5G European Validation platform for Extensive trials

Deliverable D2.1
Initial detailed architectural and functional site facilities description

Deliverable History

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List of Acronyms and Abbreviations

3GPP	Third Generation Partnership Project
5G	Fifth Generation
AGC	Automatic Gain Control
AGV	Automated Guided Vehicle
API	Application Programming Interface
APN	Access Point Name
BBU	Base Band Unit
BGW	Base station Gateway
CA	Carrier Aggregation
CEE	Cloud Execution (Ericsson) Environment
CIC	Cloud Infrastructure Controller
CI/CD	Continuous Integration/Continuous Delivery
CLI	Command Line Interface
CMG	Cloud Mobile Gateway
CMM	Cloud Mobility Manager
CoMP	Coordinate Multi-Point
CP	Control Plane
C-RAN	Cloud Radio Access Network
CU	Cloud Unit
CUPS	Control and User Plane Separation
DL	DownLink
DRB	Data Radio Bearer
DU	Digital Unit
DWDM	Dense Wavelength Division Multiplexing
E2E	End-to-End
eMBB	Enhanced Mobile Broad Band
ENM	Ericsson Network Manager
EO	Ericsson Orchestrator
EPC	Evolved Packet Core
FDD	Frequency Division Duplexing
GPRS	General Packet Radio Service
GPS	Global Positioning System
GUI	Graphical User Interface
HOM	Higher Order Modulation

HSR	High Speed Rail
HSS	Home Subscriber Server
HW	HardWare
IaaS	Interface as a Service
IRU	Indoor Radio Unit
KPI	Key Performance Indicator
LAN	Local Access Network
LB	Load Balancing
LCT	Local Craft Terminal
LIDAR	LIght Detection And Ranging
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control
MCR	Mobile Cloud Robotics
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMTC	massive Mobile Type Communication
MNO	Mobile Network Operator
NB-IoT	Narrow Band – Internet of Things
NFV	Network Function Virtualization
NFVM	NFV Manager
NFVO	NFV Orchestrator
NFVI PoP	NFV Infrastructure Point of Presence
NGC	Next Generation Core
NR	New Radio
NS	Network Slicing
NSA	Non Stand-Alone
NSD	Network Service Descriptor
OAI	Open Air Interface
ODL	OpenDayLight
ORAN	Open Radio Access Network
OSS	Operation Support System
pCPU	Physical Central Processing Units
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit

PNF	Physical Network Function		*TCO*	Total Cost of Ownership
QAM	Quadrature Amplitude Modulation		*TDD*	Time Division Duplexing
QoS	Quality of Service		*Tx*	Transmission
RAN	Radio Access Network		*UC*	Use-Case
RAU	Radio Access Unit		*UE*	User Equipment
RCC	Radio Cloud Center		*UL*	UpLink
RD	Radio Dot		*UP*	User Plane
RDI	Radio Dot Interface		*uRLLC*	Ultra-Reliable Low-Latency Communications
RDS	Radio Dot System		*USRP*	Universal Software Radio Peripheral
RLC	Radio Link Control			
RRC	Radio Resource Control		*UTRAN*	Universal Terrestrial Radio Access Network
RRH	Remote Radio Head			
RRU	Remote Radio Unit		*vCPU*	Virtual Central Processing Units
Rx	Reception		*vEPC*	virtual Evolved Packet Core
SCF	Small Cell Forum		*vEPG*	virtual Evolved Packet Gateway
SCM	Service Control Manager		*VIM*	Virtualized Infrastructure Manager
SDAP	Service Data Application Protocols		*VM*	Virtual Machine
SDN	Software Defined Network		*VNF*	Virtual Network Function
SDK	Software Development Kit		*VNF-FGD*	VNF Forwarding Graph Descriptor
SDL	Shared Data Layer		*VNIC*	Virtual Network Interface Controller
SDR	Software Defined radio			
SFC	Service Function Chaining		*VPN*	Virtual Private Network
SU-MIMO	Single User MIMO		*WAN*	Wireless Access Network
SW	SoftWare			
SWL	Smart Wireless Logistics			
TaaS	Testing as a Service			

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Executive Summary

This deliverable contains the description of the four European (France, Greece, Italia and Spain) sites facilities that compose the 5G end-to-end infrastructure of 5G EVE. Since the deployment of the four facilities is in progress at the time of delivery of this document, the information here provided is to be considered as the state of hardware and software assets in each site facility planned for the end of April 2019, when the initial access to the 5G EVE platforms will be granted to the verticals to be integrated. The site facilities evolution will follow the specifications of 3GPP – Release 16 and the roadmap of equipment manufacturers. The final state of the different sites facilities that will compose the E2E facility will be described in the D2.3 deliverable due at the end of the project (June 2021).

Each site facility is described individually, with an effort to identify the possible commonalities and inter-relations among site architectures which aims at easing the process of smooth interworking in the 5G EVE platform.

For each of the sites, we provide through this document a description of the reference high level architecture and a summary of the main vertical use-cases that is planned to integrate. A set of technical features is also provided, such as:

- the RAN architecture (RRH, BBU, Frequency bands, implemented technologies, etc.);
- the distributed cloud/MEC elements;
- the CORE architecture;
- the network management and orchestration functions;
- the tools and software used for the network deployment, supervision management and KPI testing and validation;
- the main interfaces between layers.

The individual description of each of the sites allows to analyse the possible convergence between the different approaches of network deployment and thus to give the common blocks that can build the interworking between sites and the management of the 5G EVE end-to-end facility.

In the conclusion, we present a summary table of the technologies used by each site for each part of the network framework.

1 Introduction

This document represents the first 5G EVE public deliverable, which describes the main functionalities that compose the different 5G site facilities and their general architecture. The objective of this document is to provide information, for each site facility, about the main 5G solution elements that will be deployed and implemented during the first 10 months of the project and made available by the end of April 2019. This site construction activities target the project milestone which marks the availability of initial access to the different sites facilities for the participating vertical industries to start the implementation of self-standing use-cases (i.e. without interworking since platform APIs and test tools will not be ready yet).

The 5G end-to-end facility is composed of 4 interconnected sites facilities located in Greece, Italy, Spain and France as shown in Figure 1. As detailed in Section 5.1, the French site is itself a cluster of site facilities deployed in 4 different cities.
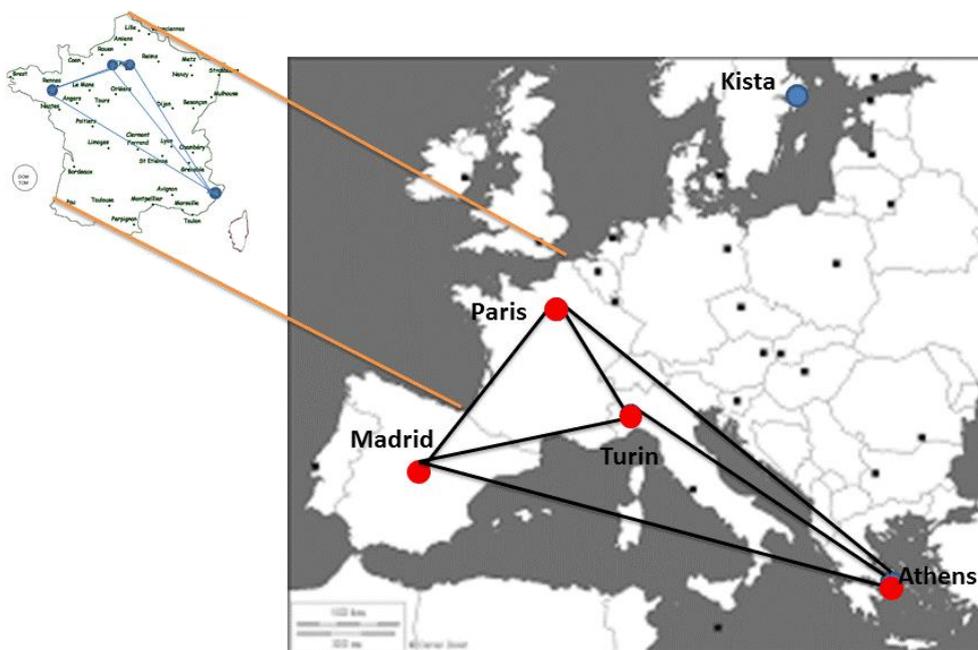
Figure 1: Location of the four European site facilities

The objective of the 5G EVE project is to build a European 5G end-to-end facility that will host a selection of use-cases to be deployed by verticals. More specifically, the project targets as part of its workplan:

- Use-case 1 - Smart Transport: Intelligent railway for smart mobility;
- Use-case 2 - Smart Tourism: Augmented Fair experience;
- Use-case 3 - Industry 4.0: Autonomous vehicles in manufacturing environments;
- Use-case 4 - Utilities (Smart Energy): Fault management for distributed electricity generation in smart grids;
- Use-case 5 - Smart cities: Safety and Environment - Smart Turin;
- Use-case 6 - Media & Entertainment: UHF Media, On-site Live Event Experience and Immersive and Integrated Media),

The 5G EVE use-cases detailed descriptions are covered by the 5G EVE deliverable D1.1 [1] planned to be issued in October 2018. These use-cases will be applied to the different site facilities following the mapping presented in Table 1, which also details the guiding vertical partner in charge of use-case planning and integration. The architecture of the site's facilities is very dependent on the requirements targeted by the service (and vertical) to be implemented (supported).

Table 1: Site facility vertical mapping, vertical partners and dominance service

Use-case	France	Greece	Italy	Spain	Dominance
Use-case 1 - Smart Transport: Intelligent railway for smart mobility			Trenitalia		URLLC and mMTC
Use-case 2 - Smart Tourism: Augmented Fair experience				SEGITTUR	URLLC & eMBB
Use-case 3 - Industry 4.0: Autonomous vehicles in manufacturing environments		OTE/ Ericsson GR		ASTI	URLLC
Use-case 4 - Utilities (Smart Energy): Fault management for distributed electricity generation in smart grids	EDF	WINGS			URLLC and (critical) mMTC
Use-case 5 - Smart cities: Safety and Environment - Smart Turin		Nokia GR/ WINGS	Comune Torino		URLLC & mMTC
Use-case 6 - Media & Entertainment: UHF Media, On-site Live Event Experience and Immersive and Integrated Media)	ORANGE			Telefonica	eMBB, URLLC and mMTC

An overview of the administrative details of the four 5G EVE site facilities is shown in Table 2. It is worth noticing that the site owner is supported by a network operator and that each sites involve a number of partners covering the various phases of design, deployment, integration and operation with specifically assigned roles. The initial locations are also reported but could change since they are very dependent on the carrier frequencies made available by each national regulator.

Table 2: Overview of 5G EVE site facilities

Site Facility	Greece	Spain 5TONIC	France	Italy
Owner (operator)	OTE	Telefonica	Orange	TIM
Location(s)	Athens	Madrid	Nice, Paris, Châtillon & Rennes	Turin
Involved partners	Nokia, Ericsson, Wings	Ericsson, UC3M (IMDEA), Segittur, ASTI, Telcaria	Nokia, b-com, Eurecom, EDF, Orange	Ericsson IT, Nextworks, CNIT, Comune Torino, Trenitalia, Ares2t

For each site facility, a "Site Facility Manager" is defined, with two partners identified as primary and secondary to guarantee operation continuity (Table 3). Site facility managers are in charge of the site facility implementation, validation and operation.

Table 3: Site facilities management

Site Manager	France	Greece	Italy	Spain
Primary	Orange	OTE	TIM	IMDEA
Secondary	Nokia	WINGS	Ericsson	UC3M

1.1 Structure of the document

The main structure of this deliverable can be summarized as follows:

- Chapter 2 contains the Greek site facility description;
- Chapter 3 contains the Italian site facility description;
- Chapter 4 contains the Spanish site facility description;
- Chapter 5 contains the French site facility description;
- Chapter 6 gives a conclusion with a table summarizing the main components of the different sites' facilities.

The description of each site facility follows the same content structure. In the introduction, a description of the deployed architecture is given as well as a brief reminder of the main vertical that will be integrated. Then, the description will cover a set of technical features that are planned to be implemented in the different facilities.

The conclusion of the document gives a summary table of the technologies used by each site for each part of the network framework.

2 Greek site facility description

The Greek 5G EVE site facility covers a region of Northern Athens, around the R&D site of the Greek National Telecommunication Organization (OTE). The OTE site serves as a testing ground for services, equipment, and new features prior to their commercial release (including [pre-] 5G equipment), while it also maintains a connection to the commercial 4G+ network of OTE. The existing equipment and network functionality are a mix of Ericsson and Nokia technologies which will be progressively extended to support 5G during the lifetime of the project by both vendors. OTE, Ericsson GR and Nokia GR with the help of WINGS ICT SOLUTIONS (responsible for input integration, software development and pilot execution for one of the use-cases) are responsible to prepare and upgrade the Greek site facility to be able to handle three 5G oriented vertical use-cases, namely:

- UC3: Industry 4.0 functionality with Automated Guided Vehicles (AGVs)
- UC4: Utilities applications on Smart Energy grid monitoring & ultra-reliable / fast fault detection
- UC5: Smart cities applications focused on Connected Ambulance

In the following sections, the high-level as well as the detailed architecture of the Greek 5G EVE testbed is described, including use-case specific set-ups, HW and SW components presentation, RAN, Cloud and Core equipment and functionalities descriptions as well as potential configurations, settings and choices made for the operation of the network.

2.1 Architecture overview

The Greek site will consist of platforms and components of Ericsson and Nokia in terms of the access and core networks and will be upgraded with MANO ETSI compliant components. As it is explained in the following sections, during the initial stages of 5G EVE, Ericsson GR and Nokia GR will support their respective use-cases with their own access and core networks (some level of interconnection will be considered at a later stage – see Section 2.9). The core networks (vEPCs) will be part of a Distributed Mobile Broadband (DMBB) platform. The main logical architecture is shown in Figure 2.
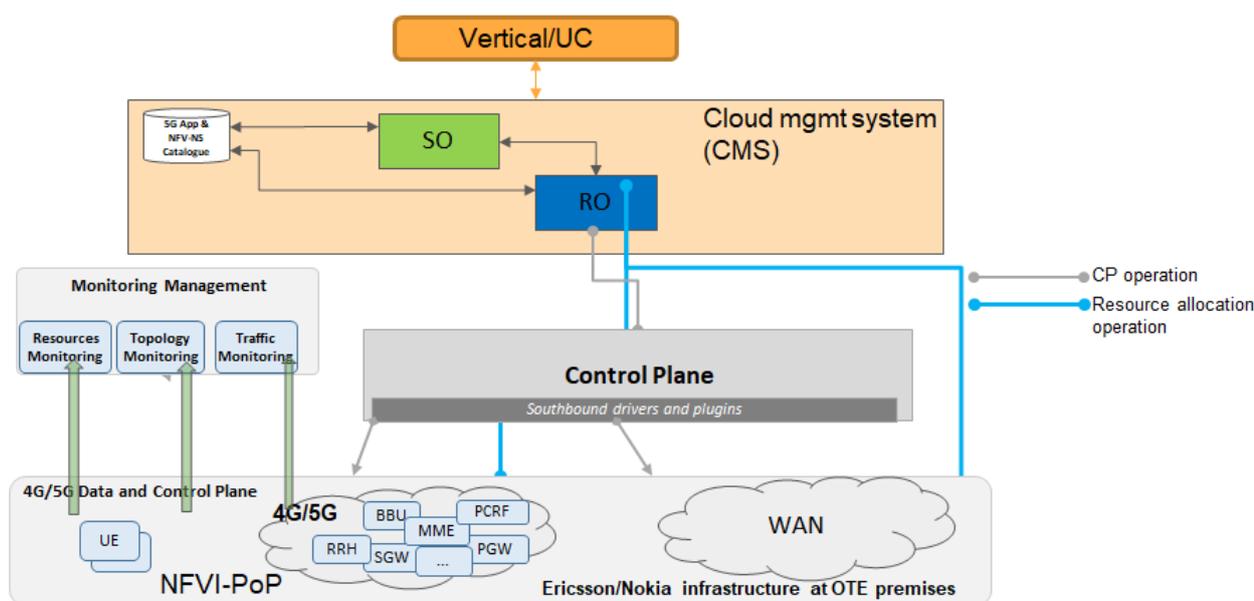
Figure 2: Generic Logical architecture of the 5G EVE Greek site facility

As it can be seen in Figure 2, the NFVI PoP will consist of physical and virtual components from Ericsson GR and Nokia GR platforms that will be installed in OTE's premises as they are explained in the following sections.

The RAN cloud will consist of different nodes for Ericsson GR and Nokia GR as explained in Section 2.2. The core network will consist of vEPCs from Ericsson GR and Nokia GR that in a second phase will be interconnected to each other. For the Ericsson GR case, a MEC cloud infrastructure will be used to advance the MEC service of AGV. The cloud management system will consist of the service and resource orchestrators. The control system will be responsible to control the VNFs lifecycle and the traffic to the underlying data plane. The monitoring management system will be responsible to collect data on metrics, topology and the resources in order to monitor the KPIs and adapt them to the needs of the project.

The three use-cases that will be executed at a first stage over the Greek site facility will utilize existing OTE facilities in combination with existing and new Ericsson and Nokia components and platforms. At the first stage of deployment (by the end of April 2019), some proprietary components will be used by both vendors to enable the respective use-cases that they are driving (i.e. Industry 4.0 for Ericsson GR and Smart City for Nokia GR), as well as to enable the execution of the utilities use-case. Later on, the interconnection of equipment between the vendors will take place, enabled by OTE overlaid components. Hence, it operates as one unified facility capable of supporting multiple use-cases. Figure 3 below depicts the use-case oriented architectural overview of the Greek 5G EVE site facility, providing insights regarding the different vendor components co-existence and cross-utilization and their respective usage by the envisioned verticals. More details regarding the detailed architecture from the point of view of each vertical and the kind of components and features to be used are provided in the following sub-sections.
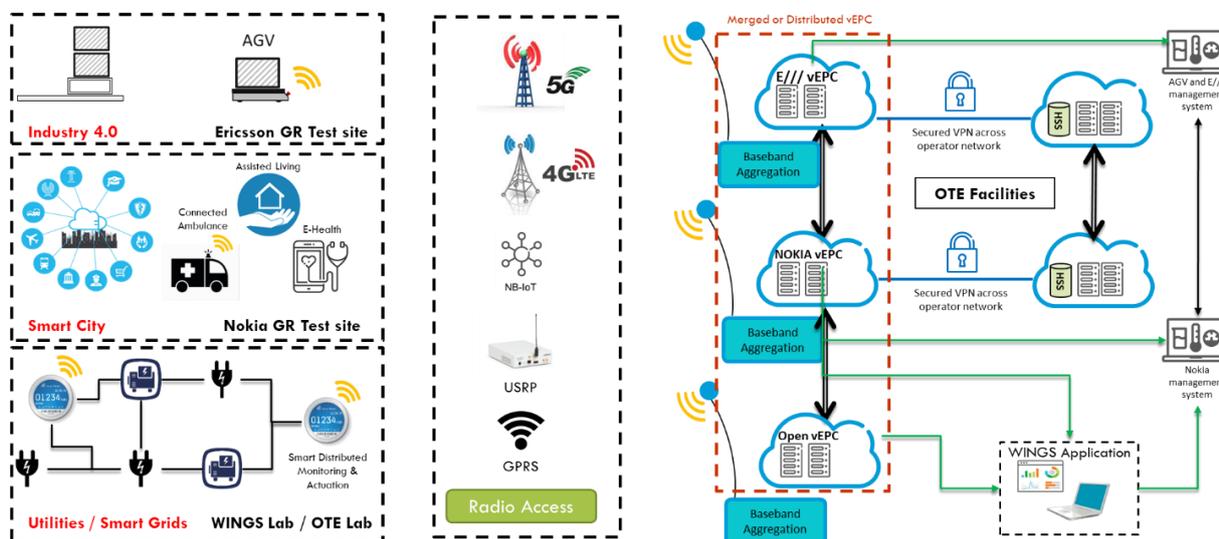
Figure 3: High level use-case oriented architectural overview of the Greek 5G EVE site facility

2.1.1 Industry 4.0 – Automated Guided Vehicle use-case architecture

Mobile Cloud Robotics (MCR) in a Smart Wireless Logistic (SWL) facility is an exciting 5G platform that will be exploited by Ericsson GR and by the development partners. Mobile robots will be used to transport goods between various stations in a process or to and from depots. Deploying mobile robots in logistics improves productivity and supports the implementation of effective lean manufacturing. As long as there are no constraints imposed in their movement capabilities caused by unexpected obstacles or dirt, robots can carry out any sequence of events to ensure that materials arrive at the right place just in time.

Realistic MCR scenarios are enabled through the replacement of traditional robots with new ones connected to the cloud. These new robots only include low level controls, sensors and actuators. So that, having their intelligence in the cloud means that they have access to almost unlimited computing power. Altogether, they are more flexible, more usable and more affordable to own and operate. The connection between MCR robots and the cloud is provided through the mobile network and will benefit from the expected 4G and 5G extremely low latency connections. The overall mobile network architecture for the Automated Guided Vehicle (AGV) is highlighted in Figure 4.
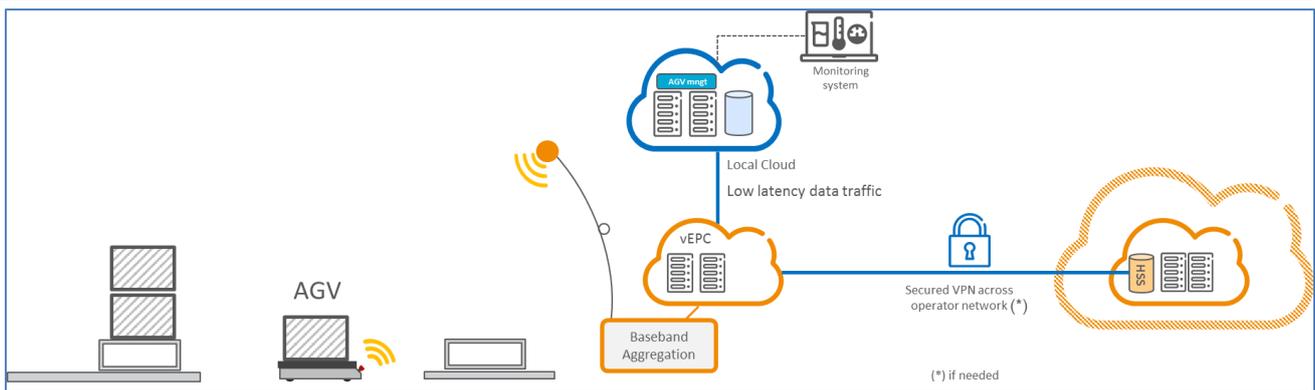
Figure 4: Overall mobile network architecture for an industrial enterprise URLLC application

The scope of the SWL is to build a stand-alone RAN and EPC solution able to fulfil the requirements of the planned use-cases. The provided solution includes packaging and configuration of an Ericsson GR LTE+/5G system suitable for manufacturing/logistics process needs. The Smart Wireless logistics solution end-to-end architecture is depicted in Figure 5.
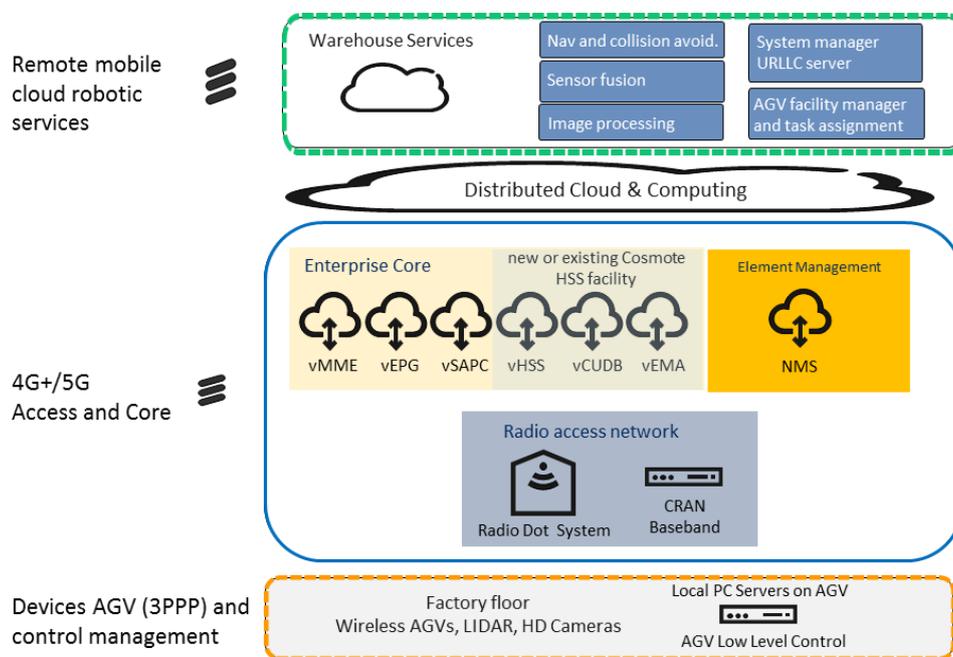
Figure 5: Architecture overview of MCR end-to-end system

The smart warehouse facility project can be easily extended to a modern factory covering an area up to several square kilometres. With a typical radius in the order of tens to hundreds of meters in manufacturing plants, several radio cells are required to operate simultaneously to serve the whole industrial area. At the same time, industrial applications need seamless, reliable and fast connectivity between the cloud and each individual robot in order to support high bandwidth and low latency. 4G+ and 5G can meet these requirements, since they can guarantee a smooth, seamless and lossless handover when robots move between radio cells and, at the same time, deliver good control over interfering signals from other machines and devices.

2.1.1.1 AGV Control Management

On the lower layer of the architecture are the devices (AGVs) and their control management. The control functions are distributed partially on a remote cloud and partly on the AGV. The lower level functions, controlling sensors and actuators, are located on the AGV, while the rest resides in a powerful remote cloud.

The benefit of this choice is mainly the enhancement of flexibility, exploiting the computation power of the cloud.

The AGV computing architecture depicts in Figure 6 includes two computers. The vehicle controller supervises the communication with the AGV system management, controls the next step movement and handles sensors and actuators. It takes care of stopping the AGV in presence of a very close obstacle to avoid an immediate collision. It collects the LIDAR information to be sent to the AGV system management and then to the main control system for navigation and collision avoidance purposes. Collision avoidance should make use of cameras and LIDAR sensors fusion to determine the change of trajectory to avoid an obstacle.

The communication computer on the AGV will act as gateway between the vehicle controller and the AGV system management taking care of radio communication. It will also collect real time videos provided by the cameras installed on the AGV and will take care of streaming them, via the mobile network, towards the main control system for scenario recognition, navigation and collision avoidance purposes. The AGV would be equipped with at most four cameras, one per direction to have about a 360° view of the environment. The cameras will be placed on the front, on the back and on both sides of the robot. The generated streams will be sent to the main control system for processing and integration.
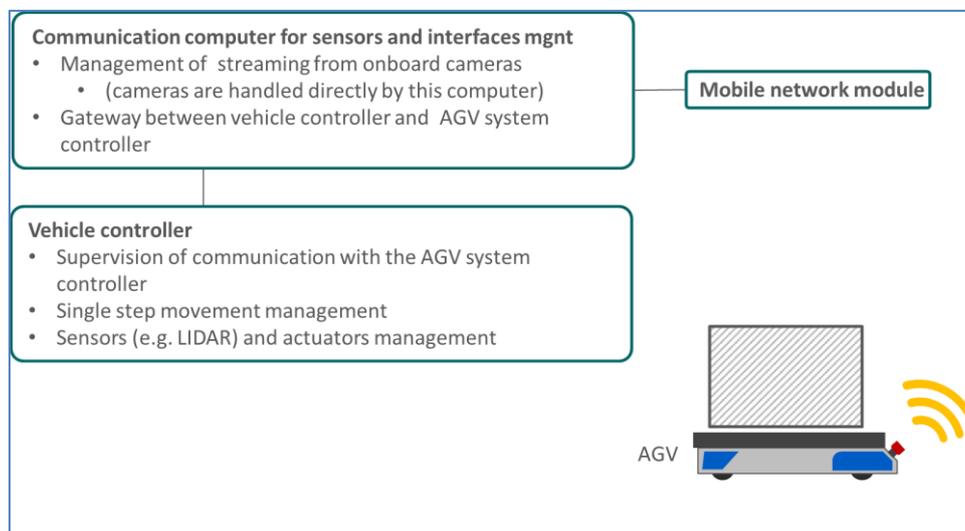
Figure 6: AGV computing architecture and controlling environment

2.1.1.2 Mobile Cloud Remote (MCR) Control System

The remote-control system will reside in a local cloud hosted on several VMs. XEN [2] will be selected as hypervisor because it has both an open source version and a commercial and professional one, so making more robust the choice for any future need.

The AGV system controller, the image recognition unit and the main control system will be residing in the cloud. The AGV system controller is a SW provided by the AGV manufacturer to handle the AGVs movements and robotic communication protocols. It behaves as an interface between the main control system and the AGV. The main control system manages the incoming service requests sent by the workers using an app running on a tablet or smartphone. A mission will consist of sending the AGV to a specific area to pick a box and shuttling it to a destination storage area. Once a request is received, the main control system decides the task be done by the AGV and plan its route. Then the AGV is asked to start its mission. The AGV navigation in the environment is controlled in real time by the navigation function. It relies on sensors information pre-processed by the image processing unit and the sensor fusion module. The video streams coming from the AGV are processed to detect and recognize objects and identify its position in the environment. Images will also be used to determine visual odometry information. The processed imaged data will then be integrated with the information coming from the

LIDAR in the sensor fusion module. Positioning related to the environment and odometry data will be used by the navigation and the obstacle avoidance modules that will compute the next movement step in real time.
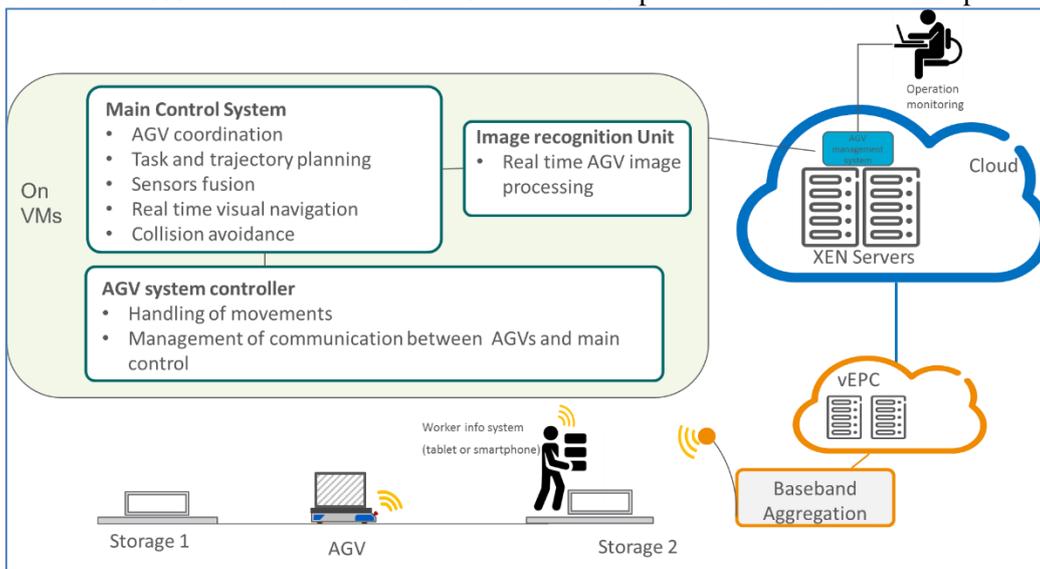
Figure 7: Remote cloud control system overview

The workers in the warehouse will have a tablet or a smartphone with a specific App for asking for services and monitoring operations. The tablet/smartphone will be connected to the mobile network and interact with the main control system in the cloud.

2.1.2 Smart City – Connected Ambulance use-case architecture

One of the Smart City use-cases that will be demonstrated in the Greek site facility is the "Connected Ambulance" (also touching upon the e-Health vertical). The concept of the use-case is the exploitation of the ambulance as a communication hub that will collect and transmit the patient's vital data and health stats, both from the accident scene as well as on route to the hospital. This will enable teleconsultation to paramedics, treatment during transport and timely informing of healthcare professionals in next point of definitive care (hospital or other health units). 5G network benefits such as capacity, coverage, reliability, mobility and virtualization will be demonstrated and verified.

As a first step, the initial architecture of the Greek site facility will aim to cover basic connectivity functionality and verification for the Nokia GR smart city use-case. A high-level overview of the corresponding architecture for the initial phase is given in Figure 8. The evolution of the architecture towards E2E 5G functionality for smart city use-cases will be provided in future deliverable [4].
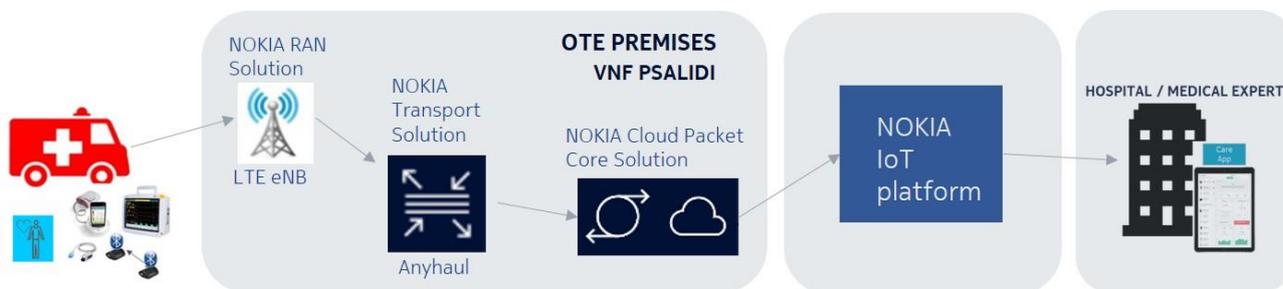
Figure 8: Initial architecture for NOK-GR smart-city use-case.

The NOKIA IoT platform solution will provide NB-IoT compatible connectivity and traffic selection between the sensors transmitting the patient's vital data to the telecommunication network and the end user facility.

Additionally, it will provide end user connectivity with IoT application(s), by which the data from the sensors and the IoT devices will be collected and processed.

2.1.3 Utilities – Smart grid monitoring & fault detection use-case architecture

The utilities use-case will be executed in OTE and WINGS facilities utilizing the RAN, Cloud and Core components provided by the Greek facility partners and the WINGS Cloud IoT platform and specialized components developed during the project. Distributed energy production and consumptions points will be monitored in real time using smart energy meters (recording multiple relevant KPIs) with programmable interfaces and a "live" analysis of the measurements using Big Data analytics techniques and AI will take place in order to achieve ultra-reliable and ultra-low latency fault detection and restoration.

At a first stage, the measurements from the various smart meters will be transmitted through the live 4G+ access network provided by OTE, utilizing NB-IoT access where available (specific OTE testing locations), while pre-5G and 5G components provided by Ericsson GR / Nokia GR will also be used for the transmission of the measurements with 5G connectivity at a later stage, once the Greek site facility is 5G ready. The evolution of the measurement transmission and actuation commands (GPRS / USRP, 4G+, NB-IoT, 5G) will provide significant insights and benchmarking data for such a use-case, where the uRLLC needs of the vertical play a crucial role to the successful completion of the use-case and the satisfaction of the industry's stringent requirements. Figure 9 below depicts the high-level envisioned architecture for the utilities use-case and the corresponding utilization of the Greek 5G EVE site facility components.
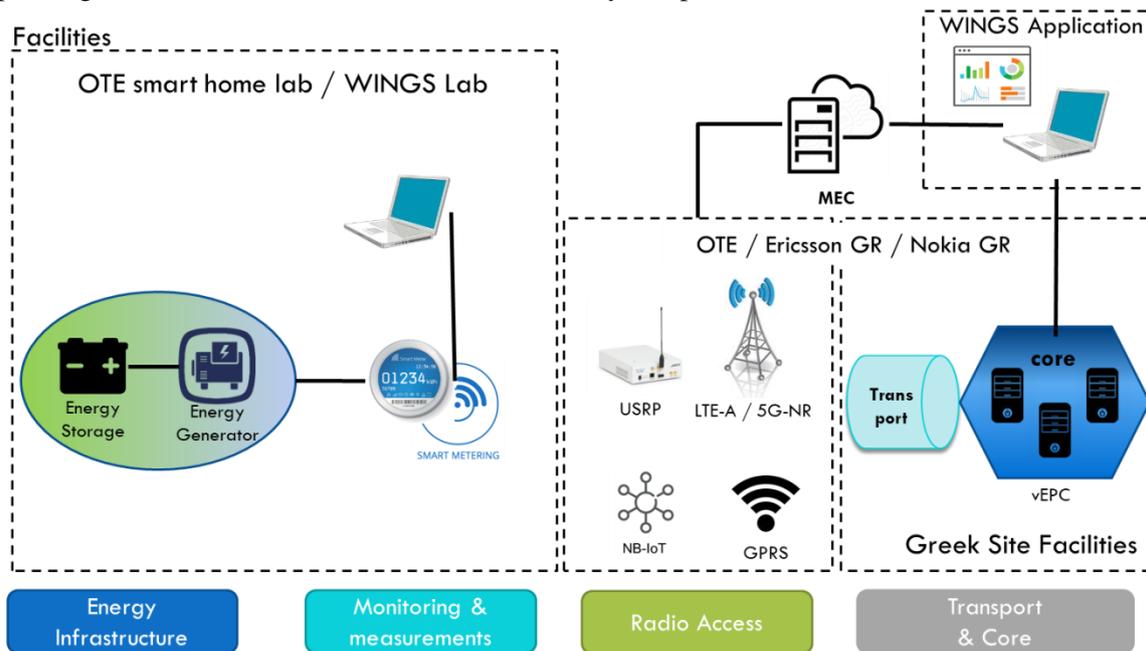
Figure 9: Smart grid monitoring – high level overview architecture

2.2 RAN architecture description

The RAN base is constituted of two parts: a hardware (HW) and a software (SW) base. The HW comprises the baseband node and one or more radio units depending on the manufacturing or warehouse coverage area. The software includes the components needed to operate the 3GPP wireless system including LTE (up to 3GPP Rel.14) and 5G (Rel. 15 and upwards). The baseband unit is common across different radio configurations. It provides the baseband processing resources for the encoding and decoding of the uplink and downlink radio signals, the radio control processing, the radio network synchronization, the IP and the O&M interface for the Ericsson Radio System. Baseband unit is described in Section 2.2.2.

It is noted that for the first project milestone in April 2019, LTE connectivity is assumed. In the rest of the sections any reference to 5G technology is given to describe the expandability of the system in future site facility

activities. The Ericsson RAN architecture builds on the **Cloud RAN concept,** which incorporates important aspects of both the network architecture and RAN functionality – today and on the road to 5G.

One of the key aspects in the Cloud RAN concept is Coordination and is provided by using advanced network coordination functionality such as for example, Carrier Aggregation (CA) and Coordinated Multipoint (CoMP) to maximize network performance and minimize interference. Low latency transport network as well as phase and time synchronization are necessary components to support the time critical L1 and L2 RAN functionality. The Greek site facility architecture is based on the <u>Centralized RAN approach</u>.

Warehouse cellular coverage to enable the AGVs service will be provided by deploying Ericsson's indoor **Radio Dot System (RDS)** solution. This is a high performance distributed active radio antenna system based on a **centralized RAN** architecture. A simplified diagram is shown in Figure 10.
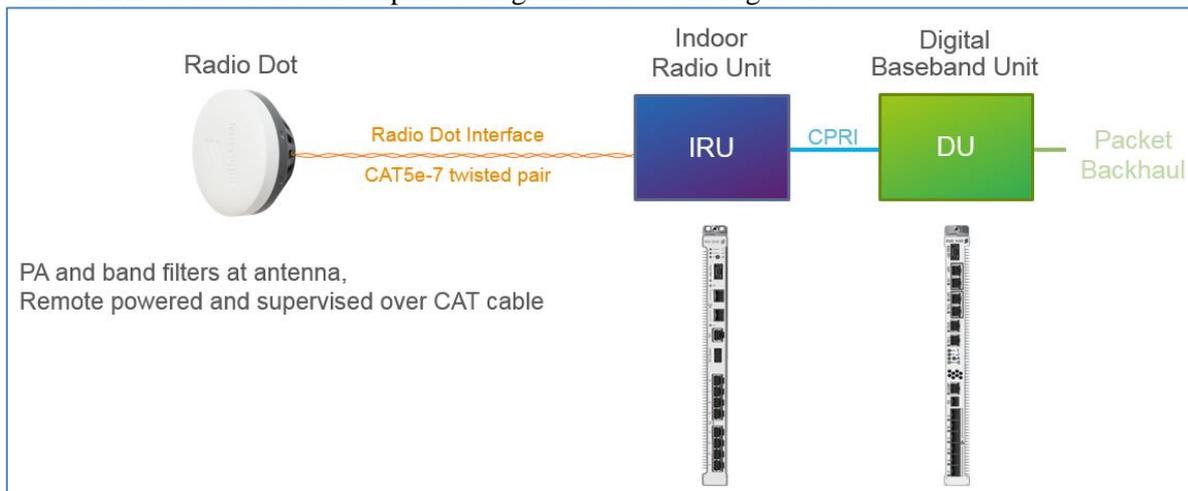
Figure 10: Radio DoT architecture optimized for medium to large scale indoor deployments

The Ericsson RDS consists of 3 key components:

- **Radio Dot (RD)**: It contains the power amplifier and filters for the frequency band(s). RDs are power fed from the Indoor Radio Unit (IRU) over up to 200 m LAN cabling. It is designed for deployment in indoor environment, in single, dual band and 5G variants.

