FUDGE-5G

FUlly DisinteGrated private nEtworks
for 5G verticals

Deliverable D3.1

FUDGE-5G Test-bed Continuous Technology Integration

Version 1.0

Work Package 3

Editor	Pousali Chakraborty and Marius-Iulian Corici (Fraunhofer FOKUS)
Month	15

Partners

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957242

Disclaimer

Project details

Project title: FUlly DisinteGrated private nEtworks for 5G verticals
Acronym: FUDGE-5G
Start date: September 2020
Duration: 30 months
Call: ICT-42-2020 Innovation Action

For more information

Project Coordinator
Prof. David Gomez-Barquero
Universitat Politecnica de Valencia
iTEAM Research Institute
Camino de Vera s/n
46022 Valencia
Spain

http://fudge-5g.eu
info@fudge-5g.eu

Acknowledgement

FUDGE-5G has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement Nº 957242. The European Union has no responsibility for the content of this document.

Abstract

This deliverable describes the integration work performed in FUDGE-5G during the first phase of the project (i.e., first half of the project until November 2021) to bring the individual technology components developed in the project into real-life 5G Stand-Alone infrastructures before performing field trials. The integration work covers the integration (on-boarding) of the vertical applications, the configuration of the 5G Core and its integration with the 5G New Radio access network. The integration of the FUDGE-5G Platform into the 5G infrastructures will be performed during the second half of the project, and will be reported in deliverable D3.2.

Contributions

Contributors

Partner	Authors
FHG	Pousali Chakraborty, Hemant Zope, Marius-Iulian Corici
TNOR	Kashif Mahmood, Ole Grøndalen, Andres Gonzalez
ATH	Daniele Munaretto, Marco Centenaro, Nicola di Pietro
CMC	Jose Costa, Mika Skarp
O2M	Peter Sanders
UBI	Thanos Xirofotos
IDE	Sebastian Robitzsch
HWDU	Zoran Despotovic, Artur Hecker, Dirk Trossen
THA	Filippo Rebecchi
ONE	Luís Cordeiro, André Gomes, António Borges
5CMM	Manuel Fuentes, Jorge Rodríguez, David Martín-Sacristán
UPV	Carlos Barjau, Josep Ribes, David Gomez-Barquero

Abbreviations

5G	5^{th} Generation of mobile communications
5GC	5G Core
AF	Application Function
AMF	Access and mobility Management Function
API	Application Programming Interface
AUSF	Authentication Server Function
eBPF	extended Berkeley Packet Filter
DNS	Domain Name Service
DNN	Data Network Name
E2E	End to End
GUI	Graphical User Interface
LAN	Local Area Network
MAC	Medium Access Control
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualization
NOW	Network on Wheels
NPN	Non-Public Network
NR	New Radio
O&M	Operation and Management
PFD	Packet Flow Description
PLMN	Public Land Mobile Network

PNI-NPN	Public Network Integrated-NPN
PTT	Push To Talk
PPDR	Public Protection and Disaster Reilef
RAN	Radio Access Network
RHCOS	Red Hat Enterprise Linux CoreOS
RHEL7	Red Hat Enterprise Linux 7
SBC	Session Border Controller
SCP	Service Communication Proxy
SEPP	Security Edge Protection Proxy
SMF	Session Management Function
SA	Stand-Alone
SHs	Service Hosts
TRL	Technology Readiness Level
TSN	Time Sensitive Networking
UC	Use Case
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
VA	Vertical Application
VM	Virtual Machine

Executive Summary

FUDGE-5G aims to perform field trials for private 5G networks for five use cases (media, PPDR (Public Protection and Disaster Relief), virtual office, industry 4.0 and interconnected NPNs (Non-Public Networks)) The project targets a Technology Readiness Level (TRL) of 7 for all components with system prototype demonstrations in an operational environment with prominent stakeholders as vertical end-users.

This document is a first release of the 5G New Radio (NR) test-bed integration work performed for the five considered use cases. The integration work has been structured in 5G Core (5GC) configuration and integration work with the NR access, and vertical applications integration and on-boarding. This document also describes the planned integration work of the overall FUDGE-5G Platform for all the use cases in the second half of the project.

The integrations that took place during phase 1 are:

- A standalone NPN named 5G Network on Wheels (NoW), including 5GC and cloud-edge applications, that provides a fully functional 5G network embedded in a mobile edge.
- Athonet's 5GC has been deployed both on a ruggedized server with minimum footprint and on an AWS Snowball Edge hardware. Both instances have been successfully integrated with the Huawei NR RAN (Radio Access Network).
- Integration of Triangula application with the AWS Snowball Edge.
- Integration of Cumucore 5GC with Openshift.
- Integration of FOKUS 5GC (Open5GCore) with Amarisoft and ZTE MC801A 5G modems.
- Integration of the 5G Modem with Cumucore 5GC and Ericsson NR RAN.
- Integration of Mobitrust with Open5GCore and Nokia NR RAN.
- Integration of the Goodmill System's router with the rest of the hardware deployed at the Network on Wheel (NOW).
- OneSource deployed its Vertical Application (Mobitrust) into the AWS SBE at the NOW, interfacing with Mobitrust devices connected via 5G SA and drone video feeds from Norsk Luftambulanse.

It should be pointed out that this deliverable does not contain any result about the first trials carried out in the project. The execution and analysis of the field trials will be reported in WP4 deliverables.

Table of contents

List of Figures

List of Tables

1. Introduction

One of the main steps of the FUDGE-5G project use case (UC) realization methodology, depicted in Figure 1, is the deployment of the 5G infrastructure hosted by Telenor in Norway and the integration of the FUDGE-5G platform and its components. This step brings the different technology components developed in the project into real-life 5G Stand-Alone (SA) infrastructures (testbeds), before performing field trials.

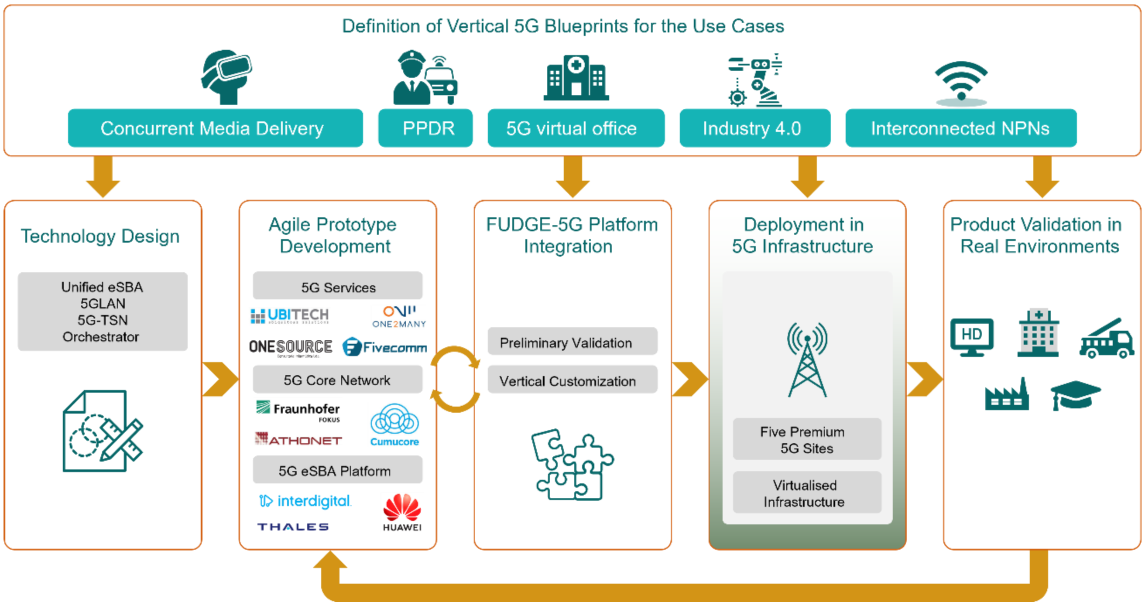


Figure 1: FUDGE-5G use case validation methodology

This deliverable D3.1 reports the 5G test-bed integration work performed during the first phase of the project (i.e., from the beginning of the project until November 2021) for the five use cases of the project [1]. Concurrent Media Delivery, PPDR (Public Protection and Disaster Relief), 5G Virtual Office for a hospital, Industry 4.0 and Interconnected NPNs. Work Package 3 (WP3) is divided into two tasks: T3.1 for test-bed continuous technology integration and T3.2 for test-bed vertical trials preparation. Both tasks are reported in this deliverable.

During the first phase of the project, individual components have been integrated into the 5G testbeds. A first description of the technical components can be found in D2.1 [2], whereas the design the overall FUDGE-5G Platform Architecture can be found in D1.2 [3]. Results and analysis of the field trials will be documented in WP4 deliverables.

Table 1 shows a summary of the partners, including stakeholder members, responsible for providing the NR RAN, 5GC, servers, vertical applications and the FUDGE-5G platform. FUDGE-5G has developed a Network on Wheels (NOW) for the PPDR use case, and it has been also used for the media use case. The Network on Wheels concept is a vehicle (typically a van) that can setup an autonomous E2E (End to End) 5G network and an edge to host applications relevant for the use case.

Table 1: Use cases and technological components providers

Use Case (Owner)	Responsible for 5GC	Responsible for NR RAN	Responsible for Servers	Responsible for applications (functionalities)	Responsible for FUDGE-5G Platform
Concurrent Media Delivery (UPV)	ATH, CMC	5G-VINNI NOW	HPE	NRK	IDE, UBI
PPDR (Thales)	ATH, O2M (CBCF)	NOW	ATH, AWS	NDMA, OneSource	IDE, THA
Virtual Office (OneSource)	FHG	Nokia Picos	HPE, FHG	OneSource	IDE, UBI (VAO)
Industry 4.0 (Fivecomm)	CMC	Ericsson, Nokia	ABB	CMC, 5CMM (TSN, 5GLAN)	IDE
Interconnected NPNs (FOKUS)	FHG	FHG, UPV, TNOR	FHG, UPV, TNOR	FHG (SBC)	IDE

The Concurrent Media Delivery use case combines virtualized 5GC components from Cumucore and Athonet to implement a multi-vendor 5GC. NRK's professional content production setup has been used as vertical application during the first phase. The first integrations have been performed within the Network on Wheels setup developed by FUDGE-5G shown in Figure 2.

The PPDR use case has deployed a 5G stand-alone Network on Wheels, with Athonet's 5GC deployed in a dedicated small form factor hardware and in the AWS Snowball edge [4]. The Network on Wheels has onboarded multiple vertical applications including several defence applications from Norwegian defense. This also includes Situational Awareness application from Onesource which was also interfaced with the video distribution platform of Norwegian air ambulance.

The Virtual Office use case leverages FHG's Open5GCore and OneSource's Mobitrust Situational Awareness application, which have been integrated with the 5GRAN from Nokia.

The Industry 4.0 use case is enabled by Cumucore's 5GC and Fivecomm's 5G modem. Both are in the process of being integrated with NR RAN equipment from Ericsson.

For the Interconnected NPNs use case, FOKUS's Open5GCore is used to interconnect the different private networks. During the first phase of the project, it has been deployed in at the campus of FOKUS in Berlin (Germany) and UPV in Valencia (Spain). At UPV campus, the Open5GCore has been integrated Amarisoft NR RAN and 5G modems from ZTE.

Figure 2: Network on Wheels (NoW) with the mast retracted (left) and deployed (right). Huawei 5GRAN in mounted on the mast.

The deliverable is structured in five chapters, one for each use case, describing the 5G test-bed integration work done during the first phase of the project. Every chapter is divided into several sections, to reflect the different types of integrations.

- Section *X*.1 provides information about the 5GC installation and configuration.
- Section *X*.2 explains the integration of 5GC with the NR RAN.
- Section *X*.3 describes the onboarding of the vertical applications.
- Section *X*.4 showcases the initial plans and ideas for the integration of the FUDGE-5G platform.

2. UC1-Concurrent Media Delivery

The Concurrent Media Delivery aims to showcase the feasibility of 5G Private Networks to adapt itself into the different workflows of the multimedia ecosystem [1]. The use case is composed of two different parts or sub-scenarios: one dedicated to Remote Production, where stringent and granular radio requirements per device is pursued, and the other focused on a Media Showroom, with the goal to provide immersive services via smart routing to devices across different access networks in a transparent way to the application verticals. Telenor is providing the radio access, devices and spectrum. Norwegian Broadcaster (NRK) (https://www.nrk.no/) acts as the main stakeholder, and it is involved in both sub-scenarios. The first phase has been focused on the Remote Production aspects of the Use Case.

The Remote Production sub-scenario Figure 3 features 5GC components from Athonet and Cumucore to evaluate the performance of a heterogeneous 5G system built of network functionalities from different vendors. The multi-vendor 5GC will be on-boarded on the virtualised infrastructure provided by Telenor Research in its main datacenter located in Fornebu. In a later stage, the multi-vendor 5GC will be integrated into the FUDGE-5G platform for automated lifecycle management, orchestration and service routing.

The multivendor 5GC setup will also be tested in hybrid cloud setup as shown in the bottom part of Figure 3 where the control plane of 5GC by Athonet will be hosted in the AWS cloud solution which will be interfaced to the UPF (User Plane Function) of Cumucore hosted in the private cloud.

Regarding the Media Showroom, the on-boarding work will happen during 2022. It is composed by products from Cumucore and Interdigital. FUDGE-5G has partnered with 5GPPP ICT-41 5GMediaHub [5], in order to perform preliminary trials leveraging the work done in FUDGE-5G for their immersive media UC1.2. The FUDGE-5G platform is necessary in order to test the Service Routing, System Slicing and Opportunistic Multicast features. However, the Service Layer functionalities expected for the FUDGE-5G platform will not be used in the interfacing with 5GMediaHub, as they implement their own stack of functionalities and cross-site APIs (Application Programming Interfaces).

