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D2.3: 5G-HEART Network Architecture and Slice Definition

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Deliverable lead	Haeyoung Lee (UOS)
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Authors	Haeyoung Lee, Seiamak Vahid (UOS), Andres Gonzalez, Per H. Lehne (Telenor), Jarno Pinola (VTT), Toni Dimitrovski, Iñaki Martín Soroa (TNO), Christina Lessi (OTE), Ioannis Tzanettis (WINGS)
Reviewers	Ilia Pietri (ICOM), Ioannis Tzanettis (WINGS), George Fourtinas (OCC), Ioannis Patsouras, Panayiotis Verrios (ACTA), Mikko Uitto (VTT)

Abstract	This deliverable provides the design of the network architecture for the 5G-HEART project. Since five network facilities, 5G-VINNI, 5GENESIS, 5G-EVE, 5GTN and 5Groningen are utilized for 5G end-to-end testbeds, the architecture of each network is investigated. In addition, configuration of the infrastructure elements and their architecture for the support of the 5G-HEART use cases with the available slices are also defined.
Keywords	5G testbed, radio network architecture, NFV, network slicing, RAN slicing

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Nature of the deliverable:	R[1]	
Dissemination Level		
PU	Public, fully open, e.g. web	✓
CI	Classified, information as referred to in Commission	
CO	Confidential to 5G-HEART project and Commission Services	

[1] R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc.

EXECUTIVE SUMMARY

Deliverable D2.3 of 5G-HEART, entitled "5G-HEART Network Architecture and Slice Definition", is mainly concerned with the analysis of network architecture and slicing definition of testbed facilities to support scenarios/use-cases of all three verticals, namely Healthcare, Transport and Aquaculture of 5G-HEART.

While this project exploits five tested facilities, which are three ICT-17 facilities (5G-VINNI, 5GENESIS, and 5G-EVE), and two national 5G test platforms (5GTN and 5Groningen), a high-level architecture of testbed facilities is firstly studied by focusing on three parts, core & transport, radio & edge, and management & orchestration. While testbed facilities commonly aim to provide an end-to-end 5G testing facility, the standards proposed by 3GPP are seriously considered in implementation of testbed facilities. Facilities are also commonly targeting their support of 5G NR in Non-Standalone and Standalone modes while the 5G-EVE platform only considers a Non-Standalone approach. The detailed analysis of the overall characteristics and architecture of each testbed facility are included in this deliverable.

Another purpose of this report is to investigate slicing methodology to support scenarios/use-cases of different KPIs of Healthcare, Transport and Aquaculture verticals. For this, the analysis of scenarios/use -cases in D2.1 [1], and specification of network KPIs required for different scenarios/use cases studied in D2.2 [2] are exploited as inputs. Identification of supportable slice types and flexible network configuration to support various types of slices are studied for each testbed facility. In order to effectively support diverse scenarios/use-cases, three types of slice are defined: eMBB, mMTC and uRLLC categories. In 5G-VINNI, for use-cases requiring rather complex KPIs of a combination of different service categories (e.g., eMBB and uRLLC), an additional customized slice type is also defined. After explanation about slice definitions, mapping of serving scenarios/use-cases with appropriate slice types is specified and configuration of the specific slices is also discussed for each facility. Serving subcases/scenarios and their slice types are listed in the following tables.

- 5G-VINNI

Vertical	Subcases/Scenarios		Type
Healthcare	H1B	AR/VR enabled ultrasound examination	eMBB, uRLLC
	H1B	Robotic-assisted ultrasound examination	eMBB, uRLLC
	H1D	Critical health event	uRLLC
	H2A	Automatic pill camera anomaly detection	eMBB, uRLLC
	H3A	Vital-sign patch prototype	mMTC
Aquaculture	A1S1	Sensory data monitoring	mMTC
	A1S2	Camera data monitoring	eMBB
	A1S4	Edge and cloud-based computing	eMBB, mMTC
	A1S5	Cable-free communication on site	eMBB, mMTC

- 5GENESIS

Vertical	Subcases/Scenarios		Type
Transport	T1S1&T1S2	High bandwidth in-vehicle Situational awareness and see-through for platooning	eMBB. uRLLC
	T2S3	Quality of service (QoS) for advanced driving	uRLLC
	T3S1	Tele-operated support (TeSo)	eMBB, uRLLC
	T4S3	Smart traffic corridors	mMTC

	T4S4	Location based advertising	mMTC
	T4S5	End-to-end (E2E) slicing	Generic functionality applicable to all scenarios
	T4S6	Vehicle sourced high-definition (HD) mapping	mMTC
	T4S7	Environmental services	mMTC

- 5G-EVE

Vertical	Subcases/Scenarios		Type
Healthcare	H1E	Aquaculture remote health monitoring	eMBB, uRLLC, mMTC
Aquaculture	A1S1	Sensory data monitoring	mMTC
	A1S2	Camera data monitoring	eMBB
	A1S3	Automation and actuation functionalities	eMBB, uRLLC

- 5GTN

Vertical	Subcases/Scenarios		Type
Healthcare	H1A	Educational Surgery; 5G for remote learning and remote attendance of clinical operations.	eMBB
Transport	T2S4	Human Tachograph	uRLLC
	T4S1	Vehicle Prognostics	mMTC
	T4S2	Over-the-air (OTA) Updates	mMTC

- 5Groningen

Vertical	Subcases/Scenarios		Type
Healthcare	H1C	Smart ambulance streaming video and patient vitals to control centre	eMBB
Transport	T2S1	Smart junctions and network assisted & cooperative collision avoidance (CoCa)	uRLLC

Since the testbed facilities are capable of supporting multiple types of slices concurrently, multiple subcases/scenarios requiring different service types (e.g., A1S1 and A1S2) can be trialled simultaneously. There are also individual subcase/scenario where multiple types of slices are utilised (e.g., H1B, H2A, A1S4, etc.) in the above mapping tables. Those trials including multiple types of service characteristics can be also implemented on top of the networks' multi-slicing capability. In addition, such capability is one of the key enablers to support the different verticals (of different type of services) on top of a single 5G network at the same time.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5GaaS	5G as a Service
5GC	5G Core
5GENESIS	5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing
5G-EVE	5G European Validation platform for Extensive trials
5GIC	5G Innovation Centre
5G NR	5G New Radio
5G PPP	5G Infrastructure Public Private Partnership
5GTN	5G Test Network
5GTNF	5G Test Network Finland
5G-VINNI	5G Verticals Innovation Infrastructure
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AI/ML	Artificial Intelligence/Machine Learning
AP	Access Point
API	Application Programming Interface
APN	Access Point Name
AR/VR	Augmented Reality/Virtual Reality
ARP	Allocation and Retention Priority
ARPU	Average Revenue per User
AUSF	Authentication Server Function
BGP	Border Gateway Protocol
CA	Carrier Aggregation
CaaS	Container-as-a-Service
CAM	Common Awareness Message
CAPEX	Capital Expenditures
CBND	Cloud Band Network Director
CC	Critical Communications
CCTV	Closed Circuit Television
CDN	Content Delivery Network
CEE	Cloud Execution Environment
CFS	Customer Facing Service
CIC	Cloud Infrastructure Controller

CN	Core Network
CNL	Converging Networks Laboratory
CoCA	Cooperative Collision Avoidance
CoMP	Coordinated Multipoint
COTS	Commercial of the Shelf
CP	Control Plane
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CSMF	Communication Service Management Function
CSP	Communication Service Provider
CSR	Cell Site Router
CUDB	Centralized User Database
DB	Database
DCI	Downlink Control Information
DCN	Desired Core Network
DÉCOR	Dedicated Core Network
DL	Downlink
DNN	Data Network Name
DNS	Domain Name System
DWDM	Dense Wavelength Division Multiplexing
E2E	End-to-End
E2E-SO	End-to-End Service Operations and Management
eCPRI	evolved Common Public Radio Interface
ECG	ElectroCardioGram device
ECU	Engine Control Unit
ELCM	Experiment Lifecycle Manager
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
EMS	Element Management System
ENM	Ericsson Network Manager
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex

FS	File Server
Funet	Finnish University Research Network
GPRS	General Packet Radio Service
G-VNFM	Generic-Virtualised Network Function Management
HD	High Definition
HOM	Higher Order Modulation
HSS	Home Subscriber Server
HT	Hyper Thread
HW	Hardware
IaaS	Infrastructure as a Service
IBW	Instantaneous Bandwidth
ICT	Information and Communications Technology
ID	Identifier
IoT	Internet of Things
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IRU	Indoor Radio Unit
ITU	International Telecommunication Union
JANET	Joint Academic NETwork
KPI	Key Performance Indicator
KVM	Kernel-based Virtual Machine
LAN	Local Area Network
LCM	Lifecycle Management
LLD	Low level design
LoA	Level of Automation
LoRa	Long Range
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MANO	Management and Network Orchestration
MBB	Mobile BroadBand
MCL	Max Coupling Loss
MCS	Modulation Coding Scheme
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
mIoT	massive Internet of Things

MME	Mobility Management Entity
mMTC	massive Machine Type Communications
MQTT	Message Queuing Telemetry Transport
MTC	Machine Type Communication
N3IWF	Non-3GPP Interworking Function
NA	Not Applicable
NasS	Network Assistance Server
NBI	North Bound Interface
NB-IoT	Narrowband Internet of Things
NCIR	Nokia Cloud Infrastructure
NEST	Network Slice Template
NetApp	Network Application
NF	Network Function
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NFVO	Network Function Virtualisation Orchestrator
NM	Network Manager
NMS	Network Management System
NR	New Radio
NRF	Network Repository Function
NS	Network Service
NSA	Non-Standalone
NSD	NS Descriptor
NSI	Network Slice Instance
NSMF	Network Slice Management Function
NSO	Network Service Orchestration
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
NST	Network Slice Template
NTP	Network Time Protocol
OAI	Open Air Interface
OBD	On-Board Diagnostics
OCP	Open Computer Project
ODL	OpenDayLight
OFDM	Orthogonal Frequency Division Multiplexing

OMGBD	OpenMTC Gateway, Backend and Dashboard
OPEX	Operating Expenditures
OSM	Open Source MANO
OSPF	Open Shortest Path First
OSS	Operations Support System
OSS/BSS	Operations and Business Support Systems
OR	Open-Rack
OTA	Over-the-Air
OTT	Over-the-Top
OVS	Open vSwitch
PCF	Policy Control Function
PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
PFCP	Packet Forwarding Control Protocol
PGW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PNF	Physical Network Function
PtP	Point-to-Point
PUCCH	Physical Uplink Control Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RD	Radio Dot
RDI	Radio Dot Interface
REM	Radio Environmental Map
REST	Representational State Transfer
RFSP	RAT/Frequency Selection Priority
RO	Resource Orchestration
ROC	Remote Operations Centre
ROV	Remotely Operated Vehicle

RSU	Roadside Unit
RTT	Round Trip Time
RRH	Remote Radio Head
SA	Standalone
SAPC	Service-Aware Policy Controller
SBA	Service Based Architecture
SCP	Secure copy
SCS	Subcarrier Spacing
SDM-C	Software Defined Mobile Network Controller,
SDM-X	Software Defined Mobile Network Coordinator
SDN	Software Defined Networking
SDU	Service Data Unit
SGW	Serving Gateway
SIM	Subscriber Identity Module
SPGW	Serving Packet Data Network Gateway
SLA	Service Level Agreement
SME	Small to Medium Enterprise
SMF	Session Management Function
SST	Slice/Service Type
SW	Software
S-VNFM	Specific-Virtualised Network Function Management
TAI	Tracking Area Identifier
TCP	Transport Control Protocol
TDD	Time Division Duplex
TeSo	Teleoperated Support
UDM	Unified Data Management
UDR	Unified Data Repository
UDR	User Defined Route
UE	User Equipment
UHD	Ultra-High Definition
UHDTV	Ultra-High Definition Television
UL	Uplink
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications

USRP	Universal Software Radio Peripheral
V2X	Vehicle-to-everything
VEPC	Virtual EPC
vEPG	virtual Evolved Packet Gateway
VCIC	Virtualized Cloud Infrastructure Controller
vCPU	virtual Central Processing Unit
VIM	Virtualised Infrastructure Manager
VIP	Virtual Internet Protocol
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualised Network Function
VNFD	VNF Descriptors
VNFM	Virtualised Network Function Management
vPGW	virtual Packet Data Network Gateway
VPN	Virtual Private Network
vSGSN	virtual Serving GPRS Support Node
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
WIM	WAN Infrastructure Manager
xMBB	extreme Mobile Broadband

1 INTRODUCTION

The 5G for Health, AquacultuRe and Transport (5G-HEART) validation trials project performs vertical validation trials on top of five testbed facilities, three ICT-17 facilities (5G-VINNI, 5Genesis, and 5G-EVE) and two national 5G test platforms (5GTN and 5Groningen), with use-cases from three different vertical domains. The selected verticals for 5G-HEART trials are Healthcare and Transport, both of which have been identified as priority vertical sectors for Europe, and Aquaculture, which is seen as an additional high potential application area by the 5G Infrastructure Association. In early works of WP2, the analysis of scenarios/use-cases was carried out and network KPIs to support different scenarios/use cases were identified. Outcomes of those works are included in D2.1 [1] and D2.2 [2].

The purpose of this deliverable D2.3 "5G-HEART Network Architecture and Slice Definition" is to study a high-level network architecture by focusing on support of 5G-HEART trials. While five test facilities are exploited, their network structure and configuration are investigated to support pre-defined scenarios/use cases in three verticals. While each testbed facility is studied in terms of their network architecture and slice definitions in each chapter, the overall characteristics of the facility are firstly presented. Then, the network architecture is presented in terms of three parts, core & transport, radio & edge, and management & orchestration. For the slicing methodology, how their network supports use-cases of different KPIs by using different types of slices is investigated. While testbed facilities will be exploited to serve multiple use-cases separately or jointly, mapping of use cases and required slice types are illustrated. In addition, network configuration to support some specific use cases is also discussed.

Although the five testbeds are developed and operated independently by different owners, their high-level architecture can be understood in the 5G PPP network architecture model [3] depicted in Figure 1.

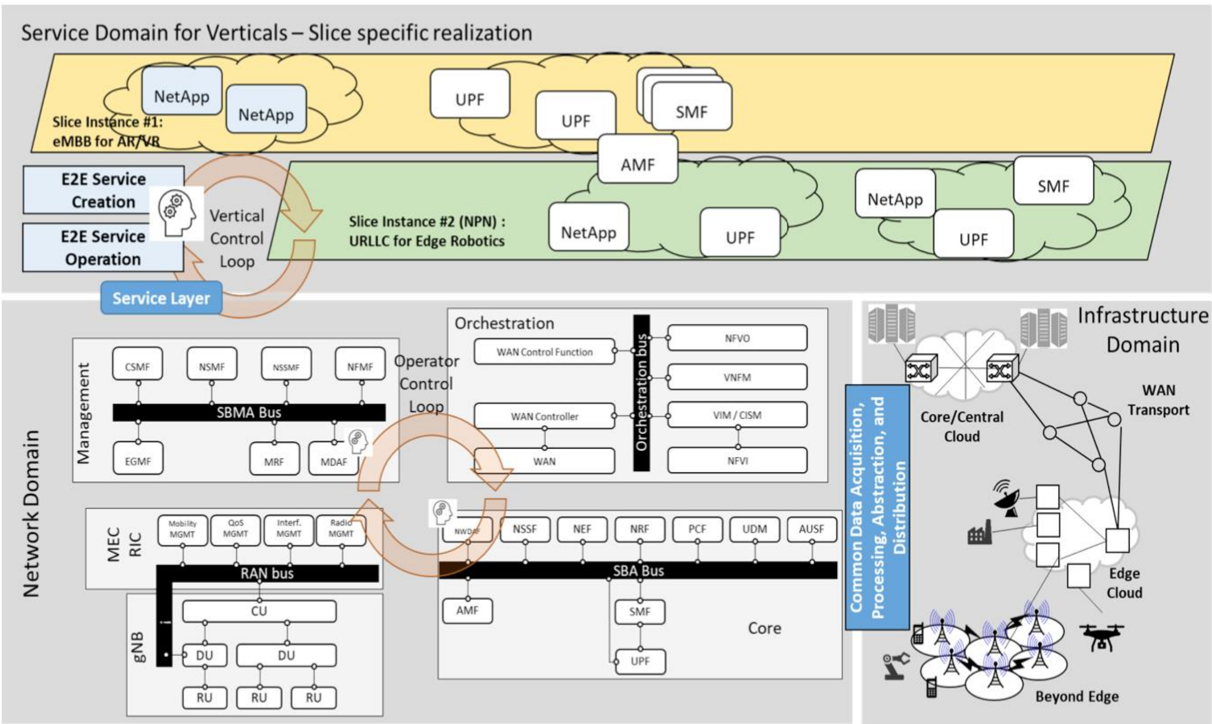

Figure 1. Overall high-level architecture [1].

The network architecture in Figure 1 consists of three domains: Service Domain, Network Domain and Infrastructure Domain. The Service Domain focus is on architecture innovations that help to serve various verticals (health, transport, and aquaculture in our case). Particularly, two parts, the service layer and the concept of NetApps (Network Applications), play an important role. The role of the service layer is to provide a common interface towards the network operation and management, enabling the interaction between the service intelligence and the underlying network. In the concept of NetApps, all 5G network can be comprised empowered applications that build a network service, through the use of network slice. Then, slices can be exploited to provide such network services, and encompass different network functions (including core and access functions), possibly orchestrated over different clouds. In the Network Domain, the various functions arranged in different slices according to the requested KPIs are operated. This domain is consisted of three parts, core, Management & Orchestration, and access. Lastly, the infrastructure domain can be considered to include even specific fields such as drone-based access.

The service domain configurations of the 5G-HEART test facilities are discussed in the “Support of 5G-HEART use cases with slicing” subsection of each chapter. The presented slice types and deployment details show both the 5G network and service components which are used to provide the required service to the trialled vertical use cases at each test site. The resources available in the network and infrastructure domains of the test facilities are discussed in the “Network architecture” subsection of each chapter. The introduced technical capabilities are the building blocks which are used to assemble and deploy the service domain slices for the trials. The detailed slice configurations and trial parameters are discussed in the WP3, WP4, WP5 and WP6 deliverables, which are dedicated to the implementation and on-boarding of the 5G-HEART vertical use case trials as well as to the validation of the utilised 5G technologies through these trials, which are performed on top of the test facilities introduced in this document.

From Chapter 2 to 6, each testbed facility is presented in detail one by one. In Chapter 2, 5G-VINNI is introduced with its architecture and slicing configuration to support use cases for Healthcare and Aquaculture. Chapter 3 contains the 5Genesis platform to be exploited for Transport vertical. 5G-EVE is explained in Chapter 4 with the scenario to support Healthcare and Aquaculture verticals. Two national 5G testbed platforms to support Healthcare and Transport verticals, 5GTN and 5Groningen are investigated in Chapter 5 and 6, respectively. Lastly, Chapter 7 contains the conclusion.

2 5G-VINNI

2.1 Overview

5G-VINNI is an EU-ICT-17-2018 project, which provides an end-to-end (E2E) 5G test facility to accelerate the uptake of 5G in Europe. 5G-VINNI will enable the validation of the performance of new 5G technologies by operating trials of advanced vertical sector services. It is based on the latest 5G standards and designs, and it is composed of 7 different facility sites around Europe, providing user friendly zero-touch orchestration, operations and management systems to ensure operational efficiencies and optimal resource use. 5G-VINNI continues to leverage the latest 5G technologies, including results from previous 5G-PPP projects. This means it employs Network Function Virtualisation, Network Slicing and a rigorous automated testing campaign to validate the 5G KPIs under various combinations of technologies and network loads [4].

5G-VINNI is composed of 4 main facilities and 3 additional experimental facilities. The main facilities follow as much as possible the finalized standards proposed by 3GPP and ETSI, while the additional experimental facilities as the name indicates, will have the opportunity to implement several experimental technologies which are not necessarily standardized. Finally in the context of 5G-HEART, it is important to mention that all use cases will be implemented in the Norway Facility.

2.2 Network architecture

In Figure 2, the 5G-VINNI global architecture is presented, including the respective network domains, the management elements and the interfaces needed for the interaction between those elements. A complete description of those interfaces is provided in [5]. Here a brief overview of those will be presented.