- **Indoor Radio Unit (IRU)**: The IRU provides the power and control for the RDs. It instantiates the RD interface on 8x RJ45 ports and connects to the Dots over standard enterprise LAN cables.

- **Digital Unit (DU) or Baseband**: The Baseband connects to the IRUs over the CPRI interface. The Baseband runs the 4G+ SW features. It supports key coordination features for running small cells in large multi-antenna indoor environments. Features include Combined Cell, Carrier Aggregation, Lean Carrier, Uplink Comp. The Baseband provides synchronization and transport security functionality and aggregates the radio traffic onto a common backhaul connection.

The provided RAN system is fully compliant with 3GPP R15 and later. The first phase of RAN SW/HW deployment will comprise functionality compliant to LTE Advanced Pro technology included up to **3GPP R14** specifications. The initial RDS architecture **is also in line with the radio network architecture of 5G**. It can coexist with pure **5G NR** by including additional RDs optimized for 5G NR. The same system will be later upgraded to include 5G NR SW/HW compatible to **3GPP R15** specifications, Option 3x.

A summary of system HW/SW capabilities can be seen in Figure 11.
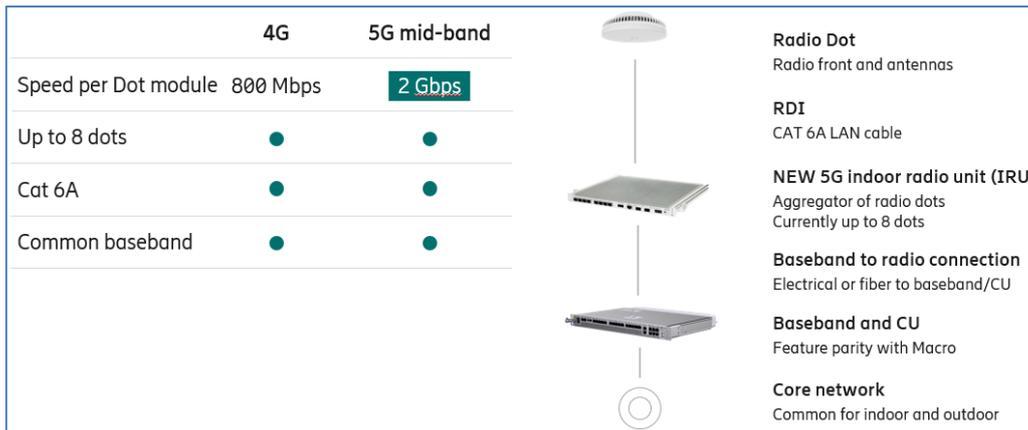
Figure 11: 4G & 5G mid-band RD capabilities - seamless evolution higher performance

2.2.1 RRH

The Radio Remote Head (RRH) solution that will initially be used offering 4G+ coverage is the (RD) type RD2243 which is a low power radio transmitter designed to provide superior indoor mobile broadband coverage along with the Indoor Radio Unit (IRU). The RD2243 is a single band RD antenna with two Rx/Tx antenna branches. The RD uses the signal and power interface from the IRU over the Radio Dot Interface (RDI). Up to eight RDs can be connected to a single IRU. Using one Radio Dot and LTE 20 MHz spectrum capacity the following peak speed up can be delivered:

- 200 Mbps using MIMO 2x2 system (CAT4 device)
- 400 Mbps using MIMO 4x4 system (CAT9 device)

The RD provides the following main features:

- Output power 2x17 dBm (2x50 mW) in a MIMO 2x2 configuration
- Higher Order Modulation (HOM) 256-QAM Downlink and 64-QAM Uplink
- Total Instantaneous Bandwidth IBW 40 MHz, 2x LTE FDD carriers of 5, 10, 15, 20 MHz
- Frequency conversion and amplifying functionality
- Single RDI cable for power and signal transmission - the RD has the power and the signal on the same LAN cable, so only one cable is required for the Dot.

Complementing the 4G Dot, RD4479 is a single band 5G RD with four Rx/Tx antenna branches which will be used on a second phase to provide NR coverage offering peak downlink speed up to 2 Gbps as shown in Figure 12. The 5G NR RD delivers speeds up to 2Gbps and supports the new 5G mid-band 3-6GHz (n78 compatible). It fully reuses the currently installed architecture for 4G+ RD with the ease of installation and flexibility and functional parity with the macro network.
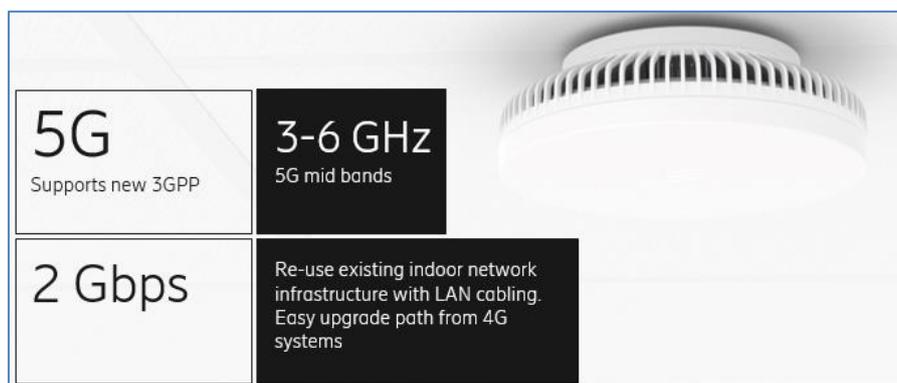
Figure 12: 5G NR Radio Dot

The IRU is an indispensable component of the overall RRH architecture and it provides baseband processing from a DU or Baseband unit, transceiver processing to the RD over the RDI and supplies power to the RD over the RDI. An analytical block diagram of the RDS front-end system is depicted in Figure 13.
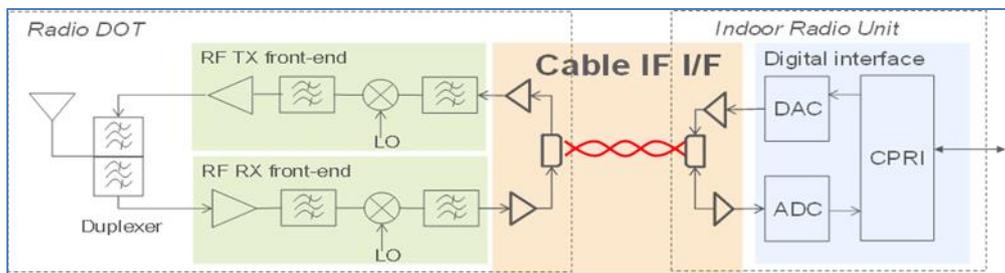
Figure 13: Innovative RDS architecture design enabling IF to transmit radio signals over the LAN

As shown in Figure 13, an IF-based design effectively extends the RD RF frontend over a LAN cable with an IF cable frontend interface, transporting the radio signals at low frequencies. The elegance and simplicity of such a design enables a neat and ultra-compact design of the RD. The design allows much lower power consumption compared to current Ethernet-based methods, and in addition to the radio and sync signals, control signalling and power are provided by the same pairs. The RDS architecture design enables advanced features for cable equalization, Automatic Gain Control (AGC), cable testing, troubleshooting, and different SON features adding value to the innovation. Further, it can support Single User (SU-MIMO 4x4) by utilizing all four pairs of the cable which makes the RDS architecture fully compatible with 5G NR 3GPP R15.

The dimensioning of the RDS depends on the achievable indoor dominance coverage level and required cell capacity. A general recommendation for achieving a balanced UL/DL link is that a single RD antenna can provide coverage to a range between 500 to 800 m^2 area. Since one IRU can be connected to 8 distributed RDs, one IRU can provide coverage to a range of 4000 to 6000 m^2 space approximately.

2.2.2 BBU – Baseband Unit 6630

The baseband processing for the uplink and downlink of LTE and NR is provided by the **baseband unit 6630** as shown in Figure 14. The RDS centralized baseband architecture enables coordination across the covered area. The baseband HW along with the interfaces front panel is shown in Figure 14 below, while its specifications are presented in Table 4.

Figure 14: Baseband 6630 front panel

Table 4: BBU 6630 key specifications

Baseband specifications for existing LTE SW (L18.Q3)	Baseband 6630
Downlink maximum throughput (Mbps)	2000
Uplink maximum throughput (Mbps)	500
Number of VoIP users (FDD/TDD)	2000/1000
Number of connected users	8000
Aggregated antenna bandwidth (MHz)	960 – 1560
Number of Cell (FDD/TDD)	24
CPRI radio interface - Hardware Prepared for NR (5G) and e-CPRI	15x SFP/SFP+
Transport interface, optical 1/10Gbps SFP/SFP+ ports	2

Baseband specifications for existing LTE SW (L18.Q3)	Baseband 6630
Transport interface, electrical 1Gbps RJ45 ports	2

2.2.3 Frequency bands

The frequency bands that will be used for 4G+ Ericsson RAN solution as described in this section are:

- The B7 which is, FDD 2600 MHz with 20 MHz spectrum deployment, based on the selection criterion to minimize interference and overlapping coverage with the commercial OTE/COSMOTE MBB network.
- The B38 (TDD, 2600 MHz) and B42 (TDD, 3500 MHz) are considered for deployment of the 5G-NR in order to provide 5G access at the second stage of the Greek site facility upgrades

The frequency bands that will be used by the Nokia RAN solution (Nokia LTE eNB) in this initial phase are:

- Band Class 1 LTE access at 1900MHz for UL and 2100 MHz for DL,
- For 5G access available access at 3.4-3.8 GHz will be considered, depending on use-case evolution.

2.2.4 Subscriber Separation

In order to ensure a good performance control of the AGV service, a separation among mobile broadband subscribers and smart facility subscribers needs to be in place. The smart facility service will only target the enterprise user providing a viable alternative to fixed access (e.g. typically xDSL, fiber) with comparable or better quality. Subscriber separation solution main goals are:

- Ensure that mobile broadband subscribers will stay only on macro LTE FDD without camping/using enterprise network resources.
- Ensure that enterprise users will stay only on the indoor LTE FDD network without camping/using the production network.
- Cause no degradation service level to enterprise usage.

2.3 Distributed Cloud / MEC

2.3.1 Ericsson solution

Distributed Cloud covers a number of aspects of local access in a small-scale system. It is typical that the operator distributed network is connected to the operator's central network via a poor (i.e. limited bandwidth and/or high latency) backhaul, e.g. satellite or E1 links. The operator distributed network may be connected to one or several different types of networks local to the distributed site. This distributed cloud provides a small optimized solution for best possible end user experience with local network connectivity. It enables carriers to address remote areas with very high transport costs, but also to provide a better user experience increasing the MBB subscription growth possibilities.
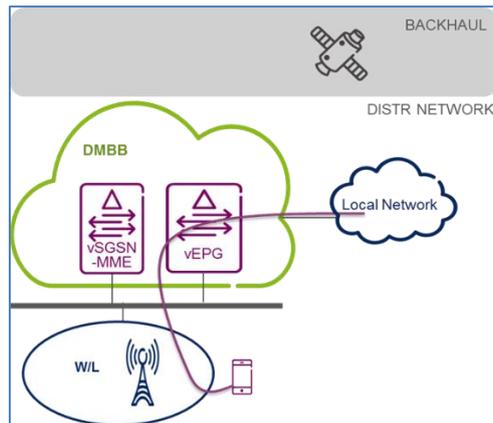
Figure 15: Distributed cloud use-case

The user experience is enhanced by using local network breakout. This is possible thanks to distributing the vEPG. In this case the mobile operator can offload traffic from the backhaul by routing traffic directly to locally available internet access or peering partners. The distributed vEPG has full control of policy and charging for connections and services, which reduces payload over the poor backhaul.

2.3.2 Nokia solution

The NOKIA Cloud Packet Core at OTE premises will comprise of a NOKIA Cloud Mobility Manager (CMM) solution, as well as a Cloud Mobile Gateway (CMG) solution, with 3GPP Rel-14 compatibility in terms of connectivity with the IoT platform. The physical resources and infrastructure for the VNF deployed in the cloud will be NOKIA Airframe. Also, the required HSS packet core solution will be provided through a Linux based emulator, which will be NOKIA product compatible, providing required real-time aspects and offering real physical interfaces towards other network elements.

2.4 CORE architecture description

The solution for the core part of the Greek site facility is based on a 5G virtual EPC. Nevertheless, Radio Access Network connectivity for the first phase of the site facility is LTE based. A 5G EPC-in-a-box is proposed that fulfils the requirements for cost-effective test systems with few subscribers and minimal footprint. It is a further evolution of the Virtual Network Function (VNF) single server deployment enabling multiple VNFs on a single server. The deployment contains vEPG, vSGSN-MME and vSAPC.

EPC-in-a-box, as depicted in Figure 16, is designed to run on top of Ericsson OpenStack IaaS i.e., Cloud Execution Environment (CEE) and can use either HDS 8000 CRU or Dell 630 as HW. It is also tuned to be as efficient as possible when all VNFs are running at the same time. However, there is no requirement that all VNFs must be deployed. For example, it is possible to only deploy vEPG.

2.4.1 Deployment Overview

EPC-in-a-box deployment is built on Ericson Cloud Execution Environment (CEE) which includes the following functions necessary for EPC-in-a-box:

- Virtualized CIC (Cloud Infrastructure Controller)
- Support to run the vCIC in a non-redundant single-vCIC mode
- Hyper-Threading
- Pinning of the VM vCPUs to specific Hyper Threads (HTs), ePC, slicing
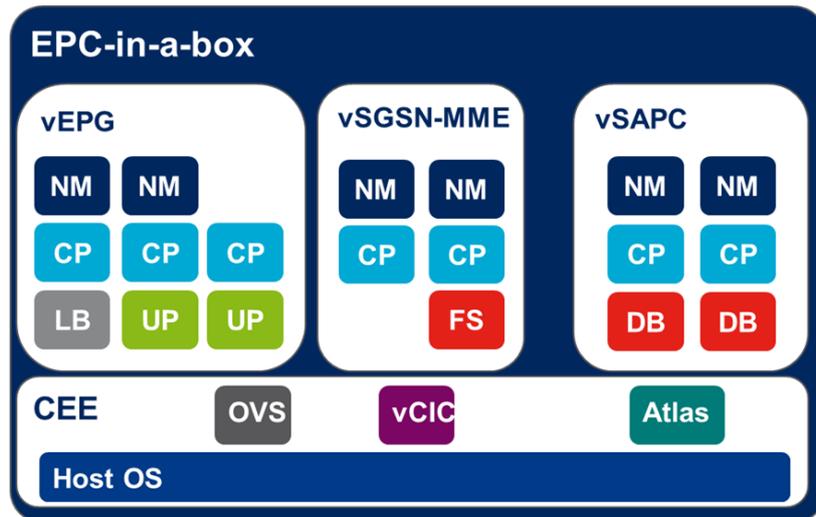
Figure 16: EPC-in-a-box

2.4.2 VM Distribution

EPC-in-a-box can be deployed on Ericsson HDS 8000 CRU hardware or Dell 630 COTS HW. Servers with Minimum 12 Core processors are required. Each core has 2 Hyper-Threads. The VMs can be divided into two types:

- VMs requiring dedicated pCPU – these VMs have CPU resource intensive processes. Payload handling processes require dedicated pCPUs. These processes are always active (busy-looping), polling for incoming packets.
- VMs that can share pCPUs – these VMs are not CPU resource intensive. When there is nothing to process, they are not taking up any processor resources. Therefore, the vCPUs of these VMs can share a range of pCPUs.

The technique used to allocate VMs to compute resources is called CPU pinning. EPC-in-a-box specifies in detail which pCPUs each VM should use. Without specifying anything CEE will have a 1:1 (v:p) ratio between vCPUs and pCPUs and assign pCPUs to vCPUs in a dynamic manner. CPU pinning is done in one of the following ways:

- Dedicated pCPU – A vCPU is pinned to one specific pCPU. The pCPU and memory allocation are optimized based on the VM type, vCPU role and the NUMA topology of the host.
- Shared pCPU – A vCPU is pinned to a specific range of pCPUs, where other vCPUs (within same VM and between different VMs) are pinned to same pCPU range. In this case the hypervisor scheduler decides dynamically which pCPU is used for each vCPU (i.e. vCPUs are floating). Sharing pCPUs between multiple vCPU is also known as CPU overcommit/oversubscription.

The EPC-in-a-box deployment provides scripts to generate the correct resource allocation by creating specific CEE flavours for each VM and a HOT file to deploy each VNF. The CPU pinning is controlled via OpenStack flavours. Figure 17 shows a high-level view of which VMs use dedicated respectively shared pCPUs. The gradient boxes show that some VMs use both dedicated and shared pCPUs. The VMs that are using both dedicated and shared pPCUs are still categorized into dedicated or shared group depending on if the majority of the VM vCPUs are using dedicated or shared pCPUs. E.g. the Load Balancer's VMs are mainly using dedicated pCPU while Control Plane VMs mainly use shared pCPUs.
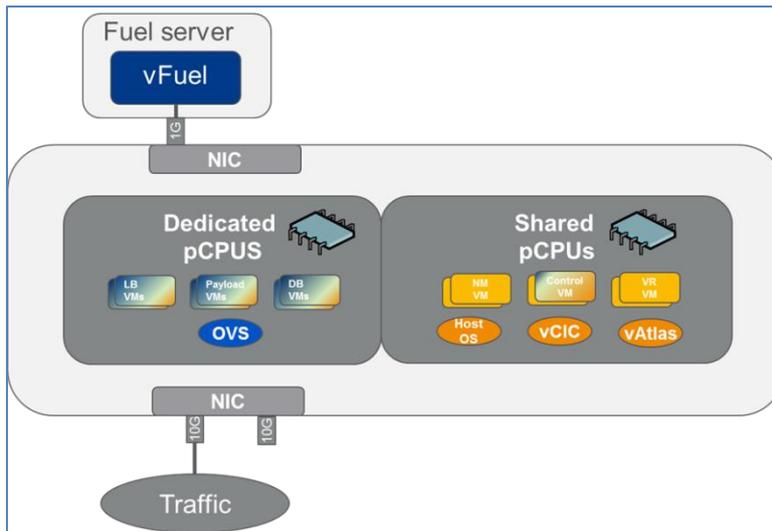
Figure 17: High-level view of EPC-in-a-box CPU allocation

2.4.3 EPC Network Functions

The following key network functions are affected:

- MME (Software functionality of proposed SGSN-MME)
- S/PGW (Software functionality of proposed EPG)
- PCRF (evolved)

2.4.4 MME enabled for 5G

The SGSN-MME software will be enhanced at a later stage to also include support for 5G. The same platform and architecture will be used but adding 5G access and related functionality.

2.5 Orchestration

2.5.1 ETSI NFV MANO

The NFV management and orchestration will be ETSI NFV MANO compatible and will be provided by NOKIA CloudBand product family, namely CloudBand Network Director (CBND), CloudBand Application Manager (CBAM), and CloudBand Infrastructure Software (CBIS), as illustrated in Figure 18.

The CBND is an NFV resource and network service orchestrator (NFVO), built for OpenStack and VMware. It manages virtual resources across geo-distributed NFV infrastructure nodes, if needed. The CBAM is a VNF Manager (VNFM) built for OpenStack and VMware, which automates VNF lifecycle management actions by managing resources and applying associated workflows. The CBIS is a multi-purpose NFV infrastructure (NFVI) and virtualized infrastructure manager (VIM), built for OpenStack. It virtualizes and manages compute, storage, and network resources. (Note: interfaces are MANO specific and can be described in one place for all testbeds).
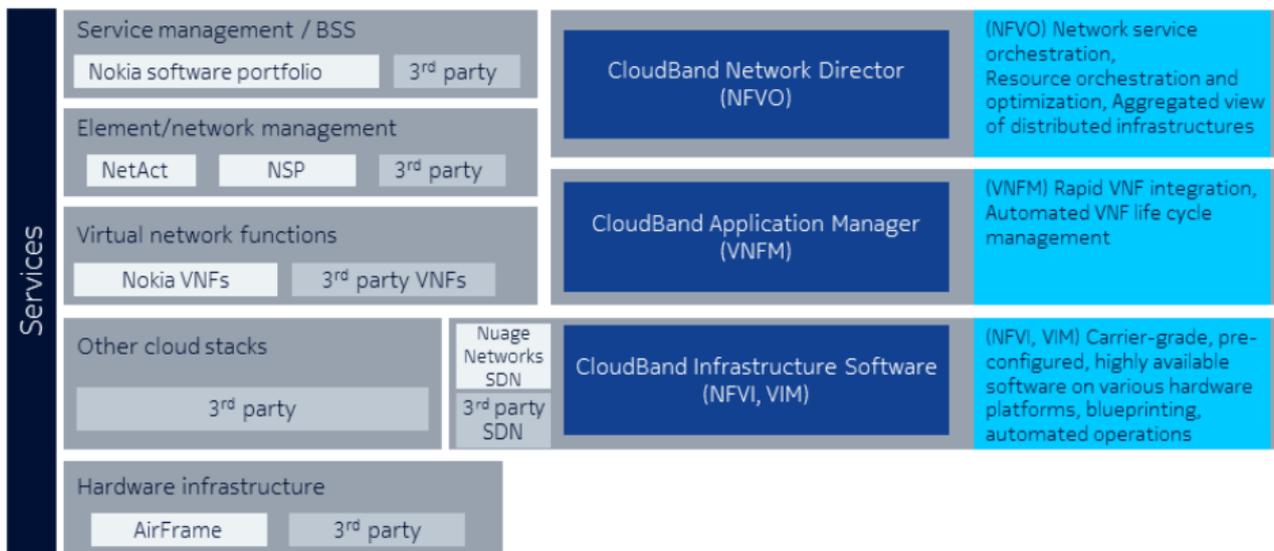
Figure 18: NOKIA Cloud-Band management and orchestration products.

2.5.2 Network management transport

Both Nokia GR and Ericsson GR have deployed transport capabilities at OTE premises and the respective use-case pilot sites. In the case of Nokia GR, the transport solution between RAN and Cloud Packet Core will be residing at OTE premises combining different transport technologies, e.g. IP, optical, microwave. In the case of Ericsson GR, the data exchanged between the AGVs and the higher-level control function will rely on more than one L3 protocol. The traffic flow will be mainly TCP and UDP based. So, they can travel directly on the mobile network without the need for further encapsulation. Traffic encapsulation could be required for some low-level communication between the AGVs and the upper layers. In such a case VXLAN or a VPN could be adopted.

2.6 Interfaces

The common interfaces that will be utilized in the initial phase are illustrated in Figure 19.
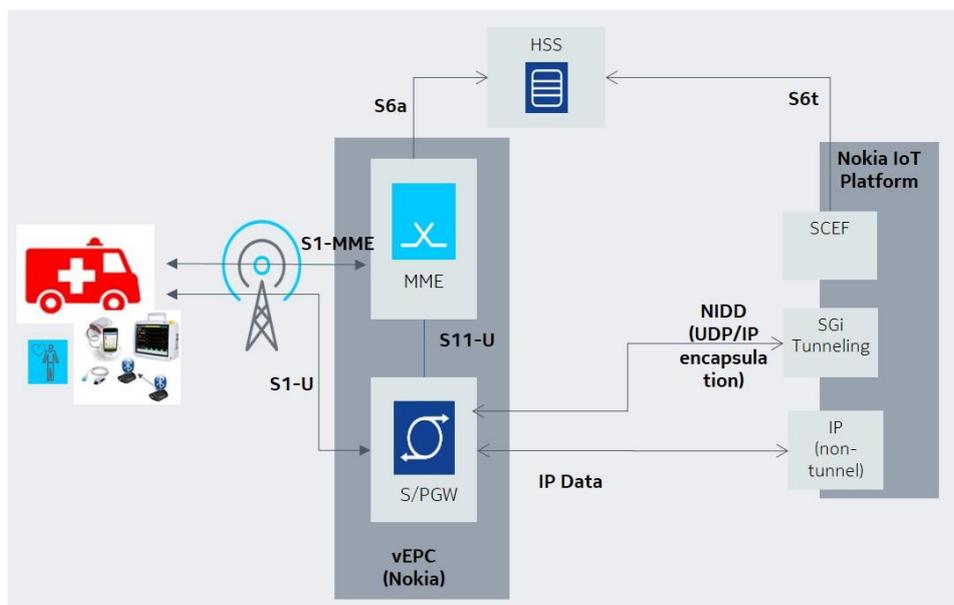
Figure 19: Initial phase Interfaces.

More specifically, those interfaces are:

- S1: eNB to MME and S-GW.
- S11: MME to S-GW.
- S6a: MME to HSS.
- S5: S-GW to P-GW.
- S6t: HSS to SCEF.

2.7 Development and deployment tools/software

2.7.1 Integrated Base station Gateway (BGW) functionality in EPC-in-a-box for networking

EPC-in-a-box includes an integrated Base Station Gateway (BSW) functionality. This functionality is provided by the vEPG, which is based on the Ericsson Virtual Router (EVR) platform. By having an integrated BGW, the vEPC-in-a-box can be deployed without relying on an external BGW. This means that communication between VNFs within EPC-in-a-box do not traverse an external BGW. VNF communication to external networks traverses the integrated BGW (vEPG). The vEPG is configured with a single LB using a single vNIC, which is shared between the EPG functionality and the BGW functionality. The single vNIC is used for both vEPC internal as well as external traffic. This is made possible by using trunk VLANs.

The EPC-in-a-box internal networks between vSGSN-MME, vSAPC and the vEPG/EVR are preconfigured. By default, a set of different Neutron networks are used to separate different logical networks. External traffic to and from the vEPG is routed by the vEPG through its LBs as usual. Between EVR and vSGSN-MME static routing is used. This static routing is preconfigured. BFD is used to supervise the static routes. All the service IP addresses of the vSGSN-MME need to be configured as static routes in the EVR.

OSPF routing is used between EVR and vSAPC. OSPF is used both for advertising the SAPC VIP addresses to EVR and to supervise the connectivity. All of the configurations for the vEPC-in-a-box internal routing, both static and OSPF, is preconfigured.

Externally VLAN separation is used for logical network separation. The box is preconfigured with a default set of networks which may be changed. In the future it will be possible to use BGP/MPLS for network separation as well. The supported routing protocols for external connectivity are static routing, OSPFv2, OSPFv3 and BGP. All of these may be used together with BFD for fast failure detection.
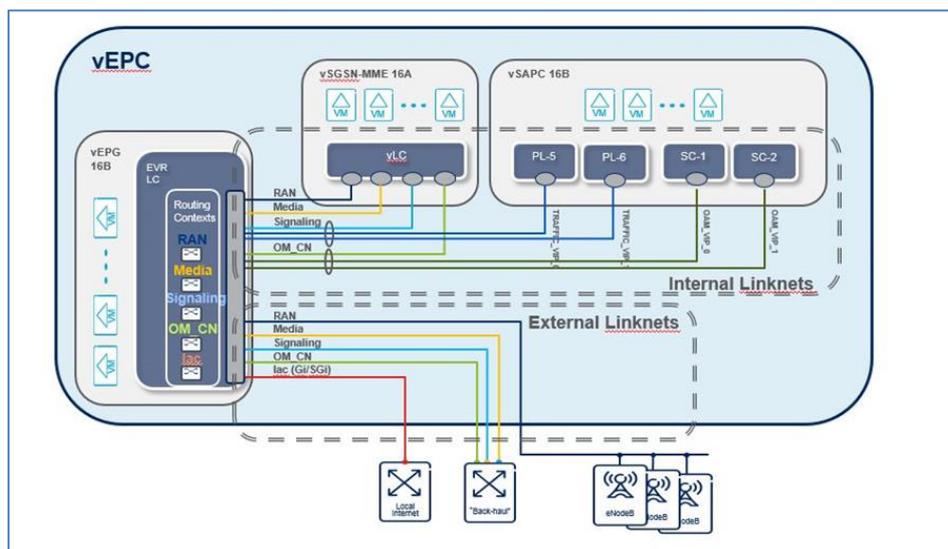
Figure 20: vEPC-in-a-box VLANs

2.7.2 Cloud Server Environment

The cloud part will make use of XEN server. XEN is a mature platform that has both an open source and a commercial proven enterprise use and its hypervisor was chosen for the cloud by Amazon and Google. A control management SW, *XENcenter*, is available for setting up and monitoring the cloud based on XEN server. However, the XEN environment comes with an API, provided in several programming languages that can be used to define a specific cloud management.

The App used by the workers on their tablet/smartphone to ask for services and monitoring will be an Android application. It will be developed using the Android Studio environment. The control and processing functions running in the cloud will be developed mainly in python using the Anaconda environment. Specifically dedicated libraries will be used for processing acceleration. Numpy and Scipy will be used for heavy mathematical operation and ski-image and OpenCV for the image processing. The FLANN library will be used for implementing approximate nearest neighbour functions required by image recognition.

The application for monitoring and statistics could make use of relational Data Bases. In this case mySQL will be adopted. The COMAU's AGV comes with its own SW. It includes the vehicle system controller, the AGV simulator and an operator interface SW.

2.7.3 Radio Access System SW

The initial RAN SW builds on the Ericsson's **5G plug-ins**. These are software-driven innovations that bring essential 5G technology concepts to today's 4G+ cellular networks enabling a flexible 5G evolution as well as improving operators' network mobile broadband performance allowing to introduce an array of new services and applications. The 5G plug-ins are built on 3GPP R13/15 specifications.

2.7.3.1 Reduced latency 5G plug-in for critical communications

Smart warehouse facility implementation based on mobile cloud robotics requires high-resolution cameras and LIDAR sensors installed on the AGVs in order to enable real-time, autonomous operation controlled by cloud-based systems. The facility operator will be able to dynamically assign different tasks to the robots and control their execution. The robots, being equipped with various sensors and actuators do not need guides on the floor and are able to avoid collisions with people and objects thanks to real-time remote processing of sensor data and images.

Of paramount importance is a high-performance mobile network connecting the robotic vehicles to the cloud-based control system. For example, a UL speed of 60 Mbps or higher, maximum acceptable jitter of less than 5 *ms*, no data buffering and end-to-end latency of less than 10 *msec* is required to ensure seamless and safe operation. Ericsson's proposed 5G plug-in SW solution can meet these requirements by deploying advanced network functionality which greatly improves network performance. One of the proposed mechanisms is the **reduced latency** functionality which builds on two steps developed in 3GPP R14 and 15 specifications. Specifically, R14 concept of **Instant Uplink Access** (IUA) eliminates the need for explicit scheduling request and individual scheduling grants. Through pre-allocation of radio resources IUA can reduce the average radio Round Trip Time (RTT) latency (i.e., UL and DL) to 9 *ms*, which is a significant improvement compared to traditional LTE R13 RTT latency of 16 *ms*.

The second method, which is specified in 3GPP R15, enables shorter transmission durations as illustrated in Figure 21. The concept is to compress the whole transmission chain while waiting for a transmit opportunity and transmitting the data. The associated control and feedback are performed faster.
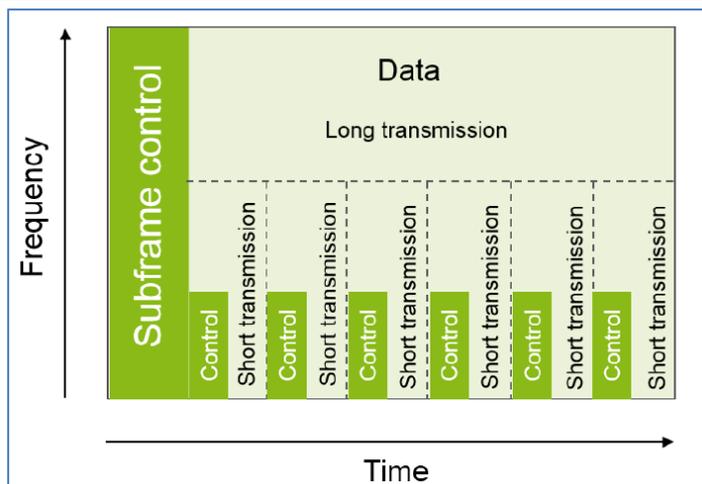
Figure 21: Illustration of an LTE downlink subframe with existing long and short transmissions

The compression is done by introducing transmissions with duration shorter than a subframe. In the downlink this is done by splitting the data part of the subframe into several parts. Each of these short transmission durations can be scheduled separately with a new in-band control channel. In addition to the downlink, the uplink subframe is split into multiple shorter transmission durations and is scheduled from the same in-band control channel. The subframes are either split into two parts, four parts or into roughly six parts for the lowest latency mode. At the highest splitting level, a one-way transmission can be done in a total of about 0.5ms including processing of data.
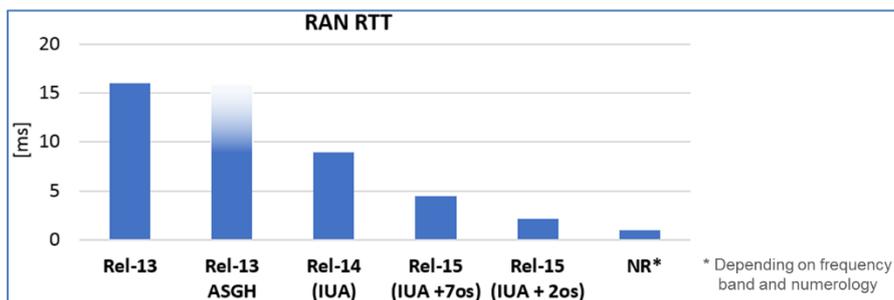
Figure 22: RAN latency towards 5G NR though Ericsson's 5G Plug-ins

2.7.4 QoS Mechanisms

The following QoS mechanisms are required on the site router and Mobile Backhaul network:

- Classification and Marking
- Rate-limiting
- Queuing and Scheduling

2.7.4.1 Classification and marking

Traffic classification is based on the DiffServ model and IP packets are marked with a DSCP value. A DSCP value is configurable for most traffic by virtual EPC VNFs. The Site Router maps the DSCP value of an IP packet to its internal QoS parameters and treatments. For traffic lacking a DSCP value (for example Gx, Gy Rf and Gom), the Site Router is responsible for traffic classification with a suitable internal QoS priority and even marking the DSCP value for the IP packet. For cross-site traffic over an MPLS network, the QoS propagation to MPLS TC/EXP should be done by the Site Router.

2.7.4.2 Rate-limiting

Rate-limiting should be set on the Site Router to reduce the risk of starving low-priority traffic and overloading the whole virtual EPC system (10 GE traffic interface versus 1Gbps throughput of the EPC capacity).

2.7.4.3 Queuing and Scheduling

The Queuing and Scheduling are done on the Site Router based on different traffic classes. There is Strict Priority scheduling with bandwidth limit for inelastic traffic while WFQ/PWFQ scheduling with optional WRED for elastic traffic may also be applied.

2.8 Testing & KPI

The KPIs and tools that will be used to assess the performance of the end-to-end system are listed in Table 5.

Table 5: List of testing tools & KPIs available at the Greek 5G EVE site facility

KPI	Definition	Tools
E2E DL latency	End to end mobile network downlink latency	Wireshark connected on both ends simultaneously and dedicated analysis SW to be developed
E2E UL latency	End to end mobile network uplink latency	Wireshark connected on both ends simultaneously and dedicated analysis SW to be developed
E2E DL latency variation	End to end mobile network downlink latency variation	Wireshark connected on both ends simultaneously and dedicated analysis SW to be developed
E2E UL latency variation	End to end mobile network uplink latency variation	Wireshark connected on both ends simultaneously and dedicated analysis SW to be developed
Uplink buffering delay	Buffering delay introduced by the network on camera streams sent by AGV to main control in uplink direction	Timing difference between packets coming through the mobile network and a direct cable connection to the camera. Wireshark and the dedicated SW developed for the latency analysis will be used
Number of collisions vs. number of obstacles	Ratio between the number of collisions of the AGV with respect to the number of encountered obstacles	Heuristic metric based on observations (use case specific)
Number optimal cruises vs. Total cruises	Ratio between the number of AGV travels following the optimal path with respect to the number of executed tasks	Heuristic metric based on observations (use case specific)

2.9 Greek Site Facility interconnection

The Greek 5G EVE site facility is based on the existing OTE infrastructure and as such it may use the established 4G+ network of OTE to interconnect to the 'outside world' and to access / be accessed by external servers (i.e. using GEANT based interconnection available).

In order to meet the strict deployment and operational schedule of the 5G Athens facility and to make sure that all three engaged use-cases (see Section 2.1) are supported during the initial roll-out of the 5G EVE facilities, the Nokia GR and Ericsson GR respective equipment / feature installation and network upgrades will take place in parallel, each connecting to OTE's main facilities. At a first stage no interconnection between the Ericsson GR and Nokia GR segments will be present and the two network segments will operate separately (from RAN access to used vEPCs), each supporting the allocated use-cases. At a later stage, and once the individual use-cases are supported by the Greek facility, an interconnection of the two segments will take place providing the possibility for certain equipment re-use, potential geo-redundancy or even partial interoperations. The Greek partners are already considering the available options and will provide a more detailed plan regarding the Greek site facility segment interconnection in Deliverable D2.2 [4].

Regarding the Greek site facility interconnection to the rest of the 5G EVE site facilities, the Greek partners have already provided the relevant data to the WP3 colleagues, who will decide on the most convenient and least troublesome setup for the 5G EVE site facilities interconnections. The Greek partners are prepared to implement the project-wide proposed solution.

3 Italian site facility description

The 5G EVE site facility in Italy is deployed in the city of Turin, where an initiative to experimentally evaluate the 5G systems has been already started by some of the partners of the project, called "Torino 5G". In particular, the Municipality of Turin, a partner in 5G EVE project, is planning a series of activities towards 5G in the area of the city.

The 5G EVE site facility in Turin will primarily serve to validate KPIs and 5G functionalities in two Use-cases under definition in Work Package 1, and specifically:

- Smart Transport: Intelligent railway for smart mobility (Use-case 1)
- Smart cities: Safety and Environment - Smart Turin (Use-case 5)

Potential synergies and interactions between the two use-cases aiming at the development of composite mobility and security services will be explored during the development of the Use-cases 1 and 5, to further extend KPI validation for more complex service scenarios in real-life 5G networks.

The 5G site facility in Turin will be a coherent synthesis of live and laboratory-based experimental environments for the evaluations of the 5G features. It will mostly rely on 5G equipment provided by Ericsson as part of "Torino 5G" project. The infrastructure will consist in 5G radio fronthaul and backhaul, open source tools for the management and orchestration of the NFV infrastructure and on various networks offered by TIM to interconnect the various edge/peripheral locations to core datacentre sites, to other 5G EVE site facilities and to external public Cloud services where needed.

This chapter is organized as follows. First, the overview of the architectural solutions employed in the Turin site facility is presented. Then, the solutions to be deployed for RAN, Cloud/MEC, and Core are presented, with a focus on the NFV orchestration solutions. Finally, a preliminary view on the interfaces definition and on the tools and KPIs to be adopted is given.

3.1 Architecture overview

The Turin site facility high level architecture is presented in Figure 23.
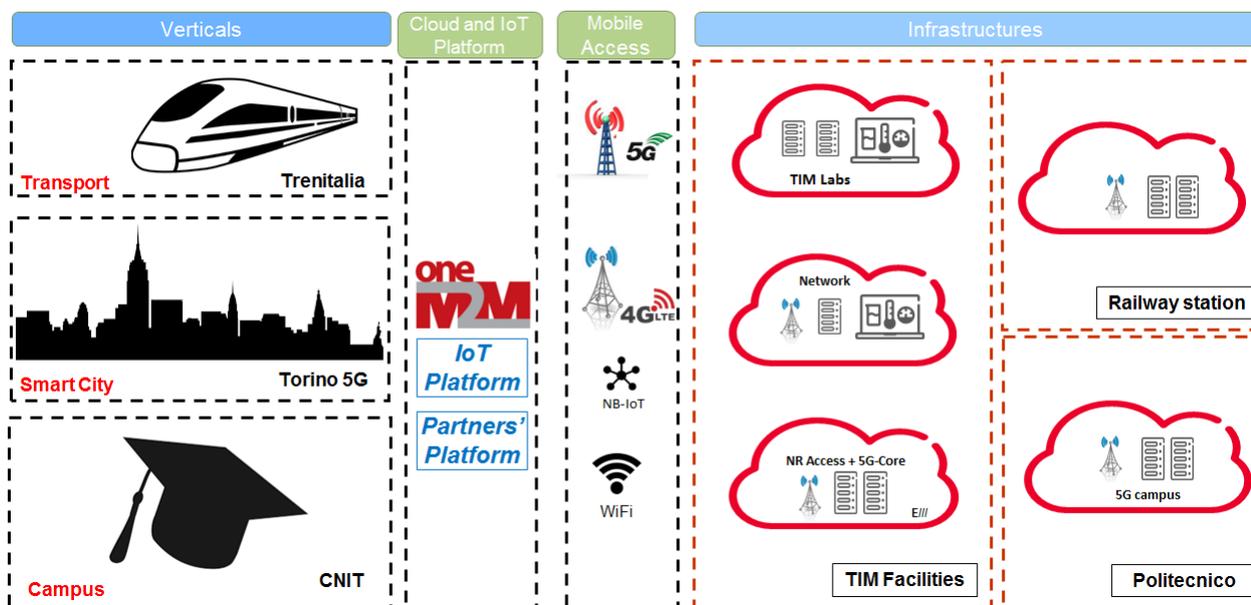
Figure 23: High level description of the 5G EVE Italian site facility in Turin

5G technology will be provided by Ericsson as part of TIM mobile infrastructure based on the Torino 5G Initiative and integrated into the 5G EVE Italian facility to support identified use-cases.