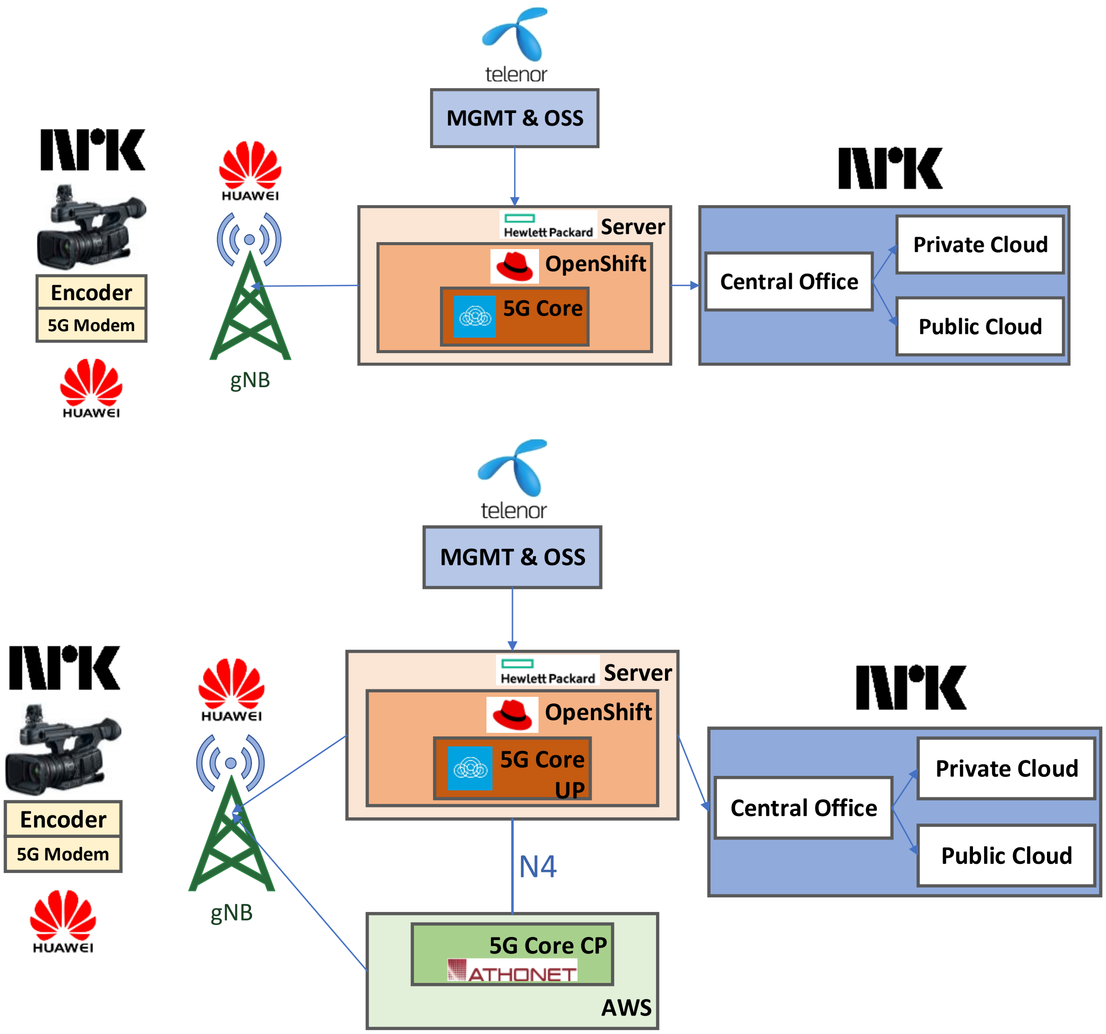


Figure 3: Remote Production sub-scenario architecture (Top) and Interoperability testing (Bottom). In the first phase, 5GCore from Cumucore is onboarded on Openshift virtualised platform by RedHat

As a summary of the work done in Phase 1, the effort was focused on equipping the Fornebu site for the Remote Production trials. Fornebu was equipped with a powerful computing server (the HPE DL110Gen10+ [6]) and received in M07, which were installed and on-boarded in the datacenter on M11. After that, Cumucore 5G Core network was installed on this machine on M14 and during the same month successfully reached an E2E connectivity. It is noteworthy to clarify that CMC 5GC works over bare metal deployment, and OpenShift [7] aswell, a Kubernetes container platform. Both have been validated. A timeline is presented in Figure 4 with the details.

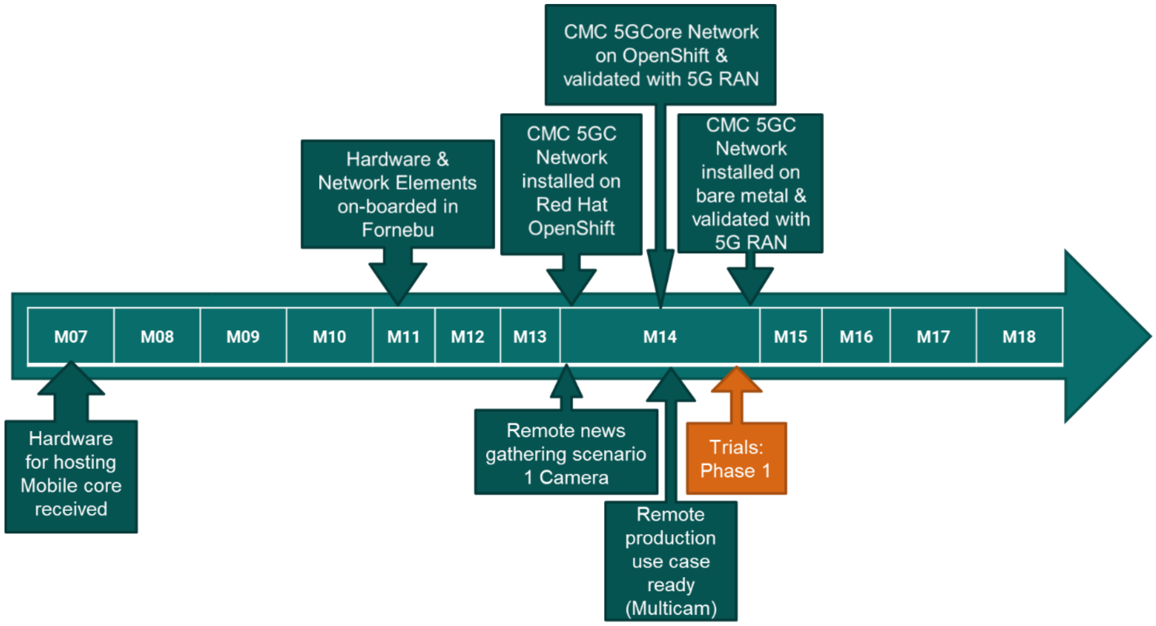


Figure 4: Phase-1 integration progress for the UC1 on Concurrent Media Delivery.

The M14 trials description and their findings will be described in D4.1.

The work for Phase-2 is already planned out, covering from M16 (equivalent to December 2021) up until the end of the project. So far, the effort in Phase-1 has been focused in integrating products from the consortium partners and directly test them in Remote Production trials. Phase-2 will finish the Remote Production trials by incorporating the interoperability testing. For the Media Showroom, the work will initially target the required multivendor 5GC between IDE and CMC components; then it will be on-boarded in the FUDGE-5G platform. The UC1 will close with trials for the Media Showroom and Concurrent Media Delivery, made of Remote Production plus Media Showroom.

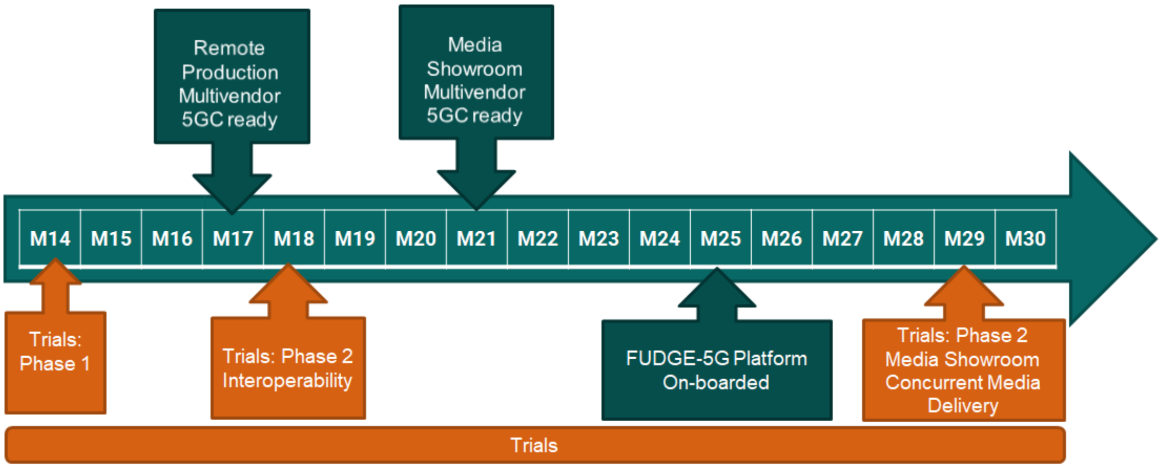


Figure 5: Phase-2 planning for the integration and trials.

The trials will be documented in Work Package 4 upcoming deliverables. Note that the dates are tentative and may be subject of modifications, based on the progress done.

The rest of the section will cover the technical details on the integration and deployments status across device and radio, 5G Core, applications and all related effort perform.

2.1. 5GC Configuration and Installation

In UC1, the 5GC uses components from Athonet, Cumucore and Interdigital, depending on the scenario covered. At this point, the interoperability of 5GC from Athonet and Cumucore has been tested against the 5GRAN from Huawei by Telenor. The UPF from Interdigital will come as part of the FUDGE-5G Platform for Phase 2.

Cumucore provides the 5GC for the Remote Production trials, with a full 5GC stack deployed on-premises. In the case of interoperability, only the UPF will be deployed and connected via N4 to Athonet AWS solution. The 3GPP Rel-16 version complaint Cumucore UPF leverages extended Berkeley Packet Filter (eBPF) [8] accelerated user plane. As such the UPF behaves similar to a L2/L3 switch depending on setup. IP planning features are configured either in SMF (Session Management Function) or as an external service to facilitate integration with fixed LAN (Local Area Network) Data Networks. In this first phase, the control plane functionalities (AMF (Access and mobility Management Function), SMF, AUSF (Authentication Server Function), UDM (Unified Data Management), etc.) are handled from a configuration, performance and fault management point of view via a local web-based Graphical User Interface (GUI) and APIs exposed for north-bound integration. For the second phase, the lifecycle management will be done in the FUDGE-5G Platform. Initially the complete Cumucore 5GC system has been onboarded on the Openshift cluster from RedHat. The system is configured by carrying out the following activities:

- System Design
- User Equipment (UE) Subscription Design
- Networking Configuration
- Control Plane Configuration

The remote production scenario will be physically implemented in two locations. One in Telenor Headquarters in Fornebu and the second in the NOW. Figure 7 shows the architecture of the former where Huawei Radio is integrated to Cumucore 5GC. The datecentre which hosts the Openshift cluster is shown in Figure 7.

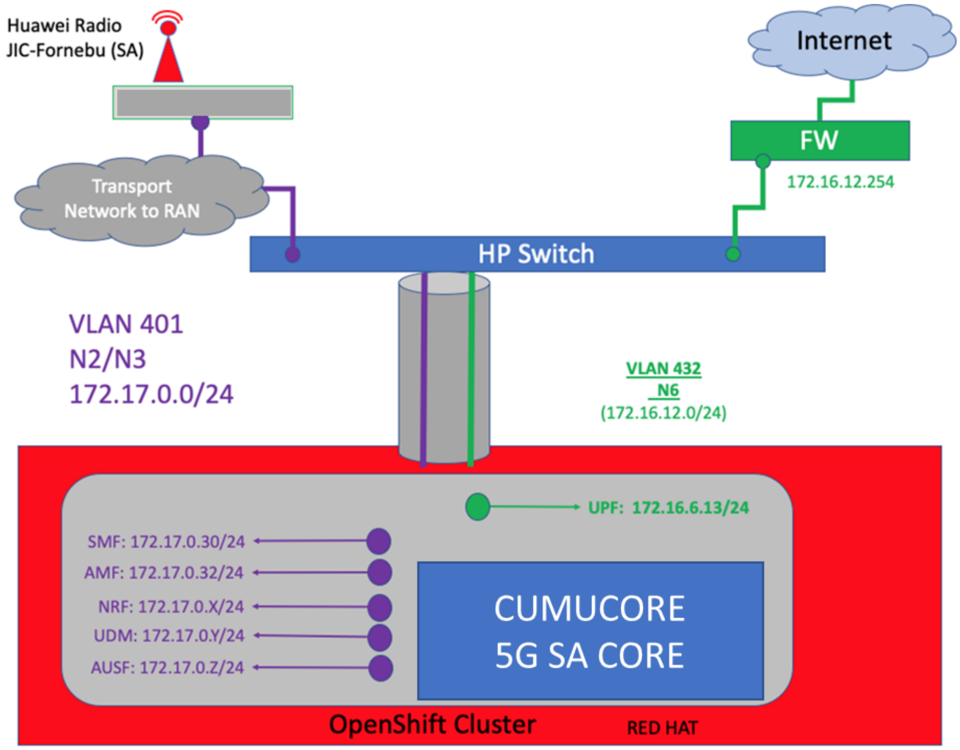


Figure 6: Cumucore's 5GC Integration in Fornebu premises.

Figure 7: Central computing server rack in Fornebu experimental network.

In addition, as shown in Figure 8, a single node openshift installation on a dedicated server has been done to onboard the Cumucore 5GC which will be eventually taken to NOW.