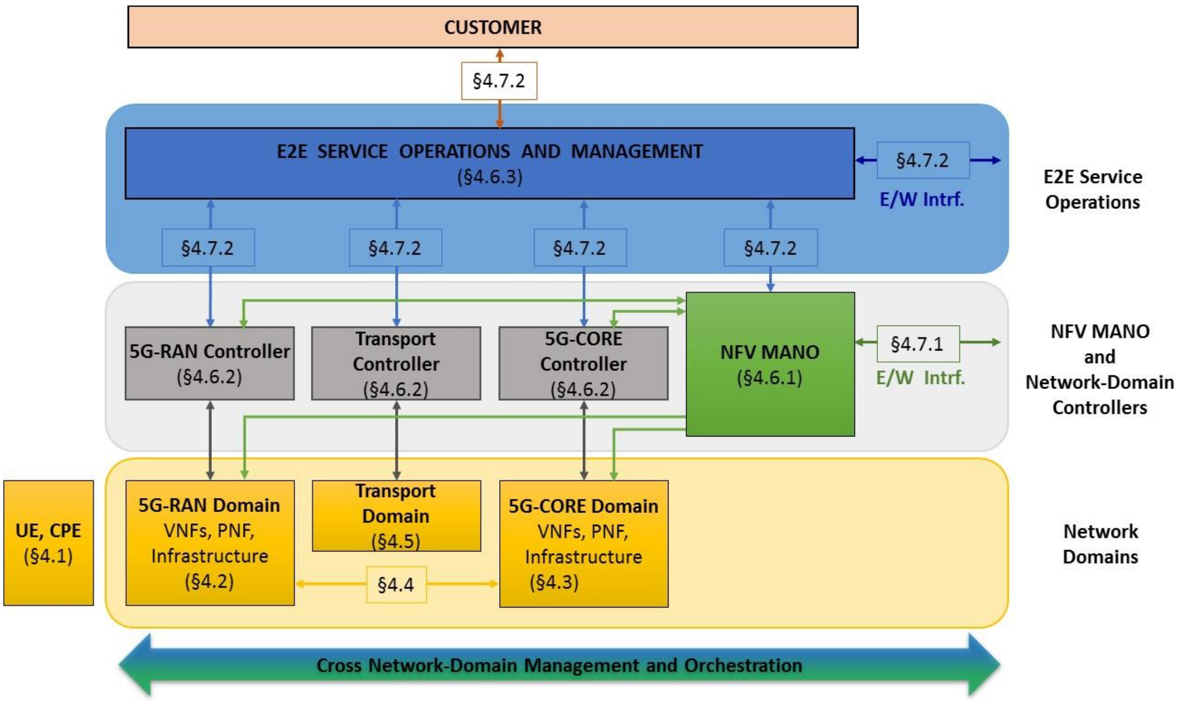

Figure 2. 5G-VINNI global architecture.

Firstly it is important to highlight the elements in yellow in Figure 2 that represent the network domains (RAN, Transport and CORE). Each of those has a controller, illustrated in the grey boxes on top of each domain. For the virtualized elements, the NFVO (Network Function Virtualisation Orchestrator) oversees the management functions, and finally the blue box E2E Service Operations and Management

(E2E-SO) has two main roles, i) the overall coordination of all elements previously mentioned (controllers and NFVO), by using southbound interfaces as illustrated in the figure, and ii) the interaction with customer requests using northbound interfaces. In the context of 5G-HEART, the customer facing interfaces are the most relevant and hence, extra detail will be provided. The interfaces used for this purpose are based on the TM Forum Open APIs (Application Programming Interface) as presented in Figure 3 [6]. The specific implementation of those interfaces in 5G-VINNI is presented in detail in the 5G-VINNI Deliverable 3.3 [7].

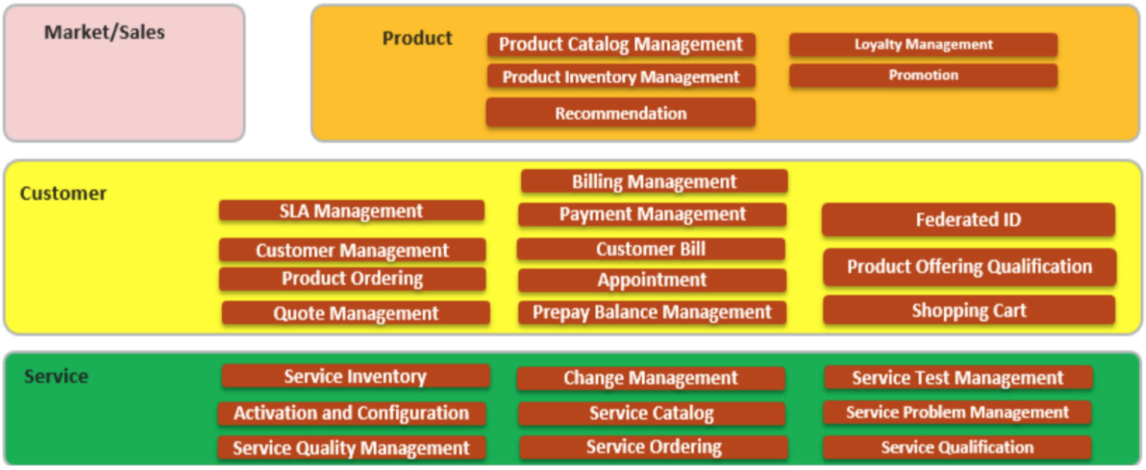

Figure 3. TM Forum Open API Map for the product, customer and service layer [6].

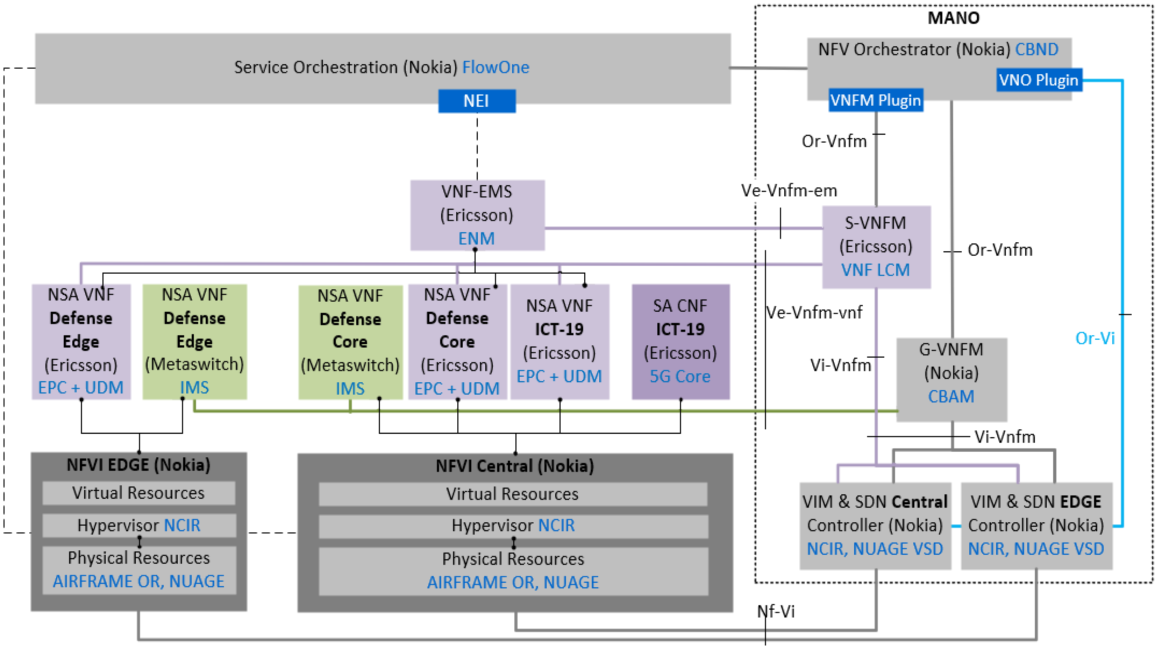

Figure 4. 5G-VINNI Norway Facility Architecture & Vendors[2].

In the following sections, specific elements implemented in the Norway facility will be presented in more detail, based on the global guidelines provided in the global 5G-VINNI framework. The main actors involved in the 5G-VINNI Norway facility are Telenor (in charge of architecture and management issues), Ericsson (in charge of CORE VNFs (Virtualised Network Functions), S-VNFM (Specific-

[2] CBAM: CloudBand Application Manager, LCM: Lifecycle Management.

Virtualised Network Function Management) and RAN), and Nokia (in charge of the NFVI (Network Function Virtualisation Infrastructure), NFVO (Network Function Virtualisation Orchestrator) and E2E-SO). Additional details of those components will be mentioned below in this section. It is important to highlight that the 5G-VINNI Norway facility has two different VNFMs (Virtualised Network Function Managements): the S-VNFM from Ericsson for managing Ericsson VNFs, and the Generic-VNFM from Nokia that is in charge of managing potential 3rd party VNFs different from Ericsson. Finally, the PaloAlto Networks, are responsible for network security of the Norway facility, implemented via several firewalls across the different components. The 5G-VINNI Norway facility architecture is presented in Figure 4, where the aforementioned components are described. Complete details on these components can be found in the 5G-VINNI Deliverable 2.1 [8].

2.2.1 Core & Transport

Transport

The transport network for Norway facility site is based on the commercial transport network of Telenor Norway. As shown in Figure 5, Cell Site Routers (CSRs) are used for connecting the RAN sites to the transport network. These CSRs exchange IP routes (OSPF/BGP[3]) with the transport network, which then assigns the whole traffic into multiple dedicated VPNs (Virtual Private Networks) that correspond to different slices.

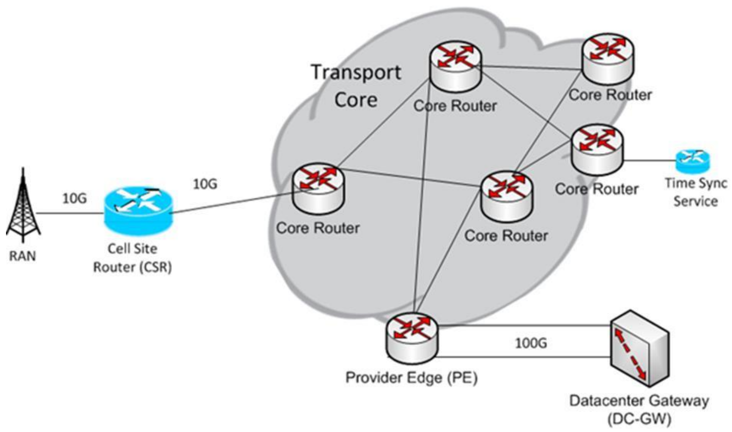

Figure 5. 5G-VINNI Norway Facility Transport Network.

Ericsson (5G) EPC

The 5G system defined in 3GPP Release 15 can be realized in two ways, a) 5G-NR connected to EPC (Evolved Packet Core), also referred to as NSA (Non-Standalone), and b) 5G-NR connected to 5G core, also referred as SA (Standalone). While the EPC used in NSA configuration (4G for signalling plane) is an evolution of the current LTE core network with additional features, the 5G core (5G used for U-plane) represents a new service-based architecture with new functional nodes.

Ericsson VNF Virtual Machines (VMs) can run on the same or different Nokia compute node as Nokia SDN (Software Defined Networking) uses internal OVS (Open vSwitch) switching. External network IP (Internet Protocol), all VNF interface IPs, Default Gateway IP and Service IP are assigned dynamically and provided to the VNF by the NFVO during onboarding. Virtual IP (VIP) addresses are used. All these parameters provided by NFVO during onboarding are specified individually in low level design (LLD).

[3] OSRF/BGP: Open Shortest Path First/ Border Gateway Protocol

For slice selection, the DECOR (Dedicated Core Network) functionality is used. It is composed of the following 4G components: MME (Mobility Management Entity), SPGW (Serving Packet Data Network Gateway), PCRF (Policy and Charging Rules Function), HSS (Home Subscriber Server) and UDR (User Defined Route), as defined in [18].

5G Core (Ericsson)

5G Core (5GC) Ericsson products are executed as a set of containers and designed to run on a Kubernetes container orchestration platform.

A Container-as-a-Service (CaaS) layer is deployed as a set of VMs on top of Nokia cloud infrastructure (NCIR) and will facilitate two SA network slices with a combination of independent NFs per slice (AMF, SMF, UPF[4]) and shared NFs (UDM, UDR, AUSF, NRF, NSSF[5]), as defined in [17].

Nokia Central NFVI and VIM

The Nokia data centre solution is based on the ETSI reference model [19] and aims at a modular and layered architecture with clear roles for each component. Nokia's hardware infrastructure in the Norway facility site is based on OCP (Open Compute Project) rack and servers. Nokia OCP-based servers are designed to meet the requirements in CSPs (Communication Service Providers), IT and enterprise data centres. OCP is now incorporated into hardware components of the Nokia AirFrame Open-Rack (OR) Data Centre Solution, including servers, switches, storage, and racks.

OCP-based infrastructure is expected to have a profound impact on cloud and data centre environments by reducing energy consumption and OPEX while still incorporating the latest CPU technology. The host OS for all nodes within a Nokia Cloud Infrastructure Real-time (NCIR) cluster deployment (Nokia's open stack-based cloud infrastructure) is CentOS 7.4 Linux. NCIR implements KVM (Kernel-based VM) alongside QEMU hypervisors in order to run virtual machines at near-native speed. The *"libvirt"* library is used as the management API for both hypervisors.

2.2.2 Radio & Edge

gNodeB New Radio (gNB NG) Radio Access Network

The Norway facility leverages gNBs from Ericsson and Huawei. The NG-RAN in Norway can support non-standalone as well as standalone deployments.

The radio components used in 5G-VINNI are based on antenna integrated radios for mid-band (3600 MHz) and high-band (24.5-27.25 GHz). The antenna integrated radio products are designed with 64T64R architecture (for 3600 MHz frequency band both for Huawei and Ericsson), 512T512R (for 26 GHz for Ericsson) and 384T384R (768 dipoles for 26 GHz for Huawei). Advanced functionality such as massive MIMO (Multiple Input Multiple Output) and 256 QAM modulation is supported.

The radios support 3GPP standardized 5G carrier bandwidths ranging from 20 MHz to 100 MHz for the mid-band frequencies and up to 400 MHz for the high-band frequencies. 3GPP standardized Time Division Duplex (TDD) patterns are supported.

For the non-standalone (NSA) deployment in 5G-VINNI, it has been decided to use 3GPP B1 (2100 MHz) as the LTE anchor band. The multi standard radio operates at 2100 MHz and is designed with 4T4R architecture. It needs to be highlighted that LTE anchor carrier bandwidth will be aligned to the spectrum situation at the specific site location in Norway.

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4 AMF, SMF, UPF: Access and Mobility Management, Session Management Function, User Plane Function

5 UDM, UDR, AUSF, NRF, NSSF: Unified Data Management, Unified Data Repository, Authentication Server Function, Network Repository Function, Network Slice Selection Function

2.2.3 Management & Orchestration

VNF Element Management System and VNF Manager

Ericsson Network Manager (ENM) is the element manager managing Ericsson VNF's. ENM provides centralized operation and maintenance of radio and core. It provides unified performance and configuration management, software, hardware and fault management, together with security, self-monitoring and system administration for the ENM. CBAM 19.5 [1] is used as G-VNFM (Generic-VNFM) for deploying the non-Ericsson VNFs. More details can be found in core site design document (5G-VINNI Deliverable 2.1 [8]) where CBAM has been deployed. There is no new deployment at the edge site.

VNF Descriptors

To achieve the widest interoperability and to simplify on-boarding, Nokia has provided guidelines for the creation of VNF descriptor templates based on ETSI specifications. Where applicable, standard open technologies, such as OASIS TOSCA modelling language, as well as Mistral work flow and Ansible playbooks can be adopted. Currently it's using TOSCA templates according to TOSCA based on the ETSI SOL001.

NFV Orchestrator

NFV Orchestrator is mainly responsible for the orchestration of virtual resources and network services orchestration and their management. It visualizes and automates the lifecycle of network services, such as virtual EPC, including their forwarding graphs and service chains. It may also include provisioning of external networks necessary for the VNFs, which may involve various types of networks like, L2, L3, SDN port mirroring, etc. In terms of architecture, CBND (Cloud Band Network Director) can be divided in five main functional blocks:

- Northbound API layer and Graphical User Interface (GUI)
- Network Service Orchestration (NSO)
- Resource Orchestration (RO)
- Southbound API layer
- CBND platform operations tools

For the 5G-VINNI edge site, the CBND 19.5 instance from core site is used for orchestration.

FlowOne. E2E Service Orchestration

This section describes the high-level design for the Norway facility site E2E service orchestration for 5G-VINNI which for this particular case is a Nokia Product called FlowOne. The overall targets for the E2E Service Orchestration are

- Deployment of the E2E Orchestration
- Process management for E2E service orchestration, automating where possible, and using FlowOne to manage manual steps where they are required
- Northbound integration supporting Service Ordering, Service Activation and Configuration and Service Catalog Management (see Figure 2)
- Southbound integration to NFVO (see Figure 2)
- Southbound integration to UDM for provisioning of UE (see Figure 2)

Nokia *FlowOne* solution takes care of the E2E service orchestration function. E2E service orchestration has responsibility for:

- Centralized service operations management, where all service delivery is managed in one place.
- Service lifecycle management for network slices and for UE provisioning, taking care of the correct delivery sequence when delivery order contains multiple hybrid services and steps.
- Service Model, containing models on how different services are delivered and their resources reserved along different delivery processes. The system can expose service model and its detailed information via API to external systems for e.g. enabling product service mapping with versioning.
- Installing base, external or internal and managing existing subscriptions and their services and resources up-to-date information.

2.3 Support of 5G-HEART use cases with slicing

The 5G-VINNI Norway facility has been deployed in two different phases.

The first part of the 5G-VINNI Norway facility only supports NSA architecture. For NSA slices selection, the DECOR (Dedicated Core Network) functionality is implemented as defined in the 3GPP Specification 23.707. The first slice available was the eMBB, followed by the URLLC and finally the mMTC. Finally, additional NSA slices can be considered in future, representing the sub-phases mentioned above. Figure 6 shows the NSA slice implementation in phase 1, using VNFs that were supported in 5G-VINNI NSA part.

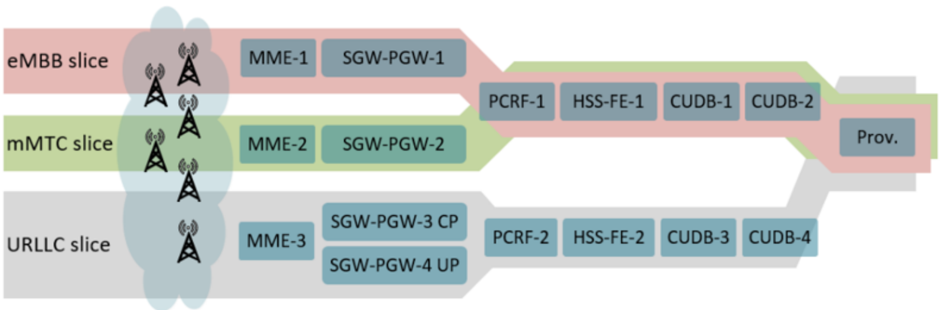


Figure 6. 5G-VINNI Norway Facility NSA Slices Phase 1[6].

Table 1 provides a brief description of each service type.

Table 1: Slice/Service types (SSTs) available for selection in 5G-VINNI Norway NSA

5G-VINNI Service Type	3GPP SST value	Description
eMBB	SST = 1	This network slice is optimized to support use cases that fall under the eMBB category. It provides enhanced data rates, capacity and coverage, serving scenarios with high traffic load and stringent QoS requirements.
uRLLC	SST = 2	This network slice is optimized to support use cases that fall under the uRLLC category. It provides very low latency and extremely high reliability for mission-critical services. The slice architecture contains in particular a split SPGW, of which one part includes the control plane (SPGW-CP), and the other part is the user plane (SPGW-UP). This enables flexibility and redundant settings.

[6] CUDB: Centralized User Database.

mMTC	SST = 3	This network slice is optimized to support use cases that fall under the mMTC category. It provides connectivity support for a very large number of power-constrained devices requiring high energy efficiency and long battery lifetime.
customised	N/A	This network slice is optimized to support use cases having performance requirements that can be formulated as a combination of two or more pre-defined service types (SST= 1, 2, and 3), or as a modified (enhanced) version of one of them. Use cases with advanced functionality (e.g. in terms of access technologies, security considerations, etc.) will be also accommodated in network slices classified under this service type.

The types of actions that can be performed on the different components for each slice type are listed in Table 2. An 'X' implies that the implemented solution performs the corresponding action type on the corresponding component in an automated way, as part of the service fulfilment process flow. An 'M' implies such a process needs to be carried out manually.

Table 2: Actions on components of network slice types

Service or Service Component	**Action Types**						
	Verify	**Instantiate**	**Configure**	**Activate**	**Modify**	**De-activate**	**Terminate**
eMBB		X	X	X	X	X	X
mMTC		X	X	X	X	X	X
uRLLC		X	X	X	M	X	X
Dedicated MME		X	M	M	M	M	X
Shared RAN			M	M	M	M	
Dedicated Core		X	M	M	M	M	X
Shared PCRF	M	X	M	M	M	M	X
Dedicated PCRF		X	M	M	M	M	X
Shared UDM	M	X	M	M	M	M	X
Dedicated UDM		X	M	M	M	M	X
Shared HSS	M	X	M	M	M	M	X
Dedicated HSS		X	M	M	M	M	X

The second part of the 5G-VINNI Norway facility supports the SA architecture, and in addition Edge nodes will be implemented for some use cases whilst remaining open to be extended and used when the use case to be implemented demands it. Figure 7 shows the full scope of the 5G-VINNI Norway facility including SA, NSA and Edge.

