and 3) remote access to the edge using SSH for configuration and management (red link in Figure 6). During the design phase, various connection possibilities were studied based on the experience of the different partners. Three different options (A, B, and C) were identified as shown in Figure 6 that depicts a high-level plan of IDIADA network architecture. At the end, it was agreed to use option A as it was the most secure and simplest option, which requires no changes in the equipment of the established network.

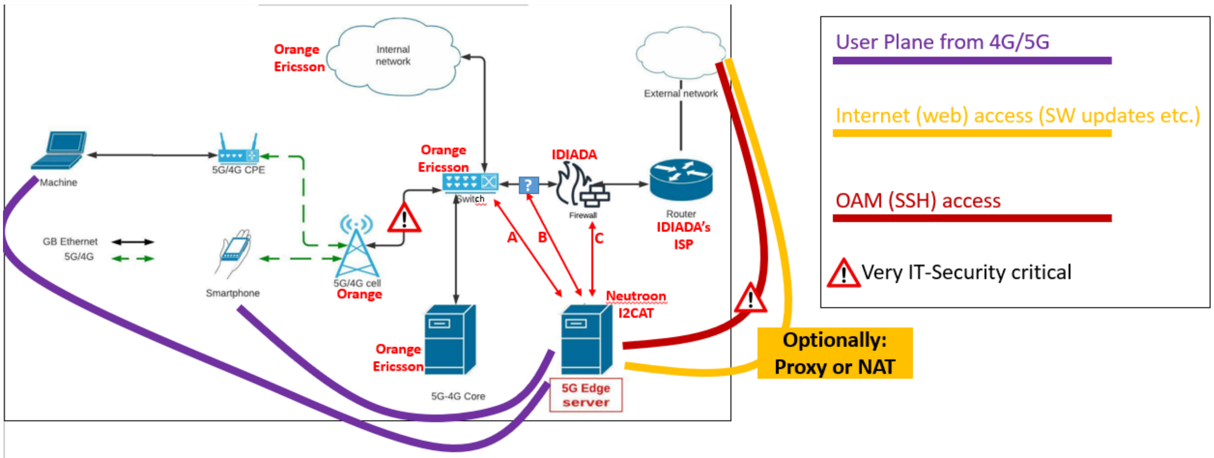

Figure 6. IDIADA Network Architecture - Edge Connections.

In developing such an architecture, a testing process was determined to confirm the Edge integration by pinging between devices and equipment for latency and using iPerf3[1] or nuttcp[2] for throughput. Results of this integration will be shown in deliverable D4.2 [TAR24-D42].

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[1] https://iperf.fr/

[2] https://www.nuttcp.net/

3 Automotive use cases

This section aims to present the different use cases that will be developed throughout the project. These use cases have been defined and planned to be able to deploy different services both on a VM hosted on the Edge node and on a server hosted on the public Internet on a hyperscale public cloud provided by AWS (see Section 2.3). This will allow us to evaluate the behaviour of these services in both environments.

Three vehicular use cases will be evaluated in the TARGET-X project: Cooperative perception, digital twins, and predictive Quality of Service (QoS) for Tele-operated Driving (ToD). In Table 2, the services and scenarios related to those use cases are presented. In the following, a brief description of the use cases and their requirements are also discussed. The detailed description of the use cases will be provided in D1.1 [TAR23-D11].

Table 2. *Use cases' scenarios and services.*

USE CASE	**SERVICES**	**SCENARIOS**
COOPERATIVE PERCEPTION	• Collision Warning Service • In-Vehicle Local Dynamic Map Service • Vehicle to Infrastructure Data Sharing Service	• Zero Visibility Intersection (1:1) • Road Damaged Vehicle (1:2)
DIGITAL TWINS	• Same services as Cooperative Perception UC	• Same scenarios as Cooperative Perception UC
PREDICTIVE QOS FOR TELE-OPERATED DRIVING	• Alarm for predicted reduction in QoS	• QoS degradation (3:1)

3.1 Cooperative perception

In the use case of cooperative perception, a vehicle entering in an unknown area will receive information from the infrastructure regarding the road layout and other static information. Thanks to this information, the data from its sensors, and the V2X messages received from other connected vehicles (e.g., Cooperative Awareness Message – CAM and Collective Perception Message – CPM), the vehicle will be able to have an accurate realization of its surroundings. However, the sensors information from other non-connected vehicles would also be required to have a full picture, having the fact that not all road vehicles are connected and able to send V2X messages. This sensors' information sharing is called "cooperative perception" and, for this use case, CPM and CAM messages will be generated by all Connected and Autonomous Vehicles (CAVs) involved in the scenario to the infrastructure, which will forward them to the nearby vehicles.