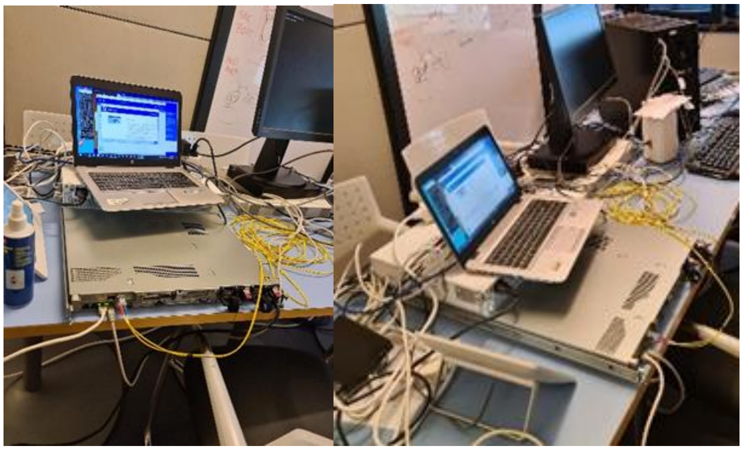


Figure 8: OpenShift deployment in Fornebu Premises.

Athonet provides the control plane functionalities of the 5GC system solution in the interoperability testing as part of Remote Production. Their 5GC Control Plane will reside in Amazon Web Services [9]. The integration of Athonet's 5GC control plane with Cumucore will happen in 2022. The core functionalities run as cloud-based NFs (Network Function) either from a public or private cloud, while the UPF will be locally implemented in the testbed. The management of the web-based GUI is performed via users that can be created with assigned roles based on a number of possible permissions.

2.2. Integration of 5G core with third party RAN

In the first phase of the project, the interoperability of the 5GC from Athonet and Cumucore with 5GRAN has been done. The 5GRAN came from Huawei which was 3GPP Release 15 compliant. The 5GCe from Athonet's was hosted on a dedicated hardware while the one from Cumucore was hosted on HPE DL110Gen10+ [6]. The integration was first done in Telenor's lab in Fornebu then moved to the NOW setup shown in Figure 2. The usecase was initially planned to be in Telenor headquarter in Fornebu but after considering the request from NRK, the usecase was replicated to the NOW. The choice of media usecase to be done in the NOW was primarily to cover skiing events in remote locations in Norway as requested by NRK.

The 5GCs deployed at Fornebu have been integrated to the 5G RAN provided by Huawei. The 5GRAN is 3GPP Rel-15 compliant and has Multi-user MIMO and uplink enhanced frame structure enabled. More specifically a frame structure of 7:3 has been used. When it comes to end devices, Huawei (CPEPro2, CPEPro3 and Smartphones such as Mate30, P40, P40Pro) have been used. The E2E preliminary test results can be seen in Figure 9. These results are for C band with 40 MHz of bandwidth.

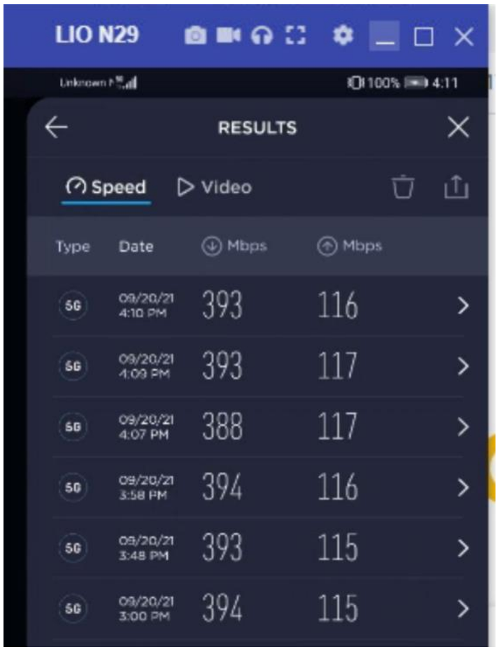


Figure 9: Speed tests from Mate30 5G SA Smartphone against Huawei gNB connected to Cumucore 5GC in NOW.

2.3. Integration of Applications

The application integration for Remote Production is an on-going process. The range of applications used for Content Production are varied and range from video decoding, camera control, image control, synchronization of audio/video from several streams, backup in case of network failure. NRK production setup is a multi-domain with components deployed on the OB van, local office, central office, private cloud and public cloud, over private links and public Internet [10]. As an example, Figure 10 shows the deployment used for the Midstubakken trials for flexible remote production.

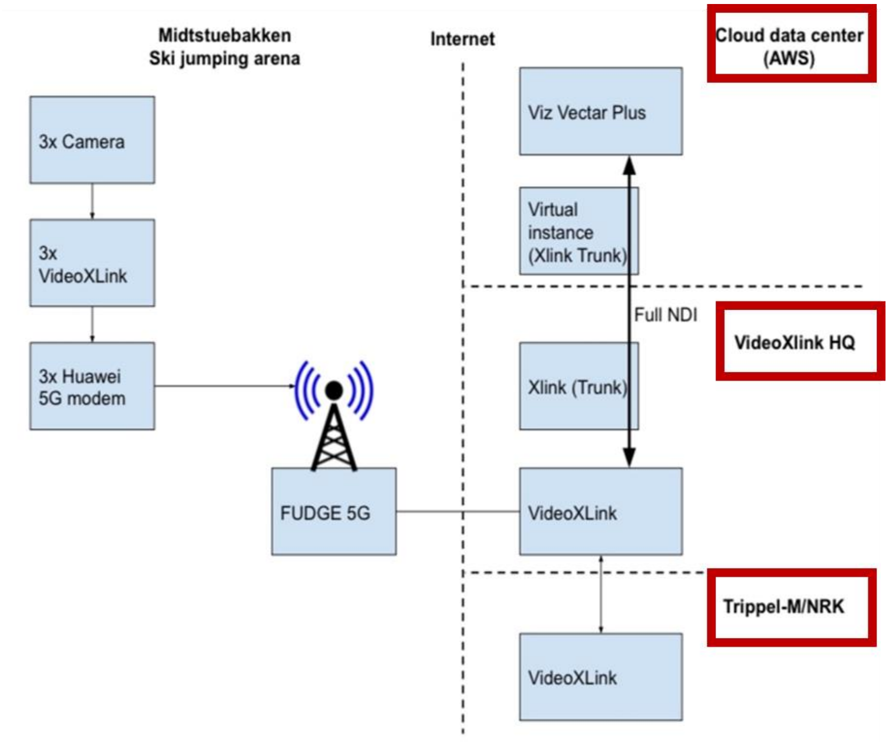


Figure 10. Deployment architecture of Stakeholder applications for the Midstuebakken trials.

During the course of UC1, it is planned to perform a gradual transition of components from the local office into the OB van and from the central office into cloud domains. This is a delicate process since the commercial workflow of NRK should not be disturbed and the current performance and features should be kept as the transition goes on. Note that there are no plans to on-board specific Remote Production apps into the FUDGE-5G Platform.

In Media Showroom, the immersive media application forms part of a cross-project collaboration with 5GMediaHub. The application interfaces with Ubitech Vertical Application Orchestrator will allocate resources and quality expected from the data pipes towards the devices.

2.4. Planned FUDGE-5G Platform Integration with 5G

The media use case poses a rather interesting scenario, as it is composed of two individual cases, i.e., remote production and media showroom. For both scenarios the same FUDGE-5G platform will be used that hosts the two logically separated 5GCs to serve the 5G UEs in each scenario. While the media production use case will see 5G-enabled ultra-high-quality cameras that continuously upstream video content, the media showroom serves as the consumption of the video content. Both use cases are interlinked through the production suite that allows editors to apply pre- and post-video production steps before presenting it to users in the showroom.

As illustrated in Figure 11, a single compute host with large enough compute, storage and memory capacities will host the FUDGE-5G platform components as Virtual Machines (VMs) or containers depending on the availability of a Network Function Virtualization (NFV) framework such as OpenStack or OpenShift. The platform components provisioned for the first trial are coloured squares in green and represent the routing and orchestration components. Enterprise services are illustrated as coloured circles and are hosted inside a platform instance, i.e., 5GC NFs inside Service Hosts (SHs) and vertical applications inside a Kubernetes cluster (K8s). As can be observed, two SHs are illustrated representing two different locations in the routing topology for the routing and orchestration logic to choose from when serving UE control plane requests.

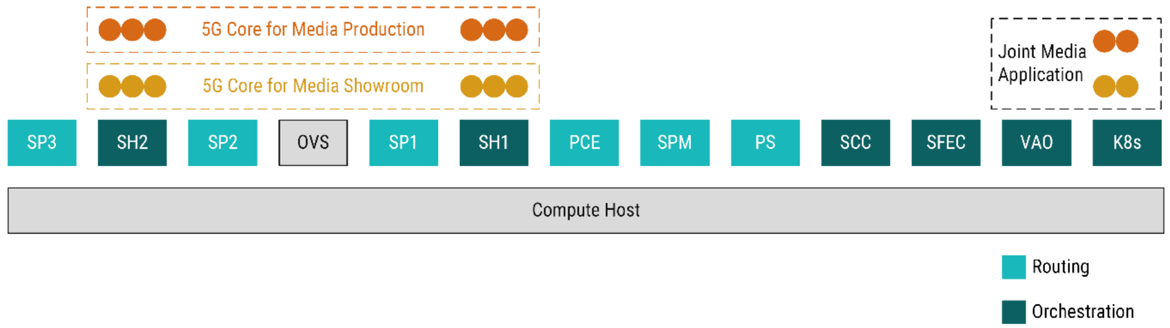


Figure 11: Planned FUDGE-5G platform deployment for media use case

3. UC2-PPDR

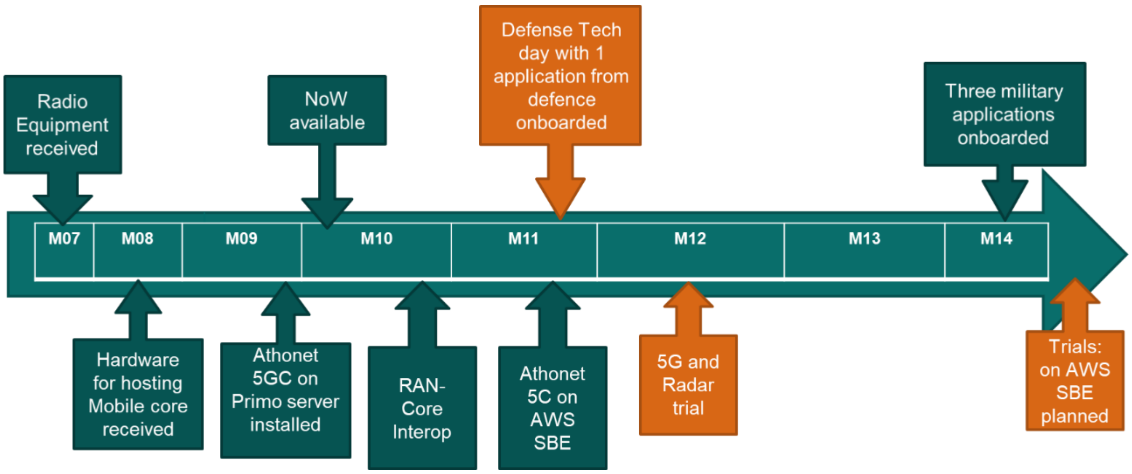


Figure 12: PPDR Phase 1 Integration Timeline

The PPDR use case aims at evaluating and demonstrating whether the advancements brought by 5G NPNs fits the purpose of being deployable during relevant PPDR operations [1]. In this use case, we plan to validate three sub-scenarios, each one highlighting different technical challenges and operational aspects.

The first PPDR scenario focuses on the integration of 5G core and cloud edge application into a standalone NPN named 5G Network on Wheels (NoW), which is depicted in Figure 2.

This first scenario provides a fully functional 5G network embedded in a mobile edge, offering broadband communication capabilities to first responders and Special Forces even in the case of remote deployments. **The first phase of the integration work has focused exclusively on this first scenario and on the integration and deployment of the associated 5G NoW**.

Indeed, the second and third scenarios will leverage and extend the first one by enabling the opportunistic use of an intermittent backhaul link between the 5G NoW and a possibly remote cloud (Scenario 2), then showcase the coexistence of multiple public and non-public networks (PNI-NPN) offering different services (mission critical or best effort) to PPDR users (Scenario 3).

Coherently with the project planning, which consist of two cycles of trial execution and validation, the integration work has been split into two phases. The first phase started at M07 (just after the delivery of the use cases and deployment scenarios blueprints) and ran until M14, when the first trials were executed. The second phase started at M15 and will last until the end of the project (M30).

The integration activities performed during Phase 1 (now completed, as reported in Figure 12) have targeted the deployment, provisioning, and integration of the 5G NoW. These activities included the integration of individual hardware and software 5G components (in particular, the Huawei RAN and Athonet 5GC) and local deployment of vertical applications (military applications such as Triangula for gunshot detection and Mobitrust for situational awareness) on the 5G NoW. These activities are described with detail in the following sections. Trials have been kick started at M11 (July 2021), and are expected to run up to M18 (February 2022). Their focus is on the validation of the standalone 5G NoW solution (limited to scenario 1) for PPDR users.