Ericsson will implement in TIM infrastructure a 5G network embedded with NR Access and 5G Core functionalities. This network will follow the 3GPP standard evolution and will implement some of its features according to Ericsson's roadmaps and agreement with partners. The physical network infrastructure will be located in Torino city and network base stations will be distributed according to the "Torino 5G" initiative.

The "verticals" involved in the validation of the Italian site facility belong to three major categories:

- "Transport", related to the testing activities of Use-case 1, having leading actor in Trenitalia, the incumbent trains operator in Italy;
- "Smart city", related to the testing activities of Use-case 5, where the Municipality of Turin has a primary role in setting requirements and defining proper tests on the basis of the 5G-empowered services under consideration in the "Torino 5G" initiative;
- "Campus", related to both Use-cases 1 and 5, in which CNIT will drive specification, deploy and evaluation of 5G services within the area of the *Politecnico di Torino*.

These verticals will deploy various types of service/application-specific functions and infrastructure components for media streaming, traffic flows and patterns analysis, device and user connectivity, etc., as described in the following subsections. For all the aspects related to integration and interfacing to IoT devices, the Turin site facility will exploit the IoT platform "One M2M" by TIM, which runs in Cloud and allows to integrate several types of sensors and devices deployed in the city area of Turin. The One M2M platform has been already experimented by Telecom Italia in research and in live initiatives in various Italian cities and is a key component of the Torino 5G ones. Other application specific platforms to be included in the site facility are still under evaluation and depend on the design of the Use-cases under development in the 5G EVE project.

The networks that will implement the mobile access in this site facility will be composite and will range from wireless networks based on 5G standards (3GPP R15_Option 3x, as initial deployment) down to 4G LTE for preliminary tests aiming at performance benchmarking, local WiFi networks and NB-IoT respectively for indoor environments and specific connectivity with IoT devices.

The infrastructures to be deployed in this site facility will include radio elements and PoPs with NFV infrastructure for computing, storage and network, where to host the 5G network functions and the application layer service functions required by the use-cases. TIM will provide its indoor testing facilities in their Labs in Turin, as well as the live networks deployment in cooperation with Ericsson. CNIT will provide testing facilities (radio and PoP) in the area of *Politecnico di Torino*.

More details on the preliminary use-case scenarios and infrastructure elements are provided in the following.

3.1.1 Smart Transport use-case architecture

The City of Turin represents the third largest node in the Italian railway network with two railway stations (Porta Nuova and Porta Susa) and main connection lines with major Italian cities nearby (Genoa and Milan) as well as with France, operated by traditional and High-Speed Rail (HSR) trains. The main railway station (Porta Nuova) is the third in Italy for number of passengers, while both stations are multimodal hubs connecting railway and local public transportation networks.

The Smart Transport use-case presents two main scenarios of practical interest from the railway operator in 5G EVE:

1) 5G On-Board Media content provisioning

This scenario mainly covers new enhanced on-board train services for passengers, based on the improved connectivity and data mobility enabled by 5G. A high-level architecture of this scenario is described in Figure 24. The new services planned by the train transport operators require URLLC and eMBB connectivity performances offered by 5G Networks, which can result in incentives for the development of high-quality on-board security and passengers' comfort services. One of them is the innovative streaming of on-board heavy media contents for entertainment and infotainment for train passengers using daily High-Speed transport services.

In the High-speed railway segment of Trenitalia train service between Termini Station in Rome and Porta Susa in Turin, passengers should be in condition to enjoy the on-board media entertainment through a high-quality

streaming service offering movies, TV shows and music on demand. The goal of Trenitalia is to deliver media contents considering the best level of image resolutions that are currently available in the market. In detail it will be considered as floor level a Full HD service (High Definition) and 4K resolutions as best service condition to be used as standard resolutions for Blue-Ray quality content streaming.

With the availability of 5G, the streaming service is expected to potentially ensure a target user data rates almost between 2 and 20 Mbps. Considering the complexity of the delivery of heavy-data loads on high speed trains, the 5G network will need to offer communication guarantees which can mitigate the handover effect, which constitutes a relevant barrier for the delivery of a high-quality streaming of media contents, in particular during high-speed trips and in critical situations like travelling in tunnels, across natural barriers, etc. Consequently, key important requirements for the 5G-based Streaming services foreseen as targets for a mature 5G network are related to:

- Continuity of the services media streaming on board – the 5G network application needs to provide stability in terms of target physical broadband spectrum coverage (also considering critical communication) and reduce the handover effect in order to offer to the passengers a high quality of on-board streaming services in terms of continuity.
- On board throughput of 5G streaming provision – considering an initial average target value of network density up to 300 devices' connections on each daily train service of high speed, it would be necessary to provide an average target value of 5G network throughput almost between 5 and 20 Mbps in order to deliver an on-board high-quality streaming service in Full HD and 4K definition for each connected passenger.
- Actual values of the above requirements will be defined in the trial phase according to the capacity and characteristics of the implemented 5G network and its evolution.
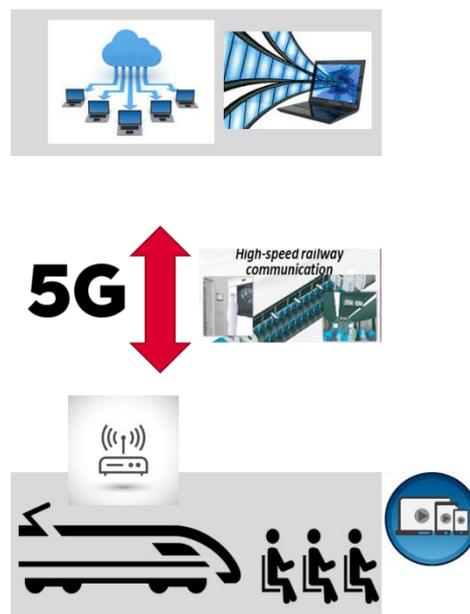
Figure 24: 5G On-board media content provisioning high level architecture

2) Urban Mobility 5G data flows analysis and monitoring

This scenario is related to the integration of 5G data and mobility data from different transport operators to enhance multi-modally between railway network and other collective transportation services.

Automatic identification of passenger mobility patterns and related transport modalities is necessary for both descriptive and predictive purposes to realize informative systems and services meeting end user's requirements and expectations in terms of mobility efficiency. Mobility profiles play a fundamental role in identifying different transportation modality demands, in performing spatial planning [5][6][7], and in enabling efficient,

context aware and user centric info-mobility services. Moreover, the vertical aims preventing situation of traffic peak by real time automatic identification of critical mobility patterns and managing bottlenecks in public transport by realizing suitable info-mobility services for both citizen and passengers by the above-mentioned On-Board Media entertainment services.

So far, traditional flow identification systems relied on GPS data and/or mobility data coming from LTE/4G networks through specific applications installed on user's mobile devices [8][9][10]. In 5G network equipped with massive IoT connectivity and MEC facilities, collection of mobility data as well as identification and recognition of aggregated mobility flows and recurrent patterns will be possible as local applications running on network side (edge site), instead of end user side. As depicted in Figure 25, RAN edge allows moving data storage and computational capabilities from web based data centers and services to the RAN edge in the mobile network, in order to collect high frequent mobility data and to monitor real time passengers mobility flows so to prevent critical situations in terms of traffic peaks and bottlenecks in city transport networks (including the road one) with particular attention to crowded multimodality hubs, like railway and metro stations (in the reference location, Porta Nuova and Porta Susa railway stations). Reliable and massive traffic flow and pattern analysis require mMTC, eMBB and URLLC performances as well as data storage and computation resources offered by edge site in 5G Networks, while accurate positioning is inherited from LTE/4G.

In this respect, target key important requirements for suitable support through mature 5G Networks are

- High connectivity density expected up to 100x number of devices per unit area compared with LTE/4G to guarantee suitable coverage of mobility patterns;
- Ultra-reliable and low latency (up to 1ms) connectivity to guarantee precise and reliable device positioning data in mobility (both on and off board the train);
- Scalable data storage and computation resources for running lightweight traffic flow and pattern recognition and analysis on RAN edge in the 5G Network.
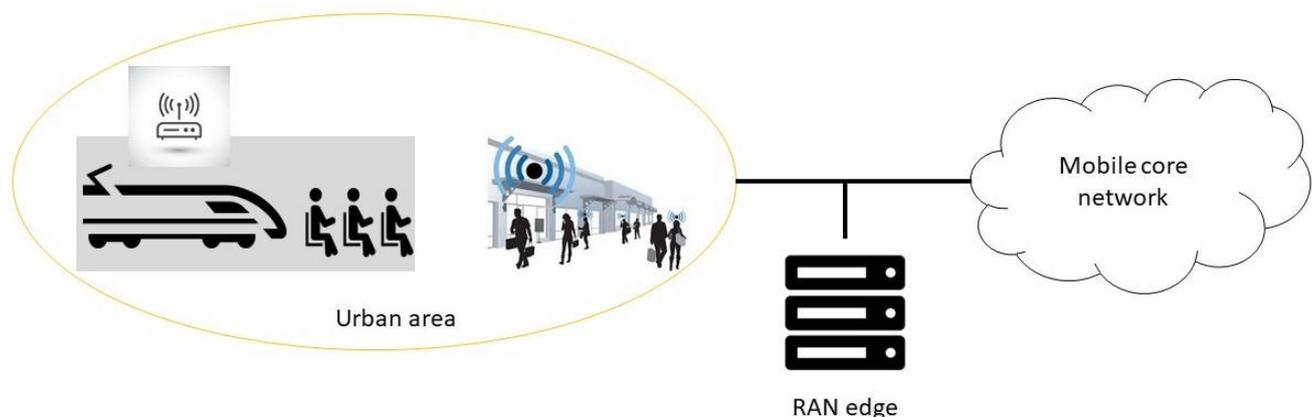
Figure 25 Urban Mobility 5G data flows analysis and monitoring high level architecture

3.1.2 Smart cities: Safety and Environment - Smart Turin

This use-case will be facilitated by the collaboration between TIM and *Comune di Torino* for the 5G deployment in the city of Turin, managed under the "5G Memorandum of Understanding" signed on May 2017, and by the collaboration between TIM and *Politecnico di Torino* (partner of the CNIT consortium) managed under the "Campus 5G" framework. The map of the site deployment is illustrated in Figure 26.

Figure 26: **Map showing *Politecnico di Torino* (red area) and Porta Susa station (blue area)**

One of the objectives of this use-case is the management of large crowds, mainly students, in their daily commute between *Politecnico di Torino* and the Porta Susa railway station. The two sites are roughly 1 km apart, connected by a large avenue with many sidewalks and a bike path. It is estimated that around 20,000 students daily attend *Politecnico* during regular class semesters. No figures are currently available to characterize the fraction of these students who move on the *Politecnico*-Porta Susa axis. So, one of the first objectives of the use-case would be to provide these figures, by monitoring the flow of students during different times of day. It is planned to achieve this goal by real-time readings from proximity sensors disseminated along the axis between the two sites, and on the sites as well. Additional information, specifically related to the movements of students on the *Politecnico* campus (classrooms/canteen/study rooms), can be provided through small-cell-based localization. It is to be remarked that a part of these students can be classified as "limited mobility" pedestrians, when they carry around large suitcases on their way to/from the railway station.

The infrastructure deployed to achieve these "basic" monitoring goals will then enable additional services:

- Inform users about the best available mobility means. Crowd monitoring and management at bus stops/station/classrooms and handling of critical events (severe weather/strikes/accidents/breakdowns) will be managed throughout push message services;
- Real-time readings from sensors (e.g., weather);
- Integration/merging of schedule of transportation and *Politecnico* events (classes, graduations, open days, etc.);
- Città di Torino will take care of the sensor placement on the *Politecnico*-Porta Susa Station routes, on board of public transportation vehicles and on areas adjacent to Porta Susa station and to *Politecnico*, integrated with the data provided by the project partners. The retrieved data will comprise anonymous telephone SIM identifiers that will allow a rich mobility analysis.

As in the "Urban Mobility" use-case, a 5G network guaranteeing mMTC and URLLC performances is needed, along with MEC-based data storage and computation resources. Accurate positioning will be guaranteed from LTE/4G.

Thus, for this use-case, 5G Networks KPIs for a mature network could be:

- High connectivity density expected from 10x to 1000x number of devices (sensors and smartphones) per unit area compared with LTE/4G;
- Ultra-reliable and low latency (up to 1ms) connectivity to guarantee precise and reliable device positioning data in mobility.

3.2 RAN architecture description

The 5G RAN architecture of the 5G EVE Italian site facility will be based on the model of standardization defined by 3GPP. In the first stage of the project it will be based on the deployment of the 5G Non-Standalone Architecture implemented with the Option 3.x as per 3GPP Release 15. The architecture will provide connectivity for combined LTE and NR systems, as depicted in Figure 27.

Option 3.x uses LTE as the control plane anchor for NR, and uses either LTE or NR for user traffic (user plane). Since LTE will be the serving network to NR coverage in the NSA architecture, the legacy LTE network will be exploited. This option of 5G deployment is supported in Ericsson Radio System and Evolved Packet Core (EPC).
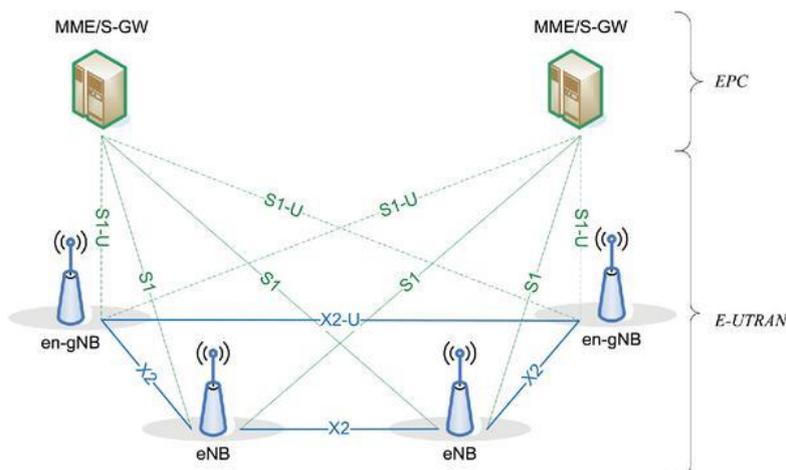
Figure 27: NG-RAN in relation to the 5G system [66]

5G NSA architecture foresees different interfaces: towards the network side the LTE eNB terminates the S1 Control Signalling (S1-C) coming from EPC and towards the UE it terminates the Signalling Radio bearer (SRB).
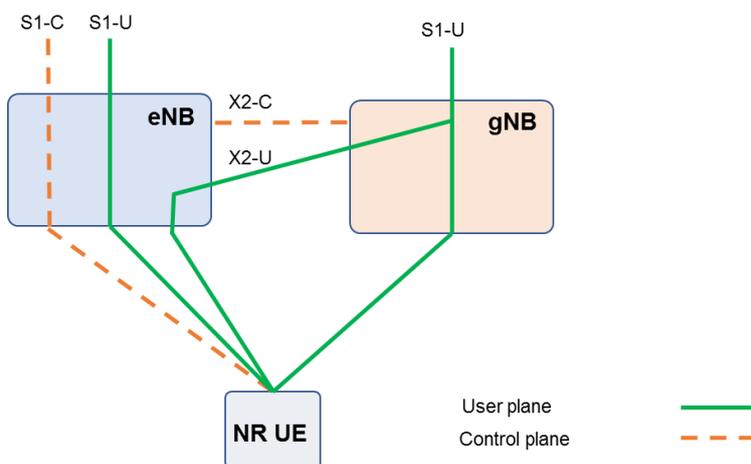
Figure 28: CP-UP flows option 3x

The user Data Radio Bearer is setup either as Split bearer, i.e. using both LTE and NR radio resource or as LTE only bearer (using only LTE radio resources). The reason to support both DRB bearers is to grant to legacy UE to be connected to 4G network and 5G UE that are out of NR coverage to benefit from the service access.

The termination point for S1-U user plane follows the rule that in case of split bearer it is the NR gNB (en-gNB in the 3GPP naming convention) that handles the termination, while in case of direct bearer it is the LTE eNB that terminates it.

This kind of configuration enables legacy LTE UEs to be connected with LTE only DRB and simultaneously any UE under NR coverage in DRB split bearer.

The eNB and en-gNB have X2-C and X2-U connections, where the user data of split bearer is carried over X2-U, and control signalling over X2-C. The possible NR cell that can be a candidate to create a split bearer will be configured to have a relationship with the specific LTE cell.

3.2.1 RRH

The Ericsson AIR6488 will be the product used for NR component in the Italian site facility, which is composed by antenna and Radio unit connecting to BBU through the e-CPRI interface. LTE component is composed by a radio unit (22xx) and passive antenna (Figure 29):

Figure 29: RRH solution components

3.2.2 BBU

The RAN includes 5G NR and LTE RAN. Ericsson deploys BBU dedicated to LTE (5216) on one side and to NR (6330) on the other side. More details are given in Section 4.2.2.1 for the 2 equipment.

3.2.3 Frequency bands

The Italian site facility will use different solutions and frequencies: LTE frequencies on bands already in use by TIM (800 MHz, 1800 MHz and 2600 MHz), new frequencies on B42 (3500 MHz) and B43 (3600-3800 MHz). The deployment and usage of these frequencies will be defined based on the results of the official frequency auction for 5G under finalization by the Ministry of Economic Development in Italy.

3.3 Distributed Cloud / MEC

3.3.1 Description of the strategy

Ericsson implements distributed cloud architecture according to 3GPP standards, as shown in Figure 30 and further described in the following sections. This architecture is deployed in a geographically distributed infrastructure composed of several edge sites, typically equipped with a limited amount of computing and storage resources, and a central site with a larger set of resources, both under the network operator's control. Moreover, the architecture can exploit further resources made available from data centers and public clouds that may be operated by third parties.

The computing resources placed at the edge of the network (i.e. the edge site in Figure 30) run a set of virtual entities implementing operators' network functions and local applications from the operator itself or from the verticals (e.g., use-case Smart Transport, scenario Urban Mobility 5G data flows analysis and monitoring described in Section 3.1.1). Following the concept of separating the control and the user plane traffic (further described in Section 3.4), the edge site hosts the functions related to the virtual EPC User Plane (UP). Another

instance of the virtual EPC UP runs at the central site, together with the vEPC Control Plane (CP) functions that are maintained fully centralized and further applications, represented as central applications in the following Figure 30.
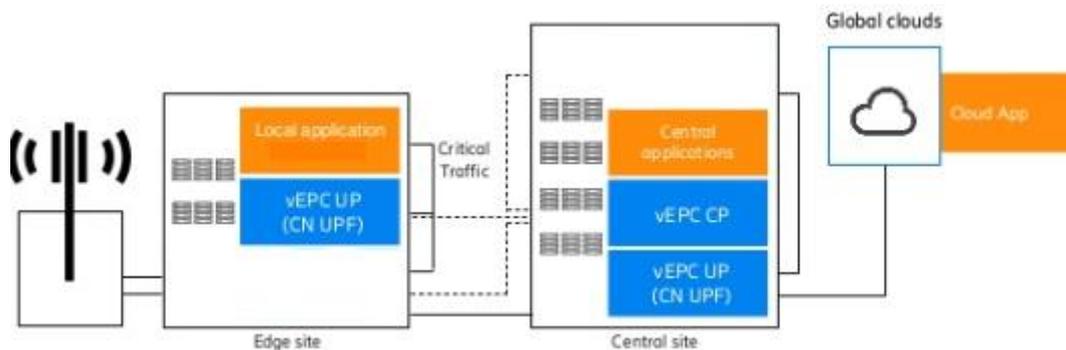
Figure 30: Ericsson Distributed Cloud

This approach allows to intercept part of the data plane traffic immediately at the edge of the network, closer to the mobile users, and to steer specific traffic flows towards the virtual applications running locally in the edge site, while the rest of the traffic proceeds towards the central site and to the cloud. Critical and delay sensitive traffic is thus elaborated directly in the edge site, through local applications that can be deployed as needed on the virtual infrastructures available at the edges, without the need to reach the core network and the central site.

Internet of Thing (IoT) and Machine to Machine (M2M) services are typical examples of applications that can particularly benefit from running specific software components in the proximity of the network edge, reducing the end-to-end delay. In this area, the Italian site facility integrates the OneM2M Platform, described in Section 3.3.2.

3.3.2 OneM2M Platform

Among the vertical application layer functionalities which are distributed between edge and core cloud segments in the run Turin site facility there is the OneM2M platform for IoT services.

The OneM2M platform developed and operated by TIM follows a «store & share» paradigm, implementing RESTful resource-oriented API compliant with OneM2M standard.

Main characteristics are:

- REST API;
- URI (Uniform Resource Identifier) resource identification;
- Service independent, interworking with legacy platforms and non-OneM2M data sources using Adapters/Proxy;
- Multi-tenancy;
- Security: HTTPS and authentication (Basic or JWT);
- Supported Interface protocols: HTTPS, MQTT, COAP transport.

A more extensive description of oneM2M standard - release 2 - could be found in the technical specification documents issued by ETSI and specifically in:

- One M2M Functional Architecture TS-0001-V2.19.0 (available at [11])
- One M2M Service Layer Core Protocol Specification TS-0004-V2.17.0 (available at [12])

3.4 CORE architecture description

3.4.1 Main functionalities

The 5G network topology and the connectivity between the different network elements are implemented in a way that the CP and UP follow different paths. This implementation is called CUPS (Control and User Plane Separation) and follows the 3GPP standards to implement the distributed core functionalities. Study of the interfaces helps to understand the connections between the different components of the system.

The solution adopted in the Italian site facility will be based on 5G Option 3 aiming to achieve a full potential of 5G while reusing existing network resources.

This will use the 3GPP-standardized options for LTE–NR interworking connected to an upgraded EPC, 5G EPC as shown in Figure 31:
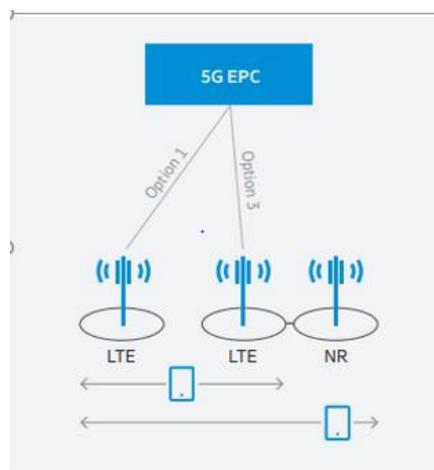
Figure 31: 5G EPC scheme

The 5G EPC supports the NSA 5G NR delivering end-to-end 5G use-cases and operates independently of access type, enables interconnection with all services to whatever resources they need (meeting different requirements for each use-case in terms of latency, battery life or usage, and data rates, for example). This core network supports 3GPP Option 3 (NSA), where NR devices are anchored in an LTE cell. The 5G EPC can further optimize the capabilities for each service through network slicing. These virtual network instances on shared infrastructure are logical networks with tailored feature sets and topology for each service, which would be more expensive to build as separate networks.

Mechanisms for efficient allocation, orchestration and management of the virtual resources in the core network infrastructure are needed to guarantee the correct operations of the 5G EVE site facility in Turin. In particular, the orchestration and control platform responsible for the core domain will provide the following features:

- Support of network slicing to implement logical groups of 5G services and resources with specified performance profiles;
- Support of multi-tenancy to manage various isolated environments in the NFV and MEC Infrastructure and correspondingly in the Management and Orchestration layers;
- Coordinated distribution of services from the core to the edge computing domain, and optimized VNF placement to fulfil specific service performance KPIs;
- Multi-layer monitoring capable of collecting and aggregating statistics from various layers: physical infrastructure, virtual resources, service (i.e. NFV Network Services) and vertical applications;
- Interfacing to external Cloud services for backend intensive computational tasks (mostly needed from the Vertical applications);
- Support for containers and lightweight VMs.

3.4.2 Infrastructure elements

The infrastructure layer of the Turin site facility is composed by a multi-site NFVI infrastructure based on the following components:

For TIM/TILab, *Politecnico di Torino*, Porta Susa Railway station: multiple compute nodes interconnected via TIM networks implementing an NFVI environment managed through OpenStack (Queen release). The OpenStack VIM will be configured to manage the various computing nodes of the site facility and to include, in addition:

- monitoring modules like Ceilometer, Panko or Monasca;
- multi-region deployment based on Tricircle;
- Cyborg module to manage hardware acceleration;
- Kuryr module to manage container networking,

Some of these OpenStack projects are still at an early stage of developments. Therefore, their inclusion in the 5G EVE operational environment will be evaluated and possibly executed in stages of incremental releases of functionality, from April 2019 onwards. The monitoring of this NFVI infrastructure will be done with the Prometheus monitoring platform, including Grafana for GUI and exporters to collect monitoring data from VMs, OpenStack and Telegraf (for monitoring application).

Ericsson will deploy an NFVI solution which can be integrated with the above-mentioned solutions. As for the physical core component and support to the 5G network setup, Ericsson will provide a 5G EPC core system. The 5G EPC system is a standalone and compact system to satisfy the following requirements: all EPC nodes in a system, easy setup, ease integration with customer network. Ericsson Core & Cloud element supported in a CEE (Cloud Ericsson Environment) region consists of a single server. This means that there is no support to deploy vEPG, vSGSN-MME on same single server in a cloud. Network element functionalities are implemented on virtual machines running in a blade server: vMME, vEPG, vUDC (vCUDB, vHSS-FE), SGW, PGW. This is illustrated in Figure 32.
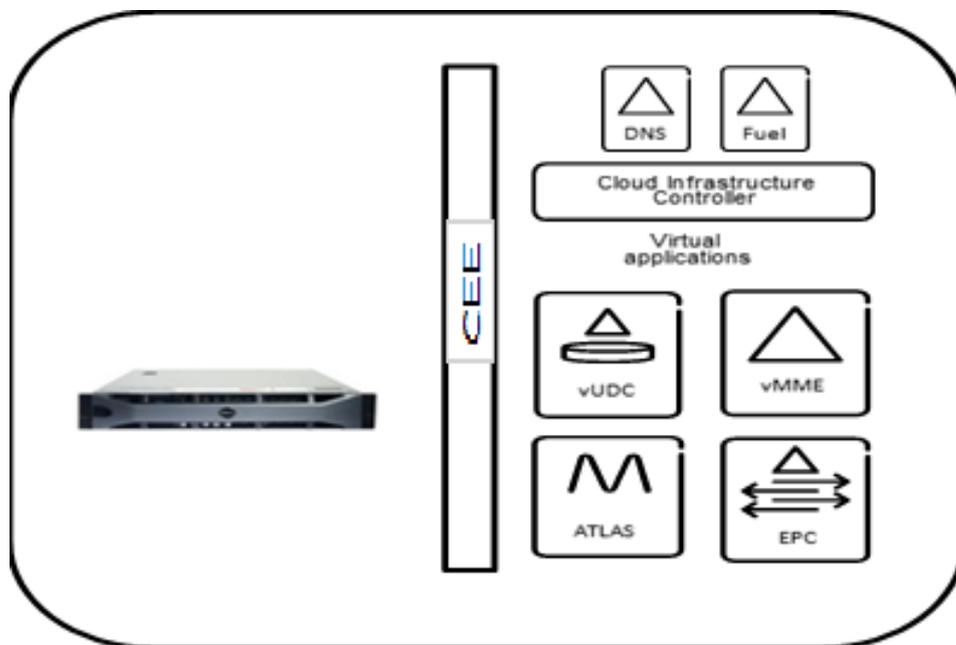
Figure 32: 5G EPC in a box

The Ericsson Cloud & Core system will contain the following VNF element and structure (illustrative):
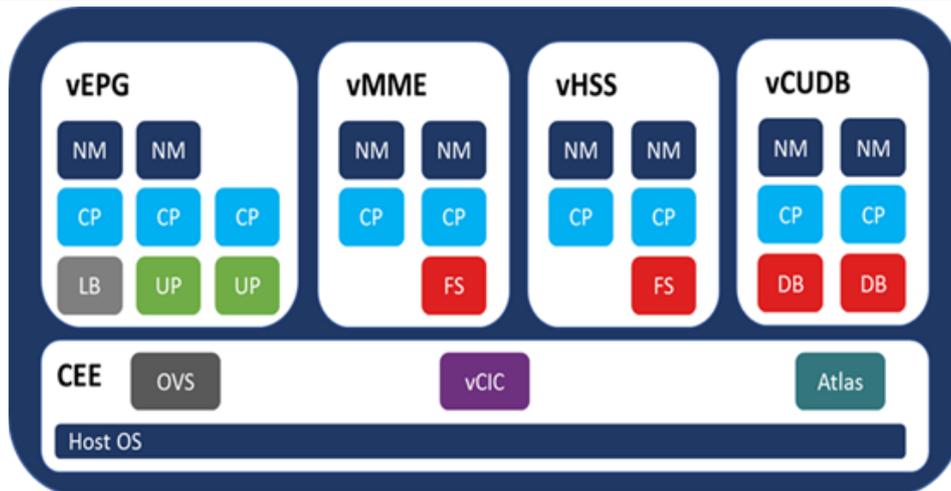
Figure 33: vCore components and the orchestration through its VNF elements

The functionalities reported in Figure 33 correspond to the following Virtual Network Functions (VNF), each related to a Virtual machine running the vCore:

In vEPG, the VMs have the following functions:

- Node Manager;
- Active/Standby;
- Load Balancer;
- Control Plane;
- User Plane;

In vSGSN-MME, the VMs have the following functions:

- Node Manager;
- Active/Standby;
- Load Balancer;
- File Server;
- General Processor, running CP, UP and SS7/SCTP.

3.5 Orchestration

Different solutions can be deployed for the Management and Orchestration of the 5G EVE Italian site facility. In particular, at the orchestration level, two possible alternatives will be considered for the deployment in Turin: the ETSI OpenSource MANO Release 4 (see Section 3.5.1) and the proprietary Ericsson Orchestrator (see Section 3.5.2). The project will also evaluate the possibility to integrate the two orchestrators, e.g. through a multi-site deployment where each component is responsible for the service and resource orchestration of specific NFV infrastructure sub-sites.

On top of the NFVO(s), additional software tools can be adopted to implement complementary and/or enhanced features for slice management, monitoring and multi-site operation, as follows:

- Slice Management, to provision and scale service-driven network slices;
- Slice Controller Factory, for the dynamic and on-demand instantiation of per-slice management, configuration, monitoring and control tools and APIs;
- One multi-site catalog for NSDs, VNF packages and MEC Application packages;
- One SDK tool to facilitate service planning, composition and provisioning;
- Interfaces to the service monitoring platform (based on Prometheus) to implement a service monitoring function for the site facility.

Part of these tools derive from mainstream open source community efforts (i.e. ETSI OSM), part configures as background of 5G PPP Phase 2 projects [13] (i.e. 5G-TRANSFORMER, SLICENET, 5G-MEDIA, 5GCity) to be adapted, enhanced and integrated in 5G EVE specific facilities and usage contexts.

3.5.1 Open Source MANO

Open Source MANO [14] is an operator-led ETSI community that is delivering a production-quality open source Management and Orchestration (MANO) stack aligned with ETSI NFV Information Models and that targets to meet the requirements of production NFV networks.

OSM provides a full solution for NFV management and orchestration, covering both design time (i.e. DevOps) and run time phases of VNFs and Network Services lifecycle management. OSM logical architecture including the functionality offered by OSM is shown in Figure 34, where different colours identify run-time and design time components.
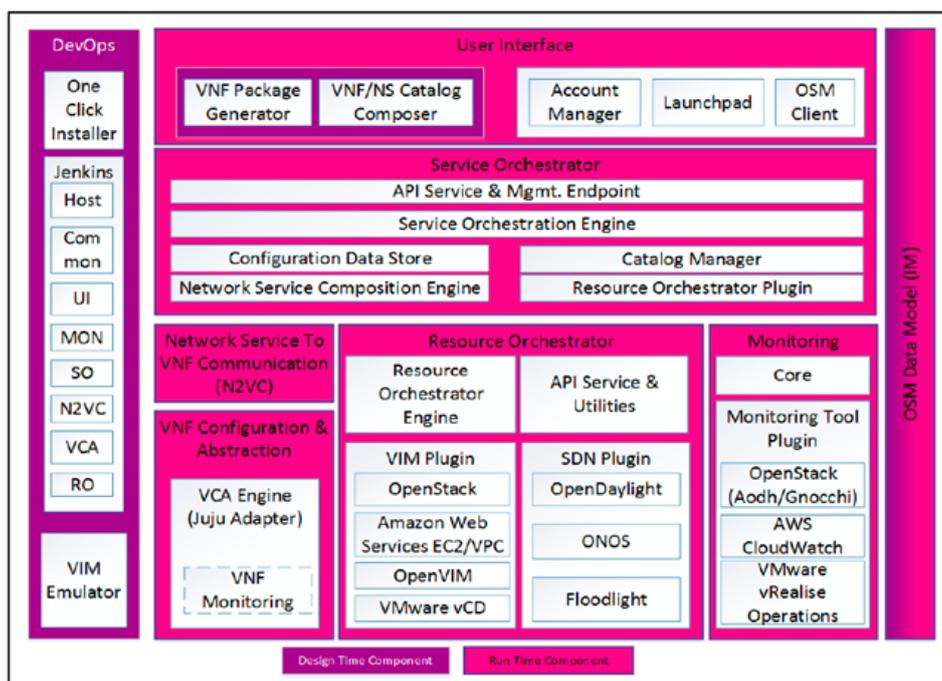
Figure 34: OSM logical architecture (source: ETSI OSM white paper [15])

The design-time scope of OSM includes: i) the capability for Create/Read/Update/Delete (CRUD) operations on the Network Service definition, ii) tools for VNF Package Generation, iii) Graphical User Interface (GUI) to accelerate the design time phase, VNFs on-boarding and deployment. On the other hand, the run-time scope of OSM mostly provides: i) an automated Service Orchestration environment as the main coordination engine, ii) plugins for integrating multiple VIMs (including OpenStack, VMWare, Amazon Web Services, OpenVIM), iii) plugins for integrating multiple SDN controllers, iv) an integrated generic VNFM with support for integrating specific VNFMs from VNF vendors, v) support to integrate Physical Network Functions into Network Services.

For the Italian site facility, it is planned to start deploying OSM Release 4 [16], which includes relevant features in the direction of the increased compliance with the ETSI NFV standards:
- New northbound interface, aligned with ETSI NFV SOL005, to cover all the phases of NSD and VNF Package management, NS lifecycle management and fault management;
- A set of optional components can be installed on top of the core NFVO components to enrich the experience in terms of visualization and service design (i.e. VIM sandbox);
- Monitoring capabilities, on-demand and descriptor-driven setting of alarms and metrics are now much simpler and convenient to configure and consume.

The OSM R4 Monitoring Module is capable to correlate telemetry related to the VMs and VNFs to the relevant Network Services.

Moreover, as an additional feature, OSM R4 introduces experimental support for VNFFGD running in the OpenStack environment, specifically in relation to OpenStack installations that support the networking-SFC capability.

3.5.2 Ericsson Orchestrator

The Ericsson Orchestrator (EO) is a service orchestrator and NFVO element. The EO architecture as depicted in Figure 35, having its main functionalities split around two key blocks:
- Service Orchestration, responsible for Network Slicing and WAN orchestration (WANO);
- Cloud manager, including the ETSI MANO functionalities for NFVO, VNFM and SCM.
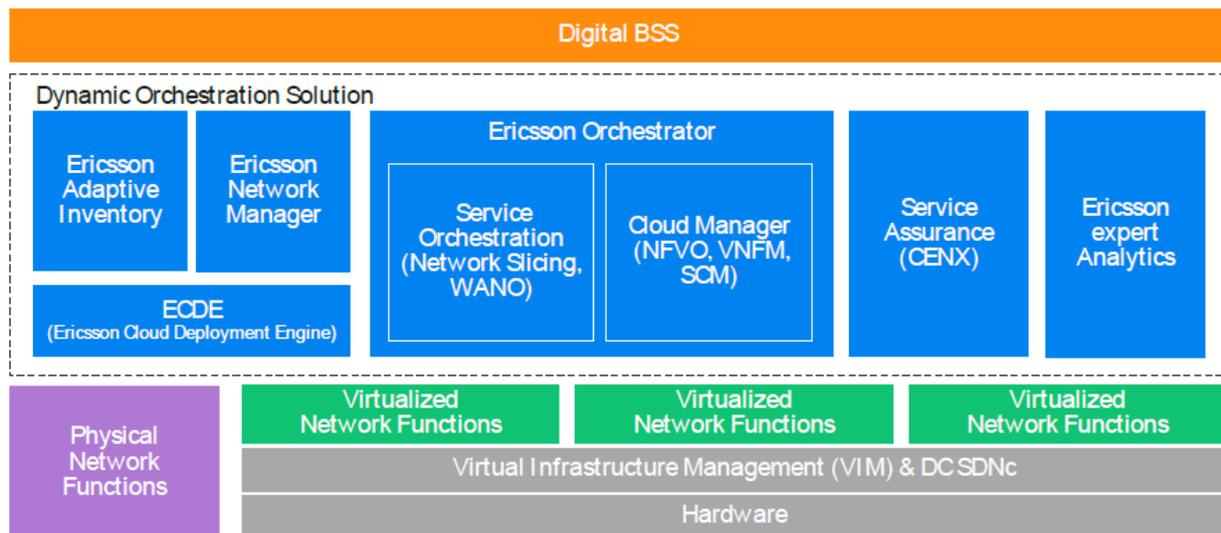
Figure 35: Ericsson Orchestrator

In more details, the Service Orchestration (Network Slicing, WANO) block is responsible of:
- End-to-end physical and virtual resource requirements identification to achieve closed loop;
- Orchestration of Slice instances to fulfil diverse and granular requirements such as policy control, security, mobility, charging, latency, reliability, etc…;
- WAN Orchestration to manage and control the transport network infrastructure.

The Cloud Manager (NFVO, VNFM, SCM) block is in charge of:
- NFV-O: NS Descriptor-driven orchestration; Tosca support for NS Description; NS Life Cycle;
- VNF Management: Generic VNFM for multivendor VNFs, VNF Life Cycle Management; Support for OVF/HOT; Integration with multivendor EMS/S-VNFMs;
- Infrastructure Fault & Performance Management: Fault and Alarm collection & correlation; Alarm enrichment with Tenant data; Performance Management;
- Resource Orchestration: Central Resource view; Multi-VIM (CEE, RH, Mirantis, VMWare, Vanilla OS); Policy-driven Workload Placement; Dynamic Flavour Management; Tenant Management with Multi-level, Quota;
- Configuration Management: Model-driven config of PNF/VNFs.

It is worth mentioning that Ericsson embraces Open Source and Standards (Figure 36):
- Drive standardization of ETSI MANO
- Contribute to ONAP architecture & code in selected areas; ensure ONAP API compliance of Ericsson portfolio
- Enhance ONAP architecture to align with MANO
- Use Tosca as "network service descriptors"

- Secure continuous parity with newest OpenStack releases
- Expand Ericsson Orchestrator with container- orchestration (Kubernetes & Docker support)

Figure 36: Open source and Standards supported by Ericsson solution

Just referring to the ETSI references, in Figure 37 is shown the EO integration with ENM or 3PP VNFs:
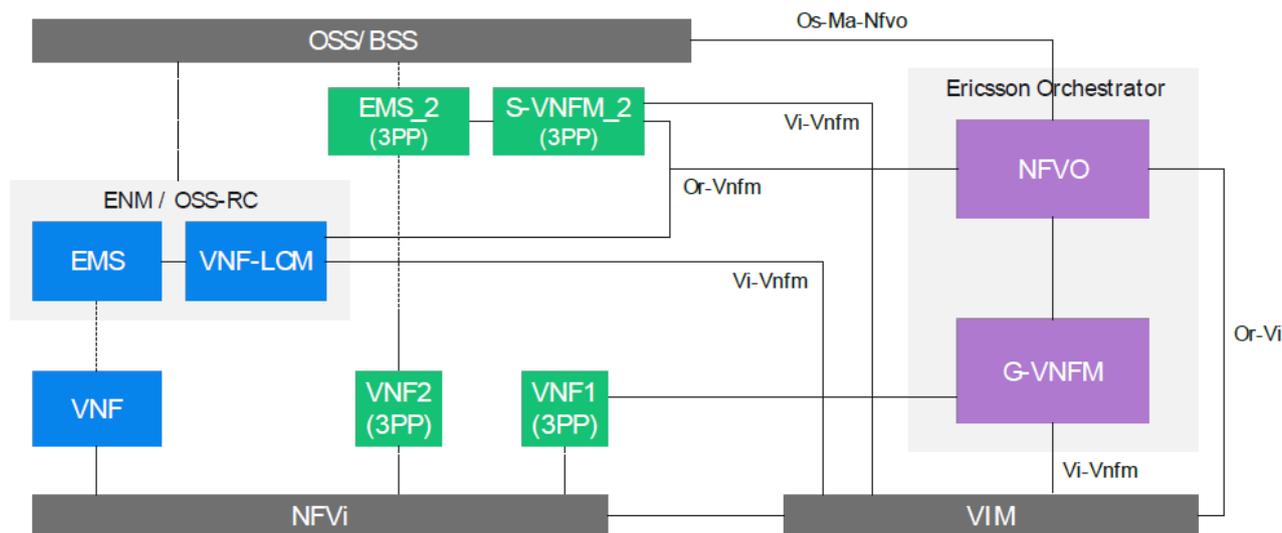
Figure 37: EO integration with ENM for Ericsson & VNFs of 3PP

3.5.3 Network management Transport

3.5.3.1 Ericsson Network Manager (ENM)

Small ENM configurations have been introduced in 2018. Now ENM can be either deployed in customer cloud or implemented in a small physical environment. This is referred to as a Small Integrated ENM, and will be deployed in TIM site facility to support the NSA architecture (exact deployment location still under definition).

