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

[H2020 - Grant Agreement No. 815178]

Deliverable D4.15

The Berlin Platform (Release C)

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1.0	Release of D4.15	FRAUNHOFER & IHP	31.10.2021

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
BBU	Baseband Unit
COTS	Commercial-Off-The-Self
Dx.y	Deliverable No y of Work Package x
DRAN	Distributed Radio Access Network
DWDM	Dense Wavelength Division Multiplexing
ELCM	Experiment Life Cycle Manager
eMBB	Enhanced Mobile Broadband - 5G Generic Service
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
NSA	Non-Stand-Alone
OSS	Operational Support Services
PTMP	Point-to-Multi-Point

QoS	Quality of Service
PoE	Power-over-Ethernet
PTMP	point-to-multipoint
RAT	Radio Access Technology
REST	Representational State Transfer
RRH	Remote Radio Head
SA	Stand-Alone
SDK	Software Development Kit
SDN	Software Defined Networking
TAP	Test Automation Platform
VIM	Virtualization Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Function
VPN	Virtual Private Network
VR	Virtual Reality
VRF	Virtual Router Functions
WIM	WAN Infrastructure Manager
WLAN	Wireless Local Area Network
WP	Work Package

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Executive Summary

This document provides the final implementation design (Release C) of the 5GENESIS Berlin Platform. The presented platform is an instance of a common reference architecture that all 5GENESIS platforms adhere to. The current status represents a final upgrade to the second release of the Berlin Platform instantiation, which was reported in deliverable D4.14 "The Berlin Platform (Release B)".

This document first presents the platform overview for Phase 3 with the final description of the topology and the sites. The final deployment of the Berlin Platform has been impacted by the COVID-19 outbreak, which has led to the redefinition of the purpose of the sites and to the choice of an alternative site for the final trial demonstration. Unfortunately, the main goal of the Berlin Platform, being the final demonstration of the 360º video service over a 5G network at the Festival of Lights 2021, has not been possible in 2021 due to the still in force COVID-19 restrictions such as social distancing. The Berlin Platform partners identified this risk in advance and proposed the IHP site as an alternative for the final demonstration. The reasons for this decision are the suburban nature of the surroundings of IHP and the lower density of inhabitants in the area. IHP has made use of external invest budget for the procurement of the necessary equipment to match the technology required for the final demonstration, and to perform its installation at IHP premises.

The multi-technology, multi-site end-to-end (E2E) 5G environment claimed in D4.14 will be therefore extended towards the IHP site for evaluation of two key 5G services, i.e., eMBB and mMTC. Still the connectivity to the main site of the Berlin Platform (Fraunhofer) is maintained for supporting the execution of the use case (UC) and for remote data processing. The set up at IHP will comprise[1] the 5G Core from Fraunhofer FOKUS (Open5GCore), 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 outside the main IHP building. Prior to the assessment of all the components at IHP, parallel testing activities involving the equipment will take place as a preliminary evaluation of the complete deployment, before the full installation of equipment takes place at IHP.

This deliverable provides the final Berlin Platform implementation in both infrastructure and software and hardware network components (WP3). Interfaces for control and monitoring, the required automation processes for experimentation, measurement and Key Performance Indicator (KPI) computation, as well as full control and security aspects have been provided to the platform. Moreover, the Berlin Platform supports the common portal for interaction with experimenters and tools for the appropriate operation of platform (Open5GENESIS Release B). With all this, the Berlin Platform is then ready for the full assessment all KPIs defined in the Description of Work (DoW) and in deliverable D6.2.

In the framework of WP4, the Berlin Platform has achieved a set of technological milestones during the three different phases, which are:

- Deployment of 100 Gbps Spine-Leaf-based switching infrastructure at the Fraunhofer FOKUS site.

[1] The deployment of the 5G testfield at IHP will involve two phases, one preliminary installation will take place in November 2021, and the full set of equipment will be installed in January/February 2022.

- Deployment of additional 5G Stand-Alone (SA) RAN in the parking decks, laboratories, and roof at 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 the Fraunhofer FOKUS site.
- Extension of the non-3GPP access technology deployment at the Fraunhofer FOKUS site.
- Deployment of IHP mmWave nodes outdoors at the rooftop of IHP.
- Extension of the Berlin Platform and the 5G capabilities to the IHP site. Deployment of 5G SA RAN at the rooftop of IHP.
- Continuous operation and maintenance of the Berlin site, including support for external users (projects) such as the EU-funded 5G-PPP ICT-19 5G-VICTORI project, whose solutions will be preliminary assessed at both Fraunhofer and IHP sites.

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1. Introduction

1.1. Purpose of the document

This deliverable provides the final description of the deployed infrastructure of the 5GENESIS Berlin Platform that was implemented within the Phase 3 of the project.

The Berlin Platform consists of two main sites: the Fraunhofer FOKUS Testbed located in Berlin, the IHP Test field located at Frankfurt (Oder); and the temporary deployment at Humboldt University (HU) Berlin used for the initial field trials. The main sites are used to validate selected 5G KPIs over realistic 5G infrastructures, including 60 GHz radio backhaul links. Thereby, the Berlin Platform addresses the specific requirements D2.1 [1] to be satisfied by each of the platforms that compose the facility and its common reference architecture D2.2 [2].

This document is the final in a series of three deliverables reporting on the consecutive progress of the implementation of the Berlin Platform [2] [3] published along the planned evaluation and experimentation cycles: April-June 2019, January-March 2020, October 2020-June 2021. As such, this deliverable should be read in combination with the preceding two; it hence focuses on the description of the newly added components in Phase 3 of the project and refers to the previous deliverables when necessary.

Table 1-1 shows the set of deliverables with which the present one shares dependencies.

Table 1-1: Dependencies with previous 5GENESIS documents

ID	Document Title	Relevance
D2.1 [1]	Requirements of the Facility	The document establishes the ground for the first set of requirements to be supported by the testbed for the realization of the planned UCs.
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.
D3.1 [5]	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 [6]	Slice management WP3 (Release A)	The document details the Slice Manager solution, its interfaces towards the MANO and NMS components in Release A.
D3.4 [7]	Slice management WP3 (Release B)	The document details the Slice Manager solution, its interfaces towards the MANO and NMS components in Release B.

D3.5 [8]	Monitoring and WP3 analytics (Release A)	The document details the Infrastructure Monitoring components and the interfaces with infrastructure elements.
D3.9 [10]	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 for Release A.
D3.10 [11]	5G Core Network WP3 Functions (Release B)	The document details the 5G Core network functions and provides input on their integration with the infrastructure and management components for Release B.
D3.11 [12]	5G Access Components and User Equipment (Release A)	The document details the 5G Radio Access components and UE devices for Release A.
D3.12 [13]	5G Radio Components and User Equipment (Release B)	The document details the 5G Radio Access components and UE devices for Release B.
D4.13 [14]	The Berlin Platform (Release A)	This document summarizes the sites and components that will form the Berlin Platform and sets the ground for D4.14 and D4.15.
D4.14 [3]	The Berlin Platform (Release B)	This document summarizes the sites and components that were part of the Berlin Platform for Release B and the roadmap for the last release.
D5.1 [15]	System-level tests and verification (Release A)	Midterm report with detailed analysis of the results from the system-level tests and the verification trials.
D6.1 [16]	Trials and experimentation - cycle 1	This deliverable includes the trials and experimentation executed on the 5GENESIS platform as well as the initial results of the first integration cycle.
D6.2 [17]	Trials and experimentation – cycle 2	This deliverable includes the trials and experimentation executed on the 5GENESIS platform during the second integration cycle.

1.2. Structure of the document

This document has the following structure:

Section 2 provides an overview of the topology of the Berlin Platform, the Platform's sites, as well as a distilled summary of the components found at the three logical layers comprising the 5GENESIS Architecture, namely the i) Platform Infrastructure Layer; ii) MANO Layer; iii) Coordination Layer, along with details of the Berlin Platform's support for multiple tenants.

Section 3 is devoted to the UCs that will be realized in the final version of the Berlin Platform, describing their components, the scenarios of utilization and the expected outcome.

Section 4 follows with a description of the Platform evolution over the period 2018-2021, listing the accomplishments during Release A / Phase 1 (2018-2019) and Release B / Phase 2 (2019-2020), as well as highlighting the accomplishments and milestones reached for this last Release C / Phase 3 (2020-2021) of the platform.

1.3. Target Audience

This document details the Release C of the Berlin Platform focusing on the integration activities that took place in the final phase of the project. The target audience includes the research and development European ecosystem and the general audience interested in the Berlin Platform for experimentation, as well as the 5GENESIS consortium itself. Additionally, it acts in combination with D4.13 [14] and D4.14 [3] as information to other ICT projects building upon and using the Berlin platform for their project work. For these projects, as well as for industry aiming at replicating a 5G testbed at their own premises, this deliverable is useful as it provides inputs for analysis and decision making in relation with future developments, integration, experiments, and requirements.

2. Berlin Platform Overview

2.1. Platform Sites Topology

2.1.1. Overall Topology

The Berlin Platform is an extension of the Fraunhofer FOKUS 5G Playground [21] that is integrated with the IHP testfield in Frankfurt (Oder), and has instantiated the Humboldt University (HU) site for field trials and large-scale events using a nomadic 5G node [3]. The platform thus combines 5G, radio and core centric infrastructures permanently deployed at FOKUS, and extensive deployments of new radio technology, e.g., 60 GHz backhauling, and 5G NR at the IHP testfield. All platforms are interconnected via a permanent VPN tunnel over the GÉANT network. Figure 2-1 depicts the different sites of the Berlin Platform.

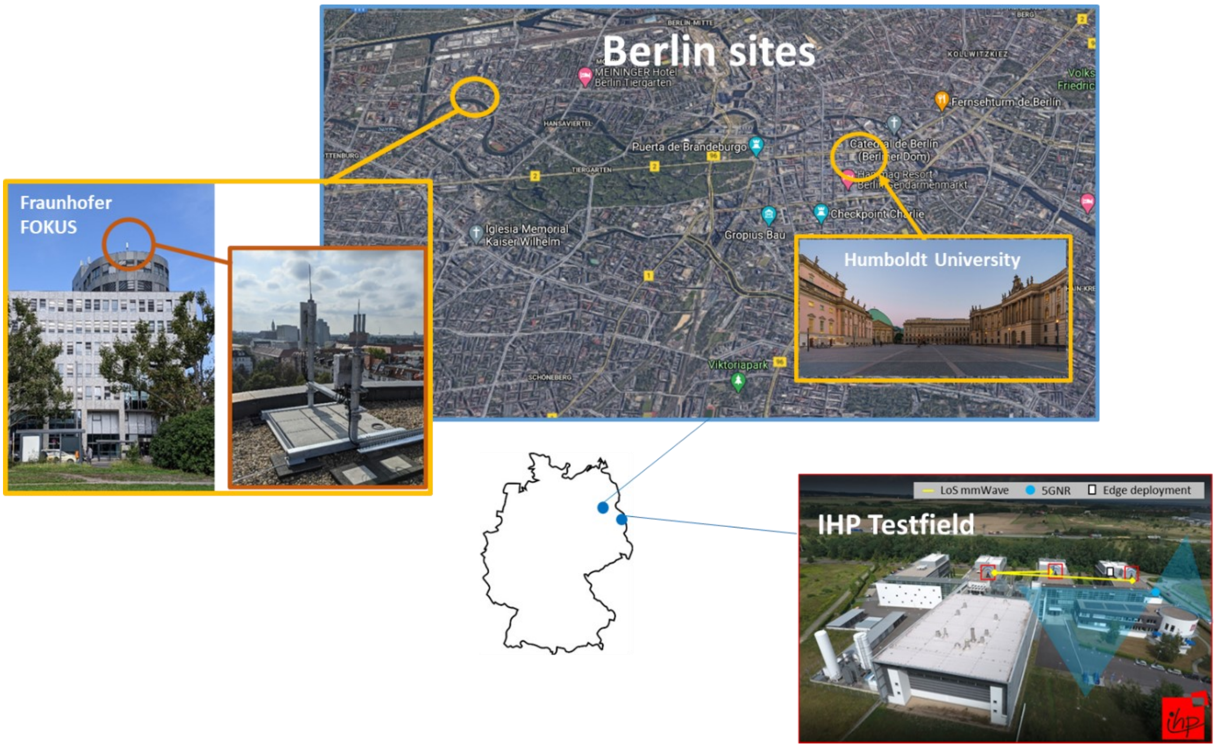

Figure 2-1: Overview of the 5GENESIS Berlin Platform and the sites involved

Additionally, the Berlin Platform is equipped with a Dense Wavelength Division Multiplexing (DWDM)-based fiber connection, which has been implemented outside the scope of 5GENESIS but is available for future use of the platform (see the inter-site connectivity in Figure 2-2). Currently, the DWDM systems extends the Berlin Platform towards two additional Fraunhofer institutes, namely the Fraunhofer Heinrich Hertz Institute (HHI) and the Fraunhofer Institute for Production Systems and Design Technology (IPK). Especially, this connection is used to add a factory shopfloor at FhG IPK at which 5G SA RAN is operated by the Open5GCore deployed at Fraunhofer FOKUS. A special feature of this extension is a second DWDM node denoted as "long distance remote location". This node is geographically located at the Berlin Platform at FOKUS but attached via a long-haul fiber connection to the rest of the platform. This allows to conduct experiments in the Berlin Platform, which replicate a provider edge-cloud deployment located hundreds of kilometers away.