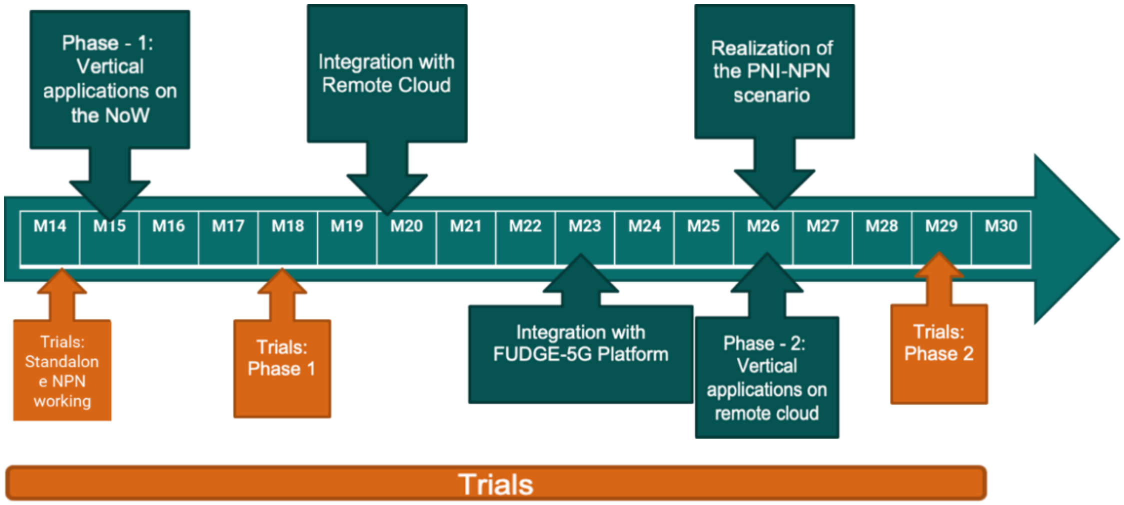


Figure 13: PPDR Phase 2 Integration Timeline plan

The plan for Phase 2 is reported in Figure 13. The planned activities will focus on the finalization of ongoing trials, and on the deployment and interworking of vertical applications on a remote cloud (to realize Scenario 2) and on the coexistence of FUDGE-5G NPN solution with public networks (to realize Scenario 3).

3.1. 5G Network on Wheels (NoW) integration

Figure 14: Internal HW deployed in the 5G NoW. (left) 5GC in the Athonet PriMo solution; (right) the AWS Snowball Edge hosting both the Athonet 5GC and the vertical application.

The integration work started on March 2021 (M07) with the provisioning of the vehicle to host the NoW, and its setup - this included the realization of cabling for power and data, and the creation of the internal work spaces.

As a radio equipment, a 3GPP release 15, 5G standalone compliant RAN solution from Huawei including the antennas, the radio heads and the baseband unit was selected and fixed to the NoW via an extensible mast (as depicted in Figure 2). The RAN employs the n78 band. Both the 3.5 GHz with 40 MHz bandwidth and 3.3-3.8 GHz were used .This task was achieved in April 2021 (M08).

Next, the platform to be integrated in the NoW for hosting the 5G core and vertical applications was selected. Initially, it was planned to have two separate platforms for hosting the 5GC and vertical applications, respectively. Specifically, the 5GC was provided by Athonet in a PriMo solution based on a ruggedized server with minimum footprint – see Figure 14 , left picture. As an alternative solution, it was decided to leverage a unique server, specifially an AWS Snowball Edge, which provides enough processing power and memory, for deploying both the Athonet 5GC as well as the PPDR-specific vertical applications. The integration of the 5G core on the AWS Snowball Edge was completed in July 2021 (M11), while the integration of local applications is currently ongoing and expected to finish by November 2021 (M15).

Finally, to allow remote management of the NoW, and in view of the Phase 2 interconnection of the NoW with a remote cloud, it was integrated a multichannel router solution from Goodmill Systems, capable of aggregating multiple links from different 4G and 5G commercial networks and a satellite modem and providing a VPN gateway.

For Phase 1 trials, the all-in-one solution comprising both the Athonet 5GC and the vertical applications on the AWS Snowball Edge shown in Figure 15 will be used.

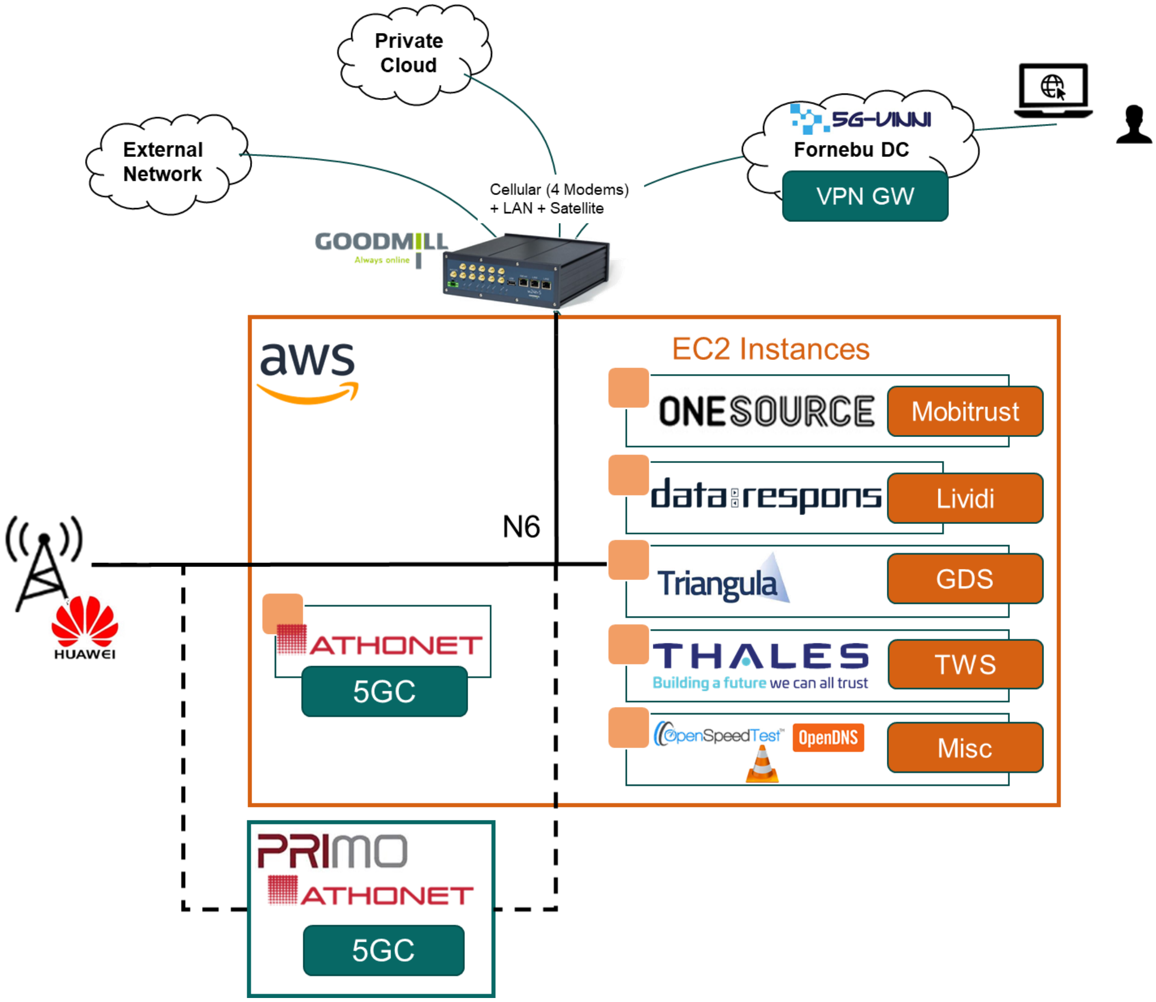


Figure 15: Current PPDR deployment architecture on the NoW. The 5GC solution from Atonet can be deployed either on the standalone PriMo solution or as a virtualized workload on the AWS Snowball Edge.

3.2. 5GC Configuration and Installation

In UC2 Athonet provides the 5GC solution as a software solution running both on (*i*) a ruggedized server with minimum footprint (PriMo solution); and (*ii*) on an AWS Snowball Edge hardware. Both these pieces of hardware are installed in the NoW equipped with further equipment such as radio, servers, switches in support of the UC. For what concerns the core network software, the system is configured by carrying out the following activities:

- System Design
- UE Subscription Design
- Networking Configuration
- Control Plane Configuration
- User Plane Configuration

The management of the web-based GUI is performed via users that can be created with assigned roles based on a number of possible permissions. Roles are separated entity; roles can be created whether user accounts are assigned to them or not.

3.3. Integration of Vertical Applications

As said earlier, aside the 5GC solution from Athonet, the AWS Snowball Edge hardware is employed to deploy several vertical applications that are required to validate the use cases. While for now the vertical applications are statically provisioned, evolutions for the Phase 2 will allow them to benefit from the cloud native orchestration capabilities of the FUDGE-5G platform.

Figure 16: Hardware inside the NoW where the applications are deployed

Initially, an EC2 Linux instance including a handful of testing and troubleshooting tools – including an iperf, an open speed test, a VLC, and DNS (Domain Name Service) servers - was deployed on the AWS Snowball Edge server. The traffic towards the backhaul is routed by a resilient router provided by Goodmill System.

Moreover, ONE's Mobitrust Situational Awareness platform[1] has been deployed on the AWS Snowball Edge. To integrate Mobitrust with the PPDR UC infrastructure, the platform was deployed into a single Amazon Linux 2 VM that was exported and will be deployed on the AWS Snowball Edge running at the Network on Wheels.

Similarly, a Gunshot Detection (Triangula) application was deployed as well on the AWS Snowball Edge.

[1] https://mobitrust.onesource.pt

Moreover, we plan to integrate further applications such as E2E encrypted communications (Lividi_Data Response), a Push to Talk (PTT) server (Thales TWS), and the O2M Cell Broadcast Centre Function (CBCF) client.

Fivecomm provides its 5G modem, which is used as an end device. Efforts directed towards integration the modem with the RAN and Core where made.

3.4. Planned Integration of the FUDGE-5G Platform

The PPDR use case demands a rather small hardware footprint due to its execution inside a van (aka NoW). Thus, the FUDGE-5G platform will be reduced to its smallest footprint to fit on a single mid-range compute host. As only a single location (i.e., SH1) is enabled as a direct result of the footprint requirement, the service routing capabilities won't come into effect in this demonstration. However, the cloud native orchestration capabilities vertical applications will be still utilised at their full capacity in the Phase 2 trials.

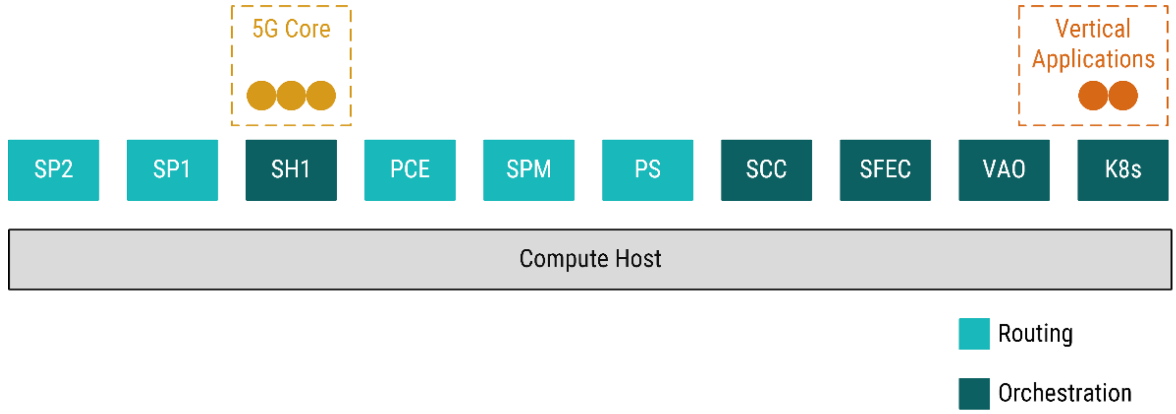


Figure 17: Planned FUDGE-5G platform deployment in the PPDR use case

The compute host in this use case might be a single compute host without any NFV framework for provisioning the platform. Instead, the FUDGE-5G platform components will be provisioned manually as VMs or containers.

4. UC3- 5G Virtual Office

The FUDGE-5G 5G Virtual Office use case aims to provide secure and seamless access to a specific set of corporate services using 5G connectivity. In the very specific context of an hospital, as considered in this use case, the hospital staff aims to be not bound by location when accessing medical devices, electronic health records, or any kind of office equipment. With such capabilities, medical staff has a better overview of their patients regardless of their location within the hospital campus, enabling monitoring from the location of emergency situations towards inpatient treatment and later to discharge.

This section describes the integration of the components that belong to the 5G Virtual Office use case with the ICT-17-2018 5G-VINNI facility deployed at the campus of Oslo University Hospital, Norway. Figure 18 provides a high-level overview of the FUDGE-5G technological components that are being integrated, as well as of the 5G-VINNI infrastructure.

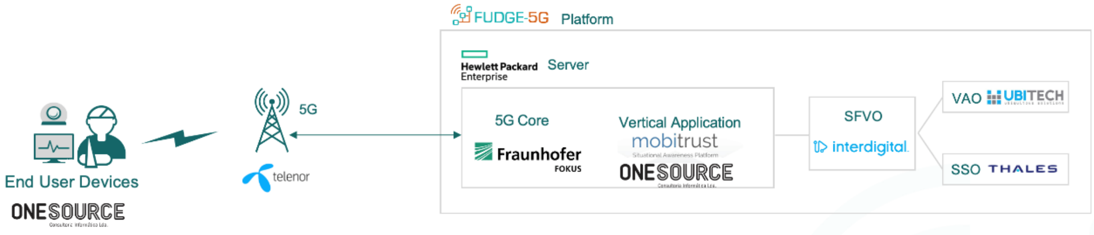


Figure 18: 5G Virtual Office Technological Components

The integration work is split into two phases. The first phase started at M07 and ran until M15, when the first trials are expected to start. The second phase started at M15 and last until the end of the project.

