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Deliverable D5.2

Description of the Experimentation Facilities

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
5GC	5G Core
5GDSS	5G Dynamic Spectrum Sharing
5GTDD	5G Time Division Duplex
AGV	Automated Guided Vehicles
AMF	Access and Mobility Management Function
ARPF	Authentication Repository and Processing Function
AUSF	Authentication Server Function
CP	Control Plane
CPRI	Common Public Radio Interface
DN	Data Networks
ExFa	Experimentation Facility
FDD	Frequency Division Duplex
gNB	gNodeB
IRU	Indoor Radio Unit
LTE	Long Term Evolution
MANO	Management Orchestrator
MEC	Multi Edge Computing
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NAO	Network Application Orchestrator
NB-OSS	North Bound OSS
NFV	Network Function Virtualization
NR	New Radio
NVFCL	Network Function Virtualization Convergence Layer
ONAP	Open Network Application Platform
OSS	Operation Support System
POTP	Packet Optical Transport Network
RAN	Radio Access Network
RDI	Radio Dot Interface
RSRP	Reference Signal Receiving Power
SA	Stand Alone
SB-OSS	South Bound OSS
SGW	Signal Gateway
SINR	Signal Interference Noise Ratio
SMF	Session Management Function
SRTT	Smooth Round Trip Time

SUCI	Subscription Concealed Identifier
SUPI	Subscription Permanent Identifier
TAC	Tracking Area Code
TDD	Time Division Duplex
UC	Use Case
UDM	Unified Data Management
UP	User Plane
UPF	User Plane Function
UPV	*Universitat Politècnica de València*

Executive Summary

This deliverable is part of the WP5 activities including the deployment of the experimentation infrastructures and the links with the industrial sector facilities. These are split into three different subtasks depending on the location of the experimentation facility.

Below, the final infrastructures and their capabilities are presented in detail.

- ExFa-SP will exploit the 5G core from 5TONIC via public connectivity. The rest of the 5G network will be placed in the facility itself, located in the premises of Ford.
- ExFa-GR will comprise the 5G core and edge level capabilities offered by OTE research lab facilities and parts of the industrial network infrastructure at PPC.
- ExFa-IT will combine Whirlpool's factory testing facility and the experimentation infrastructure at the CNIT S2N Lab testbed.

The next step after completing the activities described in the document is to proceed with the continuous deployment of the 5G platform over the experimentation infrastructures, including the network application DevOps testbed implementation.

This deliverable will be used to guide the activities of Task 5.3 and Deliverable 5.3 related to the integration activities of the of the 5G platform over experimentation infrastructures.

1 Introduction

In this section the general scope of the deliverable will be described.

1.1 Deliverable Purpose

The main purpose of the document is to provide a detailed description of the Experimentation Facilities (ExFas) in support of targeted use cases and the connection with the Network Application Orchestrator (NAO) and the Operations Support System (OSS). The description of the set-up experimentation facilities should include the 5G back-front haul infrastructure, the connectivity technologies, and the industrial sector infrastructure with the attached IoT and edge processing capabilities. Each ExFa is described separately with the components which it is composed of.

1.2 Relation to other deliverables and tasks

This deliverable D5.2 is part of the outcomes of WP5 tasks, namely *i)* T5.1 "Overall experimentation and integration work plan", *ii)* T5.2 "Experimentation Facilities in support of targeted use cases", and *iii)* T5.3 "Continuous integration of the 5G platform over Experimentation Infrastructures".

It is a continuation of D5.1 "Experimentation and Integration Workplan", which elaborates on the integration workplan, including definitions of the procedures, actions, and related time plan to be followed for the integration activities over the experimentation testbeds and the final demonstration activities. Moreover, it provides the methodology to be followed for the evaluation of the project's platform and the handling of the network applications in the targeted industrial environments.

Deliverable D5.2 is also related with the following deliverables and associated activities:

- D3.1 "5G Orchestration Platform", which describes the functional evolution of the 5G-INDUCE Orchestrator software components, namely the Network Application Orchestrator (NAO) and the Operations Support System (OSS), and the ongoing progress with respect to the 5G platform prototype delivered in WP5 and to be integrated over the testbeds.
- D3.2 "5G Orchestration Platform design, key features and operation", which reports key design features and functionalities, also providing operation information that is required for the deployment.
- In the integration Section of D5.2 there is reference to D3.4, which describes the architecture and the main features of the first released version (Version A) of the Platform prototype presented in deliverable D3.1.
- Foreseen next steps listed in Section 5 of this deliverable will be reported in detail in D5.3 "Continuous integration process over the Experimentation Facilities", with respect to the overall integration process and the experimentation platform capabilities.

Deliverable D5.2 is expected to feed the upcoming activities that will be reported in D6.1 "Testbed structure, validation and performance estimation outcomes", which provides the description of the DevOps testbed and the processes followed for the Network App use case adaptation and verification. Followingly, D6.1 will provide the validation and Network App performance evaluation outcomes from the studies over both the DevOps testbed and the related ExFas described in D5.2 and for each of the validated Network App use cases.

1.3 Structure of the Deliverable

The deliverable D5.2 is structured as follows:

Section 2 analyses the 5G Network's infrastructure overall architecture. The complete architecture is a distributed solution that spans across the three ExFas. The network infrastructure is detailed in all common layers (radio access network, edge, packet core and transport).

Section 3 is the core of the deliverable, focusing on the thorough description of the three ExFas. Each experimentation facility has its own structure and supports several use cases. In the chapter's subsections, all the infrastructure pieces and the network components are detailed.

Section 4 describes the integration of the management and orchestration platform with the ExFas. The 5G-INDUCE OSS is divided into the North-Bound OSS (NB-OSS) that represents the interface towards the NAO and is responsible for the slice management, and the South-Bound OSS (SB-OSS), which is focused on a specific ExFa and offers pluggable services depending on the underlying capabilities. Platform integration over each ExFa is written in detail.

Section 5 summarizes the overall workplan and schedules next actions. Some pending points and time deadlines/restrictions are presented as well.

2 5G Network Infrastructure Overall architecture

This section summarizes the overall 5G architecture and common key technologies to be deployed on all ExFa testbeds to hold the use cases experimentation. All 5G-INDUCE infrastructures are separated into common layers, including the access, edge, core and transport (Fig. 1). These layers are described in some detail in Section 3.

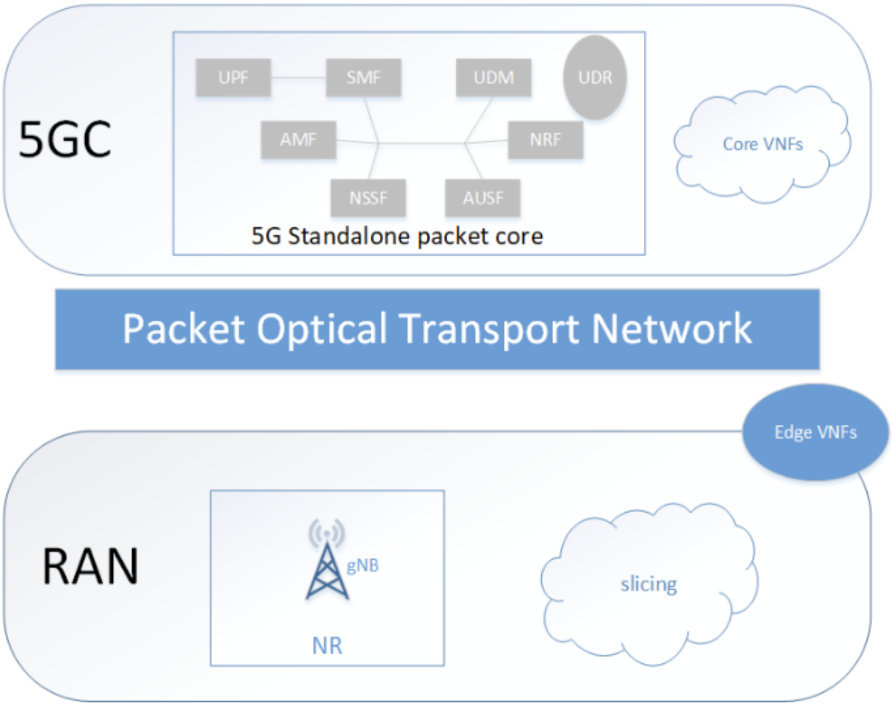


Figure 1: High level 5G network architecture

5G New Radio (NR) access and Core network are essential to permit 5G interconnection necessary to use cases; each test site has chosen different setups of band, bandwidth and TDD/FDD options to use, according to the available spectrum, regulations, and agreements on their countries. The implementation of Edge Computing assets is needed to make the user plane traffic breakout and guarantee low latency of Network Applications traffic. The 5G Network ensures User Equipment devices (UEs) have connectivity with services running on the Edge and provides good Uplink and Downlink throughput capabilities. Any solution implementing these technologies will most certainly meet the performance requirements of the use cases.

2.1 5G New Radio

5G New Radio target is to improve the network’s characteristics in flexibility and high performance, while using the available spectrum more efficiently. For example, it is built using massive MIMO in order to increase the coverage and capacity and improve the spectrum efficiency. At the same time, technologies that were used in LTE, such as beamforming, are adopted in New Radio, as well.

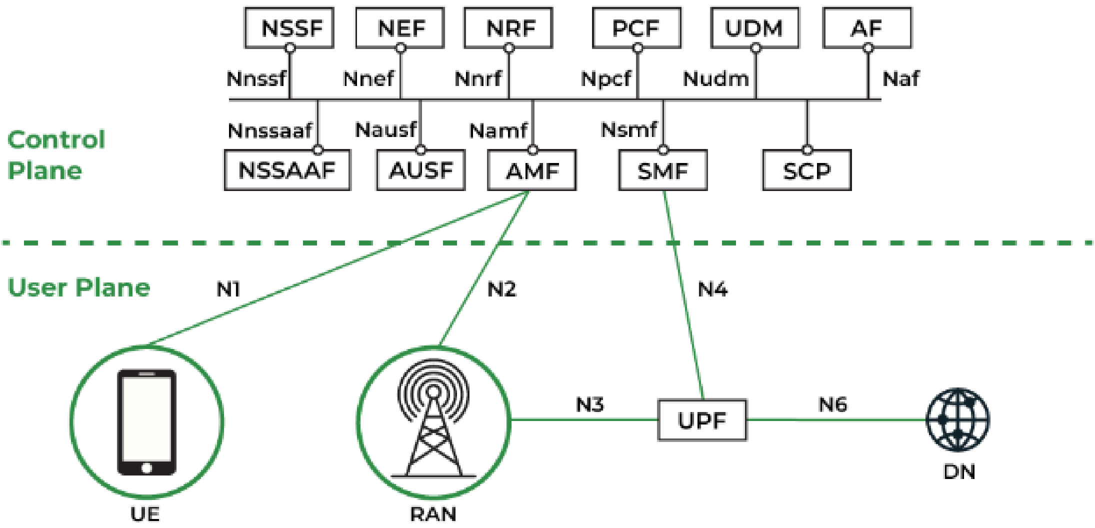


Figure 2: 5G SA architecture

In Figure 2, the architecture of Radio Access and the interfaces it uses are presented. A NR base station (gNodeB – gNB) can be connected with another base station using the Xn interface, allowing the synchronization between gNBs. Therefore, it would be feasible for a UE to be connected on multiple base stations at the same time, using different frequency links for transmission.

There are two interfaces between gNBs and 5GC: N2 between RAN and AMF, and N3 between RAN and UPF. Those two different interfaces are the basis for the Control/User Plane Split (CUPS). Moreover, the N1 control interface is defined between UE and AMF.

2.2 Packet Core

The 5G SA Core network architecture is cloud-native, funded on the concepts of containers and a Service Based Architecture. Thus, the functionalities are handled by a set of Containerized Network Functions (CNFs) that can access one another's services. The goal behind this is to enable quick launch of new services and offer enhanced adaptability. It allows flexibility in deployment by separating the User Plane (UP) functions from the Control Plane (CP), giving the opportunity to choose either a centralized approach or a distributed one regarding the user plane traffic, thus enabling Edge Computing. A new important feature in 5G is network slicing, which allows to establish independent traffic flows with different Quality of Service (QoS) conditions.

The current version of the 5G networks is based on SA Rel. 16 (3GPP Release 16) [7] architecture that is presented in Figure 3.

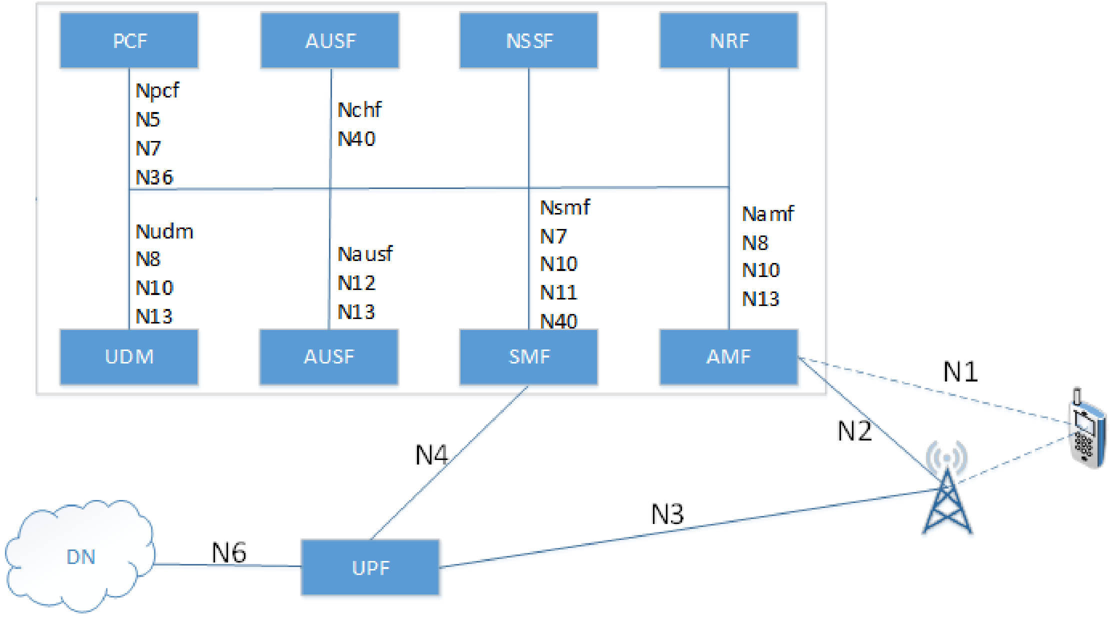


Figure 3: 5G SA Rel. 16 packet core architecture

2.3 Edge

Edge computing brings application hosting from centralized datacenters down to the network edge, closer to consumers and the data generated by applications. Therefore, it aims to reduce latency, ensure efficient network operation and improve customer experience.