The phase 2 slices run on a Kubernetes container orchestration platform (CaaS). The implementation is supported by two main clusters for each slice. In the first cluster, the AMF, UPF and SMF are implemented. In the second cluster, database related functions such as UDM, NSSF, NRF and AUSF are implemented.

A Container-as-a-Service (CaaS) layer is deployed as a set of VMs on top of Nokia cloud infrastructure (NCIR) which will facilitate two SA network slices with a combination of independent NFs per slice (AMF, SMF, UPF) and shared NFs (UDM, UDR, AUSF, NRF, NSSF).

Same as for NSA, in the SA configuration there is the possibility to provide four slice types, eMBB, URLLC, mMTC, and customized slices. The first implementation of SA in the Norway Facility includes shared functions in the second cluster that corresponds to the UDM, NSSF, NRF and AUSF functions. The components in the first cluster are independent in different slices. The container architecture allows the flexibility to tailor the functions according to the slice needs.

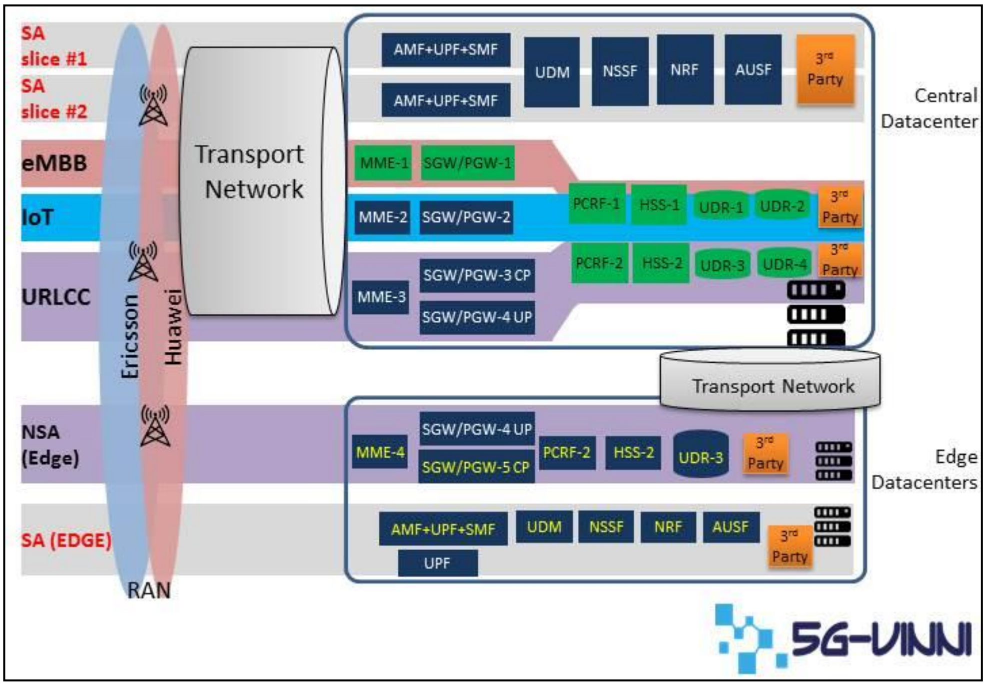


Figure 7. 5G-VINNI Norway Facility SA and NSA Slices.

Based on the slicing capabilities, 5G-VINNI is expected to serve the following subcases/ scenarios of Healthcare and Aquaculture verticals as outlined in Table 3. Subcases/scenarios are categorized into service type slices.

Table 3: List of use cases/scenarios of verticals served by 5G-VINNI

Vertical	Subcases/ Scenarios	Description	Service Type	Notes
Healthcare	H1B	AR/VR enabled remote ultrasound	eMBB/uRLLC	
	H1B	Robotic-assisted ultrasound examination	eMBB/uRLLC	
	H1D	Critical health event	uRLLC	
	H2A	Automatic pill camera anomaly detection	eMBB/uRLLC	
	H3A	Vital-sign patch prototype	mMTC	
Aquaculture	A1S1	Sensory data monitoring	mMTC	
	A1S2	Camera data monitoring	eMBB	
	A1S4	Edge and cloud-based computing	mMTC/eMBB	Mobile Edge
	A1S5	Cable-free communication on site	mMTC/eMBB	Mobile Edge

2.3.1 Healthcare

For the healthcare H1B use-case scenario, addressing remote ultrasound examination, two different approaches are pursued,

i) AR/VR enabled remote ultrasound and
ii) Robotic-assisted ultrasound examination.

2.3.1.1 AR/VR enabled remote ultrasound (H1B)

The implementation of the *AR/VR enabled remote ultrasound use case* contains two different sides that need to be communicated via 5G: The ultrasound machine side, where actual ultrasound is taken, and on the other side the remote expert side, where a medical expert can provide specialized input and support. For the implementation, first all devices in the patient-side will be connected to a common local switch, which uses the 5G-CPE router as gateway for the connection to the 5G antenna. From the antenna, the packets go to the core via the transport network. The core uses the NSA-based, Enhanced Mobile Broad Band (eMBB) slice. The packets are processed in the core, the data-plane traffic is routed from the core S/PGW to the remote-expert side. The remote expert side has a similar setting. All the devices are connected to a common local switch that uses the 5G-CPE router as gateway. In summary, Figure 8 presents the communication to/from patient-side to/from expert-side using an eMBB slice.

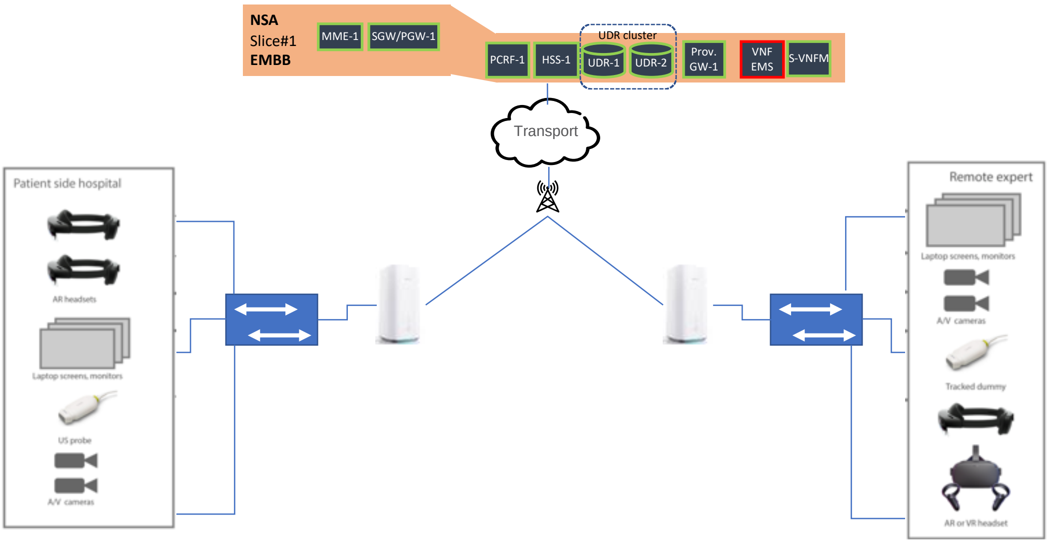


Figure 8. AR/VR enabled remote ultrasound implementation - (NSA config.).

After testing basic operability a fine-tuning of the QoS Class Identifier (QCI) in the RAN part is needed. This will allow configuring the RAN according to the corresponding requirements. Those values are presented in the 3GPP TS 23.501 specification, table 5.7.4-1 [16]. However, as it will be explained in the next section, the values presented here illustrate the methodology, since specific selected values may need to be adapted to the results observed during the trials.

2.3.1.2 Robotic-assisted ultrasound examination (H1B)

The implementation of the robotic-assisted remote ultrasound use case has a higher degree of difficulty as it has 3 different applications that demand different connectivity features (i.e., the robot arm, the ultrasound image, and the video-conference channel). Initially, all devices in the Master-Side are connected to a common local switch, which uses the 5G-CPE router as gateway for the 5G Antenna. From the antenna, the packets go to the core via the transport network. The core in this phase provides an eMBB slice (NSA Slice 1). The packets are processed in the core and routed from the S/PGW to the Slave-Side which has a similar local setting with a common switch connected to the medical equipment.

However, during implementation from the vertical point of view, better differentiation is needed based on the diverse connectivity requirements, such as a real-time control channel, a high priority video link, and a low priority video link channel. This use case includes separated 5G-CPEs per each of the channels needed, in order to be able to provide the differentiation needed (i.e., the robot arm, the ultrasound image, and the video conference channel). This is illustrated in Figure 9. For the real-time channel needs, the respective 5G-CPE will contain a SIM (Subscriber Identity Module) that will identify the user as top priority. While a top QCI will be defined in the RAN, the connectivity to the uRLLC slice (NSA Slice 3) will be offered. For the high-priority video channel, the respective 5G-CPE will contain a SIM that will identify the user as a priority user and in a similar way to the previous case, QCI in RAN (QCI 3) will be set, to fulfil the needs of this use case. Regarding the core part, connectivity to the uRLLC slice (NSA Slice 3) will be offered. Finally, the low priority video will be set with average QCI features in RAN (QCI 4), and in the core part, it will be connected to the eMBB slice (NSA Slice 1).

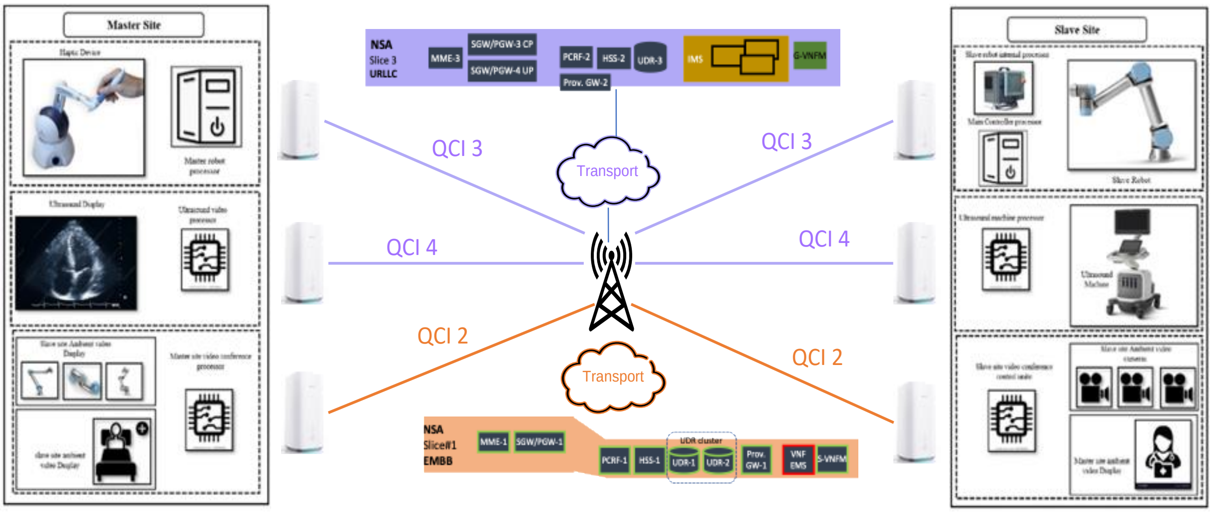


Figure 9. Robotic-assisted remote ultrasound implementation.

2.3.1.3 Critical health event (H1D)

This use case has been addressed by WP3 from the beginning of the project. However, its implementation in the Norway facility, and specifically in the 5G-VINNI platform is optional, depending on the progress on the other use cases.

2.3.1.4 Automatic pill camera anomaly detection (H2A)

The implementation of this use-case follows a similar approach to the one presented in previous cases. Basically here it is important to clarify what is at each end of the use case.

At the one end is the patient with the PillCam inside, connected to a transmission device allocated in a belt, to communicate with the pill, and also a 5G gateway (UE) to communicate with the 5G network. At the other end is the video reception devices that will process the transmitted PillCam video images. In the middle of these two end-points is the 5G-VINNI network with all the components presented previously, i.e., the 5G RAN, the transport and the 5G core. This use case is delivered over the eMBB slice as presented in Figure 10.

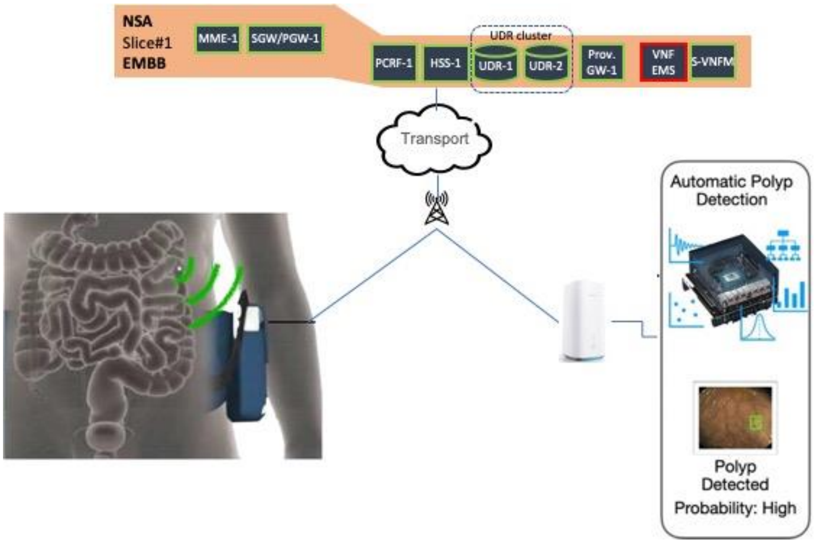


Figure 10. Implementation of the Automatic pill camera anomaly detection use case.

2.3.1.5 Vital-sign patch prototype (H3A)

Vital-sign patch prototype is developed and tested using a commercial service in the Netherlands. Later, it will be connected to the 5G-VINNI platform in Oslo. For the implementation of this case, it is important that RAN and core are able to satisfy the requirements of the patch. In the RAN the respective frequencies are enabled for that purpose, and in the core part, this use case will utilize an mMTC slice (NSA Slice 2) as presented in Figure 11.

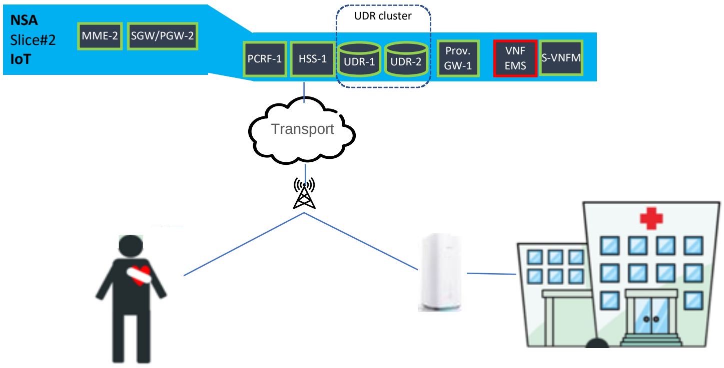


Figure 11. Vital-sign patch Implementation.

2.3.2 Aquaculture

All aquaculture trials in Norway are performed at a selected fish farm on the Norwegian coast. An outdoor 5G gNB is installed at the premises, which covers the relevant area. The main sector (B) is indicated in Figure 12, as well as the beamwidth of the 5G active antenna.

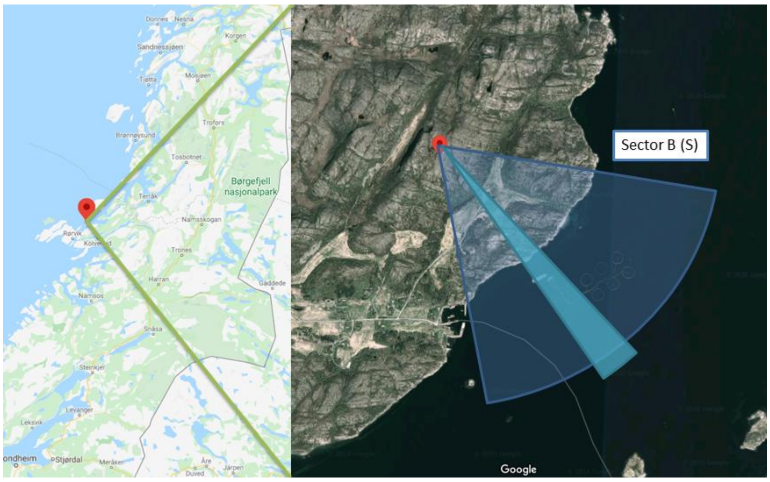


Figure 12. Geographical Location and coverage of the Aquaculture use case implemented in Norway.

The user side architecture and its integration with the network are shown in Figure 13.

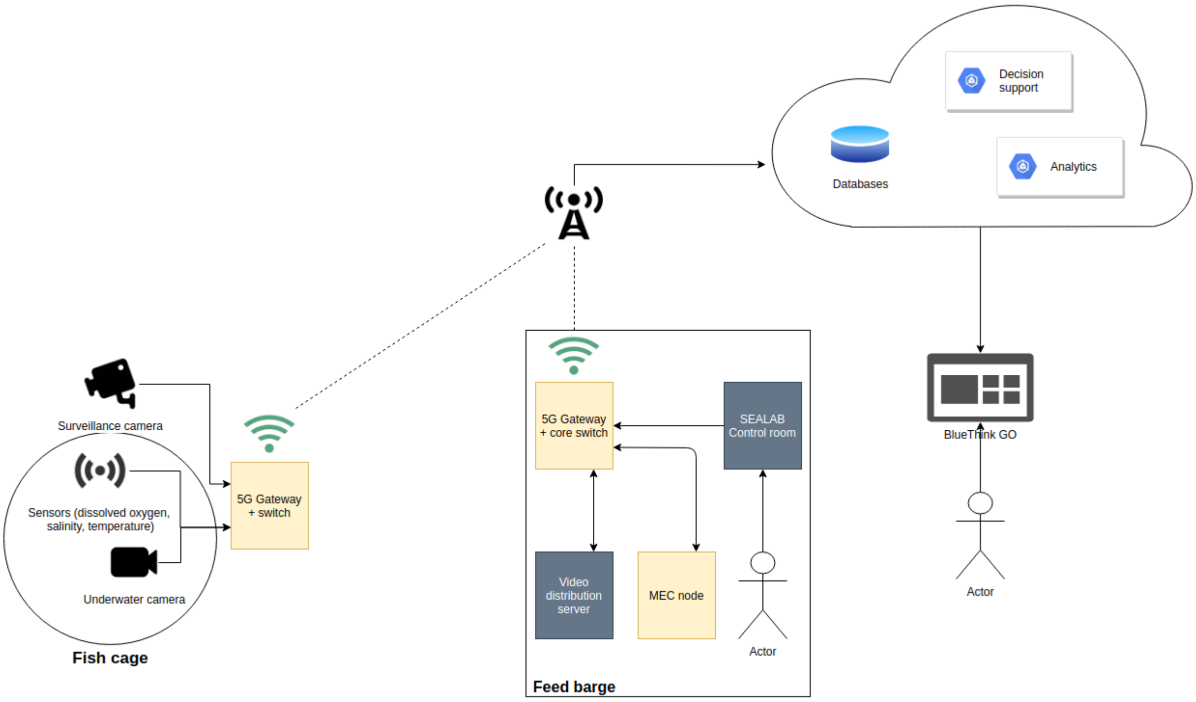


Figure 13. Architecture and connectivity Description of the Aquaculture site in Norway.

The physical connection to the 5G network is shown in Figure 14. This illustrates in detail who oversees integration of this use case into 5G-VINNI. The green box represents all the equipment of the fish farm, including cameras, sensors, etc. The network switching system from SEALABS will act as the integration point with 5G-VINNI.

The yellow box presents the equipment provided by 5G-VINNI that can be split in three parts. The first one is the 5G-CPE in charge of connecting the fish farm to the 5G network. The second one is a backup VPN solution using 4G, and it is used as a backup connection in case of failures and for basic management tasks, which will facilitate potential troubleshooting routings during operations. Finally, there is an Edge cloud which consists of a cluster of servers, where local image processing using machine learning is done.

Since the throughput expected in this use case is very high, the slice used is the eMBB (NSA Slice 1), as presented in Figure 14.

