5Genesis

5TH GENERATION END-TO-END NETWORK, EXPERIMENTATION, SYSTEM INTEGRATION, AND SHOWCASING

[H2020 - Grant Agreement No. 815178]

Deliverable D4.14

The Berlin Platform (Release B)

Editor Arun Prakash (Fraunhofer)

Contributors M. Emmelmann, F. Eichhorn, S. K. Rajaguru, A. Prakash, T. Briedigkeit, M-I. Corici (Fraunhofer), J. Gutiérrez, M. Ehrig, N. Maletic, M. Ramadan, E. Grass (IHP), A. Brunstrom, J. Karlsson, M. Rajiullah (KAU), G. Caso, Ö. Alay, C. Midoglu. M. Klausen, C. Griwodz (SRL), P. Matzakos, F. Kaltenberger (ECM), V. Koumaras (INF).

Version 1.0

Date January 31st, 2020

Distribution PUBLIC (PU)

List of Authors

Fraunhofer	FOKUS-Fraunhofer Gesellschaft e.V., Institute for Open Communication Systems
M. Emmelmann, F. Eichhorn, S. K. Rajaguru, A. Prakash, T. Briedigkeit, M-I. Corici	
IHP	Innovations for High Performance microelectronics / *Leibniz-Institut für innovative Mikroelektronik*
J. Gutiérrez, N. Maletic, M. Ehrig, M. Ramadan, E. Grass	
KAU	Karlstads Universitet
A. Brunstrom, J. Karlsson, M. Rajiullah	
SRL	Simula Research Laboratory AS
G. Caso, Ö. Alay, C. Midoglu, M. Klausen, C. Griwodz	
ECM	EURECOM
P. Matzakos, F. Kaltenberger	
INF	INFOLYSIS
V. Koumaras	
INT	Intel
V. Frascolla	

Disclaimer

Copyright

The 5GENESIS Consortium consists of the following partners:

NATIONAL CENTER FOR SCIENTIFIC RESEARCH “DEMOKRITOS”	Greece
AIRBUS DS SLC	France
ATHONET SRL	Italy
ATOS SPAIN SA	Spain
AVANTI HYLAS 2 CYPRUS LIMITED	Cyprus
AYUNTAMIENTO DE MALAGA	Spain
COSMOTE KINITES TILEPIKOINONIES AE	Greece
EURECOM	France
FOGUS INNOVATIONS & SERVICES P.C.	Greece
FON TECHNOLOGY SL	Spain
FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	Germany
IHP GMBH – INNOVATIONS FOR HIGH PERFORMANCE MICROELECTRONICS/LEIBNIZ-INSTITUT FUER INNOVATIVE MIKROELEKTRONIK	Germany
INFOLYSIS P.C.	Greece
INSTITUTO DE TELECOMUNICACOES	Portugal
INTEL DEUTSCHLAND GMBH	Germany
KARLSTADS UNIVERSITET	Sweden
L.M. ERICSSON LIMITED	Ireland
MARAN (UK) LIMITED	UK
MUNICIPALITY OF EGALEO	Greece
NEMERGENT SOLUTIONS S.L.	Spain
ONEACCESS	France
PRIMETEL PLC	Cyprus
RUNEL NGMT LTD	Israel
SIMULA RESEARCH LABORATORY AS	Norway
SPACE HELLAS (CYPRUS) LTD	Cyprus
TELEFONICA INVESTIGACION Y DESARROLLO SA	Spain
UNIVERSIDAD DE MALAGA	Spain
UNIVERSITAT POLITECNICA DE VALENCIA	Spain
UNIVERSITY OF SURREY	UK

Version History

Rev. N	Description	Author	Date
1.0	Release of D4.14	ALL	31.01.2020

List of Acronyms

Acronym	Meaning
5G	5-th Generation of cellular mobile communications
5G NR	5G New Radio
5G-PPP	5G Public-Private Partnership
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
ARM	Advanced RISC Machine
BT	Benchmarking Tool
COTS	Commercial-Off-The-Self
DRAN	Distributed Radio Access Network
DWDM	Dense Wavelength Division Multiplexing
ELCM	Experiment Life Cycle Manager
eMBB	Enhanced Mobile Broadband
EMS	Element Management System
EPC	Evolved Packet Core
E-UTRAN	Evolved Terrestrial Radio Access Network
FCAPS	Fault, Configuration, Accounting, Performance and Security
FPGA	Field Programmable Gate Array
GDPR	General Data Protection Regulation
HEVC	High Efficiency Video Coding
IaaS	Infrastructure as a Service
KPI	Key Performance Indicator
LTE	Long Term Evolution
MANO	Management & Orchestration
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mmWave	Millimeter Wave
NB-IoT	Narrow Band – Internet of Things
NLOS	Non Line of Sight
NMS	Network Management System
NSA	Non-Stand-Alone
OAI	Over the Air Integration
OSS	Operational Support Services

PFCP	Packet Forwarding Control Protocol
PTMP	Point-to-Multi-Point
QoE	Quality of Experience
QoS	Quality of Service
PTMP	point-to-multipoint
RAT	Radio Access Technology
REST	Representational State Transfer
RRH	Remote Radio Head
RTSP	Real-time Streaming Protocol
SA	Stand-Alone
SDK	Software Development Kit
SDN	Software Defined Networking
TaaS	Testing as a Service
TAP	Test Automation Platform
VM	Virtual Machine
VNF	Virtual Network Function
VNFM	Virtual Network Function Manager
VPN	Virtual Private Network
VR	Virtual Reality
WIM	WAN Infrastructure Manager
WLAN	Wireless Local Area Network
WP	Work Package

Executive Summary

The 5GENESIS Project builds up a 5G experimentation facility that comprises of five 5G platforms and a portable demonstrator distributed across Europe. The goal of the Project is to equip these 5G platforms to allow the validation of 5G Key Performance Indicators (KPIs). All platforms are instances of a common reference architecture, which was defined in deliverable D2.2 “Initial overall facility design and specifications”, in response to the project requirements, identified in deliverable D2.1 “Requirements of the facility”.

This deliverable provides additional details (Release B) on the status of the specific instantiation of the reference architecture being built in the 5GENESIS Berlin platform. The status represents an update to that included in the first release of the Berlin Platform instantiation, captured in deliverable D4.13 “The Berlin Platform Release A”. This document first presents the platform instantiation at the end of Phase 2, and the expected instantiation by the end of the project and then reports the current status (platform release B), resulted after the second integration cycle of the project (December 2019).

The main objective of the Berlin Platform is to set up a multi-technology, multi-site end-to-end (E2E) 5G environment for evaluation of eMBB and mMTC services in a city testbed in the context of the yearly event “Festival of Lights”. The overall set up consists of the 5G Core from Fraunhofer FOKUS (Open5GCore), Radio Access Technologies (RATs), among them 5G New Radio (NR) equipment, together with an enhanced millimeter wave (mmWave) transport solution, edge computing capabilities and video-related equipment to provide connectivity to multiple users in the center of Berlin (Humboldt University).

The Berlin Platform consists of three sites: the Fraunhofer FOKUS site, the IHP site and the Humboldt University site. The sites are interconnected in pairs, from the main data center in Fraunhofer FOKUS to the IHP site, and from the main data center in Fraunhofer FOKUS to the edge data center at Humboldt University. The assessment of the Berlin Platform as a whole requires parallel testing of the equipment in all those sites before the overall evaluation of the complete deployment is carried out in Berlin in October 2020.

This deliverable provides an overview of the status of the Berlin Platform in both infrastructure and software and hardware network components that are being developed in WP3, leveraging the interfaces for control and monitoring, the required automation processes for experimentation, measurement and KPI computation, as well as to implement full control and security aspects as described in the Coordination Layer, which was defined in deliverable D2.2. The Berlin Platform will also support the common portal for interaction with experimenters and tools for the appropriate operation of the Berlin Platform.

In specific, at the end of Phase 2, the following tasks have been achieved:

- Establishment of VPN for inter-site platform connectivity.

- Integration of the initial version of Slice manager into the Berlin platform.
- Initial integration of dispatcher and definition of experiment descriptors.
- Installation of the IHP 60 GHz mmWave solution at IHP premises and initial set of indoor and outdoor measurements.
- Initial Edge deployment at Humboldt University premises.
- Experimentation site preparation for Festival of Lights event in Berlin to showcase the initial use case demo at Humboldt University premises.
- Integration of Release A of Coordination layer functionalities, i.e.
    - Portal.
    - Experiment Lifecycle Manager (ELCM).
    - InfluxDB.
    - Grafana.
    - OpenTap.

Table of Contents

List of Figures

List of Tables

1. Introduction

This deliverable provides a detailed description of the layout and functionalities of the 5G experimental platform being built in the city of Berlin in the context of the 5G-PPP H2020 project 5GENESIS. The project aims to validate the relevant 5G-PPP KPIs over experimental 5G platforms and 5G use cases.

1.1 Purpose of the document

This is the second deliverable release in the framework of 5GENESIS Task 4.5 "The Berlin Platform", which belongs to Work Package 4 (WP4) entitled "End-to-end facility Instantiation". The purpose of this deliverable is to meet the following WP4 objectives:

- Follow in each implementation the specifications defined in WP2.
- Adopt the integral parts of the facility as they will be developed in WP3.
- Accomplish the requirements that are tailored to the specific use cases of the platform.
- Provide on-time the implementation required for the actions in WP6 and detail descriptions to be used in WP5.

The document release is in line with the three experimentation cycles defined in the project: April-June 2019, January-March 2020, October 2020-June 2021. Each experimentation cycle is preceded by an integration phase of components to add more subsystems with the final target of validating the relevant 5G KPIs in a full end-to-end network with real users.

Table 1-1: Dependencies with previous 5GENESIS Documents

id	Document Title	Relevance
D2.1 [1]	Requirements of the Facility	The document sets the ground for the first set of requirements related to supported features at the testbed for the facilitation of the Use Cases.
D2.2 [2]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [4]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D5.1 [40]	System-level tests and verification (Release A)	Midterm report with detailed documentation and analysis of the results from the system-level tests and the verification trials.
D4.13 [3]	The Berlin Platform (Release A)	This document summarizes the sites and components that will form the Berlin Platform and sets the ground to D4.14.
D6.1 [33]	Trials and experimentation - cycle 1	This deliverable includes the trials and experimentation results on the 5GENESIS platform, as per the deployment status envisioned in D4.13 - resulted from the first integration cycle.

D3.1	Management and orchestration (Release A)	The document presents the MANO solutions that are integrated in the infrastructure. Interfaces and deployment options are also described.
D3.3	Slice management WP3 (Release A)	The document details the Slice Manager solution, its interfaces towards the MANO and Network Management System (NMS) components.
D3.5	Monitoring and WP3 analytics (Release A)	The document details the Infrastructure Monitoring components and the interfaces with infrastructure elements.
D3.9	5G Core Network WP3 Functions (Release A)	The document details the 5G Core network functions and provides input on their integration with the infrastructure and management components.
D3.11	5G Access Components and User Equipment (Release A)	The document details the 5G Radio Access components and UE devices.

1.2 Structure of the document

Following the introduction, this document presents in **Section 2** a brief overview of the target topology of the Berlin Platform at the end of the project, the sites and the technologies used for the platform components at the three logical layers (Coordination Layer, Management and Orchestration layer, and Infrastructure Layer).

Section 3 describes the current status of the Berlin Platform towards the achievement of the objectives. It also lists the current accomplishments during Phase 1 and Phase 2, together with the milestones to be reached for Phase 3.

Section 4 is devoted to the main use case that will take place in Berlin, the "Festival of Lights" event. In this section we describe the scenarios where this use case will be showcased, the components required for running the use case and the expected outcomes.

Finally, **Section 5** concludes the document.

1.3 Target Audience

This document represents the Release B of the Berlin Platform and is the first public document that captures the status of the platform and lists the integration activities carried out up to the present date. Being the first public deliverable of the platform, the goal of the document is to reach not only the European Commission and the peer projects participating in the 5G-PPP programme, but also to broaden the audience including the general public that might be interested in the status of the platform and the possibilities it offers: use cases of general interest demonstrated in the platform and the possibility of running additional experiments and use cases on it.

The release of this document will allow the European Commission to track the evolution of the Berlin Platform, and to assess the novelty and work carried out since Release A. Additionally, the deliverable will also be of help for the 5GENESIS project partners, as it will offer valuable inputs for analysis and decision making in relation with future developments, identify upcoming joint work and activities between partners and the rest of the platforms.

2. The Berlin Platform Overview

2.1 Berlin Platform Sites overview

2.1.1 Overall Topology

The Berlin 5G Platform involves different infrastructures located in the cities of Berlin and Frankfurt (Oder). The deployment is physically distributed across three different locations, being all of them connected via a regular “Internet connection” using the DFN / GÉANT network.

Each site features different capabilities and hosts different infrastructure components infrastructure for 5G KPIs evaluation. They together complete the Berlin Platform, which is depicted in Figure 2-1. These sites are:

- **The Fraunhofer FOKUS testbed in Berlin**. Located in West Berlin, it represents the main site where the main data center is located.
- **The IHP testbed in Frankfurt (Oder)**, which acts as a remote deployment for terrestrial backhaul evaluation – mmWave solution at 60 GHz – as part of a preliminary installation to be deployed in Berlin.
- **The Humboldt University site in Berlin center**, situated in one of the main locations for sightseeing in Berlin, it represents the site where the edge capabilities of the Berlin Platform will be showcased, together with the different access solutions that allow running the main use case – the Festival of Lights – that takes place in the square located by the University building.