Multi-access Edge Computing (MEC) is an edge computing architecture standard which provides compute and storage resources closer to the end user. Several architectures for edge implementation have been proposed (Fig. 4) [MEC in 5G networks, ETSI White Paper No. 28, June 2018]. The decision is based on various operational, performance (mainly latency) or security related requirements.

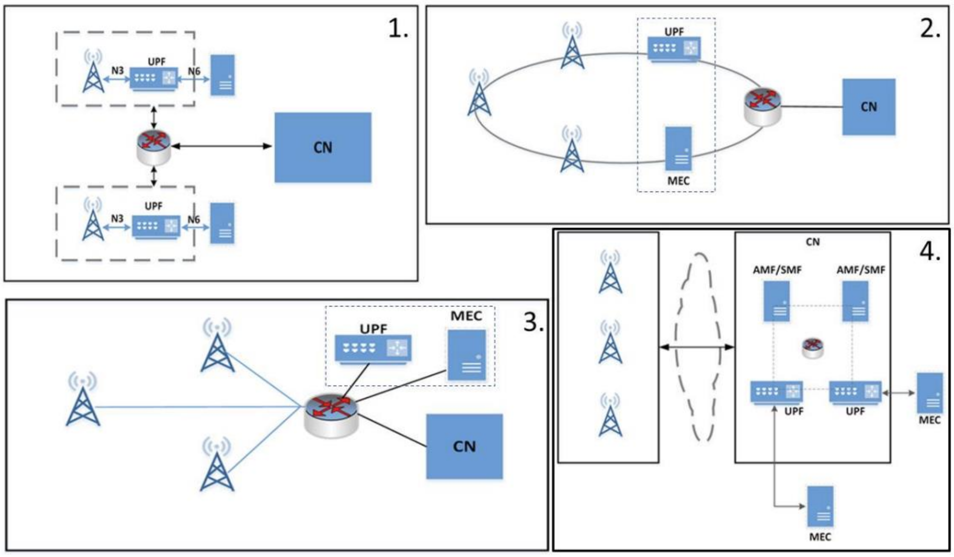


Figure 4: Physical installation of MEC components. 1. MEC co-located with the Base Station, 2. MEC co-located with a transmission node, 3. MEC co-located with a network aggregation point, 4. MEC co-located with the Core Network functions.

3 Experimentation Facilities

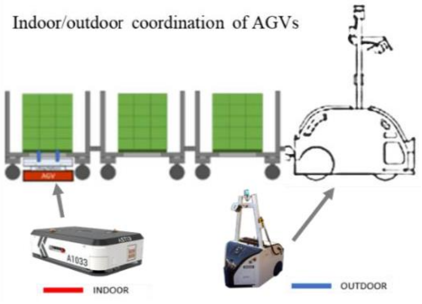
3.1 ExFa-SP

The Spanish 5G Experimentation Facility infrastructure is deployed with the goal to validate and showcase the developed network applications over a real industrial 5G environment. The main experimentation area, seen in Figure 5, is a large industrial facility, where Ford operates, located in Almussafes (Valencia, Spain).

Figure 5: Spanish 5G ExFa (Ford Almussafes)

More specifically, the experimentation area will take place in Ford's motor factory, the adjacent warehouse and the outdoor surrounding area. This ExFa covers three use cases:

UC 1: Autonomous indoor fleet management

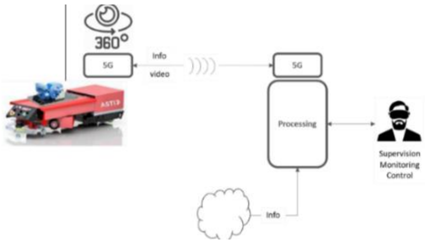


- Manage a small fleet of AGVs with simultaneous localization and mapping (SLAM) navigation through 5G and edge computing capabilities.

UC 2: Smart AGV operation based on human gesture recognition

	- Control industrial operations of AGVs through human gesticulations without using any type of special equipment.

UC 3: VR immersion for AGV control

	- Explore VR and 5G capabilities to provide an immersive live 360 view from the AGV to a remote viewer.

These use cases imply indoor transport in Ford warehouses, coordinated with outdoor transportation in which the indoor AGV is replaced by the outdoor AGV. Figure 6 shows the AGV route, represented by the red and blue line, for the use cases.

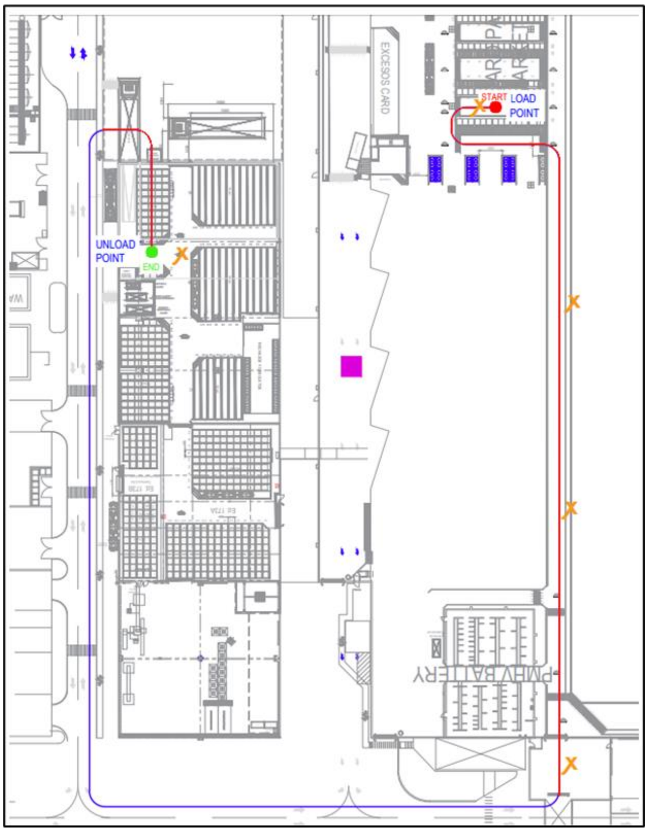
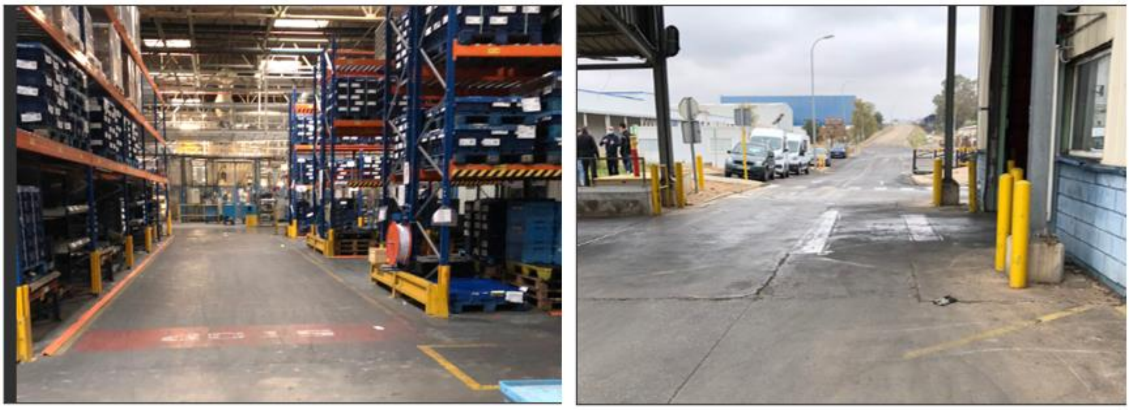


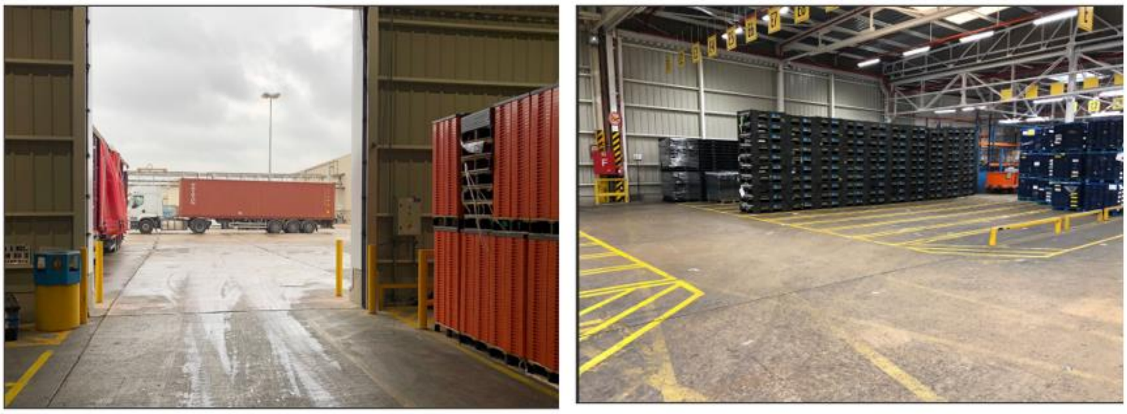
Figure 6: AGV route in ExFa-SP (Ford)

The AGV route will start on the red dot (loading point), where the user will load the AGV. The red line corresponds to indoor area and the blue one to outdoor area. The change of AGV is produced when the area changes from indoor to outdoor and vice versa. The AGV path will finish on the green dot (unloading point).

Each point of interest of this AGV path corresponds to the following areas at the Ford premises (Fig. 7).



START(Loading) *Change of AGV*



Change of AGV *END (Unloading)*

Figure 7: ExFa-SP AGV's route main areas of interest (Ford)

The targeted overall architecture is a distributed solution that spans across 4 locations: the previously mentioned Ford's I4.0 Factory in Valencia, Spain; the premises of Universidad Politecnica de Valencia (UPV) in Valencia, Spain; 5Tonic lab in Madrid, Spain; and CNIT lab in Genoa, Italy. Figure 8 illustrates how the infrastructure and components are distributed:

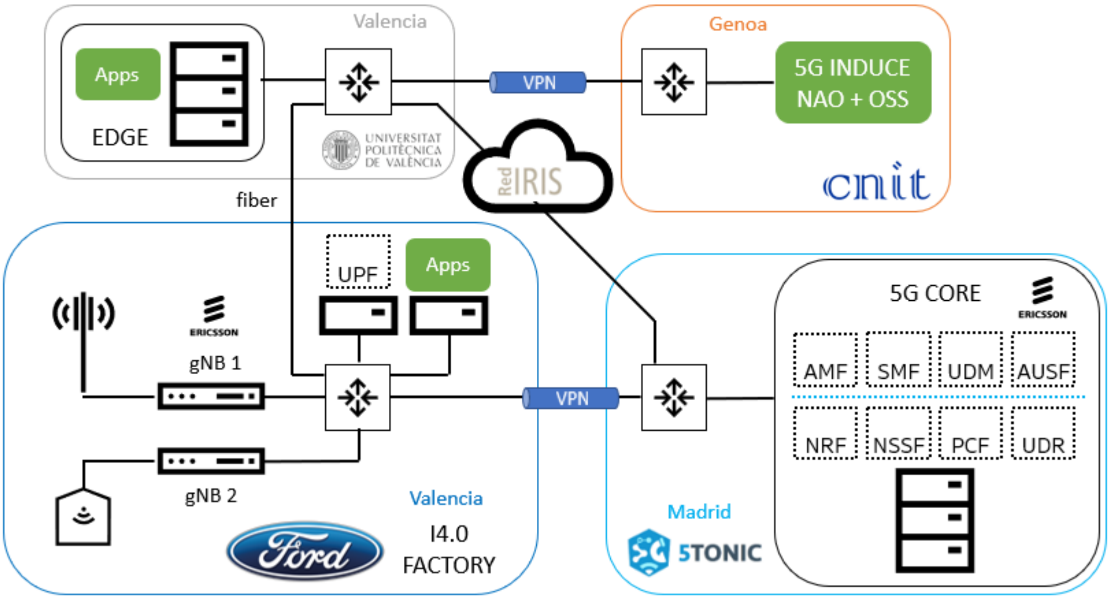


Figure 8: High level End-to-End overall architecture of ExFa Spain

Regarding 5G infrastructure, a distributed 5G Stand-Alone (SA) network architecture is being used. The 5G SA architecture adopts the new concept of Service-Based interfaces. This means that the Network Functions (NFs) that include logic and functionality for processing signalling flows are not interconnected via point-to-point interfaces but instead exposing and making available services to the rest of NFs. Thus, there is a separation that broadens the range of possible locations in which the network elements can be located. The RAN and the User Plane Function (UPF) are installed at Ford premises, while the rest of components of the 5G Core (5GC), the control plane components, are running at 5Tonic. This model is interesting because verticals do not need to have their own full 5G deployed, making the service a lot more cost-efficient for them. With this solution, the 5G RAN equipment splits the user plane traffic and the control traffic. The use cases traffic is directed via the UPF towards the vertical applications, which are running locally at Ford premises or at a nearby location such as UPV premises. This way, the user plane traffic remains geographically close to the end user devices, keeping a very low latency. Complementarily, the control and management planes of the 5G equipment are done from a remote location (5TONIC lab in Madrid, 350 km away from Ford factory), as control traffic does not require as low latency and high-speed levels as the local user plane traffic.

This solution also makes use of the Edge Computing concept. As the Edge Computing architecture provides configuration flexibility, two different topology alternatives have been implemented: The 5G-INDUCE Network Apps are deployed on dedicated servers which are installed at Ford’s factory (for on-premises/Far Edge computing experimentation), or at UPV premises located 20 km away from Ford’s factory (for Near Edge computing experimentation). The orchestration of the applications is triggered by the central Network Application Orchestrator (NAO) running at CNIT premises.