The solution can manage network elements of Radio, Core and Transport types maintaining the same level of hardware and software high availability of the traditional case. Small Integrated ENM is deployed on HPE Gen9 DL 380 rack server technology.

This rack integrates the functionalities as shown in Figure 38:
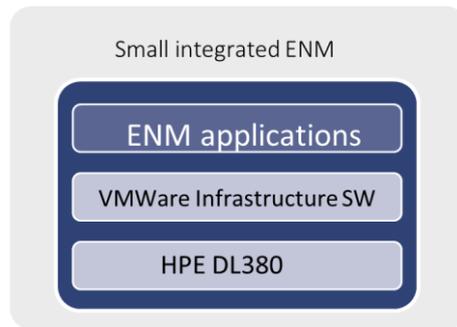
Figure 38: Small integrated ENM

3.5.3.2 SDN Controller

For the SDN controller, the ENM leverages on a refined and improved version of the open source ODL vanilla controller. Ericsson is a platinum member in OpenDaylight project.

This advanced version allows Ericsson to achieve best in class results in terms of availability and performances. The ODL SDN controller is shown in Figure 39.
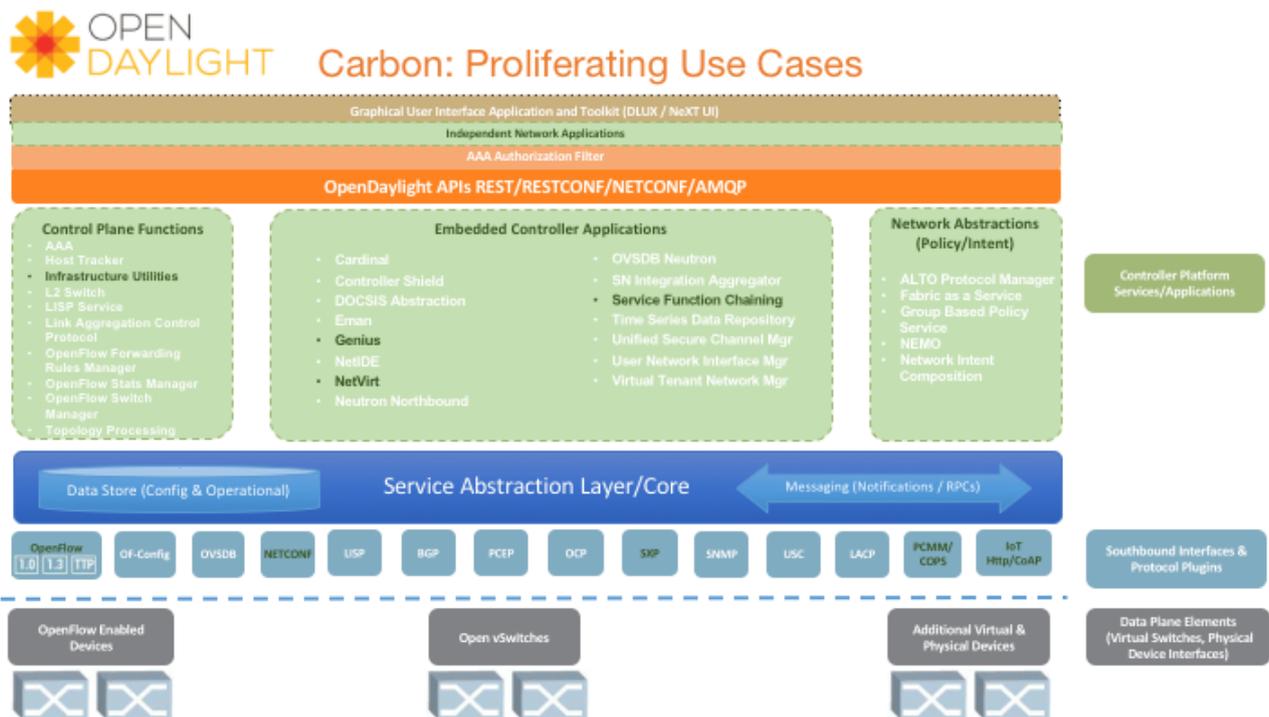
Figure 39: ENM - OpenDaylight SDN controller

3.6 Interfaces

The 5G EVE Italian site facility is a 5G architecture based on the 3G PPP R15 option 3. From protocol split point of view, 3GPP has standardized the Option 2 where the gNB consists of gNB-CU and gNB-DU. gNB-CU is defined as a logical node hosting RRC and PDCP protocols of the gNB. While gNB-DU is defined as a logical node hosting RLC, MAC and PHY layers of the gNB.

The test environment will embed all the split in the baseband. The gNB will be realized with a BaseBand connected with an e-CPRI to the AIR6488. The interface towards the AIR realizes the split Option 7 that is pending the finalization of 3GPP standardization release 16.

RAN interfaces depicted in Figure 40 are hereafter summarized:
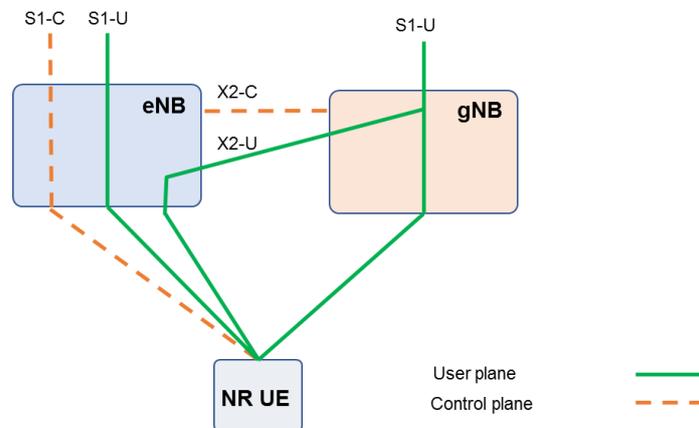
Figure 40: 5G RAN Interfaces

- S1-C: Connects RAN to EPC. Used for S1-C signalling connection, terminated by the eNB;
- S1-U: Connects RAN to EPC. It carries S1-U user plane bearer. It's terminated by the eNB for legacy UE's, and certain bearers of the NR UE such as VoLTE and it's terminated by the gNB for the NR UE bearer;
- X2-C: Connects between eNB and gNB and carries X2 control signalling;
- X2-U: Connects between eNB and gNB and carries user data of Split bear.

3.6.1 Core Network interfaces

Traditional EPC contains many network elements and interfaces. However, in this 5G test environment, the EPC will be implemented on a single server that provides all the core functionalities. Therefore, the interfaces in EPC will be logical between different virtual machines and only physical connections will be towards the RAN (eNB and gNB) and towards the backhaul (switch).

Below the core network interfaces:
- S1-MME: Reference point for the control plane protocol between E-UTRAN and MME;
- S1-U: Reference point between E-UTRAN and SGW for the per bearer user plane tunnelling and inter eNB path switching during handover;
- S5: It provides user plane tunnelling and tunnel management between SGW and PDN GW;
- S6a: It enables transfer of subscription and authentication data for authenticating/authorizing user access between MME and HSS;
- S11: Reference point between MME and SGW;
- S12: Reference point between UTRAN and SGW for user plane tunnelling when Direct Tunnel is established.

3.6.2 RRH – BBU interfaces (Fronthaul)

This section describes the high-level architecture between RRH and BBU.

The fronthaul equipment provides transport between BBUs and RRHs as part of the Ericsson Radio System. This solution can be based on an optical infrastructure (passive solution) that provide connectivity from BBU units to RRHs or can be based on an active solution that is based on transponder cards able to provide clear demarcation between RAN and transport network, thus enabling the C-RAN deployment. The high-level architecture based on a fronthaul solution consists of:

- Main site units near to the BBUs;
- Remote site units near the RRHs or AIR.

Figure 41 shows how the fronthaul is in the Ericsson Radio System architecture:
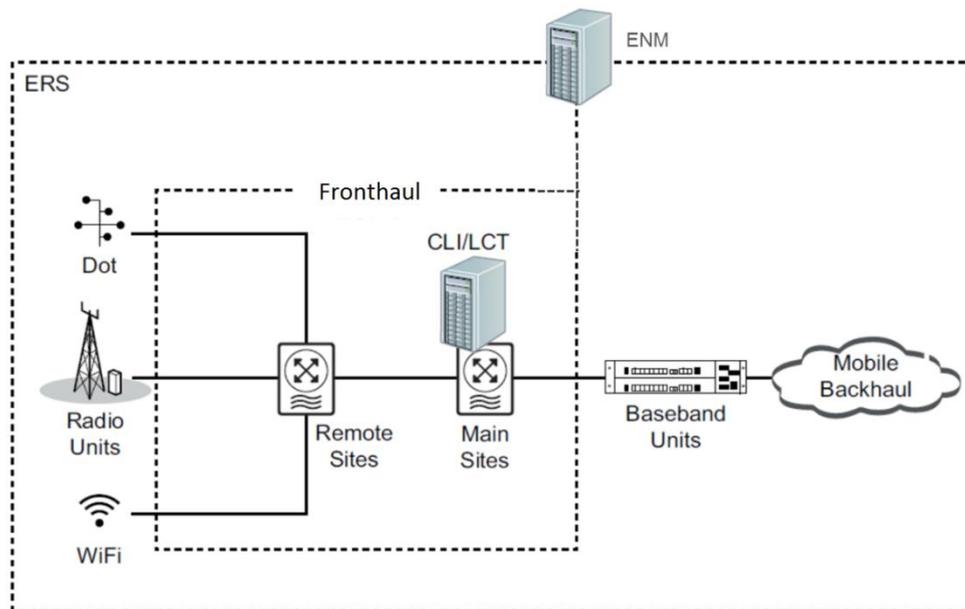
Figure 41: Ericsson Fronthaul connectivity

The main site is located near the BBU to provide functions of management, transponder between grey optical signal and DWDM signal, DWDM Mux/Demux and protection.

The remote site is located near the RRH to provide functions of DWDM add/drop and transponder between grey optical signal and DWDM signal. It can be an indoor solution (if a cabinet is present on site) or an outdoor solution suitable for pole mounting.

Moreover, fronthaul provides LCT and CLI for node management and ENM system for multiple nodes management with radio system or transport system.

3.6.3 CU CP and CU UP interface (E1)

In Italy site facilities these interfaces are embedded in the BBU.

3.6.4 IoT OneM2M Platform and application layers interfaces

OneM2M defines a request/response paradigm to interact with the CSE Entities, so HTTP methods such as GET, POST, PUT, DELETE are used in the classical REST approach to retrieve, create, modify, delete resources. Details of this interface are provided in ANNEX A.

3.7 Development and deployment tools/software

The hardware tools available for the maintenance and operations of the 5G EVE site facility elements include the basic assortments of devices to guarantee connectivity needs wherever they may arise: Switches/routers, cables (optical, ethernet and copper), network adapters, power adapters and convertors, laptops (e.g., to run network monitoring tools such as Wireshark) and server racks.

3.7.1 Software framework and storage

At the present time, there are some candidates for software development tools that are being evaluated and are mainly related to what each partner is currently using. In particular, the well-known version control system tool Git is being considered for distributed version control and source code management, along with its web-based platform GitHub.

3.7.2 Management and resource (HW/SW) provisioning

The 5G EVE site facility in Turin will largely use *OpenStack* [3], in its latest release OpenStack Queens, for management and resource provisioning. OpenStack is a cloud operating system that controls large pools of compute, storage, and networking resources throughout a datacenter, all managed through a dashboard that gives administrators control while empowering their users to provision resources through a web interface. For multi-region deployment the *Tricircle* OpenStack module might be needed: it is designed to provide networking automation in multi-region OpenStack deployments. Additional OpenStack projects that will be taken into consideration are *Cyborg* to manage hardware acceleration, and *Kuryr* to manage containers' networking, although they are still in a development phase and they may not be suitable for an operational environment.

As an SDN controller, the Site facility will use *OpenDayLight* [17], specifically the Beryllium/Nitrogen versions. Management and Orchestration of resources will be handled using ETSI *OpenSource* Mano release 4 [16].

As already mentioned in 3.5, additional software tools being developed in the context of other 5GPPP-phase 2 projects may be provided, based on specific requirements. For example:
- A Slice Manager, able to provision and scale service-driven network slices, derived from 5G-TRANSFORMER 5G PPP project;
- A Slice Controller Factory, for the dynamic and on-demand instantiation of per-slice management, configuration, monitoring and control tools and APIs, derived from SLICENET 5G PPP project;
- A multi-site catalog for NSDs, VNF packages and MEC Application packages, derived from 5G-MEDIA 5G PPP project;
- An SDK tool to facilitate service planning, composition and provisioning, derived from 5GCity 5G PPP projects.

3.7.3 Supervision tool

The monitoring and control management of the 5G EVE Italian site facility will be primarily executed via OpenStack NFVI monitoring services, integrated with the Prometheus system form monitoring and alerting.

Specific OpenStack services will be selected based on the functional requirements on the site facility. For example, suitable candidates for monitoring are *Ceilometer*, *Panko* or *Monasca*. Specifically: *Ceilometer* is designed to efficiently collect, normalise and transform data produced by OpenStack services, using it to create different views and help to solve various telemetry use-cases. *Panko* provides a metadata-indexing, event-storage service which enables users to capture the state information of OpenStack resources at a given time, enabling a scalable means of storing both short and long-term data for use-cases such as auditing and system debugging. *Monasca* is an open-source multi-tenant, highly scalable, performing, fault-tolerant monitoring-as-a-service solution that integrates with OpenStack and uses a REST API for high-speed metrics processing and querying, plus a streaming alarm engine and notification engine.

For the interaction between VIM monitoring service and NFVO monitoring service, *Apache Kafka* could be used as monitoring message bus implementation, to interconnect the various event and alarm services from OpenStack (i.e. *Aodh* and *Gnocchi*) with the OSM monitoring and performance function (as per OSM R4 architecture).

As general supervision system, Prometheus [18] will be used. Prometheus provides multi-dimensional data models, a flexible query language, a pull model over HTTP and multiple modes of graphing and dashboard support. Monitoring data from VMs, OpenStack and *Telegraf* [19] will be collected for use in Prometheus through appropriate exporters. As a Graphical Interface to Prometheus, Grafana [20] is being considered.

3.8 Testing & KPI

As is being discussed with the project framework, 5G EVE is looking into adopting a Testing-As-A-Service (TaaS) approach with the goal of providing a unified functional and operational infrastructure for vertical industry experimentation. TaaS is a service provider and consumer interaction-based model where the service consumer places a request to the provider who fulfils the request. Specifically, the service provider (the 5G EVE facility in our case) provides testing services to the consumer (a vertical industry). The key services include test consultation, planning, automation, execution, and management.

While test EPC software will be mainly used in the Core network, and standard microwave/optical/Ethernet links will guarantee backhaul connectivity, on RAN segment, KPI testing will be supported using Spectrum Analysers, test handsets and test eNB software.

In addition, RF UEs load emulator will be used. This equipment allows full load of multiple antenna sectors. On each sector, several simulated mobiles can concurrently generate load over the radio interface, to test RAN protocol stacks and their applications.

Furthermore, RF shielding environment together with RF attenuators, duplexers, directional couplers and power splitters will allow replicating real conditions in lab environments.

3.9 Potential interconnection towards outside

As described in details in the previous sections, the infrastructure under deployment for the 5G EVE Turin site facility can be functionally split into control and data plane layers, which implement the various elements of a 5G end-to-end network.

As logically summarized in Figure 42, the 5G data plane ranges from the radio fronthaul/backhaul to edge and core PoPs, where the various network and application functions can be executed in the form of virtualized network functions and virtual machines. The 5G NFV-capable infrastructure of the Italian site facility can implement network slicing: in each slice, various network services can be realized with different service profiles through the stitching of VNFs and PNFs along Forwarding Graphs. To implement such functionalities, an SDN & NFV Management and Orchestration layer is deployed, which implements the site-local 5G service orchestration, the NFV service and resource orchestration, the management of the VNFs via various VNF Managers (VNFM), the SDN-based traffic flow control within the PoP infrastructure and in the WAN. The specific solutions, tools and releases in use in the Italian site facility have been detailed in the current Section 3. The evaluation of the performance offered by this infrastructure and its specific design in terms of supported throughputs, latency, radio spectrum, service availability and continuity, etc. will be assessed with the functional and performance tests during the 5G EVE lifetime of the site facility, starting from the initial installation activities planned for the site.

In a first release, VPN tunnelling (e.g. based on IPSec, GRE, etc. via Public Internet) is considered to interconnect the 5G EVE Italian site facility to external networks, as depicted in Figure 42. In particular, two VPN gateways are logically identified at the boundary of the control and data plane areas, which are used to serve the different purposes of connecting to other external networks and to other control entities in 5G EVE.
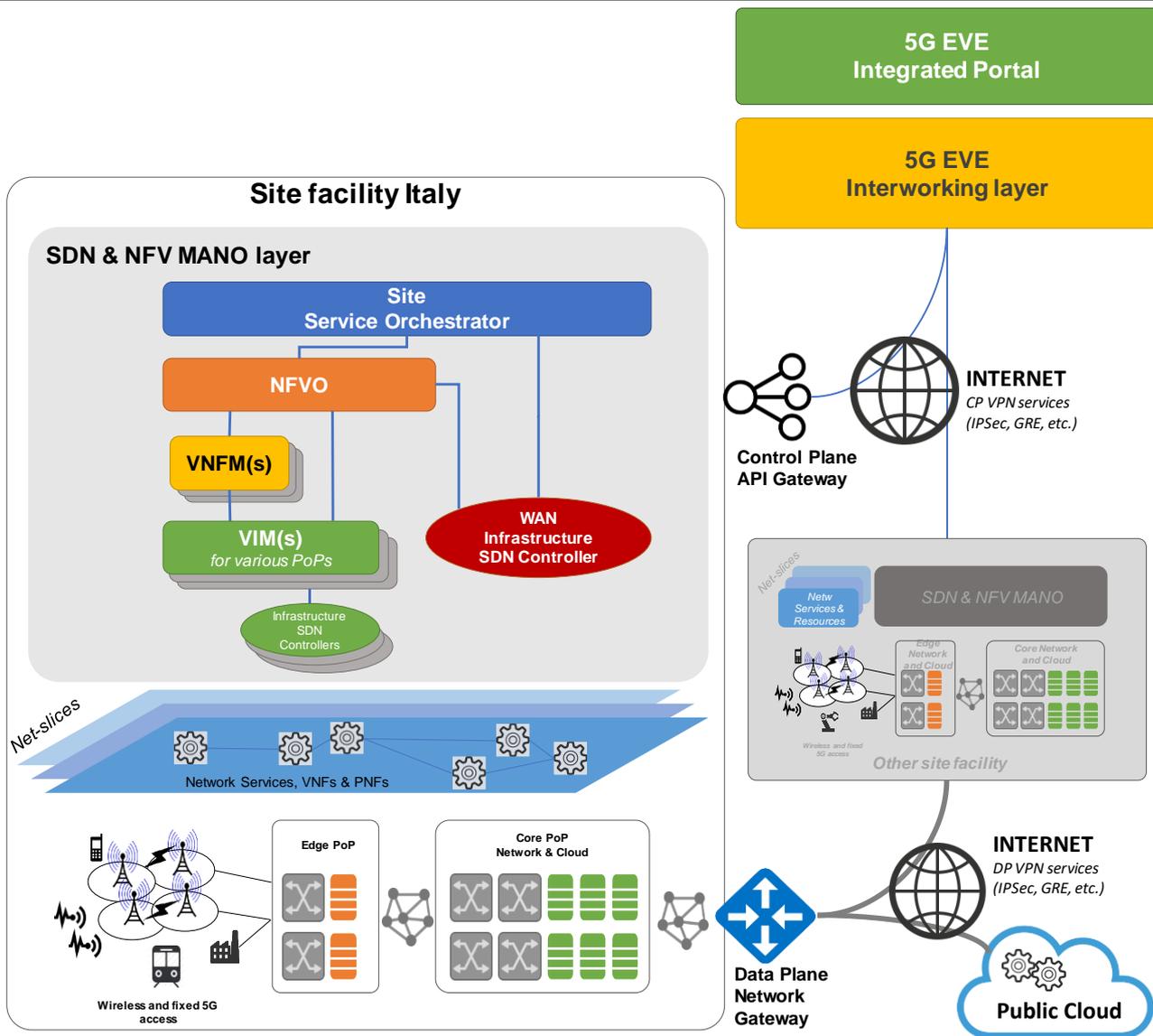
Figure 42: Initial interconnection model for the 5G EVE Turin site facility

More in particular, the CP API Gateway will allow connecting the Italian SDN & NFV MANO layer to the 5G EVE interworking layer, in order to implement the 5G EVE interworking functions for:

- Cross-site facility Network Slicing;
- Multi-domain Network / Service Orchestration;
- Per-slice Performance Measurement across multiple sites and towards the 5G EVE portal;
- Providing access and publish services and functions into the Cross-facility 5G catalog for VNF, service blueprints, slice templates, etc.

It is expected that each 5G EVE site will interact at control plane level through the 5G EVE interworking layer, and that most of the exposed APIs will be based on RESTful interfaces implementing Open API to the NFV and SDN layers, as specified by ETSI NFV [21] and by the software released of the selected SDN controllers and related applications [22].

The Data Plane Network Gateway implements the secure interconnection of the network services running in the Italian site facility with:

- Corresponding data plane elements in other site facilities;

- Vertical application functions executed in Public Cloud. This is introduced to cover cases in which some workloads need to be centrally executed because of legacy application deployments (part of which just available in Cloud services) or massive computational requirements not covered by the 5G EVE infrastructure capabilities.

At the data plane level, other interconnection modes could be analysed during the execution of the project (e.g. based on dedicated network connections with profiled QoS guarantees) depending on the evolution and specific needs of the Use-case pilots to be deployed.

4 5TONIC Spanish site facility description

4.1 Architecture overview

The 5TONIC Open 5G Lab was created in 2015 by Telefónica I+D and IMDEA Networks Institute with a clear vision of setting up an open research and innovation ecosystem laboratory in which industry and academia come together to boost technology and business innovative ventures. Since then, several leading companies have become members and collaborators of 5TONIC, with a current roster of 10 members and 5 collaborators who are listed in Table 6.

Table 6: 5TONIC Members and Collaborators

5TONIC Members	5TONIC Collaborators
• **Telefónica** • **IMDEA Networks** • **Ericsson** • **University Carlos III Madrid** • Intel • CommScope • Altran • Cohere Technologies • InterDigital • Red Hat	• IFEMA • **ASTI Robotics** • Rohde & Schwarz • Luz Wavelabs • Saguna Networks

The lab has been on the forefront of technological innovation and with an extensive track record in European 5G Research Projects and has also been recognized as a Digital Innovation Hub (DIH) by the European Union. The site already has a deployed network infrastructure for supporting pre-5G trials and a number of use-cases (information can be found at the 5TONIC website [23]).

The use-cases that will be supported in 5TONIC are:

- **Use-case #2 Augmented Fair experience**: This UC aims at transforming the experience of Trade Fair events' users (exhibitors and visitors), with the objective of improving their interactions (information sharing, discussion, networking, negotiations and transactions) by leveraging VR/AR and 5G technologies. The leading vertical for this UC will be SEGITTUR.

- **Use-case #3 Industry 4.0**: Autonomous vehicles in manufacturing environments: The UC intends to demonstrate the feasibility of centralizing the control of automated guided vehicles (AGVs) operating in complex manufacturing environments and relying on wireless connections between the vehicles and a centralized control unit close to the network edge. This centralization (in contrast with the distributed approach used today) allows for more intelligent decisions to be taken (e.g., taking advantage of artificial intelligence) and may also enable a more flexible and reconfigurable factory. The leading vertical for this UC will be ASTI.

- **Use-case #6 - Media & Entertainment: UHF Media, On-site Live Event Experience and Immersive and Integrated Media**: This UC includes three (adaptable) multimedia scenarios: Ultra High-Fidelity Media experience with highly immersive viewing experience and ultra-crisp, wide-view pictures will be made possible through the use of both linear (e.g. live programming, streaming) and non-linear (e.g. on-demand) content; On-site Live Event Experience, for large scale event sites, such as cinemas, stadiums and hall parks, providing enhanced viewing experience (replay, choose a specific camera, etc.); and Immersive and Integrated Media, providing ambient media consumption at home but

also on the move, with content capable of following the users and adapt to his / hers ambient for viewing (e.g. in the car, at home etc.). Telefónica will be the leading industrial partner for this UC.

Figure 43 gives the general overview of the 5TONIC site facility with the main use-cases, technologies and Spanish partners involved in the site facility implementation.
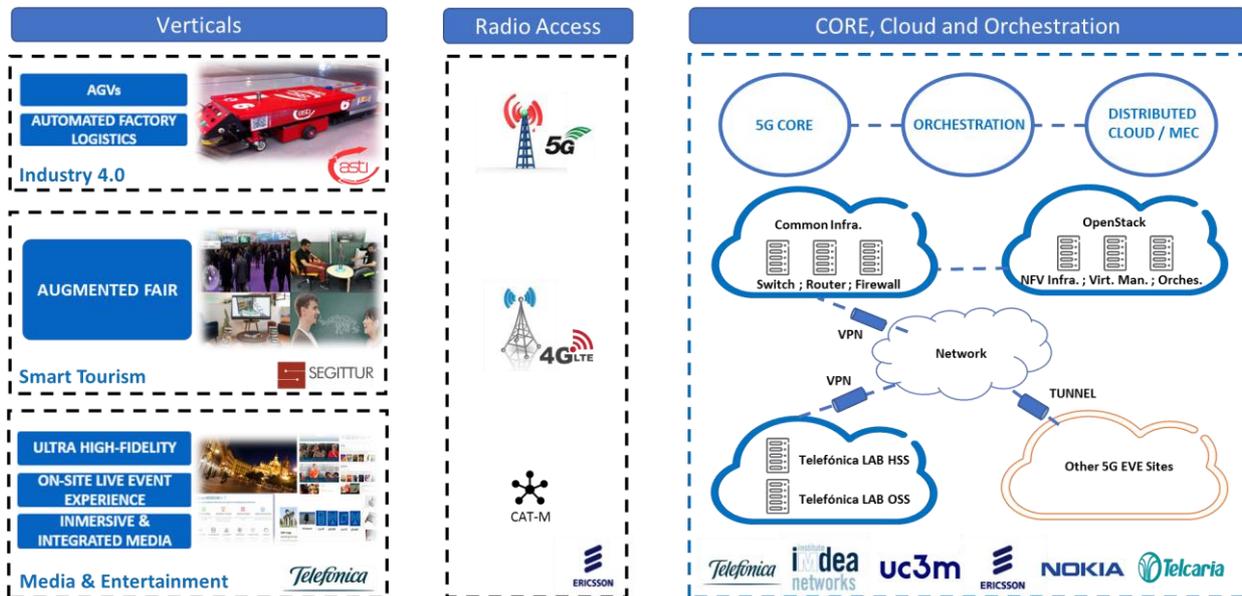
Figure 43: General overview of the 5TONIC Spanish site facility

The 5TONIC site is located at IMDEA Networks premises in Leganés, but it has access to other locations for the support of different network functions and use-cases:

- UC3M campus both at Leganés and Madrid City Center;
- Telefónica I+D lab at Almagro Central Office;
- Telefónica headquarters campus Distrito C;
- 5G IFEMA Lab at Feria de Madrid;
- Connection with Telefónica Spain lab at Alcobendas.

Due to its collaborative nature, 5TONIC is not a conventional site because in terms of available infrastructure, and it is necessary to distinguish 5TONIC as a whole, and the part that will be available to 5G EVE. In this sense, 5TONIC infrastructure provided by Ericsson, Telefónica, UC3M, IMDEA Networks and Nokia, as well as common infrastructure and services (e.g., connectivity), is the one that can be accessed by 5G EVE. However, there are network elements that are the property of companies that are not partners of the projects that will require an agreement to be able to access them. Examples of current 5TONIC elements that in principle are not available for the 5G EVE site are:

- MEC platforms by Intel and Saguna Networks;
- OneCell RAN infrastructure by CommScope;
- mmWave transport infrastructure by InterDigital.

Access to these network elements for 5G EVE activities should be agreed with 5TONIC members and collaborators in a case by case basis. E.g., agreements between Ericsson and Intel are expected to allow 5TONIC to have 5G UEs available for 5G EVE activities.

Also, it is necessary to distinguish between the infrastructure that is deployed at 5TONIC in a permanent/semi-permanent way (i.e., to be available at least until the end of the 5G EVE project), and temporal infrastructure that is deployed to support specific demos by 5TONIC members, associated with EU projects, as well as internal 5TONIC technological trials, like those carried out with Cohere Technologies, Luz Wavelabs, Saguna, etc.

Permanent infrastructure includes:

- Data center infrastructure including racks for each 5TONIC members and communications infrastructure;
- Virtual EPC provided by Ericsson, to evolve to NGC;
- LTE Radio Access infrastructure, provided by Ericsson and CommScope, to be evolved to NR;
- Virtualization, processing and transport infrastructure.

The current status of the permanent 5TONIC network infrastructure is represented in Figure 44:
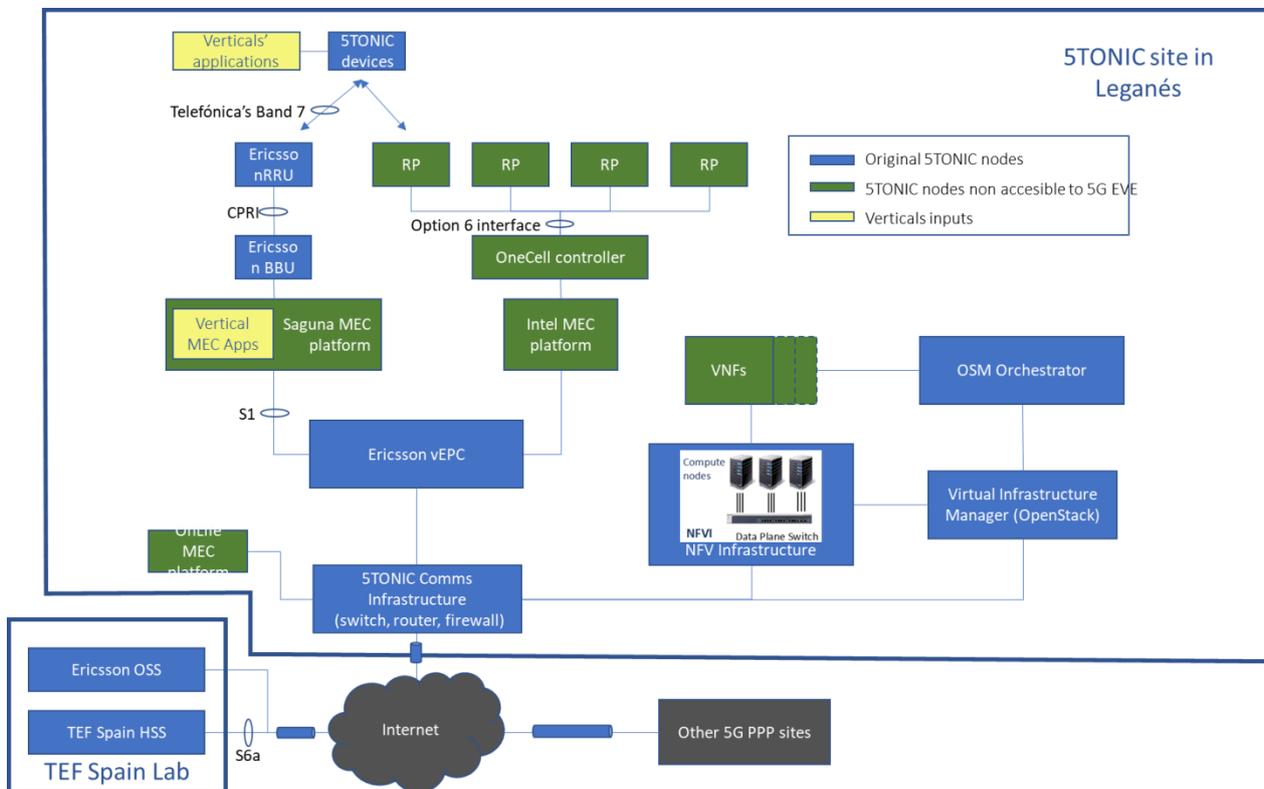
Figure 44: Current status of the permanent 5TONIC network infrastructure, 5G EVE Spanish site facility

Currently, 5TONIC network is composed of elements from different providers and not all of them can be considered as part of the future 5G EVE site (they are identified in green colour in the Figure 44, mainly Saguna's NEC platform and CommScope OneCell RAN infrastructure). It also encompasses infrastructure owned by 5TONIC itself, like the communications infrastructure and the NFV infrastructure. On top of this, there are other network components, like a photonic mesh provided by Telefónica that are still pending of integration and are not depicted in the Figure 44.

The current infrastructure is intended to evolve during the next months, so for the target date of April 2019 is planned to have **two non-integrated network infrastructures**, one based on the network elements provided by Ericsson, UC3M, Telefónica, IMDEA Networks and Telcaria (plus 5TONIC own infrastructure), and the other based on Nokia provided network elements plus 5TONIC common infrastructure. In the following, they are identified as the Ericsson site and the Nokia site, respectively. Both sites are expected to be integrated in the long term (in the sense that test cases that use network elements from both of them will be supported, and they will use the same portal for vertical accessing the services of the 5TONIC site), but this integration is scheduled to happen after April 2019.

The scheme of the Ericsson site is depicted in the Figure 45:
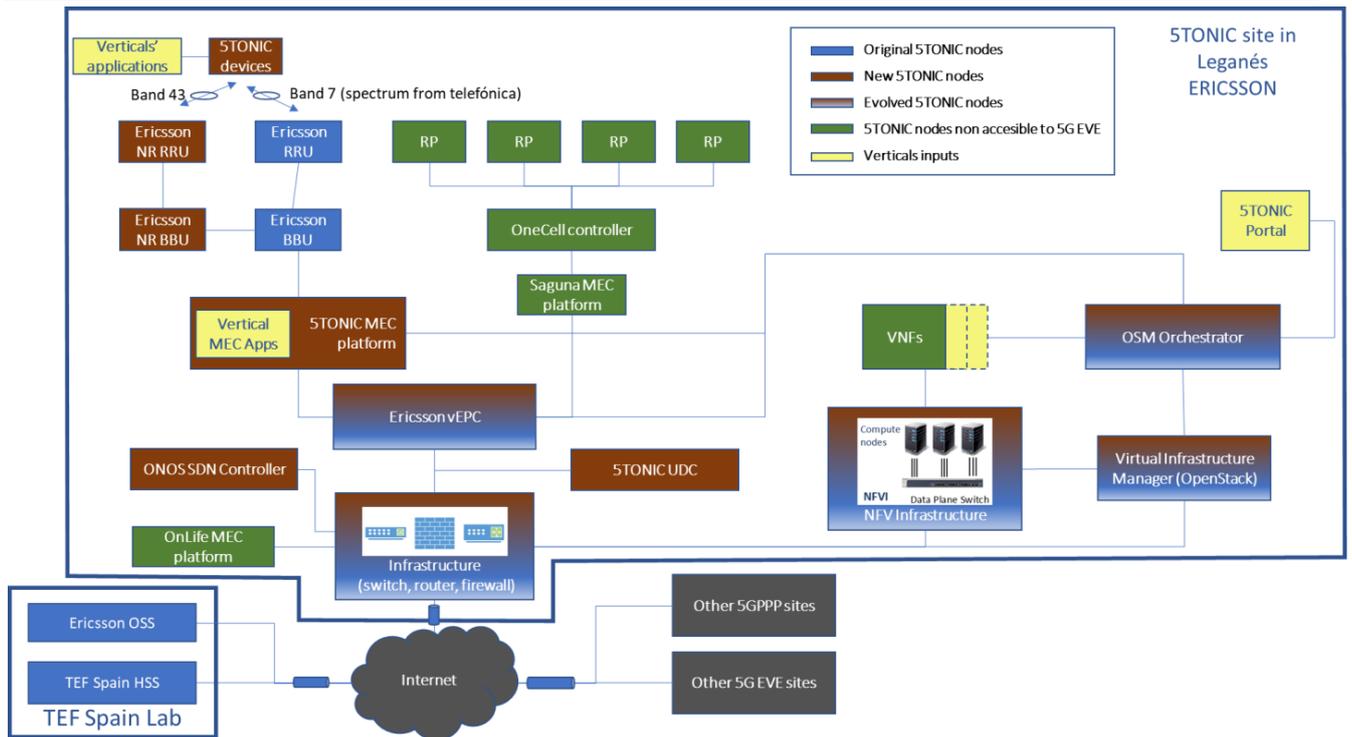
Figure 45: Scheme of the 5TONIC Ericsson site, 5G EVE Spanish site facility

The site planned for Aril 2018 differs from the current one due to both the incorporation of new network elements and the evolution of the existing ones. Also, a higher level of integration between the mobile network and the orchestration infrastructure is expected.

As the testbed is expected to initially provide 5G services in NSA option 3a fashion with dual connectivity mode, it will be necessary to keep the LTE RAN operating in Band 7 in combination with an 5G NR RAN.

Additional improvements that are expected to be achieved are:

- Evolution of 5TONIC Communications Infrastructure towards an SDN architectural framework;
- Updating of the orchestration platform for supporting multi-slicing;
- Updating of the MEC platform.

The scheme of the Nokia site is depicted in the Figure 46. The Nokia site is a complete new one.

For the milestone due by April 2019 it is not expected that Nokia and Ericsson site to be integrated, so initially they will operate as separate sites.
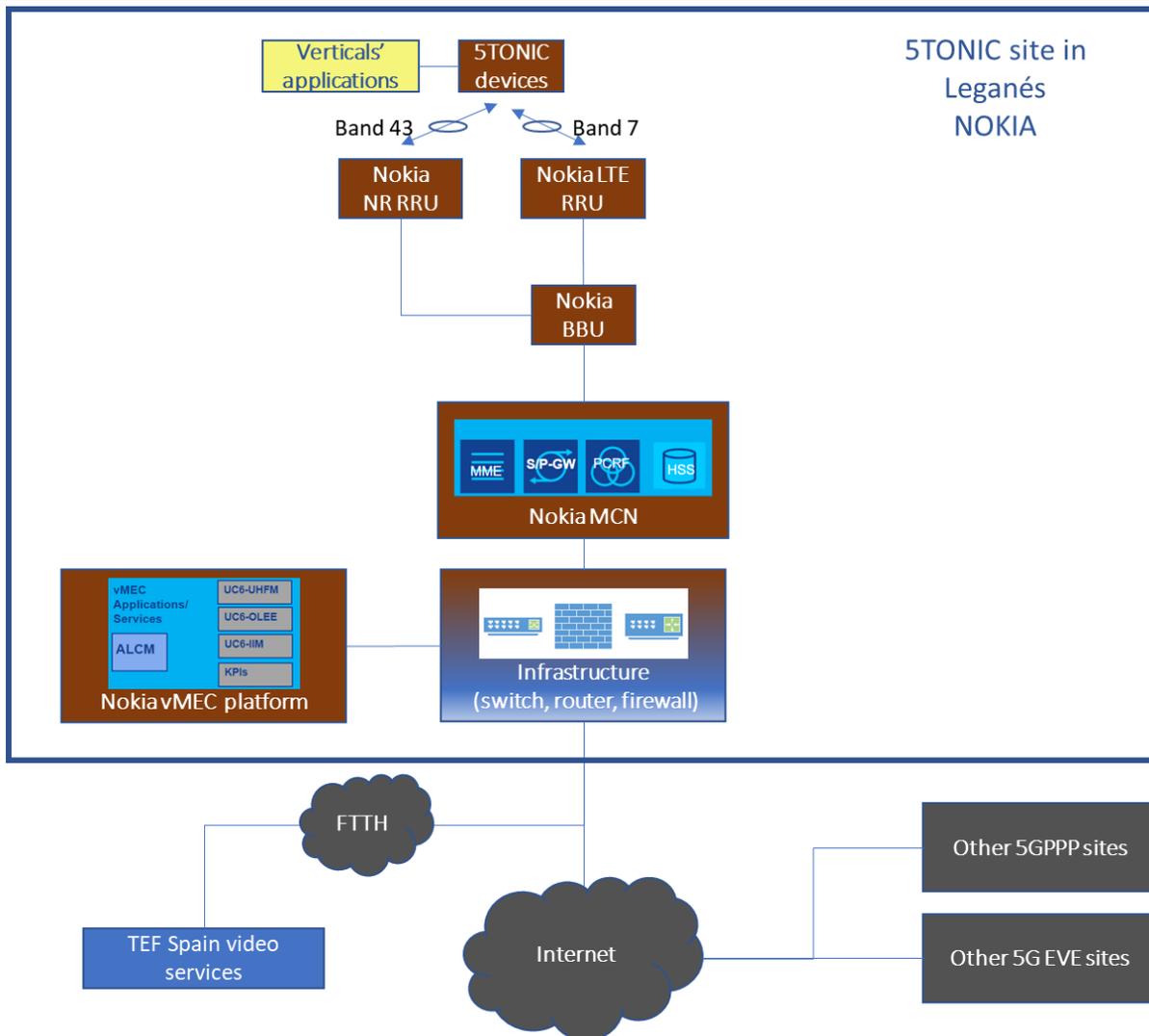
Figure 46: Scheme of the 5TONIC Nokia Site, 5G EVE Spanish site facility

Ericsson site supervision will be carried out by the Ericsson OSS deployed in Telefónica Spain labs in Alcobendas Central Office. A VPN tunnel has been established between 5TONIC and Telefónica Spain labs.