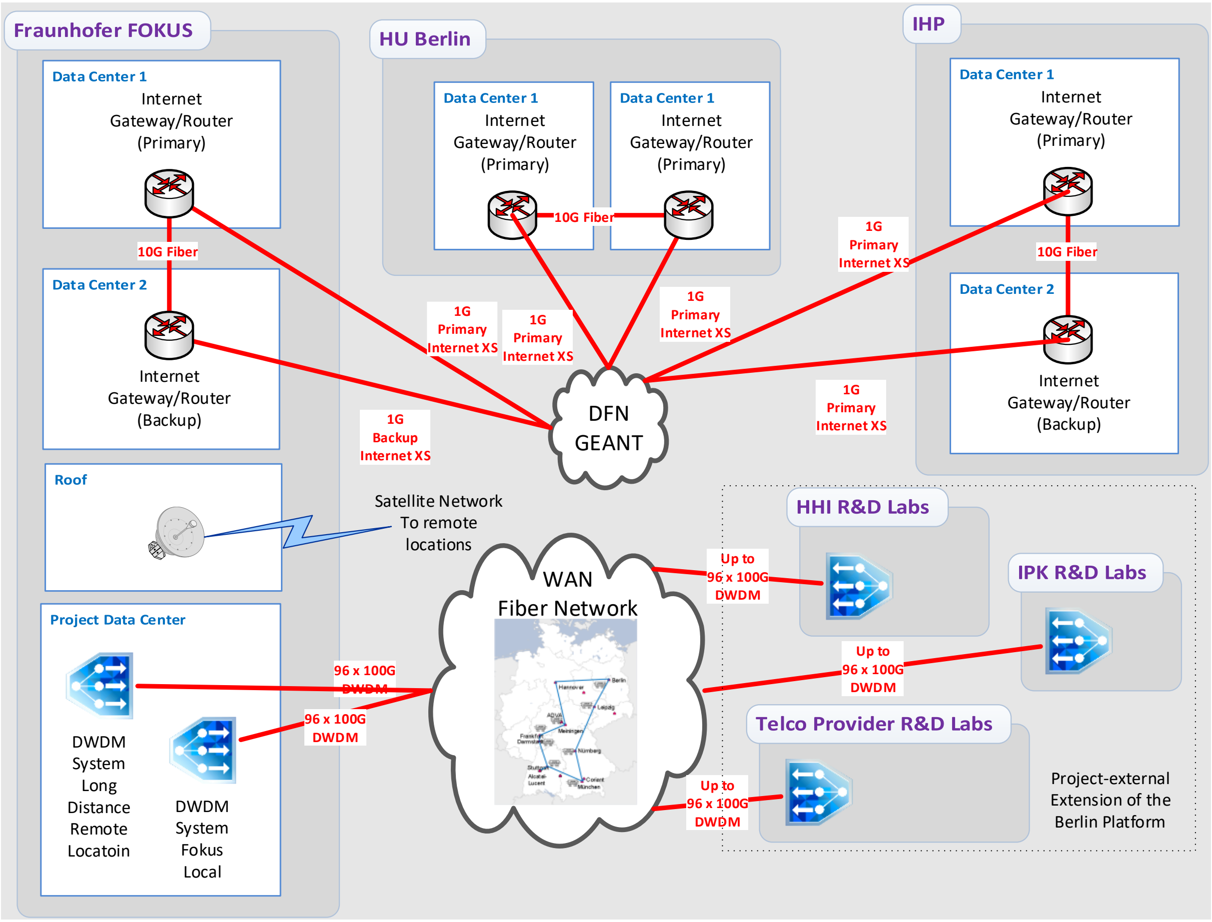

Figure 2-2 Physical Components of the Berlin Platform for Inter-Site Connectivity

A brief description of each site comprising the Berlin Platform is given in the following. Specific diagrams detailing network architecture for each platform are included in deliverables D4.13 [14] and D4.14 [3]. As the network architecture is unchanged since the initial planning of each site, those sites are only referenced and no detailed description is provided.

2.1.2. The Fraunhofer FOKUS Site

The infrastructure provided at the Fraunhofer FOKUS site is deployed across the FOKUS' premises at four locations:

- the project data center,
- the FOKUS R&D lab on the 2nd floor of the building,
- the roof of the building, and
- the parking deck.

Additionally, the core network infrastructure constituting the Berlin site is extended towards two additional data centers within the building, where high-capacity switches allow to extend the core test bed on-demand to any office within FOKUS. The network architecture is unchanged as planned and is the same as depicted in Figure 13 of D4.13 [14] (see Figure 2-3).

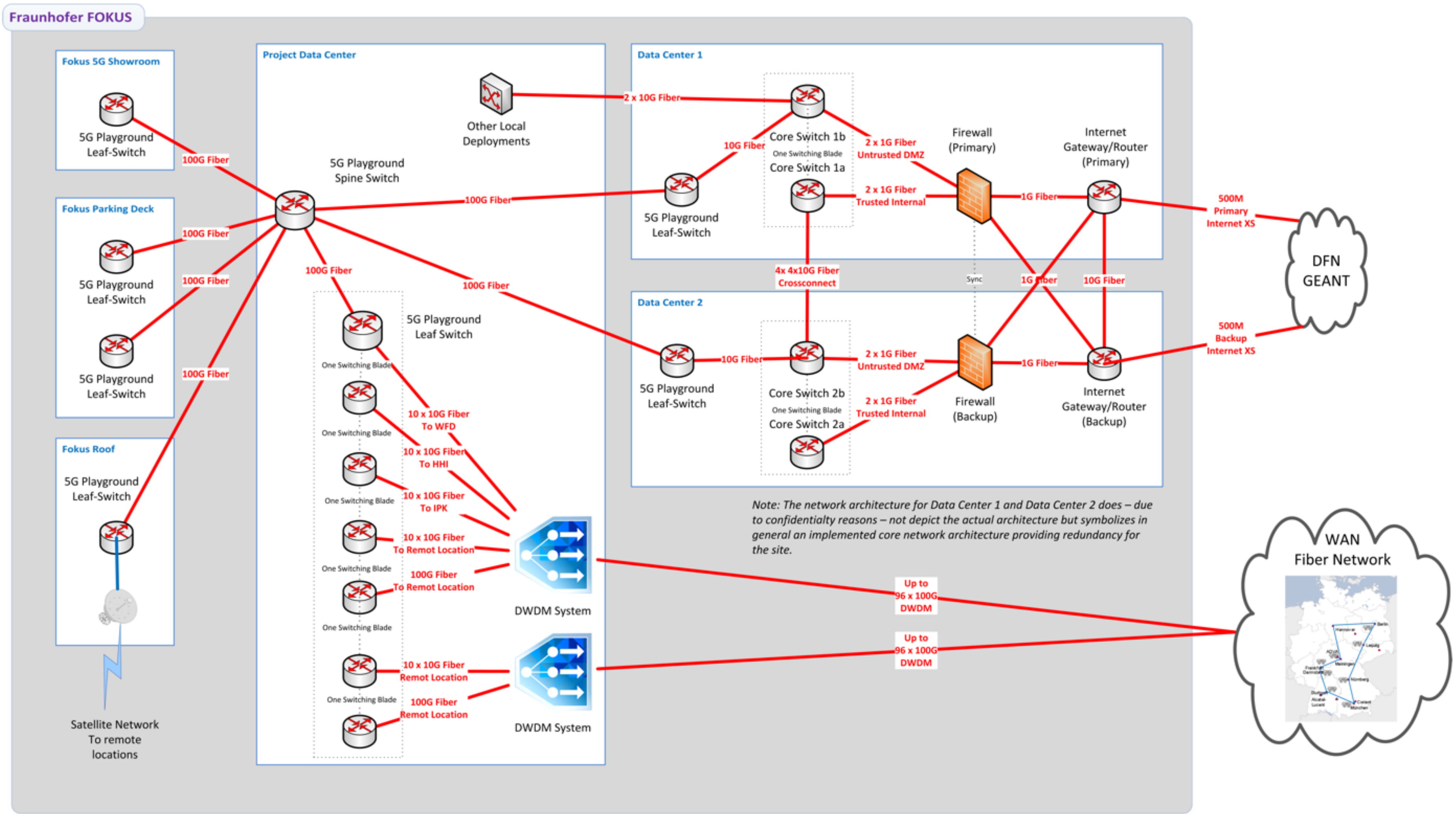

Figure 2-3: Network Core Components of the Fraunhofer FOKUS Site as described and depicted in Figure 13 of D4.13

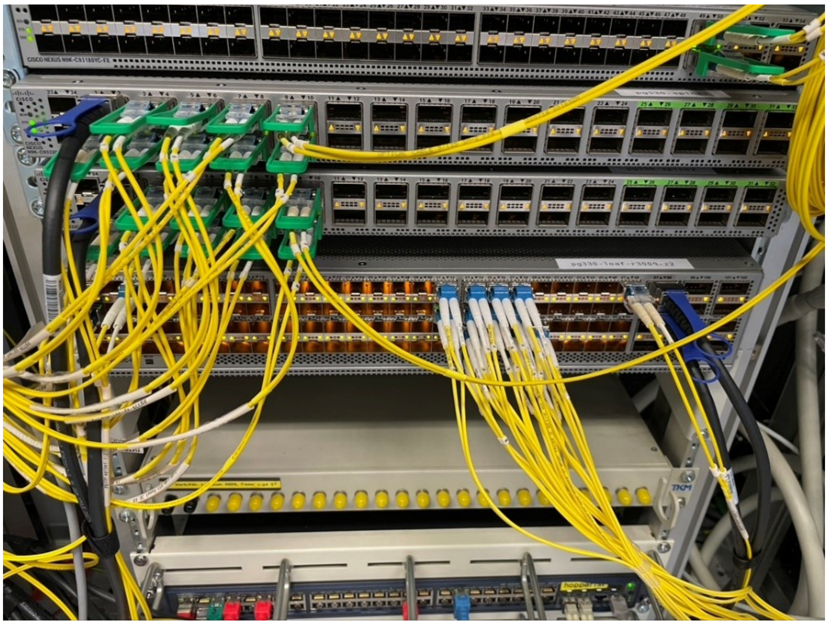

Figure 2-4 100 Gbps Spine Switches at FOKUS project data center

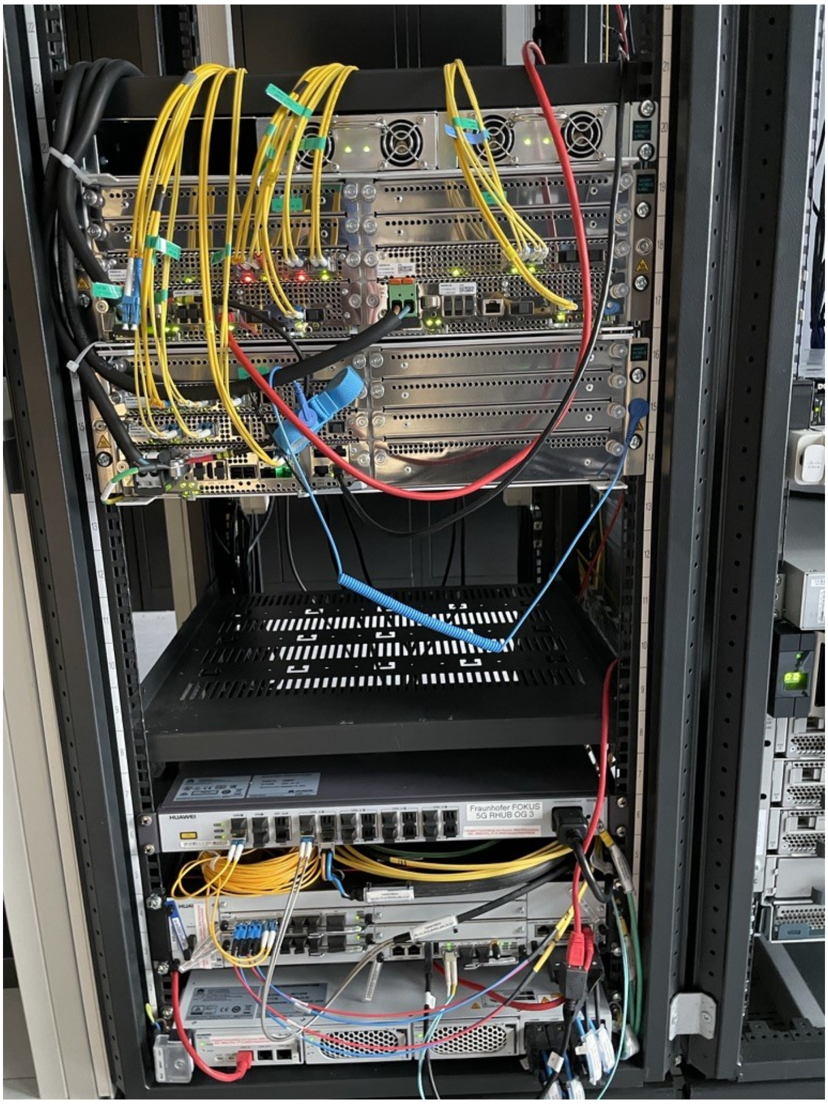

Figure 2-5 Nokia (top) and Huawei (bottom) 5G SA RAN BBUs at FOKUS project data center

The **project data center** hosts the base-band units (BBUs, see Figure 2-4 and Figure 2-5) for the 5G SA RAN installed at FOKUS, central compute and storage (see Figure 2-6), two DWDM nodes (see Figure 2-7 and Figure 2-8), the network spine switches, and two additional switches to attach additional bare-metal servers to the testbed.