Figure 9 below works as a summary for the high-level communication flows. 5G Control Plane traffic happens among the RAN equipment plus UPF at Ford’s factory and the 5GC at 5Tonic. Application orchestration traffic goes from the NAO at CNIT to the locations where the Network Apps are running. 5G User Plane traffic travels across the RAN equipment, the UPF and the Network Apps.

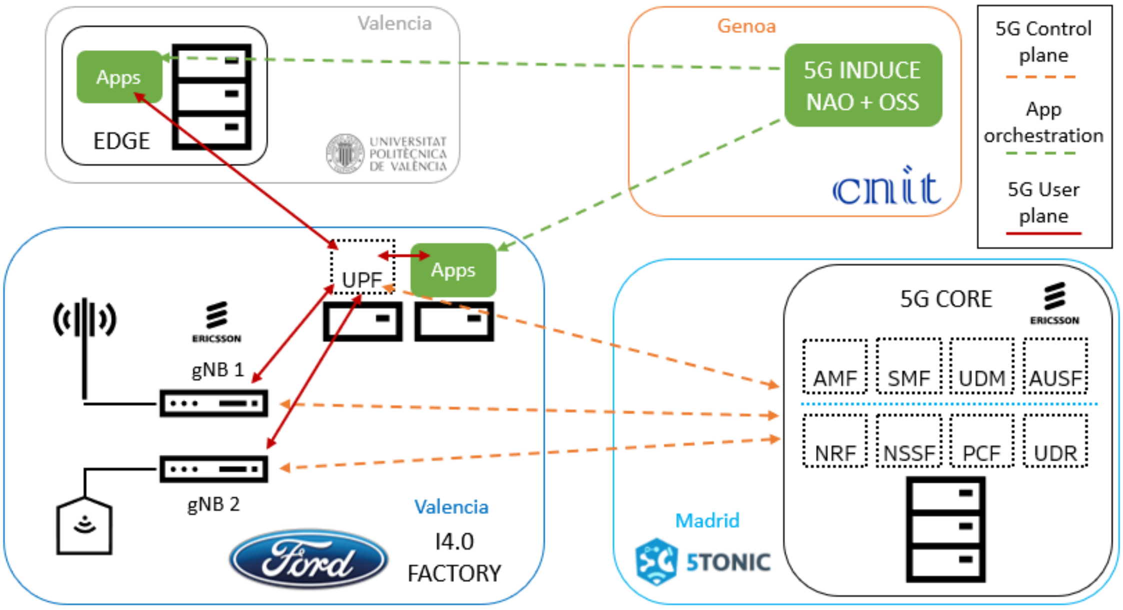


Figure 9: High level End-to-End communication flows of ExFa Spain

In the following subsections, all the infrastructure pieces and the components will be detailed.

3.1.1 RAN

The RAN required a thorough design, that included a visit on-site to determine aspects such as the places where the antennas could be installed, the kind of antennas needed, the space where a rack with equipment could be located or the cabling needed to connect everything. Based on this design, previously to the installation, also a coverage simulation was performed. The results obtained are shown in Figure 10:

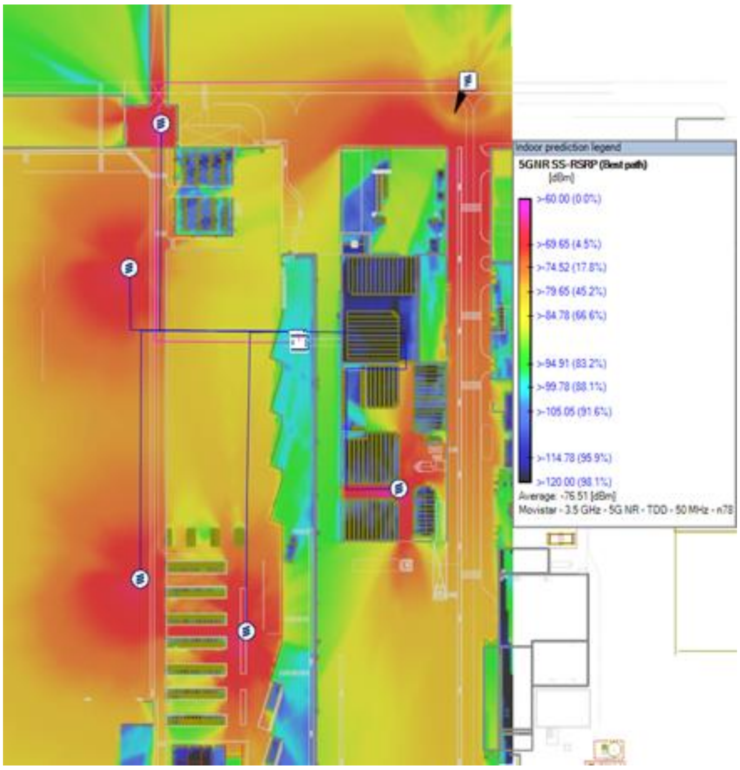


Figure 10: Coverage simulations

Most of the RAN equipment at Ford is installed on a rack. It includes two basebands BB6630, a Router 6675 and the 5G Indoor Radio Unit (IRU) 8846. The equipment, as well as the RAN installation diagram, can be seen in Figure 11.

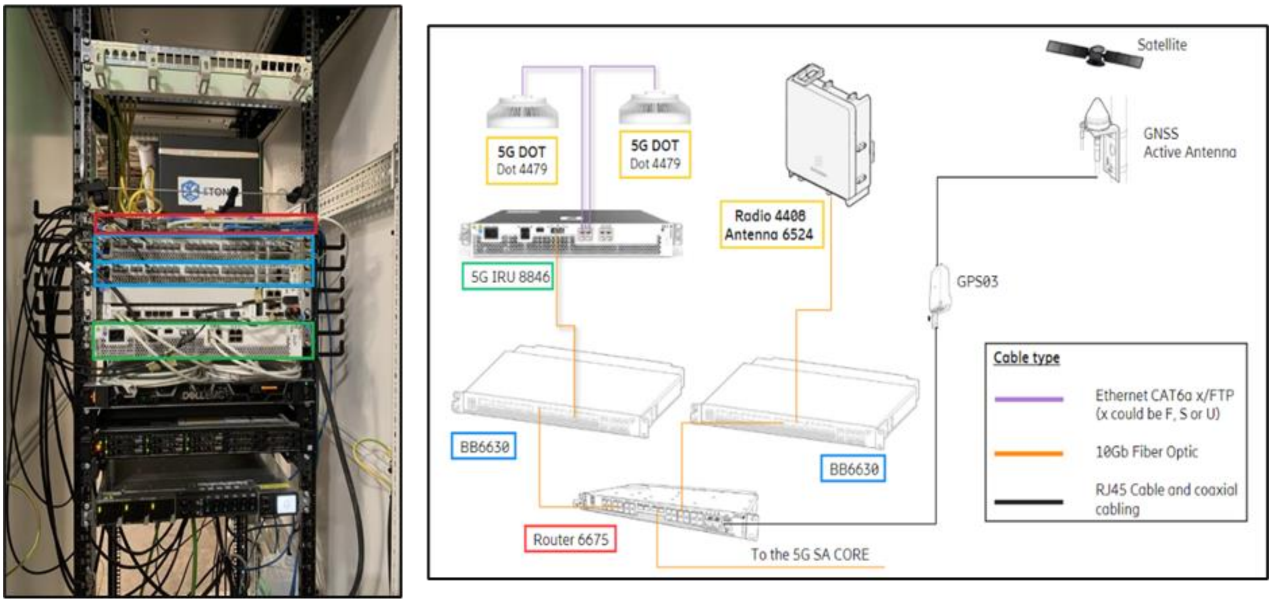


Figure 11: RAN Integration in Ford

As seen in the diagram, each baseband is used for a different area of coverage, one baseband is connected to the IRU using a 10Gb fiber optic cable (CPRI), which is linked to the 5G DOTs using an Ethernet Cat 6a x/FTP (where x could be F, S or U), and the other baseband is connected to the outdoor antenna using a 10Gb fiber optic cable. Due to using two different basebands, they will function as 2 different cells, so a handover will be done when the AGVs change between the indoor and the outdoor cell.

It is also important to consider the length of the cables. The fiber optic cable has no length issues, but the maximum distance between the IRU8846 and the DOT should be less than 160m of Ethernet (the worst-case scenario for CAT6a cabling length has been considered in the design process and is less than 160m).

The Radio 4408 needs a power supply of -48 VDC, or it can also work with alternating current (100-250 VAC) which is the option that will be used in this installation. The 5G Radio DOTs obtain the power supply from the IRU via PoE (Power over Ethernet).

In Figure 12 a cabling representation is shown, where the purple line illustrates the fiber optic cable, and the white line represents the Ethernet cable.

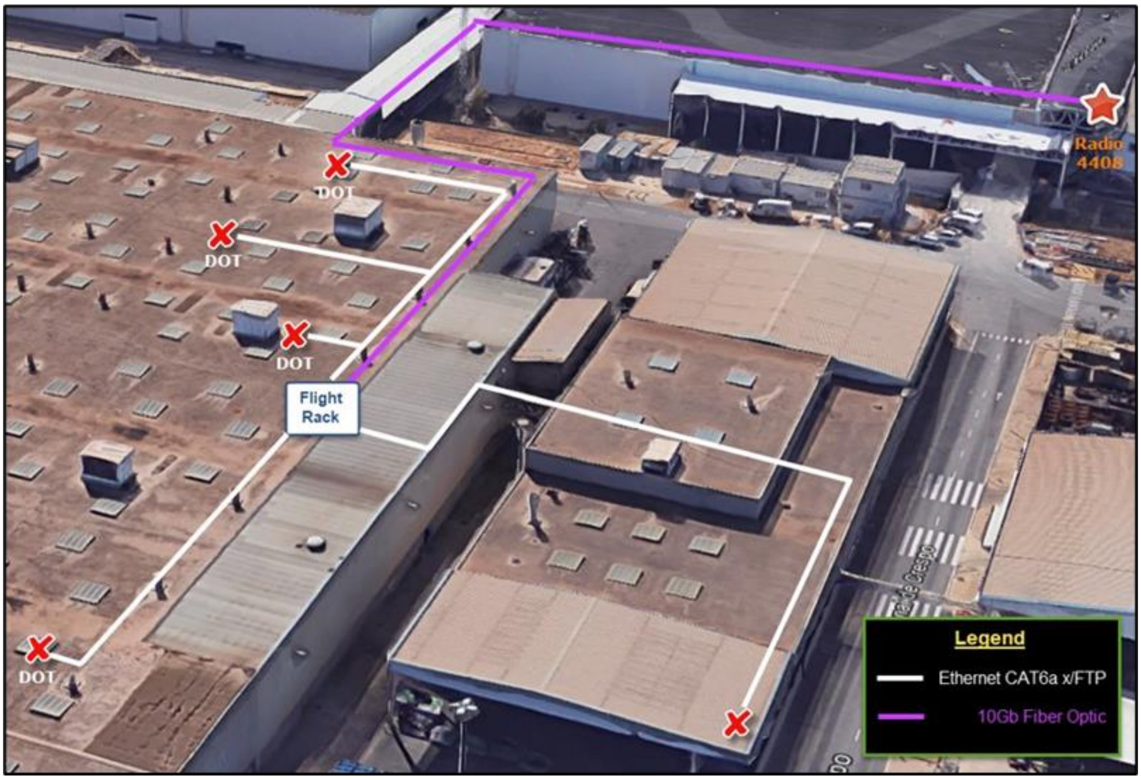


Figure 12: Cabling and antenna placement visualization at Ford

Both basebands are then connected to the Router 6675, and the router is also connected to the core network, as well as the GPS receiver. The GPS receiver consists of a GNSS Active antenna and a GPS03. The GPS signal is needed to have the time and phase synchronization required for 5G with TDD (Time-Division Duplexing) strategy. Precise signal is needed to synchronise the Downlink and Uplink frames and to synchronise between the node B sites. The GPS antenna is also located at the "Flight Rack" label shown in Figure 12.

One goal of the use cases is that the AGVs will have a part of their route inside the factory and a part of their route outdoors. So, we must provide coverage in both areas, as having coverage in only one of them is not enough. To achieve this, as mentioned before, the coverage area is divided in two parts: an outdoor area and an indoor area (using a different baseband for each one).

The indoor area coverage is provided by five 5G radio DOTs (Ericsson's antennas for indoor coverage) located inside the factory, and the outdoor area coverage is provided by the outdoor antenna, both operating on 3.5 GHz.

Outdoor Area

The outdoor antenna is located at 39.332198, - 0.420733 and it is oriented with an Azimuth of 0º so that it covers the whole outdoor testing area, and it is connected using optic fiber. The antenna location and orientation are shown in Figure 13.

Figure 13: Outdoor antenna coverage in SP-ExFa (Ford)

The antenna is composed of the RADIO 4408 and the Antenna 6524. The radio converts the analogue modulated radio signals into optical signals, to then transmit them in base band, and vice versa. The antenna carries the function of implementing the lowest layers of the architecture, including the physical layer and the RF stage.

The Radio 4408 (Fig. 14) is a micro radio designed for more flexible and easier deployments, while maintaining an efficient single and multiband micro radio. It supports LTE and NR TDD bands with four duplex TX/RX branches supporting up to 4 x 5 W output power.

The Antenna 6524 (Fig. 14) is the integrated directional antenna for Radio 4408 for the 3GPP Bands B42 B43 B 48 B78 (3400 – 3800 MHz) and is mounted on the front of the Radio 4408, replacing the cover. The antenna pattern, with a broad horizontal beam, is beneficial for small cell coverage and is sufficient to cover the selected test area. The fixed electrical tilt is -8 degrees.

Figure 14: Outdoor antenna installed at SP-ExFa (Ford)

For the outdoor radiation, Telefonica has lent 40MHz bandwidth with 3570MHz central frequency for this project to avoid interferences with neighbouring equipment, so the outdoor antenna will work on the n78 band. This antenna has an average gain of 12dBi, and it allows working with different subcarrier spacing and different number of subcarriers.

Indoor Area

To provide coverage in the indoor area, five 5G DOTs are used. These 5G DOTs function like a single unit, to avoid handovers between them, to alleviate some load from the users. They also use different multiple access and modulation techniques to achieve high throughput with low latency and massively connected devices.