The following use case is based on the fact that, today, there is a lot of information collected by the vehicle, either vehicle-specific information or external vehicle information, which, if processed and evaluated, can be used to anticipate possible events. This means that a vehicle at the right time with the right information can evolve its state of knowledge to adapt its driving strategies and thus provide greater safety.

3.1.1 Scenario description

For the cooperative perception use case, two scenarios have been defined to develop different functionalities. The first scenario (Zero Visibility Intersection) is depicted in Table 3.

Table 3 Cooperative perception scenario 1 description.

ID USE CASE	**UC 1:1**
NAME	Zero Visibility Intersection
SYSTEMS	Vehicle to Network (V2N) applications
TECHNOLOGIES	Technologies based on 5G NSA
ACTORS	Connected Vehicles, Connected and Automated Vehicles
DESCRIPTION	Intersections where there is no visibility between vehicles, due to external phenomena such as the weather or the topology of the environment itself, give rise to unsafe situations. The Collision Warning Service (CWS) will make it possible to evaluate the different environments of the vehicles involved, with the aim of sending warning messages when they approach a risky situation, thus improving road safety. This information will be sent from the vehicles to the infrastructure via a cellular network where the CWS will process and generate the appropriate warnings for each vehicle.
STATUS	Definition done. Starting with messages structure deployment.

This scenario is depicted in Figure 7 where two vehicles are approaching an intersection with zero visibility. These vehicles share their position, speed, and surroundings data with the infrastructure where a Cooperative Intelligent Transport Systems (C-ITS) platform will be deployed over the cloud (AWS) or over the Edge (Edge Server). The Collision Warning Service (CWS) deployed for this use case monitors all messages from both vehicles (i.e., CAM, CPM) and determines that there is a possible risk of an accident by identifying a risky situation. At that moment, it alerts the vehicles so that appropriate actions can be taken. The warning is sent through a Decentralized Environmental Notification Message (DENM) message, which is displayed on a Human Machine Interface (HMI).

Furthermore, the HMI has both the Local Dynamic Map Service (LDMS) and the Vehicle – Infrastructure Data Sharing Service (V2I-DSS) implemented. The V2I-DSS allows the vehicle to receive external data from the environment (from other vehicles); the In-Vehicle System (IVS) data from the sensors and the external data from the network will be merged so that both the environment and the warning events sent from the CWS can be seen on the vehicles' HMI.

Figure 7 Zero Visibility Intersection scenario.

The second scenario (Road Damaged Vehicle) is depicted in Table 4.

Table 4 Cooperative perception scenario 2 description.

ID USE CASE	**UC 1:2**
NAME	Road Damaged Vehicle
SYSTEMS	V2N applications
TECHNOLOGIES	Technologies based on 5G NSA
ACTORS	Connected Vehicles, Connected and Automated Vehicles
DESCRIPTION	Roads where there is no visibility between vehicles due to external phenomena, such as weather, create unsafe situations. The CWS is designed to collect information from the damaged/stalled vehicle(s) that is in a compromised situation in the path of another vehicle. The moving vehicle will be able to receive the appropriate warning to anticipate the situation and adapt a driving strategy in time to avoid the possible accident.
STATUS	Definition done. Starting with messages structure deployment.

This scenario is depicted in Figure 8 where a roadside damaged vehicle is in the same path of another vehicle in movement. The complexity in this scenario is the lack of visibility due to weather conditions (e.g., heavy rain, fog, or snowfall). Thanks to the CAMs and CPMs messages sent by the vehicles themselves (both from the damaged vehicle and the moving vehicle), the CWS can identify the risk and notify the vehicles using DENM messages of the existence of a damaged vehicle on the same trajectory to avoid a possible accident. The DENM will be displayed by the vehicle through its HMI, which will have executed both the LDMS and the V2I-DSS to represent the situation. Upon the reception of the DENM by its HMI, the vehicle in motion shall be able to adapt its driving strategy by taking extreme precautions due to the lack of visibility and the new event.