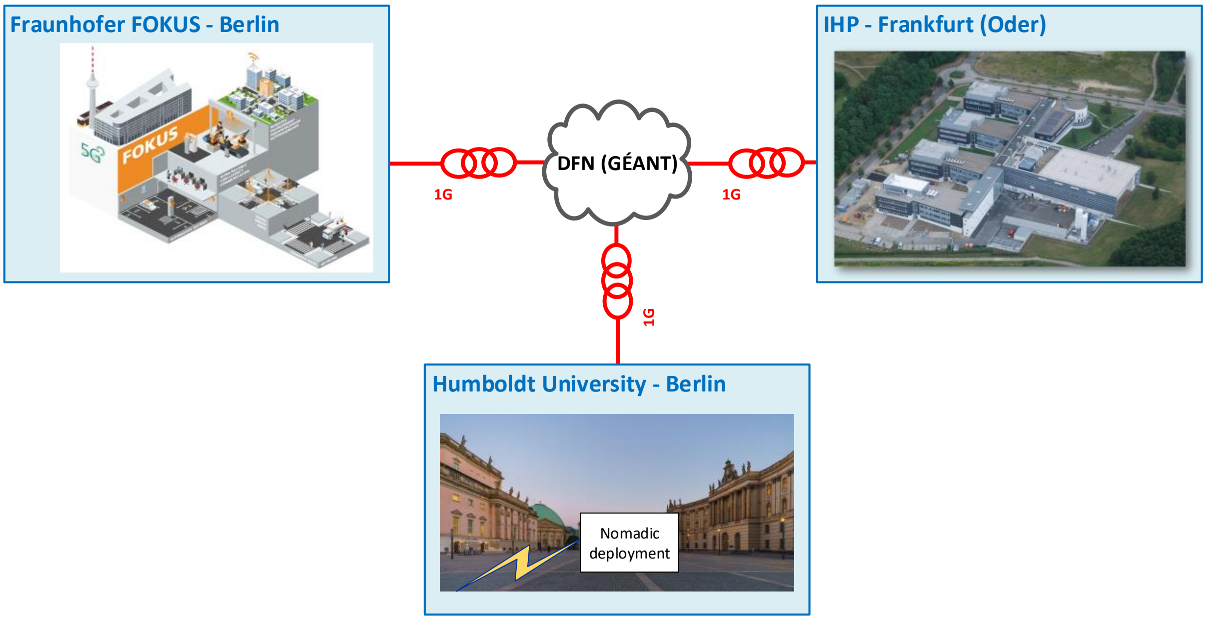

Figure 2-1: Overview of the 5GENESIS Berlin Platform

The sections to follow briefly present the platform infrastructure and assets already available at the three sites. For a more detailed presentation of the sites, please refer to D4.13 [3].

2.1.2 The Fraunhofer FOKUS site

The Fraunhofer FOKUS site serves as the central testbed among the Berlin platform sites. It provides centralized compute and storage capabilities and integrates around the FOKUS Open5GCore legacy 4G radio technologies, as well as 5G New Radio Stand-Alone equipment and non-3GPP access technologies such as WiFi6 and satellite links for interconnecting remote sites. The Fraunhofer FOKUS site hosts all management components of the Berlin platform as such being the central control point for the seamlessly interconnected HU and IHP sites.

The Fraunhofer FOKUS and IHP sites have been interconnected via VPN to support initial experiments (see D6.1 [33] Section 9, Figure 9-1 for more details). In Phase 2, the Fraunhofer FOKUS site was connected to the Humboldt University site via VPN.

Apart from the completion of the interconnection between all three sites, the following technologies have been deployed at the FOKUS site:

- Hyper-converged infrastructure providing compute and storage.
- Lab-based 5G Stand-Alone New Radio.
- Open5GCore Rel.5 supporting 5G SA NR.
- Provider-graded Dense Wavelength Division Multiplexing (DWDM) systems and satellite link to interconnect the Berlin platform towards external entities.

The installation of additional 5G SA RAN covering the parking deck and additional floors of the FOKUS site is scheduled for March 2020; installation of new 5G SA outdoor RAN consecutively in Q1/2020. The installation of additional 100 Gbps switches is planned for Q2/Q3 2020.

2.1.3 The IHP site

The IHP testbeds serves as the site for testing of the mmWave equipment that the Berlin Platform is accommodating in the overall deployment. These HW pieces will then be shipped to the Humboldt site for outdoor installation and showcasing of the main use case taking place in Berlin.

To date, the IHP testbed has been the site chosen to build up the mmWave components once these have been characterized in the Anechoic Chamber and, later on, in an indoor environment. The mmWave nodes have been designed and built up for serving as a wireless backhaul solution that will be deployed outdoors in the center of Berlin (see Section for more details on the current status of the solution).

In the context of deliverable D6.1 [33], the IHP site has been interconnected via VPN with the Fraunhofer FOKUS site in order to assess the performance indicators (throughput and latency) over the mmWave backhaul solution deployed indoors (see D6.1 Section 9 for more details). It is expected that the mmWave solution is installed outdoors in February 2020 as part of the infrastructure that will be tested in the context of the upcoming deliverable D6.2.

2.1.4 The Humboldt University site

As described in deliverable D4.13 [3], The Humboldt University site, located in the centre of Berlin, represents a nomadic, remote island of the Berlin Platform, and serves as the main site where the “Festival of Lights” use case will be showcased.

Prior to that particular event, which will take place in October 2020, the Berlin Platform team extended the Berlin Platform towards the Humboldt University building by providing connectivity to this building using a VPN tunnel from Fraunhofer FOKUS. The setting up of equipment at both sides, together with the possibility of featuring the Humboldt building with edge capabilities, allowed the preparation of the dry run of the event in 2019 [6].

Figure 2-2: Deployment at Humboldt University for the Festival of Lights 2019

Section 4.2.1 provides more details on the specific deployment and the HW and SW components that were part of the setup.

2.2 Target Deployment

Figure 2-3 depicts the extensions of the target physical topology of the Berlin Platform as implemented in Phase 2 of the project. It illustrates the main components of the system implemented to extend the connection between the Fraunhofer FOKUS site and the IHP site of the Berlin Platform (see Figure 14 in D4.13 [3]) and, as well, towards the Humboldt University site as the site where the final deployment and demonstration will take place.

This section presents an update of the different components (physical and virtualized) that are part of the Berlin Platform in its Release B. As well, it includes the Commercial-Off-The-Self (COTS) technologies the Berlin Platform makes use of.

The section is structured in three subsections, mapping the layered Experimentation Blueprint defined in D2.2 [2], which consists of three layers, namely the Infrastructure Layer, Management & Orchestration Layer and Coordination Layer.

Regarding the Infrastructure layer, the different physical components and technologies are installed as part of the Berlin Platform infrastructure in different phases, being first assessed individually at the different sites before their integration for the final demonstration activities.

As part of the upper layers, i.e. Management & Orchestration and Coordination layers, the virtualized components may be instantiated at any compute/data center location present at any of the Berlin sites. They will serve different purposes, e.g. monitoring and measurements' assessment, and will be deployed at various points of the infrastructure as part of the mechanisms towards KPI evaluation.

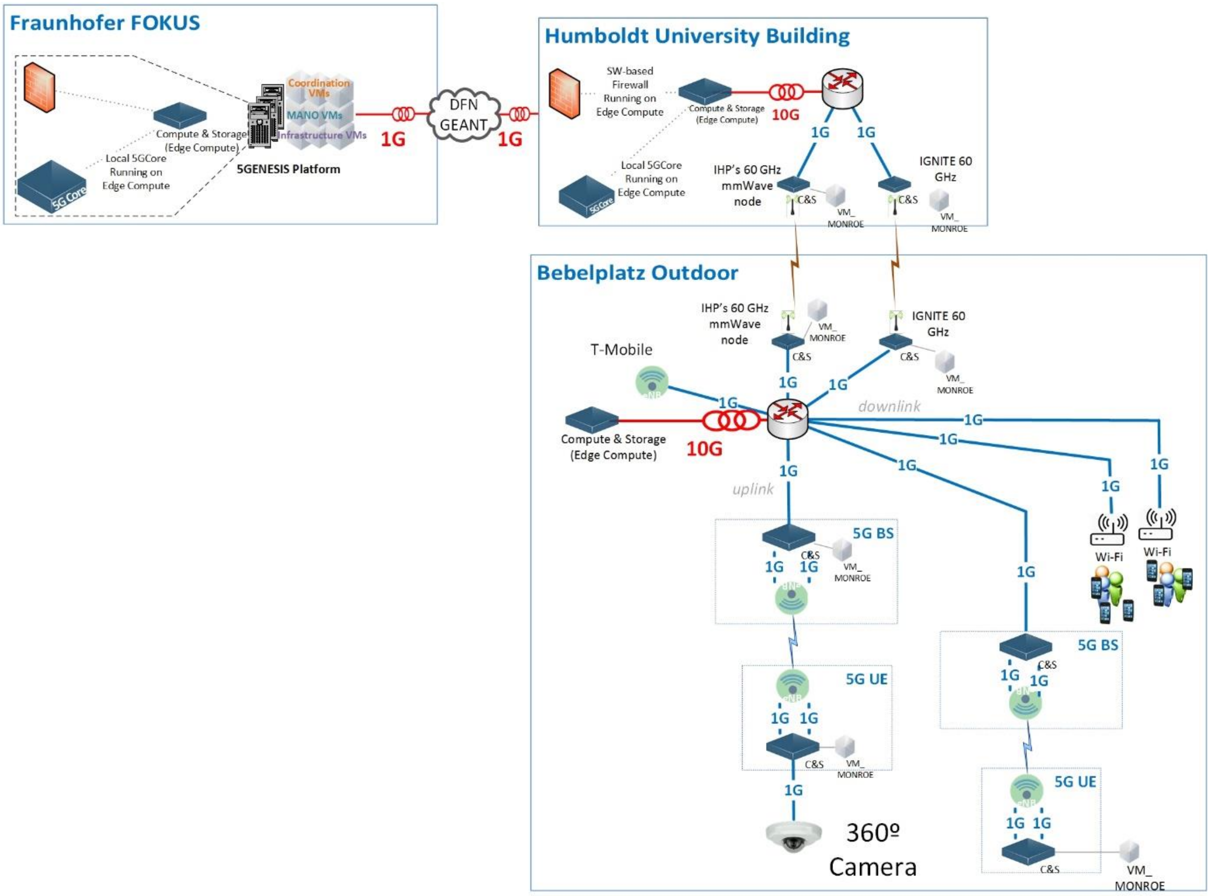

Figure 2-3: The Berlin Platform target physical topology extensions of Phase 2

2.2.1 Infrastructure Layer

2.2.1.1 Overview

This section describes the different components that will be part of the Berlin platform Infrastructure Layer. It covers in detail: the infrastructure components related to the mobile network (Section 2.2.1.2), the transport network infrastructure components (refer Section

2.2.1.3), while the devices and networking elements that encompass the core infrastructure used for experimentation are presented in section 2.2.1.4.

Some of the main components of the Berlin platform are shown in Table 2-1.

Table 2-1: Berlin platform Infrastructure layer summary

Component	Network part	Description	Tools to be used (from Section 2.2.1.4)
Open5GCore	Core	5G Packet core supporting 5G Stand Alone	Open5GCore (Core VNFs), MONROE virtual node and IXIA tools (probes)
IHP's backhaul solution	Transport	Wireless backhaul at 60 GHz used in IHP's premises and at the final deployment in Berlin	Unix-based VMs, MONROE
COTS backhaul		Wireless backhaul at 60 GHz deployed in Berlin	Unix-based VMs, MONROE
Satellite	Transport	Radio backhaul deployed at Fraunhofer FOKUS	-
COTS 5G NR	RAN	5G-Stand Alone NR	Huawei 5G Stand Alone Base Station
UE	RAN	4G/5G phone capable to run web-app	Huawei 5G Stand Alone CPE

2.2.1.2 Mobile Network Technology

(a) Mobile Core Network Products – Open5GCore

Open5GCore represents a 5G core network implementation addressing the needs of 5G testbeds for FOKUS and for partner activities. Open5GCore Rel. 5 [11] includes a large level of newly implemented functions developed on top of an accelerated software platform:

- Integration with 5G NR SA (N1, N2, N3).
- Implementing control-user plane split – PFCP (N4).
- Service-Based Architecture (HTTP/2, OpenAPI, REST).
- Local offloading and backhaul control.
- Highly customizable for vertical use cases and dedicated networks.
- Benchmarking tool for the 5G Core network.
- Basic end-to-end support for non-3GPP access.

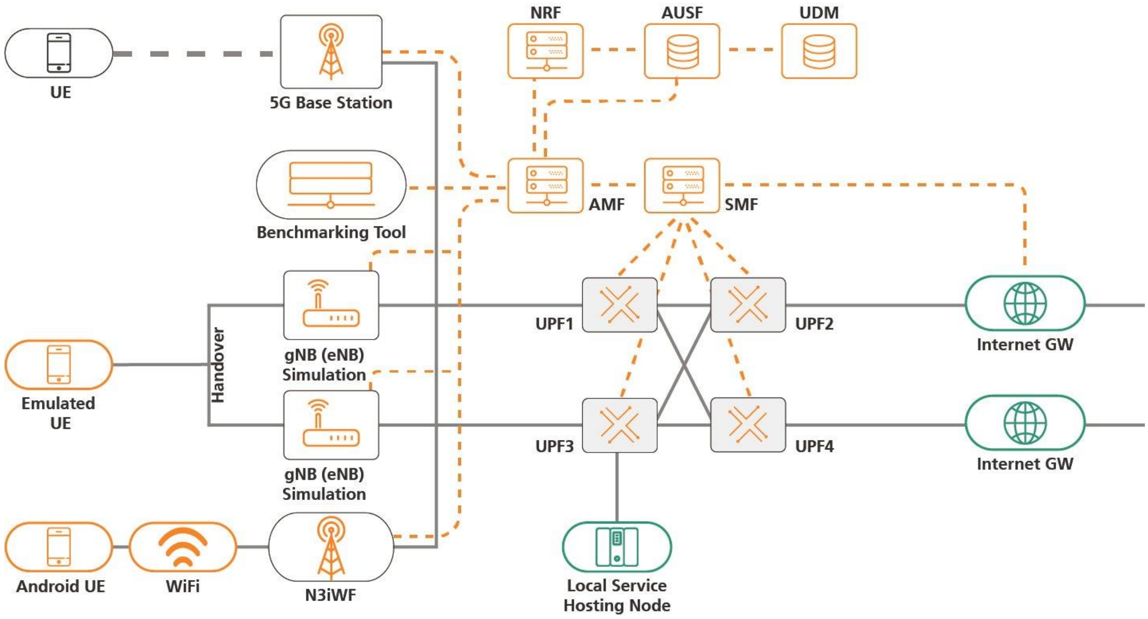

Figure 2-4: Open5GCore Architecture © Fraunhofer FOKUS

Open5GCore Rel. 5 integrates with 5G New Radio Stand-Alone (SA), off-the-shelf LTE and NB-IoT LTE and non-3GPP access networks such as Wi-Fi and 60 GHz Wi-Fi, enabling immediate demonstration of different features and applications and supporting the current need to have a genuine 5G Core Network in addition to the evolved EPC one.

Open5GCore runs on top of common hardware platforms and can be deployed with containers or virtual machines on top of a large number of virtualization environments. The required hardware for a testbed setup, highly depends on the expected capacity. Open5GCore scales from Raspberry PI to a complete rack of servers.