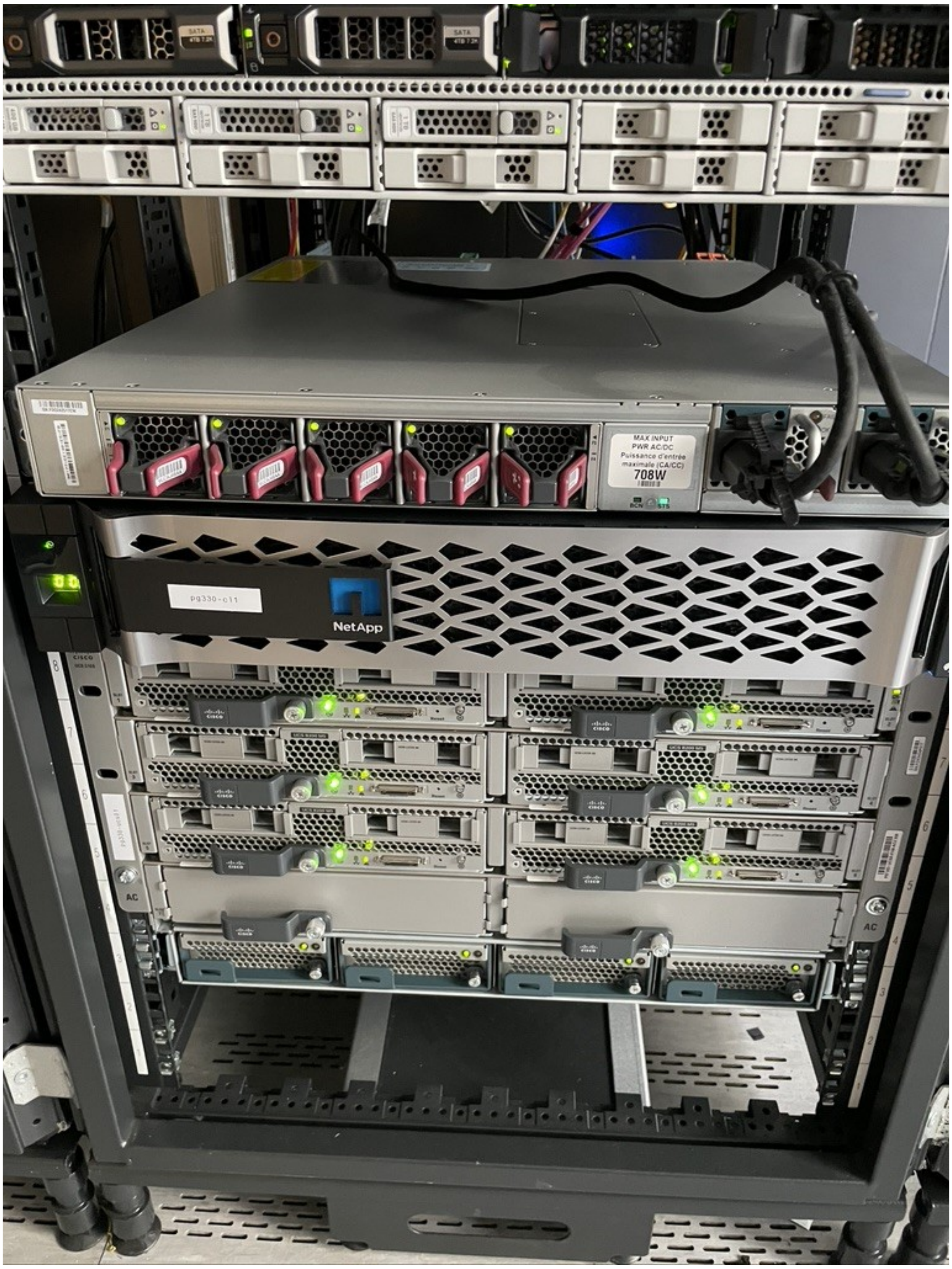

Figure 2-6 Compute and Storage Cluster (Cisco UCS & NetApp) at FOKUS project data center

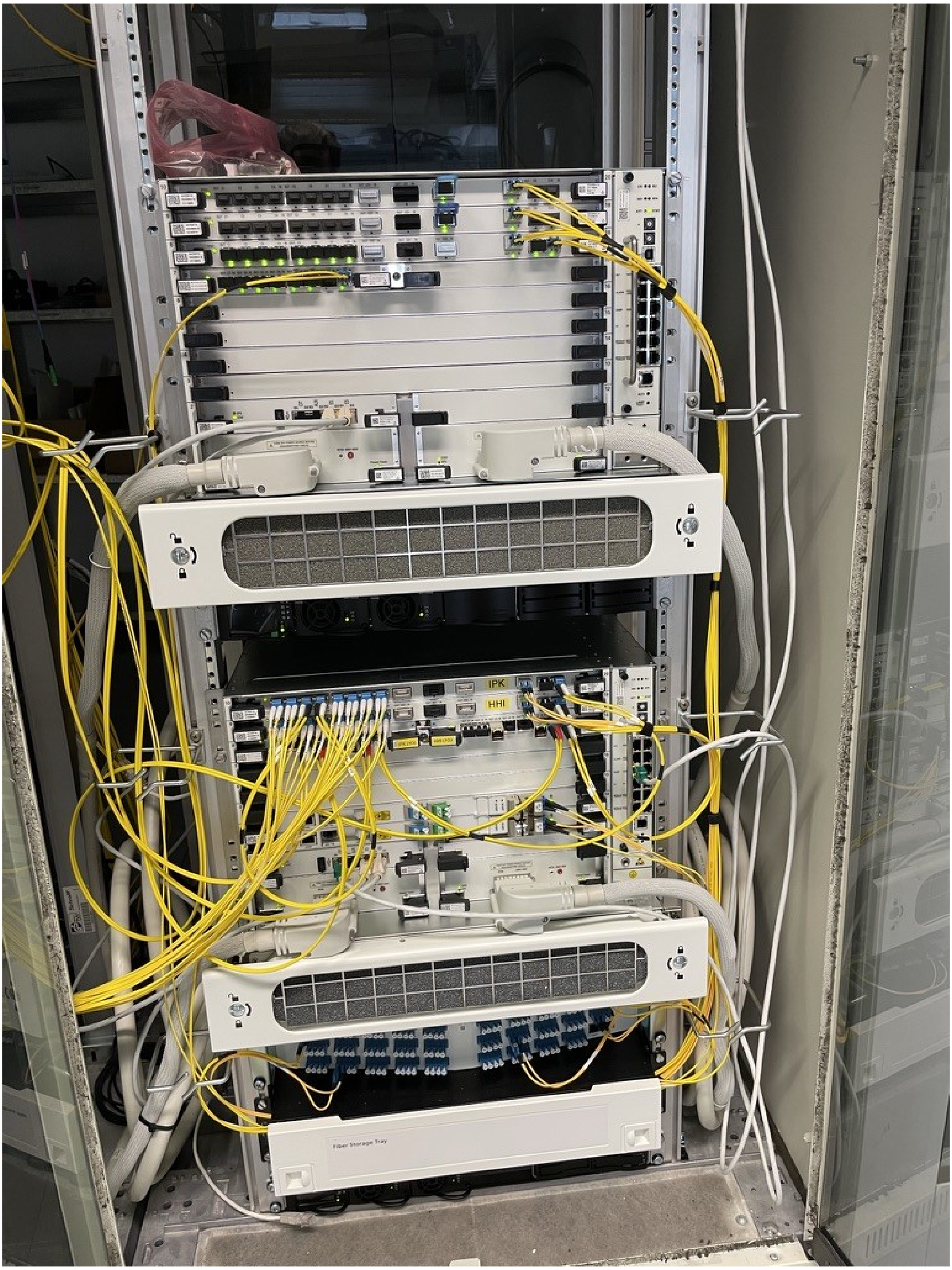

Figure 2-7 Main DWDM Node “Fokus-1” at FOKUS project data center

Figure 2-8 Remote DWDM Node "Fokus-2" at FOKUS project data center

The FOKUS R&D lab provides network access to the Berlin Platform via two spine-switches: one providing shielded-twisted-pair-based access (see Figure 2-9 and Figure 2-10) and one for high-capacity fiber-based connectivity. The lab allows for easy access to the testbed on a "daily use base" as access to the main data center is strictly regulated and restricted due to security reasons. The lab is permanently equipped with Huawei-based indoor 5G SA cells (see Figure 2-11), mmWave units from Ignite (Figure 2-13), and Ruckus Wi-Fi access points (APs) for non-3GPP access (Figure 2-14).

Within 5GENESIS, the lab is used for interoperability testing of 5G RAN provided by different vendors as well as for demonstration purposes. For the latter, the lab is attached with a demonstration wall (see Figure 2-12), which visualizes the functionality and interconnection of the various 5G core components (e.g., AMF, SMF, UPF, etc.).

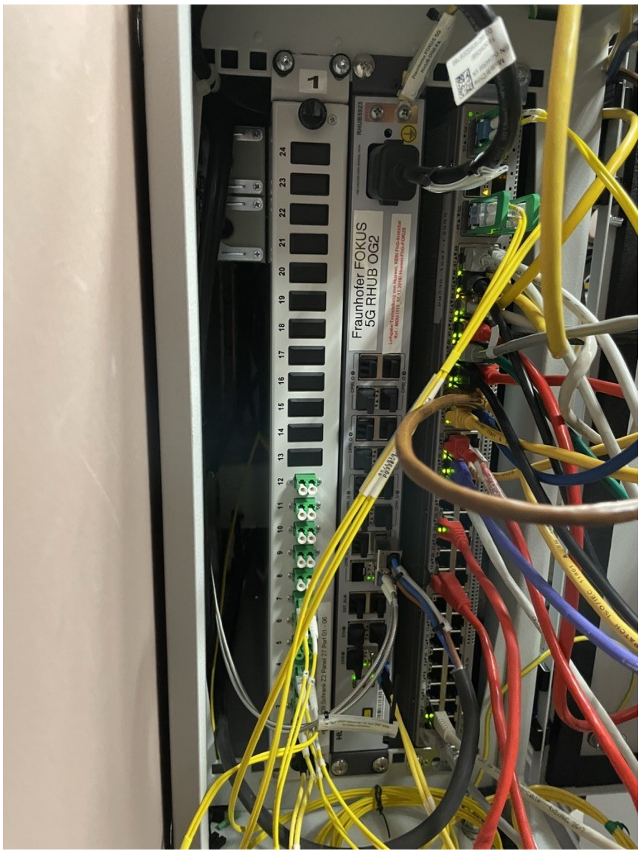

Figure 2-9 First leaf switch (RJ45 interfaces) at FOKUS R&D lab

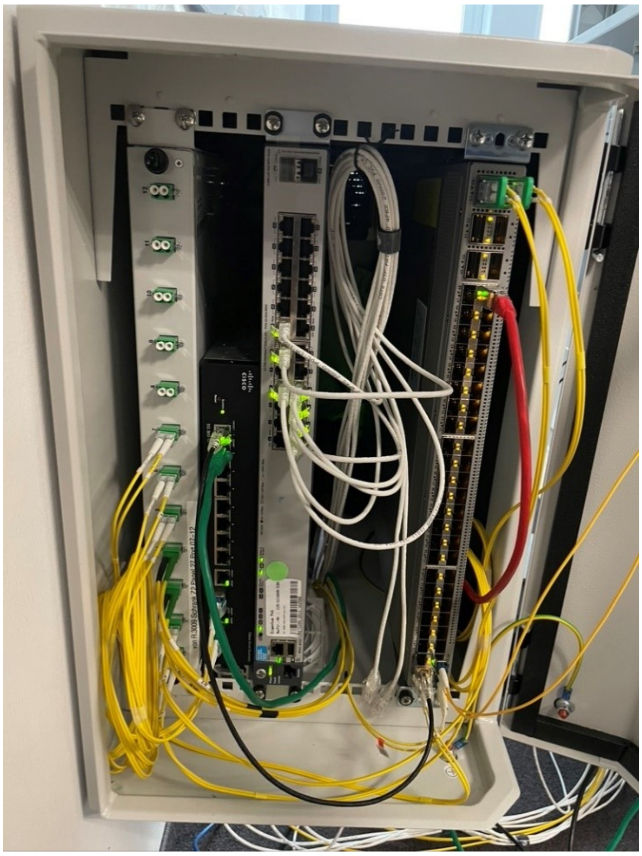

Figure 2-10 Second leaf switch (SFP interfaces) & Huawei Radio Hub at FOKUS R&D lab

Figure 2-11 Huawei Remote Radio Head at FOKUS R&D lab

Figure 2-12 Open5GCore Wall at FOKUS R&D lab

Figure 2-13 Ignite 60 GHz AP at FOKUS R&D lab

Figure 2-14 Ruckus Wi-Fi AP at FOKUS R&D lab

The **roof of the FOKUS building** is used for the deployment of the radio components covering the surrounding of the Berlin Site (see Figure 2-15 for a sketch of the interconnection of the components, and Figure 2-16 for the actual deployment). Installed radio components include a NOKIA 5G SA Radio head (Figure 2-17) as well as a LORA AP (Figure 2-18) and Wi-Fi APs providing non-3GPP access to the testbed. Besides, the facility room at the roof hosts the PTP grand master timer for the Berlin Platform (Figure 2-19).