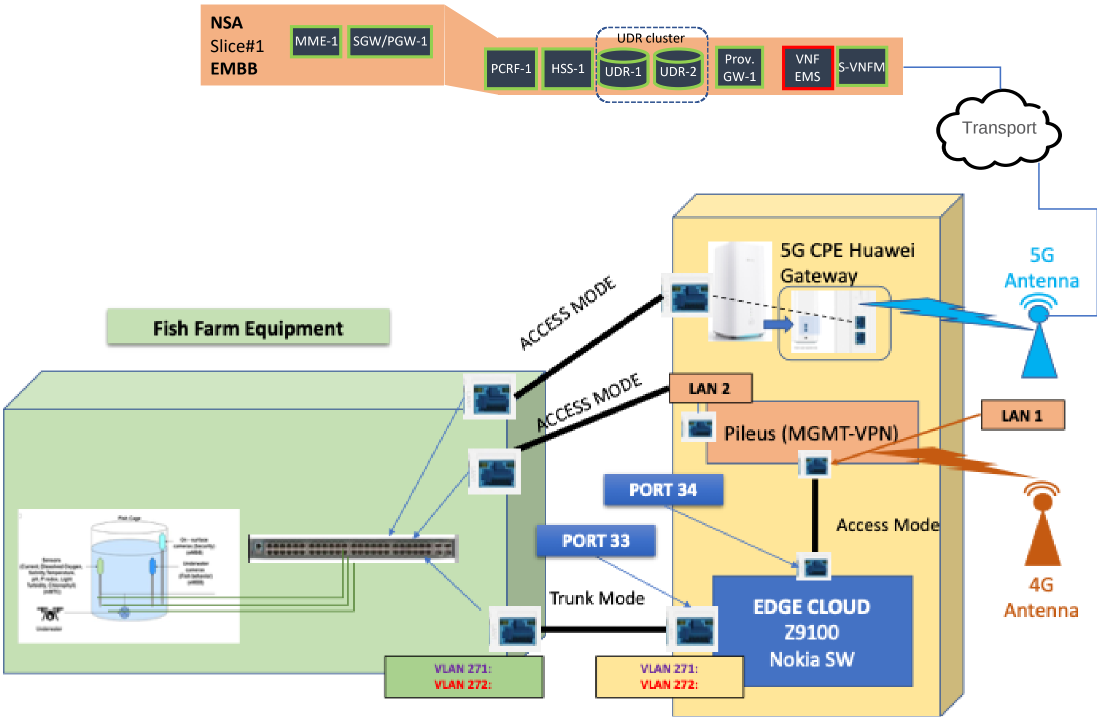


Figure 14. Aquaculture Norwegian site equipment connection to 5G-VINNI.

3 5GENESIS

Among five different platforms in the 5GENESIS project, the Surrey Platform is exploited in 5G-HEART, thus it is the focus in this chapter. The Surrey Platform is a multi-RAT environment, comprising both 3GPP and non-3GPP networks, as well as a powerful 3GPP Rel. 16-compliant 5G Core. Commercial-of-the-shelf (COTS) 5G New Radio solutions are integrated into RAN, as part of a larger flexible 5G network infrastructure. The Surrey Platform 5G core, developed in-house, fully supports the 3GPP Rel.16 for the core network (CN) functionality and Rel.16 context-aware network, to intelligently interwork with 5G NR, both in Standalone (SA) and Non-Standalone (NSA) modes. The Surrey Platform RAN also supports Narrow Band IoT (NB-IoT) Rel.15, as well as WiFi (802.11ac), integrated using the Non-3GPP Interworking Function (N3IWF), and LoRA Wide Area Network (WAN) technologies.

3.1 Overview

The Surrey Platform follows the 5GENESIS architecture depicted in Figure 15. The architecture is structured in three main blocks: Coordination Layer (yellow), Management and Orchestration Layer (green) and Infrastructure Layer (blue).

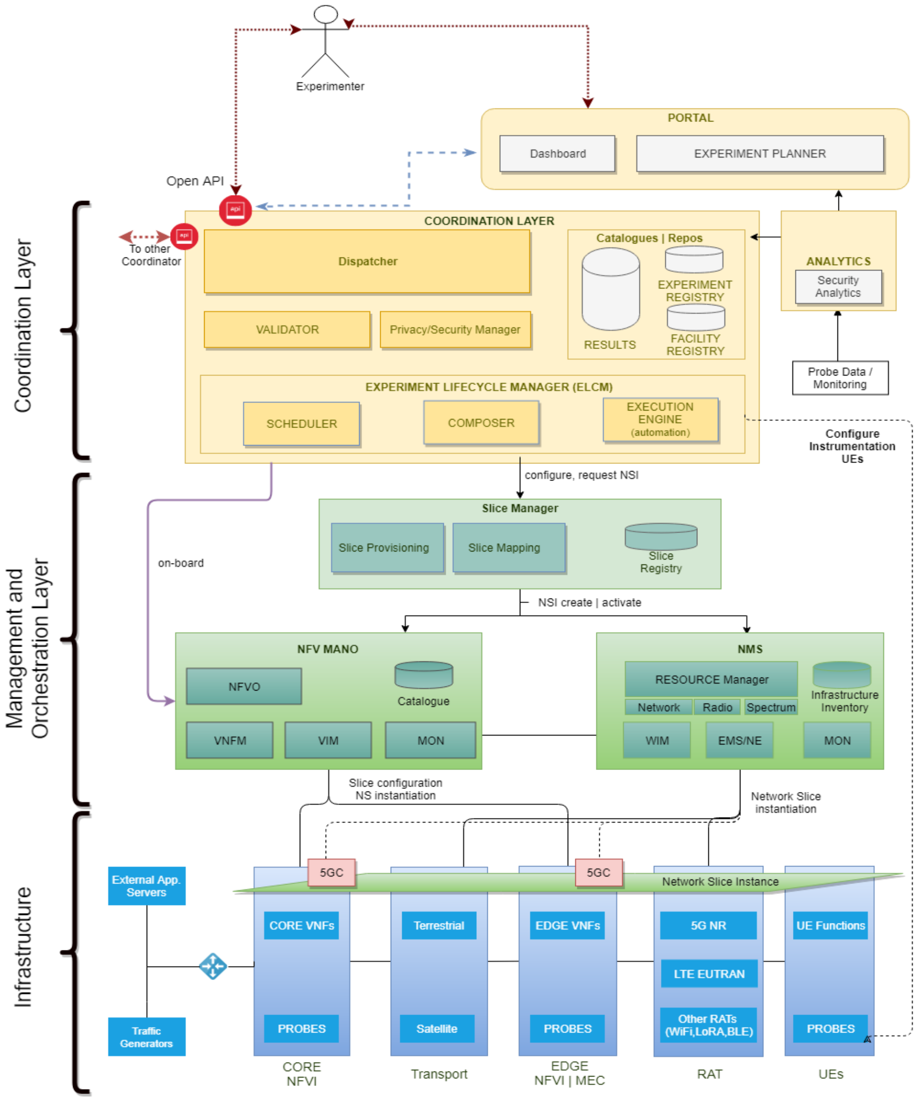


Figure 15. The 5GENESIS Architecture.Following a top-down explanation of the 5GENESIS architecture, the Coordination Layer offers the northbound interfaces for the experimenter, the Portal and the Open

APIs. It is in charge of the authentication, validation, the aggregation of the measurements and the control of the experiment lifecycle, which requires access to the components deployed at Infrastructure Layer. The technology providers who are interested in integrating their products would need to develop the plugins that will allow their components to communicate with the key components of the 5GENESIS experimentation framework, i.e., the Experiment LifeCycle Manager (ELCM), the slice manager and the monitoring system. Details and examples of the development of such plugins are included in Deliverable D5.4 of 5GENESIS [9], which also includes a comprehensive description of the Portal, the Open APIs and the ELCM. These components enable the definition and automated execution of the experiments.

3.2 Network architecture

In this section, the Infrastructure Layer and Management and Orchestration Layer in the logical architecture as illustrated in Figure 15 [10] are described from three perspectives: core & transport, Radio & Edge, and management & orchestration.

3.2.1 Core & Transport

The Surrey Platform Infrastructure Layer comprises multiple components covering different RATs, together with the 5G core (5GC) that has been developed in-house, in 5G Innovation Centre (5GIC) in the University of Surrey and continues to be enhanced and upgraded. The mobile network technologies deployed in the Surrey Platform are summarised in Table 4.

Table 4: The Surrey Platform Technology

Mobile Core Products	Radio Access Products	3GPP Rel.
5GIC 4G vEPC 5GIC 5GC NSA (Rel. 15) 5GIC 5GC SA (Rel. 16)	HUAWEI/AIRSPAN	Rel.15 and 16
	LoRa WAN	
	HUAWEI gNB (Rel.16)	
	COTS NB IoT (Rel.15)	
	WiFi Integration (N3IWF)	
	LoRA WAN	
	gNodeB/eNodeB	

The Surrey Platform is connected to the Joint Academic NETwork (JANET) via 10 x 10 Gbps aggregated fibre capacity and maintains connectivity to the data centre. Internally, the platform is comprised of a set of SDN switches to support dynamic traffic flow operations. This switching fabric connects the 5G RAN equipment to the virtualisation testbed, for virtual network services support the users. Connectivity architecture, shown in Figure 16 depicts interconnection between the newly deployed 5G network data centre and the existing 4G data centre infrastructure.

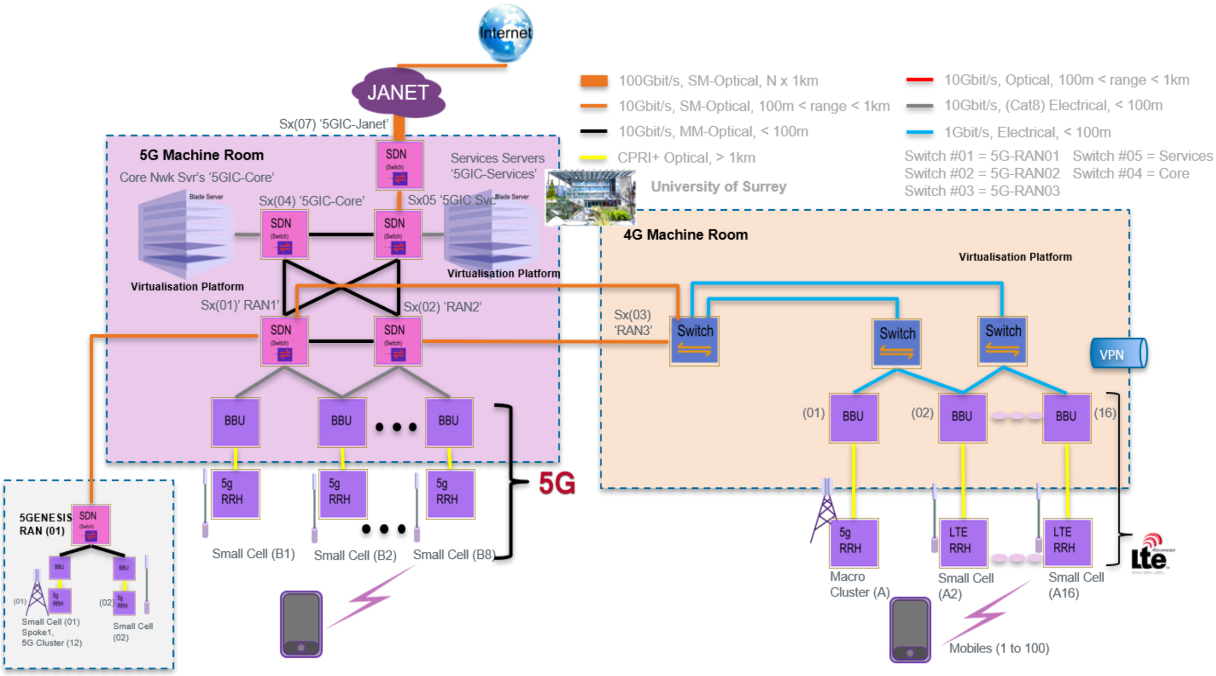


Figure 16. Deployment of the infrastructure components in Surrey Platform[7]. Multiple components consisting of Infrastructure Layer are explained as follows.

(a) Mobile Core

The 5G core, developed in-house, fully supports the 3GPP Rel.15 for the core network functionality and Rel-16 context-aware network, to intelligently interwork with 5G New Radio, both Stand-alone (SA) and Non-Stand-alone (NSA).

The 5G core network implements the new 5G components as standalone, thus enabling fast, reliable, high throughput and multi-access network capability, i.e., non-3GPP access network and satellite network connectivity.

The 5G core includes a large number of newly implemented functions:

- Integration with 5G New Radio: NSA [S1-MME, S1-U] and SA [N1, N2, N3],
- Implementation of control-user plan split – PFCP (Packet Forwarding Control Protocol) [N4],
- Implementation of Service-Based Architecture Features [HTTP/2, REST].

The 5G core integrates 5G New Radio SA and NSA prototypes and off-the-shelf LTE access networks enabling demonstration of different features and applications, while also supporting the current need to have a genuine 5G core network in addition to the evolved EPC.

The 5G core network functions (NF), run on top of common hardware platforms. NFs are deployed with Kubernetes Docker containers platform and virtual machines on top of many virtualisation environments.

(b) Data Centre

The core cloud domain currently consists of the following rack servers: 1x R430 & 2x R330 & 1x R640 & 1x R920. OpenStack runs on a Dell R640 server (72Core / 512GB / 2TB; Ubuntu 18.04). A Corsa Software Defined Network (SDN) switch (Mellanox SN2100, 16 port switch) runs on one Dell R640 server. OpenFlow 1.3 protocol is supported. The supported controllers include ODL, ONOS, FloodLight, RYU, etc. The switch throughput is 3.2Tbps. There is also support for remote VPN access.

[7] BBU: Baseband Unit

The 5GENESIS dedicated edge cloud has data centre architecture, currently consisting of 4 Dell R640 servers. For security purposes these services are attached to different virtual local area networks (VLANs) under the Surrey Platform 4G/5G core networks.

(c) Transport network

The JANET backbone provides high bandwidth and low latency enabling provision of a wide range of services. A transport network capacity of 1 Gbps throughput is available for traffic to and from the Surrey platform via JANET backbone.

In addition to the terrestrial backhaul network link provided by JANET, the Surrey site is linked to the UK-wide fibre core network over a Dense Wavelength Division Multiplexing (DWDM) connection. This setup allows the provision of high throughput connectivity between research and industry sites, and allows experimentations over an operator-grade long-distance metropolitan network.

Lastly, mmWave-based backhaul network is provided. The Bluwireless [8] mmWave carrier-grade backhaul (PtP mesh connectivity) solution for 4G/5G, already deployed at the Surrey campus, enables interference mitigation and seamless co-existence. The products are based on IEEE 802.11ad/ay standards. Bluwireless mmWave technology can deliver data rates of multiple Gbps and range over 300m.

3.2.2 Radio & Edge

The radio access part comprises different Radio Access Technologies both 3GPP and non-3GPP. Specifically, Commercial of the Shelf (COTS) 5G New Radio solutions developed for 5G are integrated as part of a larger flexible 5G network infrastructure and will allow support for a wide range of 5G use cases empowered by network slicing in the scope of 5GENESIS. Moreover, Rel.15-compliant software upgrade (from HUAWEI) to support NB-IoT is already available and deployed at the Surrey site (campus-wide). The Wi-Fi (802.11ac) deployment is based on a number of Ruckus access points (APs) interconnected to the Surrey Platform 5G core following the 3GPP Rel.16.

The LoRa devices integrated and used in the Surrey Platform serve as sensor nodes that can be connected via (5G UEs acting as) gateways, as well as another set of non-3GPP access technology exploiting unlicensed spectrum to support and facilitate operation and communication of non-mission critical IoT deployments.

3.2.3 Management & Orchestration

An overview of the Management and Orchestration Layer components and associated technologies deployed in the Surrey Platform is provided in Table 5. While the overview of the Management and Orchestration Layer is summarised in Table 5, the characteristics of three main functional components can be explained as follows.

- **Slice Manager**
  This component is in charge of the configuration and deployment of the slices. That is, it manages the creation, provision and termination of network slices over the infrastructure and is the binding element between Coordination Layer and the Infrastructure Layer and Management and Orchestration Layer. The Slice Manager receives the network slice template from Coordination Layer and then provisions the slice, deploys the network services, configures all the physical and virtual elements of the slice and finally activates the end-to-end operation.
- **NFV Management and Orchestration (MANO)**
  The Surrey Platform implements the NFV MANO functionally via Open Source MANO (OSM) and OpenStack. Among the key components of the NFV MANO, i.e., the NFVO, the Virtual Network Function Manager (VNFM) and the Catalogue, there is one to one mapping to the main

[8] https://www.bluwireless.co.uk/

components of OSM. The Virtualization Infrastructure Manager (VIM) is provided by Open Stack, the standard de-facto VIM in the ETSI NFV specification. Additionally, it is worth mentioning that the communication between NFVO (OSM) and the VIM (OpenStack) is realized by a VIM Driver, which makes the NFVO transparent to OpenStack and enables OSM to manage multiple OpenStack instances at the same time.

- **NMS**
  The NMS is a platform-specific network management system with direct access to physical resources as well as configuration interfaces. In the Surrey Platform, the NMS provides an overview of the physical resources and an interface to manage them. The management of the resources will be provided by the Resource Manager through the network and the inventory repository. The Element Management System (EMS), included in the NMS and responsible for the management of a PNF/VNF (physical/virtual network function), is provided by a component in OSM.

Table 5: Management and Orchestration Layer components

Component	**Product/Technology**
Slice Manager	Developed within the frame of the project to support network slice deployment over different management domains, i.e., Radio (Edge/Core), Cloud (NFV, MEC) and Network (SDN)
NFV Orchestrator	The platform supports OSM v5.
NMS (Network Management System)	NMS is a composition of different tools/managers: - WAN Infrastructure Manager (WIM) - EMS for the 4G/5G Radio and Core components
NFV Infrastructure Management	NFVI/VIM based on OpenStack (at the edge and the core)
WAN/VIM	SDN transport - SDN based WAN controlled by ODL

3.3 Support of 5G-HEART use cases with slices

The 5GENESIS platform slicing setup as illustrated in Figure 17 comprises of 4 domains, Core, Transport Network, Edge, and Access.

- Core: which includes Cloud and Core Services.
- Transport Network: implemented by the SDN-based wide-area network.
- Edge: includes the Edge Cloud which is complementary to the Core Cloud and can host latency-sensitive services, that need to be deployed close to the Access Domain. It can also support MEC services and applications.
- Access: It includes Radio Access equipment such as gNBs and antennas.

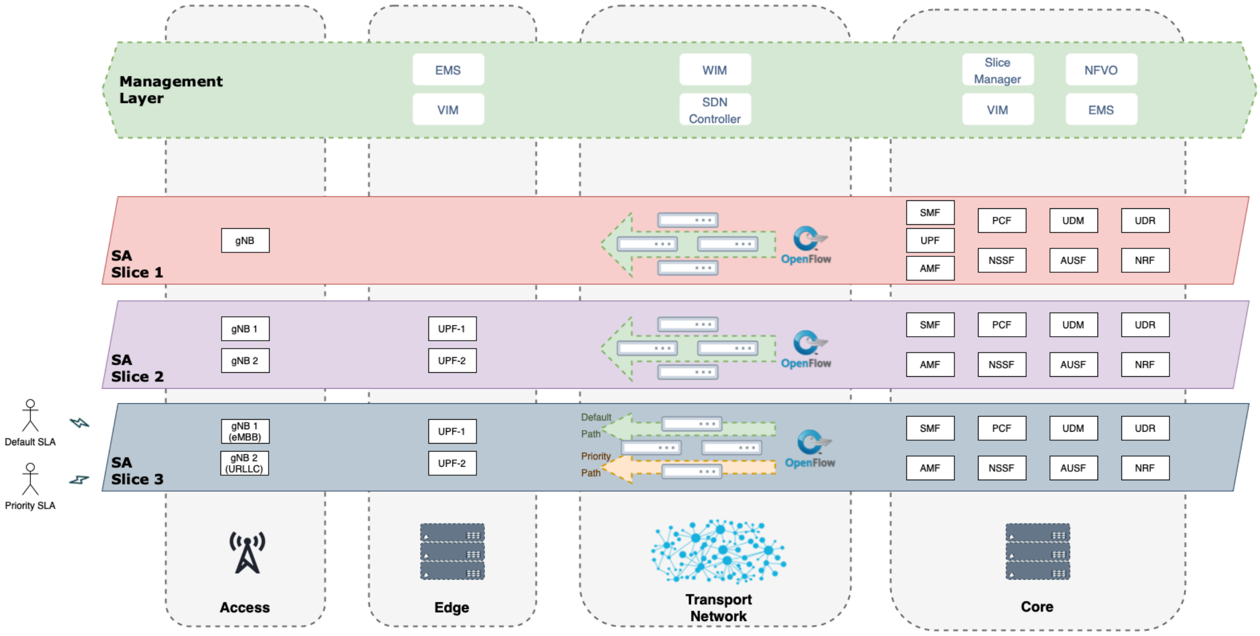


Figure 17. Network slicing setup in 5GENESIS platform.

For slice management, Katana Slice Manager is exploited which is a centralised software component providing an interface for creating, modifying, monitoring, and deleting slices. Through the North Bound Interface (NBI), the Slice Manager receives the Network Slice Template (NEST) for creating network slices and provides an API for managing and monitoring slices. Through the South Bound Interface, the Slice Manager communicates with the Network Sub-Slice Manager (NSSM) components of the Management and Orchestration (MANO) Layer, namely Virtual Infrastructure Manager (VIM), NFV Orchestrator (NFVO), Element Management System (EMS), the WAN Infrastructure Management (WIM).