Interoperability tests between the Open5GCore and COTS 5G Stand Alone New Radio have been successfully completed.

(b) Radio Access Network Products

(i) COTS 5G NR

COTS 5G NR is a solution developed for 5G which shall significantly improve the performance, flexibility, scalability, and (energy and spectrum) efficiency of the existing network infrastructure. It shall be a part of larger flexible 5G network infrastructure and shall be able to deliver wide range of use cases based 5G services empowered by network slicing in the scope of 5GENESIS. In the Berlin platform, COTS 5G NR base station and UE solution are provided by Huawei, RunEL and Eurecom. A 5G Stand-Alone NR base station is installed at the FOKUS site. The RunEL and Eurecom equipment will be tested at IHP laboratory upon availability of N1/N2/N3 interfaces and deployed later at HUB premises.

(ii) Huawei 5G Standalone NR

Huawei provided to Fraunhofer FOKUS an initial set of 5G Stand Alone new radio components for integration tests with the Open5GCore. The current deployment includes:

- BaseBand Unit (Figure 2-5).
- Radio Hub (Figure 2-6).
- Remote Radio Head (Figure 2-7).
- CPE (Figure 2-8).

Figure 2-5: Huawei 5G Stand Alone BBU

Figure 2-6: Huawei 5G Stand Alone Radio HUB

Figure 2-7: Huawei 5G Stand Alone Remote Radio Head

Figure 2-8: Huawei 5G Stand Alone CPE

Figure 2-9: Full Lab Set-Up of Huawei 5G Stand Alone NR

The current equipment operates between 3540 and 3610 MHz. The equipment is deployed at the Fraunhofer FOKUS lab and interoperability tests between the 5G Stand Alone equipment and the Open5GCore have been successfully completed. In the Fraunhofer FOKUS lab, the equipment will be replaced by components operating in between 3700 and 3800 MHz. The new components will then be used to achieve a wider deployment at the Fraunhofer FOKUS site covering the parking deck, labs, and an outdoor area in front of Fraunhofer FOKUS. The installation for the latter deployment is scheduled for the end of Q1 2020.

(iii) OpenAirInterface 5G NR UE

OpenAirInterface (OAI) software is currently operated in a non-standalone (NSA) mode that applies EUTRA-NR Dual Connectivity (EN-DC) network architecture. This approach enables introduction of 5G connectivity in an existing LTE network such that all 5G control plane traffic is transported over LTE core network. In other words, the current stage of OAI development combines the NR physical layer with the LTE RAN stack (MAC, RLC, and PDCP). The standalone version, in which the gNB directly connects to the 5G core and also handles all the control plane traffic, is expected to be introduced in the coming months within the scope of 5GENESIS project.

The Berlin platform uses the ETTUS USRP X310 [14] boards for the OAI gNB and 5G NR UE nodes which is one of the recommended boards, powerful enough to accommodate the OAI 5G-NR implementation and performance requirements in the context of 5GENESIS. IHP utilizes its own HW, consisting of high-end PCs, where OAI software will be implemented to realize the communication between an OAI gNB and an OAI 5g NR UE. A summary of HW parameters of OAI 5G NR implementation at IHP is shown in Table 2-2.

Table 2-2 Hardware parameters of 5G NR testbed at IHP

Parameter	Value
Host PC	DELL Precision 5820
CPU	Intel Core i9-7980XE @ 2.60GHz × 18
RAM	32 GB
USRP Platform	ETTUS X310
Daughterboard	UBX-160
Ethernet	10 Gbit SFP+

Two ETTUS X310 will be utilized as transceivers, one of them attached to the gNB host, and the other to the 5G NR UE host via 10 Gbit SFP+ Ethernet connectors. This setup is cabled i.e. RF antennas are replaced by cables and 30 dB attenuators. At this stage of OAI development, the 5G NR UE synchronizes to the gNB and decodes all PHY channels in real-time. Therefore, evaluation tests such as connectivity and throughput using IP downlink traffic can be performed. An external clock reference is required to ensure the synchronization. It is also planned that the OAI software will be supporting internal clock reference in the near future.

Figure 2-10 OAI testbed at IHP (1)

Figure 2-11 OAI testbed at IHP (2)

The OAI testbed shown in Figure 2-10 and Figure 2-11 is evaluated firstly in the IHP laboratory. Later, outdoor tests at IHP premises will be carried out. For the OAI software to efficiently operate in an outdoor environment, antennas will be used to provide enough output power and extended range.

Once OAI software is installed, gNB and 5G NR UE executables can be easily launched and configured through a Command Line Interface (CLI). The IHP internal performance tests have been done locally using tools like ping and iPerf. Further measurements will be carried out remotely by Fraunhofer FOKUS for KPIs evaluation as defined in the 5GENESIS project.

(iv) Non-3GPP access technologies

1. WLAN

The non-3GPP access unlicensed spectrum technology WLAN was integrated with Open5GCore, so to provide an overlapping coverage to 4G, 5G and other non-3GPP access technologies at the trial sites, and to contribute to maintaining connectivity with the end users. Several Access Points (APs) will be installed at the premises to ensure good signal coverage. The 1 Gbps link connectivity provides good quality 360 degrees video streaming as well as high speed internet access to the users. During Phase 1, WLAN has served as a downlink channel for video streaming.

A single WLAN AP has been installed for initial testing purposes (see Figure 2-12). The AP was included in the remote-island set-up temporarily deployed at Humboldt University for Phase 2 experiments. The installation will be extended towards multiple APs, which will then also be manageable via a centralized WLAN controller.

Figure 2-12: Ruckus T710 Outdoor 802.11ac Wave 2 4x4:4 Wi-Fi Access Point

2. LoRaWAN

The LoRa devices integrated over the Open5GCore serve as another non-3GPP access unlicensed spectrum technology oriented towards IoT features which complements dense urban area deployments through LoRaWAN network. The LoRA AP at the Berlin Platform is also made available to the "The Things Network"[1].

2.2.1.3 Transport Network Infrastructure

(a) Inter-platform and inter-site connection via DFN/GÉANT

The DFN/GÉANT backbone network combines a high bandwidth and low latency features providing a wide range of services. One of the envisioned terrestrial transport networks of 1 Gbps throughput to be used between the sites in Berlin platform is the DFN/GÉANT network. Further, the VPN will be established to secure the links between these sites. This already established efficient network infrastructure will provide a reliable backhaul link during the experi-

[1] https://www.thethingsnetwork.org/community/berlin/

mentation trials between Fraunhofer FOKUS (where core components are located) and Humboldt University (where edge components, 60 GHz mmWave and nomadic deployments are located) to validate the KPIs. Additionally, the DFN/GÉANT network shall be utilized for inter-platform connectivity to access some services deployed in partner's platform which is planned for Phase 3.

(b) Spine-Leaf backbone

Please refer to the Sections 5.1 and 5.2 of D4.13 [3] for details.

(c) mmWave backhauling

As initially discussed in Section 2.1.3 of this document, several mmWave nodes are being tested and characterized in a laboratory environment prior to their outdoor installation in two of the wings of the IHP building.

In deliverable D6.1 [33] we conducted several measurements using the first generation of IHP's 60 GHz nodes (see Figure 2-13). These nodes consist of an IHP developed radio-frequency (RF) chipset with non-steerable, wide beam antennas and an own baseband platform with a proprietary C-OFDM baseband processor [34]. The baseband platform features the Zynq-7045 FPGA chip [35]. Due to limited logic resources, the current solution supports only QPSK modulation with the data rates up to 1 Gbps. The analog front-end consists of separate transmitting (Tx) and receiving (Rx) antennas and is connected to the baseband board via cables. It is a laboratory prototype that is not so simple to integrate in housing for outdoor deployment. In addition, antennas are wide beam, a low gain which makes this solution more suitable for short-to-medium range, indoor, point-to-point (P2P) wireless communication.

For the reasons mentioned above, IHP is working on the second generation of IHP's 60 GHz node, which is in the final phase of development. It is a more compact solution that is suitable for both indoor and outdoor point-to-multipoint wireless communication. This solution is based on the same baseband board but with a bigger FPGA (i.e. Zynq-7100), hence more programmable logic. This allows us to implement higher modulation schemes (16QAM or higher) and add additional logic, thus supporting up to 4 Gbps data rates. The analog front-end is based on a commercial 60 GHz beamforming chipset from SiversIMA [36]. This is an RF-beamforming transceiver operating in the 57-71 GHz frequency band. The transceiver comprises 16 Tx and 16 Rx channels with separate Tx and Rx antennas. The chip is mounted on a small board with two antenna arrays of 16 dual circular patch elements, as shown in Figure 2-14. The chip has been designed for a high transmit power and low phase noise in order to support 40 dBm EIRP and up to 64 QAM with a 45 MHz reference signal [37].

Figure 2-13: Wireless link lab setup with the first generation of IHP's 60 GHz nodes.

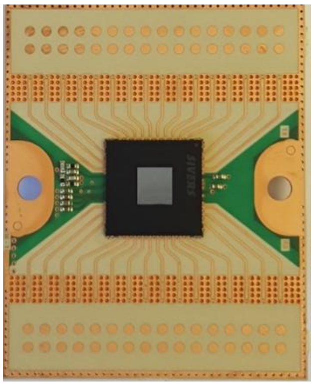

Figure 2-14: Top view of the RF beamforming module from SiversIMA.

To accommodate the beamforming module with the baseband platform, an adapter-board has been designed which interconnects the baseband board and the beamforming module. On the adapter board's bottom side are the connectors to take the baseband (BB) reference and control signals and route them to a connector on the top side to which the beamforming module is to be attached. Furthermore, there are additional GPIO pins for debugging purposes and an SFP+ cage for 10 Gbps Ethernet connection. Due to high power requirements of the baseband board components (ADCs, FPGA, LDOs, etc. consume around 30 W) and the 60 GHz beamforming chipset (10-12 W), the integrated solution is mounted on an active cooling device (Peltier) with a specially designed alumina heat sink for the 60 GHz beamforming chip. The integrated solution is depicted in Figure 2-15.

For the outdoor deployment at the IHP rooftop, we have designed a special housing, shown in Figure 2-16.

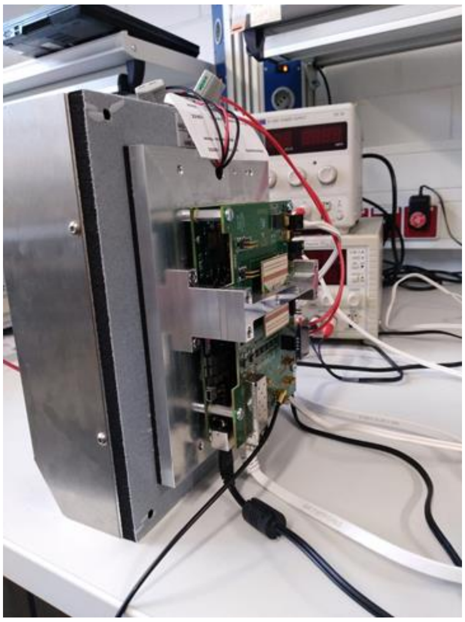

Figure 2-15: The second generation of IHP’s 60GHz node for P2MP wireless communication

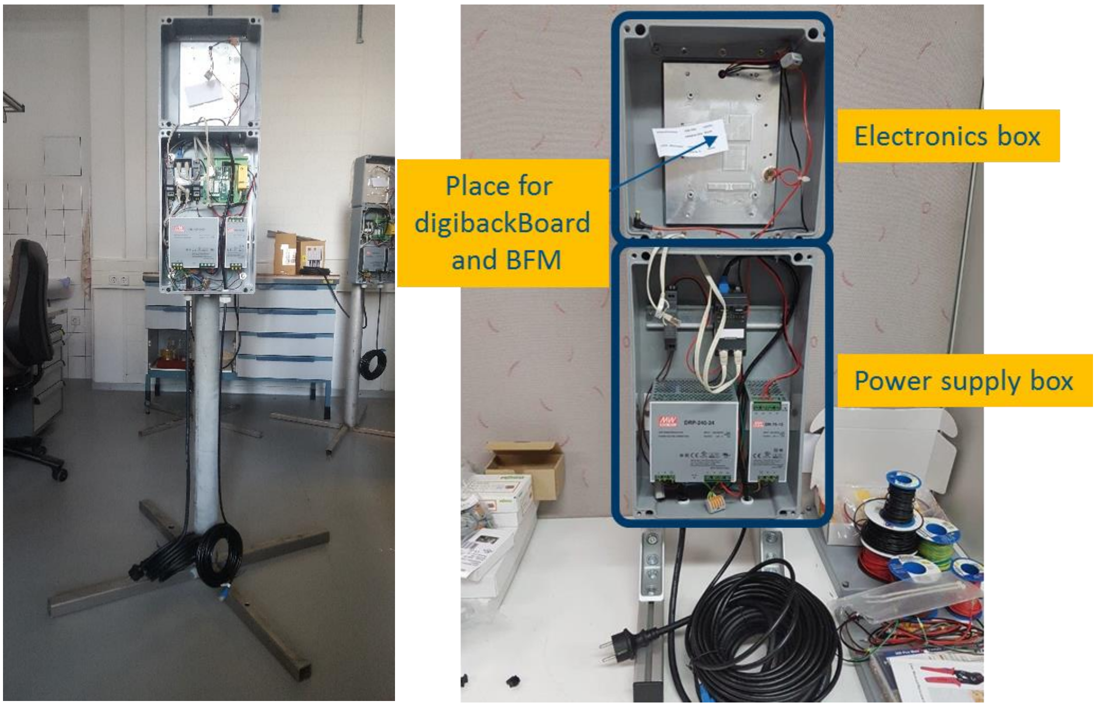

Figure 2-16: The housing for outdoor deployment

The housing consists of two boxes that are made from PVC and mounted on a metallic rod. The top box is referred to as an electronics box as it will host the integrated solution from Figure 2-16 (i.e. the baseband and RF boards). The Peltier cooling is at the backside. Power supplies (converters), Ethernet switches and Wi-Fi dongle are placed in the bottom box, denoted as a power supply box. The overall size of the two boxes is 65cm x 25 cm x 12 cm.

Before outdoor deployment, as mentioned above, the new 60 GHz nodes will be tested in an indoor setup (similar to the one shown in Figure 2-13).

(d) DWDM access to nation-wide fiber network

The components for realizing the DWDM connection of FOKUS to the nation-wide experimental fiber network have been shipped to FOKUS; the installation is scheduled by the manufacturer for the third week of February 2020. As a result of a European-wide bidding process, NOKIA has been selected as a solution provider.