The installation spots were chosen using a coverage planning tool in order to optimize the coverage along the AGV route. These spots can be seen in Figure 12 marked with red crosses.

The 5G DOTs are installed in the ceiling of the factory as seen in Figure 15.

Figure 15: 5G DOTs installed at Ford factory

As mentioned before, the 5G DOTs are connected to the 5G Indoor Radio Unit, IRU 8846. The main purpose of the IRU is the transmission of signals providing an interface to the Radio Dots through the Radio Dot Interface (RDI) and power supply to the Radio Dots through the RDI (Using Power over Ethernet).

Radio Coverage Measurements

To properly evaluate the current radio coverage of the RAN infrastructure, radio measurements were done at the Ford facilities. Specifically, they were done along the AGVs path to obtain the received power in every point of the route (Figure 16).

The measurements were done using the ROMES software from R&S, which was used to measure the Reference Signal Received Power (RSRP), Signal to Interference and Noise Ratio (SINR) and the Reference Signal Received Quality (RSRQ) of every individual transmitter in the selected frequency range. We can visualize these results in every point along the AGVs route (for the radio DOTs and the outdoor antenna), as we can see in Figure 16, where the RSRP is represented. This value represents the received power for every point of the route, where values between -60dBm and -95dBm can be considered adequate values for a good signal reception. Values are represented in different colours, where green represents good RSRP values, yellow represents acceptable values (-85dBm to -95dBm) and brown and red represent insufficient RSRP values.

As we can see in the figure, when the received signal from the radio DOTs starts degrading, the received signal from the outdoor antenna increases, which combined with the handover allows to obtain a good signal level along the route. The results obtained are very similar to the ones obtained in the simulations, as we can see in Figure 17.

The measurements can then be exported into an Excel file to better understand the results obtained; an average of all the measurements obtained per second is done and then they are represented in a graph, as shown in Figure 17.

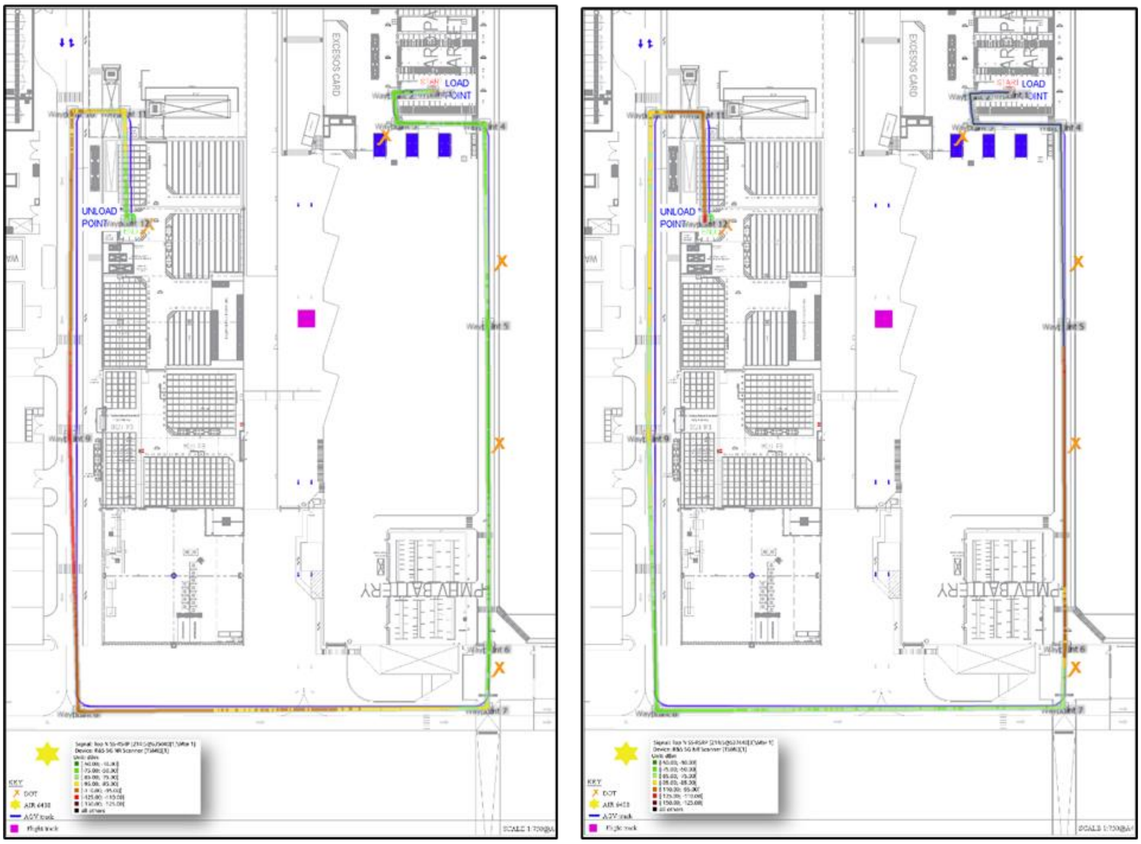


Figure 16: RSRP measurements for the indoor DOTs (Left) and the Outdoor antenna (Right) at Ford facilities

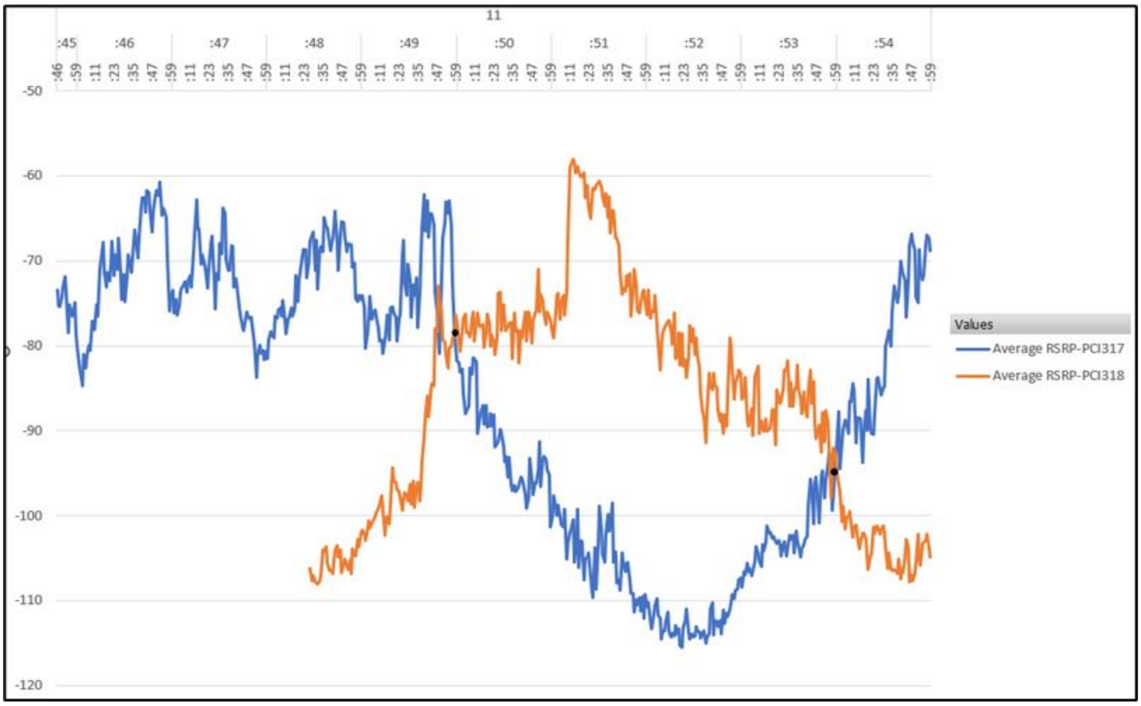


Figure 17: Average RSRP obtained for the DOTs (PCI 317) and the outdoor antenna (PCI 318) at Ford facilities

As we can see in this graph, when the received power from the PCI 317 (corresponding to the indoor DOTs) decreases, the PCI 318 (corresponding to the outdoor antenna) received power increases to cover the coverage gap. When both graphs intersect, a handover should be done, resulting in a handover from the indoor DOTs to the outdoor antenna at around -78dBm and a handover from the outdoor antenna to the indoor DOTs at around -95dBm.

Thereby, the worst received power is -95 dBm due to a lack of Line-of-Sight (LoS) from the outdoor antenna and the radio DOTs; even so, this power is still more than enough to carry out the use cases' service.

In addition to these measurements, the BCH and SIB1 messages were also decoded, verifying in this way that transmission parameters like subcarrier spacing, transmission frequency, bandwidth, etc., are being radiated correctly.

3.1.2 Edge Computing

This section describes the servers used for holding applications in the ExFa-SP.

On the one hand, there is a Dell PowerEdge R630 server installed in the rack at Ford's factory (it can be seen in Figure 11) that is available for the on-premises/Far Edge computing topology experimentation and is reachable locally by the rest of components at Ford's factory. The containerized applications can be installed and run on this server and the user end devices are able to reach them. In fact, Fivecomm's and ASTI's applications have already been installed on this server and executions of UC1 and UC2 have been performed.

On the other hand, there is a server available at UPV premises that is the one to be used for the Edge computing topology experimentation. In this case, the server is 20 km away from Ford's factory. The installation and required configuration of this server has been completed and will be able to hold the applications and to communicate with all the components at Ford's factory in the next steps. The dedicated server in UPV also hosts a database to store all relevant data collected from the Use Cases for further analysis.

Once the applications are running, on either server, the way to differentiate if the on-premises/Far Edge or the Near Edge application is used relies on the specification at the end user devices of the IP address they must point to.

3.1.3 Packet Core

At 5Tonic lab (Figure 18) there is a running full 5GC (including AMF, SMF, UDM…) that is being used for 5G-INDUCE use cases experimentation. The 5GC components are hosted by several Dell PowerEdge R640/R740 servers in a rack located at 5Tonic Data Center.

Initially, use cases were experimented at 5Tonic lab. In that phase, the whole 5G SA network was working at 5Tonic lab. This means that the network coverage was provided in some 5Tonic rooms by the RAN equipment and all the control plane components of the 5GC plus the UPF were running at 5Tonic. This enabled the proper environment to start experimenting and debugging the use case applications while the final distributed setup was being implemented. The results of these preliminary testing have been reported in several press releases [1, 2, 3]:

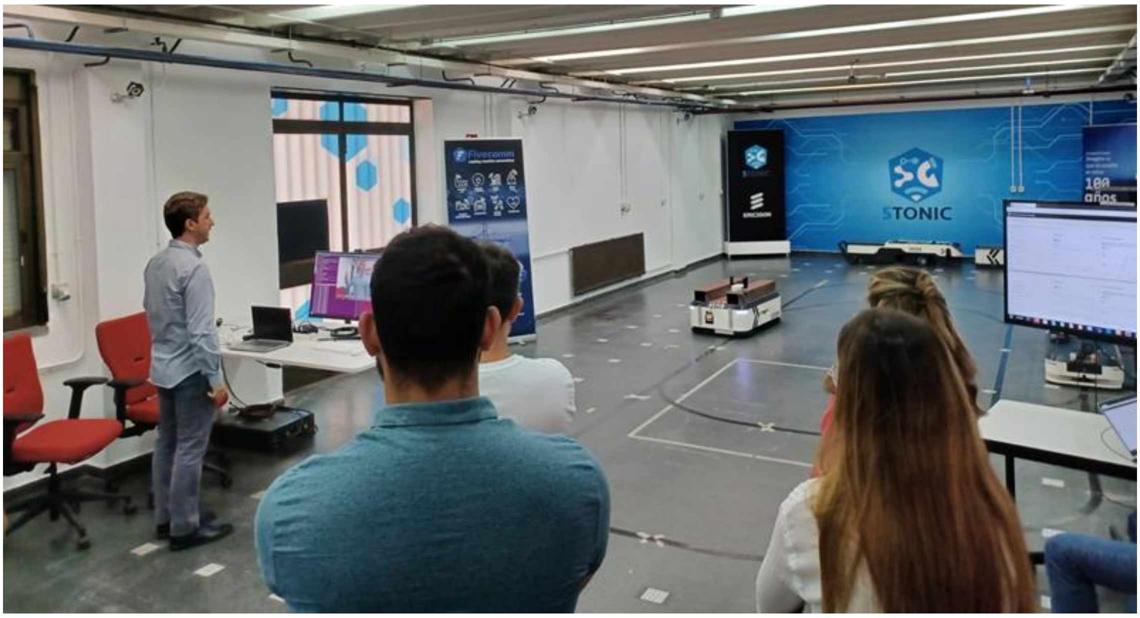


Figure 18: Experimentation at 5Tonic

Later in the project, the RAN equipment and the UPF were installed and deployed at Ford premises. From that moment, 5G coverage is available at Ford and experiments can be run at Ford. In this setup, it is intended to keep using the control plane components of the 5GC (AMF, SMF, UDM…) at 5Tonic, but not the UPF. The distinction has been done by configuring different Data Network Names (DNN) on the 5GC for each setup. The DNN specifies which UPF to use. On the UE side, the Access Point Name (APN) must be defined, pointing to the proper DNN. When the UE is attached to the 5G network and starts sending traffic, the 5GC commands the RAN equipment which UPF to use.

Regarding the UPF, it is running on a Dell PowerEdge R640 installed in the rack at Ford's factory (it can be seen in Figure 11). The 5G system establishes a GTP tunnel between the RAN node and the UPF at Ford to transfer the user plane traffic, as it is specified in the DNN.

3.1.4 Transport

This section details the current physical implementation of the transport among the Spanish sites involved in ExFa-SP: 5TONIC laboratories in Madrid (Spain), the *Universitat Politècnica de València* (UPV) in Valencia (Spain) and the Ford factory in Almussafes (Valencia, Spain). The three main locations are shown in Figure 19.

For the 5G network to work, it is essential that the RAN plus the UPF, located at Ford's factory, can communicate with the 5GC CP, located at 5Tonic. This connectivity must also be secure. It has been achieved by establishing an IPSec tunnel between both sites. The underlying physical connectivity on Ford's factory side is provided by a 4G router, which allows reachability to the Internet and to 5Tonic Fortinet router. The performance required for the 5G control plane communication is very low and is well covered by the 4G router.