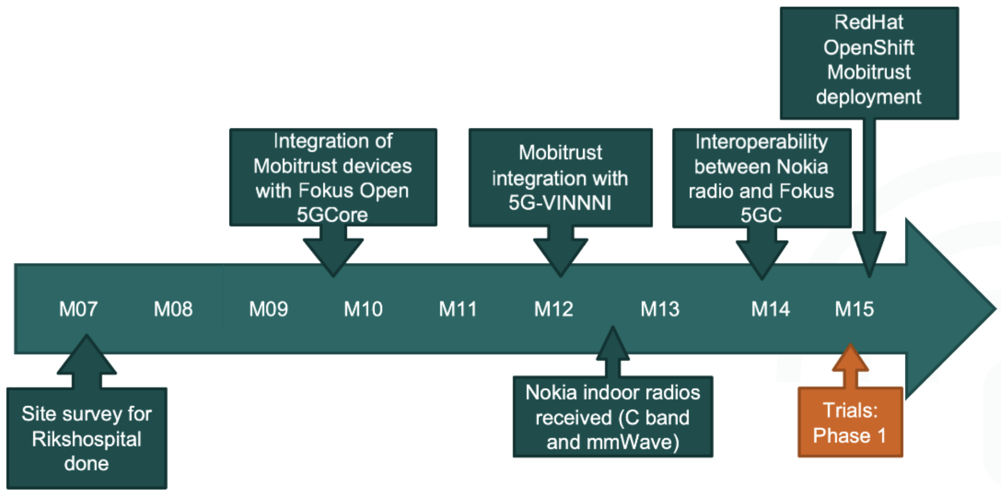


Figure 19: 5G Virtual Office Phase 1 Integration Timeline

The integration activities performed on Phase 1 (Figure 19) were focused on the integration of individual components, which included the 5GC, the Radio and the Vertical Application. These activities are described in the subsections below.

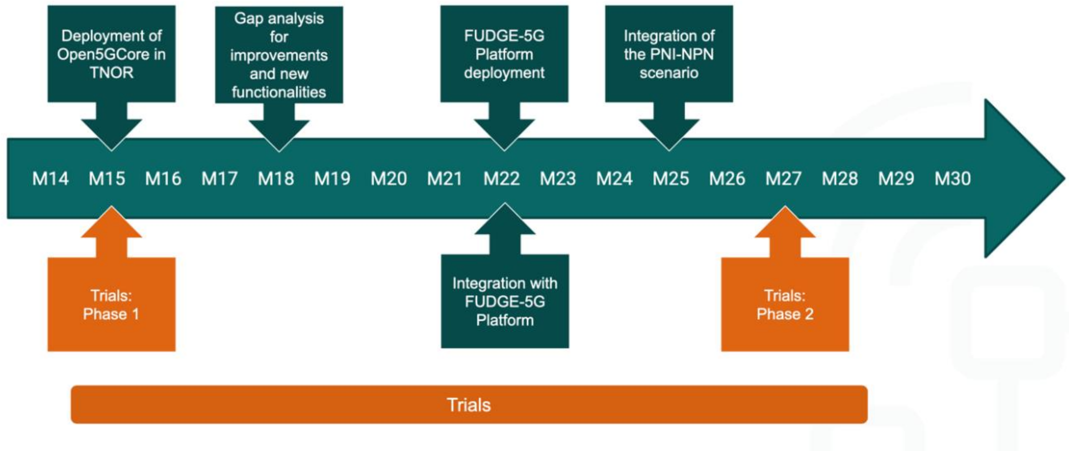


Figure 20: 5G Virtual Office Phase 2 Integration Timeline

For Phase 2 (Figure 20) the UC will be focused on the FUDGE-5G platform deployment and UC case components integration with the platform. In addition, the PNI-NPN scenario will be prepared to integrate the public network with the S-NPN at hospital Campus, providing support for the Emergency Response Vehicle Scenario.

4.1. 5GC Configuration and Installation

For this UC, the Open5Gcore from Fraunhofer FOKUS will be used for the installation on the server along with the software from OneSource. In phase 1 of the trials, the core will be deployed as a bare-metal deployment on a high-end server to achieve high performance and throughput. The different components of the 5G Core are deployed as separate processes on the host machine. This will allow sharing the resources from the host between all processes. The AMF and UPF processes which are directly communicating with the RAN are bound on the interface where RAN is connected. The AMF is listening on port 38412(SCTP-NGC) whereas UPF is listening on port 2152(UDP-GTP). Rest all components are communicating with each other over loopback interfaces. This type of deployment is easy and quickly modifiable as all the components are directly running on the host as a process and any changes can take place without any delay. The UPF is sending the traffic out via a tun interface which is then forwarded to the interface where the traffic is sent towards the internet.

In phase 2 of the trials, the deployment architecture will be update to Kubernetes on top of OpenShift platform. Kubernetes will allow horizontal scaling of the components for higher loads. All the components will be deployed as individual pods. They will be intercommunicating via DNS (Domain Name Service) services offered by the Kubernetes. The deployment will be controlled by Ansible playbook for easy management and updates.

4.2. Integration of 5G core with third party RAN

The Open5GCore from the Fraunhofer FOKUS is integrated with NOKIA RAN for this use case at Telenor Lab. NOKIA was already integrated with the 5G core along with other vendors for working interoperability during which the functionality was confirmed to be working. As integration was done before, for this use case the base station was sending NGC traffic in the direction where core was deployed. In phase 1, NOKIA RAN is connected to the core deployed at TNOR. As edge device, an Android Phone was used in TNOR for verifying the office use case which was configured with the 99999 PLMN (Public Land Mobile Network).

Figure 21: Integration of NOKIA RAN with 5G core at Telenor LAB

4.3. Integration of Applications

The Mobitrust Situational Awareness platorm[2] includes both the Vertical Application (VA) and the end user devices. The Vertical Application is prepared for deployment in any type of containers or virtual machines, which includes the Kubernetes environment supported by the FUDGE-5G infrastructure. As for the end user devices (sensor data collection, multimedia capture and pre-processing), they are 5G-enabed and include all the required components to collect sensor data, act as media hub for multimedia capture, perform pre-processing and forward data to the platform over the mobile network.

4.3.1. Integration with Open5GCore

[2] https://mobitrust.onesource.pt

This integration activity was performed in Germany, at the FOKUS lab. The integration was focused on validating the connectivity of end user devices to a test network supported by Open5GCore. The outcome was successful, as the devices were able to join the network and obtain 5G SA connectivity.

4.3.2. Integration with Telenor 5G infrastructure

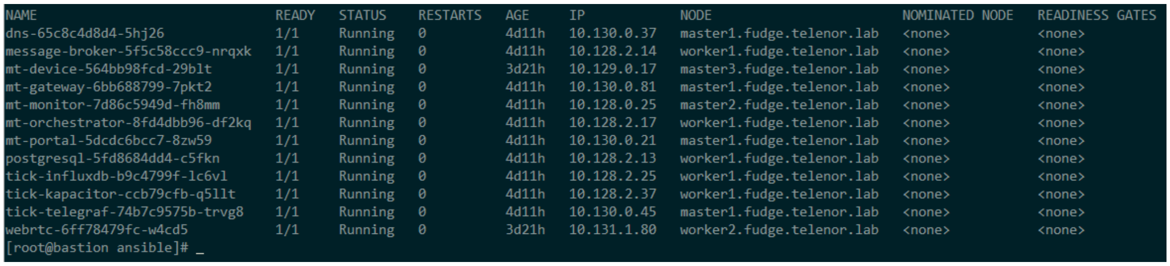
Initial integration efforts were performed in Oslo, Norway. The integration aimed to establish connection with the 5G-VINNI Mobile Network using the Mobitrust Devices as UEs (Figure 22) and to integrate the vertical application with the 5G-VINNI infrastructure deployed at the campus of Oslo University Hospital, which is officially the stakeholder for this UC.

Figure 22: Mobitrust End User Devices

4.3.3. Vertical Application Integration with the FUDGE-5G infrastructure

The FUDGE-5G infrastructure deployed at Oslo University Hospital includes RedHat OpenShift and Kubernetes and completes the NPN infrastructure delivered by the Nokia 5G radio and Fraunhofer FOKUS Open5GCore. This activity is twofold: 1) the deployment of Mobitrust platform as VA running over Kubernetes and 2) the connection of the end user Mobitrust devices to the 5G NPN.

The first task, the VA deployment, is triggered by an Ansible playbook, which enables simplified management and updates. The Ansible playbook triggers the Kubernetes deployment of the Mobitrust VA components (Figure 23) and exposes the relevant TCP and UDP ports to outside of the Kubernetes cluster.



```
NAME                                READY   STATUS    RESTARTS   AGE     IP            NODE                        NOMINATED NODE   READINESS GATES
dns-65c8c4d8d4-5hj26                1/1     Running   0          4d11h   10.130.0.37   master1.fudge.telenor.lab   <none>           <none>
message-broker-5f5c58ccc9-nrqxk     1/1     Running   0          4d11h   10.128.2.14   worker1.fudge.telenor.lab   <none>           <none>
mt-device-564bb98fcd-29blt          1/1     Running   0          3d21h   10.129.0.17   master3.fudge.telenor.lab   <none>           <none>
mt-gateway-6bb688799-7pkt2          1/1     Running   0          4d11h   10.130.0.81   master1.fudge.telenor.lab   <none>           <none>
mt-monitor-7d86c5949d-fh8mm         1/1     Running   0          4d11h   10.128.0.25   master2.fudge.telenor.lab   <none>           <none>
mt-orchestrator-8fd4dbb96-df2kq     1/1     Running   0          4d11h   10.128.2.17   worker1.fudge.telenor.lab   <none>           <none>
mt-portal-5dcdc6bcc7-8zw59          1/1     Running   0          4d11h   10.130.0.21   master1.fudge.telenor.lab   <none>           <none>
postgresql-5fd8684dd4-c5fkn         1/1     Running   0          4d11h   10.128.2.13   worker1.fudge.telenor.lab   <none>           <none>
tick-influxdb-b9c4799f-lc6vl        1/1     Running   0          4d11h   10.128.2.25   worker1.fudge.telenor.lab   <none>           <none>
tick-kapacitor-ccb79cfb-q5llt       1/1     Running   0          4d11h   10.128.2.37   worker1.fudge.telenor.lab   <none>           <none>
tick-telegraf-74b7c9575b-trvg8      1/1     Running   0          4d11h   10.130.0.45   master1.fudge.telenor.lab   <none>           <none>
webrtc-6ff78479fc-w4cd5             1/1     Running   0          3d21h   10.131.1.80   worker2.fudge.telenor.lab   <none>           <none>
[root@bastion ansible]# _
```

Figure 23: Mobitrust's Components in Kubernetes

Currently, the deployment and test of the Mobitrust VA was successful using both an end user device simulator and a real Mobitrust device connected to the 5G NPN (see Figure 24).

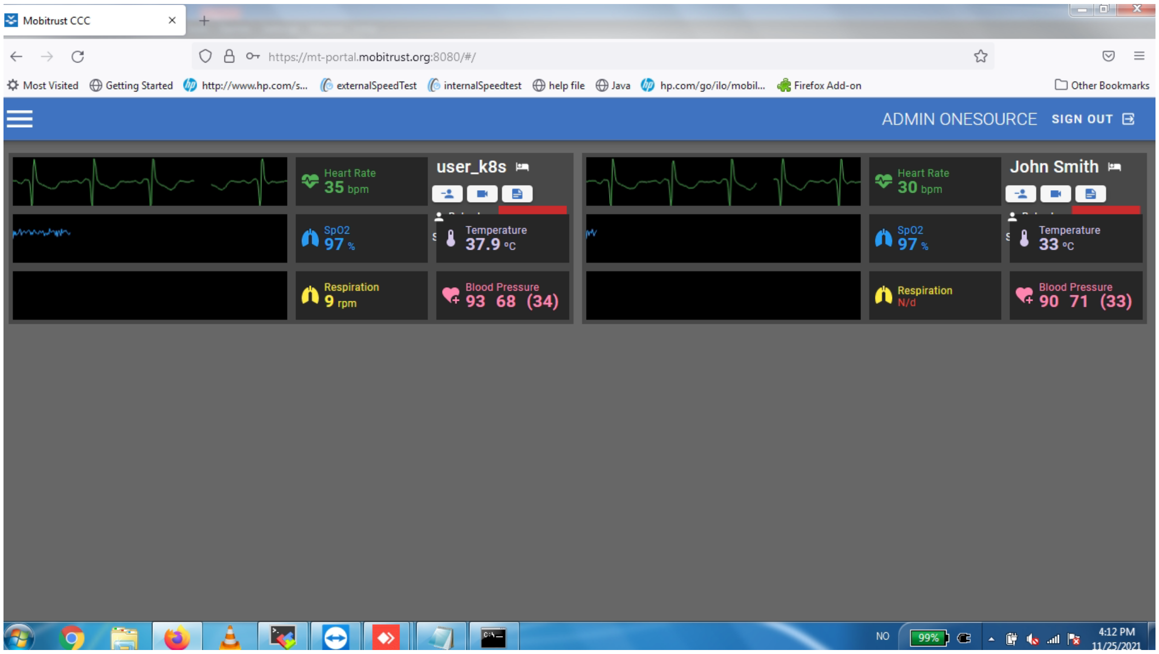


Figure 24: Mobitrust Platform at Oslo University Hospital

4.4. Planned Integration of the FUDGE-5G Platform

The integration of the FUDGE-5G platform for the Virtual Office will take place at the hospital itself with a single powerful compute host, as illustrated in Figure 25. The compute host is planned to be powered by OpenStack for an automated FUDGE-5G platform provisioning as VMs via a Heat orchestration template. The platform components provisioned for the first trial are coloured squares in green and represent the routing and orchestration components. Enterprise services are illustrated as coloured circles and are hosted inside a platform instance, i.e., 5GC NFs inside SHs and vertical applications for health monitoring inside a Kubernetes cluster (K8s).