The system architecture realized with the components is described in D4.13 [3] in Section 5.2.4 and remains unchanged. The components currently under installation at FOKUS include a PSS-16 Chassis System, which holds two long-range amplifiers for the line-side (send- and receive-path) as well as two client cards, each realizing either one 100 Gbps or 10x10 Gbps transparent point-to-point links to connected R&D institutions. Additional components, such as filters, power-supply and controller are also depicted in Figure 2-17 of the deployed configuration.

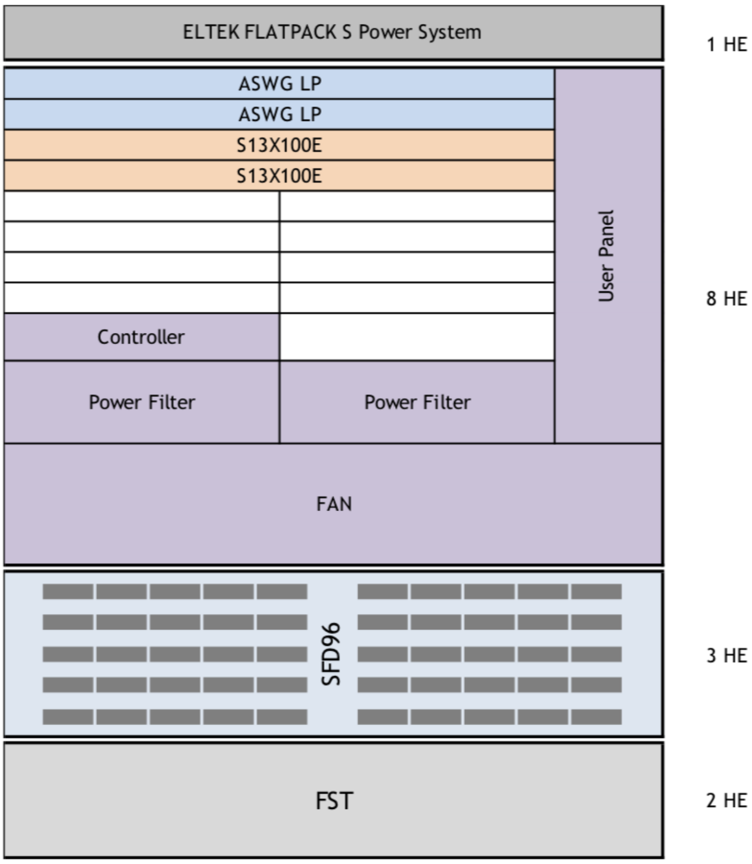

Figure 2-17: Rack Configuration of the DWDM System

The chosen configuration copes for 8 half-slots as spares for future extensions of the system. The PSS-16 shelf and required air-flow for rack-installation as well as the transponder cards are depicted in Figure 2-18 and Figure 2-19.

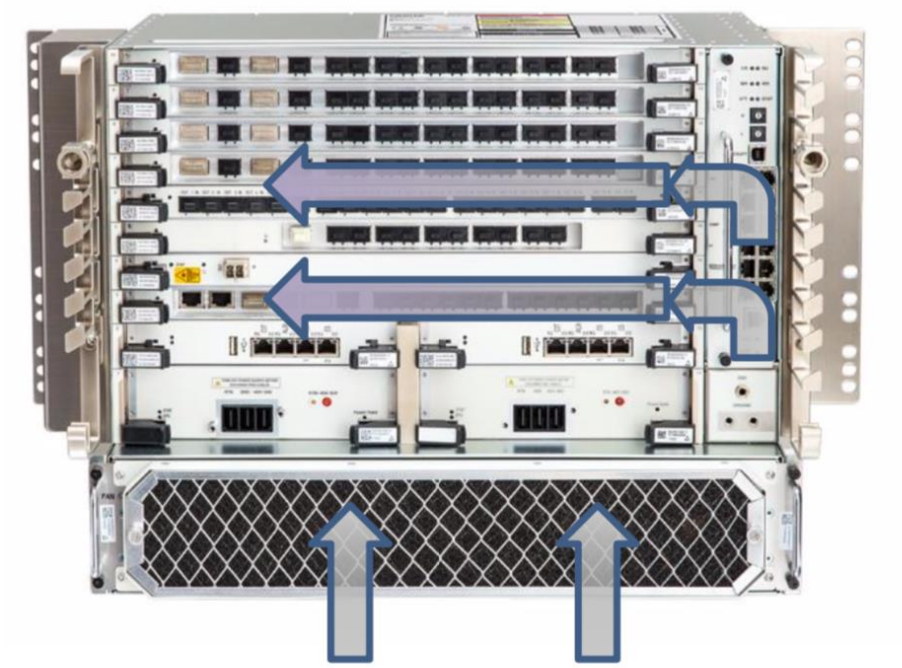

Figure 2-18: PSS-16 Self and air-flow for rack-deployment

Figure 2-19: S13X100E Transponder Card

(e) Satellite-based backhaul

To allow for experiments for long-distance use cases, the Berlin site has been upgraded with satellite connectivity across a GEO satellite. The satellite-based backhaul provides an alternative link to connect the core infrastructure with any edge deployment, and to conduct the experiments and validate the corresponding KPIs.

The central node of the satellite-based connectivity is located at Fraunhofer. For being able to use the satellite network, the central node is connected to the Betzdorf teleport of SES, where an additional edge node was installed for local offloading. The satellite connectivity used is SES "occasional usage", which could be reserved on demand at specific dates for usage in E2E tests.

A Very Small Aperture Terminal was installed in FOKUS including a 1.2m diameter wide antenna and an iQ satellite modem provided by ST Engineering iDirect. With this, a connectivity could be established between the edge node in FOKUS with the central node in FOKUS. With this setup a basic IP connectivity level can be established for testing the edge-central network split models within the Fraunhofer FOKUS Open5GCore for the eMBB, multimedia and IoT use cases. Figure 2-20 illustrates the current set-up.

Figure 2-20: Satellite Connectivity of the 5G Playground facility in Berlin

2.2.1.4 Core and Edge NFVIs and MEC

(a) Berlin platform support for edge deployments

The Berlin Platform supports the deployment of applications as well as the deployment of components of the Open5GCore at various compute and storage nodes in the Berlin Platform: either at the central compute and storage units at Fraunhofer FOKUS or in the edge. Figure 2-21 illustrates possible deployment options of the Open5GCore including:

- "Direct connectivity" of UEs to a full 5G Core deployed at the central side
- "Local Offloading" in which a UPF is placed at the edge
- "Proxy deployment" at which a backhaul is realized over another, transparent 5G link between edge and central side
- "Autonomous Edge Node" allowing a fully independent operation of the edge with temporary / optional connectivity to the central side.

The latter, i.e. a fully autonomous edge deployment, is used to instantiate the nomadic remote site deployment at Humboldt University for Phase 2 experiments.

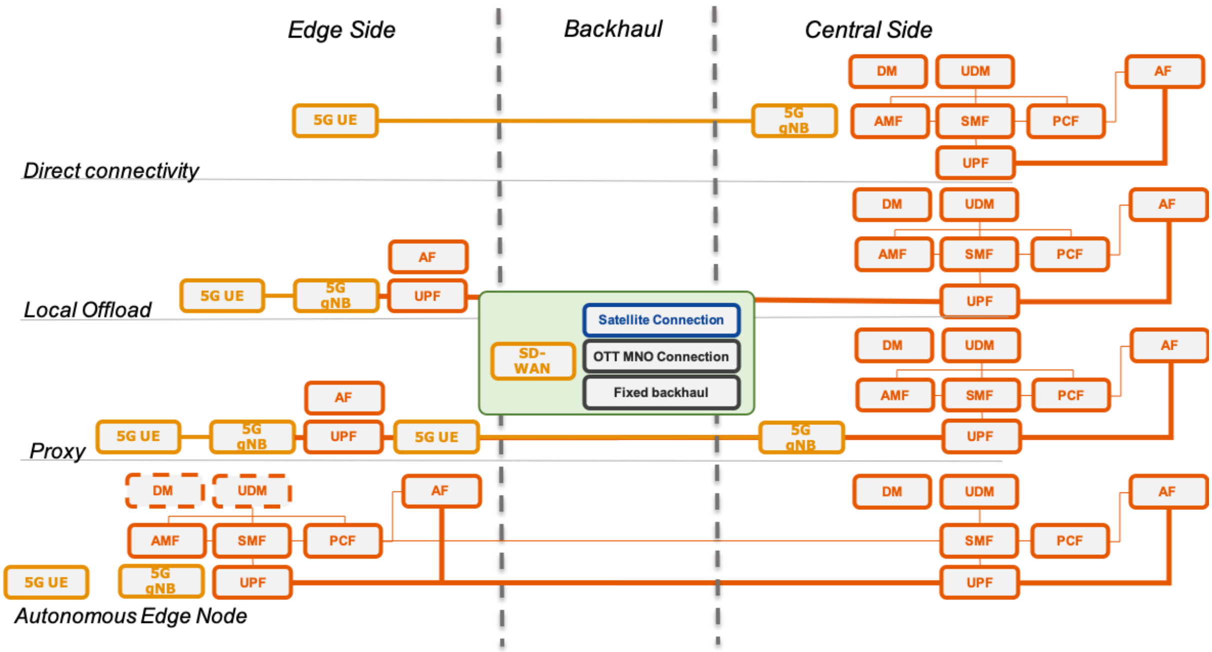

Figure 2-21: Deployment Options of the Open5GCore

(b) ZONE concept in SDN

A single OpenStack instance has been deployed across all sites of the Berlin Platform. Various compute nodes at each site have been configured to be part of individual "availability zones". An availability zone can be selected as a destination to deploy a service / VM at, thus allowing deterministic placement of services at a given geographical region.

As such, the Berlin Platform provides a fully orchestrated testbed spanning across three geographical distinct sites – namely Fraunhofer FOKUS, IHP, and Humboldt Berlin – and allowing for deterministic, dynamic placement of VNFs in each of the availability zones. This enables the deterministic placement of measurement end-points assuring repeatable experiments involving various combinations of networks elements in the transport network. A detailed explanation of the concept on how these availability zones are used for experiments is given in D6.1 [33], Section 9.

(c) Migration from Zabbix to Prometheus

Zabbix [16] was presented in deliverable D4.13 as the tool for monitoring the 4G core component. It follows the push mechanism, where all metrics from the 4G core component were pushed to Zabbix. Since, each component has their own type of metrics, the complexity increased in terms of operation and schema handling. Additionally, in push-based monitoring, the metrics are defined centrally and pushed out to assigned sub components or agents [41]. That resulted in the need for a flexible solution. The solution that provide handling of or collecting adhoc and unplanned metrics any time. Additionally, not all core components needed push-based metrics. Hence, in 5GCore, to monitor, Prometheus [31] was selected because of its simpler operation and flexible schema handling. Prometheus also provide easier support to retrieve data on demand. This is achieved by polling every 5 sec through HTTP from the exporters equipped in the 5G Core components. This provide metrics that is human-readable and easily understandable format that can be used to distinguish the errors between client and the server. Prometheus pulls Node, process type of metrics related to VMs as well as specific metrics related to the components of 5G core. Some 5G Core component such as Benchmarking Tool (BT) (see sub-section (f) below) provides metrics describing the connectivity of UEs to 5GC. The metrics retrieved by the Prometheus agents, does not the simple way to incorporate the relation between UE connectivity per timestamp; i.e. event driven time series metrics. In order to have a simpler approach, push based mechanism can be adopted for this specific metric storage, where the BT push the metrics to the InfluxDB [32]. In this way, we can have best of both the world feature. In addition to that, InfluxDB is also used to store the experiment results from the ELCM an OpenTAP [10]. These results are queried by Grafana to visualize the metrics results.

(d) NFVIs of the 5GC

The Berlin Platform leverages the Fraunhofer FOKUS Open5GCore, which is a fully virtualized 5G Core (c.f. Section 2.2.1.2). As such, each virtualized component may be instantiated as a CORE NFVI or as an EDGE NFVI.

(e) Monitoring & Measurements (Containerized Probes)

An initial version of the MONROE virtual node (VN) was developed and integrated within the Berlin platform as part of the Phase 1 Berlin Platform activities (see Deliverable D4.13 [3]), and successively used for the phase 1 Berlin platform experiments. The implementation of the MONROE VN was later generalized and the MONROE VN is integrated as one of the performance monitoring probes within Release A of the 5GENESIS Monitoring and Analytics Framework (see [28] and Section 2.2.3.3).

In line with the original MONROE software [29], the Release A version of the MONROE VN is based on the Debian 9 Linux distribution. To align and ease integration with the majority of other components in the Berlin platform, including the Open5GCore Benchmarking Tool, we have now also ported the Monroe VN to Ubuntu 18.04. While Debian is tightly integrated with dhclient and ifupdown for network configuration, Ubuntu uses the systemd-network subsystem. Since the main functionality of Monroe is centred around networking, the switch of underlying network configuration tool required modifications of how Monroe is configured and setup in the host. Use of the Ubuntu 18.04 VN thus requires new packages to be installed, but does not change the user interface or the installation procedure.

To integrate with the 5GENESIS ELCM and support controlling the MONROE VN through TAP, an agent is implemented in the VN. The agent provides a REST API that TAP can use to deploy, start and post process MONROE experiments. During phase 1, TAP together with Open Baton was used to manage MONROE experiments, where deployment of the MONROE VN within the Berlin OpenStack platform was managed using Open Baton. During Phase 2 the Berlin platform has moved to using OSM as NFV MANO. The development of the control interfaces to deploy the MONROE VN via OSM has started and is scheduled to be completed in Phase 3.

The MONROE VN allows using MONROE measurement probes in the form of Docker containers for KPI evaluation in a flexible manner. Two probes, the ping container for latency tests and the iPerf container for throughput tests [28], were integrated and used for measurements during Phase 1. These probes will be used also during Phase 2. To support the Berlin 360° video at the Festival of Lights use case, a container for application layer video QoE monitoring is being developed.

(f) Open5GCore Benchmarking Tool

The Benchmarking Tool (BT) was designed to assess the performance of core networks for different number of subscribers, different number of eNBs and with different configurations, enabling the quantitative evaluation of the different core network solutions, fitting perfectly the goal of the current project. It is a functional entity that emulates UE together with eNB 3GPP standard (Rel. 15) specific operations for both c-plane and u-plane

The BT passed through two development releases. The architecture from the first release is illustrated in Figure 2-22, where a hierarchical model was considered, later dropped due to the capacity of a single VM to perform stress/load tests against a core network. The BT:

- Includes the Northbound API – A functional component that is able to receive the benchmarking configuration from the test administrator.
- Includes the BT Module, which performs the testing process: Based on the test configuration, it registers the emulated UEs to the network and requests the specified test operations.
- Handles the EPS related functionalities like UE creation, registration, operations and acts as a singular or a group of eNBs that interact with the network.
- Includes the UE Pool which represents a runtime subscriber database in which the state information is maintained for each subscriber. As the expected number of subscribers is in the order of 10.000, the state per subscriber should be limited to a maximum of 1 KB.