Nokia site supervision will be carried out from Nokia Bell Labs in Madrid. Also, a VPN tunnel will be established for these purposes.

4.2 RAN architecture description

In a distributed, centralized, cooperative, or cloud radio access network, the base transceiver station, commonly known as eNodeB, the main functionalities can be subdivided between the BBU processing pool and a RRU or a RRH. The BBU is typically connected to the RRU with optical fiber. Separating the base station into two parts allows network operators to maintain or increase the number of network access points, while centralizing the baseband processing functions into a "master base station".

The 5TONIC Spanish site facility architecture is based on the Centralized RAN (valid for both Ericsson site and Nokia site). Plan to introduce split architecture for deployment flexibility and optimal 4G / 5G interworking with Virtualized RAN within the Ericsson site is being discussed.

The provided RAN system is compliant to **3GPP R14** specifications and it will be upgraded to include 5G NR SW/HW compatible to several **3GPP R15** specifications before April 2019.

4.2.1 RRH

4.2.1.1 Ericsson

The RRH or the RRU solution that is already being used to have LTE coverage is the **micro Radio 2203 B7**. The micro Radio 2203 is part of the Ericsson Radio System portfolio. Radio 2203 has best in class design, superior radio performance and power efficiency when it comes to medium range 3GPP radio products. Higher Order Modulation (HOM) 256-QAM Downlink and 64-QAM UL are supported. The main technical specifications of the micro Radio 2203 are given in Figure 47.
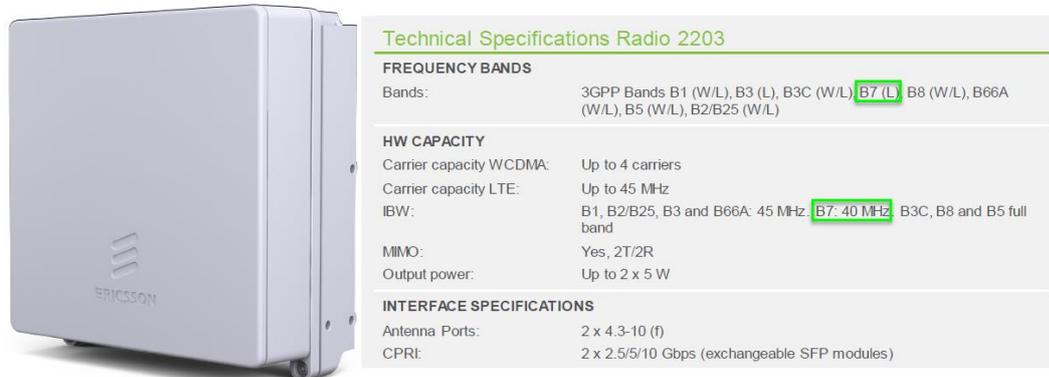
Figure 47: Ericsson micro Radio 2203 Technical Specifications

In addition, an **5G NR-capable radio will be deployed at 5TONIC before April 2019**. This could be the Ericsson **AIR 6468 B42/B43 or AIR 6468 B43**, still under evaluation.

AIR 6468 features 64 transmit and 64 receive antennas enabling it to support our 5G plug-ins for both Massive MIMO and Multi-User MIMO. The AIR 6468, where the main features are detailed in Figure 48, is designed for compatibility with the 5G NR standard while also supporting LTE.
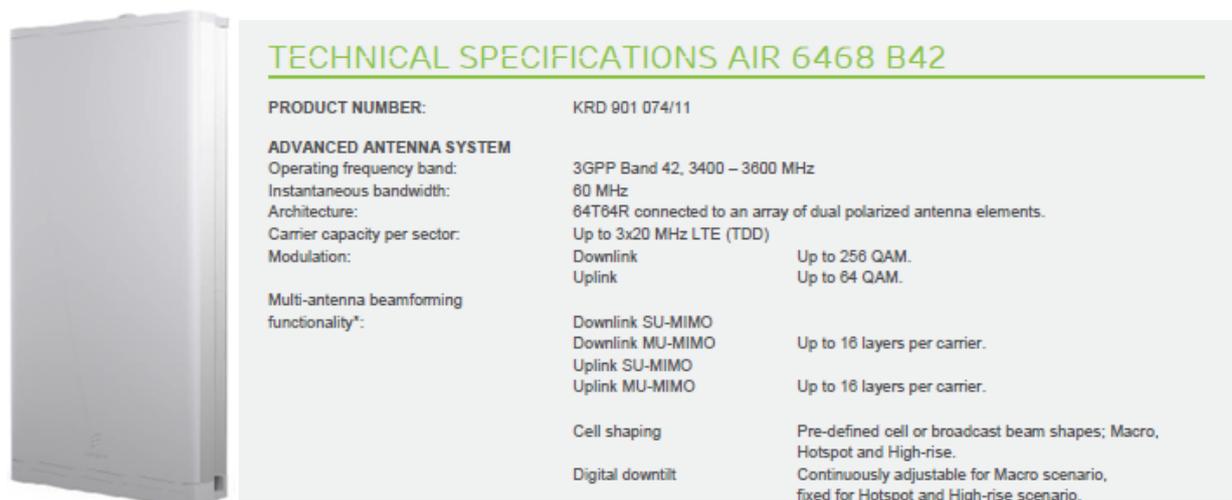
Figure 48: Ericsson AIR 6468 Main Characteristics

AIR 6488 B43 is a 64TR/64RX TDD advanced antenna system (AAS) for NR. Compared to the predecessor AIR 6468, it has an increased maximum IBW of 100 MHz, an increased maximum transmitted power of 200 W and it handles the NR standard. The AIR unit has beamforming and MU-MIMO technology, capable to fully utilize radio resources in both azimuth and elevation. The main benefits compared to previous macro solutions are improvements in:

- Enhanced coverage - High gain adaptive beamforming;

- Enhanced capacity - High-order spatial multiplexing and multi-user MIMO;
- Advanced RAN features - Vertical and horizontal beamforming;
- Improved network performance - Low inter-cell interference.

Figure 49: Ericsson AIR 6488 Front View

More radio units could be deployed in next phases after April 2019 for more flexibility depending on the requirements specified by the use-cases deployment.

4.2.2 BBU

4.2.2.1 Ericsson

The Baseband units (Figure 50) provide the baseband processing resources for the encoding and decoding of the uplink and downlink radio signals, the radio control processing, the radio network synchronization, the IP interface and the O&M interface for the Ericsson Radio System.
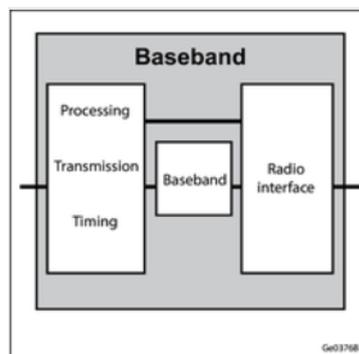
Figure 50: Baseband Block Diagram

The Ericsson Baseband portfolio is hardware prepared for current and future capacity and functionality. RAN software releases will determine the level of functionality and capacity supported by the baseband hardware. A Baseband Unit 5216 is already deployed in the 5TONIC Spanish site facility together with a RBS 6601 for power supplying and climate. This is the same equipment used in the Italian site facility (see Section 3.2.2).

You can find the baseband 5216 HW along with the interfaces front panel in the Figure 51:
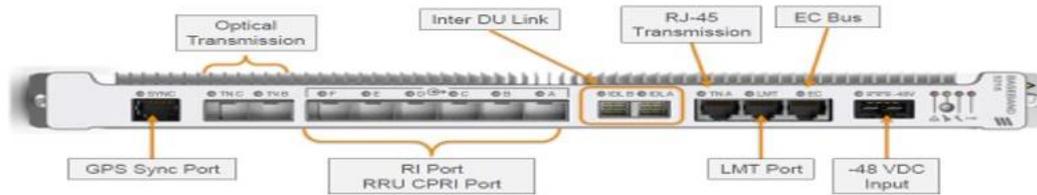
Figure 51: Baseband 5216 front panel

A GPS Antenna/receiver is deployed outdoor and connected to the Baseband. The integrated GPS Antenna/Receiver receives timing information from the Global Positioning System (GPS) and this information is used to synchronize the BBU.

An additional **Baseband Unit 6630** deployment together with AIR 6468 and virtual RAN is being considered to have a more flexible RAN Architecture. This is an evolution of the 5216 model with more radio interfaces ports and its own climate and power supply integrated. This is the same equipment used in the Italian site facility (see Section 3.2.2).

The baseband 6630 HW along with the interfaces front panel is shown in the Figure 52 below:
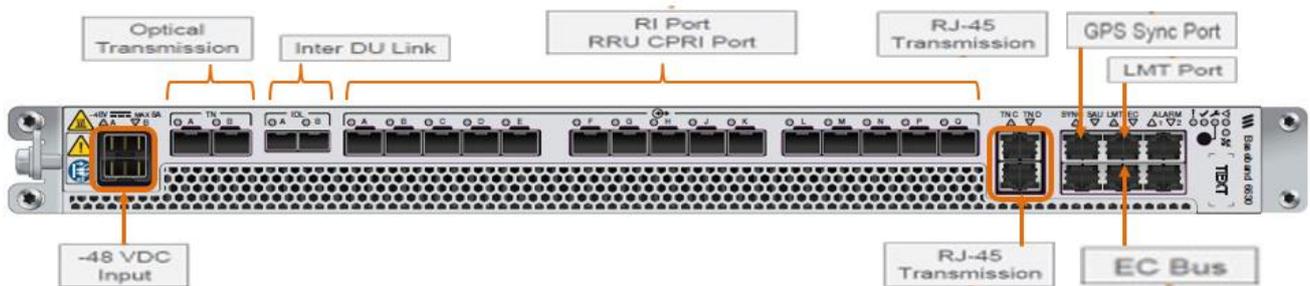
Figure 52: Baseband 6630 front panel

The Baseband 5216 & 6630 HW is prepared for the future capabilities presented in the Table 7 but they are **SW dependant:**

Table 7: Baseband 5216 & 6630 main specifications

Main Specifications	Baseband 5216	Baseband 6630
Downlink maximum throughput (Mbps)	>2000	>2000
Uplink maximum throughput (Mbps)	Up to 1000	Up to 1000
Number of VoIP users (FDD/TDD)	Up to 2000/1000	Up to 2000/1000
Number of connected users	Up to 8000	Up to 8000
Aggregated antenna bandwidth (MHz)	960	960 – 1560
Number of Cell (FDD/TDD)	24	24
CPRI radio interface	6xSFP/SFP+	15xSFP/SFP+
Transport interface, optical 1/10Gbps SFP/SFP+ ports	2	2
Transport interface, electrical 1Gbps RJ45 ports	1	2
Higher Order Modulation Support	YES	YES
Interface for Elastic RAN	YES	YES
Hardware Prepared for NR (5G) and eCPRI	YES	YES

More baseband units could be deployed in next phases for more flexibility depending on new requirements and uses cases.

4.2.2.2 Nokia

The NOKIA AirScale Base Station is compact and delivers huge capacity and connectivity to support future traffic growth as your network evolves to 5G and IoT. A key part of AirScale Radio Access, the base station is easy to install and gives you the flexibility to run all radio technologies, including 5G, and support all network topologies, including Cloud RAN.

AirScale Base Stations enabled by the new Nokia ReefShark chipsets deliver market leading throughput, up to 84 Gbps per system module. AirScale baseband module chaining supports base station throughputs of up to 6 terabits per second, which will allow operators to meet the huge growing densification demands and support the massive enhanced mobile broadband needs of people and devices in megacities.
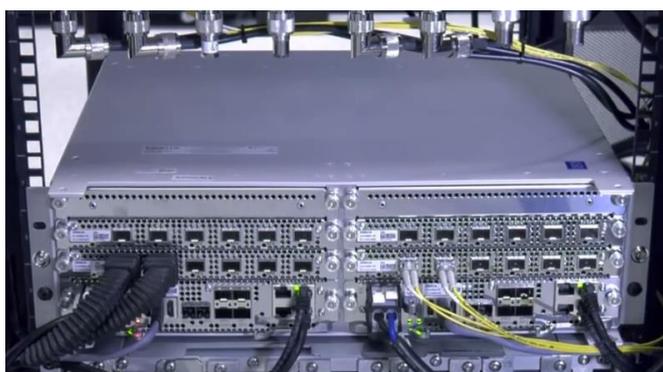
Figure 53: Nokia Airscale system module

Even more capacity can be added from the cloud. AirScale Base Station also includes single band and multiband radio heads, including the world's first triple band radio. Thanks to their compact size, energy efficiency, high output power and multiband capabilities, the radios help to reduce the site space requirement and allow faster roll out while lowering the total cost of ownership (TCO). These can support carrier aggregation, massive MIMO and Beamforming solutions to maximize the cell throughput and capacity for an enhanced overall user-experience.

Main benefits include:

- Any radio technology - software defined support for 5G and 2G, 3G, 4G (FDD/TDD), 4.5G Pro and 4.9G including concurrent operations with Single RAN
- Supports any network topology - Distributed RAN, Centralized RAN and Cloud RAN
- Scalable - expand baseband capacity by chaining system modules and using AirScale Cloud RAN
- Highest availability - platform with built in hexa-resiliency
- Easy and fast to install with Nokia OneClip zero bolt installation
- 60% more energy efficient than earlier generation base stations
- Maximum re-use of existing network assets – backwards compatible with Flexi Base Station

4.2.3 Frequency bands

In the case of the Ericsson based infrastructure, bands to be supported are:

- FDD: 20 MHz in Band 7 (currently available).
- TDD: 50 MHz in Band 43 or 40 MHz in Band 42 (to be agreed with Telefónica Spain and the Spanish Regulator).

In the case of the Nokia based infrastructure, the spectrum to be used is still under study, but the most likely options are Band 7 for LTE and Band 43 for 5G NR.

4.2.4 Techno supported (slice) statistic/dynamic

5TONIC is considering the incorporation of a new RRU, operating in band 20, to support NB-IOT and CAT-M1 IoT services. This will also require updating the Ericsson virtual EPC software. The support of these technologies may allow for the implementation of initial slices before the integration of the orchestration platform and the mobile network is achieved (this is expected to happen after April 2019).

4.2.5 User Equipment

For testing flexibility, the use of several types of user equipment is under discussion. An amount of 5-10 units could be used, including:

- LTE routers with higher order modulations;
- LTE+ mobile phones including 5G M-MIMO functionality and high order modulations;
- 5G UE prototype depending on availability.

More details will be shared during the project.

4.2.6 Subscriber Separation

5TONIC Spanish site facility uses APN based user differentiation to isolate the RAN deployed in the lab from the commercial network. Several APNs are defined in the HSS and vEPC for different uses cases and purposes.

4.3 Distributed Cloud / MEC

In the Ericsson 5TONIC sites, current MEC platforms are provided by Saguna Networks and Intel, that are not part of the 5G EVE project. Saguna's software platform can be used for the support of the 5G EVE use-cases, but no support for either deployment or maintenance can be expected. Potential use of the Intel MEC SDK is under discussion.

In the NOKIA 5TONIC site, the MEC platform is provided by NOKIA. The MEC can be used for the support of the Multimedia Use Case 6.

Additionally, there are plans to integrate Telefónica's OnLife MEC platform in 5TONIC site

4.3.1 Nokia MEC platform

In the Nokia site, a full end to end virtual MEC solution will be available, with the following characteristics:

- AirFrame hardware solution for data centres
- Red Hat Enterprise Linux 7.x OS
- MEC Applications (both from Nokia or 3rd party)
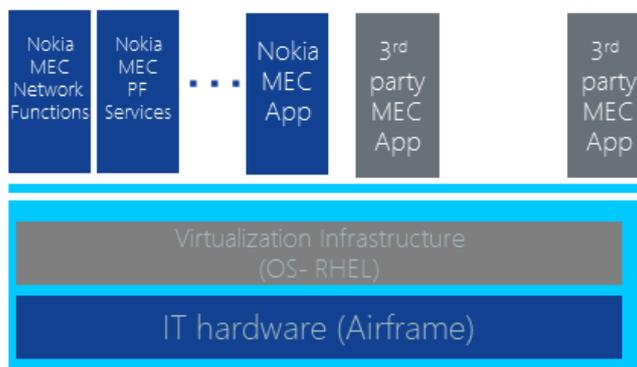
Figure 54: Nokia site virtual MEC platform.

4.4 CORE architecture description

5TONIC Spanish site facility has already deployed an Ericsson 5G vEPC with and EPC-in-a-box deployment and a Nokia Distributed EPC will be deployed in next phases.

4.4.1 Ericsson

The Ericsson vEPC portfolios are virtualized EPC products and provide the packet core as software only, to be integrated in a cloud environment. Ericsson vEPC is based on COTS hardware platforms. The virtualization is done according to the following principles (some exemptions exist):

- Each Packet Core product is virtualized into a Virtual Network Function (VNF);
- The VNFs have feature parity with the physical network functions (PNFs);
- The boards in the PNFs are corresponding to VMs in the VNFs.

As already represented in previous Sections 2.4.1 and 3.4.2, the EPC-in-a-box, Figure 16Figure 33, is designed to run on top of Ericsson Openstack IaaS, i.e., Cloud Execution Environment (CEE) and can use either HDS 8000 CRU or Dell 630 as HW. It is also tuned to be as efficient as possible when all VNFs are running at the same time. However, there is no requirement that all VNFs must be deployed. For example, it is possible to only deploy vEPG. CEE includes functions necessary for EPC-in-a-box as:

- Virtualized CIC;
- Support to run the vCIC in a non-redundant single-vCIC mode;
- Hyper-Threading;
- Pinning of the VM vCPUs to specific Hyper Threads (HTs).

The deployment contains vEPG, vSGSN-MME and vSAPC. Additional HW deployment is under study to allow the creation of more virtual network functions.

4.5 Orchestration

4.5.1 Open Source MANO

After an initial study to analyse the different open source solutions for the Management and Orchestration (MANO) of NFV, 5TONIC decided to deploy their MANO based on the ETSI OSM (Open Source MANO). This solution is aligned with the architecture and interfaces proposed by the ETSI NFV team, providing several services and a good performance. Due to the constant improvement of ETSI OSM, 5TONIC has decided to have a production solution, based on Release TWO (September 2018), and a testing solution, which is based on Release FOUR (September 2018). Our goal is to upgrade the production solution only when the testing solution is stable enough to move to the production part. The OSM manages a local NFVI composed by three high-profile servers, which are controlled by an OCATA OpenStack acting as the VIM.

5TONIC is providing this NFV infrastructure to several projects, like 5GinFIRE, 5G-TRANSFORMER, 5G-Crosshaul, etc. Due to the necessity to manage and orchestrate network functions in different sites, a very flexible solution is designed to interconnect different sites, using the MANO stack centralized at the 5TONIC premises. This MANO can manage other NFV infrastructures controlled by the local VIM available at each site. The connectivity between the 5TONIC laboratory and other sites require a VPN connection, a service that can be offered by the 5TONIC too depending on the agreements with the other sites. Figure 55 shows a simple diagram explaining how to establish inter-site connections with 5TONIC.
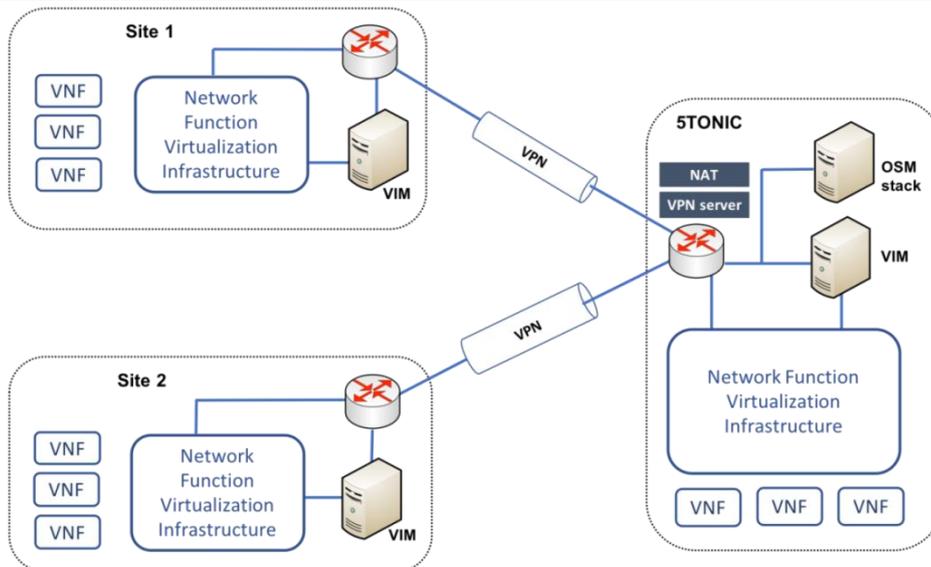
Figure 55: 5TONIC orchestrator managing local and external infrastructures.

Starting with OSM Release THREE, the administrator of the MANO solution can define different users, granting different rights in any active project. This functionality has been tested in our testing platform and we plan to include this service when we move the testing solution to the production platform in the next months.

4.6 Interfaces

4.6.1 Between RRH – BBU (Fronthaul)

The interface to interconnect the RRH and BBU is the CPRI cable. The CPRI i/f is designed as a latency critical internal radio interface that allows for mounting of the RF power generating equipment closer to the antenna. The main RRH/BBU interfaces are mentioned in Figure 56.
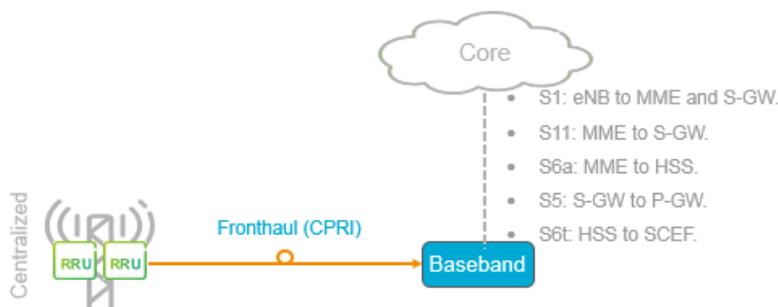
Figure 56: RRH - BBU Interface

4.6.2 Between CU CP and CU UP (E1)

This interface is embedded within the Baseband Unit HW.

4.7 Testing & KPI

In terms of testing the performance of the network, the equipment required is expected to be provided by the contributing partners, based on the specific KPIs of the use-cases to be tested. For basic network performance measurements, 5TONIC has adopted the sprintbit-testbed tool developed in the context of the MAMI project [65].

5TONIC also has a Collaboration agreement with Rohde & Schwarz, which allows getting on loan testing equipment for specific trials that may not be available by the partners. Similar collaboration agreements are feasible with other companies.

4.8 Potential interconnection towards outside

The potential interconnection towards the outside is mainly managed by the 5TONIC Communications Infrastructure module that encompasses a number of elements that allows the management of the internal communications in 5TONIC premises, the secure connectivity with Internet and other sites. The security infrastructure deployed allows for the implementation of VPNs with IPSec.

5TONIC infrastructure has been already used for the support of several multisite trials associated to H2020 projects, like 5G-Ex or 5GinFIRE. The following figure depicts the inter-site connectivity that supports remote orchestration. In this case, Site 1 was located in Portugal and Site 2 in UK.
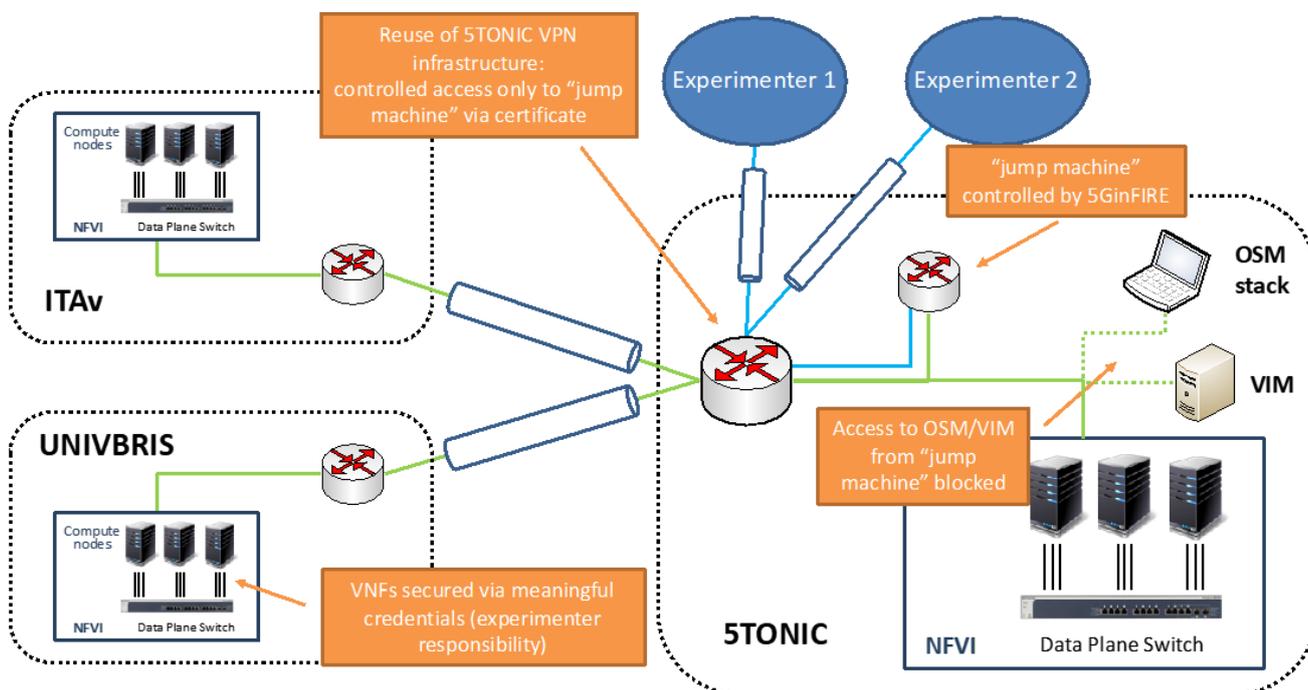
Figure 57: Inter-site connectivity in 5GinFIRE

5 French site facility description

The French site facility is composed of a cluster of 4 nodes located in different cities. Its main feature is that it rests on two main pillars. The first pillar comprises pre-commercial Nokia 4G/5G E2E network facility composed of the pre-commercial 5G platform based on open-source and inner-source products developed by Nokia Mobile Networks Business Unit (so-called "NOKIA pre-commercial platform" or IFUN that stands for "Internal Friendly User Network") that is located in Paris-Saclay.

The second pillar is based on Open Source building blocks and distributed on several facilities interconnected by VPN, namely:

- Plug'in platform located in Châtillon-Paris (operated by Orange). This innovative 5G platform proposes a whole framework for developing 5G components;
- *Flexible Netlab* platform located in Rennes (operated by b<>com). It is a multi-tenancy dedicated environment, taking benefit from some key corporate resources like a private cloud infrastructure
- OpenAir5G playground located in Sophia Antipolis (operated by Eurecom);
- "NOKIA research platform" that is a research platform based on open-source and inner-source developed in Nokia Bell Labs that relies, on terms of hardware, on specific and local resources (Edge and Central). In terms of software, it relies on NGPaaS technology [26] based on cloud-native and microservices. RAN and CORE are deployed on different platforms operated by an end-to-end service orchestration.

5.1 Architecture overview

The overall architecture is layered as follows:

- Upper layer is an end-to-end service layer based on Plug'in platform and hosted in Orange Châtillon.
- The service platform interfaces "northbound" with EVE global portal and "southbound" with each site.
- Each site runs its own services, platform and infrastructure:
    - EURECOM runs in Sophia-Antipolis a 5G platform based on Open Air Interface that is mainly described in this chapter 5.
    - NOKIA runs in Paris-Saclay a dual 5G platform based on both pre-commercial NOKIA products and Bell Labs research platform.
    - b<>com runs in Rennes a 5G platform based on Open Air Interface. B<>com site facility will act as an edge cloud orchestrated by the Orange Plug'in platform. Within the scope of the project, it will be possible to instantiate VxFs on the local VIM from the Orange Plug'in orchestrator, access the radio resources, and collect monitoring metrics from the VIM. Metrics from various nodes will be aggregated on the Orange Plug'in node.
    - ORANGE runs in Châtillon a 5G platform based on Plug'in platform that proposes a framework of development to create innovative components for 5G. Main of these components is based on opensource developments such as Open Air Interface, ONAP [24], etc. More details about Plug'in framework is given in Section 5.7.1.1. This is an open-platform that can be used by all 5G EVE partners for 5G components development and reuse.

The French facility partners will operate the whole cluster of building blocks as a distributed cloud enabling common deployment and monitoring capabilities while at the same time presenting a unified, single facility image towards the rest of the 5G EVE facilities as well as towards external third parties (vertical industries). Each cluster is composed of infrastructure pods provided by different facilities and the various components are issued by the respective cluster partners and deployed in different pods according to their capabilities.

The French node distributed architecture is depicted in Figure 58.
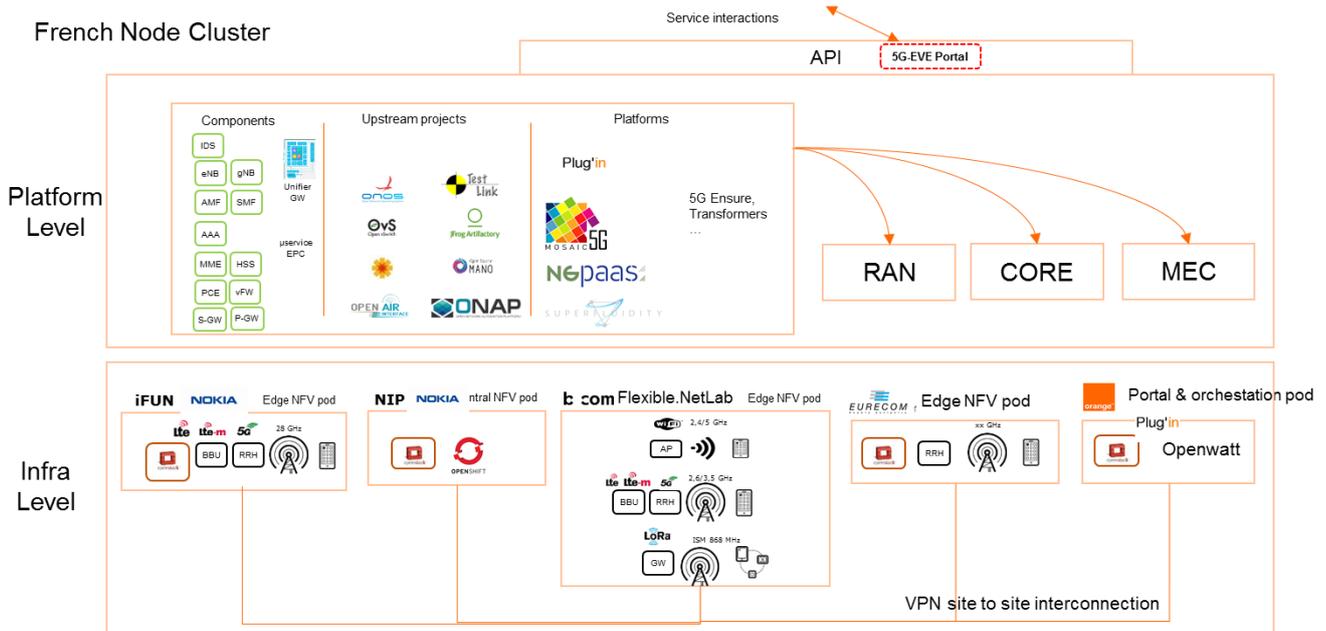
Figure 58: French nodes distributed architecture.

Some of these components and clusters have been a significant part of previous and on-going 5G PPP projects (Superfluidity [25], NGPaaS [26], 5G Ensure [27], etc.) and are expected to be heavily reused in 5G EVE, taking also into account any insights that have or will arise from these projects. The French site facility aims at first hosting two use-cases in the 5G EVE framework that will be completed by others issued from ICT-19.

The first vertical, proposed by EDF deals about critical utilities (Smart Energy) and focuses on fault management for distributed electricity generation in smart grids. The main issue addresses URLLC and critical mMTC scenario. Currently, fault detection and management in energy grids, takes place through fibre connectivity among the centralized electricity generation points (e.g. power plants). The move towards Distributed Generators (DG) offers great potential but also makes a fibre-communication monitoring solution prohibitive due to its deployment cost. 5G can enable ultra-fast and ultra-reliable fault detection and management among an extensive number of DGs, with decreased CAPEX and OPEX. Such a fault management system is essential for modern smart grids, enabling immediate reaction to changes in the network thus avoiding unwanted islanding, providing dynamic stability and protection to the network and eventually allowing for the integration of an even greater number of DGs. The use of smart metering and fault detection mechanisms in combination with MEC functionality for ultra-fast processing, could even lead towards a centralized grid protection system, elevating the level of control over the energy grid.

The use of 5G NR may control the system and only disconnects the equipment in alarm as depicted in Figure 59. EDF will provide a platform emulating the system that will be linked to 5G NR transmission.
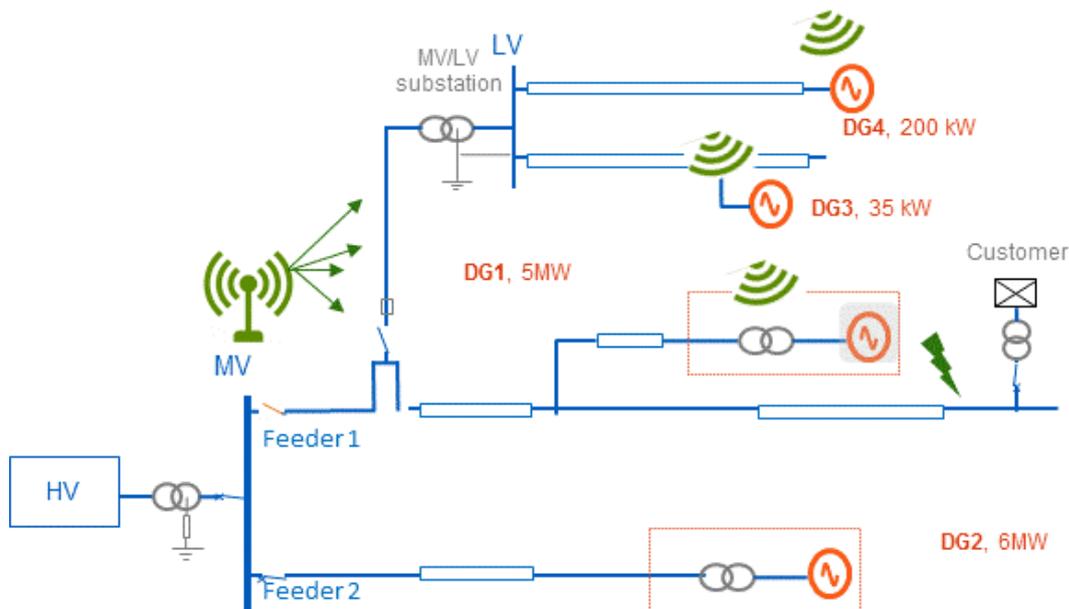
Figure 59: Remote decoupling using 5G

The second use-case that is proposed by Orange France is related to use-case#6 [1] about video 360° transmission. This use-case promotes eMBB and URLLC scenario with high data rates and low latency requirements. The main objective is to contribute on the identification of application-layer performance metrics relevant to a 360° video streaming service as well as on the identification of 5G performance metrics that are expected to be the key drivers for the performances of a 360° video streaming service. Orange France will integrate a 360° video streaming platform including contents, streaming servers and head-mounted-displays to 5G EVE's site facility. On this basis, the tools necessary for collecting the application-layer performance metrics will be developed and integrated with the testing frameworks developed in the project in order to feed a cross-layer dataset that would then be leveraged by Orange to provide an analysis of the correlation 5G network performances and 360° video streaming performances (KPI requirements). Figure 60 illustrates this use-case.

Figure 60: Video 360° use-case & architecture deployment

As already mentioned, the French site facility has a hybrid approach, combining both pre-commercial equipment from Nokia-FR and/or open-source components. Eurécom, b<>com and Orange network deployments are mainly based on Open Air Interface [28] which provides the main functionalities/components for the 5G NR (and 4G) RAN and CORE network.

The rest of this chapter is composed in 2 main parts: the pre-5G Nokia infrastructure and the Open-source infrastructure mainly based on OAI. OAI is a collection of open-source tools managed by the OpenAirInterface Software Alliance (OSA). The collection is housed on two git repositories:

- openairinterface5g [29], comprising the set of functional entities for LTE/NR eNodeB/gNodeB and UE;
- openairCN [30] comprising the set of functional entities for a 4G EPC and 5GCORE.

5.2 RAN architecture description

Both Nokia pre-commercial 5G RAN and OAI open-source solutions are used in the French site facility.