UPV site and Ford Factory are being directly connected through an optical fiber line with 1 Gb Ethernet speed. The communication required between those two sites will be mainly the user plane traffic between the UPF and the application running at UPV server, which could demand up to hundreds of Mbps and big data volumes. This is well covered with the direct fiber line. The location of the fiber node at UPV will be in the parking lot of building 6A of the UPV University Campus, as is shown in Figure 21.

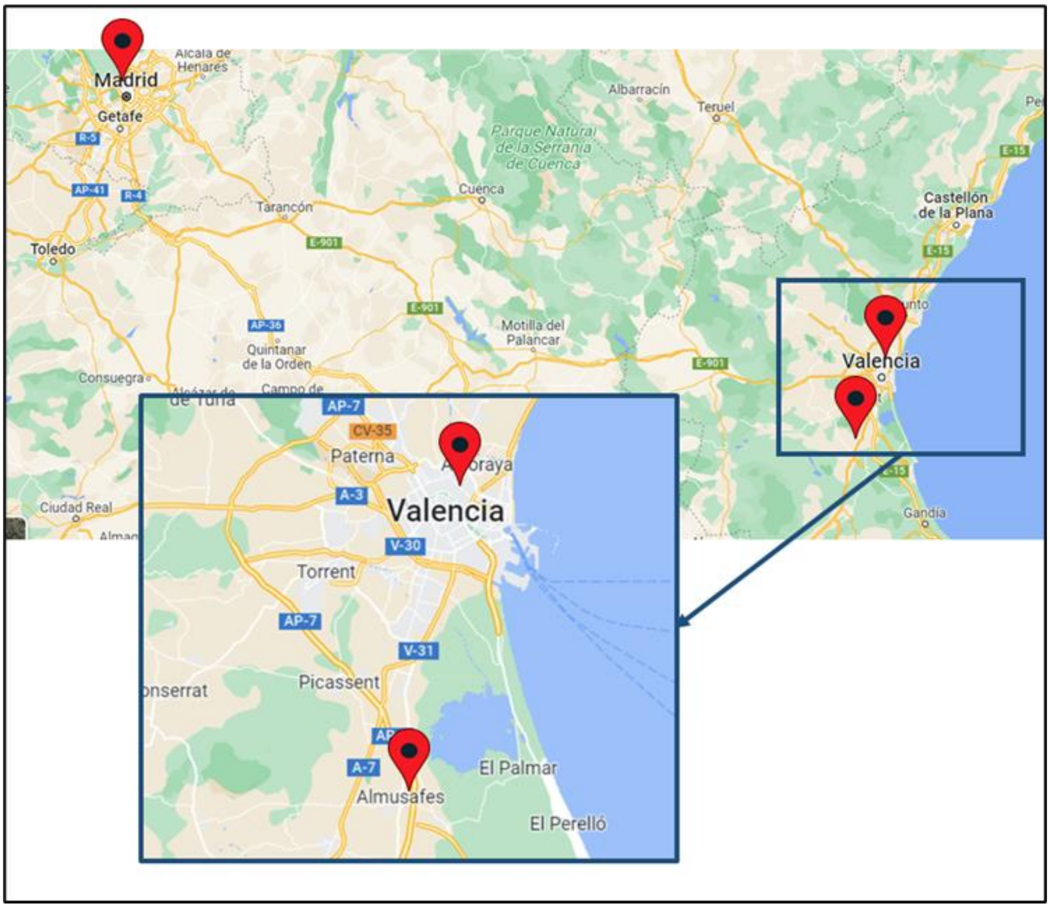


Figure 19: Location of the distributed network places, Madrid, Valencia and Almussafes

Figure 20: Red dot indicates the location of the fiber node at UPV

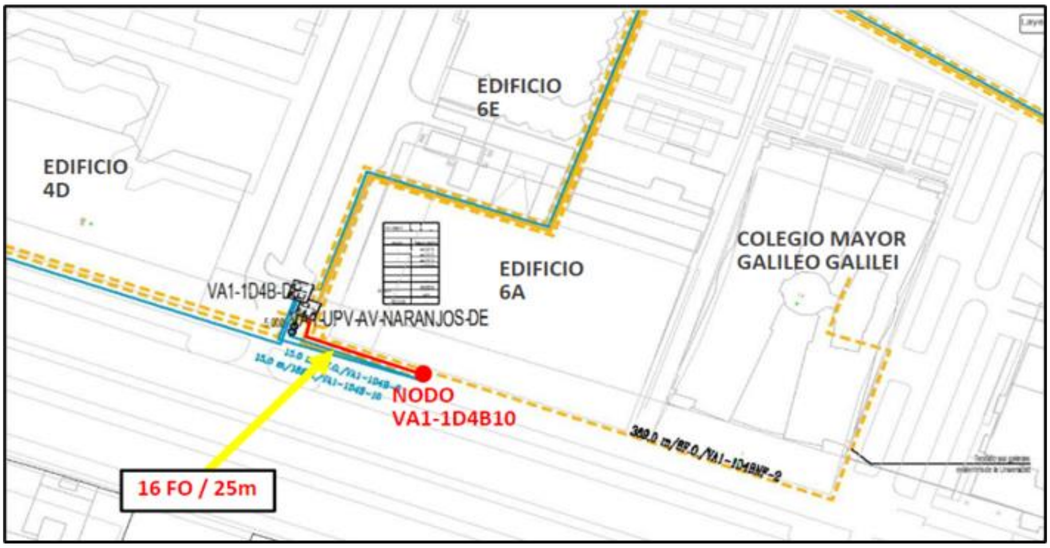


Figure 21: Detail of the fiber node in the parking lot of building 6A

Most of the 5G Core Network Functions are deployed and controlled from 5TONIC in Madrid, 350 kilometres away from Valencia. That is why there is a huge need to establish a reliable connection between both locations. There is an agreement with RedIris to provide a dedicated 10 Gbps speed line between 5Tonic and UPV. RedIris is a Spanish academic and research network that provides advanced communication services to the scientific community and national universities. This communication will be developed through IPSec tunnelling, which is a protocol that routes the virtual connection and protects it via a security tunnel.

Additionally, there must be a connection between UPV and the CNIT premises in Genoa (Italy), as there is where the main Applications Orchestrator is located. This connectivity is done through a VPN.

3.1.5 KPI Measurements System

For measuring network infrastructure metrics, a passive software probe that can sniff the network traffic during the experiments is being used. It is called 5Probe. It extracts networking KPIs from end-user traffic by analysing the packets with programmable Shallow Packet Inspection using a packet-capture (pcap) library to generate the 5G network metrics. It was developed for the 5Tonic laboratory and has already been used for other EU projects such as 5G EVE and 5Growth.

5Probe allows to measure the following KPIs:

- Uplink throughput for TCP and UDP flows, in bytes per second
- Downlink throughput for TCP and UDP flows, in bytes per second
- Smooth Round Trip Time (SRTT) for TCP flows, in milliseconds

5Probe stores the obtained KPIs in an existing influxdb on a server in 5Tonic, and the graphs are visualized with Grafana. It is a requirement that 5Probe has connectivity with 5Tonic environment to be able to store the KPIs in the database.

5Probe can be deployed on any Linux machine. It can be deployed in different points of the network, those being: the UE side, where it directly captures the UE incoming and outgoing traffic; the Core side, where it is able to de-capsulate GTP traffic, or the App server side where it directly captures the Application incoming and outgoing traffic.

3.2 ExFa-GR

The ExFa-GR will be used to validate the following 5G-INDUCE UCs:

UC 4: Predictive maintenance for Power Generator

	• Power generator used to aid ML-predictive maintenance using edge analytics and federated learning. • Initial datasets from the existing machine available at PPC premises have been extracted and have been used to train the algorithms.

UC 5: UAV inspection and surveillance

	• Effective inspection and surveillance of critical industrial infrastructures • Perform automatic UAV-based tank and pipeline inspection and area surveillance monitoring, based on • advanced AI-assisted object status and human identification algorithms linked to efficient warning mechanisms. • PPC has provided the required datasets for corrosion and intruder's detection.

UC 6: AR assistance for maintenance procedures

	• Main goal of this UC is to deliver new and advanced safety and security features for Remote Assistance in maintenance applications. • It will be shown that 5G environments can provide added security in remote maintenance use cases to prevent personal injury or confidentiality breaches. • The maintenance procedures and test sites have been fully described.

3.2.1 RAN

GR-ExFa trial site is in PPC premises. To cover the trial site a radio access network has been installed by OTE covering the required multi-floor area, as is presented in Table 1. The radio will be based on New Radio (NR) technology, and it will be connected to a 5GC that is located in OTE premises. NR is integrated with the SA Rel. 16 architecture. In Table 2 all the equipment that is used in PPC site is presented, while in Figure 22: (a,b,c) Radio Dots installed indoor, (d) Radio Unit and Baseband Unit integrated in the network infrastructure, (e) outdoor antenna this equipment is presented.

Table 1: Area covered in PPC premises

Area	Dimensions (m)
ground floor	18.7x21x6
1st floor	8.8x8.5x3
basement	18.7x21x6 and 20x3x6
outdoor	30x20

Table 2: RAN equipment used

Type	Manufacturer	Model	Information	Quantity
Radio Unit	Ericsson	ERS4408	4x4 MIMO, Carrier Aggregation and 256 QAM	1
Radio Unit	Ericsson	Radio Dots	4x4 MIMO, Carrier Aggregation and 256 QAM	4
Network Equipment	Ericsson	6630	Baseband Unit, 15 CPRI/9 eCPRI, LTE+NR with up to 12 CCs LTE and 12 CCs NR in dual mixed mode	1
Transport		IDU	FO Bridge	1

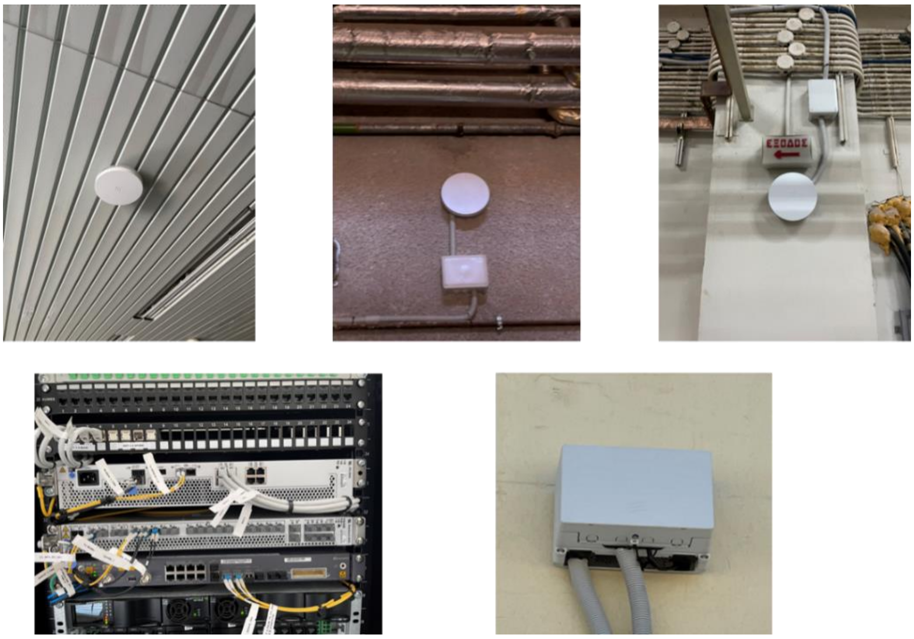


Figure 22: (a,b,c) Radio Dots installed indoor, (d) Radio Unit and Baseband Unit integrated in the network infrastructure, (e) outdoor antenna

3.2.2 Edge Computing

The two main sites of the implementation are the Core site, where the packet core is installed, and the RAN site, where the access part of the network is installed. The distance between the two sites is about 15km (Figure 23). In between, there is the packet optical transport network (POTP), which includes the transport network and network elements, such as servers and switches. OTE switches are interconnected to the OTE IP Core, using a 10 Gbps capacity line, to interconnect the infrastructure located at OTE Labs (Core site) with the RAN site in PPC.

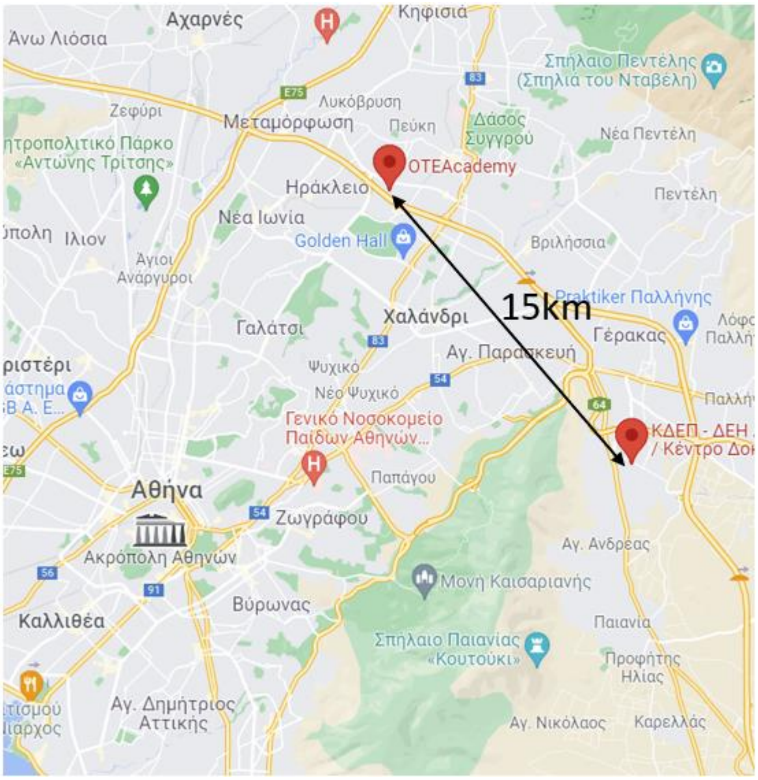
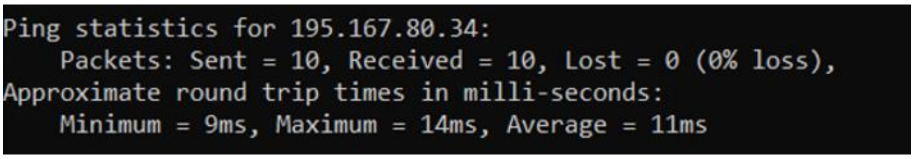


Figure 23: GR-ExFa main sites in Athens

Transport network testing has been performed and the delay is measured to be 200ns. However, as was expected, the rest of the network elements are adding extra latency. Therefore, the measured end-to-end latency was 4-10ms. In Figure 25, the round-trip latency (UE-5GC-UE) measured from one specific spot on site (Figure 24), is presented.