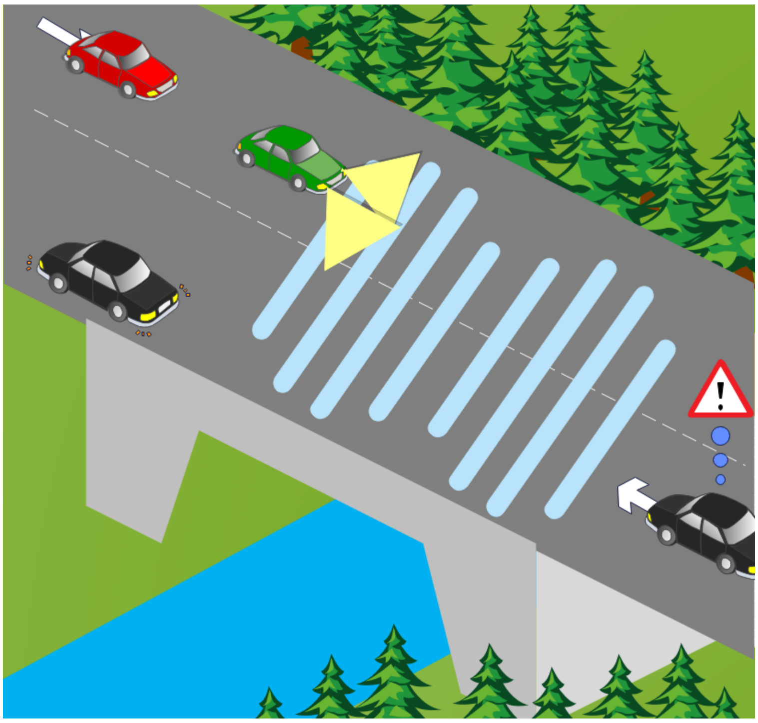

Figure 8 Road damaged vehicle scenario.

3.1.2 Requirements and KPIs

For each of the scenarios mentioned above, the communications between the vehicles involved as well as the communications between infrastructure and vehicles must be robust, as the loss or delay of data packets can lead to an accident or unsatisfactory driving experience. In this section, the description of the required KPIs for the use case as well as the target values to be met for the development are presented. In Table 5, the list of KPIs and description of each one is provided:

Table 5 Monitored KPIs for Cooperative Perception.

KPI Name	**Unit**	**Definition**
CAM Success RX Rate	[%]	CAM messages success transmission rate from the vehicle to the C-ITS platform over the cloud or Edge server.
CPM Success RX Rate	[%]	CPM messages success transmission rate from the vehicle to the C-ITS platform over the cloud or Edge server.
DENM Success RX Rate	[%]	DENM messages success transmission rate from the C-ITS platform over the cloud or Edge server to the vehicle
Data transfer Latency	[ms]	Latency between the vehicle and the C-ITS platform while sending sensor information and/or sending CAM/CPM/DENM messages

The target values of the KPIs presented in the table above are depicted in the Table 6. The values are based on those presented in [5GC20-D21].

Table 6. KPIs for Cooperative Perception.

KPI Name	**Target value**	**Explanation**
CAM Success RX Rate	99.80%	A cost-benefit consideration. Every solution has its cost and its benefit. There are no immediate consequences of a lost message, the system is just not providing its "benefit". We consider 1 out of 500 times an acceptable rate for the system to not perform as expected. Targeting a higher value might result in unreasonably high cost with potentially negative impact on cost-benefit. In many cases the next message after the one that was lost, if correctly received, allows to still get the information on time.
CPM Success RX Rate	99.80%	
DENM Success RX Rate	99.80%	
Data transfer Latency	40 – 50 ms	Intended for human- and algorithm-controlled vehicles. For humans, requiring less than 50 ms would not make much difference, as human perception and reaction times are much higher. For assistance or automation algorithms, it represents a worst-case scenario. This could, for example, be two vehicles approaching an intersection at 70 km/h, where the breaking distance is 26 m. Within 50 ms they each move 1 m. In ideal conditions, they will then need another 25 m to stop, if the situation requires it. 1 m, caused by the communication delay, is considered acceptable within the overall breaking distance of 26 m at 70 km/h for each vehicle. The 40 ms requirement is for vehicles approaching at 90 km/h that can be explained in the same way. The breaking distance in this case is 40 m in best case.