An example workflow of the slice creation process is the following:

1. A user requests the creation of a new slice using Slice Manager's NBI. Parameters to create the Slice are defined in the NEST that is sent to the Slice Manager.
2. Slice Manager runs the Slice Mapping process, analysing parameters in the NEST. Then, as the output of this process, the virtual and physical network functions of each Network Sub-Slice are created based on the availability of underlying components of the infrastructure and the Slice requirements.
3. Slice Manager runs the Placement process to determine where to instantiate each network function and create the slice's Network Graph.
4. Following the Placement results, Slice Manager communicates with the underlying NSSMs (VIM, WIM, NFVO, and EMS) in order to provide and configure the required resources.
5. VIM creates a new tenant for the slice on the Network Function Virtualization Infrastructure (NFVI) domains that will be part of the network slice.
6. WIM creates virtual links or/and flows on SDN switches with specific resource-QoS requirements, as declared in the NEST, to activate appropriate traffic steering.
7. EMS provides the required resources and configurations (e.g., associate traffic or user IDs to APNs, spectrum band allocation, bandwidth, etc.) on specific components of the slice.
8. NFVO proceeds with the deployment and configuration of the virtual network functions included in the Communication Service.

5GENESIS platform provides the four types of slice: SA Slice 1, SA Slice 2, SA Slice 3, and optionally Slice 4 based on SA and NSA. Four types of slices are explained in Table 6.

Table 6: Summary of Slice types supported in 5GENESIS

Slice Type	Description
SA Slice 1	This option is for SA eMBB slice. While it includes 5GC deployment on Core Cloud and APN/DNN (Access Point Name/Data Network Name) based slicing.
SA Slice 2	This option is for SA URLLC slice. This is designed to utilize 5GCs Service-based Architecture which allows for decoupling control and data plane and moving internet GW closer to the end-user.
SA Slice 3	This setup offers SA eMBB and URLLC slices at the same time. SLA Priority rules both on mobile and transport network are used to optimize performance.
(SA+NSA) Slice 4	This setup offers NSA eMBB and SA URLLC slices at the same time.

5GENESIS is planned to serve a number of scenarios in Transport vertical as shown in Table 7.

Table 7: List of subcases/scenarios of verticals served by 5GENESIS

Vertical	Subcases/ Scenarios	Description	Service Type
Transport	T1S1& T1S2	High bandwidth in-vehicle Situational awareness and see-through for platooning	eMBB URLLC
	T2S3	Quality of service (QoS) for advanced driving	URLLC
	T3S1	Tele-operated support (TeSo)	eMBB/URLLC
	T4S3	Smart traffic corridors	mMTC
	T4S4	Location based advertising	mMTC
	T4S5	End-to-end (E2E) slicing	Generic functionality applicable to all scenarios
	T4S6	Vehicle sourced high-definition (HD) mapping	mMTC
	T4S7	Environmental services	mMTC

Based on the slice types explained in Table 6, subcases in Transport are implemented. For instance, eMBB services (T1S1) will be served by SA Slice 1 type. In URLLC service provision, since low latency performance achievement is really important, modifications have been applied both on core and radio systems: 1) User traffic with the higher SLA APN/DNN is prioritised, 2) gNB configuration includes higher numerology, changes in TDD pattern and scheduling request period.

Given that integration of Release B software of 5GENESIS on the Surrey platform is currently in progress and 5G based trials have not started, details on the use and specific configuration of slices used on a per trial scenario basis are under investigation.

4 5G-EVE

4.1 Overview

The 5G-EVE testbed, which is used in 5G-HEART Aquaculture scenarios, is located in OTE R&D Lab premises, in northern Athens. The 5G network components, that are parts of the access and core layers, are provided by Ericsson and will be presented in Chapter 4.2. The transition from 4G to 5G takes into consideration the massive amount of new hardware that must be deployed. Therefore, a Non-Standalone (NSA) approach has been proposed in order to continue using the LTE core. The NSA version will not affect negatively the requirements and expectations proposed in 5G-HEART project since the user requirements will be met with greater adequacy and efficiency.

4.2 Network architecture

The high-level network architecture of the Greek site of 5G-EVE is presented in Figure 18. Looking at different levels of the architecture, there are two main levels: the Radio Access Network (RAN) level and the Core Network (CN) level.

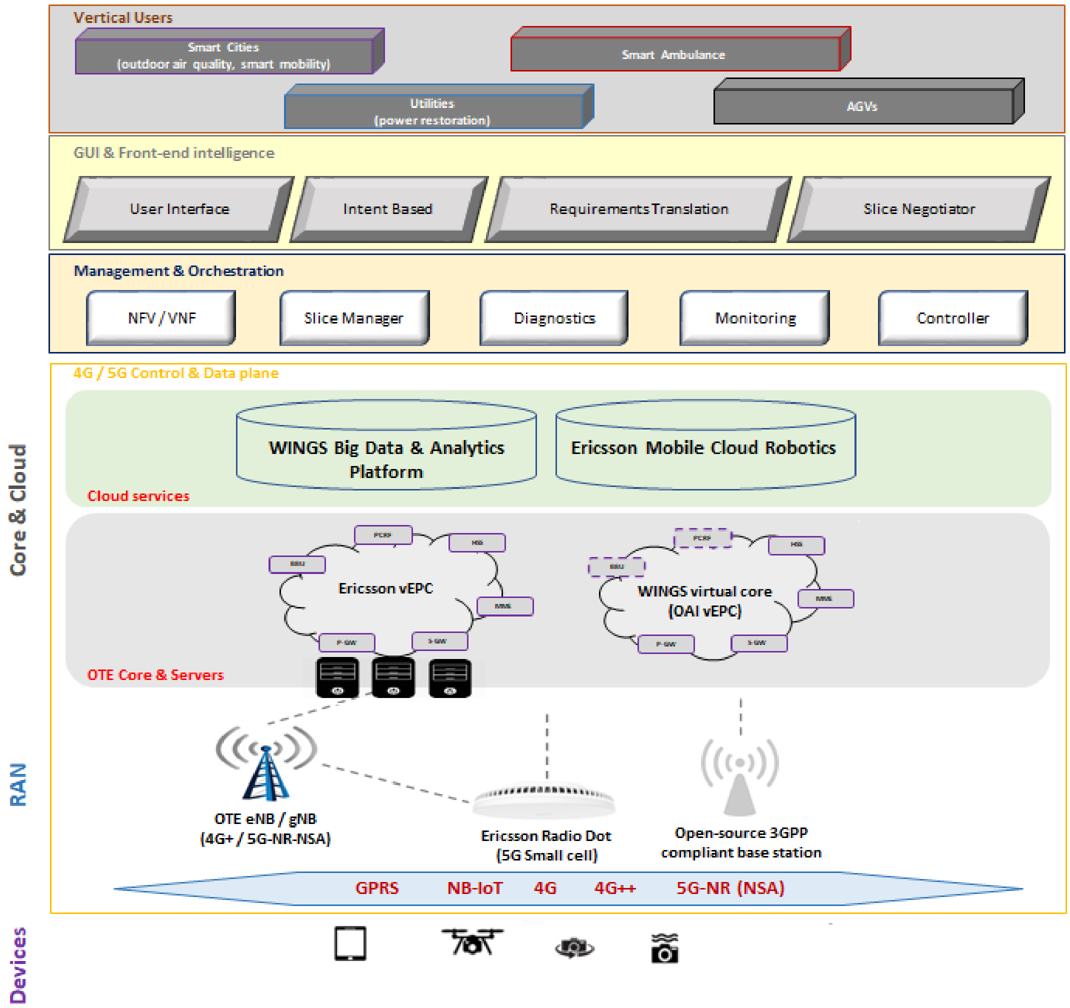


Figure 18. High-level network architecture of 5G-EVE testbed in OTE R&D Lab premises.

RAN consists of a hardware (HW) and a software (SW) part. The HW part includes the baseband node and the radio units. Additionally, there are small SW programs that are used in order to support the LTE operation (up to 3GPP Rel.14) and the 5G operation (Rel. 15 and upwards).

The core network architecture is based on a 5G virtual EPC (vEPC) approach. More specifically, since the subscribers in the 5G-EVE project are limited, a 5G EPC-in-a-box is chosen to be used in order to achieve a minimal footprint while also remaining cost-effective.

4.2.1 Core & Transport

The EPC-in-a-box approach is used as the CN part. In Figure 19, its components are presented in details. EPC-in-a-box 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. EPC-in-a-box deployment is built on Ericsson Cloud Execution Environment (CEE) which includes the following functions necessary for EPC-in-a-box [11]:

- Virtualized Cloud Infrastructure Controller (vCIC)
- Support to run the vCIC in a non-redundant single-vCIC mode
- Hyper-Threading
- Pinning of the VM vCPUs (virtual central processing units) to specific Hyper Threads (HTs), EPC, slicing

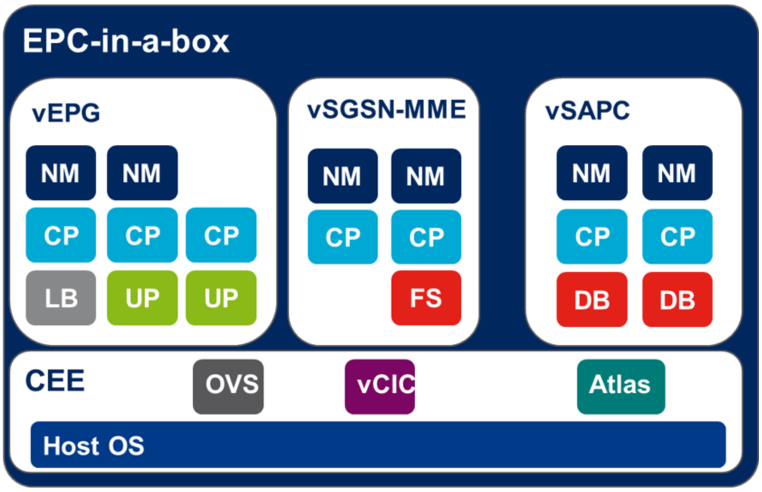


Figure 19. EPC-in-a-box[9].

The key EPC-in-a-box network functions are:

- Mobility Management Entity – MME (Software functionality of proposed SGSN-MME):
  MME is responsible for the user authentication. Additionally, it generates temporary identities to user equipment (UE) and verifies whether the UE is authorised to camp on the service provider's Public Land Mobile Network (PLMN).
- Serving/Packet Data Network Gateway – S/PGW (Software functionality of proposed Evolved Packet Gateway (EPG)):
  S-GW is responsible for packets routing to and from the gNB, while P-GW filters user traffic in order to ensure the QoS.
- Based on the Policy and Charging Rules Function -PCRF (which is a software component which operates in real-time and determines policy rules in a multimedia network), the Service-Aware Policy Controller (SAPC) is responsible for the policy control and charging rules and supports the optimized utilization of network resources.

[9] vEPG: virtual Evolved Packet Core, NM: Network Manager, vSGSN: virtual Serving GPRS Support Node, FS: File Server, DB: Database

4.2.2 Radio & Edge

Focusing on the RAN layer, its architecture is based on the Centralized Cloud RAN approach. The components that make up this architecture and their capabilities are presented in Figure 20 [11].

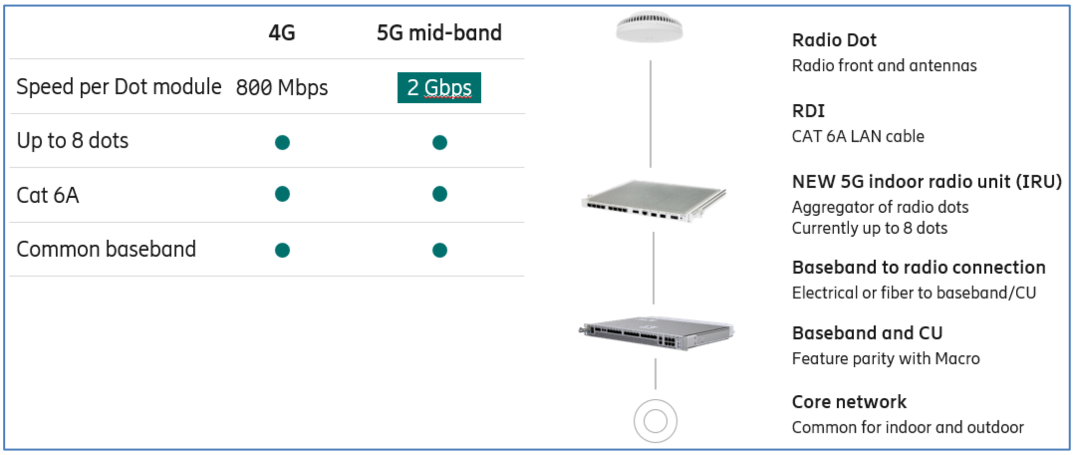


Figure 20. RAN components and their capabilities.

There are three main components:

1. The Radio Dot (RD) is used in indoor environments. RD is a single band antenna providing:
    - Output power 2x17 dBm (2x50 mW) in a 2x2 MIMO configuration
    - Higher Order Modulation (HOM) 256-QAM Downlink and 64-QAM Uplink
    - Total Instantaneous Bandwidth (IBW) 40 MHz, 2x LTE FDD (Frequency Division Duplex) carriers of 5, 10, 15, 20 MHz
    - Frequency conversion and amplifying functionality
    - Single Radio Dot Interface (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.
2. The Indoor Radio Unit (IRU), which controls the RD. More specifically, it provides baseband processing from a Baseband unit, transceiver processing to the RD over the RDI and supplies power to the RD.
3. The Baseband, which runs the SW features, such as Combined Cell, Carrier Aggregation and Lean Carrier. Its specifications are presented in Table 8.

Table 8: BBU 6630 specifications [11]

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
Transport interface, electrical 1Gbps RJ45 ports	2

4.2.3 Management & Orchestration

The management and orchestration (MANO) is a network layer where the orchestration takes place as well as the management of the hardware, the network resources and virtual network functions (VNFs) is served. ETSI-hosted OSM was preferred to be used in 5G-EVE testbed, among a variety of available options. The choice was based in its highly mature framework, production readiness and ease of initiation. Additionally, there is a large and continuous activity at the community level about OSM, which produces new versions offering new features.

Orchestration, management and monitoring of services rely on Open Source MANO to orchestrate functionalities that require a highly configurable infrastructure to be deployed and run the required VNFs. OpenStack is widely used in private cloud use cases by many enterprises and has all the characteristics to be the perfect choice for infrastructure. After introduction of NFV by ETSI, OpenStack has emerged as a key infrastructure platform for NFV and used as the VIM layer to give a standardized interface for managing, monitoring and assessing all resources within the NFV infrastructure and all of these actions can be orchestrated by OSM. A high-level view of the System is provided in Figure 21. The role of Kafka in Figure 21 is to process messages and plays like a broker to distribute messages between producers and consumers through unit messages called topics.

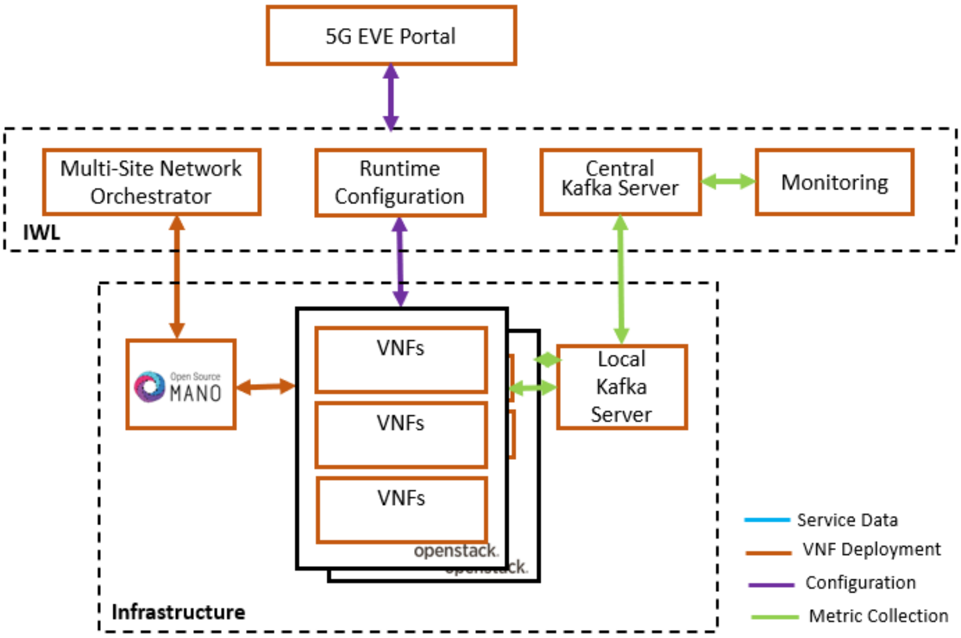


Figure 21. High level view of OSM, Openstack and Kafka.

The main information and specifications of OSM is summarised in Table 9.

Table 9: OSM specifications

OSM characteristic	Specification
Virtualization environment	Virtual Machines
VNF life-cycle operations	Modelling, On-boarding, NS creation, NS operation, NS configuration, NS finalization
NS actions	instantiate, start, stop, delete
VNF descriptors	YAML and Json
VNF images	QCOW
OSM Messaging bus	RabbitMQ
OSM & VIM Interfaces	Dashboard (Web UI), CLI

4.3 Support of 5G-HEART use cases with slicing

Network slicing is an important feature that offers benefits in network resources management. It allows multiple logical networks to be created on top of the existing common shared core and RAN infrastructure, offering flexibility to the existing core network.

At the first stage of the deployment, the 5G-EVE testbed consisted of one slice. It statically called and ran a service using an Access Point Name (APN). Then, the APN differentiation slicing mechanism was implemented in order to provide partitioning of the virtual Packet Data Network Gateway (vPGW) resources that could be allocated to a 3rd party application, which could be a MBB or MTC type of application.

More specifically, the APN is the basic mechanisms to provide access to services in a 4G/5G NSA network. It identifies a specific service type and, indirectly, a Packet Data Network (PDN) that provides the subscriber with access to that service.

The desired APN is indicated by the UE to the MME during attachment. The MME then selects the SGW/PGW (Serving/Packet Data Network Gateway) responsible for the requested APN. The selection is based on Tracking Area Identifier (TAI) and APN. An SGW/PGW can support multiple APNs or be dedicated to a specific APN. APN configuration is provisioned in HSS and includes default bearer QoS parameters (QoS Class Identifier (QCI), Allocation and Retention Priority (ARP), data rate limits (APN-Aggregate Maximum Bit Rate (AMBR)), and PDN type (IPv4/IPv6)).

The use of APN can be used for slicing the CN network by separating different APNs on different PGWs. This approach achieves a higher level of isolation among slices, compared to the case where the same PGW serves multiple APNs. It can be used to bring traffic belonging to a specific APN to a PGW that provides an appropriate handling of the traffic. For instance, placing the PGW closer to the access network to achieve lower latency. When APNs are utilized as slicing approach almost the complete network infrastructure is shared; therefore, it is most appropriate to apply when the network slices belong to the same mobile operator APN. The selection of the PGW(s) that is associated to a specific APN is the main resource partitioning approach behind APN slicing. There are two alternative solutions: Either static APN/PGW selection based on APN configuration in HSS or dynamic APN/PGW selection based on mobility policies configured in PCRF. Both methods are illustrated in Figure 22. In 5G-EVE, the implementation is based on the APN configuration in HSS and not in the dynamic selection.

In an NR NSA network, if there are multiple PGW/SGW pairs serving one APN, it is possible to select a specific PGW/SGW node for the EN-DC capable UEs based on NR usage information configured in MME. It is also possible to have APNs for different services (e.g., voice or data) belonging to a single CN slice that is serving a group of UEs.

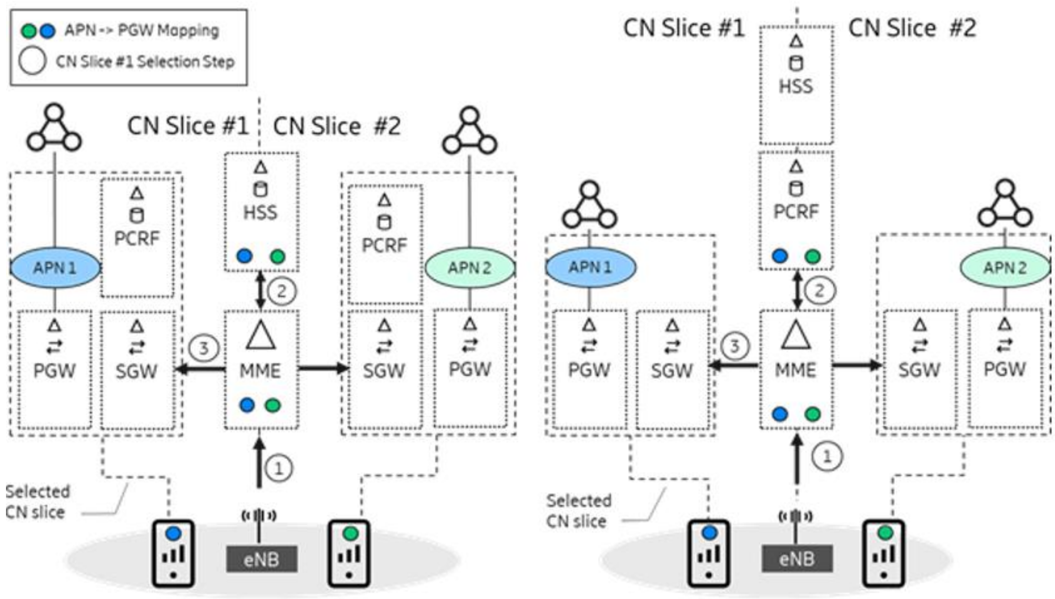


Figure 22. APN differentiation slicing mechanism.