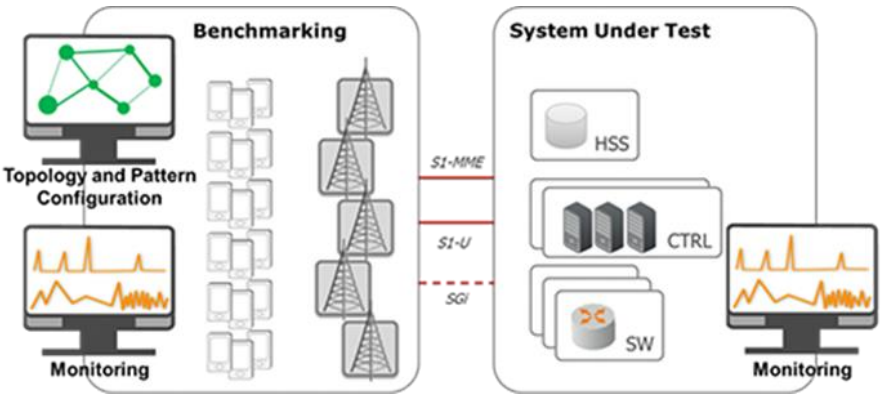

Figure 2-22 Benchmarking tool architecture.

The BT supported functionalities are:

- Network attachment (E-UTRAN) – User registration is a mandatory process so that the subscriber can receive service from the network.
- Network detachment (explicit/implicit) – User de-registration is the counterpart of registration. Once it is performed, the terminal has no more access to the network.
- Idle mode – User can be deactivated and go into idle mode.
- Network triggered service request (paging) – The inactive user in idle state is activated when there is new downlink traffic.
- UE triggered service request – The inactive user in idle state wishes to get activated when there is new uplink traffic.
- S1-based intra-E-UTRAN handover – When there is no direct communication (X2 interface) between source and target eNodeBs, the MME is no longer transparent to the handover process and acts as a signaling relay between the two eNodeBs.
- S1 Setup – The connection between MME and eNB is established.
- Non-IP Data Delivery - Support for NB-IoT.

(g) IXIA Toolchain

The Keysight IXIA [18] toolchains provide a Testing as a Service (TaaS) framework for complex performance testing of core network by emulating different types of traffics to generate realistic scenarios for the validation of KPIs and infrastructure components. Real world applications are simulated to predict E2E system and network performance by tapping every network link under different load conditions. The E2E network infrastructure consisting of physical and virtualized components needs to go through stress testing to ensure it can support huge traffic volume flows while maintaining the desired quality of service to the end users. In order to validate these minimum requirements, toolchains such as IxLoad [19] and IxLoad VE [20] are proven to be efficient to quickly identify the network degradations and isolate breaking points during stress tests. The Berlin Platform will deploy these toolchains in the infrastructure to ensure the functioning of packet core and to validate the KPIs as described in 5GENESIS deliverable D2.1 [1].

2.2.1.5 Upgrade of Platform with video service

With multiple points of potential failure/bottleneck in the delivery chain, the E2E distribution of real-time 360° video needs to be evaluated in a wholesome manner, considering all aspects from video capture to encoding, delivery, and playback, as well as timely and appropriate analytics, with a focus on end-user Quality of Experience (QoE). This requires a measurement and experimentation framework which allows for the collection of metrics from multiple dimensions (such as encoding parameters, delivery network information, player configuration and adaptation logic, end-user hardware/software, and objective/subjective QoE metrics for the video session) at the same time, as well as the benchmarking of selected parameters (such as different video tiling strategies, network technologies, video players, and bitrate adaptation algorithms). Within 5GENESIS, we develop such a framework for evaluating real-time adaptive

360°video streaming in the Berlin Platform, which allows for investigating different aspects of the E2E video delivery chain over a 5G network. The framework of the video processing that will be used for the Berlin use case is presented in Section 4.2.1.2

External Application Servers

The infrastructure of the Berlin Platform allows to connect any application server, which is external to the Berlin platform, via a regular Internet connection using the DFN/GÉANT network. This allows experimenters to connect to any external application services without worrying to onboard them on the Berlin platform infrastructure.

Connecting an external application server might involve establishing a VPN between the server and the Berlin platform, depending on the kind of application to connect and depending on the kind of services that are internal to the Berlin platform, the application server needs access to.

In addition, a dedicated compute and storage system is deployed at the Fraunhofer FOKUS testbed to allow to onboard any services in a secured, multitenancy environment onto the Berlin Platform.

2.2.2 Management and Orchestration Layer

2.2.2.1 Overview

The Management and Orchestration Layer of the 5GENESIS architecture comprises three main components, namely:

- NFV MANO,
- Network Management System (NMS),
- Slice Manager.

Previously, the Berlin Platform used Open Baton to realize the NFV MANO functionality. However, to align with other platforms as well as with current industry standards, Open Baton has been replaced by OSM (refer Section 2.2.2.2). The OSM orchestrates the creation, configuration of VNFs, NSs and network Slices. OSM also provides support to integrate cloud native approach by enabling CI/CD frameworks into orchestration layers [26]. The Virtualization Infrastructure Manager (VIM) is provided by OpenStack, the standard de-facto VIM in the one conformant to ETSI NFV specification. OpenStack simplifies the management of virtualized and containerized infrastructure by providing lean and simple process to manage and orchestrate [26].

The NMS is a platform-specific network management system with direct access to physical resources as well as configuration interfaces. In the Berlin platform, the NMS will provide the overview of the physical resources and an interface to manage them.

The Slice Manager is common to all 5GENESIS platforms and is developed in WP3, specifically within Task 3.2 as described in D3.3 [42]. It provides management service for network slicing for different domains by communicating with South Bound components. This provides the much-needed link between the orchestration and the coordination layer. Due to the modular architecture of Slice Manager, It provides flexibility and scalability in building and maintaining the applications. It exposes APIs that would be used by ELCM to perform CRUD operations on NSIs, NFVOs.

2.2.2.2 Open Source MANO (OSM)

Open Source MANO, commonly referred as OSM in the community, is an open-source, production-grade Management and Network Orchestration (MANO) framework for Network Function Virtualization (NFV) developed by the NFV MANO working group at the European Telecommunications Standards Institute (ETSI) Industry Specification Group for NFV (ETSI ISG NFV) [25][26]. The stated goals of the NFV MANO framework is to provide for the management and orchestration of all resources in *a virtualized data center including compute, networking, storage, and virtual machine (VM) resources* [26].

Thus, as described in [26], [27] and illustrated in Figure 2-23, NFV MANO can be broken up into three fundamental parts:

- **The NFVI and VIMs/WIMs:** The first part is the NFV infrastructure (NFVI) which hosts VMs and/or containers and connects them together with virtual links (VLs). For the purposes on this white paper, the infrastructure management systems (VIMs and WIMs) which control the creation of VMs, containers and virtual links are also include with the infrastructure [27].
- **VNFs, NSs, and Network Slices:** The second part is the collection of VNFs themselves including the interconnected composition of VNFs into network services (NSs) and the composition and sharing of NSs to form network slices. The VNFs are interconnected compositions of specific VMs and/or containers which are hosted on the NFVI [27].
- **Management and Orchestration (MANO):** The third part is the management and orchestration system which controls the life cycle of the VNFs, NSs, and network slices, controls and maintains their configuration, and monitors their in-life health and performance [27].

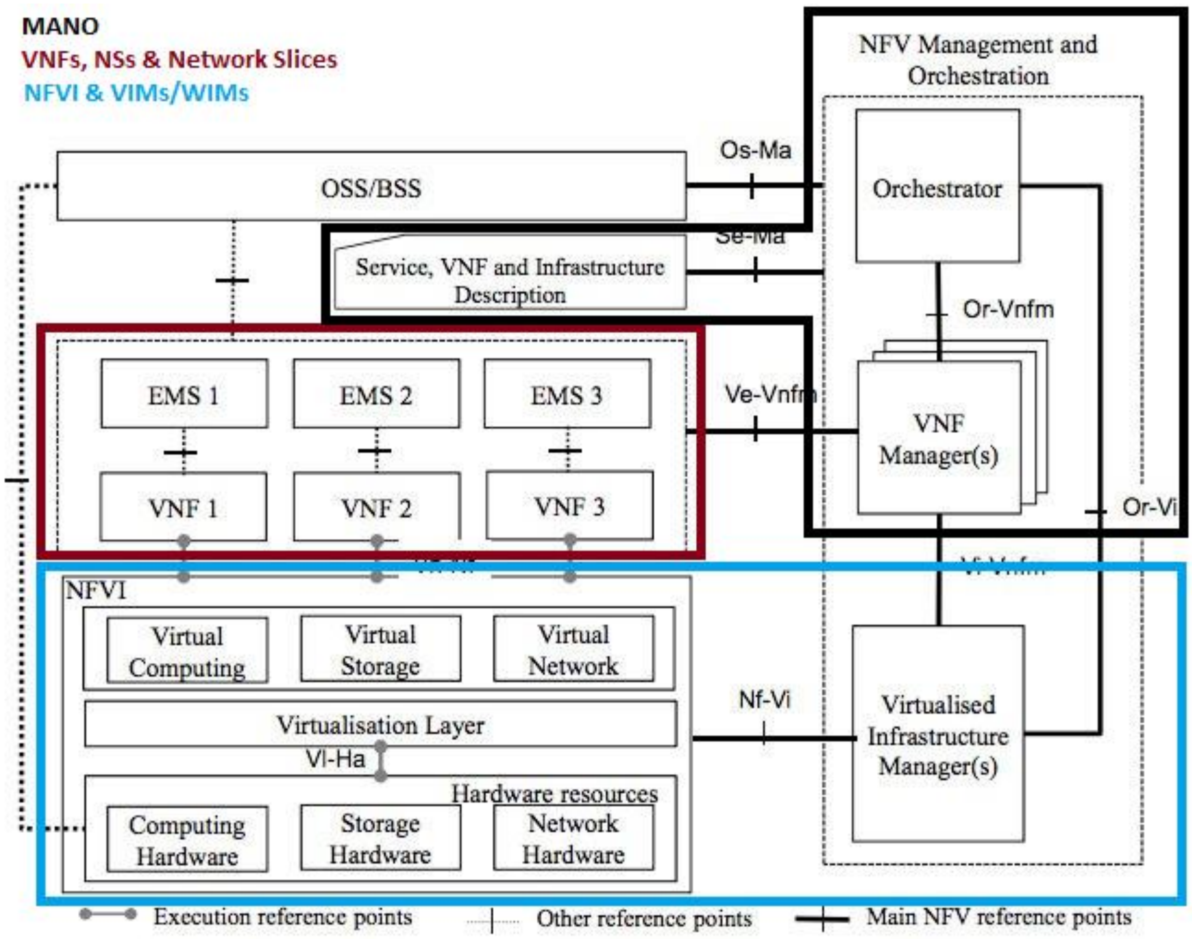

Figure 2-23: NFV MANO Framework Architecture broken down into fundamental blocks [27]

OSM is the open-source solution to the third component, i.e., the MANO block of the NFV MANO framework. From a solution point of view, OSM plans to support a wide variety of NFs, VIMs, WIMs, network-slicing solutions, and so forth, and aims to become the de-facto industrial E2E network management and service orchestration component. This overview of the OSM from service platform view is illustrated in Figure 2-24.

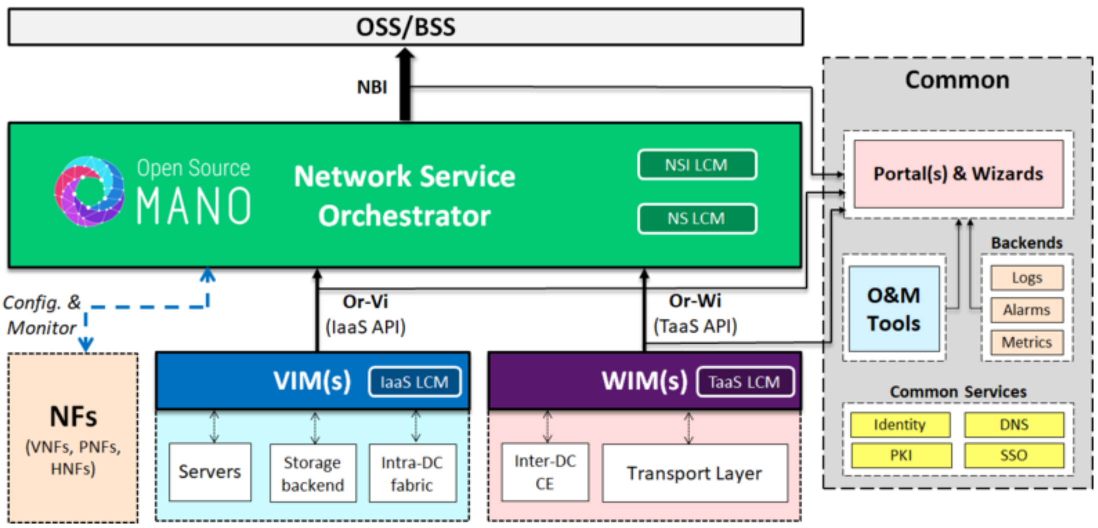

Figure 2-24: OSM Reference Architecture of Service Platforms and Common Management

Thus, as part of this release cycle in the 5GENESIS project, we have migrated from Open Baton to ETSI OSM, in line with current industry standards and best practices.

2.2.3 Coordination Layer

2.2.3.1 Overview

The Coordination Layer is common to all 5GENESIS platforms. The corresponding software components are solely instantiated at each platform, i.e. they run independently, but functionality-wise they are exactly the same.

The Experiment Lifecycle Manager (ELCM) provides the common agreed layer in each platform interfacing project-wide, common 5GENESIS coordination layer components and site-specific realizations of the lower layers of the 5GENESIS architecture. The project agreed to use Keysight Test Automation Platform (TAP) as the tool to implement the ELCM [4].