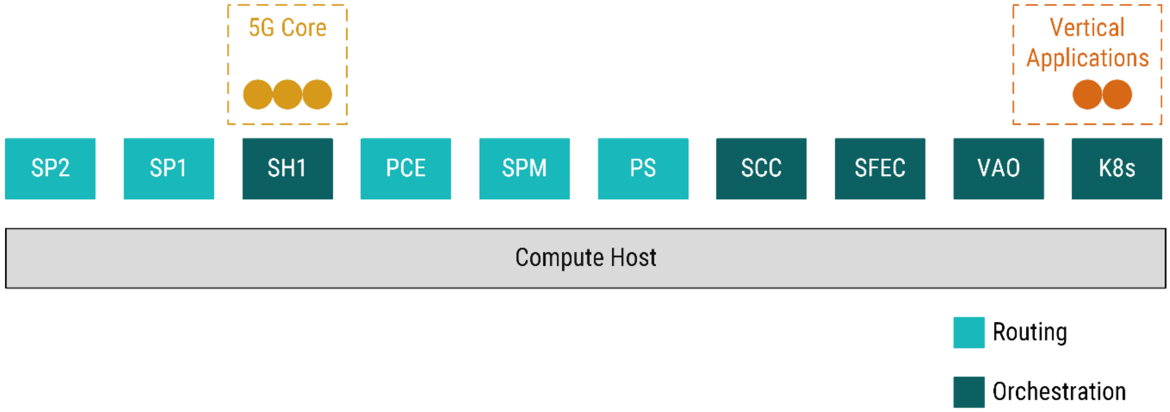


Figure 25: Planned FUDGE-5G platform deployment in the Virtual Office use case

The entry point for control plane message from a UE via the gNB is provided via extending the SCP (Service Communication Proxy) on the N2 interface represented by the SP2 routing component in Figure 25.

5. UC4-Industry-4.0

The fourth use case of the FUDGE-5G project aims at demonstrating the applicability of 5G NPNs and their integration with 5G LAN and Time Sensitive Networking (TSN), replacing fixed and wired alternatives for industrial communications with 5G. The intention is not to replace the whole infrastructure but to integrate 5G with the existent wired infrastructure and use wireless links when needed. To do so, it is first key to perform some integration work between both 5G and industrial components, which will permit the consortium to setup and run the trials in WP4.

To demonstrate the great advantages of 5G NPNs in industrial environments, FUDGE-5G will implement and validate a use case in which a controller interacts with sensors and actuator devices, located within a small area in a factory environment. This validation will be done through a series of components, which are shown in Figure 26.

Figure 26: Industry 4.0 use case configuration for the test cases

The vertical stakeholder of this use case i.e., ABB, will bring to the consortium end-user devices and their respective controlling stations to be used in the considered applications. Such devices will be connected to the 5G network via 5G modems. The 5G SA RAN is delivered by Ericsson, 5G SA Core is delivered by Cumucore and needed modems are delivered by Fivecomm. Note that the 5G network integration is being done in Telenor premises in Fornebu (Norway), before delivery to ABB premises for the trials.

The integration work towards the trial has been divided into two main phases.

The first phase of integration consists of a standalone NPN to be used within a controlled environment. It spans from the beginning of the project, i.e., M1, to M16, where the first trial is planned. This first integration will include limited TSN and 5G-LAN functionalities, which will be expanded upon in the second phase. The integration plan has been divided into tasks, each one of them related to the interoperability of different components. The timeline and milestones associated to each task in phase-1 is shown in Figure 27.

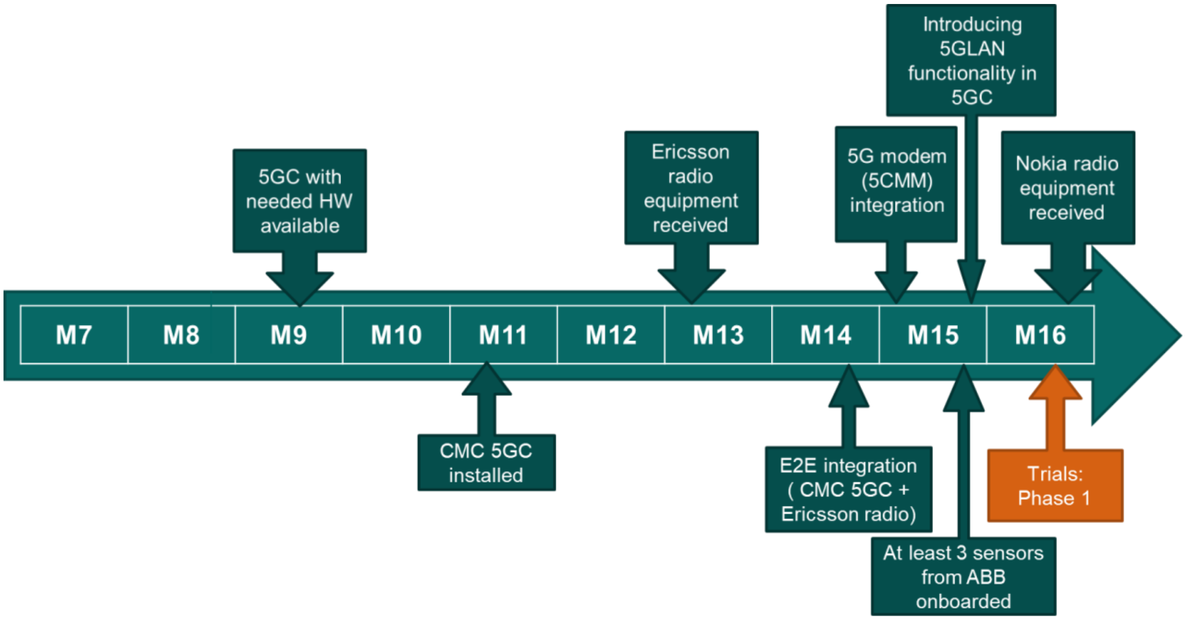


Figure 27: Use case 4 timeline and milestones: phase-1

The second integration phase goes from M17 to M30, and expands the functionalities integrated in phase-1. The FUDGE-5G solution will be integrated in this case in a cloud-hosted 5GC, while. The location for the final trial will be also ABB premises, but in a different building.

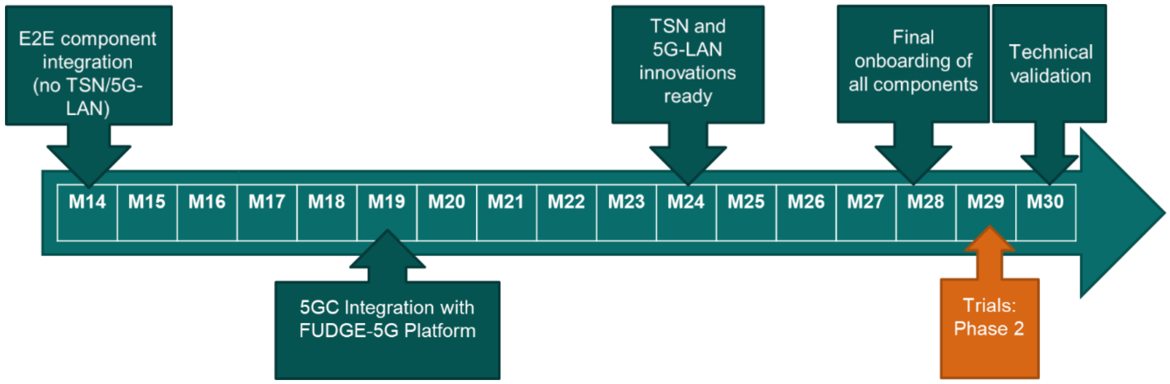


Figure 28: Use case 4 timeline and milestones: phase-2

The rest of the section will cover the integration work as of today between all necessary components.

5.1. 5GC Configuration and Installation

The 5G SA Core has been deployed in containers on the orchestration platform from RedHat delivered by Interdigital (in London). The deployment consists of 3 master nodes running Red Hat Enterprise Linux CoreOS (RHCOS), 3 workers running Red Hat Enterprise Linux 7 (RHEL7) and a bastion node running RHEL8.

The bastion node is used to run the services required by the cluster, such as a DNS server, a DHCP server, a HAProxy, a NAT gateway, a web server and an NFS server. This is the only node in the deployment that has two network interfaces, i.e., those available in the office network and in the internal OpenShift network. All the other nodes are using the OpenShift network for internal traffic and the bastion node as a gateway when they need to access the Internet.

Currently, the 5GC from Cumucore has been successfully configured, installed, and tested in Fornebu, in Telenor premises. Its integration with the 5G modem from Fivecomm has been also successfully tested, this time in Cumucore premises, prior to final integration in Fornebu. The next step is the integration with the 5G network available there, as well as the integration of advance functionalities, i.e., 5G-LAN and TSN. More details about these steps are provided in next sections.

5.2. Integration of 5G core with third party RAN

This blueprint will rely on gNBs installed in the ABB factory environment, using ABB regular design and installation processes. Prior to that, integration between the 5G core and the radio part is needed. This integration work is currently ongoing. There are 3GPP standardized interfaces that need to be installed between the 5G RAN and the 5G Core. In this particular use case, there are two alternatives for the radio network equipment. The first one is from Ericsson, which is currently available for integration and testing. There were some delays in the shipment, and this produced a chain effect that affected and postponed the whole use case integration. The other alternative, which was acquired due to these circumstances, is from Nokia and will be ready by December 2021 to be used in the context of the phase-1 trials in ABB. The radio equipment is procured by Telenor. The Cumucore 5G SA Core has been tested first against the Ericsson RAN available in Ericsson's laboratory in Kirkkonummi (Finland).

Figure 29: Fivecomm 5G modem delivered for integration in Cumucore's lab

User equipment is also an important part of the radio integration. In the context of use case 4, the Fivecomm 5G modem has been successfully integrated and tested against Cumucore 5G SA in Cumucore's lab in Espoo (Finland). A picture of the modem is shown in Figure 29.

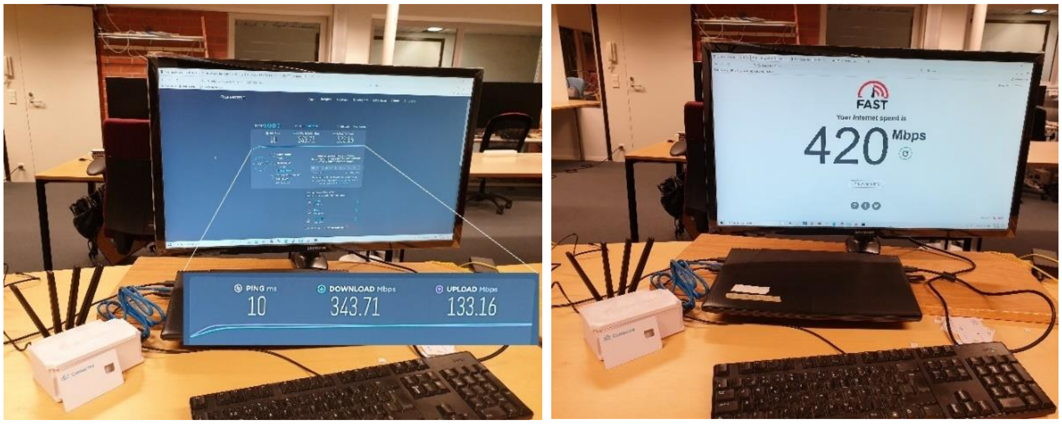


Figure 30: Throughput and latency tests done for validation of the 5G modem and 5GC integration in Cumucore premises

The final step before the phase-1 trial takes place is the end-to-end network integration (5G modem, RAN and Core). This will be done first in Telenor's laboratory before delivery to ABB at the end of 2021.

5.3. Integration of Advanced Functionalities

This use case will use 5G technology to control industrial robots. It is therefore needed to deliver extremely accurate signals to provide synchronization between them. To achieve the highly demanding requirements, TSN functionality has been developed and demonstrated on top of 5GLAN implementation. It is important to note that 5GLAN and TSN are network features requiring UE support.

5.3.1. Implementation of 5GLAN and TSN at the 5GC

This section provides an overview of the features that are being implemented in the 5GC for 5GLAN and TSN support.

During the PDU Session Establishment procedure, the SMF retrieves SM subscription data related to 5GLAN type service from the UDM as part of the UE subscription data for the DNN (Data Network Name) and S-NSSAI. A Network Exposure Function (NEF) may also support a 5GLAN Group Management Function, that is, the 5GLAN Group Management Function in the NEF may store the 5GLAN group information in the Unified Data Repository (UDR) via UDM as described in TS 23.502 [4].

UDR will store application data (including Packet Flow Descriptions (PFDs) for application detection, AF (Application Function) request information for multiple UEs, 5GLAN group information for 5GLAN management). Storage and retrieval of NF Group ID corresponding to subscriber identifier (e.g. IMPI, IMPU, SUPI).

The information of a 5G VN group is provided by the AF to the NEF, and it is stored in the UDR, by using the NEF service operations information flow procedure. The SMF shall create a group-level N4 session on the UPF for a 5G VN group when N19-based forwarding is applied. The group-level N4 Session management procedures enable the SMF to create, update or delete the group-level N4 Session, e.g., add or delete N4 rules, allocate or release the N19 tunnel resources.

```
# go-upf main conf
global:
  logLevel: debug
  useNRF: true

networking:
  HTTP:
    # specify NRF API URL
    # eg. NRFAPIURL: https://satest:9090/debug
    NRFAPIURL: https://192.168.9.172:9090
    #NRFAPIURL: https://127.0.0.1:9000
  N4:
    # Listen for control plane messages on interface IP
    # PFCP port is 8805/udp
    interface: enp3s0
  userplane:
    # interface connectivity abstractions
    # lan,wan,ran: ifaces to install BPF application on
    lan: enp1s0
    wan: enp3s0
    ran: enp3s0
  dnns: [internet, ims, morednns, market, asd] # networks to be served

# define lan cidr with MAC OUI 3bytes without separator
#lan1:
#    cidr: 192.168.9.0/24
#    mac: aaba00
lans:
  lan1:
    cidr: 10.128.2.0/24
```

Figure 31. When UPF starts it will register into the NRF

The CNC obtains the 5GS bridge VLAN configuration from TSN AF according to IEEE Std 802.1Q. The TSN AF shall be pre-configured (e.g., via OAM) with a mapping table. The mapping table contains TSN traffic classes, pre-configured bridge delays (i.e., the preconfigured delay between UE and UPF/NW-TT) and priority levels.