The 5G-EVE testbed will serve the scenarios that are presented in Table 10.

Table 10: List of sub-cases/scenarios of verticals served by 5G-EVE

Vertical	Subcases/ Scenarios	Description	Service Type	Notes
Healthcare	H1E	Aquaculture remote health monitoring	eMBB uRLLC mMTC	Concurrent with aquaculture testing
Aquaculture	A1S1	Sensory data monitoring	mMTC	
	A1S2	Camera data monitoring	eMBB	
	A1S3	Automation and actuation functionalities	eMBB uRLLC	

4.3.1 Healthcare

4.3.1.1 Aquaculture remote health monitoring (H1E)

The WINGS remote health monitoring system comprises of: (a) Devices/cameras/sensors (as well as device management functionality), (b) data management functionality, (c) AI/ML analytics functionalities (useful insights and predictions for conducting decision making) and image processing, (d) a dashboard for visualization purposes.

OTE will manage the network architecture that is going to be used during the trials, while ERICSSON will be providing the network equipment. The SKIRONIS aquaculture site will be connected, via OTE premises at the City of Megara, to OTE's testbed. There will be a connection to the Ericsson virtual Evolved Packet Core (vEPC) and finally, there will be a connection with the cloud applications.

4.3.2 Aquaculture

The user side architecture of the Greek site and its integration with the network is displayed in Figure 23.

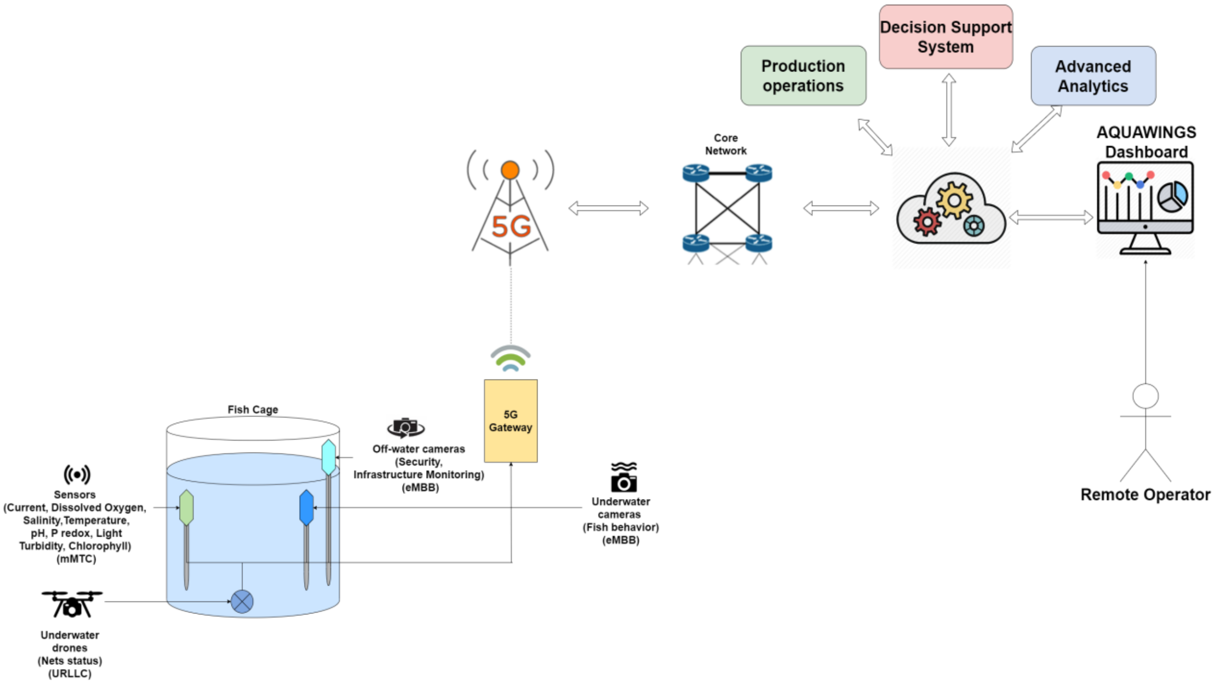


Figure 23. Greek site user side architecture.

The connectivity of the aquaculture site to the 5G network along with the installation of the network probes is displayed in Figure 24.

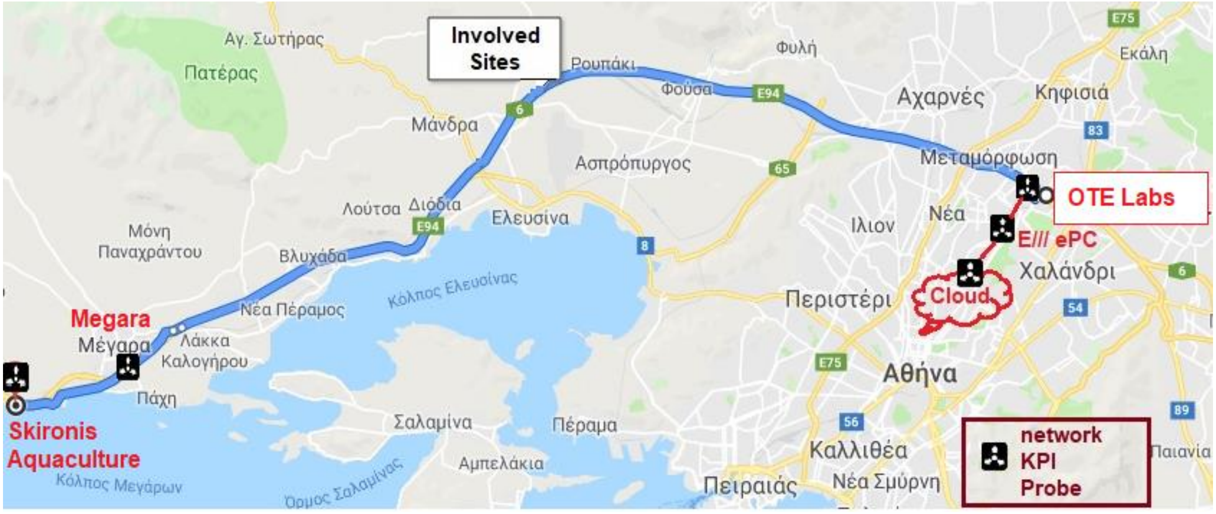


Figure 24. Greek aquaculture site connectivity to network.

As it was described, the Skironis aquaculture site is connected to the Ericsson virtual Evolved Packet Core (vEPC) in OTE testbed. There is also a connection with the cloud platform. This topology is presented in more details in Figure 25, where the 5G New Radio access network (5G NR) is connected to a Network Time Protocol server (NTP), which is used in order to factor out the network latency. The NTP server is connected to the local cloud environment and, through the network-edge interface SGi, to the vEPC.

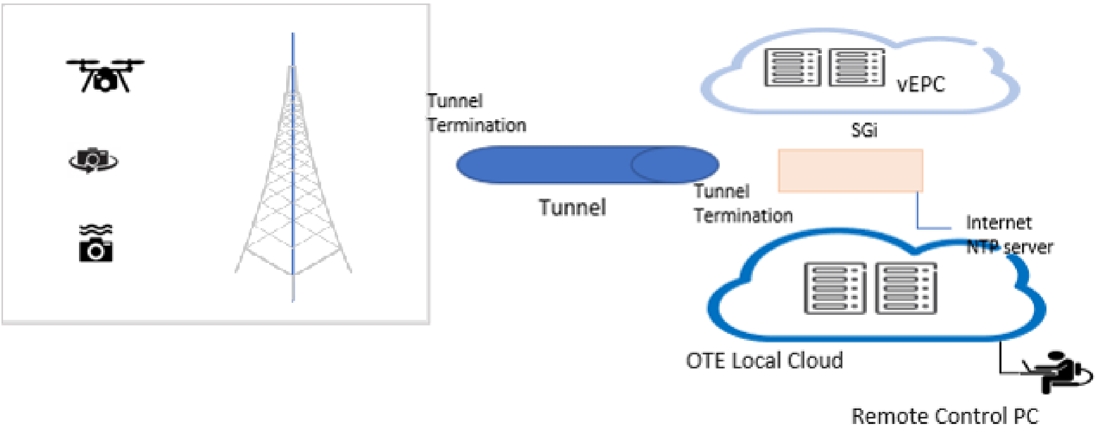


Figure 25. Greek site 5G network topology.

The A1S3 scenario which is related to the uRLLC slice has been designed. Additionally, the A1S1, A1S2 scenarios are finalized in order to assess and evaluate the functionality of mMTC and eMBB slices. This way all scenarios will be tested in the coming months, as part of WP6 activities, for assessing the main pillars of 5G-PPP related to mMTC, eMBB and uRLLC cases.

5 5GTN

5G Test Network (5GTN), operated by VTT, enables the testing of the performance of new communication technologies and services in a realistic environment. The network is a 5G technology and service development platform including a continuously evolving Radio Access Network (RAN) and a cloud-based core network. The RAN part contains both 4G and 5G technologies for flexible utilisation in a variety of vertical industry use cases. The core network part is fully virtualised, supporting distribution of network functionalities both in control plane and user plane. Multi-access Edge Computing (MEC) and evolved Multimedia Broadcast Multicast Service (eMBMS) functionalities are also available. The architecture has integrated testing and network management frameworks implemented, enabling new functionalities in these domains to be built on top of the existing platform or as parallel implementations complementing the existing functionality.

5.1 Overview

An overview of the 5GTN test facility's main capabilities is presented in Figure 26. The 5GTN architecture is connected to VTT's Converging Networks Laboratory (CNL) infrastructure, which provides the service cloud platforms and internet connectivity for the 4G and 5G networks. Together these two networks form the 5GTN-VTT test facility utilised in the 5G-HEART use case trials. 5GTN is also part of the Finnish 5G Test Network Finland (5GTNF) collaboration network, which contains several interconnected sites around Finland and opens additional possibilities for research project cooperation. There is a possibility for remote access networks through a dedicated fibre connection, virtual private network (VPN) tunnel or as connected private network deployment.

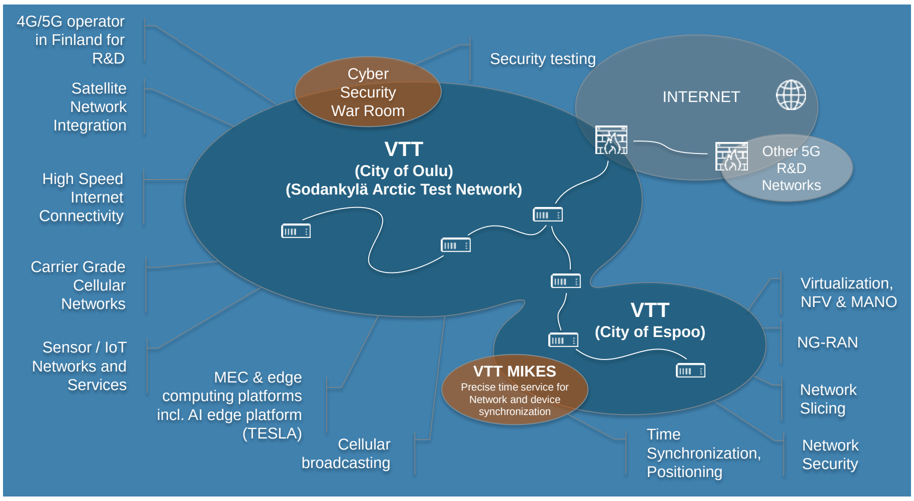


Figure 26. 5GTN-VTT test facility overview

The key features of 5GTN-VTT facilitate versatile deployment and trialling of vertical industry use cases of varying scale. The provided combination of commercial carrier grade and open source network components enable the test setup to be built with either maximum flexibility or performance in mind. The integrated monitoring framework provides full visibility into the network infrastructure and utilisation of open and standardised interfaces guarantee inter-operability and inter-connectivity. VTT acts as the network operator for 5GTN and multiple dedicated frequency bands for cellular connectivity enable fully controlled indoor and outdoor testing with commercial user equipment. The test facility is continuously developed and maintained in Finnish national jointly funded research projects as well as in VTT's internal research infrastructure development activities, which guarantees support for 5G-HEART trials until the end of the project. 5GTN has already been utilised in a variety of national and international 4G and 5G trialling collaborations from 2016 onwards.

5.2 Network architecture

The logical architecture of the 5GTN-VTT test facility is presented in Figure 27. All user plane functionality of the operated 4G and 5G networks is running locally in VTT Oulu premises. Some control plane functionalities (e.g., related to IP Multimedia Subsystem (IMS) services) are hosted in remote external networks. Due to the local availability of the network functions and their interfaces, the integrated management, monitoring and testing framework can be used for both passive monitoring and active testing of the infrastructure.

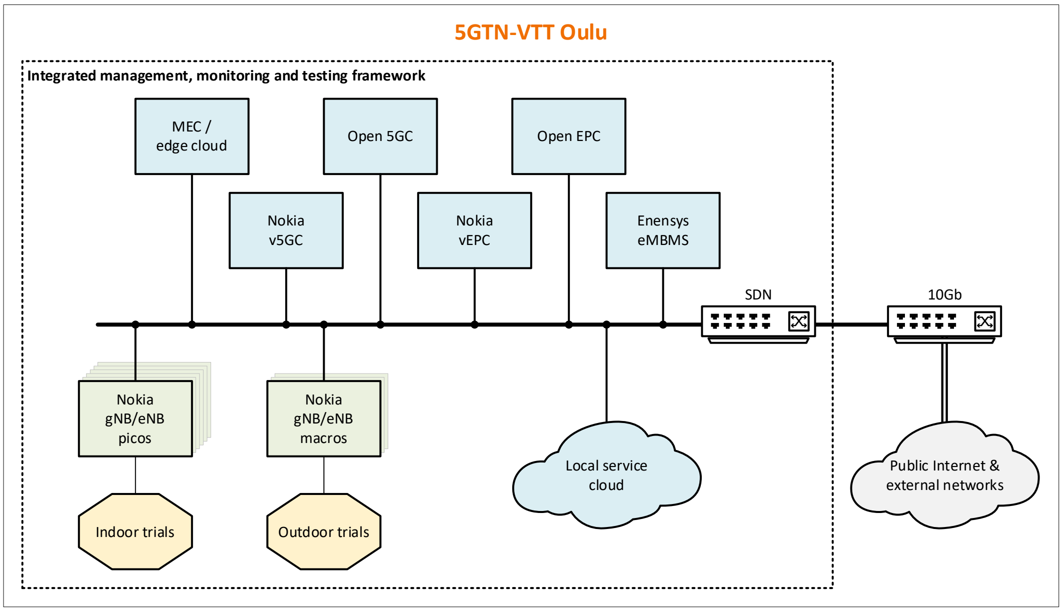


Figure 27. 5GTN-VTT logical architecture.

The key technology components of the 5GTN-VTT test facility are presented in Table 11. The listed network equipment focuses on the requirements stemming from the 5G-HEART's VTT-led trial use cases. Hence, the provided list is not exhaustive from the point of view of the entire 5GTN-VTT infrastructure.

Table 11: 5GTN-VTT technology components

Mobile Core Products	Radio Access Products	3GPP Release
Simulated 4G EPC Open source 4G EPC Nokia 4G vEPC Open source 5GC Nokia 5GC NSA Nokia 5GC SA	Nokia 4G NB-IoT base station Nokia 4G macro base stations Nokia 4G pico base stations Nokia 5G macro base stations Nokia 5G pico base stations	Rel. 15 and 16

The physical architecture of the 5GTN-VTT test facility is presented in Figure 28. The installed technology components (from Table 11) depicted in the architecture are discussed in the following subchapters.

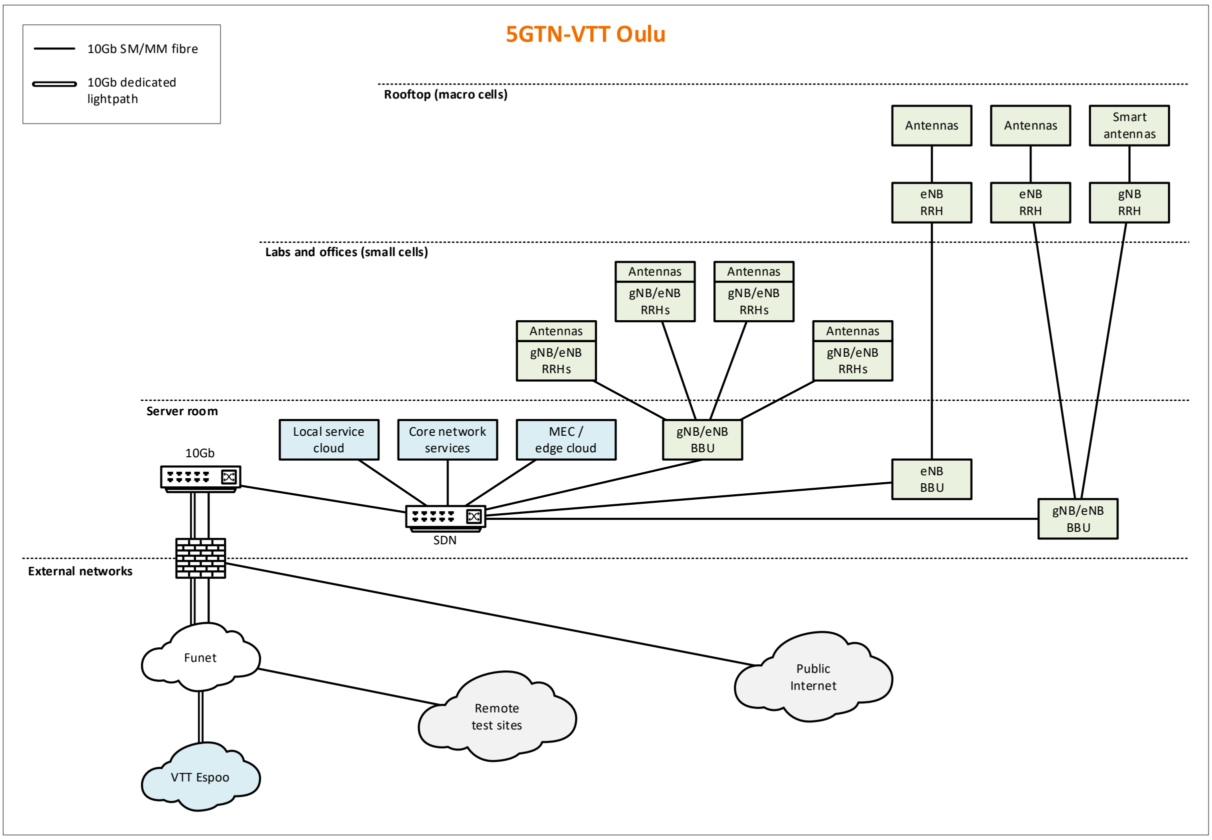


Figure 28. 5GTN-VTT physical architecture in Oulu, Finland.

5.2.1 Core & Transport

(a) Mobile core

The mobile core network services are running as Virtual Network Functions (VNFs) on VMs or dedicated server hardware installed in the local data centre at VTT Oulu premises. Depending on the required functionality and performance, different implementation options are available for the trials. The desired core network functionality can be provided as a lightweight or carrier-grade 4G evolved packet core (EPC) and 5G core network (5GC) deployments based on open source or commercial telco cloud components.

In addition to the basic cellular network functions, the 5GTN-VTT also supports MEC/edge cloud for both 4G and 5G, as well as cellular multicasting and broadcasting in the 4G network via eMBMS provided by Enensys.

(b) Data centre

The local cloud environment runs on top of Dell PowerEdge M1000e Blade Center in an on-site data centre at VTT premises, providing physical blade servers for hosting of virtualised service instances from verticals and other third parties. The physical service cloud infrastructure resides in the same data centre as a cellular network function, and it provides additional deployment possibilities for use cases relying on lightweight edge deployments and near-edge computing scenarios. The virtualisation is mainly based on OpenStack and VMware software platforms, but other environments can also be flexibly utilised.

(c) Transport network

The 10 Gbps transport connections to remote test sites is provided by the Finnish University and Research Network (Funet) fibre infrastructure. There is also a dedicated 10 Gbps fibre connection between VTT's Oulu and Espoo premises enabling resource sharing between the two test facilities.