Figure 61 gives the main architecture of the Nokia Research platform. Both Nokia and pre-commercial platforms will be interconnected via the local Service Orchestration in a second step in order to reuse IFUN radio coverage together with micro-service. The idea is to reuse the Service Orchestration from the Research Platform to operate end-to-end resources spanning both pre-commercial and research platforms as shown in Figure 62.
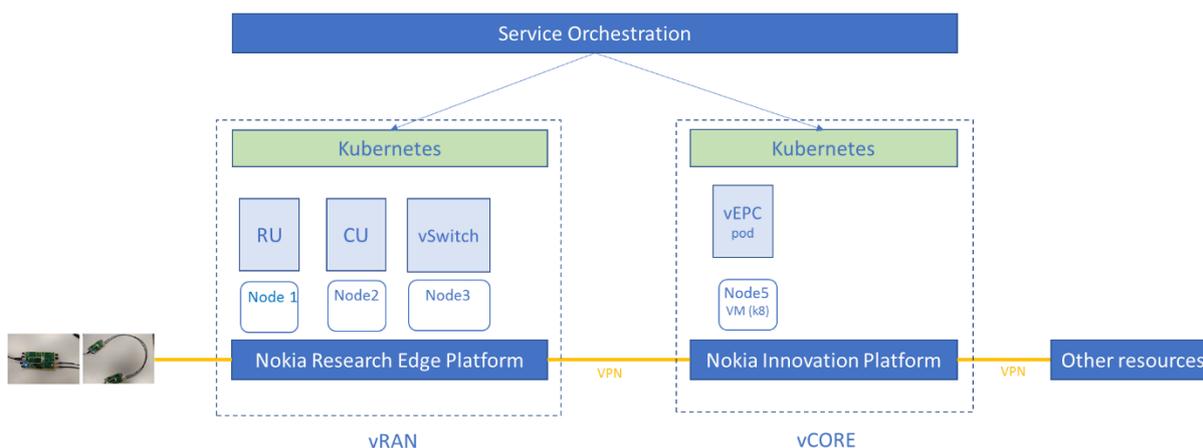
Figure 61: NOKIA Research Platform
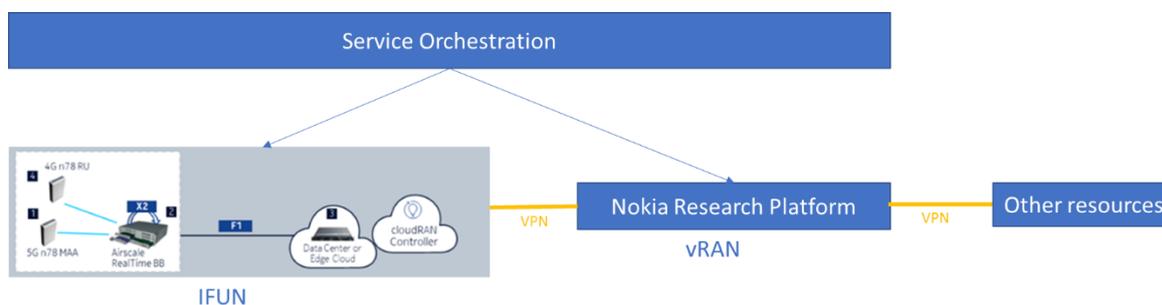
Figure 62: controlling end-to-end services spanning pre-commercial and research platforms

5.2.1 NOKIA pre-commercial RAN platform (IFUN)

IFUN is depicted in Figure 63 that is authorized to transmit following the rules imposed by the French ARCEP regulator. The target is to use 5G band n78 and more specifically 100MHz BW between 3700-3800MHz. For the 4G band, Nokia is using the 700MHz carrier loaned by Orange for that experimentation.
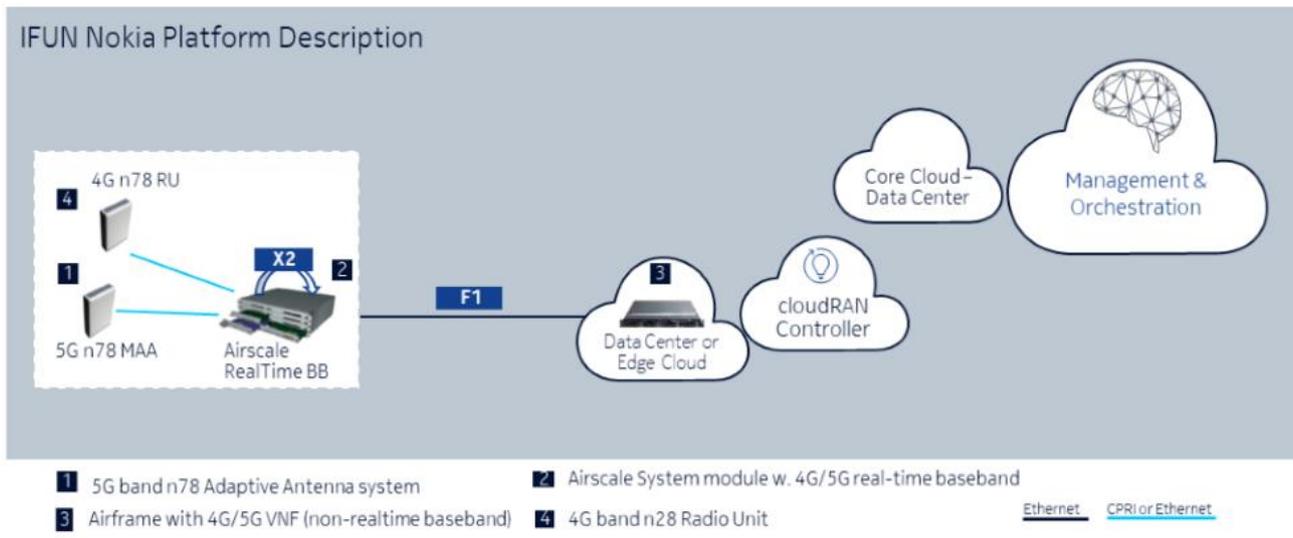
Figure 63: IFun over-the-air platform

The platform supports 3GPP R15 3.x network architecture as depicted in Figure 64.
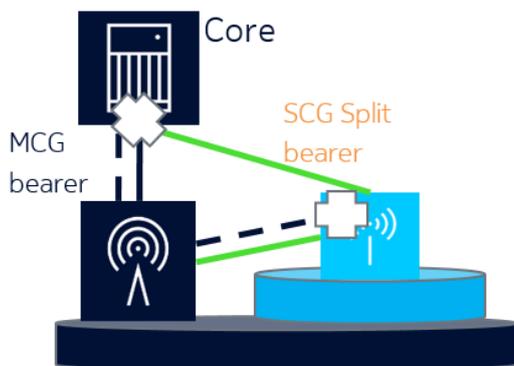
Figure 64: network radio architecture mode 3x

Both 4G & 5G Radio Access Network solutions are virtualized using Cloud RAN architecture as shown in Figure 65. RU is based on AirScale Radio Access portfolio offering a modular approach to building networks that deliver the extreme capacity, massive connectivity and ultra-low latency required for 5G services. RU supports all radio access technologies including 4.9G, which provides future service continuity with 5G networks. Cloud Unit (CU) infrastructure is based on Nokia Airframe product using the Nokia Cloud Infrastructure for Radio VNF hosting.
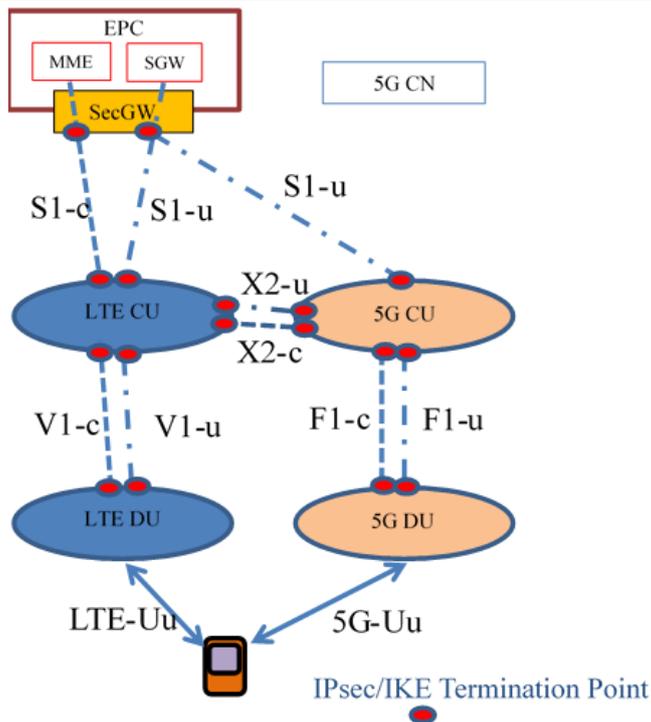
Figure 65: cloud RAN architecture

5.2.2 Nokia Research platform

The research platform is relying on NGPaaS technology (www.ngpaas.eu) using micro-service approach. The RAN is:

- Deployed over an Edge infrastructure specifically developed;
- Developed using micro-service technology;
- Supports distributed (cloud) deployment separating central and remote units;
- Supports various 3GPP options such as 4G and 5G;
- Connects to research RRH and CORE components.
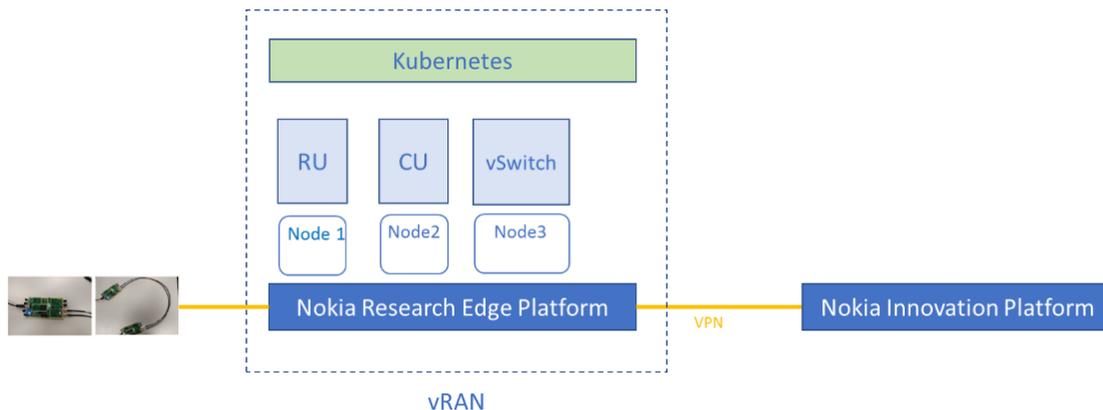
Figure 66: RAN research platform

5.2.3 OAI 5G RAN platform

An overview of the functional entities and their interconnection interfaces corresponding to the current OAI implementation is shown in Figure 68. OAI currently implements several RAN entities in openairinterface5g. The implemented and planned interfaces are described as well as their level of completion.

The entities referenced with prefix NR (New Radio or 38-series 3GPP specifications), along with SDAP and NB-IoT are currently under development and are integrated with the LTE architecture by the community. Each of the OAI entities comprises (Figure 67):

- A *northbound interface* (backhaul/midhaul/fronthaul and in-band configuration);
- A *southbound interface* (midhaul/fronthaul and in-band configuration);
- One or two management interfaces. These are used to dynamically manage (instantiate, configure, delete, migrate, etc.) the entity via a network interconnection;
- A configuration file which can be used to statically configure the entity at boot-time when it is read in.
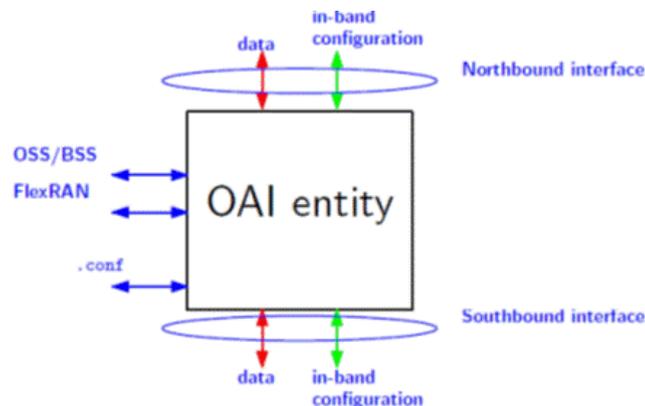
Figure 67: Generic Interface Ports for OAI Entities

Three computing nodes are proposed in the current architecture:

- Radio Cloud Center (RCC): multiple RRC/PDCP/SDAP entities. This computing node corresponds to the NGRAN *Central Unit (CU);*
- Radio-Access Unit (RAU): multiple MACRLC entities with medium-latency midhaul and potentially L1 entities with low-latency fronthaul. An RAU without L1 entities would correspond to the *Small-Cell Forum (SCF) Virtual Network Function (VNF)*. The RAU is functionally equivalent to the NGRAN *Distributed Unit (DU);*
- RRU: Equipment at radio site. It includes various processing elements depending on fronthaul/midhaul interface. The RRU with at least one LTE-L1 entity corresponds to a *SCF Physical Network Function (PNF)*.

5.2.3.1 RU Software Module

LTE/NR-RU comprises the basic functionality for preparing and processing the signals going to and coming from the radio units, which can be either local or remote. It implements the eNodeB/gNodeB OFDM Fourier transform operators for modulation/demodulation as specified in [[33] in Sections 6.12 and 6.13] and [35] in Sections 5.3 and 5.4] as well as arbitrary precoding functions for sharing physical antenna ports across several logical protocol instances. In addition, the interconnections between the LTE-RU entity and the RRU are Ethernet-based (UDP) and can be compressed in both directions. Computation can be partitioned between the central and remote units. In the current OAI implementation, the LTE-RU operations are referred to as *radio-units (RU)* and have software components both in DU and RRU. In the case of a split L1 deployment, the DU RU component can be seen as an agent, which manages the fronthaul link to a particular RRU.

5.2.3.2 L1 Software Module

LTE/NR-L1 comprises the remaining physical layer eNodeB procedures from several Technical Specifications [33][34][35][36][38][39][40] This block receives protocol data units (PDU) on the LTE transport channels and implements the mapping to all LTE and NR 5G downlink physical channels based on the configurations received from the LTE-MACRLC for each PDU. It also generates indications for the received PDUs from the uplink physical channels. The input and output of this entity on the interface with the LTE-RU are signals on logical antenna ports in the frequency-domain. The input and output of this entity on the transport channel

interface are structured packets according to the NFAPI specifications [37] for the so-called P7 interface. LTE/NR-L1 also receives configuration information from the LTE-MACRLC entity in the form of structured packets according to the NFAPI P5 interface specifications. These information elements originate in the LTE/NR-RRC entity and are relayed by the LTE/NR-MACRLC in the form of in-band configuration. The NR-FAPI interface is currently being created using the same semantics as the LTE-FAPI interface but adapted to NR physical and transport channels. This work is under discussion for collaboration between the OAI community and the Small-Cell Forum.
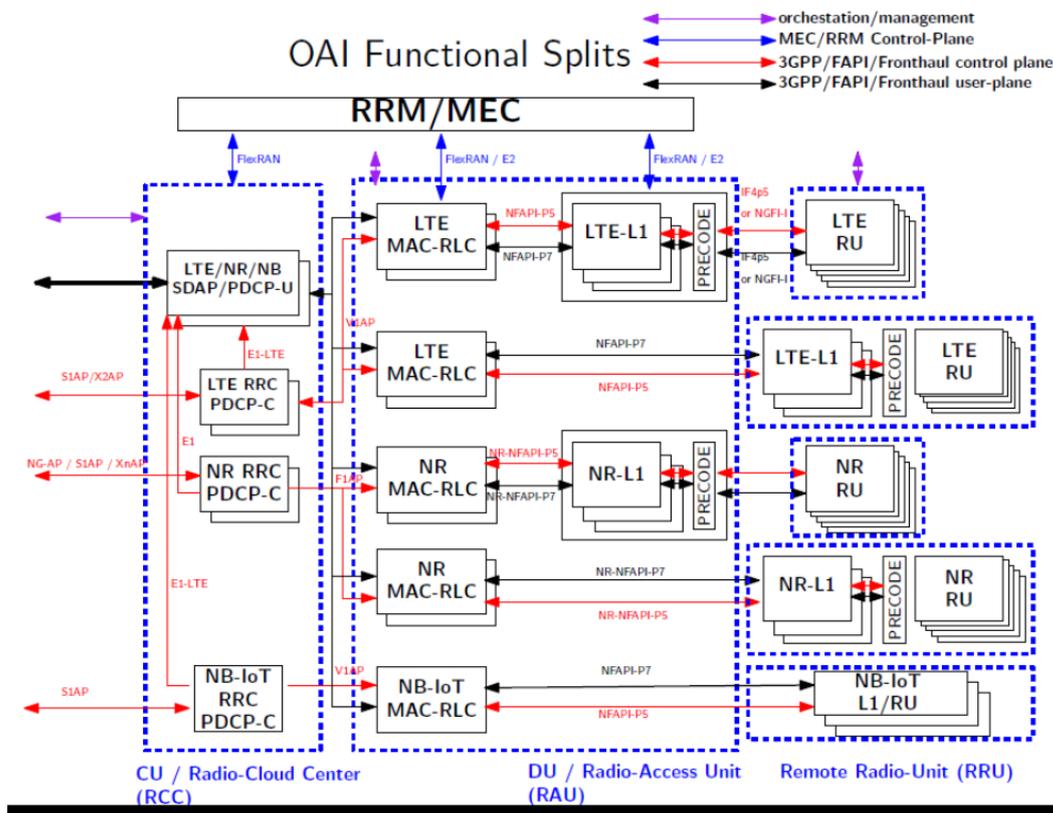
Figure 68: OAI Software Modules and Interface

5.2.3.3 PRECODER Module

PRECODER corresponds to the entity performing both UE-based and cell-based precoding and provides both switching and beamforming functions. It allows for a soft mapping between logical L1 entities and physical antennas managed by the RU entities. The southbound interface is either the frequency-domain IF4p5 OAI fronthaul protocol (corresponding to IEEE 1914.3 split option 7-1) or a new protocol proposed in the context of the ORAN. The PRECODER function is currently run in a common machine/container with the L1 entity. OAI is planning to allow for this function to be separated from the L1-entity in the case of a large number of RRUs. In this case, the northbound protocol is the IF4p5 frequency-domain protocol used to interconnect machines/containers in a common data center (BBU pool).

5.2.3.4 MACRLC Module

LTE/NR-MACRLC implements the 3GPP MAC [41][42] and RLC [43][44] procedures. This block receives control and user-plane PDUs from the LTE/NR-RRC (Master Information Block and System Information) and LTE/NR-PDCP (Signalling and Data Radio Bearers) entities as well as configuration from the LTE/NR-RRC entity (common and dedicated radio-resource configurations). These interfaces follow the 3GPP specifications for the so-called F1-U and F1-C interfaces. An adapted version based on the F1 specification for LTE (V1AP) is used in OAI. The configuration information contains information elements both for the LTE-MACRLC entity and the LTE-L1 entity. The MACRLC entities provide a real-time SDN interface for remote-control of the

scheduling function. This is currently used with the FlexRAN [31] MEC framework from EURECOM site facility. Other SDN interfaces proposed in the context of ORAN can be also accommodated.

5.2.3.5 PDCP-U-SDAP Module

LTE/NR-PDCP-U/SDAP implements the user-plane portion of 3GPP Packet Data Convergence protocols [45][46] and SDAP protocol [47]. It receives information from the LTE/NR-RRC (signalling radio bearers) and core network via the S1-U interface. The configuration interface with LTE/NR-RRC is currently OAI-specific but will follow the 3GPP specifications for the E1 interface [51] by April 2019.

5.2.3.6 RRC-PDCP-C Module

LTE/NR-RRC/PDCP-C implements the 3GPP Radio Resource Control protocols [48][49] and the PDCP-C protocol[45][46] which is used to convey signalling radio bearers (SRB1,SRB2). It receives non-access-stratum (NAS) information from the core network (MME) via the S1-C interface and provides configuration information to LTE/NR-PDCP over the E1-LTE/E1 interface and LTE/NR-MACRLC over the V1/F1-C interface (V1AP/F1AP). Signalling information is transported by LTE-PDCP (signalling radio-bearers) and transparently by MAC (Master and System Information) via the V1/F1-C interface.

5.2.4 b<>com *Wireless Library*

As part of its Wireless Library, b<>com has developed its LPWA SDR Platform that can accommodate several proprietary (LoRa for instance) and 3GPP based access technologies (NB-IoT for instance) and that offers outstanding reception performance thanks to cutting-edge digital filtering and patented demodulation algorithms.

It includes various components
- LPWA RF Front-End [61]: Analog RF front-end specifically developed for SDR receivers that integrate automatic gain control and filtering. By enabling reception of real-world radio signals, it turns laboratory equipment into real outdoor IoT gateways;
- LPWA SDR Platform [62]: Accommodates several proprietary and 3GPP based access technologies and that offers outstanding reception performance thanks to cutting-edge digital filtering and patented demodulation algorithms;
- Channel Processor [63]: is a parallel and efficient all-in-one IP architecture for both transmitter and receiver sides. Its generic FEC core supports many common standards such as Wi-Fi, LTE or 5G-NR by setting some specific parameters and configuring the mutualized architecture on the fly.

For 3GPP based access technologies, this VNF includes the presence of the following third parties software:

openairinterface eNB, UE Radio Access Network (RAN) which is licensed under OAI Public License V1.1.

5.2.5 RRH

5.2.5.1 Nokia Pre-commercial platform

In the part of pre-commercial 5G experimentation, Nokia will work with pre-commercial and commercial Radio Unit. For the 4G part, the RU will be either a new 700 RU or the legacy currently deeply used for deployment. Its main features are:
- 3GPP FDD bands: 28/n28: UL (RX) 703 MHz – 733 MHz + DL (TX) 758 MHz – 788 MHz;
- n83: SUL (RX only) 703 MHz – 733 MHz
- RF Output Power: 2 x 40 W per sector

For the 5G part, a pre-commercial Adaptive Antenna system will be used having the following characteristics:
- 5G RF Unit with an integrated antenna
- Digital beamforming for multi-user MIMO
- Operating bandwidth (Band 43): 3.6 GHz ... 3.8 GHz
- Number of TX / RX layer/ports per carrier: 64

- Max output power: 35 dBm per TX (200 W in total)

5.2.5.2 Software Defined Radio

Depending on the French site facility and the use-case requirements, different "on-the-shelve" equipment from National Instrument (Ettus [32]) issued from the SDR community are used. For instance, the use of:

USRP B210 SDR Kit: The USRP B210 provides a fully integrated, single-board, Universal Software Radio Peripheral (USRP™) platform with continuous frequency coverage from 70 MHz – 6 GHz. Designed for low-cost experimentation, it combines the AD9361 RFIC direct-conversion transceiver providing up to 56MHz of real-time bandwidth, an open and reprogrammable Spartan6 FPGA, and fast SuperSpeed USB 3.0 connectivity with convenient bus-power. The integrated RF frontend on the USRP B210 is designed with the new Analog Devices AD9361, a single-chip direct-conversion transceiver, capable of streaming up to 56 MHz of real-time RF bandwidth.

USRP N200 SDR Kit: The USRP N200 series provides high-bandwidth, high-dynamic range processing capability. The product architecture includes a Xilinx® Spartan® 3A-DSP 1800 FPGA, 100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit Ethernet connectivity to stream data to host processors. A modular design allows the USRP N200 to operate from DC to 6 GHz. An expansion port allows multiple USRP N200 series devices to be synchronized and used in a MIMO configuration. An optional GPSDO module can also be used to discipline the USRP N200 reference clock to within 0.01 ppm of the worldwide GPS standard. The USRP N200 can stream up to 50 MS/s to and from host applications, and users can implement custom functions in the FPGA fabric, or in the on-board 32-bit RISC softcore. The FPGA offers the potential to process up to 100 MHz of RF bandwidth in both transmit and receive directions. The FPGA firmware can be reloaded through the Gigabit Ethernet interface.

USRP B205 mini SDR Kit: very close in terms of specification to the B210, this module presents a small format (like credit card) that could be easily integrated to the platform (module used by b<>com for IoT transmission).

USRP N310: this equipment is very interesting in terms of performance and is suitable for implementing 5G NR since it proposes high processing bandwidth. This equipment is available at Eurecom, b<>com and Orange site facilities.

As an example, the current opensource 5G RRU (Eurecom site facility) consists of the following components shown in Figure 69.

- Outdoor waterproof enclosure with:
  o National Instruments (Ettus) N310, 4 channel 100 MHz channel bandwidth (Analog Devices AD 9371 RF chipset), GPS-based synchronization
  o Medium-end server (R440 Xeon Silver 4114) for RRU baseband processing and fronthaul management and transport interconnected via 2x 10 Gbit/s 78thernet with N310. Fronthaul interface using 10 Gbit/s SR optics (OM3) with 300 m fiber interconnection
  o 4x RF TDD front-end (30 dBm total transmit power @ 3.6 GHz) with corresponding type-N antenna port connector. These will operate in NR band 78 with an 80 MHz channel (3600-3680 MHz) according to the experimental license obtained by EURECOM for the SophiaTech campus.
  o GPS antenna for synchronization
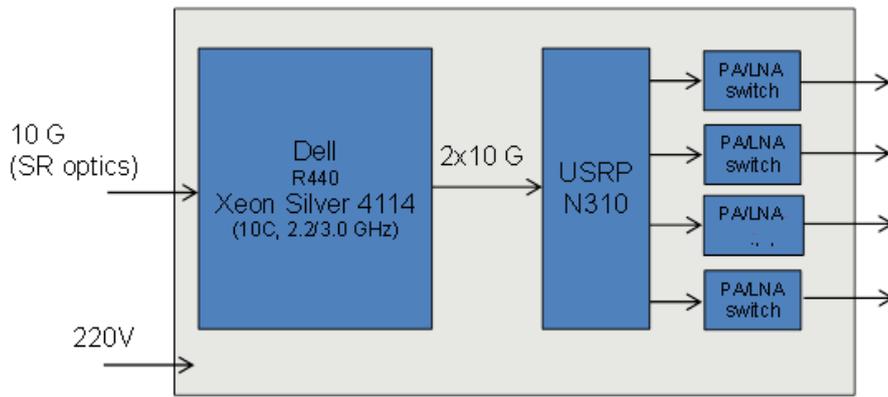
Figure 69: open-source 5G NR RRU

For transmission purpose, at the output of the USRP, RF components (switches, filters, AGC, amplifiers, antennas) are implemented depending on the frequency bands. Each French site facility has adopted its own solution:

Eurecom site facility

- Kathrein **3.5 GHz** 4-port panel antenna or 2.6/3.5 GHz [67] 16-port panel Amphenol (8-port per band) [68] used for implementation. By April 2019, the objective is to provide 16 radiating elements in one sector covering the Eurécom SophiaTech campus with approximately 36 dBm (53 dBm EIRP). The 8-port antenna configuration will require only two panels on the rooftop. The RRU will be connected to the server room via four 10 Gbit/s optical Ethernet links.
- RRU deployment in Band 38 (TDD, 2.6 GHz) with up to 30 MHz of usable spectrum. The indoor component currently covers two floors of the EURECOM building. The RRUs contain similar components to the NR version although are much simpler and smaller. The internal view of the LTE RRU is shown in Figure 70.
- One or two OpenCellular devices will be deployed in Band 68 (5 MHz channel, 698 – 703/753 – 758 MHz) or Band 14 (3 MHz channel, 733 – 736/788 – 791 MHz) for NB-IoT and LTE-M coverage. This is conditional receiving the frequency allocation from French authorities. The OpenCellular devices are fully integrated remote radio units which can function with the OAI software and interconnect over 1 Gbit/s Ethernet to the EURECOM data center.
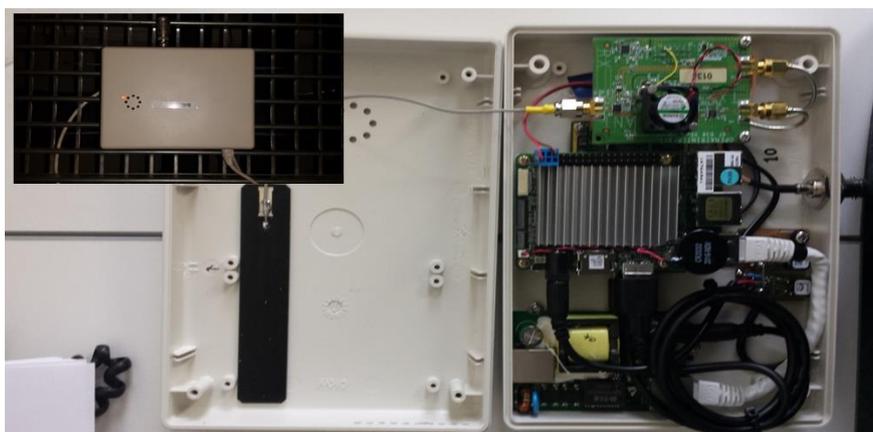
Figure 70: LTE 2.6 GHz RRU (EURECOM site)

The initial radio and EPC configuration will be ready for integration with the other French sites under the common orchestration and management components by April 2019. The Eurecom site facility envisages up to 64 radiating antenna elements on the SophaTech campus with fully centralized and synchronized L1 processing.

b<>com site facility

b<>com ***Flexible Netlab*** platform provides various RAN infrastructures including all RRH functionalities (antennas, filtering, power amplifier, baseband processing …). The architecture design has been defined in order to work in standalone (all the layers being implemented in the cabinet located in the 5th floor of the b<>com premises). The omni-directional antennas (illustration in Figure 71) located on the b<>com's roof have large bandwidth from 700 to 2700 MHz. The cabinet located at the 5th floor is composed of 2 main parts. The first one (on the top of the cabinet) is dedicated to IoT transmission/reception whereas the second one to the 4G LTE/5G transmission/reception. Figure 72 gives the main requirements embedded into the RAN 5G/LTE and IoT cabinet that is composed of active and passive components (filters, switches, splitters, amplifiers, AGC …) for on-air transmission (Figure 73).

Figure 71: b<>com IoT and LTE Antennas located in the roof
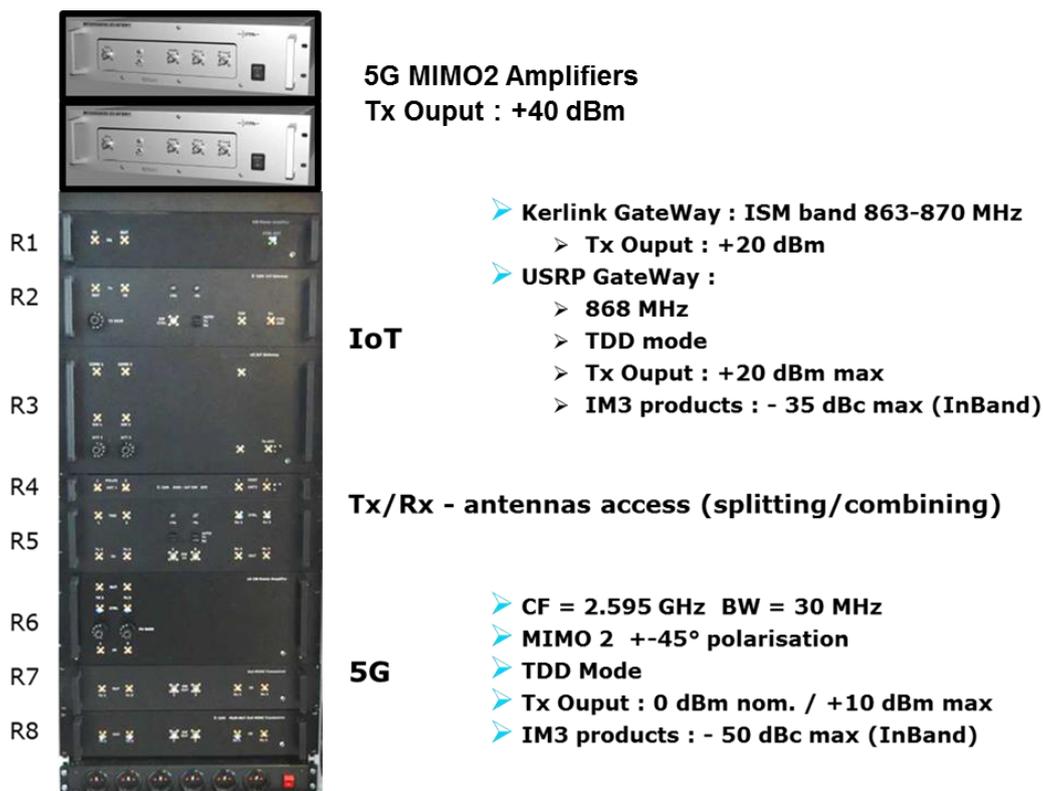
Figure 72: Main requirement of the b<>com cabinet
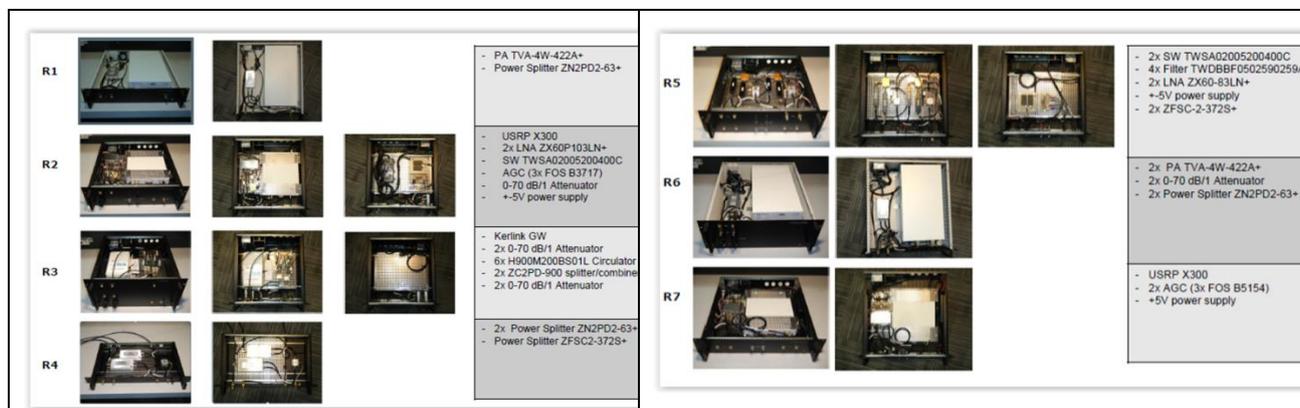
Figure 73: IoT/LTE/5G racks equipment and functionalities

ORANGE site facility

Orange-FR aims at deploying RRH equipment in the scope of 5G EVE. The French spectrum regulator allowed Orange to use the 100 MHz bandwidth for 5G experimentation around 3.5 – 3.7 GHz. The objective is to test in real conditions, 5G innovations currently deployed in labs, based on OAI and developed in the framework of the Orange Plug'in platform. Some RRH solutions are currently identified: those presented above coming from Eurécom and b<>com, and others "on-the-shelve" like [52][53]. The OAI RAN is wrapped around a Cloud Native SDK (see Section 5.7.1.1.) to allow RESTful lifecycle management operations such as configuration, start, stop. This is a work in progress already open sourced on GitHub [54]. Possible enhancements to the framework could involve better use of the FlexRAN Agent API included in OAI RAN Software (e.g. metrics, configuration) [31].

5.2.6 BBU

Each French site facilities has deployed its own servers and defined its interfaces and protocols RRH/BBU, fronthaul/backhaul connections.

5.2.6.1 Opensource SW 4G/5G BBU

As explained when introduction OAI, the baseband, MAC, RLC and RRC are based on **software** processing, hosting by powerful servers with several cores, high storage memory. Then, specific interfaces, described in Section 5.5 allow to interconnect the equipment together. The main specifications of the servers implemented by the different French partners are detailed in Section 5.6.

As an example, the EURECOM site network and computing functions are depicted in Figure 74 that gives the split between the resources processing sharing.
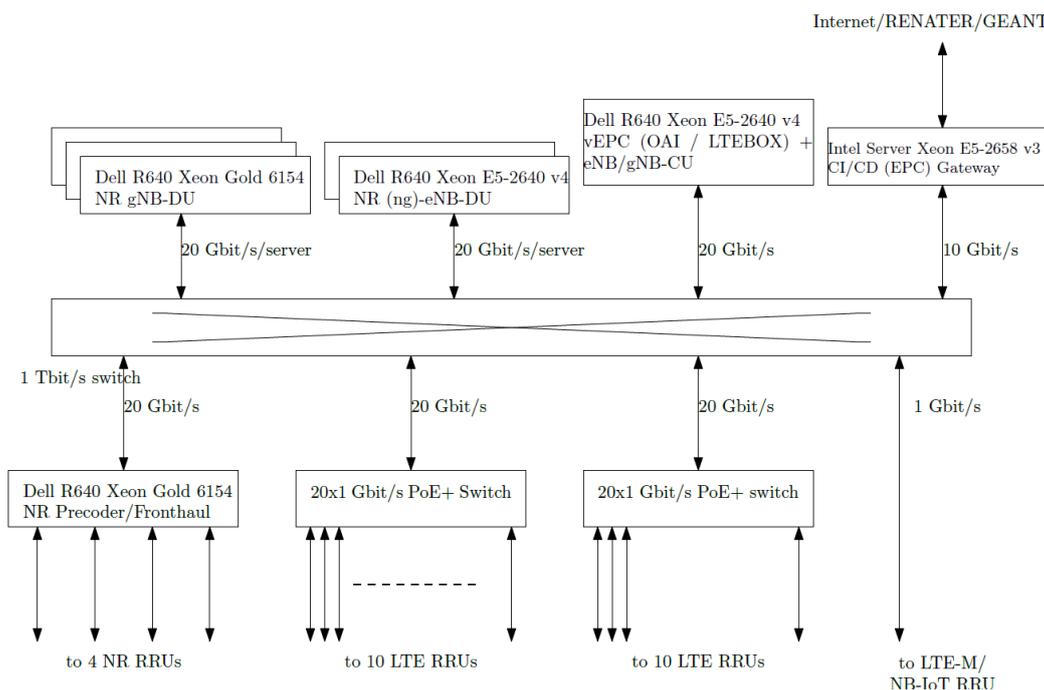
Figure 74: EURECOM site network configuration

5.2.7 Frequency bands

Table 8 gives the frequency bands that are currently available in the French sites facilities for 5G experimentation.

Table 8: French site facility frequency bands that are available for on-air transmission

Site	Band (Frequencies)	EIRP (dBm)	Antenna Height (m)	Duplex	Status
EURECOM – Sophia Antipolis	LTE band 38, 2580-2610 MHz	unspecified	unspecified	TDD	Granted, to be renewed bi-annually
EURECOM – Sophia Antipolis	NR band 78, 3600-3680 MHz	61 dBm	3m	TDD	Granted, to be renewed bi-annually

EURECOM – Sophia Antipolis	LTE band 68, 698 – 703/753 – 758 MHz)	pending	pending	FDD	Application filed
EURECOM – Sophia Antipolis	LTE Band 14 (733 – 736/788 – 791 MHz)	pending	pending	FDD	Application filed
Nokia - Paris-Saclay	NR band 78, 3700-3800 MHz	pending	pending	TDD	
Nokia -Paris-Saclay	NR band 28, (708-718/ 763-773 MHz)	pending	pending	FDD	
b<>com – Rennes & Lannion	LTE band 38, 2580-2610 MHz	unspecified	unspecified	TDD	Granted, to be renewed bi-annually
b<>com – Rennes & Lannion	NR 5G band, band n°42, 3500 – 3520 MHz	unspecified	unspecified	TDD	Granted, to be renewed bi-annually
b<>com – Rennes & Lannion	Unlicensed bands, 868 MHz, WiFi 2.4/5 GHz	Regulated	unspecified	FDD	Applicable
Orange – Châtillon/Paris	NR band 78, 3700-3800 MHz	unspecified	unspecified	TDD	Granted, to be renewed bi-annually

5.2.8 Technologies supported (slice) statistic/dynamic

The main technologies supported by the French site facility are: NR 5G, LTE, WiFi, NB-IoT, LoRa, LTE-M. These technologies are not all implemented in the 4 sites facilities. At the top, slices could be provisioned for addressing different technologies on separate sites.

5.2.9 User Equipment

Some User Equipment will be provided such:

- COTS 4G smartphones that are seen as "blackboxes"
- COTS LoRa endpoints
- COTS NB-IoT endpoints

The OpenAirInterface UE implementation running on top of an USRP (same solution as for eNodeB) considered a "whitebox".

5.2.10 Responsibilities

Each French site facility is responsible to provide the HW and SW equipment that will host the main 5G functionalities for network deployment. Orange will provide the interconnection between the different sites via secured VPN tunnels. The user management will be provided by Orange who will also manage the French site supervision.

5.3 CORE architecture description

5.3.1 Nokia pre-commercial platform

5.3.1.1 Overview

The block diagram in Figure 75 depicts the Network Elements building the complete ePC. All functions are virtualized and deployed on Nokia AirFrame servers (see infrastructure Section 5.3.1.3).
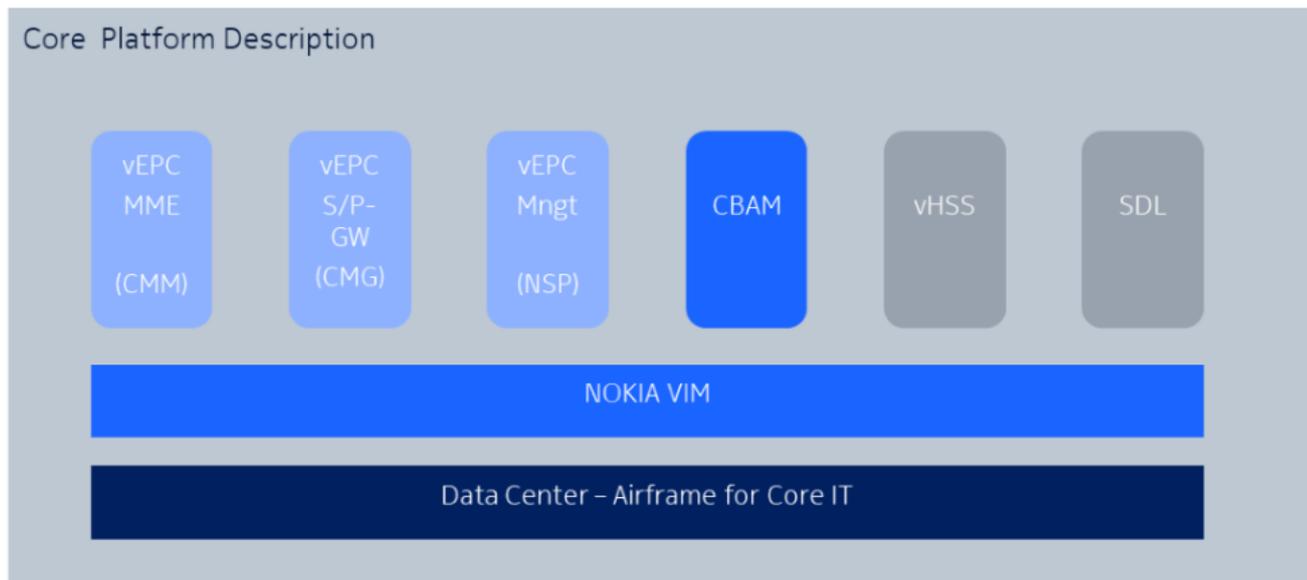
Figure 75: Core platform description

5.3.1.2 Main functions

Shared Data Layer: Core networks have changed dramatically in recent years, becoming Cloud based with virtualization technology transforming conventional servers, functions and entire networks. SDL is dramatically simplifying networks providing a single point of storage for all the data used by Virtualized Network Functions (VNFs) in all network areas from the core to the radio. Provides a common database for all VNF related data such as subscription, policy, charging and session data, which can be accessed by VNF via industry standard protocols. Open APIs allow seamless integration with third party services and applications. With the Shared Data Layer at its heart, the new programmable core network will give operators the business agility they need to ensure sustainable business in a rapidly changing world and gain from the increased demand for high performance connectivity. The Nokia SDL is the cloud native database for telco cloud applications. SDL is specifically designed and created for mobile telecommunications networks on cloud, provides an open centralized database that ensures Telco Grade network availability of services. With SDL, Nokia is building on the experience with One-NDS that has been highly successful by enabling the transformation to Subscriber Data Management. SDL is the Nokia flagship product for implementing the 5G Data Layer that is currently under standardization (refer to [55]).

vHSS: CMS-8200 HSS is the key component that provides business logic for EPS/ EPS' domain for mobile broadband access management towards MME. CMS-8200 supports the long-term evolution (LTE) access network and the features necessary to support 5G access. For the 5G EVE project, a compact VNF configuration is proposed.

vEPC: With new Internet of Things (IoT) services emerging and 5G on the horizon, the EPC network will be required to connect to a greater variety of devices and deliver a broader range of new services. However, the difference between today's 4G consumer mobile broadband services and the new emerging services is that there is wider range of variability in the network requirements to support them. Simple move of legacy EPC to a virtualized platform does not address the new network requirements. A fundamentally new cloud Packet Core (CPC) built with cloud design principles is required to satisfy the mobile network operator's (MNO) service requirements, both today and in the future. As a result, Nokia is providing the evolution of its virtual Evolved Packet Core (vEPC) architecture beyond existing network functions virtualization (NFV) architecture to an innovative cloud-optimized design that provides scaling at web capacities, network deployment flexibility and an IT operations model to meet the dynamic service demands of 4G consumer services, IoT and the evolution to 5G.

Cloud Mobility Manager (CMM): The Nokia CMM performs the 3GPP mobility and session management control functions in the evolved packet core (EPC) and GERAN/UTRAN network. Deployed as either a standalone 4G MME or combined MME/Serving GPRS Support Node (SGSN) in 2G/3G/4G networks, the CMM uses field-proven application software to ensure feature and service consistency between cloud and physical network function implementations. The CMM delivers the scalability, flexibility, high availability, and performance to meet growing network signalling loads for consumer mobile and Internet of Things /Machine Type Communications (IoT/MTC) services. Built with a cloud-native architecture, the CMM provides web-scale and state-efficient design needed to meet the growing control plane demands — scale and flexibility — for 4G, IoT/MTC and the transition to 5G.