Also, deployed outside the scope of 5GENESIS, a satellite dish on the roof allows to connect the FOKUS site with a nomadic 5G node, which is in part also used for the HU site. This extension is implemented to use the Berlin platform for future 5G projects, in particular to evaluate 5G for first responder scenarios, requiring backhauling to remote and rural locations. A 100G spine switch is used to attach the roof to the spine switches in the main data center. The network architecture of the roof deployment is depicted in Figure 14 of D4.13 [14] (see Figure 2-15).

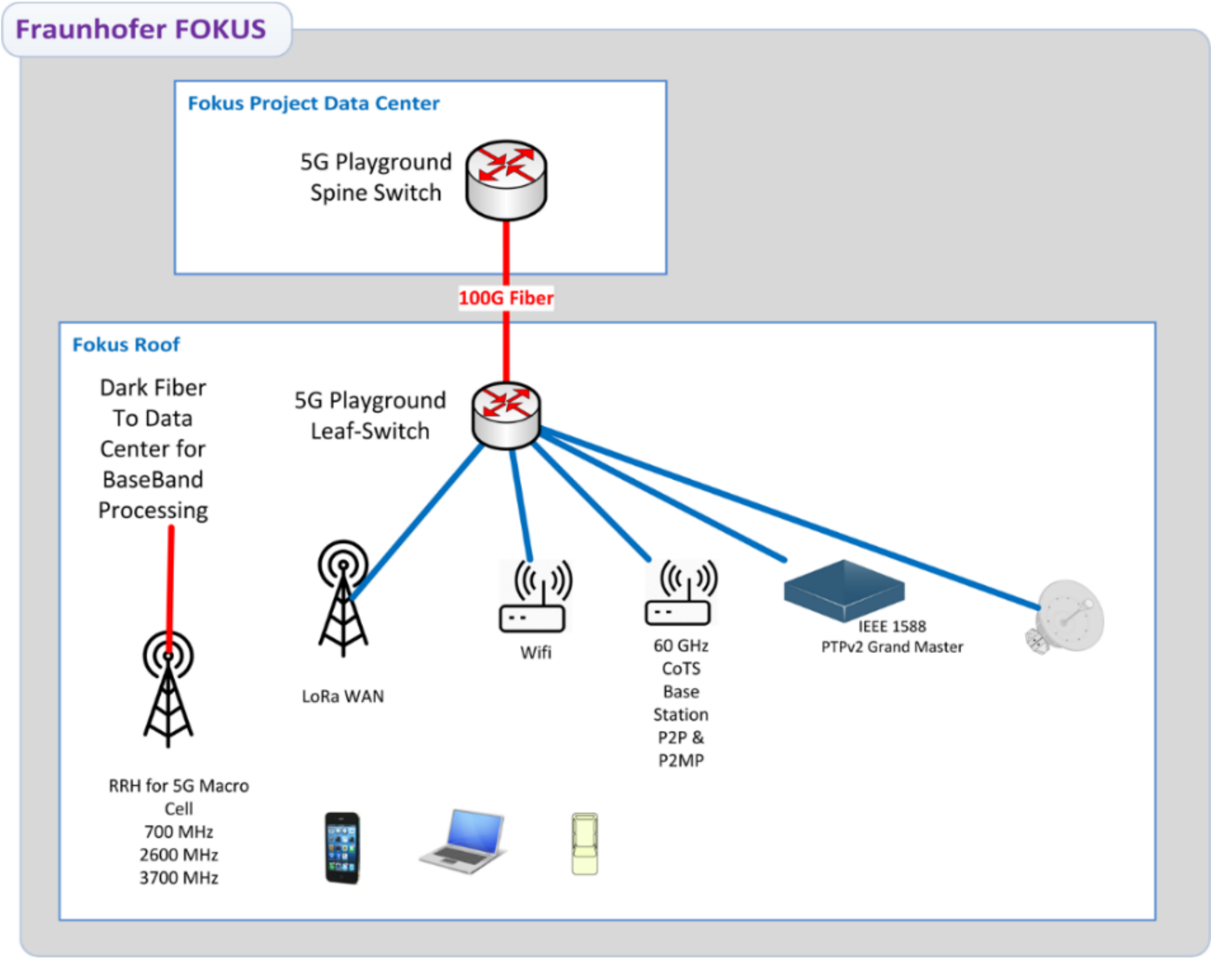

Figure 2-15: Network components at the Roof deployment of Fraunhofer FOKUS site as depicted in Figure 14 of D4.13

Figure 2-16 5G Radio Units on top of the FOKUS building

Figure 2-17 Nokia Radio Unit and Sector-Antenna on the FOKUS roof

Figure 2-18 LORA access point on the FOKUS roof

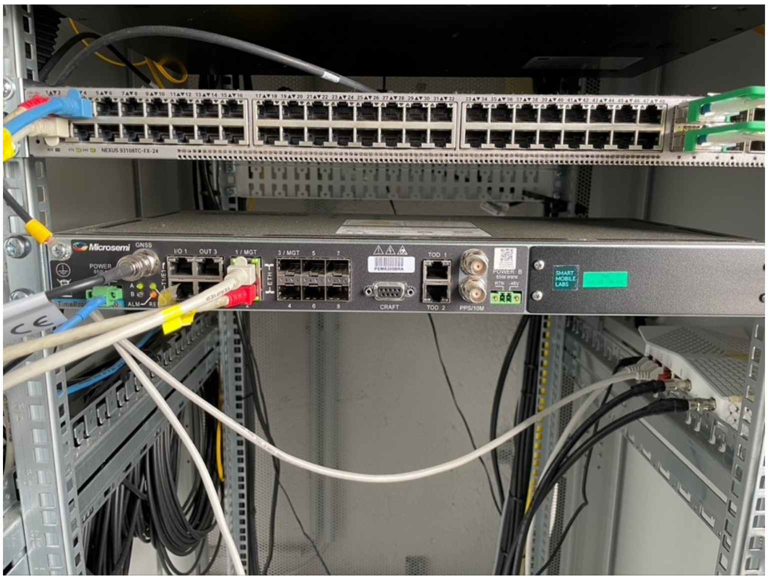

Figure 2-19 Leaf switch & PTP Grand Master Time Provider on the FOKUS roof

Figure 2-20 Satellite dish on the FOKUS roof

The **parking deck** of FOKUS offers 5G SA radio access as well as Wi-Fi-based access. For that, a Huawei- and a NOKIA-based infrastructure is deployed there. The installation can be configured to provide 5G access via several radio cells (see Figure 2-22). Both, the Huawei and Nokia infrastructure can be configured as such to provide up to two radio cells per manufacturer / BBU. This allows to assess intra-BBU handover as well as handovers between two BBU and two different RAN manufacturers. Like the roof, the parking deck is attached to the network spines in the data center via two spine switches deployed in the parking deck (see example in Figure 2-23). The network architecture of the parking deck deployment is illustrated in Figure 15 of D4.13 [14] (see Figure 2-21).

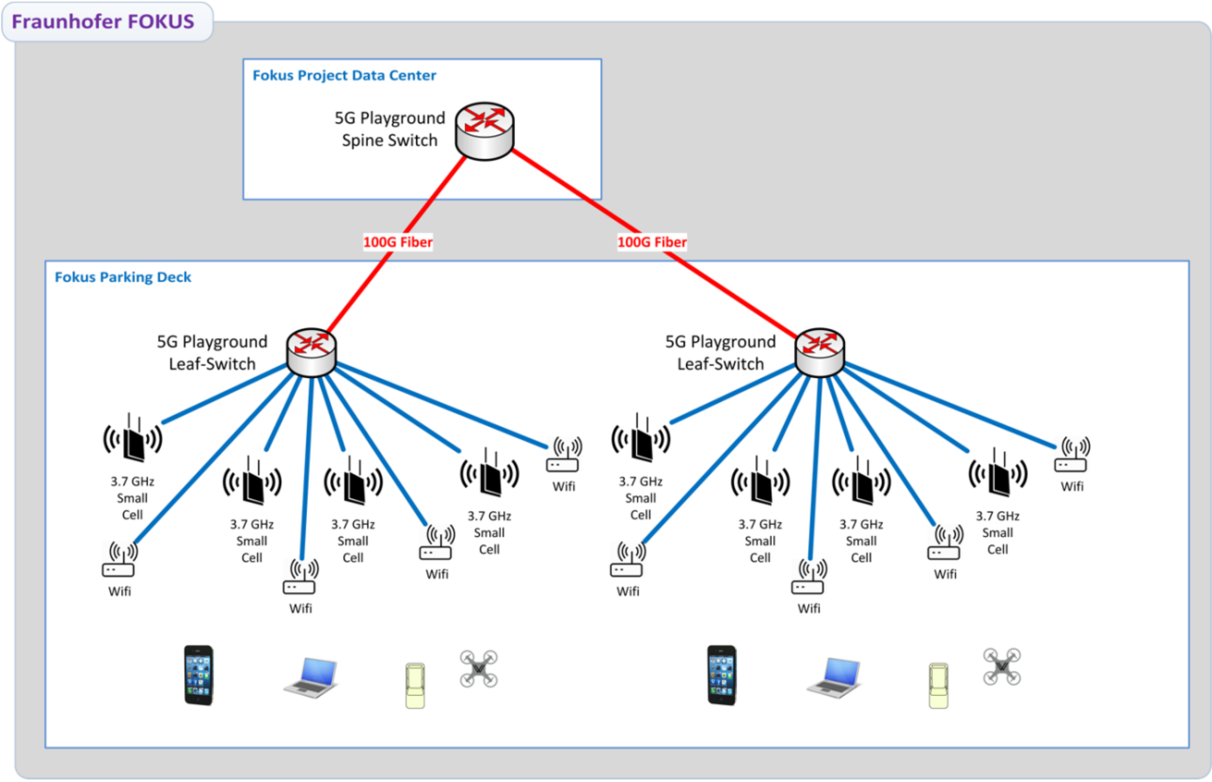

Figure 2-21: Network Components of the Parking Deck at the Fraunhofer FOKUS Site as depicted in Figure 15 of D4.13

Figure 2-22 Remote Radio Head deployed at the FOKUS parking deck

Figure 2-23 Leaf-switch, Huawei Radio Hub and Nokia Radio Hub deployed at the FOKUS parking deck

2.1.3. The IHP Site

The comprehensive description of the IHP site is provided in deliverable D4.13 [14]. The IHP testing site was initially intended for indoor and outdoor testing of millimeter wave (mmWave) links within the Berlin platform prior to the final installation in Berlin.

The description of indoor mmWave setup at IHP was provided in deliverable D4.14 [3], and deliverables D6.1 [16] and D6.2 [17] reported the results of KPI (throughput and latency) evaluation with two different generations of proprietary 60 GHz hardware. More recently, IHP has deployed its own-developed 60 GHz wireless link outdoors. The hardware description, setup, and initial performance evaluation are described in deliverable D3.12 [13].

In 2021, the still ongoing COVID-19 Pandemic restrictions and related social distancing has resulted in the inability for the Berlin Platform members to have access and demonstrate the final UC co-located with the Festival of Lights 2021 in Berlin. In view of this situation, the 5GENESIS Berlin Platform decided to search for a new location for the final demonstration that is less prone to involving close contacts among people.