The common components of the Coordination Layer and their implementation are described in detail for all platforms in WP3 deliverables and, hence, they are not included in this document. Most of them are planned to be available at Month 15 (September 2019) of the project. As an example, a short description on how TAP interacts in a platform-specific way with the lower layers in the Berlin platform is provided in Section 2.2.1.4.

2.2.3.2 Instantiation status of Coordination Layer

The components instantiated for Berlin platform are as follows:

- Portal – a web portal for creating definition of experiments that can be executed in the platform and for displaying the experiment results of execution.
- ELCM – A Manager for supervising the execution of experiments throughout their lifecycle.
- OpenTap – A KeySight Test Automation tool for providing test automation plan.
- Slice Manager – Slice Manager provides management service for network slicing for different domains by communicating with South Bound components.

The components of the coordination and orchestration layer is deployed in OpenStack cloud. The OpenStack version that is used for instantiating the component is “Stein”. The installation procedure is followed by the instruction provided by corresponding WP3 components. Portal, ELCM and OpenTap is deployed on Windows Instance in OpenStack. In order to create the Windows image for OpenStack, first a Windows VM is created inside virtual box. Windows Server 2019 is installed in the VM and configured it to be used as bootable image. This image is then uploaded to the OpenStack for Windows instance creation. Slice Manager is deployed on Linux instance. The details of the installation are represented in Table 2-3.

InfluxDB is installed in an ELCM instance to save the results of the executed experiments. Grafana is installed to visualize the results in a dashboard. To validate the experiments, a test was executed through Portal with IperfAgent to show Throughput, Packet loss and Jitter, as illustrated in Figure 2-25.

Table 2-3. Installation Details of Coordination and Orchestration Layer Component

Component	Host	IP Address	Environment	Installed Requirements
ELCM	OpenStack (Stein)	192.168.243.225	Windows	Python 3.7.5 Grafana 6.5.2 Influx DB 1.7.9
Portal	OpenStack (Stein)	192.168.243.225	Windows	-
OpenTAP	OpenStack (Stein)	192.168.243.225	Windows	-
IperfAgent	OpenStack (Stein)	192.168.243.238	Linux	Iperf-2.0.9
Katana Slice Manager	OpenStack (Stein)	192.168.243.226	Linux	Docker 19.03.5
OSM R6	OpenStack (Stein)	192.168.243.230	Linux	-

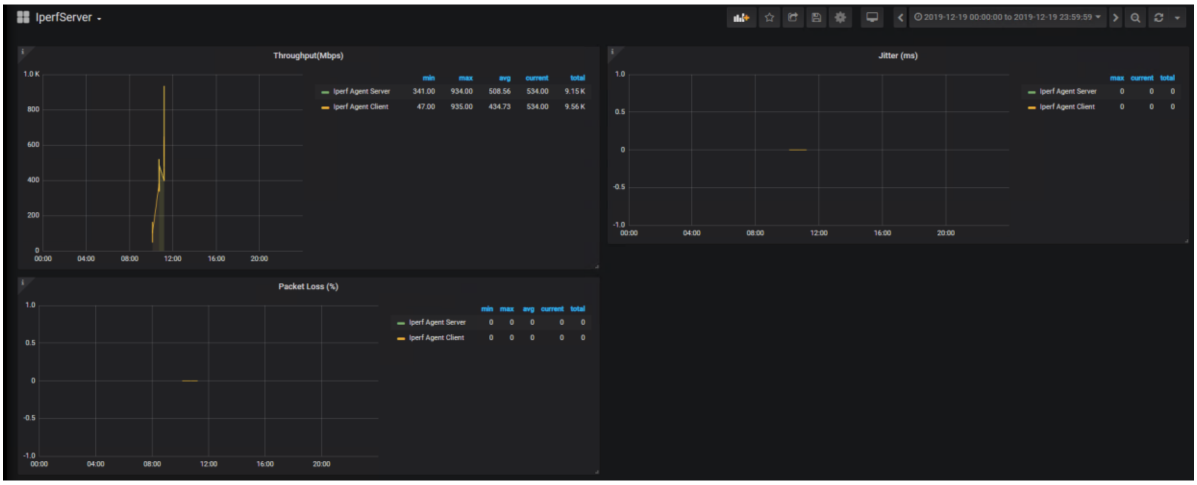

Figure 2-25 Iperf Test Results

To validate the installation, the test cases are defined in the D5.1 [40] Section 5. The executed test results from the Berlin Platform are provided in deliverable D5.1, Section ANNEX 1.

2.2.3.3 Monitoring and Analytics

Following the 5GENESIS goal of validating and showcasing 5G KPIs, the project is designing and developing a full-chain Monitoring and Analytics (M&A) framework. This latter is devoted to the collection and analysis of the heterogeneous data produced during the usage of the 5GENESIS Facility, aiming to ensure all the components of the infrastructure are working as expected during the experiments, and in turn 5G KPIs can be reliably assessed.

As documented in detail in Deliverable D3.5 [28], the "Release A" of the 5GENESIS M&A framework has been thus designed and developed during Phase 1, and it is being currently integrated in the 5GENESIS platforms. It includes advanced Monitoring tools and both statistical and Machine Learning (ML)-oriented Analytics, comprising overall of three functional blocks:

- *Infrastructure Monitoring (IM)*, which focuses on the collection of data that synthesize the status of architectural components, e.g., UE, radio access and networking systems, computing and storage distributed units;
- *Performance Monitoring (PM)*, which is devoted to the active measure of QoS/QoE indicators;

- *Storage and Analytics*, which enables efficient management of large data amounts, and drives the discovery of hidden values, correlation, and causalities among them.

Such blocks span across all layers of the 5GENESIS reference architecture, from Infrastructure to Coordination, via MANO. Moreover, they interconnect with the architecture through the ELCM, which is based on the Keysight TAP software [30].

In the Berlin platform, several activities have been done towards both development and integration of the M&A framework. As regards IM, the platform has used the Zabbix software [16] during the first experimental phase, due to its lightweight integration with Open Baton. However, due to the ongoing transition to OSM as NFV MANO, the platform is planning to replace Zabbix with the Prometheus system [31], resulting in full alignment with the other 5GENESIS platforms. More details on this aspect are given in Section 2.2.1.4.

With respect to PM, the Berlin platform partners have actively participated to the design, development, testing, and use of the MONROE Virtual Node (VN), which currently allows hardware-transparent and on-demand monitoring of throughput and latency KPIs. The platform has also initiated the activities resulting in the implementation of both TAP Plugin and Agent for MONROE VN, which jointly enable automatic activation and usage of this probe under the TAP-based ELCM. More details on MONROE VN usage and planned extensions are given in Section 2.2.1.4. Furthermore, within the scopes of the M&A framework, the Open 5GCore Benchmarking Tool is used to evaluate non-functional aspects of the Fraunhofer FOKUS Open5GCore, such as the emulation of users and traffic realistic behaviors. Detailed description of the Benchmarking Tool is given in Section 2.2.1.4.

As regards the Storage, the Berlin platform is fully aligned with the other platforms in using InfluxDB [32] as common tool for the creation of a platform-specific instance for long- term storage. The activities for the InfluxDB instantiation and usage under the ELCM, and particularly via the TAP InfluxDB Result Listener, are completed.

Finally, considering Analytics functionalities, the Berlin platform partners have significantly contributed to the definition of a proper methodology for the statistical analysis of the KPIs measured during the experiments executed in the 5GENESIS Facility. The methodology is described in detail in deliverable D6.1 [33], and Python-based scripts for executing such analysis and obtaining statistical indicators have been produced and make available to the Consortium. Next steps target the use of ML Analytics scripts on the data collected in the platform, in order to study further aspects related to data correlation and causality, as well as KPI prediction, forecasting, and anomaly detection. Finally, a specific target for the M&A framework in the Berlin platform is its usage for experiments involving real users, such as the Dense Urban Video Streaming use case, to be performed during the 2020 Festival of Lights event. To this scope, the MONROE VN is being upgraded to perform application-level, video-specific performance monitoring, while the Analytics component is being extended for the study of the correlation between network QoS and user-centric QoE. This activity also includes the use of proper data anonymization tools, in order to deal with privacy regulations [28].

3. Evolution of the Berlin platform

3.1 Phase 2 Instantiation of the 5GENESIS architecture

The Berlin platform follows the 5GENESIS system architecture, which was defined in deliverable D2.2 [2].

The per-phase instantiation of the 5GENESIS architectural blueprint in the Berlin platform is shown inFigure 3-1. It shows the functional blocks implemented and integrated in Phases 1 & 2, as well as the functionalities planned for integration in Phase 3.

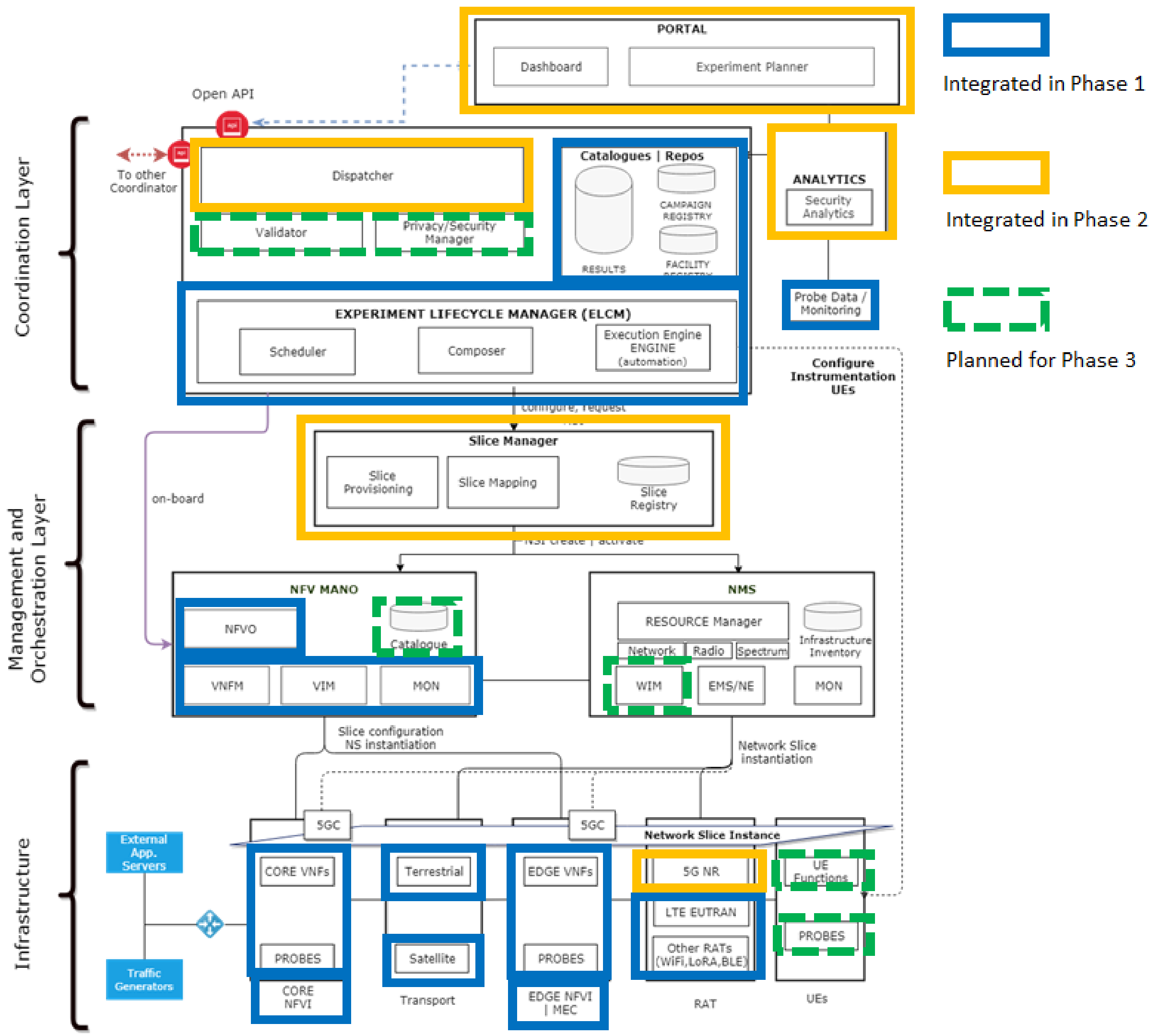

Figure 3-1 Instantiation of the 5GENESIS Architecture for the Berlin Platform.

For Phase 1 (end of March 2019), the objective of the Berlin platform was to feature only a small flavour of the infrastructure layer. Having reached Phase 2, most parts of the infrastructure layer are already completed, and most of the Coordination layer components have been integrated. This will allow running automated experiments in the Platform whose results will be captured in deliverable D6.2.

By Phase 2 (end of December 2019), an experimentation site preparation for the Festival of Lights [5] at HUB premises was carried out, where the first version of use case was showcased in October 2019. For that, the IGNITE 60 GHz mmWave backhaul was installed at designated locations at HUB premises. For the nomadic deployment at *Bebelplatz*, a 180/360 degree camera, local compute and storage unit, 60 GHz mmWave backhaul and RAT for consumer devices were installed. See section 4 for more details.

The Phase 3 (end of 21 March, 2021) will exhibit the complete flavour of E2E 5G deployments with the integration of Open5GCore with network slicing, 5G radio units and other software components from Coordination Layer being integrated into the Berlin Platform to be able to do full E2E experimentation trials at the designated sites, so to realize the use case as described in D2.1 [1] and validate the proposed E2E KPIs.

3.2 Phase 1 Accomplishments

As the first integration cycle concludes in March 2019, the Berlin Platform accomplished the following tasks:

- First integration of MONROE virtual instrument in the Fraunhofer FOKUS testbed with TAP and Open Baton in an OpenStack environment. This allows performing some experiments to calculate KPIs such as latency and throughput of the sub-section of the testbed, involving some key components,
- Overall Berlin Platform architecture plans are aligned with the proposed 5GENESIS architectural blueprint defined in D2.2 [2],
- The logical and physical infrastructures of the different testbeds that comprise the Berlin Platform are specified in details. The internal infrastructure details will help for accounting on parameter values for KPI calculations,
- The public acquisition process of core network equipment and 5G-NR has been initiated based on the detailed technical specifications per site,
- Infrastructure at Fraunhofer FOKUS has been upgraded with new single- and multi-mode fibre cabling and new power supplies for the new 5G-NR infrastructure,
- Experimentation site survey is completed at HUB premises, and plans are made for further deployment and installations of equipment,
- The Evolved Packet Core (EPC) is installed and tested in conjunction with RAT technologies such as E-UTRAN and WLAN,
- Setting up of mmWave nodes with enclosure for outdoor installations is done, and
- Purchases of Hosts (PCs) for OAI integration are made at IHP premises.