Figure 24: Network KPI measurement setup



```
Ping statistics for 195.167.80.34:
    Packets: Sent = 10, Received = 10, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 9ms, Maximum = 14ms, Average = 11ms
```

Figure 25: Round-trip latency measured on site

As a result, in the ExFa-GR network a MEC implementation on RAN side will not offer any significant advantage. Therefore, a MEC implementation in Core could be an alternative architecture. A server has already been installed at the Packet Core side, in order to host the application server for use cases demonstration.

3.2.3 Packet Core

For the needs of 5G-INDUCE project, a 5G SA Rel. 16 testbed is installed based on the architecture that is presented in Figure 26, using ATHONET Packet Core, which is an enhanced implementation of network functions.

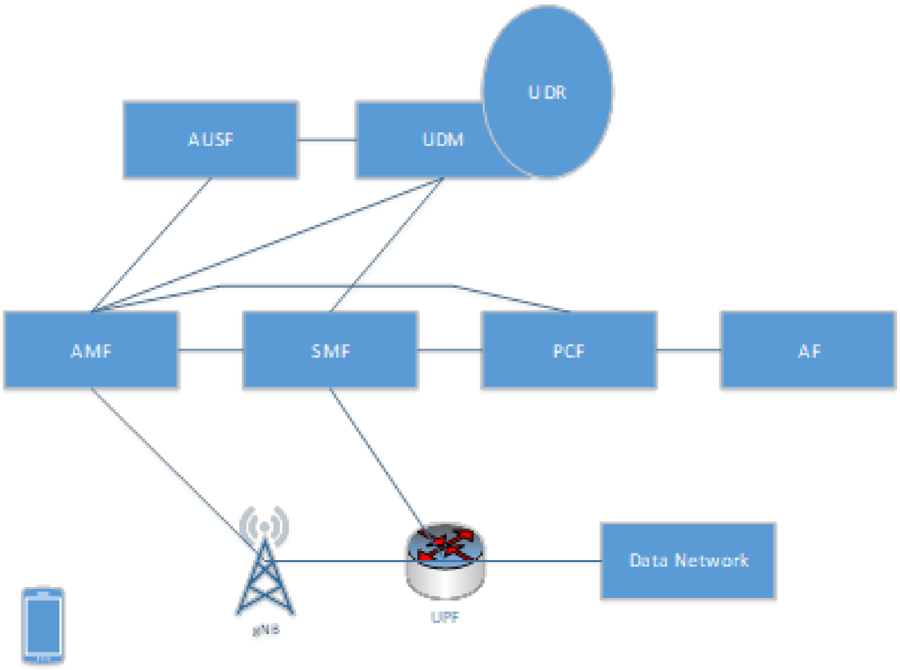


Figure 26: 5G SA architecture

The Packet core is separated in two main parts (Figure 27): the Control Plane Function (CPF) and the User Plane Function (UPF), both implemented as OCI containers. In the CPF component, four Network Functions are installed based on the 3GPP standard:

- Access and Mobility Management Function (AMF): The AMF component in the CPF can be accessed by any number of gNBs. Each gNB is assumed to be locally configured to access the AMF.
- Session Management Function (SMF): It can be configured to access any number of UPFs, including the UPF which is co-located. However, a UPF may only be controlled by one SMF. Although a gNB may connect to multiple AMF instances in different instances, each 5GS configuration containing an AMF is an independent 5GS.

- Authentication Server Function (AUSF): It enables the authentication of 3GPP access over NR
- User Data Management (UDM) Function: It supports the ARPF function, the SIDF function to de-conceal the SUPI from the SUCI, the 5G Authentication Vector Generation, the UE Subscriptions and the Authentication credential Repository and Processing Function (ARPF) to store the USIM long-term keys.

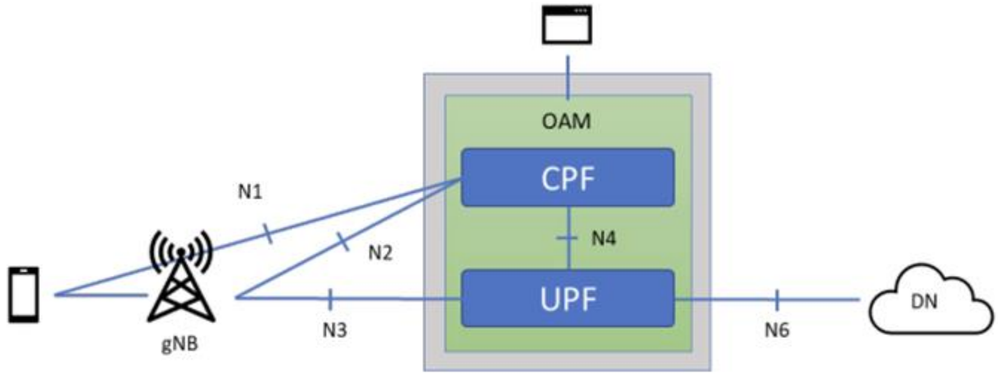


Figure 27: Athonet Architecture

Athonet packet core exposes the following 3GPP interfaces:

- N1: NAS over N2 between the gNBs and the AMF
- N2: NG-AP over SCTP between the gNBs and the AMF
- N3: NG-U over UDP between the gNBs and the UPFs
- N4: PFCP over UDP between the SMF and the UPFs
- N6: IP connectivity to external Data Networks (DN)

3.2.4 Transport

RAN and Packet Core interconnection will be achieved through the public transport network that has been installed. The distance between PPC and OTE premises is about 15km and the fibre optics link has been installed and tested. The transport network includes:

- High Speed 10Gbps Connection
- IP/MPLS Core infrastructure
- Local Access Network Segments
  - Huawei Packet Over Transport Equipment
  - Cisco 10/100Gbps LAN Switches

3.2.5 KPI Measurements System

In order to monitor testbed KPIs and ensure the network QoS, several monitoring tools (probes and a management server) are planned to be installed. These tools are not part of the testbed, but external pieces of equipment that will be installed in several spots within the network, such as in the RAN and in the packet core, as it is presented in Figure 28.

The monitoring tools could allow the accurate measurement of both the network parameters monitoring and the time relevant parameters (such as packet loss or latency). More specifically, these tools will provide values about:

- Latency (packets will be transferred through the network and the time that a packet needs to be received will be measured)
- Throughput (UL and DL throughput could be measured since packets sent and received will be measured)
- Availability and reliability (by measuring the packet error rate at the IP/Application layer)

Currently an IPerf server has been installed at the Packet core side (Probe 2), while an IPerf client has been installed at the UE side (Probe 1), allowing initial network KPIs testing.

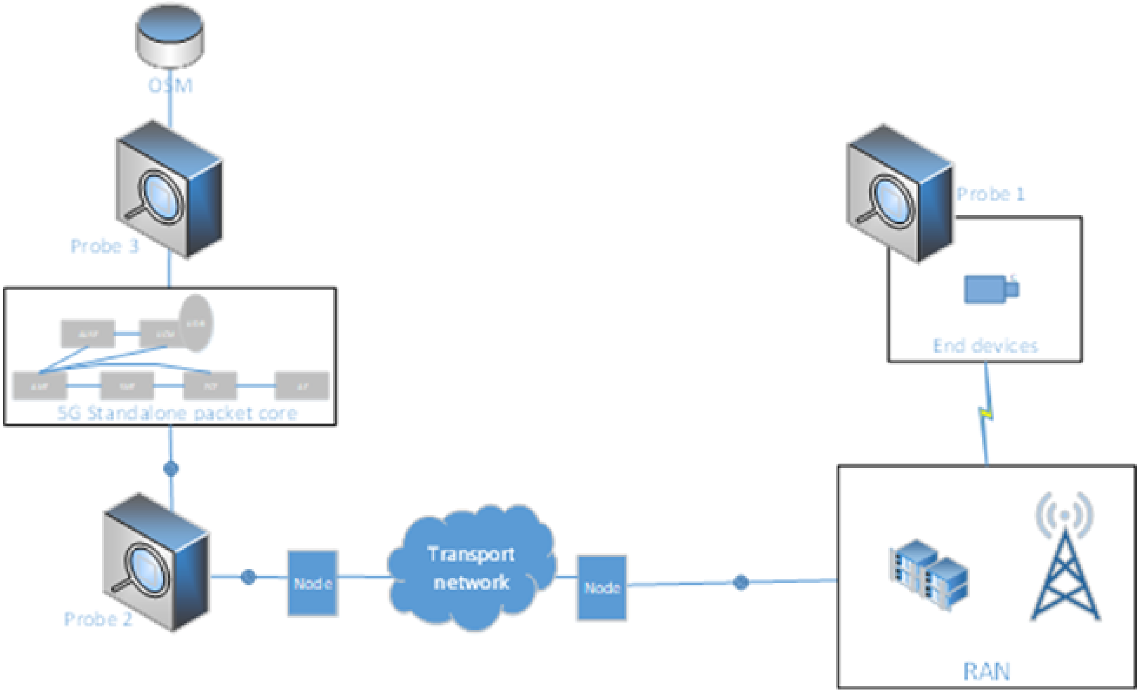


Figure 28: Setup for network KPIs measurement in ExFa-GR

3.3 ExFa-IT

The Italian 5G Experimentation Facility demonstrator will be held with the specific objective to demonstrate that the 5G connectivity implemented at the factory shop floor may ensure higher performances than the actual 4G Wi-Fi infrastructure, opening to the opportunity of a cheaper and profitable way for asset connection than the actual wiring solution. The experimentation area is the Whirlpool industrial site of Cassinetta (Italy) where 3 production plants (Refrigeration, Ovens and microwaves) are located, along with other central departments like Operation excellence, which provides engineering services for all the Whirlpool EMEA factories (Figures 29, 30).

Figure 29: ExFA-IT – Whirlpool's site in Cassinetta (Italy)

More specifically, the experimentation area will be implemented in the Refrigeration factory through the deployment of 4 use cases:

- UC 4: Predictive maintenance for thermoforming machine (Suite5's Network App)
- UC 6: AR support for maintenance operation in primary process (Oculavis's Network App)
- UC 7: Crossroad safety control (Ilink's Network App)
- UC 8: Network performance monitoring (Inin's Network App)

Figure 30: ExFA-IT – Whirlpool's Refrigerators Factory

UC 4: Predictive maintenance for thermoforming machine

The Use case is focused on the deployment of the Suite5 predictive maintenance system to support the maintenance activities planning of the thermoforming machine (COMI5) in the Whirlpool Refrigeration factory (Figure 31).

Figure 31: ExFA-IT - Thermoforming machine COMI5

In the demonstrator, the Network App will be installed on a mobile device connected to the orchestrator via the Wind3 5G network.

The network application will be connected with Whirlpool private cloud to ingest the data used for predictive analytics. All big data will be transferred via 5G network to the Network Application to be processed, and the specific information will be offered to the user through the mobile device interface.

The main business objective is the demonstration that 5G connectivity and analytics resources running at the edge may efficiently support the machine real time connectivity, ensuring an end-to-end latency, at application layer, at least <200ms and signal quality and availability fit to manufacturing purposes.

UC 6: Augmented reality for bending line maintenance

The Use case is focused on the deployment of the Oculavis SHARE platform to support the maintenance activities execution of the 2 twin doors stamping machines (COSMA1 and 2) in the Whirlpool Refrigeration factory (Figure 32).

Figure 32: ExFA-IT - Door stamping machine COSMA1

In the demonstrator the Network Application will be installed on a mobile device and smart glasses will be used for augmented reality functionalities, managing data visualization, video calls and video recording and sharing.

The main business objective is the demonstration that 5G connectivity may efficiently support the visualisation of huge data amounts like video/images/data uploading >10 Mb/s for single user point, with a high number of users points, an end-to-end latency, at application layer, at least <200ms and a wideband, a signal quality and availability fit to manufacturing purposes.

UC7: Crossroad safety control

The Use case is focused on the deployment of the Ilink's Network App platform to support the safety control in a selected area (doors warehouse) of the Refrigeration factory shopfloor (Figure 33).

Figure 33: ExFA-IT – Doors warehouse crossroad

In the demonstrator the Network App will be installed on mobile devices (tablet, smartphones...) and it will be able to capture moving assets (forklifts, tuggers, trolleys, people...) moving in the area covered by the ultra-wideband anchors which will be installed in the selected area and connected via cable to the 5G gateway, which will connect to the orchestrator via the Wind3 5G network.

The main business objective of the demo is the verification that 5G technology applied to moving asset tracking may boost the safety conditions in shop floor environment, ensuring end latency, at application layer, at least <100ms and a signal quality and availability fit to safety purposes.

UC 8: Network performance monitoring

The Use case is focused on the deployment of the ININ's Network Application platform to support the network performance monitoring in the Whirlpool Cassinetta industrial site (Figure 34).

The demonstrator will be implemented in 2 different operational modes. The first one will have a fix probe installed in a specific area (in this case the same area identified and used for UC7) in order to continuously monitor the network performances: it will be connected to 5G network through a 5G gateway installed in the UC7 area. The second one will deploy the Network App in a mobile device (smartphone) moved around the various areas of the factory to detect performance gaps in the network and it will be connected directly via 5G to the NAO. The main business objective of the demo is the verification that 5G technology applied to moving asset tracking may boost the safety conditions in shop floor environment, ensuring end latency, at application layer, at least <100ms and a signal quality and availability fit to safety purposes.

Figure 34: ExFA-IT – Refrigerators Factory shop floor

Infrastructure design

All the use case will be connected to the Wind3 data center using the orchestrator installed at CNIT premises through the Wind3 VPN. according to the infrastructure design below (Figure 35).