Simultaneously, as part of an invest external to 5GENESIS, IHP decided to build up a 5G campus that further extends the Berlin Platform in 5GENESIS. This upgrade in the IHP infrastructure allows running 5G NR related demonstrations to be carried out before the end of 5GENESIS. Moreover, it ensures the usability of the Berlin Platform in the framework of running ICT-19 5G-PPP projects (e.g., 5G-VICTORI) and also in potential Horizon Europe projects. The network connectivity of IHP has been already updated to accommodate this addition, and the IHP 5G campus will be deployed at IHP premises by the end of 2021 for hosting the final 5GENESIS

Berlin Platform trial, and it will be completed with additional sets of components by Jan/Feb 2022. The final 5G NR installation will involve two sets of 5G equipment that will be installed at the rooftop of IHP as indicated in Figure 2-24.

Taking all that into account, and after the assessment of the different possibilities to run the final 5GENESIS Berlin Platform demonstration, we decided to choose the IHP site to conduct the final 5GENESIS demonstration. The reasoning for these decisions stems from the location of IHP: suburban area that ensures social distancing in big open spaces. The infrastructure provided by the IHP testfield HW&SW components can be flexibly deployed across different parts of the infrastructure, being three locations within the IHP site chosen for the 5GENESIS final demonstration (see Figure 2-24):

- the edge data center, which is based on the FOKUS datacenter, deployed at Wing A,
- the roofs of wings A and C, where the mmWave and 5G NR equipment will be installed, and
- the entrance of IHP and the parking deck, where the Wi-Fi access point(s), 360º camera and users with 5G handsets will be experiencing the 360º service (see section 3 for more details).

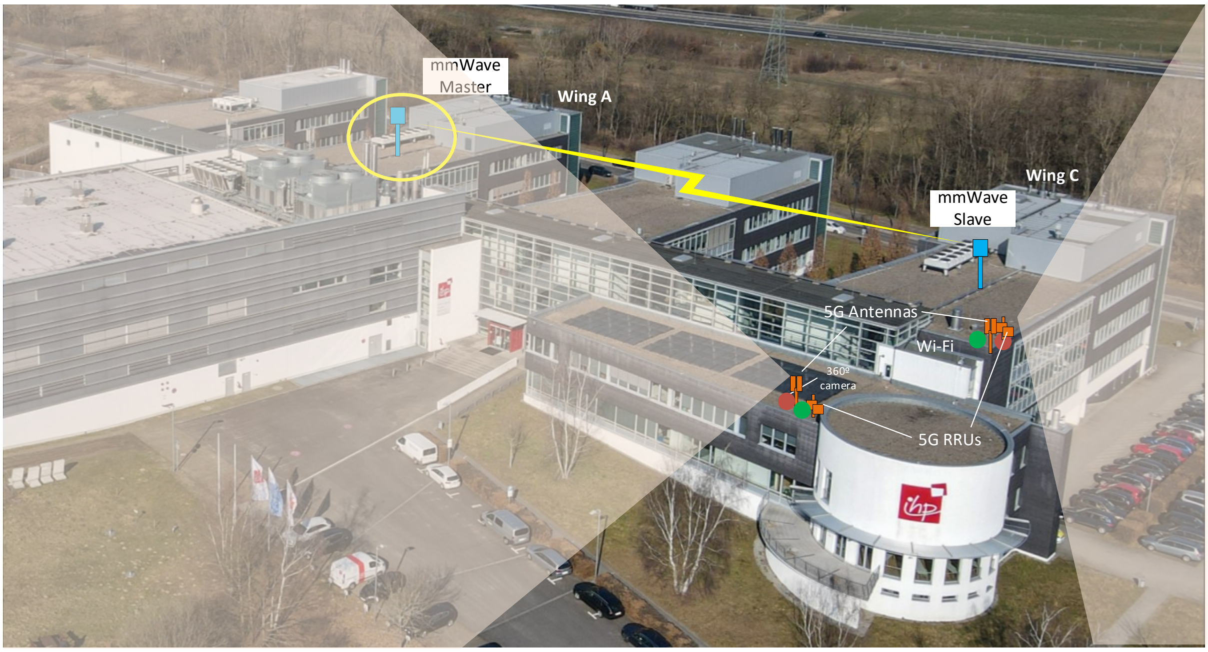

Figure 2-24 IHP's 5G Campus network supported by mmWave backhaul

2.1.3.1. IHP's 5G Campus Network

IHP will deploy a 5G NOKIA-based infrastructure (BBU+RRU+RRH) at IHP's premises to upgrade the network infrastructure and to integrate the RAN network with the existing terrestrial wireless backhaul sets available in-house [13]. Two sets of 5G equipment will be available for running the experiments, and are compatible to those deployed at Fraunhofer FOKUS and presented in Section 2.1.2. By the time this document is delivered, fiber, Ethernet and power has been provided to the different spots where the mmWave/5G equipment will be hosted at the different wings. The flexibility of deploying HW and SW components allows different configurations of the network infrastructure.

Examples of the connectivity for the final demonstration in two different scenarios are depicted in Figure 2-25 and Figure 2-26. The former assesses the Open5GCore connectivity over the mmWave link installed at the roof, the latter provides connectivity to the video server over the mmWave link.

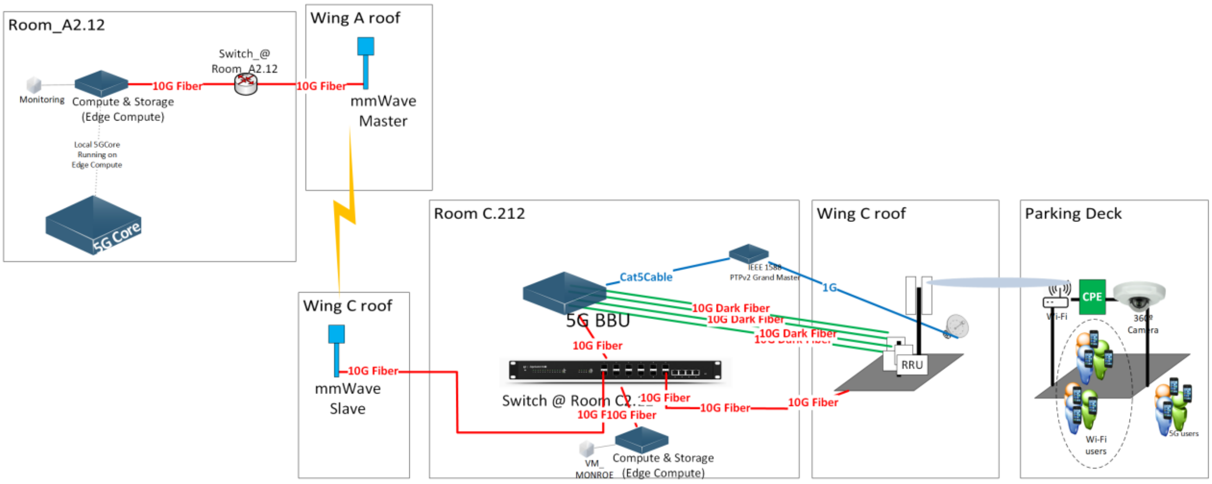

Figure 2-25 5G and mmWave deployment for the 5GENESIS Berlin Platform final demo (possibility #1)

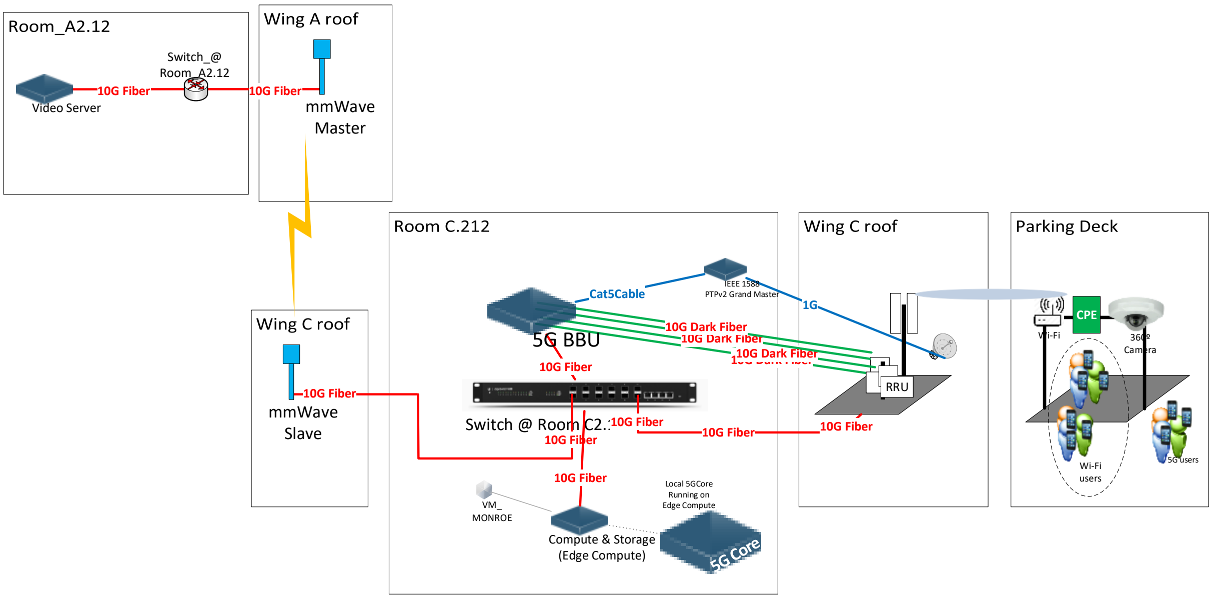

Figure 2-26 5G and mmWave deployment for the 5GENESIS Berlin Platform final demo (possibility #2)

2.1.3.2. Outdoor mmWave Connectivity

To date, the IHP site deploys a proprietary 60 GHz link on the roof, connecting two wings of the building (see deliverable D3.12 [13] for additional details). The updated network connectivity diagram is shown in Figure 2-28. Each 60 GHz device is connected to IHP internal network infrastructure via a one-gigabit (1G) fiber link. The 1G fiber link is configured as a trunk. The 60 GHz devices are equipped with an internal 6-port 1G Ethernet switch, whose ports are VLAN tagged as data, management or trunk. The management link allows access to the device and different peripherals for control and management, whereas the data link is used for data communication. An interested reader can find more information about the 60 GHz device, its peripherals, and internal connectivity in deliverable D3.12 [13].

Two Linux-based measurement stations (high-performance computers) are available for KPI evaluation, as reported in D6.1 [16] and D6.2 [17]. One station remains located in the mmWave laboratory (A wing) and has a data VLAN connection to the 60 GHz device on the roof of wing A. The second station is located in the server room of wing B and is connected to the 60 GHz device on the B wing roof via a data VLAN link. Currently, access to the second station is possible only through the data VLAN (via 60 GHz link). We plan to install by the end of October an additional network interface card (NIC) for accessing the second Linux station through the management link as well.

The outdoor deployment is shown in Figure 2-27.

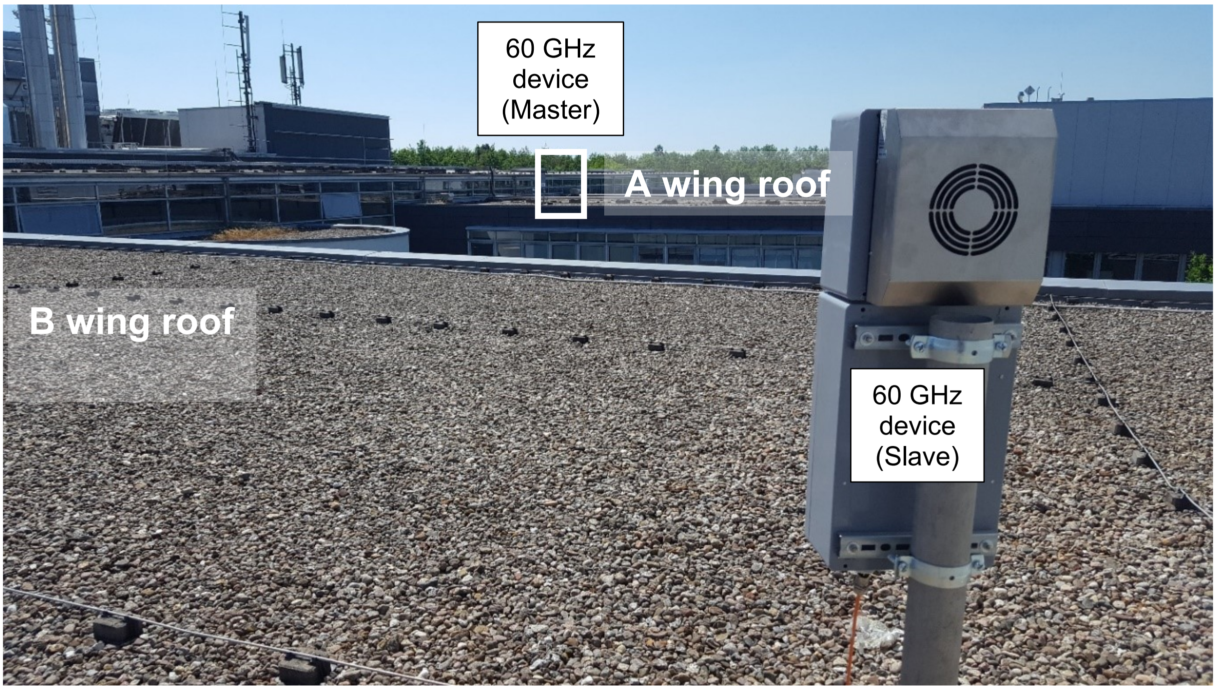

Figure 2-27 A proprietary 60 GHz wireless link installed at the roof of IHP

At the beginning of November 2021, at the time the deployment of the 5G equipment for the final demonstration takes place, IHP will set up the third mmWave device at the roof of Wing C, which will support the wireless connectivity over a distance of 65 meters to the 5G NR system installed at this wing.