Besides the use case's KPIs in Table 6, use-case-agnostic throughput and delay measurements will also be collected and geo-referenced.

3.2 Digital twin

The second use case is characterised by the development of methodologies for the creation of digital twins. Digital Twins are defined as accurate digital replicas of real-world systems, processes, or environments [NVI23]. In the context of digital twins for automotive vertical, vehicles and traffic systems are modelled as digital objects to represent physical spaces (on the road) by virtual spaces (in digital computers) [GBQ+22].

3.2.1 Scenario description

For the TARGET-X project, the way to create a digital twin will be developed based on the scenarios of the first use case (i.e., Cooperative Perception). This use case focues on collecting all the necessary data from both UC 1:1 and UC 1:2 (see Figure 7 and Figure 8). In this way, two digital twins will be available; one is focused on the environment of an intersection where two vehicles are approaching at a certain speed where they have no visibility between them. The second is focused on a road environment where visibility is not available due to weather conditions, where one vehicle suffers an emergency, and the other moving vehicles must correct its path to avoid possible accident. By having two digital twins (one for each scenario), we will be able to recreate the scenarios as often as necessary to evaluate different features. For this use case, the tool will be developed so that we can visualise and replay the different scenarios via web.

With this use case, the TARGET X project aims to continue the promotion of test tools that can evaluate and process information in a digital way to reduce human errors. In turn, it will enable IDIADA to improve its processes and tools to meet the different connectivity requirements of Original Equipment Manufacturers (OEMs) coming from the emerging connected vehicle markets, which are increasingly demanded and trained in the European ecosystem.

3.2.2 Requirements and KPIs

The digital twin service is an asynchronous exercise that allows to visualise the behaviour of the vehicles in the first and in the second scenario. Therefore, latency and throughput KPIs are not of the same importance as in the cooperative perception use case. However, the reliability of the network should be at the same level as it is important to have an accurate replica of the environment.

3.3 Predictive quality of service for tele-operated vehicles

The predictive QoS use case is designed around an architecture that allows the network to provide the V2X service applications with alarms related to possible reduction in the QoS in the upcoming locations of the vehicle. The aim of this use case is to show how QoS prediction can help in enhancing the quality of experience in ToD, especially when the QoS provided by the mobile network is not stable.

3.3.1 Scenario description

In this use case, one scenario has been defined, i.e., QoS degradation, to show the importance of the proposed architecture as shown in Table 7.

Table 7 Predictive QoS for ToD scenario description

ID USE CASE	**UC 3:1**
NAME	QoS degradation
SYSTEMS	V2N applications
TECHNOLOGIES	Technologies based on 5G NSA
ACTORS	Tele-operated Vehicle (ToV), Teleoperated Centre (ToC), QoS prediction unit
DESCRIPTION	As the required QoS may not be always guaranteed to tele-operated vehicles due to network conditions (radio channel quality, vehicle speed, network congestion), safe driving may imply to adapt ToD functions (e.g., speed, safe stop, vehicle steering) to QoS changes. Knowing these conditions in advance will allow proactive adjustment of abovementioned ToD functions and provide vehicles or humans teleoperating vehicles with a sufficient window of time to take the necessary actions. The aim of this scenario is to allow the network to detect an event that can reduce the communication QoS (e.g., a 5G site is down, signal level is low) and notify the ToC. The latter will reduce the speed of the car in accordance with the current network state.
STATUS	Definition done. Starting with architecture design and deployment.

The scenario is depicted in Figure 9. In this scenario, the ToV is in a cell where the QoS provided is meeting the requirements of the speed with which the vehicle is running. However, the next cell will not be able to provide the same QoS. This reduction in QoS will be detected by the network that will send an alarm signal to the ToC. The latter will notify the remote driver about the situation. This a priori notification will allow the driver to act without being under pressure. Therefore, a QoS predictor module will be developed in TARGET-X project in addition to the necessary Application Programming Interfaces (APIs) that interconnect this module to the 5G network from one side and the ToC from the other side.