Transport connections to external networks or remote access sites which are out of reach of the Funet infrastructure are relying on VPN tunnels over public Internet.

The transport network as well as the backhaul and fronthaul connections inside the 5GTN-VTT infrastructure are based on 10 Gbps fibre links. The transport and backhaul parts of the network support Software-Defined Networking (SDN).

5.2.2 Radio & Edge

The RAN infrastructure has both 4G LTE and 5G NR base stations deployed. The coverage of the network is focused inside and around the VTT Oulu premises using the base station equipment listed in Table 12.

Table 12: 5GTN-VTT base station equipment and radio access technologies

Site Type	# of Sites	# of Cells	Access Type
Outdoor macro, 2x2 MIMO	2	3	4G LTE-A, one cell supporting NB-IoT
Outdoor macro, 4x2 MIMO	1	1	5G NR
Indoor pico, 2x2 MIMO	6	9	4G LTE-A, one cell supporting LTE-M and NB-IoT
Indoor pico, 4x2 MIMO	4	2	5G NR, multiple RRHs per cell

The supported frequency bands for the base stations listed above are:

- 700 MHz – Band 28 FDD with 10 MHz bandwidth for NB-IoT
- 2.1 GHz – Band 1 FDD with 10 MHz bandwidth for 4G LTE and NB-IoT
- 2.6 GHz – Band 7 FDD with 10+5 MHz bandwidth for 4G LTE
- 3.5 GHz – Band n78 TDD with 60 MHz bandwidth for 5G NR

5.2.3 Management & Orchestration

The integrated management, monitoring and testing framework has been deployed using a combination of proprietary and open source tools. The management of individual network components in the RAN and telco cloud core are done using Nokia network management software. Monitoring of the network traffic is performed using software-based passive Qosium [12] measurement probes placed around the virtualised network infrastructure and in the user equipment. In addition, performance counter data from individual network components are collected with the Nokia network management software, processed and forwarded to an InfluxDB [13] database for further use with visualisation tools, such as Grafana [14], or in post-analysis. For field testing and troubleshooting purposes, Keysight Nemo Handy [15] software is used in the user equipment.

5.3 Support of 5G-HEART use cases with slices

The 5GTN-VTT test facility supports rudimentary slicing for 5G NSA through assignment of dedicated eNBs and gNBs in the RAN and dedicated EPC instances to different slices as shown in Figure 29. The EPC instances run as VMs in the local cloud environment or on dedicated server hardware in the local data centre at the VTT Oulu premises. In the NSA deployment, all core network services are allocated to slices as complete integrated packages. Individual network functions from different core network entities cannot be mixed if resource isolation between the slices is needed.

For 5G SA, VNFs can be allocated and interconnected to form slices in the 5GC as shown in Figure 29. The 5GC VNFs are running in the local cloud environment in the local data centre at the VTT Oulu premises. In the RAN, dedicated gNBs are used to isolate the slices from each other either in space (cells not overlapping) and/or frequency (cells on different frequency bands). The test facility can provide eMBB slices and the configuration process to set up the slices is still mostly manual. Partial support for uRLLC slices is also provided through specific configuration of the gNBs and placement of VNFs in the architecture, e.g., by bringing application data processing closer to the network edge with MEC. Use cases requiring specific support for mMTC-type communication in the air interface can utilise the eNBs supporting LTE-M and NB-IoT in the 5G NSA setup. Otherwise, partial support for mMTC slices can be provided by modifying the configuration of the 5G SA eMBB or URLLC slices.

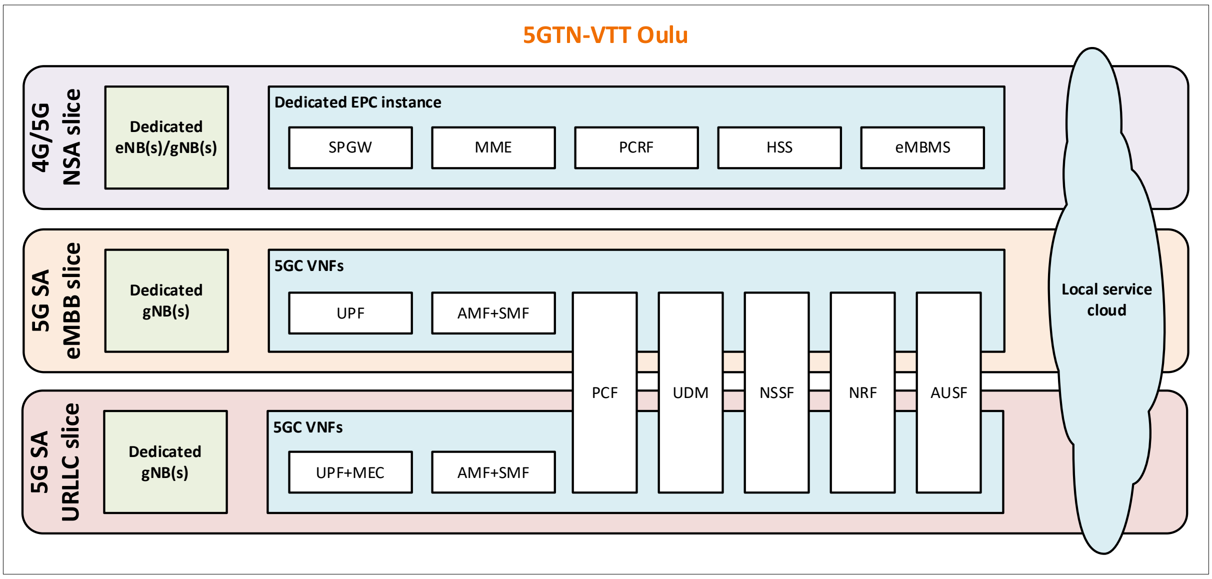


Figure 29. 4G/5G NSA slicing with dedicated RAN and core network components.

Table 13 presents the trial scenarios running in the 5GTN-VTT test facility. The required service type support includes eMBB and mMTC as well as uRLLC with emphasis on the low latency over ultra-reliability. In the transport vertical, the three scenarios are going to be trialled in an integrated manner, where the implementation of core scenario T2S4 is going to be extended with key functionalities for uplink and downlink data transfer from T4S1 and T4S2.

Table 13: List of subcases/scenarios of verticals served by 5GTN

Vertical	Subcases/ Scenarios	Description	Service Type	Notes
Healthcare	H1A	Educational Surgery; 5G for remote learning and remote attendance of clinical operations.	eMBB	Requires MEC & eMBMS with 5G NSA & SA.
Transport	T2S4	Human Tachograph	uRLLC	Emphasis on low latency over ultra-reliability. Requires MEC.
	T4S1	Vehicle Prognostics	mMTC	
	T4S2	Over-the-air (OTA) Updates	mMTC	Requires eMBMS with 5G NSA and SA.

5.3.1 Healthcare

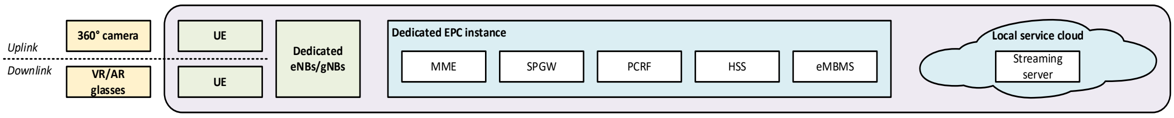
5GTN-VTT test facility hosts one healthcare vertical trial. The eMBB configuration of the 5G NSA and 5G SA slices provided for the trials is presented in the following subchapters.

5.3.1.1 Educational Surgery (H1A)

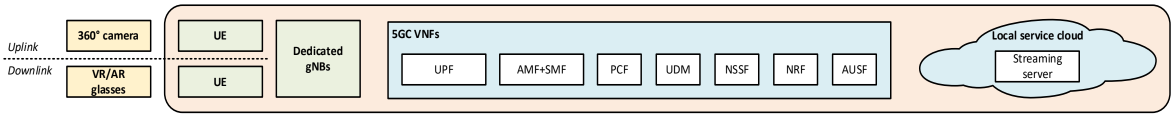
The Educational Surgery subcase targets to find improved solutions supported by 5G for remote learning and remote attendance of clinical operations. The main target in the Educational Surgery subcase is to provide a 360° video streaming platform aiming to deliver a low latency feed from an operational facility towards a classroom for the educational purpose. The later secondary target is to provide enhanced experience by utilising 2-dimensional mobile cameras for focus areas, providing sensor data alongside video, and to provide a live audio feedback channel for viewers.

The trial setup for Education Surgery runs on top of the 5GTN-VTT test facility in a laboratory environment. The related slice components for 5G NSA and 5G SA deployments are shown in Figure 30. At the server side the main actor consists of a video streaming server performing the video distribution operations from the hospital site. The 360° camera can also act itself as the streaming server, but in our setup it is connected to another hardware machine (Intel NUC PC), which is subsequently connected to the network via eNB/gNB. This allows improved parametrization of the encoding parameters as well as easier connectivity to and configuration of the mobile network. The streaming server can include the actual video encoder, video packetizer and streamer, and these components can be located either on the same server or distributed in the network considering especially MEC-based solutions.

At the client side, several different UEs can be used for video reception and playback. The best visualisation is realised when a UE receives the live 360° stream at VR glasses connected wirelessly to the access point. In case of multiple clients receiving the same streaming content simultaneously at the same area, cellular multicast/broadcast in the form of eMBMS (supported only by the 5G NSA slice) is required to make resource usage in the network more efficient.



a) 4G/5G NSA slice components



b) 5G SA slice components

Figure 30. 4G/5G NSA and 5G SA slice components for the H1A trials.

5.3.2 Transport

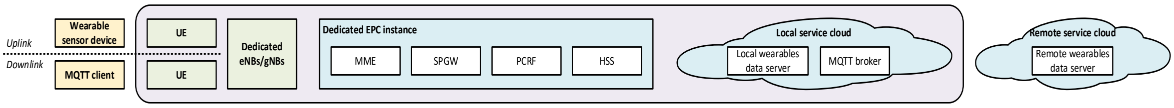
5GTN-VTT hosts three transport vertical trials. The eMBB and uRLLC configurations of the 5G NSA and 5G SA slices provided for the trials are presented in the following subchapters. Even though two of the transport trial scenarios require support for mMTC service type in large-scale deployments as shown in Table 13, the basic eMBB slice configuration will be utilised in the trials to provide the best baseline performance for the gNBs and scalability assessment for the trialled applications will be performed using data traffic emulation.

5.3.2.1 Human Tachograph (T2S4)

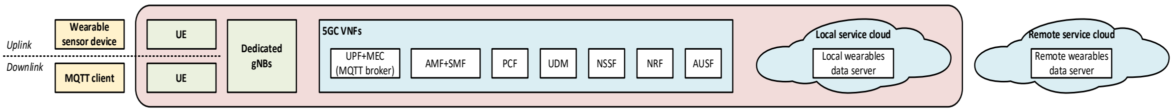
The Human Tachograph service provides solutions for reliable detection and sharing of information about drowsy or otherwise impaired drivers, which in turn provides valuable extra information to variety of systems improving cooperative road traffic safety services. In order to provide accurate assessment of the driver condition and efficient distribution for the detected risks, the trial scenario combines ubiquitous wearables-based measurement and analysis methods with 5G connectivity. As life outside the vehicle (e.g., sleep and diet) is also important for fatigue and fitness to drive, the combination of the real-time driver monitoring data measured while driving and the historical data collected outside the vehicle enables the driver condition to be assessed more accurately than with currently used on-board systems.

The Human Tachograph trials on top of the 5GTN-VTT test facility divide the overall functionality of the service into two parts, i.e., wearable sensor data collection and analysis in the uplink direction, and warning message triggering and distribution in the downlink direction. In the wearable sensor data collection and analysis phase, the real-time sensor data measured from the driver is streamed to the network for analysis and combination with previously analysed historical data. The wearables data analysis is based on algorithms developed by Polar. In the warning message triggering and distribution phase, a detected anomaly in the driver condition triggers an anonymised warning message, which is distributed to the other road users in the area through the network. The warning message distribution is handled through an MQTT (Message Queuing Telemetry Transport) broker, which sends the triggered message to the subscribed MQTT clients.

The Human Tachograph trials are performed on top of both 5G NSA and 5G SA slice configurations. The 5G NSA slice provides eMBB service type as shown in Figure 31, whereas the 5G SA slice is configured to provide uRLLC service type. The trial setup also requires MEC/edge cloud components in order to place parts of the sensor data analysis and warning message triggering as close to the users as possible for minimised end-to-end service latency.



a) 4G/5G NSA slice components



b) 5G SA slice components

Figure 31. 4G/5G NSA and 5G SA slice components for the T2S4 trials.

5.3.2.2 Vehicle Prognostics (T4S1)

The Vehicle Prognostics service enables the vehicle to upload its on-board diagnostics – second generation (OBD-II) status messages wirelessly to the network for analysis and, in case of detected issues, guidance for required repairs. The upload is expected to happen while the vehicle passes by a single roadside unit (RSU) or gNB. The Vehicle Prognostics trials on top of the 5GTN-VTT test facility have focused on the performance of the 5G uplink data transfer when typical format of OBD-II messages is used in terms of its length and data packet payloads. The data transfer from the vehicle to the application server is handled by an MQTT client, which sends the data to the MQTT broker at the network edge.

The Vehicle Prognostic trials are performed on top of 5G NSA and 5G SA slices providing eMBB service type as shown in Figure 32. The mMTC component in the trials is related to the scalability of the trialled application which will be validated using emulated data traffic in the presented 5G SA setup.

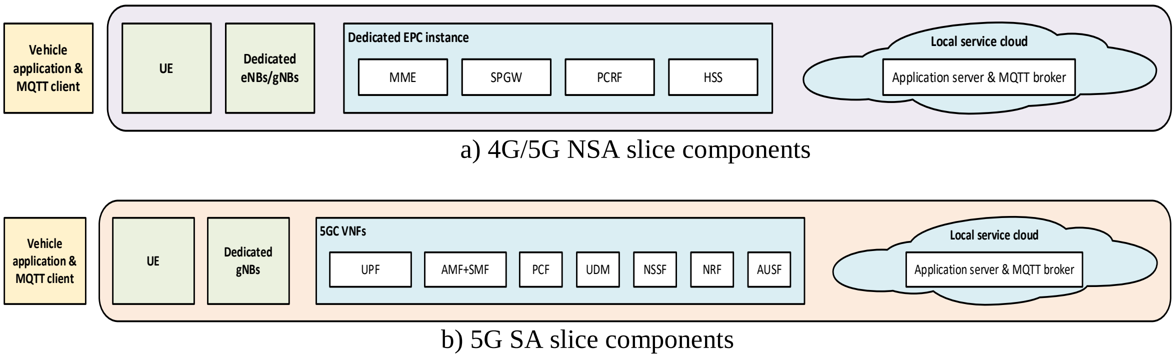


Figure 32. a) 4G/5G NSA and b) 5G SA slice components for the T4S1 trials.

5.3.2.3 T4S2: Over-the-air Updates (T4S2)

The Over-the-air Updates service enables the vehicle to receive software updates for different on-board systems wirelessly through the cellular network infrastructure. The updates can be small incremental updates for critical system such as the engine control unit (ECU) or large system updates, e.g., for the vehicles infotainment system. Depending on the type of the update and the number of users receiving it, the update packages can be delivered to the vehicles using unicast transmissions or multicast/broadcast with eMBMS. The Over-the-air Updates trials on top of the 5GTN-VTT test facility have focused on the performance of the 5G downlink data transfer when different size update packages are being downloaded from the application server. The data transfer from the application server to the vehicle is handled using Linux secure copy (SCP) over transport control protocol (TCP).

The Over-the-air Updates trials are performed on top of 5G NSA and 5G SA slices providing eMBB service type as shown in Figure 33. The feasibility of using eMBMS-based cellular multicast/broadcast in the use case will be tested using the 5G NSA slice setup. The mMTC component in the trials is related to the scalability of the trialled application which will be validated using emulated data traffic in the presented 5G SA setup and comparing the achieved results against the eMBMS-based performance measurements.

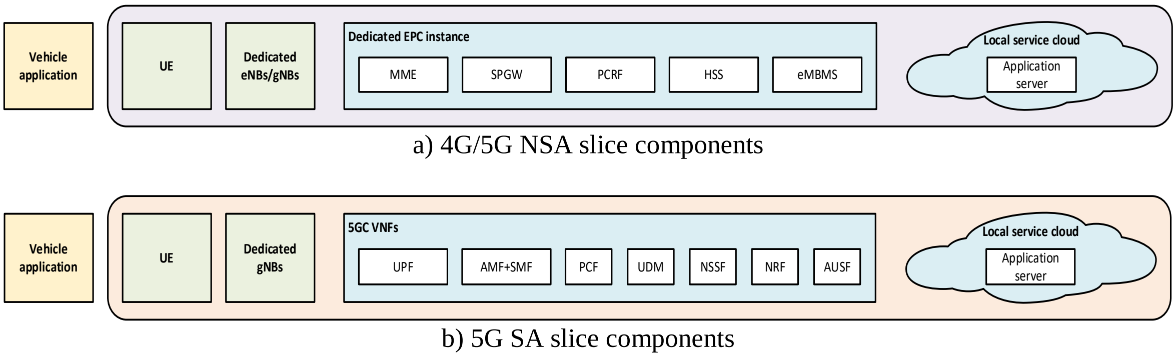


Figure 33. 4G/5G NSA and 5G SA slice components for the T4S2 trials.

6 5GRONINGEN

6.1 Overview

5Groningen is an end-to-end infrastructure aimed towards showcasing the potential of next generation networking for different applications. It is currently being used for developing, testing and piloting applications in different verticals, including healthcare, energy, traffic & logistics, agriculture, and living environment. All these verticals can benefit from the use of next generation mobile communications by either increasing the bit rate, reducing the latency or providing better location services among other benefits. These advantages will in turn impact society and improve quality of life.

5Groningen encompasses 4 different locations, including several wireless network access nodes and multiple servers capable of hosting core functions in different locations, as shown in Figure 34. Altogether, this infrastructure is capable of showcasing novel uses for mobile communications using among other technologies 4G and 5G cores, 4G, 5G and non-3GPP radio access technologies, slicing and edge computing.

Figure 34. Physical architecture of 5Groningen.

6.2 Network architecture

An overview of the network architecture can be seen in Figure 35. The platform can be divided in two pairs of edge and core locations. Hoogezand is paired with Groningen, and Helmond is paired with Den Haag. Despite that division, the two pairs are not completely independent, as they share a common database located in Den Haag. With a central database accessed by all the network functions that perform subscriber authentication and authorization, it is possible to have a single point of provisioning. Altogether, this setup allows to explore different core network setups and different radio network setups simultaneously, while enabling also edge computing in both edge locations (Helmond and Hoogezand). The setup in Hoogezand together with the core networks in Groningen can perform 5G NSA (Option 3) and 5G SA (Option 2), while the setup in Helmond works together with the core network in Den Haag providing 4G (Option 1, currently not used) , or 5G SA (Option 2).

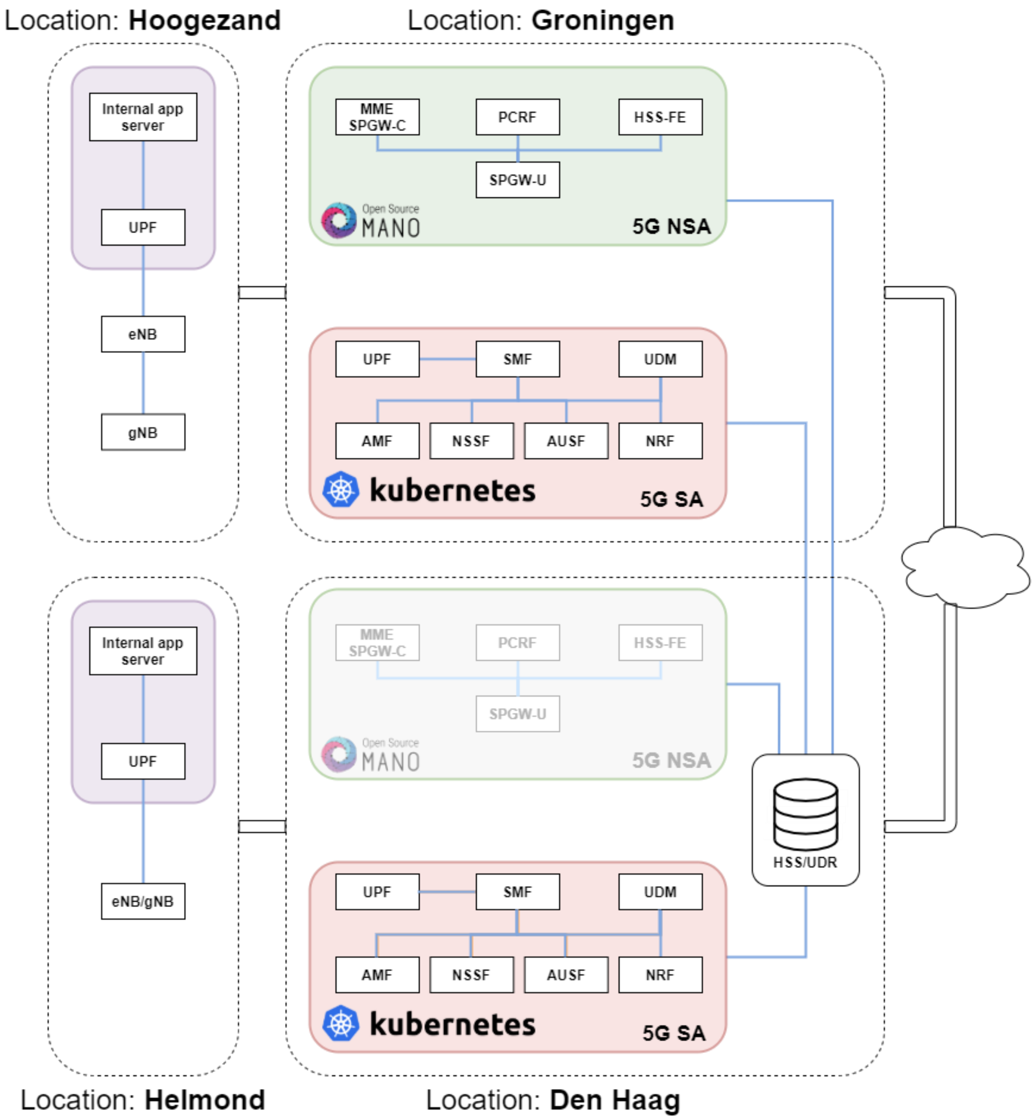


Figure 35. Logical architecture of 5Groningen.