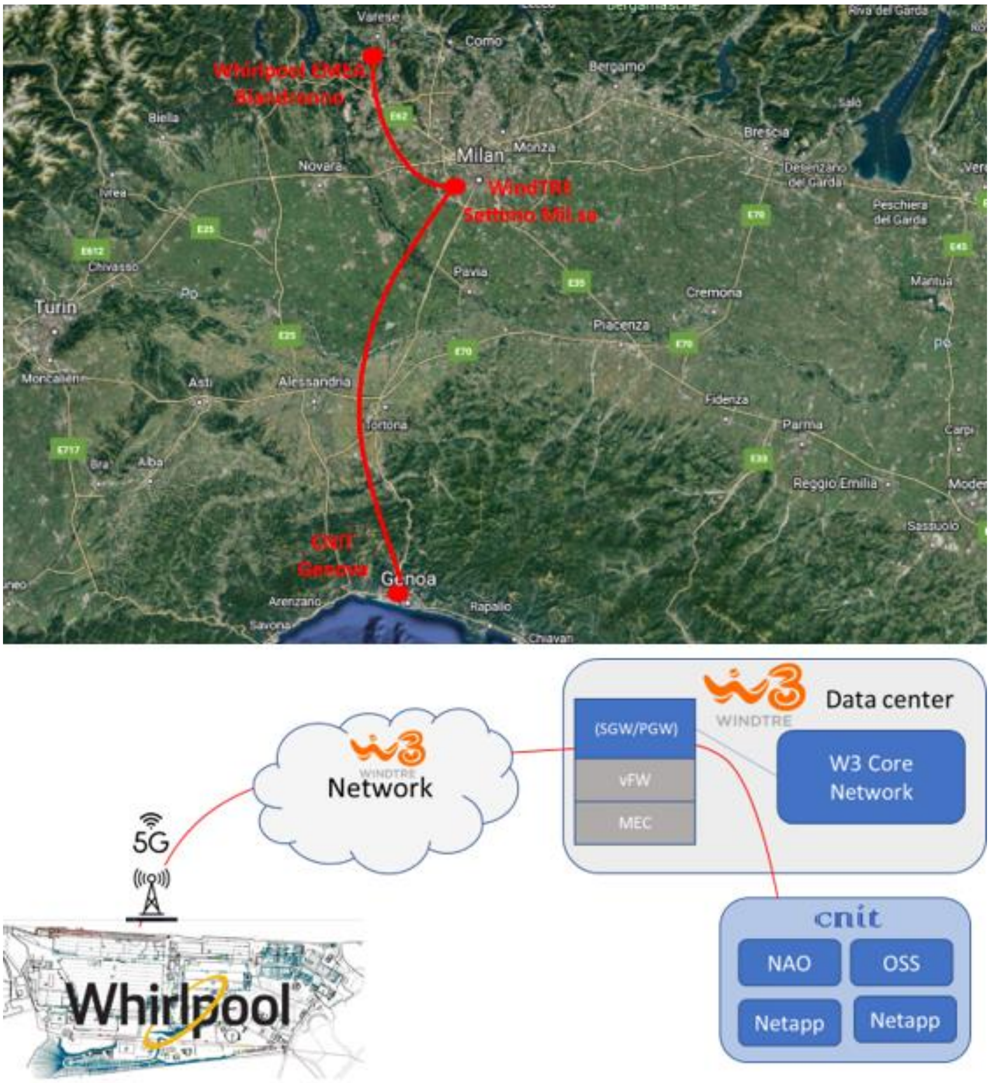


Figure 35: ExFA-IT – ExFA-IT infrastructure design

The mobile devices to be used in all the use cases will be connected to the 5G network and they will provide both the access to data (stored in the private Whirlpool cloud) and the interface toward the users.

The Wind3 network coverage is ensured on the whole demonstrator scope both for 5GDSS and for 5GTDD, as shown in Figure 34.

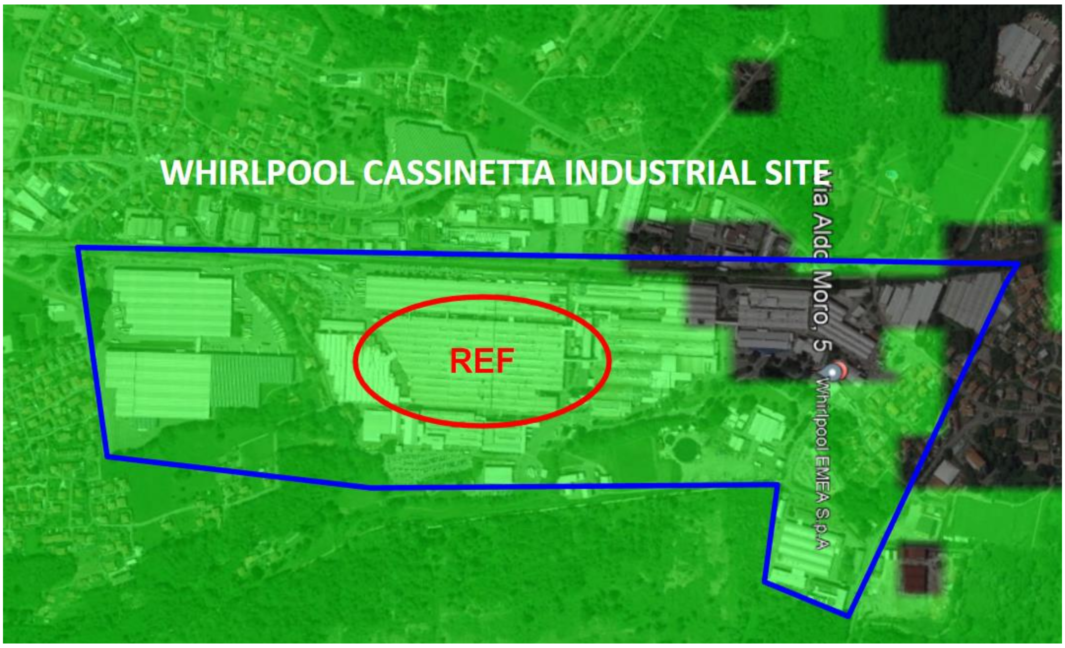


Figure 36: ExFA-IT – ExFA-IT 5G network coverage

W3 guarantees connectivity to MEC with two SIMs configured with private APN while two other SIMs are configured with public APN to guarantee connectivity to the external server using a public IP address.

3.3.1 RAN

The trial exploits the existing infrastructure including the bands of the W3 network deployment in that area according to the Option 3.x which makes use of the E-UTRAN – NR Dual Connectivity. W3 has already made a massive rollout of 5G, making use of Base Band Units (BBUs) and Radio Remote Units (RRUs) supporting the "Dynamic Spectrum Sharing" (DSS) solution between LTE and NR and supporting TDD. W3 guarantees 5G radio coverage in Cassinetta site with antenna VA138 (Table 3). The tracking area related to VA138 is configured in W3 network to permit connectivity between 5G radio coverage in Cassinetta and MEC server.

Backhauling guarantees radio access connectivity to an IP Backbone that permits to reach the MEC server installed at the W3 datacenter in Settimo Milanese and to reach the W3 core network.

Table 3: ExFA-IT 5G antenna detail

Site	Information	Quantity
VA138	TDD, spectrum 60MHz, Frame Configuration 7:3 (7 subframes in Downlink e 3 subframes in Uplink, Massive MIMO 32x32, 256QAM DOWNLINK	1
	DSS, spectrum 20MHz, MIMO 2X2, 256QAM DOWNLINK	

3.3.2 Edge Computing

The MEC server by Athonet is implemented in W3 datacenter in Settimo Milanese in W3 commercial network. A first server is configured as SGW/PGW in order to emulate a local core network; a second server is locally connected to the first server and contains the applications necessary for guaranteeing low latency at the edge. The MEC with SGW/PGW functionality is equipped with 4x10Gbps Ethernet interfaces, 2x10GE-LR optical interfaces towards the W3 core network and 2x10GE-LR optical interfaces towards the W3 radio network. 2x10GE copper interfaces are used for connecting to server dedicated to vApps. The Operating System installed is Ubuntu server 18.04; MEC applications are virtualized using Docker. The MEC server can have connectivity to external servers through a secure connection to manage applications. A virtual firewall is configured to protect the SGW/PGW by potential unauthorized access.

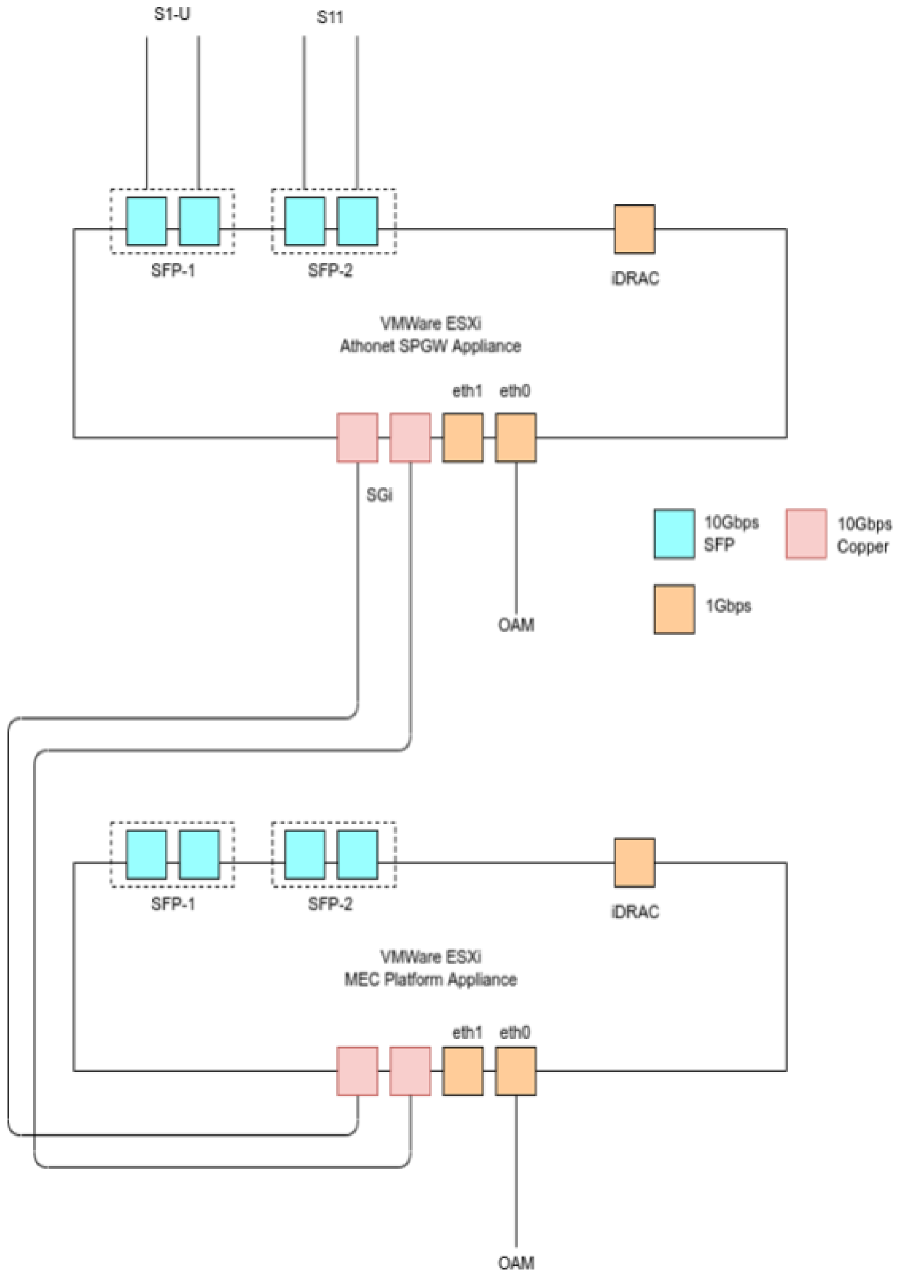


Figure 37: ExFa-IT MEC platform

In NSA configuration the S1U interface is used for communication between eNBs and SGW in the MEC host, while the S11 interface connects SGW in the MEC host to the core network. The SGi interface connects PGW to MEC host's data plane (see Figures 37 and 38).

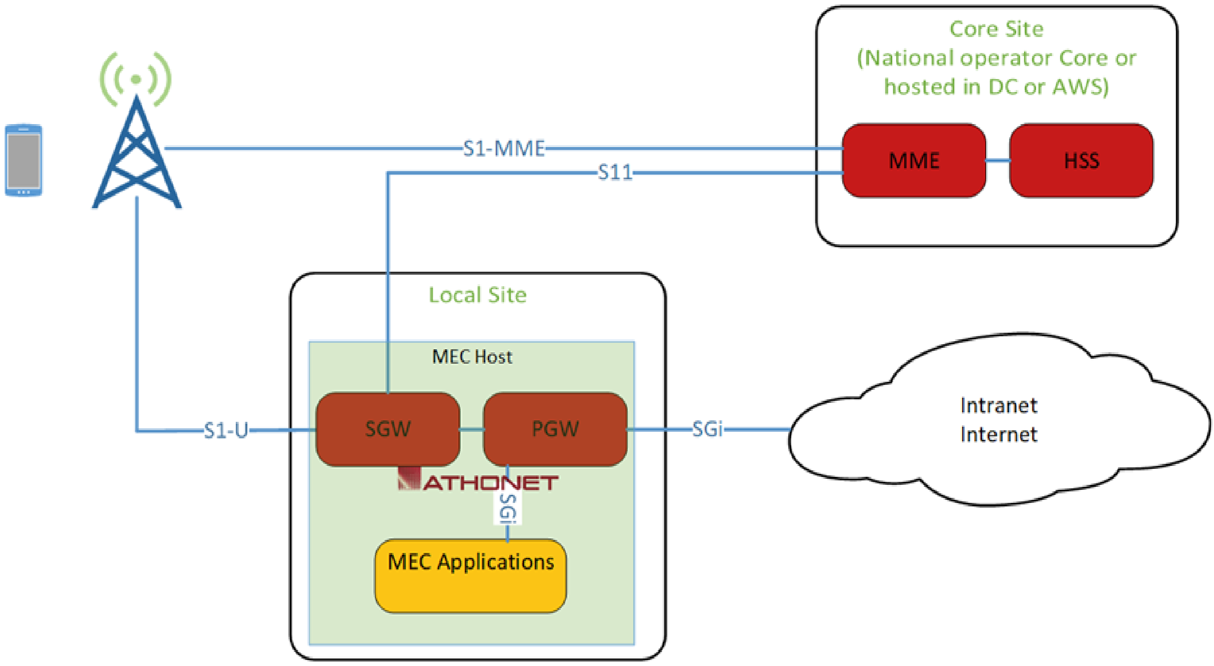


Figure 38: ExFA-IT MEC integration in W3 network

3.3.3 Packet Core

The Non-Standalone core network according to the Option 3.x is the virtualized infrastructure implementing Network Functions; this commercial network will be used for testing in Cassinetta site.