Cloud Mobile Gateway (CMG): The Nokia CMG has been built from the ground up on the principles and design requirements of cloud networking and web scale. The CMG performs a wide variety of gateway functions, including SGW, PGW GGSN. These network functions can be deployed as separate instances or in combination, providing maximum configuration flexibility. Its high-performance, elastic, and state-efficient design addresses the growth of mobile broadband and the delivery of new IoT/MTC services and provides an evolutionary path to 5G. The CMG control plane is highly resilient and delivers bearer and system level management with the reliability that is expected in the packet core network. The data and forwarding plane use a distributed processing architecture that takes advantage of the NFV's dynamic scale and flexibility. The CMG is designed to provide service performance comparable to that of dedicated hardware platforms. Its advanced software design and capabilities leverage technologies such as distributed symmetric multiprocessing (SMP) to maximize the use of multi-CPU architectures and a native 64-bit OS to maximize the access to multicore memory.

As part of Nokia Cloud Infrastructure framework, **Nokia Data Centre Solution (NDCS)** is the Telco-grade common virtual hardware platform for cloud deployments. It consists of server, switch, and storage products. Power Distribution Units, interconnection/power cables and rack/installations accessories are additional products to build system-level solutions.

5.3.1.3 Infrastructure

Basic building blocks of AirFrame hardware setup are:

- Rack and PDU;
- Server ;
- Management switch ;
- Leaf/spine switch ;
- Memory: using the Hyper Converged Infrastructure (HCI) approach, storage co-exists on the compute nodes with the VM workloads;
- Network: The solution provides leaf/spine data centre networking architecture which in turn provides high-availability support for external and internal cluster networks. The fundamental connectivity concept is based on the division of host (infrastructure) and guest (VNF) traffic into separate physical networks. This division provides additional reliability, since in possible fault scenarios (which may impact either the host or guest network), the respective networking of the host and guest do not interfere with each other.

The hardware blueprint has been specified in such a fashion that there are no single points of failure (SPOFs). Networking, power supply, cabling and software component selections are done with the Telco grade robustness requirements in mind and failure of any single link, component or device does not result in the outage of the implemented cloud system.

AirFrame NDCS is the platform part of Nokia Core VNF products (HSS, SDL, vEPC, and NSP) but can be more generally implemented as a standalone infrastructure solution for the Telco domain (IaaS).

5.3.2 Nokia Research platform

The research platform is relying on NGPaaS technology using micro-service approach. The CORE is:

- Deployed over a Central infrastructure (Nokia Innovation Platform);
- Developed using micro-service technology;
- Supports various 3GPP options such as 4G and 5G;
- Connects to RAN platform and to other 3rd party platforms.
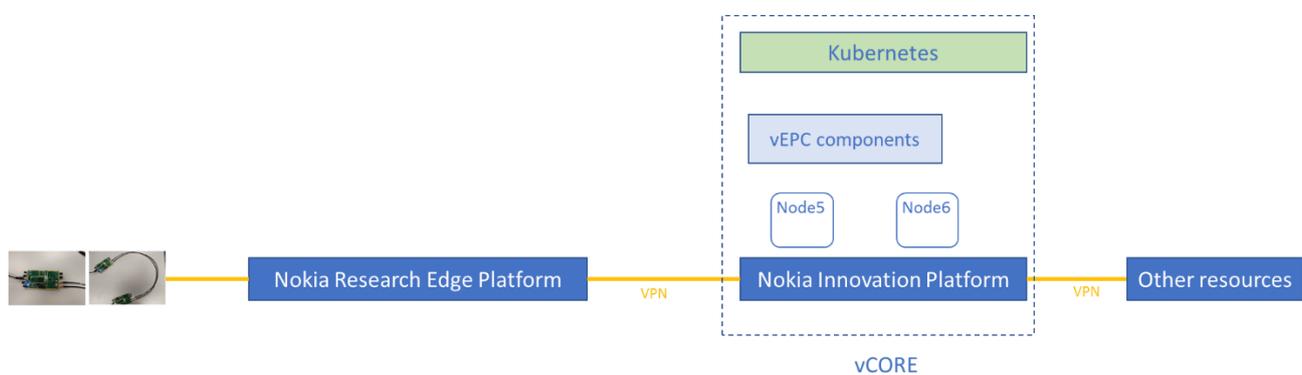
Figure 76: CORE research platform

5.3.3 OAI CORE network

openairCN [30] is a 4G mobile core network infrastructure software implementation of the 3GPP EPC. The network functions implemented are the HSS, MME, S-GW and P-GW (S-GW and P-GW are actually bundled together). A pictorial description of the software elements is shown in Figure 77, and the current functionalities and interfaces are described in ANNEX B. It should be noted that the HSS element is not mentioned in the table. It is based on the release 14 3GPP EPC specifications and makes use of an Apache Cassandra database. Certain elements, in particular the MME, are being migrated to the 5G Service-based Core Network architecture. It is expected that during the course of 5G EVE, the openairCN architecture will include full compliance with the 3GPP 5G core network procedures.
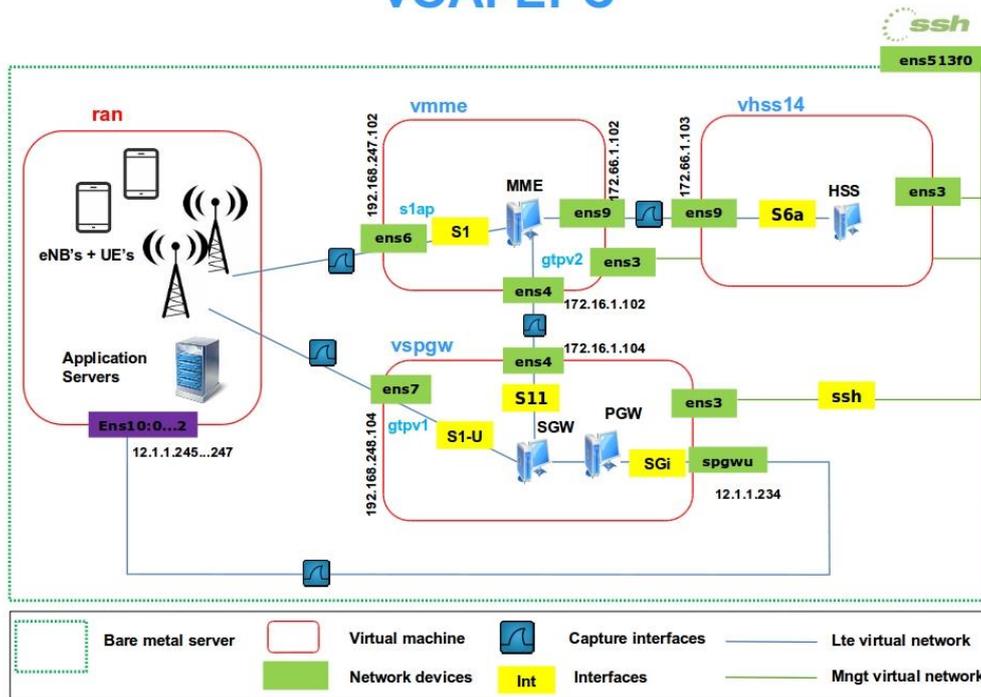
Figure 77: openairCN elements shown as three virtual machines

5.3.4 b<>com *Wireless Edge Factory*

5.3.4.1 Overview

b<>com *Wireless Edge Factory* [64] is an SDN based private network framework enabling end to end broadband, IoT and WebRTC critical communications to be carried out in a fully secure manner in small to medium size buildings or industrial sites.
Current specifications are:

- SDN (OpenFlow v1.3, OpenDaylight controller);
- Preloaded with Full LTE EPC (MME, S/P-GW, HSS) based On OpenAirInterface CN;
- WLAN 802.1x protocols;
- Preloaded with LoRa Core Servers (NS, AS, CS);
- EAP-AKA, EPS-AKA SIM based authentication mechanisms.

New releases of b<>com *Wireless Edge Factory* are regularly issued by b<>com Research Institute of Technology and is moving to a 5G SBA implementation. The actual VNF version of the *Wireless Edge Factory* proposes the distributed multi-site architecture depicted in Figure 78 right below:
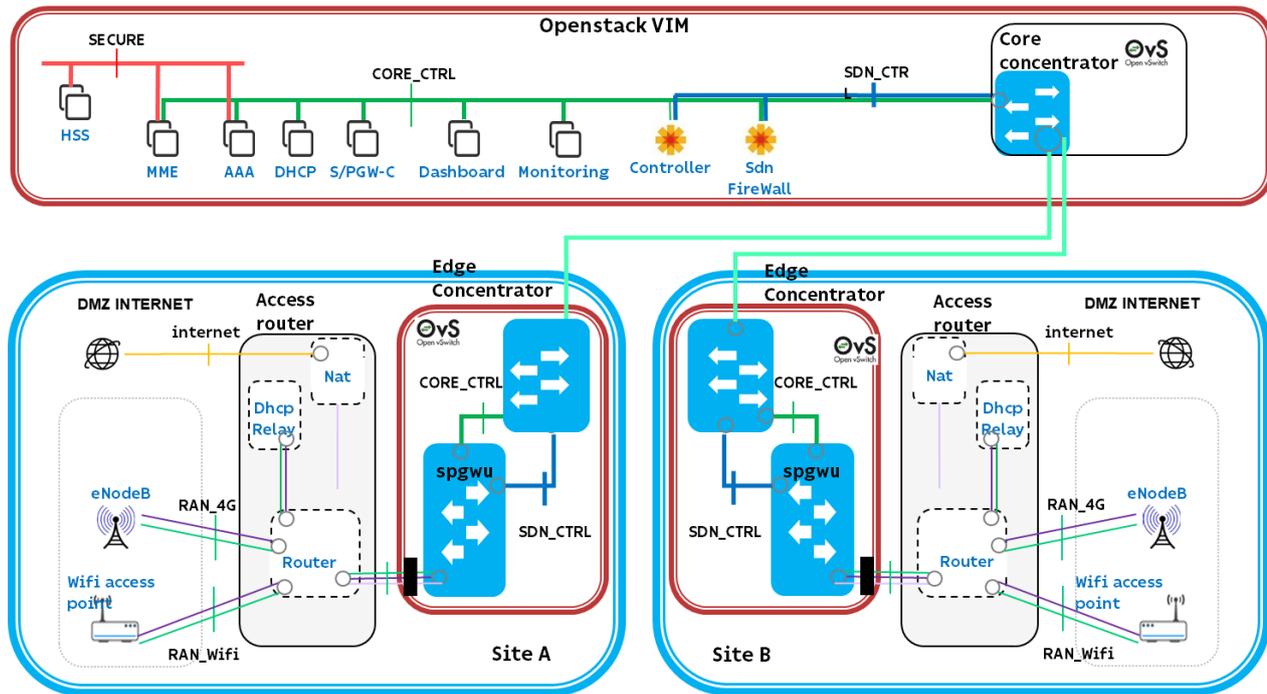
Figure 78: *Wireless Edge Factory* architecture

5.3.4.2 Infrastructure

The NFV Infrastructure in b<>com site to host the *Wireless Edge Factory* VNF and future experimentation VxFs is composed of **Dell PowerEdge R640** servers with the characteristics described in Section 5.6.2 of this document. A Ceph cluster provides 12 TB of distributed storage connected to the OpenStack VIM with a 2x10 Gbps aggregated link. Internal VIM datapath is 2 x 10Gbps aggregated link, while the external VIM connectivity is 1 Gbps.

5.4 Orchestration

Different orchestrators are used in the different French site facilities. The main goal is to use a major one that will be interfaced with the others. Orange FR via its ORA PL entity aims at implementing ONAP in the Plug'in platform to orchestrate the site facility. However, interface should certainly be developed to interconnect the different edge sites.

5.4.1 Which one?

With the advent of SDN, NFV and 5G, the network services will consist in dynamically deploying functions and programming connectivity paths among them instead of re-architecting the network. This will largely depend on the success of network-wide service management.

Network-wide orchestration is associated with the replacement of the individual device configuration by a more powerful network services management mechanism to provide network-wide services definition, configuration, deployment and monitoring. By using network-wide orchestration, services are not deployed, configured and managed in a node-by-node fashion as it is originally done in legacy systems. The increasing complexity that 5G will impose on the delivery and maintenance of services, supported by the slicing concept, force to manage the network in an integrated and coordinated way, and not as a collection of individual boxes and layers. In order to do so, higher-level abstractions and automated procedures are needed to manage and configure each single component of the whole network service at once [57].

5.4.1.1 Cloudify

Cloudify [58] is an NFV orchestration project that relies on the Topology and Orchestration Specification for Cloud Applications (TOSCA) standard for life cycle management and control VNFs and the underlying NFVI. The Cloudify orchestration engine is composed of Topology, Workflow, and Policy engines. The system provides a set of design tools such as the Deployment Management UI and the Blueprint Composer for designing blueprints. Currently, the Plug'in platform is Cloudify orchestrated for the deployment of cloud native and open source VNFs.

5.4.1.2 Open Networking Automation Platform (ONAP)

The Linux Foundation's Open Network Automation Platform (ONAP [24]) project is an open source project pushed by an MNO (AT&T) and currently gaining momentum among Telco industry. ONAP aims at simplifying the design, creation, orchestration, monitoring, and life cycle management of VNFs, SDNs, and higher-level services. ONAP is considered by the Plug'in platform to be the next Orchestration framework to be addressed after cloudify. Since ONAP is also based on multiple features of Cloudify, the transition between both orchestrators make sense. The TOSCA models used to deploy VNFs on Cloudify will be theoretically usable AS-IS in ONAP. By April 2019, after having integrated the ONAP Beijing Release, the ONAP Casablanca version should be implemented and will be followed by the ONAP Dublin Release in November 2019. As mentioned in Section 5.7.1.2, ONAP installation and configuration are very complex since ONAP is very big platform, consumes a lot of resources and has plenty of containers to implement.

5.4.1.3 Nokia CloudBand

Nokia CloudBand Infrastructure is the Telco grade framework that enables the deployment and life-cycle management of virtual applications. Nokia CloudBand Infrastructure lays the foundation for robust, cloud-based, Telco applications. As the telecommunication industry evolves, new requirements arise for open, reliable and easy to maintain service platforms. Communication service providers expect to benefit from the constant evolution of such platforms. Nokia brings the required infrastructure to enable proper deployment and operation of the applications. In addition to the expected capabilities, inherent to the known principles in the telecommunications industry, considerable amounts of new functionalities are now enabled by cloud technology.

The introduction of virtualization technology allows the network element software to be independent from its underlying hardware and virtualization technology is leveraged in many of our network products today. The virtualization approach ensures that network functions run on commodity server hardware. Moreover, the software architecture of core network products is well suited for cloud deployments. The Nokia CloudBand product portfolio manages all aspects of virtualized network functions and services as shown in next diagram. Operators can launch innovative services rapidly, while enjoying reduced operational costs. CloudBand's production-grade portfolio of products for hosting, orchestrating, automating and managing virtualized network functions (VNF) and services is aligned with the ETSI Network Functions Virtualization (NFV) framework and the TM Forum ZOOM effort. The three CloudBand products – CloudBand Infrastructure Software, CloudBand Application Manager and CloudBand Network Director – are optimized to fit key roles in the hierarchy of orchestrators, with open northbound and southbound APIs. This modular design allows both single and multi-vendor deployment.

The French site is moving towards the choice of ONAP orchestrator as a basis that should be potentially interfaced with the others available on the different nodes. However, the choice is not strictly fixed at the present time.

5.4.2 Network management Transport

SDN controller based on ODL is used for the network management transport. This topic is also described in Section 5.7.1.1.

5.5 Interfaces

The Table 9 gives the main interfaces implemented in OAI and/or Nokia platform to split the multiple network instances. As described previous in Figure 63, Figure 65 and Figure 68, the different interfaces position in the infrastructure networks are shown.

Table 9: Main interfaces implemented for C-RAN splitting

Interface	Protocol	Release	Status	Framework
S1-C	S1AP/SCTP	14.3	Available	OAI / Nokia
S1-U	GTPU	14.3	Available	OAI / Nokia
F1-C	F1AP	15.2	Available	OAI / Nokia
F1-U	GTPU	15.2	Available @ Apr. 2019	OAI / Nokia
E1	E1AP	15.2	Available @ Apr. 2019	
X2-C	X2AP	14.3	Available	OAI / Nokia
X2-U	GTPU	14.3	Planned	OAI / Nokia
Xn-C	XnAP	15.2	Planned	
Xn-U	GTPU	15.2	Planned	
NG-C	NGAP	15.2	Planned	
NG-U	GTPU	15.2	Planned	
P5	NFAPI control-plane	-	Available	
P7	NFAPI user-plane	-	Available	
IF4p5-U	OAI proprietary fronthaul user-plane	-	Available	
IF4p5-C	OAI proprietary fronthaul control-plane	-	Available	
IF5-U	OAI proprietary fronthaul user-plane	-	Available	
IF5-C	OAI proprietary fronthaul control-plane	-	Avaiable	
NGFI-I / XRAN	Fronthaul	-	planned	
E2 (ORAN)	Radio-Resource Management/MEC	-	planned	
FlexRAN (OAI)	Radio-Resource Management/MEC	-	Available	

The objective of the French cluster is to develop interfaces issued from the ORAN alliance. ORAN alliance aims at combining and extending the efforts of the C-RAN Alliance and the xRAN Forum into a single 'operator led' effort. There are two main ideas here: evolving the radio access networks to make them more open and

smarter than previous generations by using real-time analytics for machine learning systems and artificial intelligence. Secondly, to equip virtualized network elements with open, standardized interfaces through ORAN Alliance reference designs. The group wants to bring in technologies from open source and open whitebox network domains along with practises like maximising COTS hardware and merchant silicon, minimizing the proprietary and exploring open source. Orange is part of the ORAN alliance and aims at pushing efforts to adopt the ORAN interface in the French site facility.

5.6 HW/SW infrastructure

As explained, each French site facility provides its own HW/SW resources for use-case deployment.

5.6.1 Eurecom site

The fronthaul portion consists of one high-density Dell server (36-core Intel Xeon Gold 6154) driving up to four outdoor NR-RRUs via 10 Gbit/s optical Ethernet (SR OM3). The machine will implement the precoder function of the gNB-DU and interconnect with other similar servers used for the gNB-DU L1 and L2 procedures via an existing 1 Tbit/s switch shared with the LTE components. The existing LTE network consists of two distribution switches with 20 Gbit/s optical interconnections driving up to 10 RRUs each via 1 Gbit/s (1 GBASE-T copper). In addition to the Ethernet fronthaul, a 10 MHz frequency distribution reference is provided to the indoor RRUs. Time synchronization is achieved over-the-air.

The compute portion of the network consists of high-density Dell servers (Intel Xeon Gold 6154 36-core) for the NR L1 and MAC-RLC procedures alongside the two existing Dell servers (Intel Xeon 20-core E5-2640 v4) for the LTE/LTE-M/NB-IoT network components (Band 38 TDD, Band 68 FDD, Band 14 FDD). An additional Dell server (Intel Xeon 20-core E5-2640 v4) is used for vEPC/5GC software. Finally, an additional server is used to implement the CI/CD framework for the OAI EPC (openairCN) and act as a gateway for the Internet and external network interworking (RENATER/GEANT could be used by Eurecom and b<>com).

5.6.2 *Flexible Netlab*

Dell PowerEdge R640 servers

These servers are the core NFVi of *__Flexible Netlab__*. They will be used as compute and infrastructure nodes inside OpenStack.

Processor: 2 x Intel® Xeon® Gold 5115 2.4G, 10Cores/20Threats

Memory: 128GB RDIMM, 2666MT/s

Storage:

- SD card: 2 x 64 GB microSDHC/SDXC
- HDD: 240GB SSD SATA

Network:

- Broadcom 5720 2 Port 1Gb Base-T
- Broadcom 57412 2 Port 10Gb SFP+
- Mellanox ConnectX-4 Lx Dual Port 25GbE SFP28

Dell Precision Tower 5810

It is a desktop server allowing to instantiate the enablers and other components running outside the datacentre. For instance, this kind of desktop server used to host BBU's software in the labs.

Processor: 2 x Intel(R) Xeon(R) CPU E5-1620 v3 @ 3.50GHz with 4 x 3,5 GHz Cores

Memory: 16 - 32 GB DDR3 RAM

Storage: 1 TB SATA Hard Disk

Network: 5 x 1 Gbps NICs

Some other equipment like laptops may be used for the use-case needs.

5.6.3 Plug'in platform

In terms of hardware and software resources, Plug'in is running on multiple OpenStack virtual machines and 3 bare-metal servers. In the Table 10, are provided the properties of each host and the corresponding hosted tool.

Table 10: Plug'in HW/SW resources

Host	Characteristics	Hosted tools
VM1		AtomStore
VM2	2 vCPU, 4GB RAM, 40GB Storage	AtomDocs, Formulas, Toolbox
VM3		Wall
VM4	4 vCPU, 16GB RAM, 40GB Storage	1st instance of PlayGround
BM1		2nd instance of PlayGround
BM2	12 CPU, 128 GB RAM, 2TB Storage	AtomInsight

The provisioning of the servers is done using Ansible playbooks and docker-compose files. Currently Vagrant combined with Ansible is considered and is able to create a PlayGround of Virtual Machines and Bare-Metal resources.

In addition, a 4 Dell servers R630 OpenStack cluster is used to host ONAP platform. On top of the VIM, a Kubernetes cluster is setup to deploy to create ONAP instance. The same OpenStack and its compute resources are used for deployment of VNF orchestrated by ONAP.

Servers have the following specifications

- 128 GB RAM
- 2xCPU – each 12 or 14 cores (2,5 or 2,4 GHz)
- 4.8 TB HDD each in RAID 10 config

5.7 Development and deployment tools/software

5.7.1 Software framework and storage

First of all, it is mandatory to explain what exactly the Plug'in platform provided by Orange is.

5.7.1.1 Plug'in: A research platform to experiment on 5G

In terms of software development and integration frameworks, some building blocks of the Orange 5G research platform Plug'in are available. As shown in the Figure 79, the platform offers an integrated set of tools that can be seen as an Integrated Development Environment (IDE) for continuous: Learn Develop, Document, Experiment, Publish, and Reuse.
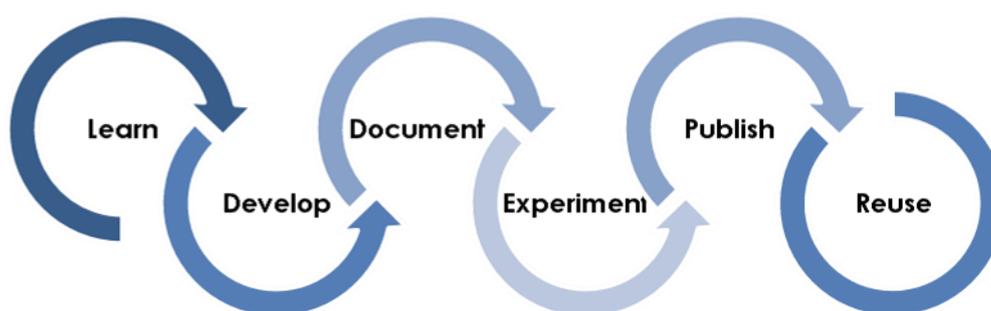
Figure 79: Plug'in platform cycle.

The generic term **"Atom"** designates any software component: binary file, vagrant virtual machine image, docker container image, or deployment script. In this case, developers and users are not necessarily limited to a single delivery format. In order to finally get something homogenous out of all of these possibilities, some guidelines have been defined that instruct developers to deliver their software component in a standardized way: the software project needs to include some information in certain format, and it also needs to be documented.

In the following, the role is explained for each tool of the platform:

- **AtomStore**: this tool is the entry point to the IDE. It's the place where users and developers can find the list of all atoms, classified in categories for a better user experience. Each atom is presented with a visual illustration and brief description to understand at a glance its basic idea. Additional information is provided using links to redirect the user to the Atom's documentation or its home page. Some metadata on the Author of the Atom, the creation date, version, or rate are also provided. The AtomStore is not only a Graphical User Interface (GUI) but also an API service. Currently, the REST API provides basic operation to manage Atom information for example.
- **AtomDocs**: this tool provides a cleaned view of the documentation of each Atom. The workflow of generating an Atom's documentation is automated and puts together: a file server, a pre-processing engine, a conversion engine and finally a web server. It also integrates team collaboration tools such as "slack" or "mattermost", to notify the developer when the documentation is updated. The idea of AtomDocs is to allow developers to document their software using their development environment, always deliver the latest version of the documentation, and never worry about the HTML formatting and rendering of the documentation which helps them focus on their developments.
- **AtomGen**: as stated before, in order to provide a homogeneous development environment, a tool called "AtomGen", which is a project skeleton generator, has been defined. The idea of this tool came from the open source world, where different sub-modules of the same project are not always organized or even coded with the same "style". This introduces an additional effort to explore and understand the code in the project. To tackle this issue, "AtomGen" provides a standardized structure of all Atoms where users and developers can quickly locate different information.
- **Toolbox**: the concept of toolboxes is about providing a starter toolkit for multiple domains that researchers can use to quickly get involved in those domains. For example, a SDN toolbox may contain an SDN controller such as OpenDayLight or ONOS, a network emulator such as Mininet to create virtual switches, and a set of network topologies, benchmarks, and/or deployment scripts to help a first year PhD to get a ready-to-use SDN environment. Multiple SDN toolboxes may be provided, each with a different set of tools or use-cases.
- **Formulas**: this tool is HTML GUI and a REST API to provide a set of formulas that can be deployed on the PlayGround with a single button click. A Formula is basically a docker stack that deploys unitary software. For example, it is possible to create a Formula for Kibana, Jupiter notebook, Prometheus, etc.
- **Cloud Native SDK**: Since the NFV world is accelerating towards Cloud Native Computing design, a Cloud Native SDK is provided to help researcher to adopt the design and to think cloud native from early development stages of their VNFs. The SDK provides a VNF life cycle management REST API.

This API allows most of the management operations such as configure, start, stop, health check and status. This work is in progress and next version may integrate scaling out option for example. At the beginning, this API was developer to wrap the OpenAirInterface eNodeB and Core Network but it evolved to a more generic development kit.

- **PlayGround**: this tool is one of the corner stones of the platform. It offers computing, networking and storage resources to researchers to test and experiment not only on Atoms, but basically any software. The "PlayGround" provides ephemeral computing sessions in which Alpine is instantiated, Ubuntu or CentOS – based on computing instances. The idea of the "PlayGround" is to enhance reproducible research mindset and share resources.
- **Wall**: the "wall" is a publishing tool that helps record experiment provenance, publish results, share experience, write notes, publish tutorials, and more. It is equivalent to a social network for the platform's community. It provides a HTML GUI and a REST API through which posts are managed.
- **AtomInsight**: this tool is designed for learning purpose. Using a HTML GUI interface and the "PlayGround" SDK, the "AtomInsight" provides a set of tutorials to help developers easily learn about new technologies. The "PlayGround" SDK is used to allocate computing resources from the "PlayGround" to execute a given tutorial. A stable version of this tool is available. In future releases, the "AtomInsight" will be able to be automatically populated by a given Atom's tutorials that are written by the Atom's developer himself.

The Figure 80 illustrates the different tools of the Plug'in platform:
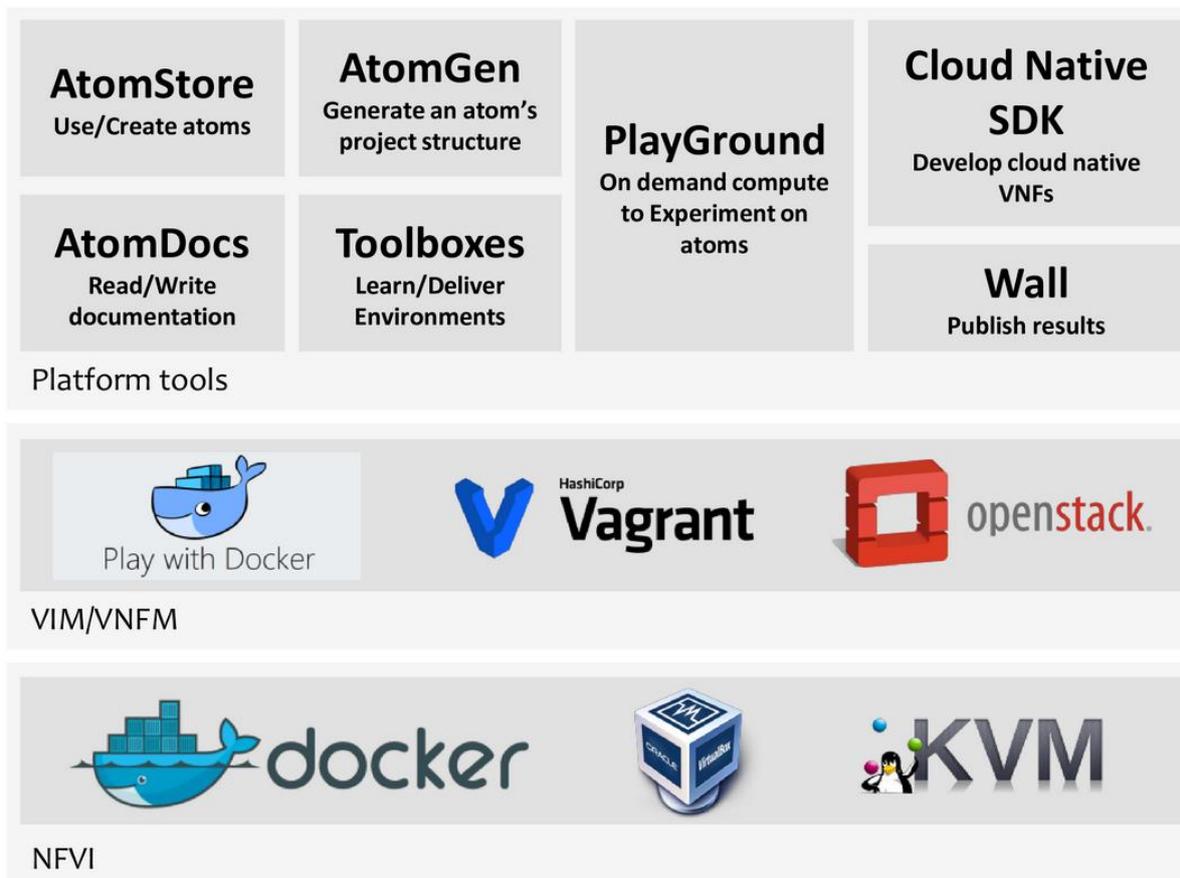
Figure 80: Overview of the Platform's tools and the underlying technologies

5.7.1.2 Plug'in Continous Integration

For instance, the Plug'in platform tools leverage multiple DevOps tools for Continuous Integration/Continuous Delivery (CI/CD). For example, Gitlab is used to host all the code of the platform tools, Atoms, Toolboxes, and Formulas. Gitlab-ci and Jenkins are also used to automate the documentation generation as illustrated in the Figure 81.
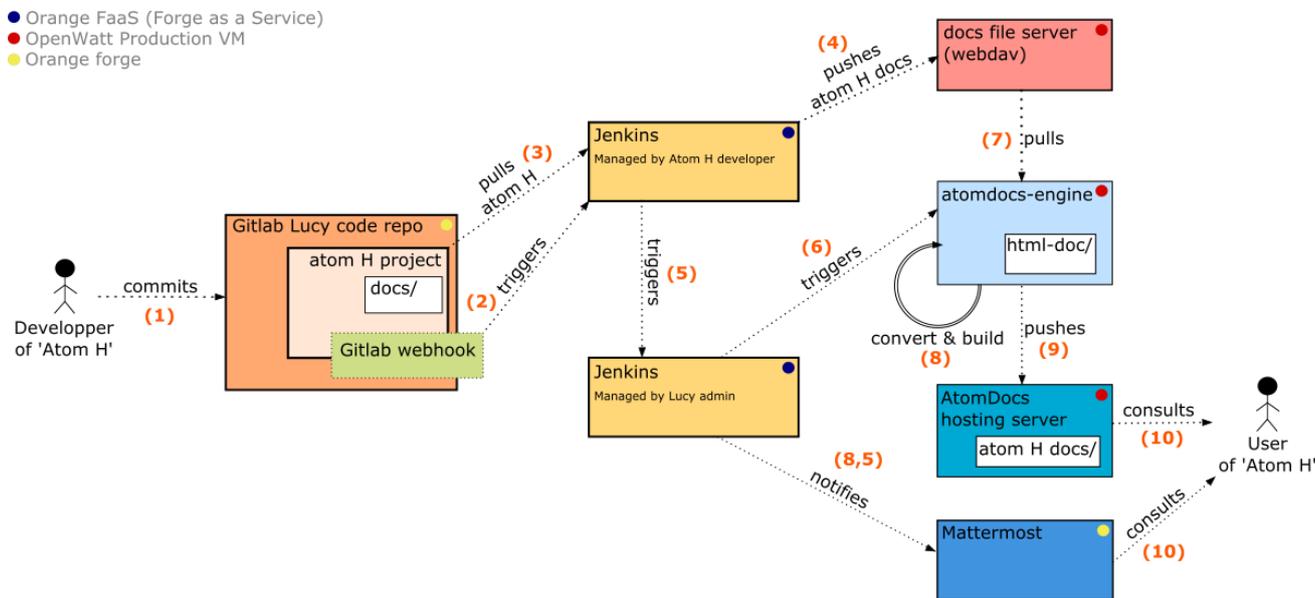
Figure 81: CI/CD Workflow of the AtomDocs.

The DevOps tools are currently using and are summarized in Table 11.

Table 11: DevOps tools used in Plug'in platform

Properties	Tools	Class
Version control	git	Publish
Code hosting	Gitlab, Github	Publish
CI/CD	Gitlab-CI, Jenkins-CI, Travis-CI	Schedule
Infra. deployment	Ansible, Docker Compose, Vagrant	Deploy
Artifacts hosting	JFrog Artifactory, local deb/rpm repos	Publish
Communication and Collaboration	Attlassian Jira, Mattermost, Slack	Collaborate
Logging	Elastic Stack	Trace
Monitoring	Prometheus, Netflix Victor	Measure

5.7.1.3 OAI Continuous Integration

The OAI CI framework is a semi-automated process where builds and tests are automatically triggered to help human decisions on merge/pull requests coming from developers. Acceptance of a merge/pull request is still a human decision based on the automated feedback from CI, but also based on the Technical Committee review of the proposed changes.

Both eNB/gNB and EPC/5GC projects are following the workflow described in Figure 82.
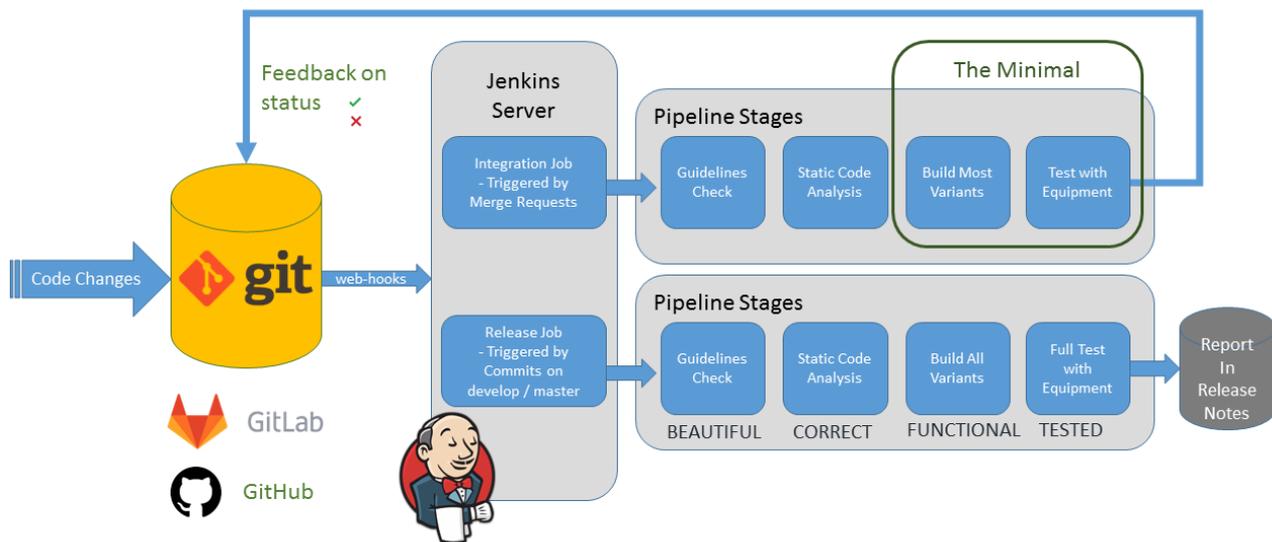
Figure 82: OAI Continuous Integration / Continuous Development Workflow

In the case of the eNB CI workflow, various builds for several Ubuntu and RedHat distributions are performed in isolated Virtual Machines from the ground-up. Then testing is performed on simulators and targets using radio hardware with COTS UEs if available. The tools used in the different pipeline stages are:

- `astyle` for the Guidelines Check
- `cppcheck` and optionally `Coverity Scan` for static code analysis
- building is done using the standard OAI build script in a VM environment for various targets (gNodeB/eNodeB, UE, NR-UE, fronthaul, USRP, etc.) and O/S (Ubuntu 16.04/18.04 Low-Latency, CentOS 7.5 RT). The VM framework for testing is currently based on `uvt-kvm` for Ubuntu.

For RF testing with COTS UEs, several different USRP platforms are used for the RRU/eNodeB/gNodeB targets (USRP B2x0, X3x0, N3x0) along with remotely-controllable COTS UEs in a Faraday cage. The UEs can be configured along with traffic generators (e.g. iperf) using Android `adb-shell` in order to simulate the air-interface. OSA and EURECOM make 16 Cat6 UE + 1 NB-IoT + 1 Cat-M1 available in the test framework for on-demand testing by the OAI community. The live network in Sophia Antipolis put in place during 5G EVE will be made available to the community for testing using this framework.

<u>Full RAN testing tool</u>

For testing the OAI RAN a testing module has been developed including all L1 functions as shown in Figure 83. This mechanism should be used during initial development of new scheduling algorithm extensions to OAI and during continuous integration. This mechanism makes use of the full OAI UE air interface (L1 and protocol stack) replicated to emulate many concurrent UEs connected to the the eNodeB/gNodeB protocol stack via the fronthaul. It allows for a full software emulation and testing of the radio network. The eNodeB/gNodeB portion is identical to the version used for real-time operation. The entire system can easily be deployed in an NFV environment for CI.
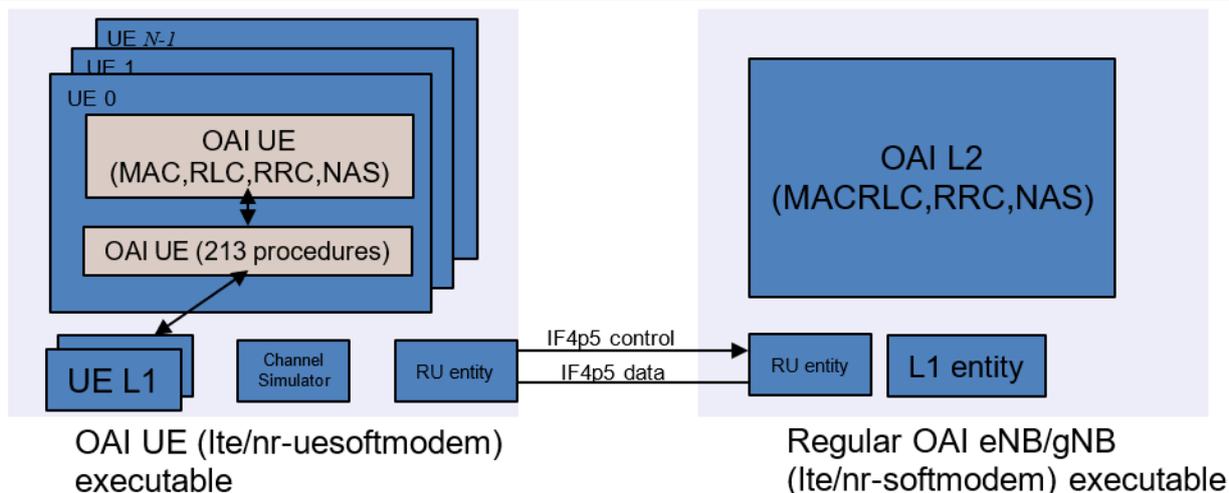
Figure 83: RAN Testing module (IF4p5 interface)

RAN Protocol-only CU and DU testing tool

In order to test either the CU or the DU at the MACRLC-entity interface both for development and regression OAI provides a pure software testing architecture shown in Figure 84. This mechanism should be used during initial development of new scheduling algorithm extensions to OAI and during CI. It is primarily interesting for testing with a large number of synthetic UEs since computation intensive signal processing procedures are not performed. This method should supplement a full test using commercial UEs and different RF platforms or through testing equipment such as Cobham TM500. This mechanism makes use of the OAI UE protocol stack replicated to emulate many concurrent UEs connected to the eNodeB/gNodeB protocol stack via the NFAPI interface. An arbitrary number of UEs can be emulated using this framework, although specific test cases still have to be developed based on the needs of developers. This involves changing the software implementation of the UE testing stub.
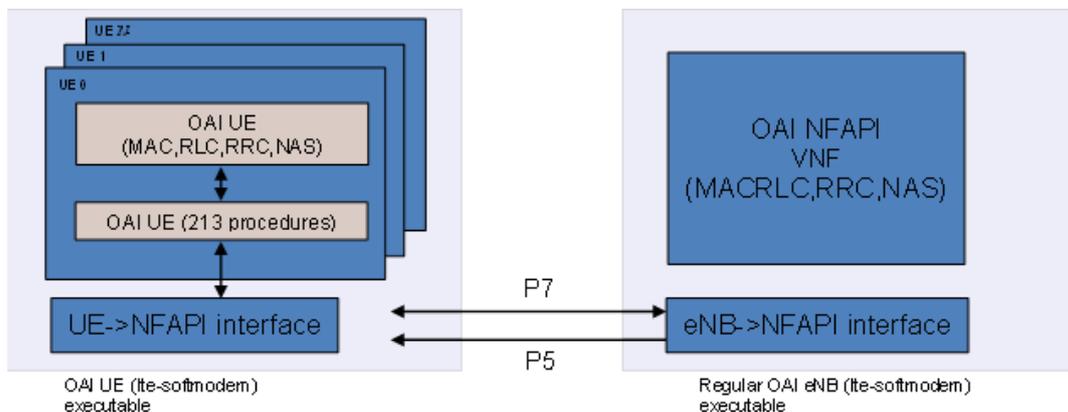
Figure 84: RAN testing module (NFAPI interface)

CI bench for EPC/5G OAI Core Network

The CI framework is also applied to the OAI EPC/5G Core Network (CN) software. The OAI CN software resides in Github [60]. CN developments are tested with third party testers (ng4T, others). In that framework, the ORAN interface developments can benefit from the 5G CN CI bench allowing for testing a number of settings starting with:

- S-GW+P-GW Test
- MME testing (including AMF/SMF split in 5G context)
- HSS/PCRF

- Others

Currently the tests carried out in the OAI CN CI bench Load will focus on functional testing. In future load testing can be negotiated with third party testers as per requirements of the 5G EVE partners.
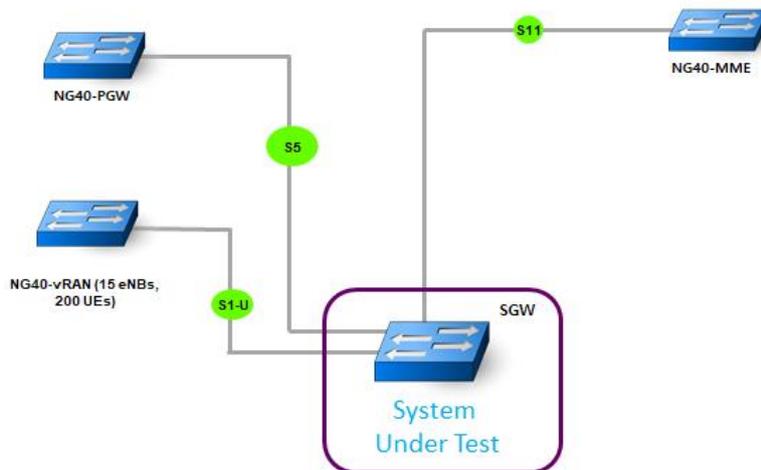
Figure 85: Example of OAI test setting

Figure 85 shows one of the test settings triggered by the CI bench whereby the OAI-SGW is tested with a commercial tester provided by NG4T. Similarly other configurations listed above and 5G variations of them will be available for testing in the CI framework.