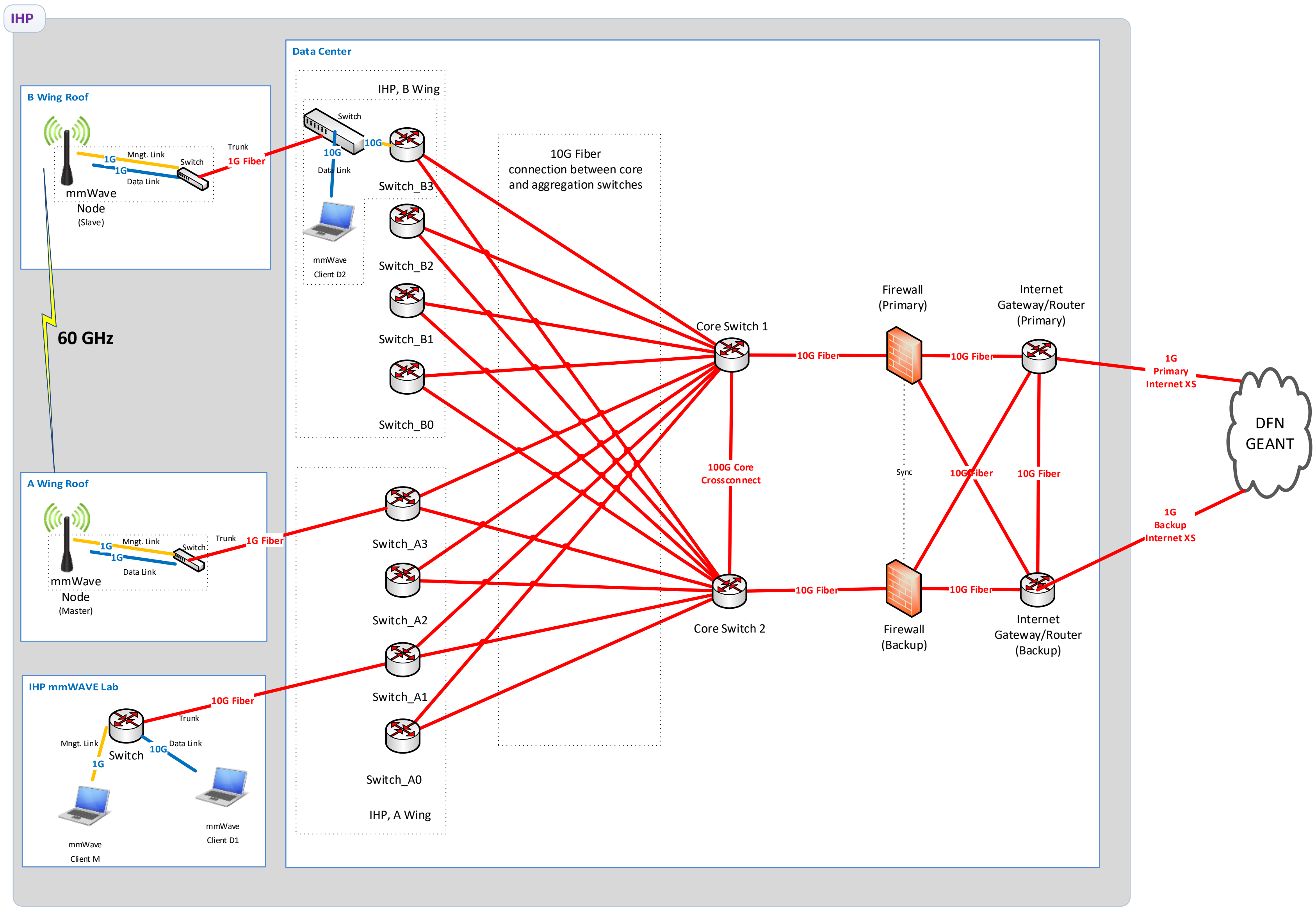

Figure 2-28 The network connectivity diagram including an outdoor 60 GHz wireless link

2.1.4. The Humboldt University Site

The HU site is one of the most prominent sites for witnessing the Festival of Lights Event. This event, organized each year in the city of Berlin in October, was disrupted due to the COVID-19 outbreak in 2020. The plan of the Berlin Platform was to demonstrate the 360º video UC at the main building of the Humboldt University in 2021. However, by summer 2021, the still existing uncertainties about whether the festival will take place or not, together with the unknown restrictions for visitors to gather in the outer part of the building, led us to seek for an alternative site for the final demonstration.

The Festival of Lights 2019 HU setup was actually a nomadic /mobile node deployed outdoors and connected to the main building of the HU via mmWave. HU was then interconnected via VPN with Fraunhofer FOKUS. The demonstration was a success and the details of this integration effort and trial in October 2019 was included in deliverables D4.14 [3] and D6.2 [17] [20].

The same principle of the 5G nomadic node can be used at other locations for future projects, which is already being assessed for deployment in the ICT-19 5G-VICTORI project.

2.2. Platform Deployment Setups

Table 2-1 summarizes the evolution of the Berlin Platform from Release B towards its final Release C. It should be noted that the Berlin Platform went through major upgrades within the final phase of the project. The delivery of new core network components and the 5G SA installation at the Berlin Site were - due to the COVID-19 outbreak - delayed and hence shifted into the first part of the final project Phase. The major upgrades from the platform include:

- Replacement of the entire core network infrastructure towards a 100 Gbps application centric leaf-spine architecture,
- Migration of the core cloud infrastructure to a high-performance storage and compute system,
- Permanent deployment of 5G SA radio unit at the Fraunhofer FOKUS site, providing indoor and outdoor coverage.

Additionally, Table 2-1 provides an outlook on planned additional extensions of the Berlin Platform to extend its capabilities to satisfy ongoing and future research activities.

Table 2-1: Berlin Platform final deployed status and extension plans

	5G Products / Technology Options		
Description	Release B	Release C	Future extensions
Core Cloud	OpenStack	OpenStack & Cisco ACI	
Edge Cloud	OpenStack	OpenStack	
Edge Locations	2 (IHP & HU)	3 (addition of FhG IPK)	4 (addition of Berlin Central Station)
MANO	OpenBaton	OSM	
NMS	TAP	TAP	
Monitoring	Prometheus	Prometheus	Keysight Hawkeye

3GPP Technology	5G SA	5G SA	
Non-3GPP technology	Wi-Fi	Wi-Fi	LiFi
Backhaul	Satellite, commercial 60GHz at Fokus and HU, 60GHz lab set-up at IHP	Satellite, commercial 60GHz at Fokus and permanent 60GHz deployments at IHP	2nd satellite link
Core Network	Open5GCore	Open5GCore	
RAN	Huawei and Nokia loans for pre-commercial testing	Huawei, Nokia (indoor and outdoor deployments)	Open RAN technology
UE	UE emulation	COTS UEs	
Network infrastructure	Dell switches	Cisco ACI 100Gbps backbone; Dell switches	
Compute and Storage	Dell blades	NetApp Storage System and Cisco UCS Blade for high performance virtualization; Dell blades	
Inter-site connectivity	GEANT	GEANT & DWDM (100 Gbps)	

2.3. Platform Implementations

2.3.1. Overview

The Berlin Platform has been completed in Phase 3 according to the network architecture plans outlined in deliverable D4.13 [14]. The following figures of the network architecture hence describe the final platform implementation of Release C:

- Overall infrastructure at the FOKUS Site (c.f. Figure 13 in D4.13)
- Roof deployment at FOKUS Site (c.f. Figure 14 in D4.13)
- Network Components of the Parking Deck at the FOKUS Site (c.f. Figure 15 in D4.13)
- Network Components of the DWDM System at the FOKUS Site (c.f. Figure 16 in D4.13)
- Network Core Components of the IHP Site (c.f. Figure 17 in D4.13)
- Network Components to be evaluated in the lab at IHP premises (c.f. Figure 18 in D4.13)

In addition, during Phase 3 of the project, a further extension of the IHP Site was planned in order to provide as well 5G SA radio access on premise of IHP. Hence, the originally planned infrastructure was extended. Figure 2-29 provides the updated network architecture of the IHP Site.

The following sections provide a summary of the technical specification of the infrastructure available in the Berlin Platform as of Release C.

2.3.2. Platform Infrastructure Layer

2.3.2.1. Main Data Center

The main data center located at the FOKUS Site hosts the main compute and storage infrastructure of the Berlin Platform.

For compute and storage, a CISCO UCS mini and VMware vSphere with IP-based data storage is deployed. The attached storage unit is a NetApp AFF A220 storage system directly attached to the UCS mini. In total, the systems feature 12 CPU units (providing 192 compute cores) with 2048 GB RAM; and 23.040 GB attached flash storage.

Technical details of the systems are given as follows:

CISCO USC mini, equipped with:

- Six (6) B200 M5 compute blades
- Configuration of *each* blade:
  - Two (2) CPUs (2.1 GHz Gold 6130 16 Core CPU with 22 MB Cache)
  - 256 GB RAM (via eight (8) 32GB DDR4-2666-MHz RDIMM/PC4-21300/Dual Rank RAM modules)

AFF A220 Flash-Storage system, equipped with:

- Twenty-four (24) flash SSDs
- Each SSD providing 960 GB storage
- Total available storage: 13 tebibyte (TiB)

2.3.2.2. Edge Data Center

The edge data center is unchanged with respect to Release B of the platform. It is based on servers deployed at the IHP Site as well as within the nomadic node used for the field trials executed at HU. The only change for Release C of the Berlin Platform was the installation of the components into a ruggedized, mobile rack to allow deployments in the field (see Figure 2-30, Figure 2-31 and Figure 2-32).

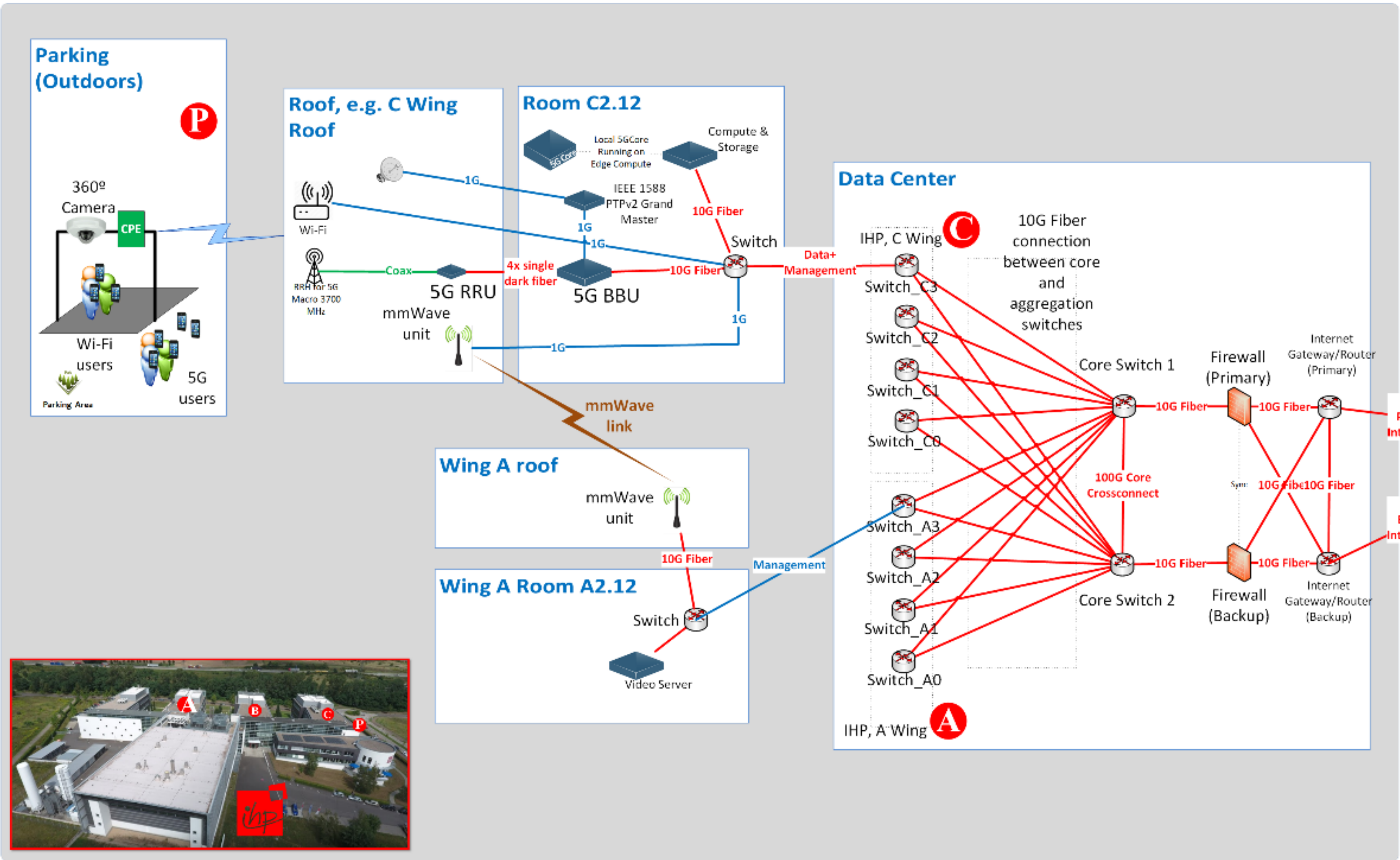

Figure 2-29 Extension of the IHP Site to provide 5G SA radio access capabilities

Figure 2-30 Compute storage and switching

Figure 2-31 Front view of the compute storage and switching with UPS

Figure 2-32 Back view of the Ruggedized, mobile edge data center with power-supply