3.3 Phase 2 Accomplishments

- Open5GCore instances
  Provisioning of standard 5G Core instances: VMs for the various components of a default Open5GCore provisioning were be created; the core components on each of the latter were be configured.
- Migration from Open Baton to OSM
  Due to restructuring of the department, Fraunhofer FOKUS stopped supporting Open Baton as a MANO tool. As such, the entire Berlin Platform migrated towards OSM for Management and Orchestration. OSM is fully operational and deployed at the Berlin platform enabling (semi-)automated management testbed.
- Extension of Outdoor coverage at Fraunhofer FOKUS
  The extension of the outdoor coverage using new base stations for providing network services around Fraunhofer FOKUS. These base stations are shipped and will be installed, configured, and integrated into the Open5GCore installation by the end of Q2 2020. The initial deployment is based on Huawei 5G Stand-Alone new radio and will be further extended by equipment from other providers in the final phase of the project. Coverage of the new Radio Access Technologies (5G SA NR) was assessed to optimize transmission power setting and avoid interference with ongoing commercial network deployments.
- KPI evaluation support
  The Berlin Platform supports the evaluation of the KPIs in Phase 2. This feature has been provided to the platform by creating and adapting the interfaces to support the aggregation of measurements out of the 5G Core.
- Satellite capabilities
  The Berlin platform has been extended with GEO satellite capacity.
- DWDM connection
  DWDM connection to German-wide fiber network: The procurement process of the DWDM system has been completed and the equipment is shipped to the Berlin platform. Wavelength assignments for the deployment have been arranged with the telco providers and the full system will be configured and go operation by the end of Q1 2020.
- Establishment of VPN for inter-site platform connectivity
  Interconnection of the Fraunhofer FOKUS testbed with the IHP testbed to allow the inclusion of mmWave technology deployed at IHP. Planning and deployment of remote nomadic node at Humboldt University, where a nomadic remote deployment of the Berlin Platform was created at the Humboldt University premises and interconnected with Fraunhofer FOKUS.
  Further extensions are considered in Phase 3 as part of the onboarding process of the 5G-VICTORI project. The latter requested to extend the Berlin Platform towards the Deutsche Bahn's Berlin Central Station (Berlin Hauptbahnhof).
- Integration of the initial version of Slice manager into the Berlin platform

The Slice Manager is developed as a WP3 component that provides management service for network slicing. The Slice Manager services are tested for both Queens and Rocky versions of OpenStack. To align with other platforms, this component has been is installed following the instructions from the integration manual. Though the installation is successful, the integration could not be validated yet. Initial analysis indicated, that the cause is an incompatibility between different OpenStack releases and the 5Genesis Slice Manager. The Berlin Platform deploys the latest OpenStack release (Stein version) whereas the 5Genesis Slice Manager is based upon a former OpenStack release. Moving the 5Genesis developments towards the most recent stable OpenStack release – or alternatively downgrading the installation at the Berlin Platform – are currently under discussion.

- **Initial integration of dispatcher and definition of experiment descriptors**
  The Portal, component developed under WP3, is used to create the definition of experiments. The test automation plan configured by OpenTAP is stored as ELCM test to be mapped by the Portal. The Portal maps these ELCM test and create experiment definitions based on those tests. This also provides the support for displaying the execution results of the experiments. In Release A, For the Portal, the dispatcher didnot exist as a separate entity. Hence, the dispatcher is configured to the ELCM.
- **Installation of the IHP 60 GHz mmWave solution at IHP premises and initial set of indoor and outdoor measurements**
  The IHP 60 GHz units presented in Section 2.2.1.3have been installed at IHP premises in order to conduct experiments (indoor and outdoor) whose results will be part of the contributions to deliverable D6.2.
- **Initial Edge deployment at Humboldt University premises**
  The 5GENESIS Partners that are part of the Berlin Platform, i.e. Fraunhofer FOKUS, IHP, Simula Research, Karlstad University and Humboldt University, did jointly work on a preliminary trial of the Festival of Lights event in October 2019. An edge deployment was installed in the courtyard of the Humboldt University as part of the integration activities of the Berlin Platform towards the preparation of the "Festival of Lights" event in 2020. See Section 4.2.1 for more specific details on the deployment.
- **Experimentation site preparation for Festival of Lights event in Berlin to showcase the initial use case demo at Humboldt University premises**
  Together with the edge deployment mentioned in the previous subsection, the concept of dynamic placement of VNFs for running experiments in different availability zones presented in deliverable D6.1 was set up in the edge deployment at the Humboldt University. This allowed the dynamic instantiation of measurement endpoints – also known as "virtual instruments" – at each availability zone for the execution of test cases to assess throughput or delay. See Section 4.2.1 for more details.

3.4 Next Milestones

The activities planned for Phase 3 of the Berlin 5G Platform development include the following:

- Deployment of 100 Gbps Spine-Leaf-based switching infrastructure are the Fraunhofer FOKUS site.
- Deployment of additional 5G SA RAN in the parking decks, laboratories, and roof of the Fraunhofer FOKUS site.
- Deployment of 5G SA NR of additional COTS at the Fraunhofer FOKUS site.
- Deployment of additional compute and storage supporting multi-tendency at FOKUS site.
- Extension of the non-3GPP access technology deployment at FOKUS site.
- Integration of RunEL and Eurecom 5G RAN (OAI) upon availability of corresponding N1/N2/N3 interfaces.
- Deployment of IHP mmWave nodes outdoors in IHP, to then install them at the Humboldt University site.
- Continuous operation and maintenance of the Berlin site, including support for external users (projects) such as the 5G-VICTORI project.

4. The Berlin Platform Use Case specific extensions

Each 5GENESIS platform focuses on the validation of a subset of 5G KPIs. In particular, as introduced in Deliverables D2.1 [1], D2.2 [2] and D2.3 [4], the Berlin platform will focus on requirements for speed, reliability, user density and service creation time KPIs. The scenario described in the previous sections is oriented to analyze these KPIs under different test environments. The use case for the Berlin platform will conduct the validation of relevant E2E 5G KPIs in realistic scenarios.

4.1 Use case target deployment: Festival of Lights

The Berlin Platform follows the 5GENESIS architecture proposed in D2.2 [2]. The sites at Fraunhofer FOKUS, IHP and Humboldt University have their own network architecture, which are described in Section 5 of deliverable D4.13 [3] and their interconnections are realized through terrestrial DFN/GÉANT high throughput backhaul link. Later in Phase 3, the secondary link shall be provided through Satellite. These connections are secured through VPN across the sites.

The Fraunhofer FOKUS and IHP will perform experiments utilizing 60 GHz mmWave backhaul at IHP premises where mmWave nodes will be configured and air interface will be tested. Once the KPIs are validated through parameters tuning at IHP, the setup will be transferred to *Babelplatz* where actual experiment trials are performed. Figure 2-3 shows the overall final topology design which will be deployed to realize the use case and validate target 5G KPIs.

The Berlin Platform addresses a dense urban scenario, where thousands of users (or UEs) are expected to connect to the Open5GCore 5G network through different RATs (such as WLAN or 4G/5G using a SIM card) and 60 GHz mmWave backhaul to access the resources (i.e. live feed) during Festival of Lights event in Berlin. The huge amount of traffic generated by the 360 degrees high resolution camera are fed to the media server in the edge computing unit where it is processed and sent to the endpoints (UEs). This will help to evaluate overall performance of the Berlin Platform along with its core components such as virtualized Open5GCore, 60 GHz backhaul physical links, 5G-NR devices, etc. The extension of this experimentation may lead to understand the capability and service provided by 5G networks in the Berlin Platform and can further be applied in different dense urban network scenarios where high throughput is the main concern to maintain QoS and QoE.

4.2 Use Case Phase 2 accomplishments

4.2.1 UC1: Festival of Lights

The Berlin Platform demonstrated the use case related to eMBB 5G service by deploying several hardware/software core and edge components at different sites of the Berlin Platform (Fraunhofer FOKUS and Humboldt University, the latter as the nomadic edge deployment) to evaluate the target 5G KPIs and metrics related to the performance of the core network.

4.2.1.1 Festival of Lights 2019 Deployment

A graphical representation of the deployment for the Festival of Lights event in October 2019 is depicted in Figure 4-1. Fraunhofer FOKUS was connected via VPN to the main building of the Humboldt University. An edge deployment was installed in a van in the center of the courtyard of the university.

Figure 4-1: Remote (edge) deployment at the courtyard of the Humboldt University.

A 180 degree camera (model: Vivotek FE9391-EV) recorded the surrounding light installations at the Festival of Lights. Instead of sending the data to a central cloud, the videos were transmitted via a 60 GHz antenna system connecting the main building of the Humboldt University and the edge deployment in the middle of the Humboldt University courtyard. This "Edge Cloud" was located in a van on site (see Figure 4-2). The Edge Cloud consisted of NetApp's "hyperconvergent infrastructure" (HCI), which tightly integrates computing power and storage, Simula's application software and Fraunhofer FOKUS' Open5GCore software for a virtualized core network.

A web app from the partner Simula (SRL) made possible to watch the light installations on a smartphone connected to the Wi-Fi network provided at the site (Figure 4-3). Figure 4-4 presents an overview of the deployed solutions installed at various points of the Humboldt University Courtyard and at the Humboldt University main building.

The field test at the Festival of Lights 2019 has shown that it is possible to dynamically set up a 5G core network on site for local use in a short period of time (minutes) and to support end applications with low network loads and high computing capacities on the basis of a powerful, mobile infrastructure in the Edge. An analysis of the resulting KPI evaluation carried out using this deployment will be provided in deliverable D6.2, with due date end of March 2020.

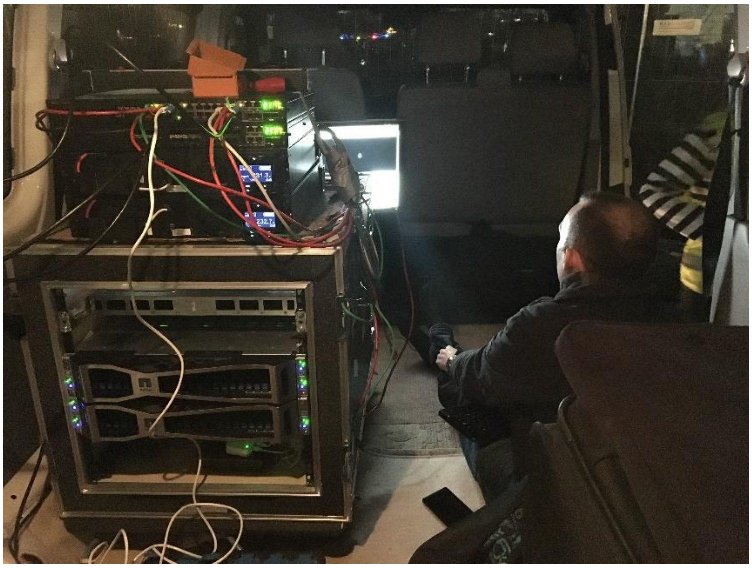

Figure 4-2: Edge deployment of the Berlin Platform installed in a Van.

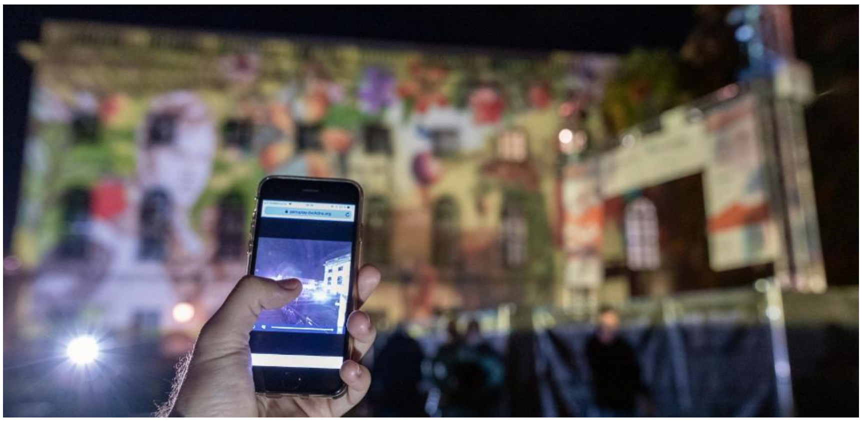

Figure 4-3: Web app from Simula running in a smartphone. © Philipp Plum/ Fraunhofer FOKUS

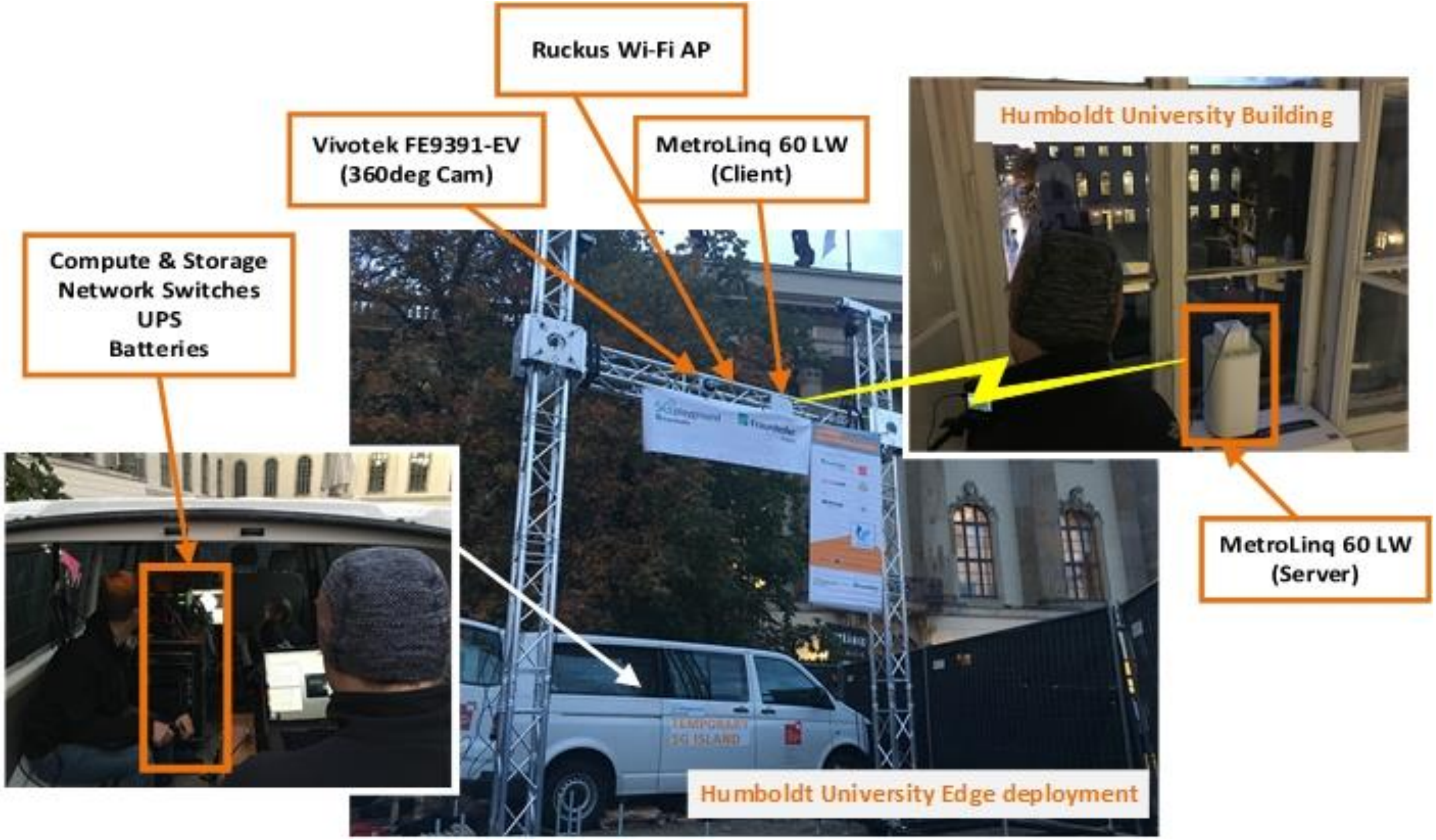

Figure 4-4: Deployment at the Festival of Lights 2019.