5.7.2 Management and resource (HW/SW) provisioning

The capacity to manage the deployment and the service configuration with a high degree of automation is a requirement for 5G networks. In this way the French site facility use each of them their own approach to manage the underlying infrastructure while exposing standard interfaces to the orchestration engines. As an example, Nokia research platform is based on the outcomes of the 5G-PPP NGPaaS [26] project to deliver a Continuous Deployment approach.

In the case of *Flexible Netlab*, the infrastructure is managed by Ansible [69] playbooks and roles, allowing to manage from the low-level server hardware configuration, up to the service deployment and configuration. The structure used in order to manage the system configuration is depicted in Figure 86:
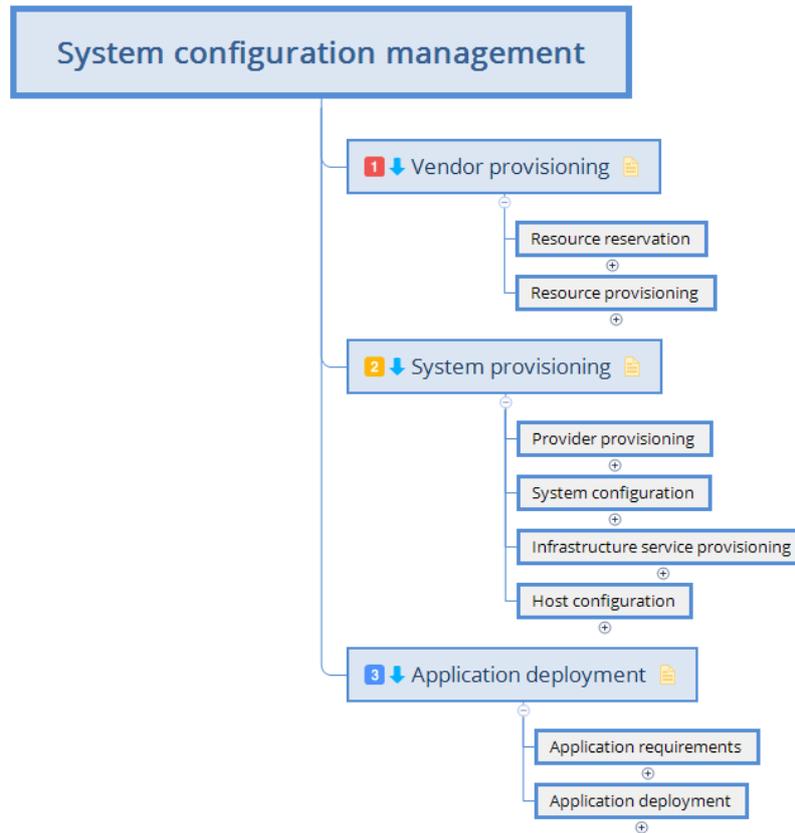
Figure 86: System configuration management overview

The configuration management system has been specified in a modular approach to allow a great flexibility and extensibility. It uses plugins (Ansible roles) to manage each service that is used in the deployment workflow. The following items describe the organization that has been defined to manage the configuration within b<>com ***Flexible Netlab***.

- The vendor provisioning allows to book a physical resource from the DC that performs the low level configuration when needed (provisioning), and manages its status. The vendor provider only manages physical resources, so it will only take part of the deployment workflow when deploying bare metal hosts.
- The system-provisioning manage the instantiation of bare-metal machines, virtual machines and system containers. It allows to apply the system engineering rules adapted to the specific environment where the instance runs.
- The application deployment contains the required information to deploy an application and configure it on the target environment.

As an example, the OpenStack deployment in Flexible Netlab is managed using this tool which allows to book the physical server on the Datacenter, deploy the operating systems, apply the ***Flexible Netlab***system engineering rules, apply the openstack system requirements to each host, and deploy the OpenStack application modules using Open-Stack Ansible[70]. Then, and based on the OpenStack-Ansible functionalities, it allows to manage the OpenStack cluster life cycle: Configuration management, upgrades, scaling up and down.

5.7.3 Supervision tools

Different supervision tools are using to control and having diagnostics about the site facility.

Plug'in monitoring tools: In terms of monitoring tools, Plug'in platform currently use the following open source tools: **Prometheus**, PCP and Vector. Prometheus is used to monitor multiple metrics of the PlayGround such as the number of sessions, and the number of created compute instances, the garbage collection cycles, and

more. The Performance Companion (PCP) and Vector are used in common to monitor our bare-metal servers: CPU and memory usage, load average, networking, I/O to name a few. This combination could be used to supervise all sorts of computes with metrics ranging from system to containers. Other tools could be considered, in no order of importance, among them:

- The TICK suite from influxdata: Telegraf (a metric collector or probe), InfluxDB (timeseries database), Chronograf (a visualization dashboard), and Kapacitor (a data processing engine for alerting) [59];
- Cadvisor (metrics probe) with Grafana (dashboard);
- Cadvisor with an elastic stack (Elastic search for metrics and Kibana for dashboard);
- Statsd (metrics probe) and Graphite (time series database for metrics).

Flexible Netlab proposes a monitoring platform that will provide inputs to the plug'in platform to supervise the French site a single logical site facility. As depicted in the Figure 87, there are two different pipelines.
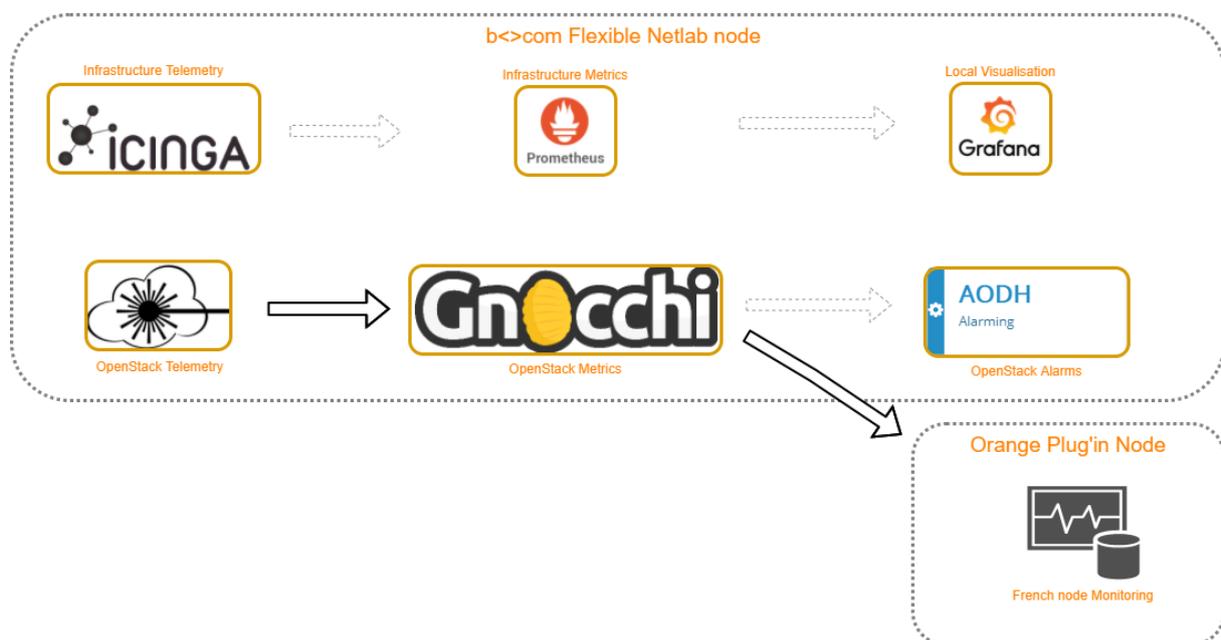
Figure 87: b<>com *Flexible Netlab* Monitoring

- The first pipeline allows to collect data from the global infrastructure and allows b<>com operators to control the infrastructure and the services health status. It is composed by **Icinga telemetry service** which allows to have the infrastructure status in real time. **Prometheus metrics** and **Grafana visualization services** collect the metrics and provides a time series visualization.
- The second pipeline is composed of OpenStack modules providing monitoring and alarming as a service to OpenStack tenants. Here, the metrics are collected by **Ceilometer Telemetry service**. They are collected out of the different OpenStack modules like Nova, Neutron, etc. and aggregated by Ceilometer. These metrics are them sent to **gnocchi metrics service** which provides **metrics-as-a-service** to VIM authorised users.

The way the interconnection is foreseen at the moment, consist in providing the capacity to the Plug'in site facility to access the gnocchi service and collect metrics from VIM about the tenants that are actually deployed to host 5G EVE related experimentations.

5.8 Testing & KPI

One of the 5G EVE ambitions is to deliver Testing-As-A-Service (TaaS) to provide a unified functional and operational infrastructure for vertical industry experimentation. The French site facility will comply with the TaaS requirements.

The OAI UE and eNodeB software grants full access to all the radio transmission layers allowing to collect and analyse all the data required for vertical experimentation.

Wireshark probes will provide the capacity to collect network traffic at the relevant points of the 5G infrastructure. This will enable the KPI collection close to those exposed in Section 2.8 of this document.

5.9 Potential interconnection towards outside

The French sites facilities should be interconnected together to be viewed as a unique site facility that itself should be interconnected with the other European sites for E2E transmission. The 4 French nodes will be interconnected via VPN IPsec tunnels as shown in Figure 88 and viewed as single by the other site facilities. VPN tunnels will be opened towards outside for connecting the other 5G EVE site facilities.
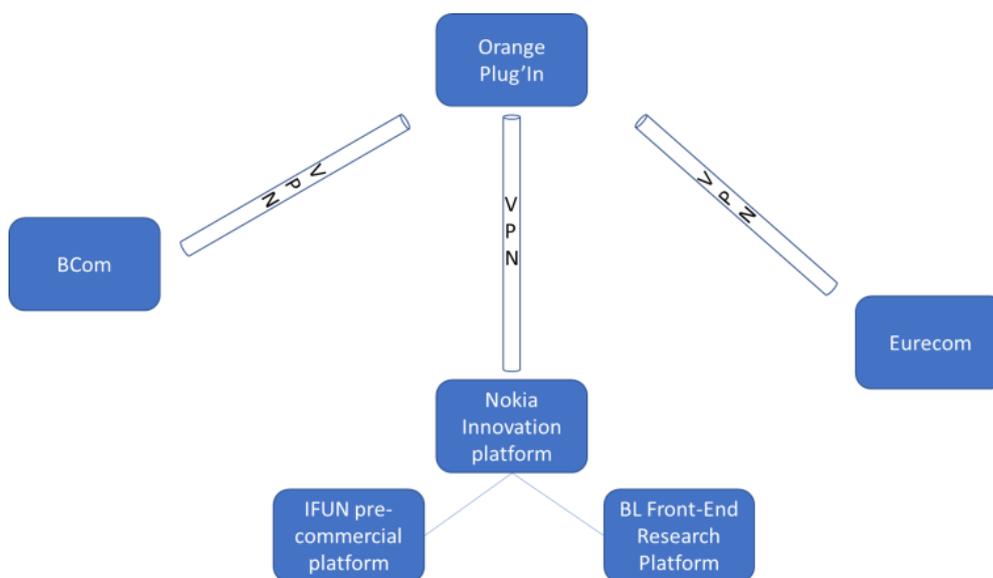
Figure 88: VPN interconnection

Depending on the KPI to support, specific connection should be also studied.

Resources booking and experimentation support will implement. The b<>com experience could be a good example for this management. Indeed, b<>com *__Flexible Netlab__* aims at running several 5G experiments from different projects. While hosting the different VxFs in the datacenter, isolation between the different projects is quite straightforward, thanks to OpenStack tenant isolation. This is not easily achievable on the RAN. While expecting to implement slicing solutions in the future to allow the sharing of radio resources, in the meantime, the RAN resources (eNodeB for instance) are to be booked for a given project with an exclusive usage for a specific period.

For this reason, and while waiting for the project's centralized booking solution, a mail address will be communicated to book the resources.

In the manner, experiments require to have support from the site facility operator when preparing and driving their experimentation. As it is also expected a project's centralized helpdesk solution, a mail address will be used to manage the support requests.

6 Conclusions

This deliverable has provided comprehensive details about the site facilities and their planned implementation by April 2019. For each site facility, the first use-cases that will be implemented, tested and validated in terms of KPI are reminded. Then, the main specifications, components, resources are listed that give information about the 5G network functionalities that will be implemented. These functionalities show that some components are similar from one site to another as well as some specific tools (management, control, etc.). This site facilities description aims at converging towards the common architecture and tools definition that will allow to build the 5G EVE E2E facility.

As a synthesis, Table 12 summarizes these main specifications per site facility.

Table 12: List of the site facility specifications

Specifications	Greek site	Italian site	5TONIC Spanish site	French site
Use-case	Industry 4.0, Smart Energy, Smart Cities	Smart Transport Smart Cities	Smart Tourism, Industry 4.0 Media & Entertainment	Smart Energy, Media & Entertainment
RAN	Ericsson & Nokia	Ericsson	Ericsson & Nokia	Nokia / OAI
Frequency bands	B7/ B38 / B42	B42/B43	B7, B43 (potentially also B20)	14/28/38/42/78/68 + unlicensed
Technologies	NB-IoT, Wi-Fi, 4G+ radio & core, 5G non-standalone, 5G-NR	5G (3GPP R15_Option 3x, as initial deployment) 4G LTE, local WiFi networks and NB-IoT	4G LTE, LTE-M, 5G NR NSA, NB-IoT under evaluation,	5G NR/4G/NB-IoT/LTE-M/WiFi/LoRa
UE	under evaluation	under evaluation	Under evaluation	COST/UE-OAI
CORE	Ericsson vEPC Rel 14/15 Nokia vEPC	3GPP Option 3 (NSA)	Ericsson virtual EPC Release 14 and 5G NSA	Nokia / OAI / Wireless Edge Factory
Orchestration	ETSI NFV MANO	ETSI OpenSource MANO Release 4 (see Section 3.5.1) and the proprietary EO Ericsson Orchestrator	ETSI OpenSource MANO Release 4	ONAP/Cloudify/OSM/ Nokia CloudBand
Interfaces	S1, S11, S6a, S5, S6t	protocol split 3GPP Option 2		FlexRAN/C-RAN/NGFI/ORAN (Table 9)
Software tools	vEPC in-a-box development, XEN, Numpy, Scipy, various	Git/GitHub, OpenStack, (incl. TriCircle, Cyborg, Kuryr) OpenDayLight, OpenSource MANO	OpenStack	OpenStack, ODL, Docker, Vagrant, KVM,
Supervision tools	-	Ceilometer, Panko Monasca, Kafka, Oodh, Gnocchi, Prometheus/Grafana	Supervision tools provided by ETSI OSM Release 4. Ceilometer, Gnocchi, Prometheus/Grafana	Prometheus, Grafana, Inciga

HW/SW resources	USRPs, spectrum analyzers, distributed power generators/ consumers, smart city cloud IoT platform, AGVs, smart ambulances, etc.	Spectrum Analysers, test handsets, test eNB software, RF UEs load emulator, RF attenuators, duplexers, directional couplers, power splitters	3 high-profile servers, each with 8 cores @2.40 GHz, 128 GB for RAM, 8 10Gbps optical Ethernet ports. 24-ports optical switch	Nokia/USRPs/Dell servers/bare-metal servers Specific for RRH
CI/CD				Git/GiTub/GiTLab
Interconnection	GEANT based interconnection available		VPN IPSec Tunnels, GEANT based interconnection available	VPN IPsec tunnels

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Annex A: OneM2M standard interfaces (Http_Rest, Mqtt and COAP)

OneM2M HTTPS

Producer: Data sending according to oneM2M standard

POST https://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>

Http Headers:

X-M2M-Origin: <originator>

X-M2M-RI: <timestamp/random_value>

Content-Type: application/vnd.onem2m-res+json; ty=4
Authorization: Basic *Base64*(<username>:<password>)

Accept: application/json

Example of POST request body:
```
{ "m2m:cin": {
      "con": {
           "temperature":19.1,
           "humidity":56.5,
           "pressure":985,
           "transits":0,
           "sittings":0,
           "pollution":433,
           "light":0.0889
        },
      "cnf": "application/json:0",
      "lbl": ["label1", "label2", "label3"]
   }
 }
```
Note:
- the field "**lbl**" contains a strings array: these are labels that could be used for data search in the container
- the field "**con**" stands for "content" and is the real payload, which can be a JSON but also a text/number single value or other MIME type (specified in the "cnf" field , contentInfo)

Response:

Status: 201 CREATED

X-M2M-RSC: 2001

X-M2M-RI: <timestamp/random_value>
Content-Location: <resource URI>

Consumer: Data reading according to oneM2M standard

GET https://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>

Http Headers:

X-M2M-Origin: <originator>

X-M2M-RI: <timestamp/random_value>
Authorization: Basic *Base64*(<username>:<password>)

Accept: application/json

The above GET request provides only metadata of the container (e.g. container creation date).

To retrieve data use children resource "latest/oldest" or query parameters:

- The following URL is used for reading the latest data inserted in the container:

  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>/la

  ('la' stands for latest)

- The following URL is used for reading the oldest data inserted in the container:

  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>/ol

  ('ol' stands for oldest)

- The following URL is used for reading all the instances stored in the container (note: use this option only for small number of data):

  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5

  In order to limit the number of instances add the query parameter lim

  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5&lim=30

- The following URL is used for reading instances that contain a specific label (the label must be inserted during the creation of the instance):
  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5&lbl=label1

- The following URL is used for reading instances created in a specific period of time:
  http://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5&cra=<dateFrom>&crb=<dateTo>

  ('cra' stands for createdAfter, 'crb' stands for createdBefore)
  The parameters dateFrom and dateTo use the date format yyyyMMddThh:mm:ss and are expressed in UTC (e.g. 20170325T094522)

Consumer: subscription to Data according to oneM2M standard

It is possible to make a subscription to be notified when data are received in a container. The mechanism involves creating a Subscription resource within that container, indicating the target endpoint (accessible via public internet) where you will receive a POST http notification whenever a resource (containing data) is created in the inbox.

Create subscription

POST https://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER

Http Headers:

X-M2M-Origin: <originator>

X-M2M-RI: <timestamp/random_value>

Content-Type: application/vnd.onem2m-res+json; ty=23
Authorization: Basic *Base64*(<username>:<password>)

Accept: application/json

body:

```
{
        "m2m:sub": {
                "rn": "<sub_name>",
                "enc": {
                    "net": [3]
                },
                "nu": ["<url_endpoint>"],
                "nct": 2
        }
}
```

The url_endpoint must be an HTTP/HTTPS endpoint publicly accessible.

Example of response:

Status: 201 CREATED

body:

```
{
    "m2m:sub": {
        "rn": "my_sub",
        "ty": 23,
        "pi": "rJGwZkhhrW",
        "ri": "SJGv7O63B-",
        "ct": "20170719T115303",
        "et": "20270719T115303",
        "lt": "20170719T115303",
        "st": 0,
        "nu": [
            "http://www.mysite.com:8080/api/"
        ],
        "acpi": [
            "/onem2m/acp_nbiot"
        ],
```

```
        "enc": {
            "net": [
                  3
            ]
        },
        "nct": 2,
        "cr": "nbiot_prod"
    }
}
```

HTTP notification sent on data received

When new data are received on the oneM2M platform (inside the container where there is a sub), an HTTP POST is done to url_endpoint specified in subscription:

Example of json object sent via POST to url_endpoint:

```
{
      "m2m:sgn" : {
            "net" : "3",
            "sur" : "/onem2m/livorno/parking/01/sub",
            "nec" : "",
            "nev" : {
                  "rep" :
                  {
                      "m2m:cin": {
                        "pi": "Byf34qb0pg",
                        "ty": 4,
                        "ct": "20170505T092155",
                        "ri": "ByfhVN6Y1b",
                        "rn": "4-20170505092155986eBfi",
                        "lt": "20170505T092155",
                        "et": "20270505T092155",
                        "acpi": [ "/onem2m/acp_livorno" ],
                        "lbl": [ "03" ],
                        "st": 4186,
                        "cs": 15,
                        "cr": "livorno_prod",
                        "cnf": "application/json:0",
                                        "con":          "{\"D_TS\":\"2017-05-
05T09:21:59.4\",\"F_VALORE1\":0,\"F_VALORE2\":5.5,\"F_VALORE3\":42949
67295,\"F_VALORE4\":444,\"F_VALORE5\":555,\"F_VALORE6\":0,\"S_ID_SENS
ORE\":\"3\"}"
                      }
                  }
            }
      }
}
```

OneM2M MQTT

OneM2M defines a request/response paradigm to interact with the CSE Entities. Since the MQTT protocol uses a different paradigm (publish/subscribe), an adaptation has to be done.

To achieve this communication via the MQTT Protocol, a **request topic** has been defined where the client will be able to send the serialized request. Then the response will be posted on a **response topic** where the client will retrieve the serialized response. All information concerning the operation, the response status and other parameters will be held into the serialized request/response.

The **request topic** is formulated as the following:

```
/oneM2M/req/<originator>/<cse-id>/<serialization-format>?auth=<authorization>
```

The <cse-id> shall be the CSE-ID that is listening on the broker and the <originator> correspond to the originator usually provided into the X-M2M-Origin header.

The <cse-id> for ICON-Lab platform is *onem2m_e65baa96*.

Then the last information of the topic is serialization format of the request, <serialization-format>:

* xml for XML format, or
* json for JSON format

After standard topic definition has to be added a query string parameter named auth where <authorization> is equal to *Base64*(<username>:<password>)

The **response topic** is constructed based on the request topic.

```
/oneM2M/resp/<originator>/<cse-id>/<serialization-format>
```

The payload published into the topic has these main parameters:

short name	Parameter name	Usage
fr	From	Originator of the request (same as X-M2M-Origin)
to	To	Destination of the request
op	Operation	The operation to perform (CREATE, RETRIEVE, ...), see table below
rqi	Request Identifier	Correlation ID for the request and response (same as X-M2M-RI)
pc	Primitive Content	Content of the request (e.g., resource to be created)
ty	Type	The type of the resource to be created
rsc	Response Status Code	The oneM2M response status code

The Operation values are:

Operation	Value
CREATE	1

RETRIEVE	2
UPDATE	3
DELETE	4
NOTIFY	5
DISCOVERY	6

Producer: Data sending according to oneM2M standard

1. **Connect to 156.54.99.159:1883**

2. **Subscribe to topic /oneM2M/resp/<originator>/<cse-id>/json**

3. **Publish to topic /oneM2M/req/<originator>/<cse-id>/json?auth=<authorization> the message:**

```
{
    "m2m:rqp" : {
        "op" : "1",
        "to" : "/onem2m/<APPLICATION_ENTITY>/<CONTAINER>",
        "fr" : "<originator>",
        "rqi" : <timestamp/random_value>,
        "ty" : "4",
        "pc" : {
            "m2m:cin" : {
                "cnf" : "application/json:0",
                "con": {
                    "temperature":19.1,
                    "humidity":56.5,
                    "pressure":985,
                    "transits":0,
                    "sittings":0,
                    "pollution":433,
                    "light":0.0889
                }
            }
        }
    }
}
```

4. **Message received on topic /oneM2M/resp/<originator>/<cse-id>/json:**

```
{
    "m2m:rsp" : {
```

```
        "rsc" : 2001,
        "rqi" : <timestamp/random_value>,
        "pc" : {
            "m2m:cin" : {
                "rn" : "4-201709291012319322cCt",
                "ty" : 4,
                "pi" : "rkMBzfQVGb",
                "ri" : "S1Mdc35sj-",
                "ct" : "20170929T101231",
                "et" : "20270929T101231",
                "lt" : "20170929T101231",
                "st" : 412,
                "cs" : 3,
                "con": {
                "temperature":19.1,
                "humidity":56.5,
                "pressure":985,
                "transits":0,
                "sittings":0,
                "pollution":433,
                "light":0.0889
              },
                "cnf" : "application/json:0",
                "cr" : "<originator>"
            }
        }
    }
  }
```

Consumer: Data reading according to oneM2M standard

1. **Connect to 156.54.99.159:1883**

1. **Subscribe to topic /oneM2M/resp/<originator>/<cse-id>/json**

2. **Publish to topic /oneM2M/req/<originator>/<cse-id>/json?auth=<authorization> the message:**

```
{
        "m2m:rqp" : {
                "op" : "2",
                "to" : "<RESOURCE URL>",
                "fr" : "<originator>",
                "rqi" : <timestamp/random_value>,
                "pc" : ""
        }
}
```

3. **Message are received on topic /oneM2M/resp/<originator>/<cse-id>/json.**

The <RESOURCE URL> defines the data requested by means path and/or query parameters (same as HTTP):

- The following URL is used for reading the latest data inserted in the container:

  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>/la

  ('la' stands for latest)

- The following URL is used for reading the oldest data inserted in the container:

  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>/ol

  ('ol' stands for oldest)

- The following URL is used for reading all the instances stored in the container (note: use this option only for small number of data):

  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5

  In order to limit the number of instances add the query parameter lim

  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5&lim=30

- The following URL is used for reading instances that contain a specific label (the label must be inserted during the creation of the instance):
  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>?rcn=5&lbl=label1

- The following URL is used for reading instances created in a specific period:
  /onem2m/<APPLICATION_ENTITY>/<CONTAINER>? rcn=5&cra=<dateFrom>&crb=<dateTo>

  ('cra' stands for createdAfter, 'crb' stands for createdBefore)

The parameters `dateFrom` and `dateTo` use the UTC date format `yyyyMMddThh`:mm:ss (e.g. 20170325T094522)

<u>Consumer: MQTT subscription to Data according</u>

It is possible to make a subscription to be notified when data are received in a container. The mechanism involves creating a Subscription resource within that container, indicating MQTT broker where you will be notified with a messege whenever a resource (containing data) is created in the inbox.

<u>Create subscription</u>

Request:

POST https://<ONE_M2M_SERVER>/onem2m/<APPLICATION_ENTITY>/<CONTAINER>

Http Headers:

X-M2M-Origin: <originator>

X-M2M-RI: <timestamp/random_value>

Content-Type: application/vnd.onem2m-res+json; ty=23
Authorization: Basic *Base64*(<username>:<password>)

Accept: application/json

body:

```
{
      "m2m:sub": {
            "rn": "<sub_name>",
            "enc": {
               "net": [3]
            },
            "nu": ["<mqtt_url_broker >"],
            "nct": 2,
            "nec": "tim_ri"
      }
}
```

The mqtt_url_broker must be the MQTT endpoint publicly accessible of our OneM2M platform.
The originator is the same of X-M2M-Origin.

Example of response:

Status: 201 CREATED

body:

```
{
    "m2m:sub": {
        "rn": "my_sub_mqtt",
        "ty": 23,
        "pi": "rJGwZkhhrW",
```

```
        "ri": "SJGv7O63B-",

        "ct": "20170719T115303",

        "et": "20270719T115303",

        "lt": "20170719T115303",

        "st": 0,

        "nu": [

            "mqtt://156.54.99.159:1883"

        ],

        "acpi": [

            "/onem2m/acp_nbiot"

        ],

        "enc": {

            "net": [

                3

            ]

        },

        "nct": 2,

        "nec": "tim_ri",

        "cr": "nbiot_prod"

    }

}
```

MQTT notification published on data received

When new data are received on the oneM2M platform (inside the container where there is a sub), a message will be published to topic **/onem2m/<APPLICATION_ENTITY>/<CONTAINER>/<SUB_NAME>**.

Example of json published on /onem2m/tester/prova2/sub_mqtt:

```
{
        "m2m:rqp" : {
            "op" : 5,
            "net" : "3",
            "to" : "/onem2m/tester/prova2/sub_mqtt",
            "fr" : "onem2m_e65baa96",
            "rqi" : "rqi-20180302083549116bwxa",
            "pc" : {
                "m2m:sgn" : {
                    "net" : "3",
                    "sur" : "/onem2m/tester/prova2/sub_mqtt",
                    "nec" : "tim",
                    "nev" : {
                        "rep" : {
                            "m2m:cin" : {
                                "rn" : "4-20180302083549016ixKn",
                                "ty" : 4,
                                "pi" : "rkMBzfQVGb",
                                "ri" : "SyM6k6tUOG",
                                "ct" : "20180302T083549",
                                "et" : "20280302T083549",
                                "lt" : "20180302T083549",
                                "st" : 434,
                                "cs" : 8,
                                "con" : "01AA0022",
```

```
                                             "acpi" : ["/onem2m/acp_tester"],
                                             "lbl"   :   ["udp",   "ip:172.23.0.59",
"port:5683", "length:4", "test"],

                                             "cnf" : "plain/text:0",
                                             "cr" : "tester_prod"
                                    }
                            }
                    }
                }
            }
        }
}
```

OneM2M CoaP

OneM2M use CoaP methods such as GET, POST, PUT, DELETE to retrieve, create, modify, delete resources and binary CoaP options to map HTTP headers.

Consumer: Data access with OM2M standard

COAP GET REQUEST OPTIONS: (client Nodejs example)

```
host:      156.54.99.159
port:      5683
method: get
pathname: <Resource URI>
confirmable: true
options: {
        'Accept':'application/json'
}
```

<Resource URI>: represents the resource to be retrieved.

COAP BINARY VALUE OneM2M Request Options:

256 (X-M2M-Origin): <originator>

257 (X-M2M-RI): <timestamp/random_value>

COAP BINARY VALUE OneM2M Custom Request Options for Basic Authentication:
271 (Custom Auth): *Base64*(<username>:<password>)

Example with COAP Node.js javascript client (read last value "la"):

```
var options = {
   host: '156.54.99.159',
   port: 5683,
   pathname: "/onem2m/tester/prova2/la",
   method: 'get',
   confirmable: 'true',
   options: {
       'Accept': 'application/json'
    }
};
var bodyString = '';
var responseBody = '';
var req = coap.request(options);
req.setOption("256",new Buffer("tester_cons"));// X-M2M-Origin
```

```
req.setOption("257", new Buffer('123'));     // X-M2M-RI
req.setOption("271", new Buffer(Base64.encode(username+":"+password))
req.on('response', function (res) {
      res.on('data', function () {
        responseBody += res.payload.toString();
      });
      res.on('end', function () {
          if(res.code == '2.05') {
              coap_state = 'ready';
              console.log('[pxy_coap] coap ready, text request OK');
           }
      });
});
req.write(bodyString);
req.end();
```

Producer: Data creation with OM2M standard

***COAP POST REQUEST OPTIONS*:**

host: 156.54.99.159
port: 5683
method: post
pathname: <Resource URI>
confirmable: true
options:{
        'Accept':'application/json'
}

<Resource URI>**:** Represents the resource to be created, the type must be specified in the oneM2M-TY option.

COAP BINARY VALUE OneM2M Request Options:

256 (X-M2M-Origin): <originator>

257 (X-M2M-RI): <timestamp/random_value>

267 (X-M2M-TY): 4 (ContentInstance)

COAP BINARY VALUE OneM2M Custom Request Options for Basic Authentication:
271 (Custom Auth): *Base64*(<username>:<password>)

Example with COAP Node.js javascript client:

```
var options = {
    host: '156.54.99.159',
    port: 5683,
    pathname: "/onem2m/tester/prova2",
    method: 'post',
    confirmable: 'true',

    options: {
        'Content-Format': 'application/json'
    }
};

    var bodyString = new Buffer('{"m2m:cin":{ "con":{"temperature":"44"}}}');
    var responseBody = '';
    var req = coap.request(options);
    req.setOption("256", new Buffer("tester_prod"));       // X-M2M-Origin
    req.setOption("257", new Buffer('0001'));     // X-M2M-RI
    req.setOption("267", new Buffer([4])); // ty
```

```
   req.setOption("271", new Buffer(Base64.encode(username+":"+password))
   req.on('response', function (res) {
       res.on('data', function () {
           responseBody += res.payload.toString();
           console.log(responseBody);
       });


   res.on('end', function () {
       console.log("on end response: ",JSON.stringify(res));
       if(res.code == '2.05') {
           coap_state = 'ready';
           console.log('[pxy_coap] coap ready, text request OK');
        }
   });
});
req.write(bodyString);
req.end();
```

Annex B: Current OAICN functionalities & interfaces

large classification	middle classification	small classification	3GPP Reference	Status	Comment	Commit/Date/Tag/Branch
P-GW	interface	GTP-based S5/S8 interface		not supported	missing split between SGW and PGW	
P-GW	interface	Gx interface		not supported	contribution of a tiny pcef and pcrf written in C++.	
P-GW	interface	SGi interface		supported		
P-GW	functionality	Per-user based packet filtering (by e.g. deep packet inspection)	3GPP TS 23.401 V10.13.0 4.4.3.3	supported	Would not speak of DPI, based on OVS capabilities.	
P-GW	functionality	Lawful Interception	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UE IP address allocation	3GPP TS 23.401 V10.13.0 4.4.3.3	supported	Dynamically allocated by PGW	
P-GW	functionality	Transport level packet marking in the uplink and downlink, e.g. setting the DiffServ Code Point, based on the QCI, and optionally the ARP priority level, of the associated EPS bearer	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	Accounting for inter-operator charging: for home routed roaming, the P-GW shall collect and report the uplink and downlink data volume (per EPS bearer) as received from and sent to the serving node	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UL and DL service level charging as defined in TS 23.203 (e.g. based on SDFs defined by the PCRF, or based on deep packet inspection defined by local policy)	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	Interfacing OFCS through according to charging principles and through reference points specified in TS 32.240	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UL and DL service level gating control as defined in TS 23.203	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UL and DL service level rate enforcement as defined in TS 23.203 (e.g. by rate policing/shaping per SDF)	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UL and DL rate enforcement based on APN-AMBR (e.g. by rate policing/shaping per aggregate of traffic of all SDFs of the same APN	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		

		that are associated with Non-GBR QCIs)				
P-GW	functionality	DL rate enforcement based on the accumulated MBRs of the aggregate of SDFs with the same GBR QCI (e.g. by rate policing/shaping)	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	DHCPv4 (server and client) and DHCPv6 (client and server) functions	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	The network does not support PPP bearer type in this version of the specification. Pre-Release 8 PPP functionality of a GGSN may be implemented in the PDN GW	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	packet screening	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
P-GW	functionality	UL and DL bearer binding as defined in TS 23.203	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported	BBERF not implemented	
P-GW	functionality	UL bearer binding verification as defined in TS 23.203	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported	BBERF not implemented	
P-GW	functionality	Functionality as defined in RFC 4861	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported	IPv6 not supported	
P-GW	functionality	Accounting per UE and bearer	3GPP TS 23.401 V10.13.0 4.4.3.3	not supported		
S-GW	interface	GTP-based S5/S8 interface		not supported	missing split between SGW and PGW	
S-GW	interface	S1-U interface		supported		
S-GW	interface	S11 interface		supported		
S-GW	functionality	the local Mobility Anchor point for inter-eNodeB handover (except when user data is transported using the Control Plane CIoT EPS Optimisation)	3GPP TS 23.401 V10.13.0 4.4.3.2	supported	X2HO supported	
S-GW	functionality	sending of one or more "end marker" to the source eNodeB, source SGSN or source RNC immediately after the Serving GW switches the path during inter-eNodeB and inter-RAT handover, especially to assist the reordering function in eNodeB	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported		
S-GW	functionality	Mobility anchoring for inter-3GPP mobility (terminating S4 and relaying the traffic between 2G/3G system and PDN GW)	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported		

S-GW	functionality	ECM-IDLE mode downlink packet buffering and initiation of network triggered service request procedure and optionally Paging Policy Differentiation	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported	buffering is not supported for paging in idle mode	
S-GW	functionality	Lawful Interception	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported		
S-GW	functionality	Packet routing and forwarding	3GPP TS 23.401 V10.13.0 4.4.3.2	supported	Nat of UE traffic is no more supported on P-GW	
S-GW	functionality	Transport level packet marking in the uplink and the downlink, e.g. setting the DiffServ Code Point, based on the QCI, and optionally the ARP priority level, of the associated EPS bearer	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported	could be supported	
S-GW	functionality	Accounting for inter-operator charging. For GTP-based S5/S8, the Serving GW generates accounting data per UE and bearer	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported		
S-GW	functionality	Interfacing OFCS according to charging principles and through reference points specified in TS 32.240	3GPP TS 23.401 V10.13.0 4.4.3.2	not supported		
MME	interface	S1-MME interface		supported	Still rel 10 should be upgraded to rel 14 soon	
MME	interface	S11 interface		supported		
MME	interface	S6a interface		not supported	Rel14	develop branch
MME	interface	S10 interface		supported		develop branch
MME	functionality	NAS signalling	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	NAS signalling security	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	Inter CN node signalling for mobility between 3GPP access networks (terminating S3)	3GPP TS 23.401 V10.13.0 4.4.2	not supported	Intra LTE HO only	
MME	functionality	UE Reachability in ECM-IDLE state (including control, execution of paging retransmission and optionally Paging Policy Differentiation)	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	Tracking Area list management	3GPP TS 23.401 V10.13.0 4.4.2	supported		

MME	functionality	Mapping from UE location (e.g. TAI) to time zone, and signalling a UE time zone change associated with mobility	3GPP TS 23.401 V10.13.0 4.4.2	not supported		
MME	functionality	PDN GW and Serving GW selection	3GPP TS 23.401 V10.13.0 4.4.2	supported	spgw selection & neighboring MME selection via WRR	
MME	functionality	MME selection for handovers with MME change	3GPP TS 23.401 V10.13.0 4.4.2	supported	S1 (inter (S10) and intra MME S1AP handover), X2 HO supported. Dbeken: multi bearer handover partly implemented (focus first on mesh enabled PCRF, later direct dedicated bearer establishment via S1AP handover.	develop branch
MME	functionality	SGSN selection for handovers to 2G or 3G 3GPP access networks	3GPP TS 23.401 V10.13.0 4.4.2	not supported		
MME	functionality	Roaming (S6a towards home HSS)	3GPP TS 23.401 V10.13.0 4.4.2	not supported		
MME	functionality	Authentication	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	Authorization	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	Bearer management functions including dedicated bearer establishment	3GPP TS 23.401 V10.13.0 4.4.2	not supported	establishment of dedicated bearer will be automatically triggered internally. Dbeken: only network (pcrf/pcef) initated dedicated bearer establishment supported	
MME	functionality	Lawful Interception of signalling traffic	3GPP TS 23.401 V10.13.0 4.4.2	not supported		
MME	functionality	Warning message transfer function (including selection of appropriate eNodeB)	3GPP TS 23.401 V10.13.0 4.4.2	not supported		
MME	functionality	UE Reachability procedures	3GPP TS 23.401 V10.13.0 4.4.2	supported		
MME	functionality	Support Relaying function (RN Attach/Detach)	3GPP TS 23.401 V10.13.0 4.4.2	not supported		