The SGW and PGW network functions are deployed at the edge site on the MEC, whereas the control plane functions such as the Mobility Management Entity (MME) and HSS are located at the W3 core network.

The local SGW selection is performed by the central MME according to the 3GPP standard DNS procedures and based on the Tracking Area Code (TAC) of the radio where the UE attaches to. This architecture allows offloading the traffic based on the APN. This deployment permits W3 to maintain total control over the MME, whereas the data plane flows through a separated network that does not impact any existing network nor business. Rel.15 is the current release deployed in CN.

Three steps are required to implement this solution: configure SGW Selection Based on IMSI Number Series and Geographical Area function on MME, configure a new APN on DNS to select the MEC PGW, configure a new APN on HLR and HSS.

3.3.4 Transport

Wind3 transport network is based on IP technology (router) and WDM technology.

Three hierarchical levels can be classified (Figure 39):

- The Access layer collects traffic from mobile and fixed sites.
- The Regional layer aggregates traffic at the regional and metropolitan level.
- The Backbone level creates high-capacity connections at a national level between the nodes of the Core Network (mobile or fixed) and towards the international Big Internet.

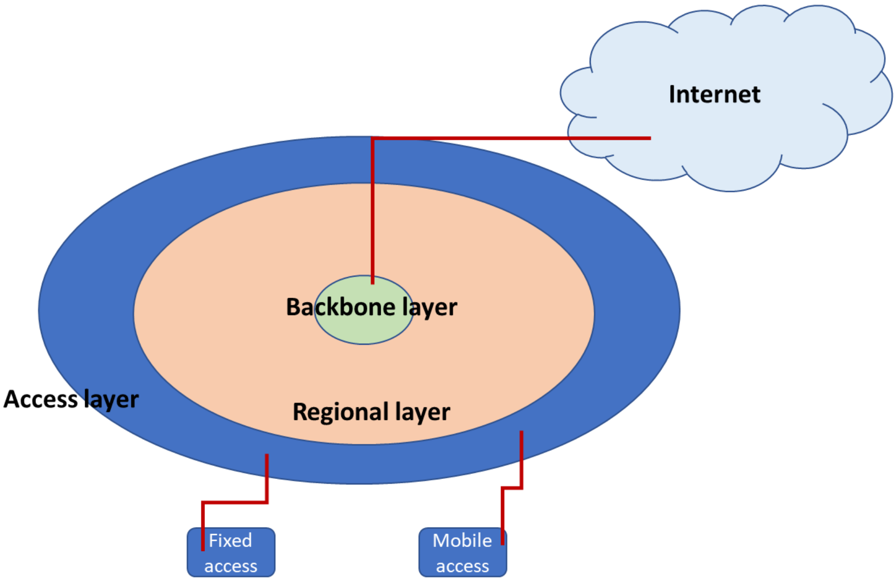


Figure 39: ExFA-IT IP Backbone

The IP over WDM network permits transport between 5G RAN (in which the VA138 site is included) and the MEC server for sending traffic to MEC host and permit transport between 5G RAN and W3 core network in order to guarantee connection with MME/HSS. The same IP over WDM network is useful to create a connectivity between MEC and CNIT site for configuring a VPN that permits access to the MEC from a remote site. The IP backbone is equipped also with the firewall necessary to terminate the VPN for guaranteeing secure access toward the MEC server.

3.3.5 KPI Measurements System

The main objective of the ExFA-IT demonstrator is the validation of the usage of the 5G solution to offer services at the shop floor with better performance versus the current infrastructural solution (like 4G Wi-Fi or wired cables)

Specific business relevant KPI's have been defined for all the use cases in order to prove the solution validity from the user point of view:

- Signal quality and coverage (indoor/Outdoor)
  - Signal strength >-76dBm on covered area
  - Signal stability within covered area +/-5%
- Latency
  - Transport layer: Communication latency (end-to-end) <100ms
  - Application layer: Processing Latency (including transport)
  - <200ms for control purpose as today
  - <500ms for monitoring purpose as today
- Bandwidth
  - video/images/data uploading >10 Mb/s for single user point
- Availability
  - 99.99% as today

- Health and Safety
    - Wearable devices: energy interference (electric and magnetic field intensity) equal or lower than other reference devices/ technologies in use (e.g., mobile device)
    - Italian regulation compliance DPCM 8.7.2003 (GU 199 29.08.2003)

Signal quality, coverage and availability performances will be evaluated trough the UC8 network application usage bot in fix probe mode and in travelling mode (indoor/Outdoor).

4 Integration

As thoroughly described in deliverable D3.4 [4], the 5G-INDUCE OSS is divided into two modules: the North-Bound OSS (NB-OSS) represents the interface towards the NAO and is in charge of managing the slice negotiation, as well as to maintain information about the coverage and operational capabilities offered by the SB-OSS, which is dedicated to a specific ExFa and offers pluggable services depending on the underlying capabilities.

Among these services, the SB-Core is the one that is always available, while the NFV Convergence Layer (NFVCL), in charge of abstracting the lifecycle management of NSs, VNFs and PNFs, and the Metal Convergence Layer (MetalCL), devoted to the management and terraforming of the VIMs, operating systems and bare-metal resources, are plugged depending on the level of programmability exposed by the ExFa. Namely, referring to Figure 40 three macro-programmability tiers can be identified. The bottom tier includes the maximum levels of programmability, from bare-metal resources to operating systems and VIMs. This tier requires the presence of both the NFVCL and the MetalCL, but the latter has limited features moving up from the bare-metal layer. The central tier covers IaaS and PaaS-level programmability and sees the presence of the sole NFVCL, which is unauthorized to handle VIM-Level resources for IaaS as well as, additionally, non-cloud-native network services for PaaS. Finally, the top tier covers configurable domains, in which onboarding and the updates of NSs are handled through ETSI NFV-SOL 006 APIs [5], and non-programmable domains that simply provide a catalogue of the pre-allocated network slices.

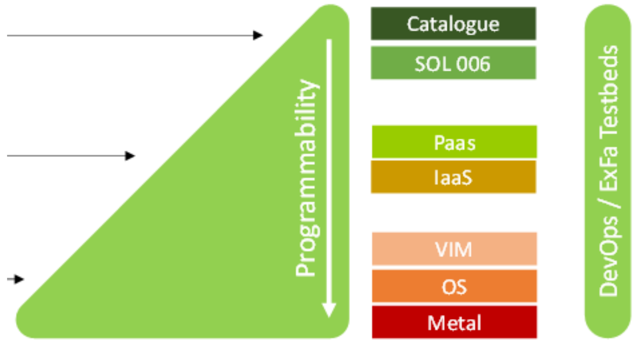


Figure 40: The levels of programmability that can be handled by the 5G-INDUCE platform

The SB-Core is the component currently undergoing most of the extensions/enhancements required for fostering the integration of the 5G-INDUCE platform over the ExFas. While the actions performed to embrace the peculiarities of the individual facilities will be described in the next sub-sections, current activities can be narrowed to the ones related to the initial slice materialization and Network App deployment, and the ones enabling Day-2 operations.

In order to make the integration process as streamlined as possible, the prototype has been equipped with native OpenAPI [6] documentation. In this way, it will be easier for the ExFas to develop, if necessary, simplified versions of the NFVCL for the independent management of their own slices upon reception of a slice intent.

Moreover, the SB-Core is being extended with a monitoring framework aimed to drive decisions on Day-2 operations. In more details, a REST command is being introduced to trigger the monitoring of the automated KPIs observed, where available, by Prometheus. Such KPIs are collected at infrastructure/PaaS level, hence from Kubernetes for KNFs and from OpenStack for VNFs. The REST command also lets external applications retrieve the list of the collected metrics for a specific NS: in this way, ExFas have the means to detect potential bottlenecks and perform scaling operations in a timely manner.

4.1 Platform Integration over ExFa-SP

The integration of the 5G-INDUCE platform has started in February, as soon as the physical infrastructure distributed over the ERC, FORD and UPV facilities have been available. For this ExFa, programmability will be handled with a black-box "approach": the involved parts have agreed upon using ETSI NFV-SOL 006 as reference API to represent the NS descriptors according to the YANG modeling language. The onboarding of NSDs will provide the positive feedback requested to guarantee the feasibility of the slice-intent; upon onboarding, the NS instantiation will trigger the actual slice materialization. Initial testing campaigns will prove whether a local installation of the NAO and NB-OSS is required or if their external connectivity should be provided via VPN.

4.2 Platform Integration over ExFa-GR

The integration of the platform over the Greek facility is currently stalled due to the imminent finalization of the OpenStack deployment. Following, the next step will regard a decision on the most suitable level of programmability for the Athonet 5GC: in the case that the exposed APIs would provide suitable degrees of freedom, the integration will follow similar steps with respect to ExFa-SP; otherwise, the SB-Core will perform admission control for slice intent requests upon a provided catalogue of pre-allocated slices. Regarding the deployment of the 5G-INDUCE platform, the same considerations as for ExFa-SP hold true, with a slight propensity, at the time of writing, for the local installation of the NAO and the NB-OSS.

4.3 Platform Integration over ExFa-IT

For ExFa-IT, the beginning of the integration should start very soon, as the W3 site will be made available in a matter of days. Most of the strategic decisions on how to proceed with the integration have already been taken for a long time. The 5G-INDUCE platform will be located in the DevOps testbed in the CNIT premises and will be connected to W3 via VPN. W3 will further provide 5G connectivity to WHP.

4.4 OSS – Packer Core

In the W3 core network, NFV Management and Orchestrator (MANO) provides the real-time automation of network services and lifecycle management, optimising network resources. MANO at the Italian testbed is composed by the following systems:

- E2E Service Orchestrator
- NFV Orchestrator (NFVO)
- VNF Manager (VNFM)

The systems operated in this testbed are:

- E2E Service Orchestrator includes the NFVO functionality. Furthermore, it manages end-to-end network services, allocates resources, triggers instantiation and configures VNFs.
- The NFVO orchestrates NFVI resources across multiple VIMs, manages the lifecycle of Network Services and manages the Repository.
- The VNF Manager administrates the lifecycle of VNF instances.

In this setup the Orchestrator is based on ONAP standard. This is the current orchestrator in W3 commercial network.

The MEC server is stand-alone equipment. The device is not managed by W3 MANO because the server is deployed only for trial. A VPN can be configured to permit remote management of the MEC server: resources' utilization (RAM/CPU/HDD), throughput, packets sent and received.

5 Next Steps

5.1 ExFa-SP

From all the infrastructure described in the previous sections regarding ExFa-SP, we note the following recently implemented or pending points (ongoing or planned in the near future):

- The direct optical fiber line installation between UPV and Ford's factory has been completed during February 2023.
- The establishment of the IPSec tunnel via RedIris between UPV and 5Tonic has been achieved in February 2023.
- As the previous points are completed, the works for migrating the 5G CP traffic from the temporary 4G connection to the final solution over cable are ongoing at the moment of producing this document.
- The VPN connectivity between UPV and CNIT has started in February 2023.

These are the only pending points regarding the infrastructure, which reveals the ExFa-SP is in good shape and the on-site experimentation can progress. A round of experiments has already been performed in the week of January 23, 2023, covering UC1 and UC2 at Ford premises. There will be more iterative experimentation sessions including UC3 and adding increasingly more complex features such as orchestration of the applications.

5.2 ExFa-GR

The 5G SA network installation for the ExFa-GR has been completed and initial tests have been performed. During the next period, the integration of the 5G testbed with the NAO will be completed allowing the end-to-end ExFa-GR validation testing. At the same time, the monitoring of the network performance will continue, improving the network characteristics when required according to the requirements of the end user.

5.3 ExFa-IT

After some issues arisen and due to the mandatory requirement of compliance with Italian communication regulation, the feasibility of the setup of the VPN solution between WIND3 and CNIT has been confirmed and the connectivity activities are proceeding to be able to complete the 5G integration test by mid-March when also the NAO full integration will be available. However, an alternative setup to be used in case of further delay has been identified and is being tested at the time of writing, which consists of a datacenter and access network "in-the-box" that can be installed by CNIT in Whirlpool premises in a stand-alone fashion. In the meanwhile, the test of the Network applications in the shop floor environment has been scheduled by the end of March, in order to have the full readiness once the VPN connectivity will be fully in place on ExFa-IT.

6 Conclusion

This deliverable has presented an in-depth description of the three experimentation facilities in Spain, Greece and Italy, as well as their individual components including RAN, edge, packet core, etc. Also, the use cases that each ExFa implements and supports has been briefly briefly recalled.

The Spanish 5G Experimentation Facility infrastructure (ExFa-SP) is deployed with the goal to validate and showcase the developed Network Apps over a real industrial 5G environment.

The Greek 5G Experimentation facility (ExFa-GR) will comprise the 5G core and edge-level capabilities offered by OTE research lab facilities.

The Italian 5G Experimentation Facility demonstrator (ExFa-IT) will be held targeting to demonstrate that the 5G connectivity implemented at the factory shop floor may ensure higher performances than the actual 4G / Wi-Fi infrastructure.

Overall, the scope of the document is to provide an advanced starting point for the successful integration implementation over the ExFas, minimizing the associated risk of failures and feed future activities. The statuses of the ExFas to be ready for the final demonstration of the network applications usage scenarios are at a satisfying level. Next steps include testing and monitoring for improved network performance, preparation for the integration activities, additional software and hardware installation in the ExFas and various experiments.

7 References

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