6.2.1 Core & Transport

The core networks are instantiated in the core locations, Groningen and Den Haag. The location in Den Haag serves as the main site and it contains many physical servers that are part of a virtual infrastructure managed by OpenStack and capable of hosting a wide variety of computing workloads, including the core network and the central subscription database for it. The site in Groningen also has multiple servers in a virtual infrastructure managed as a separate OpenStack cloud.

Groningen hosts the core networks that serve the Hoogezand site. It can host EPC cores, which contain an MME/SPGW-C, a PCRF, a SPGW-U and an HSS-FE, and 5G cores, which contain a UPF, an SMF, a UDM, an AMF, a NSSF, a AUSF and an NRF.

Den Haag has a similar setup to the one in Groningen, but it serves the Helmond location. At the moment, this location does not host any EPC cores.

The connection between the edge locations and their respective core locations are done through VPN tunnels. VPN tunnels are also used in the connection between the core locations. There is no connection between the edge locations.

6.2.2 Radio & Edge

The edge sites (Helmond and Hoogezand) contain the radio part of the network and small servers capable of holding some application servers and a UPF (enabling MEC). The function in those servers can be orchestrated as described in Chapter 6.2.3.

Helmond has a single RAN which can be configured to work as an eNB or a gNB. It uses an Ericsson 6318 baseband unit, two Ericsson 4422 RRUs, and two Ericsson 2203 RRUs. With only one RAN, it is only possible to do SA deployments, either 4G (using the eNB capabilities with the EPC core) or 5G SA (using the gNB capabilities with the 5G core). This setup uses the 2.6GHz LTE band and the n78 NR band.

Hoogezand has a separate gNB and an eNB. Having two RAN enables the use of other deployment options, such as 5G NSA (Option 3), but also single RAN setups like 5G SA (Option 2). In this setup we use the n78 band (for 5G NR) and n7 (for LTE). There is a combination of passive directional and passive omnidirectional antennas.

For the experiments that do not require the use of real radio setups, it is possible to use emulated UEs and gNBs. In those cases, the emulated UEs and gNBs can be deployed as VMs in any of the 4 locations, but as the servers on the core locations are more capable, those functions are generally deployed on the Den Haag or Groningen sites.

6.2.3 Management & Orchestration

The servers are part of a research cloud platform managed with OpenStack. In fact, as described above, there are two cloud APIs used for infrastructure control and one of them has a partition at an edge site. OpenStack APIs allow to simultaneously run different workloads with different form factors, such as bare metal, virtual machines, as well as containers on top. Virtual network functions can be instantiated directly or using orchestration systems. The servers in Helmond are managed separately and are not part of the OpenStack/OSM orchestration system. The structure of the orchestration system is illustrated in Figure 36.

For the 5G NSA cores (EPC cores from 4G), virtual network functions are orchestrated with OSM (Open Stack MANO) and Juju. OSM makes the necessary API requests to the infrastructure manager and sets up the VMs and all the required networks between them. Then the Juju charms configure the software within the VM, installing all the required libraries and dependencies, configuring the network functions, and starting the functions. OSM uses separate descriptions for the virtual network functions (VNFs) and the network services (NSs), VNF descriptors (VNFDs) and NS descriptors (NSDs), respectively. This separation facilitates reusing the same type of VNF in different networks, for example in 2 different types of core networks that share the same type of HSS-FE. This does not mean that the same instance of the function is shared, but it is a copy with the exact same proven behaviour.

The flexibility of these orchestration systems allows deploying new dedicated core networks quickly on demand, making it possible to explore new ways of using mobile networks. One of those possible new ways involves using 5G as a service (5GaaS). 5GaaS works as an API for third parties sitting on top of the orchestration layer and allows them to easily configure and deploy 5G networks, similarly to how IaaS (Infrastructure as a Service) adds a layer of abstraction over the underlying complex system to facilitate access to third parties. Using this platform, a third party can easily deploy a 5G network with the desired characteristics for the desired duration. These dedicated core networks can be customized to provide the desired quality of service (QoS), for more details Chapter 6.3. The API has an easy to use interface that sends requests to OSM, making it simple to use for people without mobile networks experience.

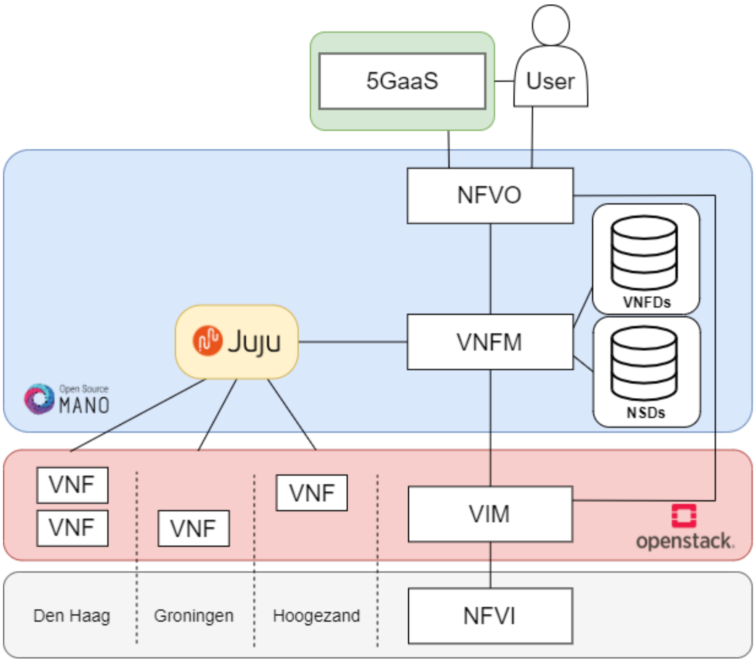


Figure 36. Orchestration using OSM for EPC.

As show in Figure 37, the 5G SA cores (5GC from 5G) are instantiated using containers since it is more suitable for a Service Based Architecture (SBA) such as the one in 5GC. These are Docker containers and are orchestrated using Kubernetes. Kubernetes can deploy the whole core network and all the necessary services. Similarly to the orchestration case for EPC cores described above, there is a division between services and containers, allowing for great modularity and reusability of different components of the network. In cases where MEC is required, a single Kubernetes cluster can be used by assigning different containers to nodes in different physical locations (i.e. placing a UPF container on the edge Kubernetes node). The Kubernetes node in Den Haag has the roles of master and worker, while the additional worker nodes are placed in Groningen, Hoogezand and Helmond. The workers in the edge locations, have local breakouts for the N6 interface and a direct connection to the eNB/gNB with the N3 interface, separate from the rest of the Kubernetes network, enabling edge-computing.

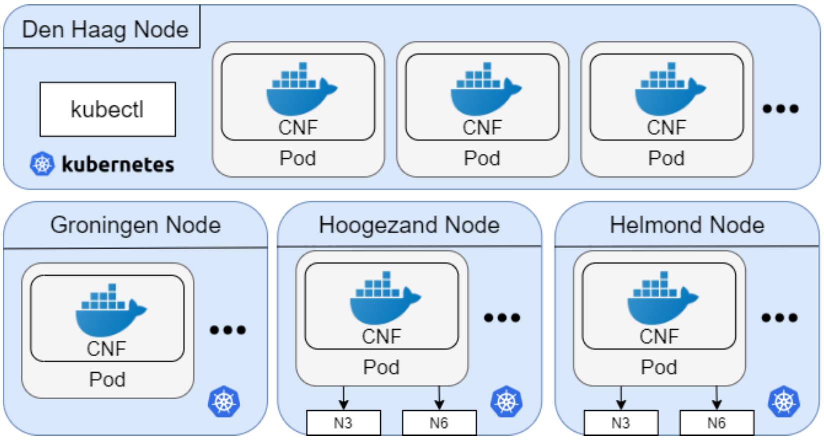


Figure 37. Orchestration using Kubernetes for 5GC.

6.3 Support of 5G-HEART use cases with slicing

The 5Groningen platform supports different types of slices for 5G NSA and 5G SA networks and are managed in different ways.

In the networks using EPC for the core, slicing is done by using 3GPP's Dedicated Core Networks (DECOR) feature in order to select the desired core network (DCN). With this technology, there can be several different core networks within the same Public Land Mobile Network (PLMN) and each of them is used for specific user types. The core network supports also enhanced DECOR (eDECOR), but this feature is not supported in any of the available UEs, and therefore it is not used.

Each dedicated core network can be customized in several ways. Each DCN has a different RAT/Frequency Selection Priority Index (RFSP Index), which in effect creates different radio partitions that are allocated to different DCNs. Different radio partitions allow to allocate a larger radio capacity to each of the core networks. On top of that, the MME and SPGW-U of each DCN can be configured differently providing further customization of the quality of service (QoS) for different user types. Finally, the resources allocated to each VNF can be modified, providing a lighter or more capable VNF.

The network slices can be instantiated and removed using OSM. Acceptance testing of the slices and applications deployed can be done using the ROBOT framework. These different slices can cover different use cases such as video aggregation, VR streaming or simple IoT use cases. These use cases can be served by attaching different service functions to the core network. The service functions are usually separate NSDs that are connected to the core network NSDs. Furthermore, different core networks are also sometimes consisting of multiple NSDs. Hence, slices can be in the form of a single NSD consisting of all core network functions and all service functions, or many NSDs connected into a single slice.

Some example DCNs have already been defined for certain applications. For example, the DCN for end-to-end video aggregation uses a single slice consisting of an EPC core network, an emulated eNB, two (or more) emulated UEs that work also as video sources, a network assistance server (NAsS) and a video aggregation function. This DCN is implemented in a single NSD including several features convenient for the application such as the authentication options offered by the NAsS, high bandwidth and reliability.

For certain VR applications such as social VR, the DCN is capable of edge computing, where an edge server can perform the bulk of the required processing and reduce the traffic load on the network by transmitting to the end device only the required information, for example transmitting only the video feed of the section being looked at by the user. This feature can also reduce the required computing power on VR headsets.

As a final example, for IoT applications the NS implements a dedicated core network together with several emulated UEs that simulate as IoT sensors, an emulated eNB, and an OpenMTC Gateway, Backend and Dashboard (OMGBD). The OMGBD server is a simple implementation of OneM2M protocol for communicating with IoT devices.

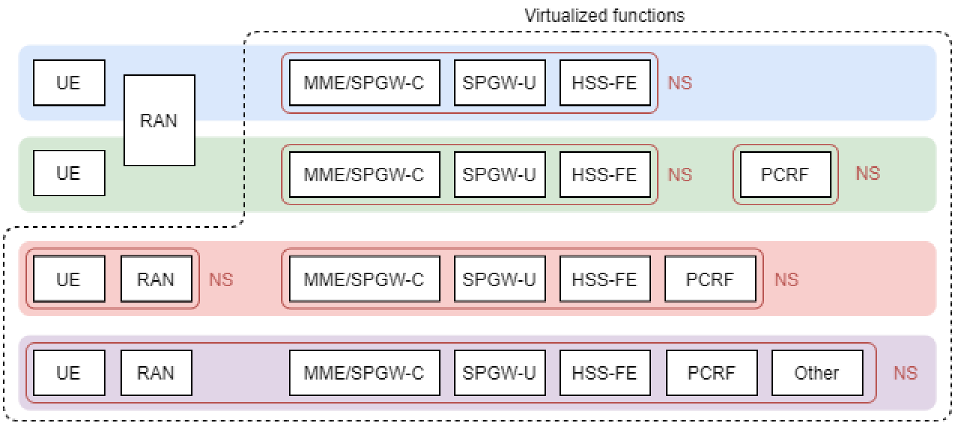


Figure 38. Slicing in 5G NSA using DÉCOR.

Figure 38 shows different possible configurations for slicing in 5G NSA. Any UE can connect to a single core network. The core network can have different components depending on the slice requirements, e.g., it can prescind from using a PCRF, or add some other non-3GPP slice-specific function. On top of that, for certain demos it is also convenient to virtualize the UE and RAN, providing an end-to-end virtualized infrastructure. On top of that, it is possible to orchestrate them using a single NS or combining several NSs, depending on the project specifics.

In the networks using 5GC for the core, slicing is done as defined by 3GPP for 5G networks. The different network slices can be selected by the UE by using the NSSAI (Network Slice Selection Assistance Information). Using this slicing technology, it is possible to avoid using a full dedicated core network for each different slice, instead different components can be shared as needed, making slices more lightweight and modular. Also, a single UE can connect to several slices simultaneously, which can be useful for different types of traffic. A clear example for this is a self-driving vehicle exchanging messages with other vehicles and streaming some entertainment content. The messages exchanges are vital for safety so they use a very reliable low latency slice (uRLLC), while other streaming content can use a high bandwidth slice (eMBB). Orchestration of services on slices is still a work in progress.

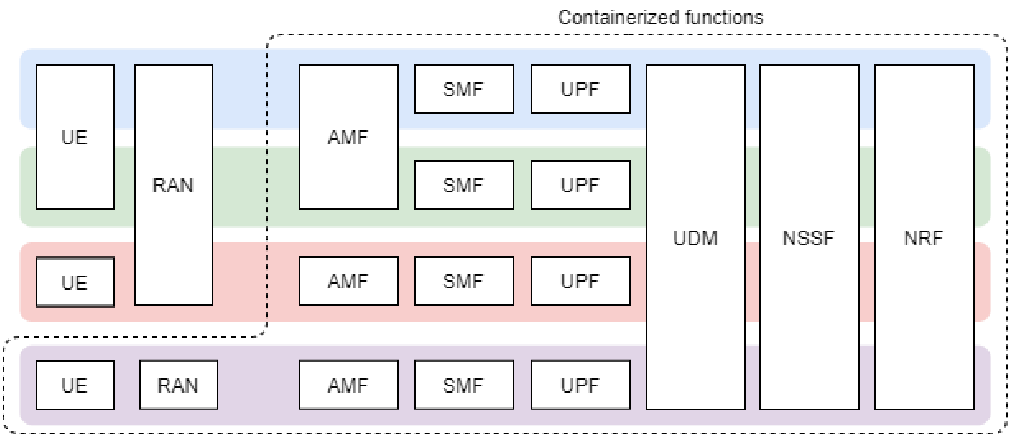


Figure 39. Slicing in 5G SA networks.

Figure 39 shows the concept used for slicing in 5Groningen's 5G SA networks. A single UE can connect to several different slices, and a single slice can also serve several UEs. The UDM, NSSF and NRF are shared among all the slices, while the UPF and SMF are slice specific. While a UE can be connected to multiple slices, it can only connect to a single AMF, thus the AMF must be shared between all the slices serving a UE. Finally, a slice can contain several different AMFs, although in practice a single AMF is used. Aside from 3GPP functions, the slices can contain other functions that provide further functionalities to specific slices.

Table 14 presents the trial scenarios running in the 5Groningen facility. The required service type support includes eMBB and uRLLC for the Healthcare and Transport verticals, respectively. Both scenarios are tested together.

Table 14: List of subcases/scenarios of verticals served by 5Groningen

Vertical	Subcases/ Scenarios	Description	Service Type	Notes
Healthcare	H1C	Smart ambulance streaming video and patient vitals to control centre	eMBB	5G SA
Transport	T2S1	Smart junctions and network assisted & cooperative collision avoidance (CoCa)	uRLLC	5G SA, Edge computing

6.3.1 Healthcare

On the healthcare vertical, 5Groningen supports the H1C case study. In brief, the H1C case study aims to demonstrate the feasibility of using 5G connectivity to relay real-time information from a moving ambulance to a central control centre where medical specialists can provide instructions and counselling to the medical personnel on board the ambulance.

This use case involves slicing when tested together with the T2S1 use cases detailed in Chapter 6.3.2. In this combined use case there are 4 different devices connecting to the 5G network: an ultrasound scanner, wearable glasses, an electrocardiogram device (ECG) and the ambulance on-board-unit. Each device uses a different UE as gateway to reach the 5G network, as they do not have 5G capabilities integrated. Medical flows and traffic priority control flows are split in two separate slices, where the ultrasound scanner, the wearable glasses and the ECG are considered medical flows and the ambulance on-board-unit is considered traffic priority control flow, see Figure 40.

With this setup, each UE needs to connect to only one slice at a time. The traffic priority control flow is routed through the edge UPF, while the medical flows are routed through the core UPF.

Both slices can be given different radio capacities, for example in this case, dropping a few frames on the wearable glasses can be acceptable, but missing some CAMs (Common Awareness Messages) can be fatal, so more capacity is given to the traffic priority control slice. The used radio setup is described in Chapter 6.2.2. This application uses 5G SA, with 2 types of slices, each of them with a single NSI.

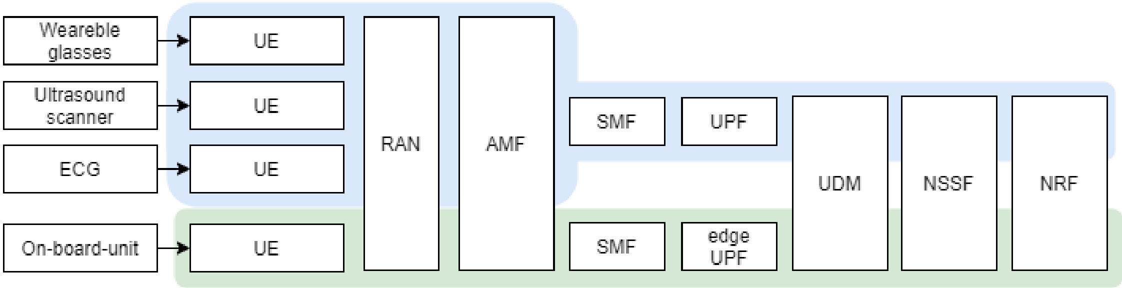


Figure 40. Slicing proposal for use case H1C combined with T2S1.

6.3.2 Transport

On the transport vertical, 5Groningen serves as the testbed for use cases T2S1. These use cases study the use of 5G capable on-board units on vehicles passing through smart junctions. These smart junctions use sensors and information relayed by other vehicles to provide all the vehicles with safety information. On top of that, the gathered information can be used to optimize the traffic flow actuating on the traffic lights, this can for example be used to give green light to ambulances. These use cases require slicing when used together with the use case H1C. The slicing architechture used in this combined use case is detailed in Chapter 0.

7 CONCLUSIONS

In this document, the network architectures of five testbed facilities which are used in 5G-HEART have been illustrated: 5G-VINNI, 5GENESIS, 5G-EVE, 5GTN and 5Groningen. The overall characteristics of testbed facilities are firstly overviewed and then their networks are investigated in terms of three component parts, core & transport, radio & edge, and management & orchestration.

While testbed facilities commonly aim to provide an end-to-end 5G testing capability, facilities are also shown to target their support of 5G NR in Non-Standalone and Standalone modes.

Multiple use cases of three verticals are designed to be served separately or sometimes jointly at testbed facilities. Slicing methodology of each facility which is to show how the network can be configured to effectively support use cases of different QoS is also studied. For this, the analysis of use cases studied in D2.1 and network KPIs of different use cases in D2.2 are utilised. Three types of slices, eMBB, mMTC, and uRLLC, are commonly defined in testbed facilities and slice types for different use cases are also explained as well as specific network configuration for slice types. There is a case to define a customized slice for use cases requiring rather complex KPIs such as a combination of eMBB and uRLLC services. In addition, the capability of testbed facilities to support multiple types of slice concurrently is introduced. By using such capability, it is shown that the different verticals (of different types of service) can be supported at the same time at the testbed facilities.

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