The CNC reads the capabilities of all bridges and calculates the traffic paths and schedules in the network. The CNC then provides the bridge configuration to the 5GS through the TSN AF, which contains, e.g., scheduled traffic, PSFP, and traffic forwarding information. In order to support QoS for Ethernet and TSN traffic, the traffic flows are mapped to 5G QoS flows. The CNC configures the traffic handling in the 5GS bridge for the different traffic classes according to the capabilities that have previously been reported by the 5GS bridge. The 5GS maps the Ethernet/TSC traffic classes or TSN traffic streams to the corresponding 5G QoS flows.

3GPP has defined 5G VN groups consisting of a set of UEs using private communication for 5G-LAN type services. A 5G VN group can be utilized for IP or Ethernet based services. A specific data network, identified by a DNN, is one of the possibilities to realize a 5G VN group, where the VN group can be either provided by Operation and Management (O&M) or by an TSN-AF

```
root@dstt:/home/dstt/tsn-project/dstt# tshark -i enp2s0
root@dstt:/home/dstt/tsn-project/dstt# make run
sudo ./dstt.out
DSTT agent started...
HW Timestamp enabled. tx_type = 1 and rx_filter = 1
HW Timestamp enabled. tx_type = 1 and rx_filter = 1
SYNC message sentcalculated rateRatio = 1.000000
        Ingress Timestamp       == 1638352174990930200
        Egress Timestamp        == 1638352174476904028
        Residence Time          == 0.514026172
        Residence Time (sec)    == 0
        Residence Time (nsec)   == 514026172
FOLLOW_UP message sent

Peer_Delay_Resp sent

PEER_DELAY_RESPONSE_FOLLOW_UP message sent

SYNC message sentcalculated rateRatio = 1.000000
        Ingress Timestamp       == 1638352175115853880
        Egress Timestamp        == 1638352174601916948
        Residence Time          == 0.513936932
        Residence Time (sec)    == 0
        Residence Time (nsec)   == 513936932
FOLLOW_UP message sent
```

Figure 32. Network-side TSN translator (NWTT) is started

5G VN group where the SMF has full control of the Ethernet network topology among the 5G VN group members (by control of forwarding decision on all Ethernet PDU session from different UEs).

For a centrally managed Ethernet network, it is required that the NMS/CNC can configure the VLAN handling for all bridges and all ports, including the 5GS bridge, as specified in IEEE 802.1Q. The 5GS bridge performs frame forwarding as specified in IEEE 802.1Q. The frame forwarding should include the ability for flooding and MAC (Medium Access Control) learning. The 3GPP Release-16 support for TSN, traffic forwarding is set using pre-configuration and static filtering entries (used for traffic forwarding) provided by the CNC only for uplink traffic.

5.3.2. TSN support at the 5G modem

The first phase-1 of the integration was finally based on a 5G modem that does not include 5GLAN and TSN functionalities. Such functionalities are currently being implemented and will be integrated with Cumucore 5GC. The main feature to be implemented at UE level is the device-side TSN translator (DS-TT).

The device will use the gPTP protocol for synchronization, with transparent clock. In the transparent clock mode, measures are done between the ingress and egress ports, with a residence time for correction. This means that Quality of Service (QoS) needs to be established for related messages that ensure a specific delay time. In this mode, the network topology needs to be known and there are two elements that are needed, i.e., the NW-TT for establishing connection to the TSN system of the network, and one or more DS-

TT elements for establishing the connection to the TSN local system. Both elements need to be in the same domain.

Since the 5G modem is based on a Raspberry Pi 4, tools such as ModemManager and NetworkManager could be used for the managment of the 5G module and the network connection respectively. The implementation would be based on a script that runs over Linux. Such script would manage de state machine, perform operations in a simple way, read and write in the serial port (USB in this modem) and add the functionalities needed for PTP conversion.

5.4. Planned Integration of the FUDGE-5G Platform

For the Industry 4.0 use case a set of three compute hosts with medium to small compute, storage and memory capacities will host the FUDGE-5G platform components as a mix of VMs and containers. The platform components provisioned for the first trial are coloured squares in green and represent the routing and orchestration components. Enterprise services are illustrated as coloured circles and are hosted inside a platform instance, i.e., 5GC NFs inside SHs and vertical applications inside a Kubernetes cluster (K8s).

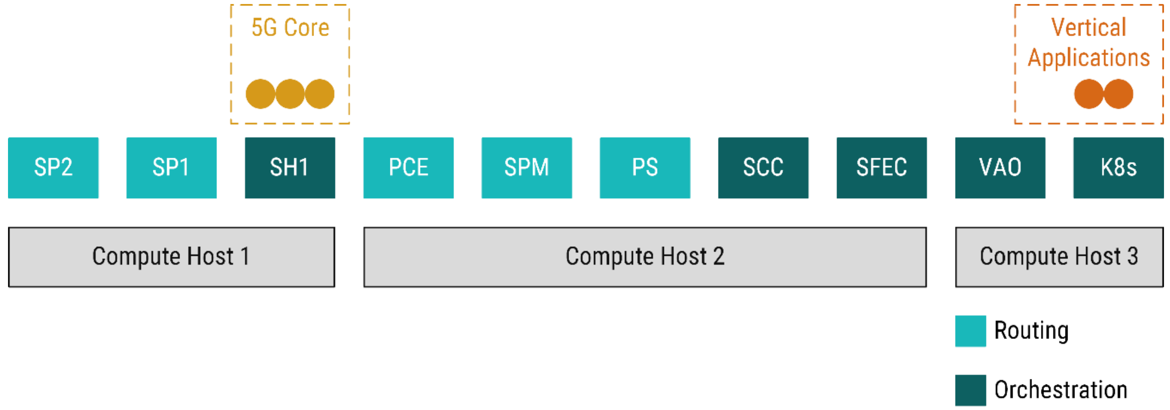


Figure 33: Planned FUDGE-5G platform deployment for the Industry 4.0 use case

The entry point for control plane message from a UE via the gNodeB is provided via extending the SCP on the N2 interface represented by the SP2 routing component in Figure 33.

6. UC5-Interconnected NPNs

5G technologies and the deployment of small-sized non-public networks, is enabling the network ecosystem to transform towards a multi administrated environment [5]. The use case Interconnected NPNs will demonstrate the capability to deploy locally administrated non-public campus networks and interconnect them to provide a coherent, secure, and reliable communication environment [1]. The main aim of this use case is to cover two scenarios- when subscribers are at their local network and when they are in the roaming network are authorized to have access to the local network services.

To interconnect the NPNs and exchanging messages between the domains one component was developed. Session Border Controller (SBC) has the functionality of SCP and is responsible for forwarding inter domain messages [3]. SBC stays at the control plane of 5G Core and has the information about other SBCs of the connected domains.

The stakeholders for this use case are Telenor (Norway), Universidad Politécnica de Valencia (Spain), and Fraunhofer FOKUS (Germany). To realise the use case Fraunhofer FOKUS Open5GCore will be deployed in the stakeholder's premises as the NPNs (shown with Figure 34). For validating the use case, devices with SIM cards having different PLMN will connect to 5G Core networks through the local RAN. The devices which have PLMN same as the local 5G network will be authorized by the local network and the devices, whose PLMN belongs to any of the interconnected remote network, the local SBC will forward messages to the remote SBC to authorize the device.

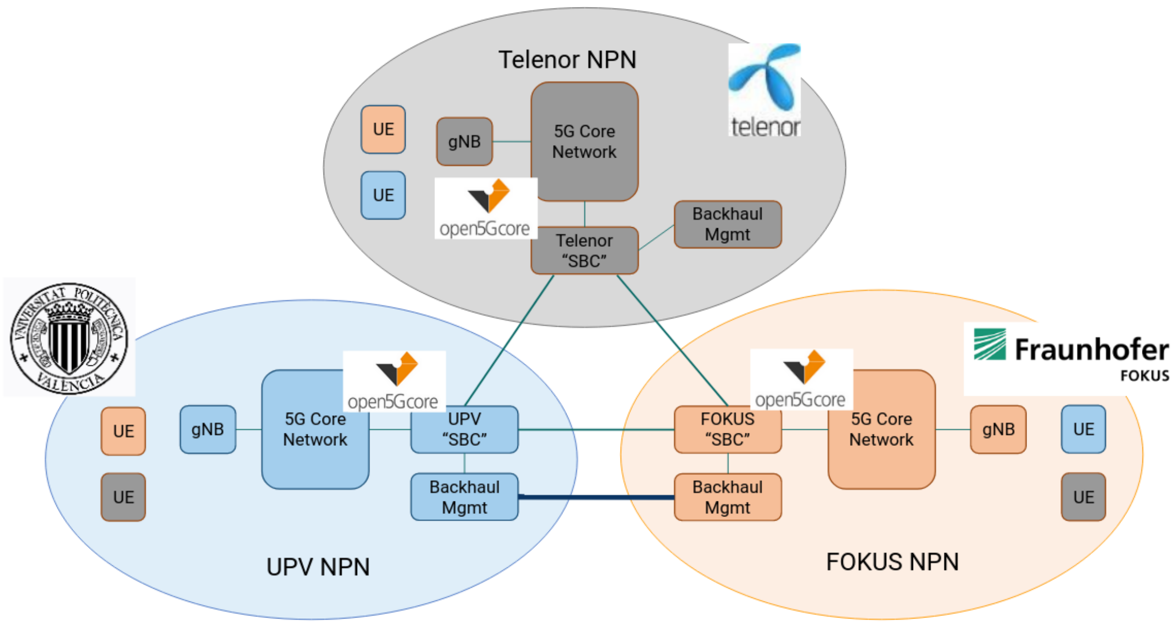


Figure 34: Interconnected NPNs use case configuration for roaming

As part of Phase-1, the work done so far is shown using Figure 30. At the stakeholder's premises 5G RAN was deployed by M09. Before deploying the NPNs at the three locations, SBC was developed and integrated with Open5GCore by M10. For the first phase of verification and validation of the use case, 5G Cores were deployed at Fraunhofer FOKUS lab and UPV lab. These NPNs were interconnected over a secured VPN tunnel and the interoperability testing was performed. Both local and roaming users were getting successfully authorized by the core networks.

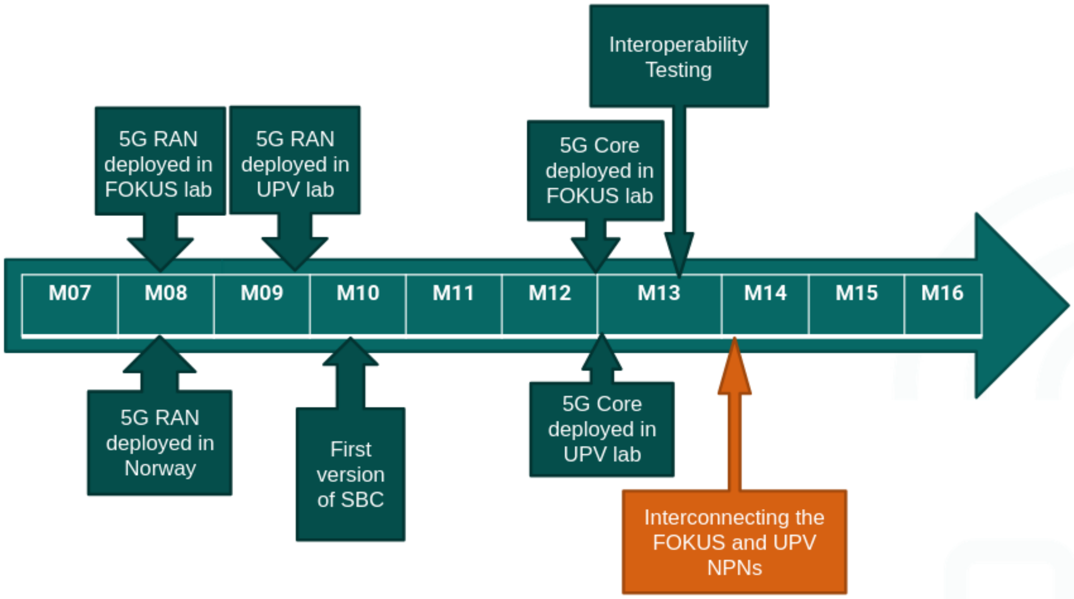


Figure 35: Interconnected NPNs use case Phase-1 Progress

As part of Phase-2, the next plan is shown using Figure 36. Here the focus will be to interconnect all three NPNs and check the interoperability. Also extending Open5GCore platform with basic Security Edge Protection Proxy (SEPP) and home routed roaming support. Verifying the distributed authentication architecture and validating different scenarios for the use case with the extended features. The following sub sections are covering the details of the integration work.

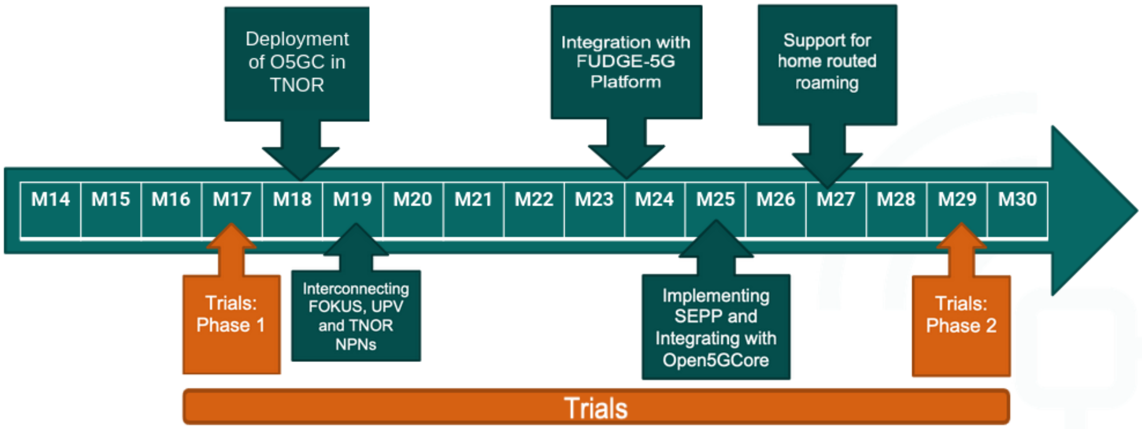


Figure 36: Interconnected NPNs use case Phase-2 Planning

6.1. 5GC Configuration and Installation

For this use case, the Open5Gcore will be deployed preliminary in light weight container system created by FOKUS. This allows quick deployment and configuration of the core. The core will be deployed at UPV, TNOR and FOKUS. Each core will have an SBC deployed and the SBCs will be configured with the details of other SBCs of connected core networks.