4.2.1.2 Framework for end to end performance evaluation of 360 video

In Figure 4-5 we present our designed framework. A live event (e.g., in our case, the Festival of Lights) is captured with an omnidirectional camera setup, and the feed is subsequently fed to the encoding server. The encoding server prepares the live stream for playback and passes it to the web server. The web server incorporates the streaming page with the video player. Each page is integrated with a video analytics module. End-users can stream the event over the Berlin platform's 5G network serving a designated test area. QoE parameters are collected with automatic video analytics data, and insights are derived regarding the performance of different encoding parameters, tiling strategies, video players, adaptation algorithms, and network technologies. Details regarding each framework component are provided below.

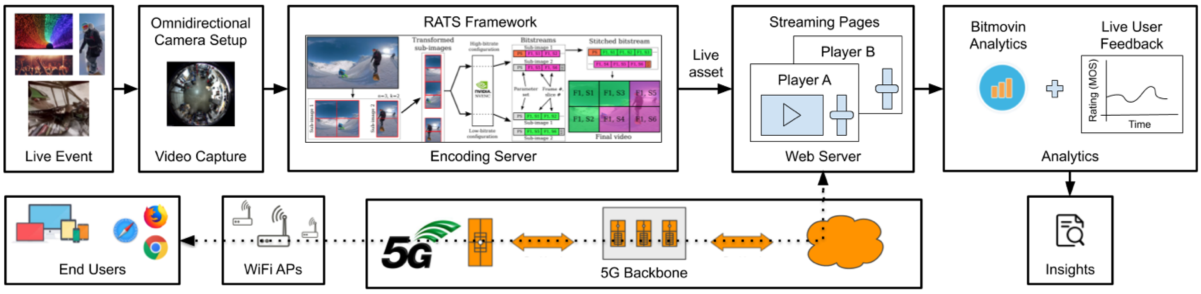

Figure 4-5: Proposed evaluation framework for end to end performance evaluation of 360 video

Omnidirectional Video Capture: Specialized hardware is required for the purpose of filming 360°videos. We consider a high-end fisheye camera, which yields a rectangular compressed video at 12MP with a black boundary around a circular recording. The camera delivers a single-lens image without other visual artifacts other than regular distortion. We capture the spherical video as a real-time byte-stream.

Tiled Adaptive Bitrate Encoding: Approaches to stream 360°video adaptively (i.e., transferring only parts of the video such as the current and predicted viewport in high quality, while transferring the rest of the video tiles in lower quality) present significant bandwidth savings at little risk of stalling. Most recently, Ballard et al. [38] demonstrate a framework called Real-time Adaptive Three-sixty Streaming (RATS), where a GPU-based High Efficiency Video Coding (HEVC) encoding is utilized to tile, encode, and stitch 360°video at different qualities in real time. They show measurement results for the encoding speed, amount of output data, and output quality for different tiling configurations, establishing that their approach is feasible for live streaming scenarios as well as VoD. We utilize the RATS framework and place it in a larger context of real-time adaptive 360°video streaming over a 5G network. The stitching is implemented on the server side, which allows for deployment in 5G edge computing scenarios.

Multiple Player Support: 360°videos can be viewed via mobile devices such as smartphones and tablets, where users can pan around the video by clicking and dragging. Internal sensors can also be used to pan the video based on the orientation of the device. However, the ultimate user experience depends on how well a video player exploits these features. There are numerous video players which claim to have 360°support, however existing literature on the comparison of different players have mostly focused on VoD streaming [39]. In our framework, we used Video.js Player[2], but the framework can easily be extended to support more players and player configurations.

Video Analytics: As part of our framework, we use a commercial OTT video analytics product to extract video performance metrics in real-time with low overhead. We select Bitmovin Analytics[3], due to its easy integration with many open-source and commercial video players, large set of video performance metrics, user-friendly dashboard, and extensive developer documentation. The product is free to use up to 5000 impressions for any new user, and provides a cloud-based data export service.

4.2.2 Topology and Architecture

The overall topology and architecture of the Berlin platform as detailed in D4.13 remains unchanged (see Figure 2-2).

4.2.3 Milestones for Phase 3

The next milestones to be accomplished for the next phase will be:

- Extension of the coverage of the deployment at the Humboldt University site towards *Bebelplatz.* Use of IHP's mmWave backhaul solution for providing the wireless terrestrial backhaul connectivity at 60 GHz.
- Integration of COTS 5G SA NR at the Humboldt University site for the field tests.
- Integration of all portable components into a ruggedized casing infrastructure to support the nomadic deployment at the Humboldt University site as well as additional use cases requiring a fully autonomous 5G Core network deployment including edge compute and storage.
- Operational deployment of nomadic node components for the Festival of Lights 2020

[2] https://videojs.com/
[3] https://bitmovin.com/video-analytics/

5. Conclusions

This deliverable provides additional details on the status of the specific instantiation of the reference architecture being built in the 5GENESIS Berlin platform. The deployment status represents an update to that included in the first release of the Berlin Platform WP4 deliverable, captured in deliverable D4.13 "The Berlin Platform Release A".

This document first presents the platform instantiation as expected by the end of the project and then reports the current status (platform release B), resulted after the second integration cycle of the project (December 2019). More specifically, an overview of the infrastructure, software and hardware network components that are being developed in WP3, leveraging the interfaces for control and monitoring, the required automation processes for experimentation, measurement and KPI computation, as well as to implement full control and security aspects as described in the coordination layer defined in the deliverable D2.2. The platform will also support the common portal for interaction with experimenters and tools for the appropriate operation of the Berlin platform.

Finally, details on the remote deployment at the Humboldt University courtyard were provided. This field test at the Festival of Lights 2019 showed that it is possible to dynamically set up a 5G core network on site for local use in a short period of time (minutes) and to support end applications with low network loads and high computing capacities on the basis of a powerful, mobile infrastructure in the Edge. The obtained evaluation results will be provided in deliverable D6.2, with due date end of March 2020.

Self-assessment

The Berlin platform in its current status is on purpose, on schedule and on budget as follows from the instantiation of the 5GENESIS platform blueprint, platform instrumentation to support the experiments, and the design of its physical architecture following the IaaS principle.

Commercial relevance and exploitation potentials

The Berlin platform supported by the 5GENESIS project adds the -above described values to the following commercial services offered by Fraunhofer FOKUS.

- The first added value is a service, called 5G Playground, which is an open testbed designed to enable innovative product prototyping in a realistic, comprehensive 5G E2E environment, including calibration, benchmarking and interoperability tests between new prototypes and products. For this purpose, the testbed infrastructure can be flexibly augmented by infrastructure, software network functions and service components from third parties.
- The second added value is another service - called*5G Ready Trial Platform*, which provides a consolidated turn-key solution of the Fraunhofer FOKUS software components. It integrates with selected access networks, devices, applications and infrastructure elements, providing additional benchmarking and assessment mechanisms. It provides as

well efficient means to integrate, to initially evaluate – over a large number of network conditions – the maturity level of the existing technologies, to test the interoperability and the configuration flexibility as well as the efficiency of underlying infrastructure in order to create comprehensive customized solutions trialling new products in small or medium deployments.

In the future release of this deliverable (Release C) the assessment of additional commercially relevant values such as anonymization of analytics will be provided.

REFERENCES

[1] 5GENESIS Deliverable D2.1, "Requirements of the Facility", 2018, https://5genesis.eu/wp-content/uploads/2018/11/5GENESIS_D2.1_v1.0.pdf
[2] 5GENESIS Deliverable D2.2, "Initial overall facility design and specifications", December 2018, https://5genesis.eu/wp-content/uploads/2018/12/5GENESIS_D2.2_v1.0.pdf
[3] 5GENESIS Deliverable D4.13, "The Berlin Platform (Release A)", March 2019.
[4] 5GENESIS Deliverable D2.3, "Initial planning of tests and experimentation", February 2019, https://5genesis.eu/wp-content/uploads/2019/02/5GENESIS_D2.3_v1.0.pdf
[5] "Festival of Lights"[Online], https://festival-of-lights.de/en, retrieved FEB/2019
[6] Press Release "Festival of Lights" 2019 by Fraunhofer FOKUS, https://www.fokus.fraunhofer.de/en/fokus/news/BerlinFestivalofLight_2019-11
[7] OpenStack [Online], https://www.openstack.org
[8] OpenBaton [Online], https://openbaton.github.io
[9] "MONROE Project" [Online], https://www.monroe-project.eu/access-monroe-platform/, retrieved FEB/2019
[10] "Keysight TAP" [Online], https://www.keysight.com/en/pc-2873415/test-automation-platform-tap?cc=US&lc=eng, retrieved FEB/2019
[11] Open5GCore [Online], https://open5gcore.org
[12] ETSI NFV MANO [Online], http://etsi.org/technologies/nfv
[13] Florian Kaltenberger, Guy de Souza, Raymond Knopp, Hogzhi Wang, "The OpenAirInterface 5G New Radio Implementation: Current Status and Roadmap", [Online], http://www.eurecom.fr/publication/5822
[14] "ETTUS USRP X310" [Online], https://www.ettus.com/product/details/X310-KIT, retrieved FEB/2019.
[15] Docker [Online], https://www.docker.com
[16] Zabbix [Online], https://www.zabbix.com
[17] Iperf [Online], https://iperf.fr
[18] Ixia [Online], https//www.ixiacom.com/Keysight-technologies
[19] IxLoad [Online], https://www.ixiacom.com/products/ixload
[20] IxLoad-Ve [Online], https://www.ixiacom.com/products/ixload-ve
[21] Hesk [Online], https://www.hesk.com
[22] Osticket [Online], https://www.osticket.com
[23] Slack [Online], https://www.slack.com
[24] Github [Online], https://www.github.com
[25] OSM [Online], https://osm.etsi.org/
[26] What is NFV MANO?, [Online], https://www.sdxcentral.com/networking/nfv/mano-lso/definitions/nfv-mano/
[27] OSM Scope, Functionality, Operation and Integration Guidelines, [Online], https://osm-download.etsi.org/ftp/Documentation/201902-osm-scope-white-paper
[28] 5GENESIS, Deliverable D3.5 "Monitoring and Analytics (Release A)" [Online], https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.5_v1.0.pdf, Accessed: Jan. 2020.
[29] Özgü Alay, Andra Lutu, Miguel Peon-Quiros, Vincenzo Mancuso, Thomas Hirsch, Kristian Evensen, Audun Hansen, Stefan Alfredsson, Jonas Karlsson, Anna Brunstrom, A. Safari

Kha-touni, Marco Mellia and Marco Ajmone Marsan “Experience: An Open Platform for Experi-mentation with Commercial Mobile Broadband Networks”, ACM MOBICOM 2017.
[30] “Test Automation Platform” [Online], https://www.keysight.com/en/pc-2873415/test-automation-platform-tap, Accessed: Jan. 2020.
[31] “Prometheus” [Online], https://prometheus.io, Accessed: Jan. 2020.
[32] “InfluxDB” [Online], https://www.influxdata.com/products/influxdb-overview/, Ac-cessed: Jan. 2020.
[33] 5GENESIS, Deliverable D6.1 “Trials and Experimentations – Cycle 1” [Online], https://5genesis.eu/wp-content/uploads/2019/08/5GENESIS_D6.1_v1.00.pdf, Accessed: Jan. 2020.
[34] M. Piz, Wideband OFDM System for Indoor Communication at 60 GHz. Phd, Brandenburgische Technische Universität Cottbus, 2010.
[35] M. Petri and M. Ehrig, "A SoC-based SDR Platform for Ultra-High Data Rate Broadband Communication, Radar and Localization Systems," 2019 Wireless Days (WD), Manchester, United Kingdom, 2019, pp. 1-4. doi: 10.1109/WD.2019.8734240
[36] BFM6005 Product Brief, [Online:] https://www.siversima.com/product/bfm06005/
[37] E. Oejefors et al “A 57-71 GHz Beamforming SiGe Transceiver for 802.11ad-Based Fixed Wireless Access” in Proc. of IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2018), Philadelphia, USA, 2018
[38] T. Ballard et al. RATS: Adaptive 360-degree Live Streaming. International Conference on Multimedia Systems (MMSys), 2019.
[39] A. Zabrovskiy et al. AdViSE: Adaptive Video Streaming Evaluation Framework for the Au-tomated Testing of Media Players. International Conference on Multimedia Systems (MMSys), 2017
[40] 5GENESIS Deliverable D5.1, “System Level Tests and Verification”, December 2019
[41] S. Mushero, “Push vs. Pull Monitoring Configs”, [Online] https://medium.com/@steve.mushero/push-vs-pull-configs-for-monitoring-c541eaf9e927
[42] 5GENESIS Deliverable D3.3, “Slice Management” [Online], https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.3_v1.0.pdf, Accessed: Jan. 2020