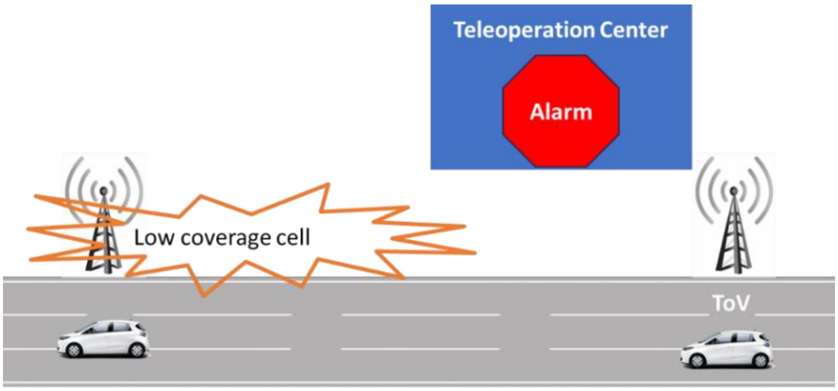

Figure 9 Predictive QoS Scenario.

3.3.2 Requirements and KPIs

Any functional errors in the ToV can lead to uncomfortable situation to passengers or in the worst case can jeopardize safety on the road. These errors can be related to vehicle hardware, software, or wrong decision of the tele-operating person. However, in the TARGET-X we are only interested in the errors related to the communication between the ToC and ToV. Therefore, we define in the below table the KPIs that will be monitored during the tests in the CVH for this use case.

Table 8 Monitored KPIs for predictive QoS for ToD.

KPI Name	Unit	Definition
Command Latency	[ms]	Latency between the ToC and ToV while sending tele-operation commands (e.g., speed value, changing direction, etc.). It is one way application layer delay.
Data transfer Latency	[ms]	Latency between the ToV and ToC while sending sensor information (i.e., camera videos, current position, speed, etc.). It is one way application layer delay.
Command Reliability	[%]	Ratio between correctly received command messages packets by the ToV and the packets sent by the ToC.
Data transfer Reliability	[%]	Ratio between correctly received sensor information packets by the ToC and the packets sent by the ToV.
Uplink Service Data-Rate	[Mbps]	Number of correctly received sensor information bits by the ToC within a certain time window.
Downlink Service Data-Rate	[Mbps]	Number of correctly received command messages (e.g., desired speed, steering control) bits by the ToV within a certain time window.

The target values of the KPIs presented in the table above are depicted in the table below. The values are based on those presented in [5GC20-D21][5GM22-D21].

Table 9 Target KPIs for predictive QoS for ToD use case.

KPI Name	**Target value**
Command Latency	20-50 ms for a vehicle speed between 80 km/h and 130 km/h [5GM22-D21]
Data transfer Latency	100 ms [5GM22-D21]
Command Reliability	99 % [5GM22-D21]
Data transfer Reliability	95% [5GM22-D21]
Uplink Service Data-Rate	10 - 50 Mbps [5GC20-D21]
Downlink Service Data-Rate	Maximum of 0.5 Mbps [5GC20-D21]

All the KPIs will be measured and shown in a dashboard developed by TARGET-X.

4 Summary and conclusions

This deliverable described IDIADA's testbed that will be used to evaluate the impact of 5G features on the quality of experience provided to the automotive vertical. The testbed includes a 5G NSA network in addition to 2G/3G/4G networks, an edge computing facility, a hyperscaler public cloud, several 5G modems and routers, and connected vehicles. These testbed elements were described in detail in the document. In addition, the document presented the status of the infrastructure deployment and system integration, where 5G connectivity is finalized and the architecture to integrate edge facilities is designed.

The evaluation of the 5G features will be done using three use cases that are briefly described in this document: Cooperative perception, digital twins, and Predictive QoS for tele-operated vehicles. Furthermore, the requirements of these use cases in terms of measured KPIs were described and preliminary thresholds were presented. The detailed description of the use cases will be provided in the first deliverable of work package 1. In addition, the document presented the status of the infrastructure deployment and system integration, where 5G connectivity is finalized and the architecture to integrate edge facilities is designed.

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