For the initial phase, the 5G cores with SBC are deployed at Fraunhofer FOKUS and UPV campus. The connection between UPV and FOKUS is currently based on tunnel over SSH. The connection will be changed to another method (HTTPs or Wireguard) in the later phases of the project. The SBCs in FOKUS and UPV are configured with the details of SBC in UPV and FOKUS respectively. The UEs in FOKUS are configured with the PLMN of UPV. Hence when we register these UEs, the core forwards the authentication request to SBC in FOKUS via existing tunnel. Same way UEs in UPV are configured both with the local PLMN and FOKUS PLMN for the testing of roaming scenario.

6.2. Integration of 5G core with third party RAN

The Open5GCore from the Fraunhofer FOKUS is integrated with Amarisoft RAN for this use case. Amarisoft RAN will be used on both sides i.e., UPF and FOKUS. Amarisoft was already integrated with the core along with other vendors for working interoperability during which the functionality was confirmed to be working. As integration was done before, for this use case the base station sent NGC traffic in the direction where core was deployed. In phase 1, Amarisoft RAN is connected to the core deployed at UPV. As edge device, a modem was used in UPV for verifying the NPN use case which was configured with the FOKUS PLMN.

In the phase 2 of this trial, RAN will be used in FOKUS side as well. This will allow to test devices from both sides with local and roaming PLMNs.

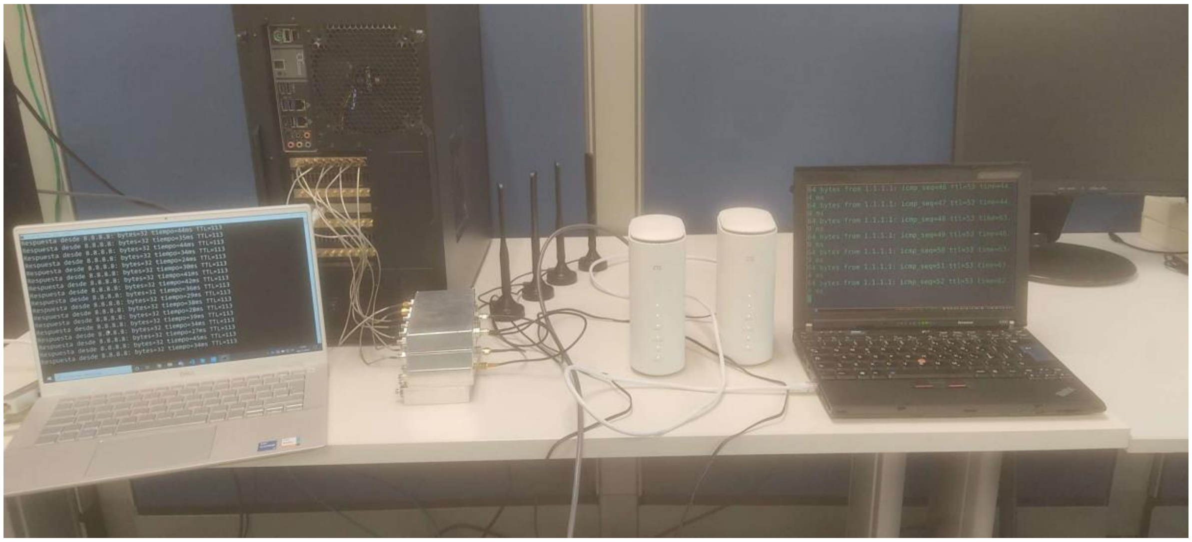


Figure 37: Integration of 5G core with Amarisoft RAN at UPV

The Figure 38 shows a log of the Open5GCore's AMF installed at UPV that indicates that the Amarisoft is properly connected.

```
14:40:36>AMF.amf.ng.print_nodes
140577651676928/4074002 14:40:37   INFO:command:execute_module_cmd():161> cmd reply:
amf_comm_reply
---------- [ngran_node_ht] -----------
Number of entries: 1 empty slots: 31 out of 32
Hash 10,        entries: 1
        -----------  gNB  ----------
         gNB ID:        4098
         RAN Node Name: gnb0001002
         NG-C addr:     172.30.0.241:55835
         SCTP Assoc ID: 25810
        ---------------------------
-------- [ngran_node_ht] end ---------
```

Figure 38: Amarisoft connected to Open5GCore

6.3. Interconnecting NPNs

UPV has deployed a virtual machine in its 5G testing facilities where the *Open5GCore* with included SCP is deployed. To allow this virtual machine to communicate with the 5G Core deployed at FOKUS, the UPV's firewall has been configured to allow the traffic of the TCP ports 8080 and 22.

To be able to test and validate that the roaming between 5G cores deployed at the UPV and the FOKUS works correctly, the core UPV is deployed a gNB and UEs alongside the core, allowing to validate the functionality by authenticating the UEs located at the UPV to the FOKUS core.

For the gNB, UPV provided an *AMARI Callbox Ultimate*. The UEs that were used are *ZTE MC801A*. During the initial the initial setup, UPV detected problems with the interaction between the *ZTE MC801A* and *Open5GCore*, and the modem could not register in the network successfully. FHG and UPV fixed the problem, and the UE was able to register and authenticate in the network. At UPV lab local UE got registered at core at UPV and roaming UE got registered at the core at FOKUS.

The Figure 39 contains a trace taken at the UPV that shows a UE connecting to the UPV node and getting authenticated by the FHG node (the MCC and MNC used by the FHG node are 999 and 99, as shown in the figure).

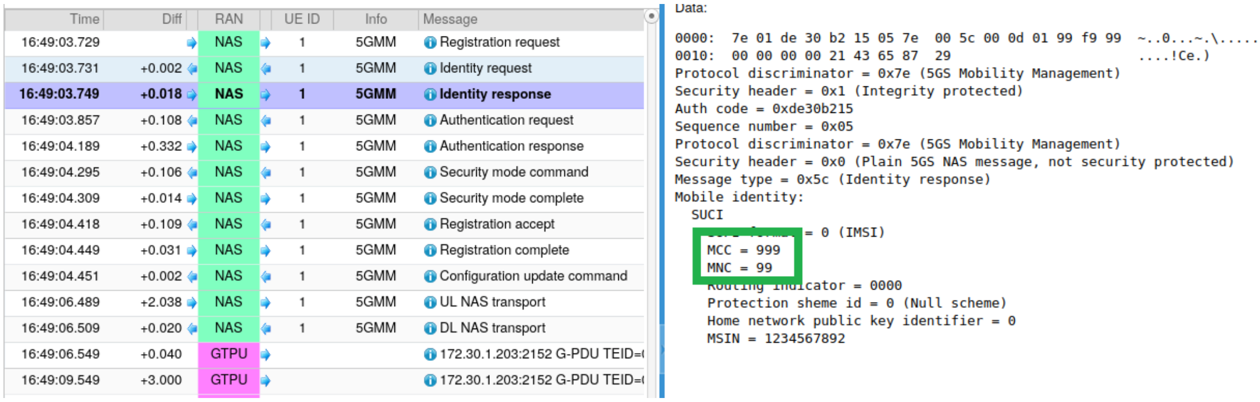


Figure 39: Trace showing the UE connection

6.4. Planned Integration of the FUDGE-5G Platform

This use case will have two NPNs are two locations that are interconnected. As illustrated in Figure 40, the two locations are Valencia and Berlin with a large enough compute host to provisioning the FUDGE-5G platform as VMs. While the Berlin's compute host is powered by VMware, the Valencia one is foreseen to be a standard host without any NFV framework.

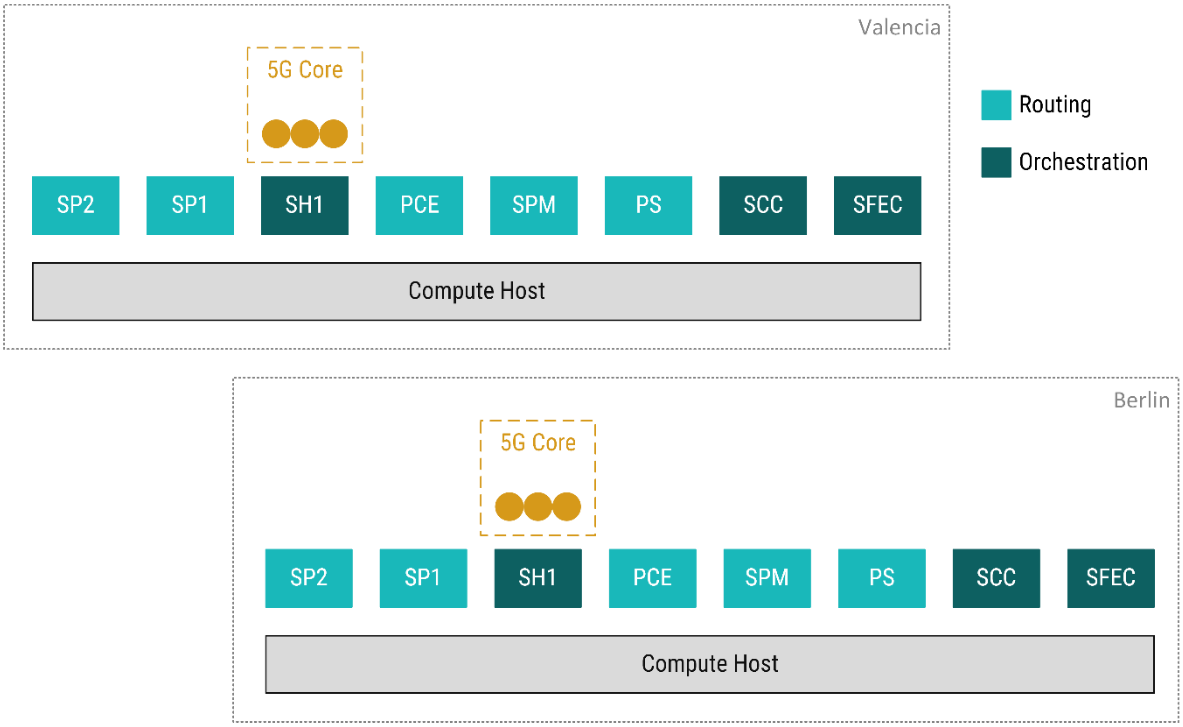


Figure 40: Planned FUDGE-5G platform deployment for the Interconnected NPNs use case

The entry point for control plane message from a UE via the gNodeB is provided via extending the SCP on the N2 interface represented by the SP2 routing components in each location in Figure 40.

7. Conclusion

This document provided the progress on the integration of the technological elements, which were discussed in D2.1 deliverable and are developed so far in the project. The information about integrating the testbed depending on the scenarios defined in D1.1 for each of the use cases are captured in this deliverable. The structure of the deliverable is giving an outline of the technologies provided by the partners for each of the use cases and how they are integrated to make the way for the trials to be performed.

Based on the high-level architecture of the use cases denoted in D1.1, this deliverable showed how the platform is integrated. For each of the use cases the overall roadmap for phase-1 and phase-2 was mentioned here. The installation and configuration of the 5G cores to deploy NPNs are presented. Which RAN is being used to do interoperability testing and the status on that is also reported in this document. The advanced features like 5GLAN, TSN how these will be configured with 5G core was also discussed here. The work done so far to integrate the platform for the use cases was shown with pictures captured from the labs, where the integration work is going on to validate the frameworks and prepare for the vertical trials.

This document is an interim release of the integration work to be performed for the use cases. The platform integration for the vertical trials is an ongoing process till the life of the project and further work done on this area to integrate the FUDGE-5G platform will be reported by D3.2.

8. References

[1] FUDGE-5G, "D1.1 Technical Blueprint for Vertical Use Cases and Validation Framework".

[2] FUDGE-5G, "D2.1 FUDGE-5G Technology Components and Platform – Interim Release".

[3] FUDGE-5G, "D1.2 FUDGE-5G Platform Architecture: Components and Interfaces".

[4] AWS, "AWS Snowball Edge Specifications," AWS, 2021. [Online]. Available: https://docs.aws.amazon.com/snowball/latest/developer-guide/specifications.html.

[5] J. Montesa, “5GMediaHub D1.1. Use case analysis and target KPIs - Initial,” August 2021. [Online].

[6] HPE, "HPE ProLiant DL110 Gen10 Plus Telco server," HPE, 2021. [Online]. Available: https://buy.hpe.com/emea_europe/en/servers/proliant-dl-servers/proliant-dl100-servers/proliant-dl110-server/hpe-proliant-dl110-gen10-plus-telco-server/p/1013324922.

[7] Red Hat, “Red Hat Openshift 4 is here,” 2021. [Online].

[8] Cilium, "eBPF Documentation. What is eBPF?," 2021. [Online].

[9] Athonet, “Athonet Bubblecloud. AWS Marketplace,” [Online].

[10] M. Keltsch, “Remote production and mobile contribution over 5G networks: scenarios, requirements and approaches for broadacst quality media streaming,” June 2018. [Online].

[11] 3GPP, "Procedures for the 5G System (5GS) TS 23.502," 3GPP, 2021.

[12] 5G-VINNI 5G PPP, "ICT-17-2020 5G Verticals INNovation Infrastructure," Dec 2019. [Online].

[13] Huawei, "Huawei 5G CPE Pro 2," 2021. [Online]. Available: https://consumer.huawei.com/en/routers/5g-cpe-pro-2/.