The main focus when designing the system components for the portable edge data center was – in addition to providing a compute and storage unit – to make available a variety of network interfaces to connect various end-systems to. Specifically, we encountered the need for shielded-twisted-pair connections with and without power over Ethernet (PoE) capabilities, as well as interfaces for fiber-based connections ranging from 1 to up to 100 Gbps line speed. The technical details of the components are given as follows:

Dell PowerEdge R640 Rackserver:

- Motherboard: PowerEdge R640 Motherboard
- Processor: 1x Intel(R) Xeon Gold 6146:
    - Base Frequency: 3.2GHz
    - Turbo Frequency: 4.2GHz
    - Cores/Threads: 12C/24T
    - Transfer rate: 10.4GT/s
    - Cache: 24.75MB L3
    - Thermal Design Power (TDP): 165W
    - Memory Types: DDR4-2666
    - Lithography: 14nm
- Memory: 4x 16GB RDIMM, 2666MT/s, Dual RankStorage:
    - 10 2.5” hot-swappable disk bays
    - 5x 240GB SSDs SATA Mixed Use 6Gbps 512e 2.5” Hot Plug S4610 Drive
- Interfaces:
    - 1 RJ45 1GbE OOB management interface
    - Intel X710 Quadport: 4 SFP+ 10GbE interfaces
- PSU: 1x750W

Dell EMC PowerSwitch N3024EP-ON:

- **Interfaces:**
    - 12x RJ45 10/100/1000Mb PoE+ (up to 30.8W) auto- sensing ports
    - 12x RJ4510/100/1000Mb PoE 60W auto-sensing ports
    - 2x SFP+ 10GbE ports
    - 2x GbE combo media ports
    - 1 RJ45 1GbE OOB management interface
    - 2 Mini-SAS 21Gbps dedicated rear stacking ports
- PoE+
- Power Consumption Max: 1287W (during loading of batteries)

Dell EMC PowerSwitch N3024EF-ON:

- Interfaces
    - 24x 1000-SX (up to 500m distance) or 1000-LX (up to 10km distance) SFP GbE ports
    - 2x SFP+ ports
    - 2x GbE combo media ports
    - 1 RJ45 GbE Ethernet OOB management interface
    - 2 Mini-SAS 21Gbps dedicated rear stacking ports
- Power Consumption Max: 67.1W

Dell EMC S4112F-ON:

- Interfaces
    - 3 QSFP28 100Gbps Ethernet interfaces
    - 12 SFP+ 10Gbps Ethernet interfaces
- Switching Capacity 840 Gbps
- Throughput 630 Mpps
- Power consumption 180W

The N3024EF/P switches are interconnected via a dedicated backplane. The S4112F-ON is from a different product line and does not support the backplane stack connection to the N3000 series switches out of the box. It was therefore connected to the other switches via an aggregated link of SFP+ front-ports.

Additionally, the mobile edge data center provides two uninterruptable power supply (UPS) units, which are also mounted in ruggedized portable rack cases. The units allow to operate a small-scale deployment in-the-field for approximately 1.5 hours, in case of external power outage. Figure 2-33 shows one of the UPS units in its rack.

Figure 2-33 Front-view of the power supply in the Ruggedized, mobile edge data center

Each of the portable UPS units consists of a Smart UPS and two battery modules. Both units can hold up to 5 replaceable batteries. The specific hardware installed is listed in the following:

- 1xSchneider Electric APC SRT1500RMXLI Smart UPS
  - Input Voltage: 220-240V
  - Output voltage: 230V
  - Maximum configurable power: 1500W
- 1xSchneider Electric APC SRT1000RMXLI Smart UPS
  - Input Voltage: 220-240V
  - Output Voltage: 230V
  - Maximum configurable power 1000W
- 2xSchneider Electric Smart UPS Network Card (RJ45 1Gbps Ethernet)
- 4xSchneider Electric APC SRT48RMBP Smart UPS external battery module 1kW/1,5kW
- 10xSchneider Electric APCRBC155 replaceable lead-acid battery

The units together can supply up to 2500W of power to consumers. Based on the installed PSU's ratings, the total draw of the mobile node should not surpass P_MAX= 2x750W + 3x200W

= 2100W. However, the average power draw can be significantly lower because the number of PoE devices will be limited and hence the PoE switch will consume less.

Aside the portable edge data center available for field-trials, the Berlin Platform includes compute and storage units located at the IHP site (see Figure 2-34). They are mainly available to allow for a local deployment of the UPF of the Open5GCore for 5G SA radio components deployed at IHP.

Technical Specifications

- Intel® Core™ i9-7980XE Extreme 2,6 GHz, 4,2 GHz Turbo, 18C, HT, 24,75 MB Cache (165 W) DDR4-2666,
- 32 GB DDR4-UDIMM (2 x 16 GB), 2.66 6 MHz,
- Intel® X550-T2 10-Gigabit-Ethernet-Network Card, 2 Ports, Copper

Figure 2-34 Edge compute and storage unit at IHP site

2.3.2.3. Transport Network

Leaf-Spine-based Application Centric Infrastructure

The core network components of the spine-leaf infrastructure are illustrated in the following figure. The figure also shows the compute and storage units (c.f. Section 2.3.2.2.).

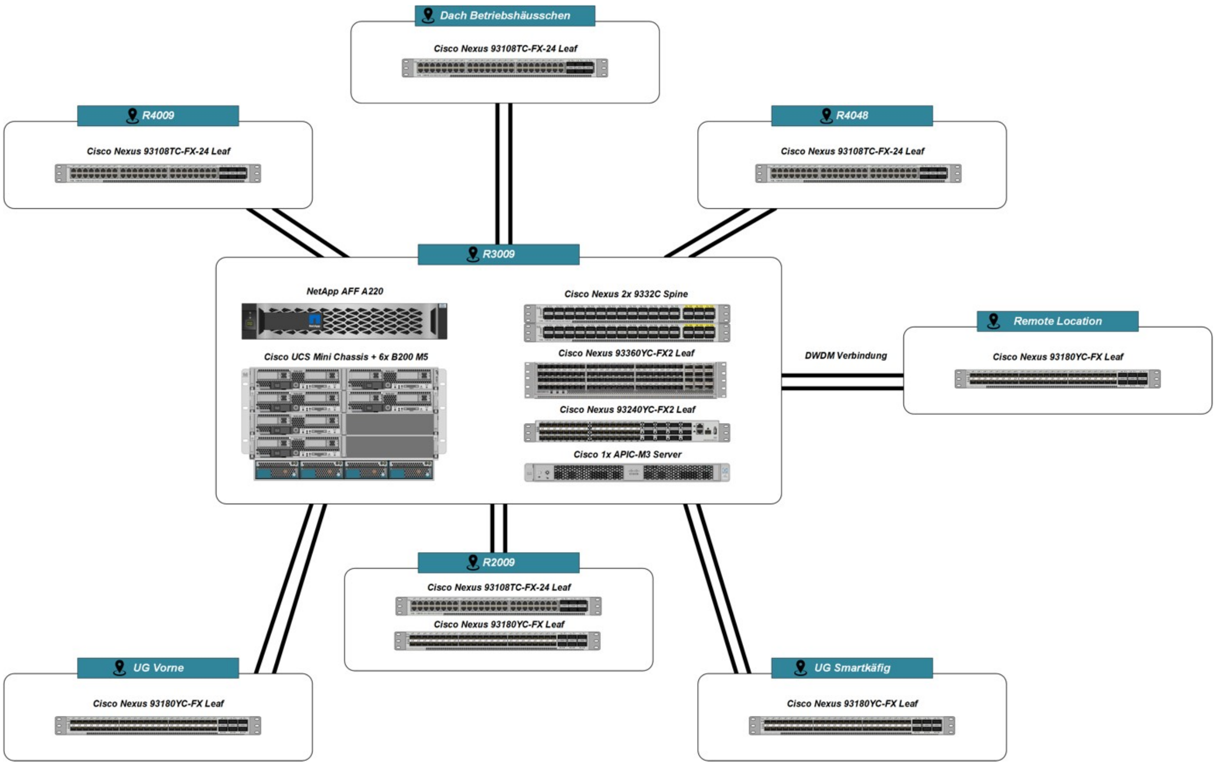

Figure 2-35 Spine-Leaf Deployment at FOKUS Site

Each leaf switch is attached via two 100-Gbps uplinks to each spine, thus having a total core switching capacity of 200 Gbps. It should be noted that the leaf switch denoted as "remote location" is connected via a wide-area fiber-based DWDM system, mimicking a location, which is geographically far away. This connection is realized via a long fiber-based connection, providing a long-haul loop, hence having the actual delay and transmission characteristics of a commercial wide are telco provider network.

The technical details of the spine-leaf network infrastructure are as follows:

Cisco Nexus 9332C Spine switches:

- Two spine switches, located in the main data center of the FOKUS site
- Each switch providing:
    - 32-port 40/100G QSFP28 ports
    - 2-port 1/10G SFP+ ports
    - Buffer: 40MB
    - System memory: 16 GB
    - SSD: 128GB
    - Management ports: 2 (1 x 10/100/1000BASE-T and 1 x 1-Gbps SFP)
    - Broadwell-DE CPU: 4 cores

Cisco Nexus 93360YC-FX2 Leaf switch:

- One leaf switch providing:
    - 96 x 1/10/25-Gbps fiber ports
    - 12 x 40/100-Gbps QSFP28 ports
- Located in the main data center of the FOKUS site, used to attach the ACI leaf-spine switching fabric to the following connections to remote locations
    - Fraunhofer Heinrich Hertz Institute:
        - 9 x 10 Gbps channels
        - 9 x 1 Gbps channels
    - Fraunhofer Institute for Production Techniques:
        - 9 x 10 Gbps channels
        - 9 x 1 Gbps channels
    - Remote data center (located at FOKUS, attached via long-haul DWDM fiber)
        - 2 x 100 Gbps channels (to connect the remote leaf switch)
        - 9 x 10 Gbps channels
        - 9 x 1 Gbps channels

Cisco Nexus 93180YC-FX Leaf switches:

- Located at the main data center of FOKUS. Attached to the spines via long-haul DWDM fiber connections to mimic a remote location attached via a DWDM telco operator network
- Providing:
    - 48 x 1/10/25-Gbps fiber ports
    - 6 x 40/100-Gbps QSFP28 ports

Cisco Nexus 93180YC-FX Leaf switches:

- Two leaf switches, located at the parking deck "UG" at the FOKUS site
- Each switch providing:

  - 48 x 1/10/25-Gbps fiber ports
  - 6 x 40/100-Gbps QSFP28 ports

Cisco Nexus 93108TC-FX24 Leaf Switches

- Two leaf switches located in the data center rooms on the 4th floor
- Two leaf switches located in the laboratory on the 2nd floor
- Each providing:
  - 24 x 100M/1/10GBASE-T ports (upgradable to 48 ports)
  - 6 x 40/100-Gbps QSFP28 ports

DWDM Deployment connecting additional remote locations

In addition to the leaf-spine-based core network, the FOKUS site features a DWDM system to connect the Berlin Platform to additional remote locations, which allow to use the platform outside the scope of 5GENESIS in other current and future research projects. The deployed connections are illustrated in Figure 2-36.

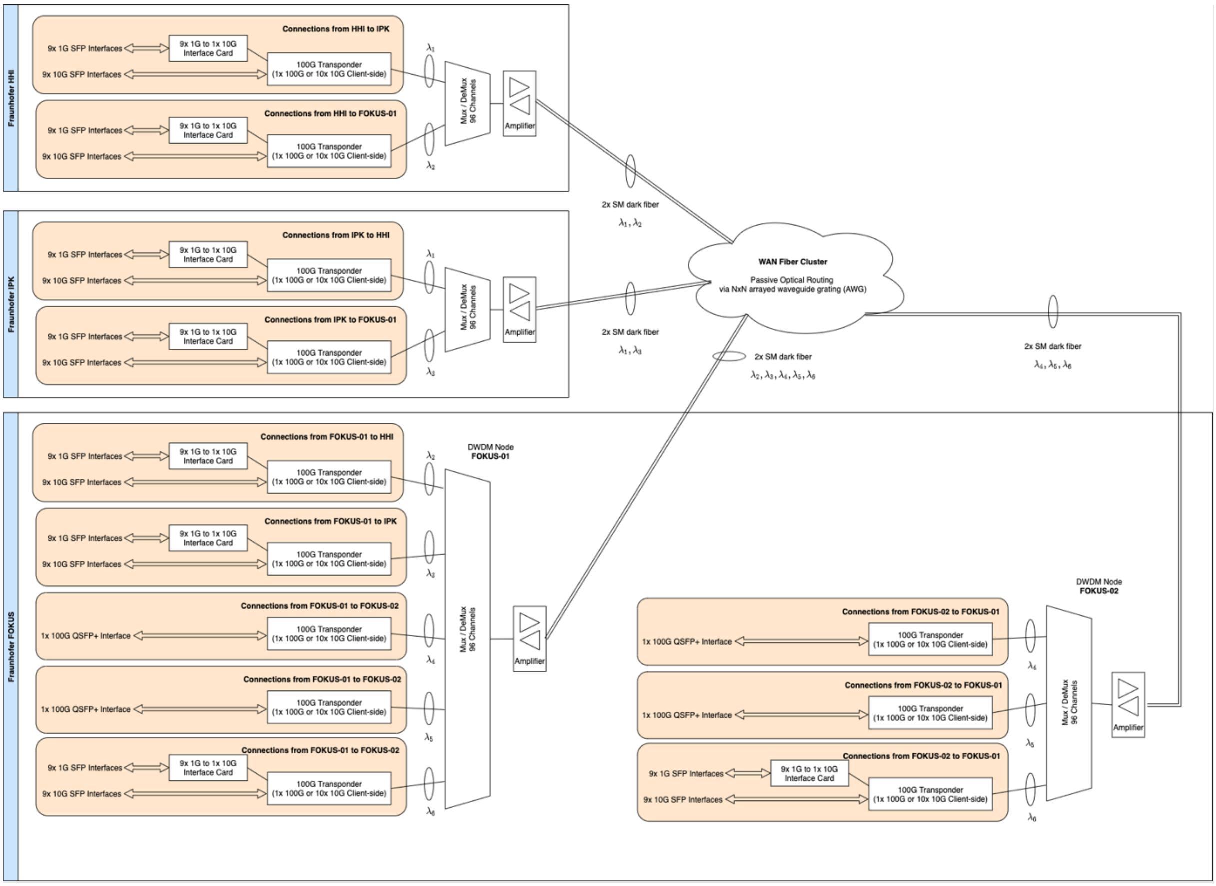

Figure 2-36 DWDM System deployed at FOKUS Site

At each location, i.e., at FOKUS-01, FOKUS-02 (remote), IPK, and HHI, the DWDM system consists of the following core components:

- Nokia 1830 PSS-16II Shelf
- Nokia SFD96 channel Multiplexer / Demultiplexer
- 2x Nokia AHPHG amplifier (line side, TX and RX direction)
- Power supply unit

In addition, the DWDM systems are equipped with:

FOKUS-01 system:

- 5x S13x100E interface cards (each providing either 1x 100G or 10x10G channels to connected DWDM systems.
- 2x 1G interface cards (each splitting one 10G channel into 9x1G subchannels).
- Additional 1830 PSS-16II Shelf.

FOKUS-02 system:

- 3x S13x100E interface cards (each providing either 1x 100G or 10x10G channels to connected DWDM systems.

HHI system:

- 2x S13x100E interface cards (each providing either 1x 100G or 10x10G channels to connected DWDM systems.
- 2x 1G interface cards (each splitting one 10G channel into 9x1G subchannels)

IPK system:

- 2x S13x100E interface cards (each providing either 1x 100G or 10x10G channels to connected DWDM systems.
- 2x 1G interface cards (each splitting one 10G channel into 9x1G subchannels).

Additional information on the system concept providing an DWDM-based interconnect between additional locations as well as additional information on the used hardware can be found in Section 5.2.4 of D4.13 [14] and Section 2.2.1.3-d of D4.14 [3].

GEANT-based interconnection between FOKUS and IHP Site of the Berlin Platform

The system concept and technical realization of the interconnect between the FOKUS and IHP Site are unchanged. Please refer to Section 4.3 in D4.13 [14] and Section 2.2.1 in D4.14 [3] for details.

60GHz backhauling at IHP Site

The terrestrial backhaul solution developed by IHP (cf. section 2.1.3.2.) has been assessed and the KPIs (throughput and latency) have been reported in deliverable D6.2 [17]. The solution has been finally deployed at the rooftop of IHP between A Wing and B Wing and another unit will be installed at C Wing to become part of the final demonstration.

Additionally, portable 60 GHz COTS units will be deployed at the beginning of November 2021 and their performance will be assessed against those developed by IHP. Back in 2019 at the festival of lights a backhaul link was established between the main HU building and the nomadic node (van) parked at the courtyard of HU [3]. This link was interconnecting the nomadic node with the network infrastructure of HU and, in turn, over the VPN connecting FOKUS and the HU.

2.3.2.4. Mobile Network Technology

(a) Radio Access

Available radio access technologies include Huawei- and Nokia-based 5G SA indoor and outdoor deployments at the FOKUS and IHP site. Additionally, the FOKUS site features a Ruckus-wireless-based Wi-Fi for non3GPP access. The technical details of the deployed components are given below.

Nokia-based 5G RAN at FOKUS site

Table 2-2: System Components for Nokia-based indoor and outdoor 5G SA coverage at FOKUS site

gNB14 (outdoor coverage)	Description
ASIK	System Module
ABIL	Baseband Unit
AZQH	Remote Radio Head
S4-90M-R1-V2	CommScope
AW3372	Alpha Wireless
gNB15 (indoor coverage)	**Description**
ASIK	System Module
ABIL	Baseband Unit
APHA/AsirMod1	ASiR Hub
APHA/AsirMod2	ASiR Hub
AWHQB/AM1AP1	5G Access Point
AWHQB/AM1AP2	5G Access Point
AWHQB/AM1AP3	5G Access Point
AWHQB/AM1AP4	5G Access Point
AWHQB/AM2AP1	5G Access Point
AWHQB/AM2AP2	5G Access Point
AWHQB/AM2AP3	5G Access Point
AWHQB/AM2AP4	5G Access Point

Huawei-based 5G RAN at FOKUS site

Table 2-3: System Components for Huawei-based indoor 5G SA coverage at FOKUS Site

FOKUS Building	Count
DBS5900 LampSite (NR 2 Cells) (NR:3500M; NR:100M; DC -48V, Indoor; NR:V100R002)	1

BBU5900 Box	1
Universal Main Processing & Transmission Unit (2 Electrical FE/GE&2 Optical FE/GE/XGE,UMPTe2)	1
Universal Baseband Processing Unit g2a	1
RHUB5923	3
DC Power Distribution Unit	1
pRRU5935,LampSite(TX3600~3800MHz/RX3600~3800MHz,TX3600~3800MHz/RX 3600~3800MHz,1000mW,inner antenna)	6
Embedded Telecom Power Subrack	2
Rectifier Module, R4850, 1U, 3000W, High Efficiency	2

Nokia-based 5G RAN at IHP site:

Table 2-4: System Components for Nokia-based indoor and outdoor 5G SA coverage at IHP site

gNB (outdoor coverage)	Description
ASIK	System Module
ABIL	Baseband Unit
AZQH	Remote Radio Head

Ruckus-based Wi-Fi components at FOKUS site:

Table 2-5: System Components for Ruckus-based Wi-Fi deployment at FOKUS site

Product name	Description
T710 outdoor AP	Outdoor Dual-band 802.11abgn/ax Wireless Access Point
R850 indoor AP	Dual-band 802.11abgn/ac/ax Wireless Access Point with Multi-Gigabit Ethernet backhaul, 8x8:8 streams (5GHz) 4x4:4 streams (2.4GHz), OFDMA, MU-MIMO
T750 outdoor AP	802.11ax Outdoor Wireless Access Point, 4x4:4 Stream, Omnidirectional Beamflex+ coverage, 2.4GHz and 5GHz concurrent dual band
SmartZone 3.0	SmartZone Wi-Fi AP controller appliance

Ruckus-based Wi-Fi components at IHP site:

Table 2-6: System Components for Ruckus-based Wi-Fi deployment at IHP site

Product name	Description
T750 outdoor AP	802.11ax Outdoor Wireless Access Point, 4x4:4 Stream, Omnidirectional Beamflex+ coverage, 2.4GHz and 5GHz concurrent dual band

(b) Mobile Core

Fraunhofer FOKUS operates the Berlin Platform's 5G SA networks, using its own Open5GCore: an implementation of a 3GPP aligned mobile core network that is aimed at research and development. Since the previous deliverable, the Platform's Open5GCore was upgraded to release 6 (Rel.6). With this release, Open5GCore evolved to further support the 3GPP specifications for the 5G core network defined in Releases 15 and 16. The Rel.6 provides several additional features and enhancements:

- Data path diversity
- Advanced session management
- Network slice support
- Non-3GPP access support
- An android UE application
- Overall improvements if 4G and 5G components
- Improvements to the Benchmarking tool
- An improved management UI

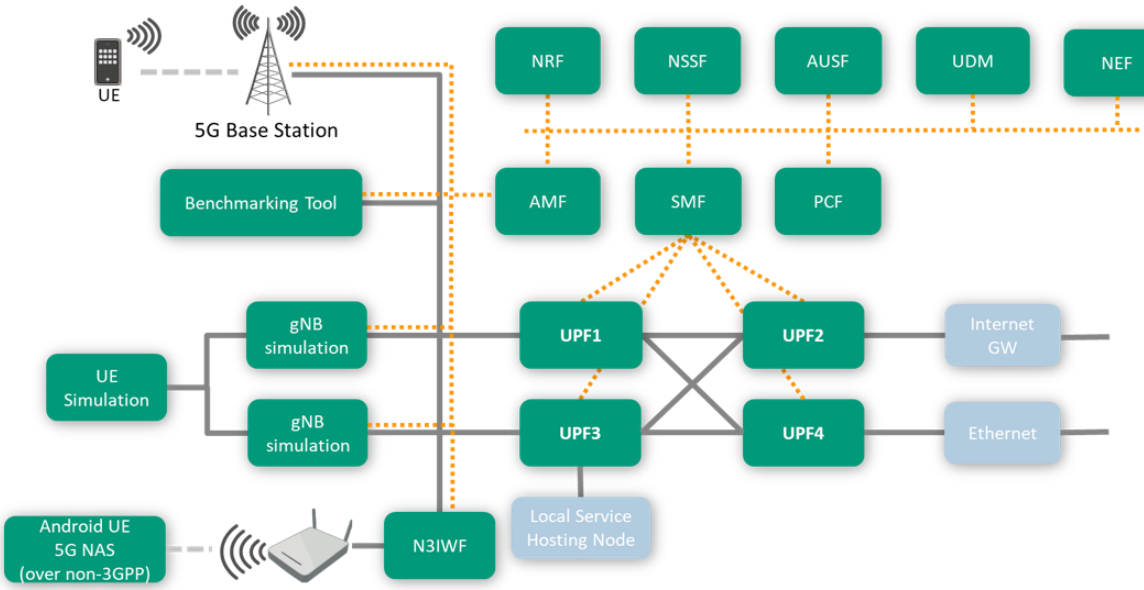

Figure 2-37: Open5GCore Architecture Components

The 5G NFs of Open5GCore Rel.6 are depicted in Figure 2-37. A few new NFs joined the ones already present in previous releases: The Network Exposure Function (NEF), the Network Slice Selection Function (NSSF) and the Policy and Charging Function (PCF). They complement and extend the functionality of Open5GCore, to enable more of the 3GPP standard features. The new features of Open5GCore Rel.6 have been further detailed in D3.10 [11].

Taking advantage of a microservice architecture, Open5GCore supports a variety of deployment options. The different NFs can be combined to meet the requirements of different scenarios, such as from a reduced set of NFs with a minimal footprint to distributed deployments spanning multiple locations, such as edge and central commonly referred to in

MEC. Figure 2-38 illustrates how the components can be split between edge and central locations in an MEC scenario:

- Local Offload: To provide local connectivity for AF, a UPF is deployed at the edge.
- Local Mobility: With the AMF deployed at the edge, it can provide mobility management features locally.
- Local Network: Adding an SMF to the edge side allows direct management of local connectivity sessions.
- Autonomous Edge Node: All the required components are deployed at the edge, to create an autonomous network with the UDM replicated on the central side.

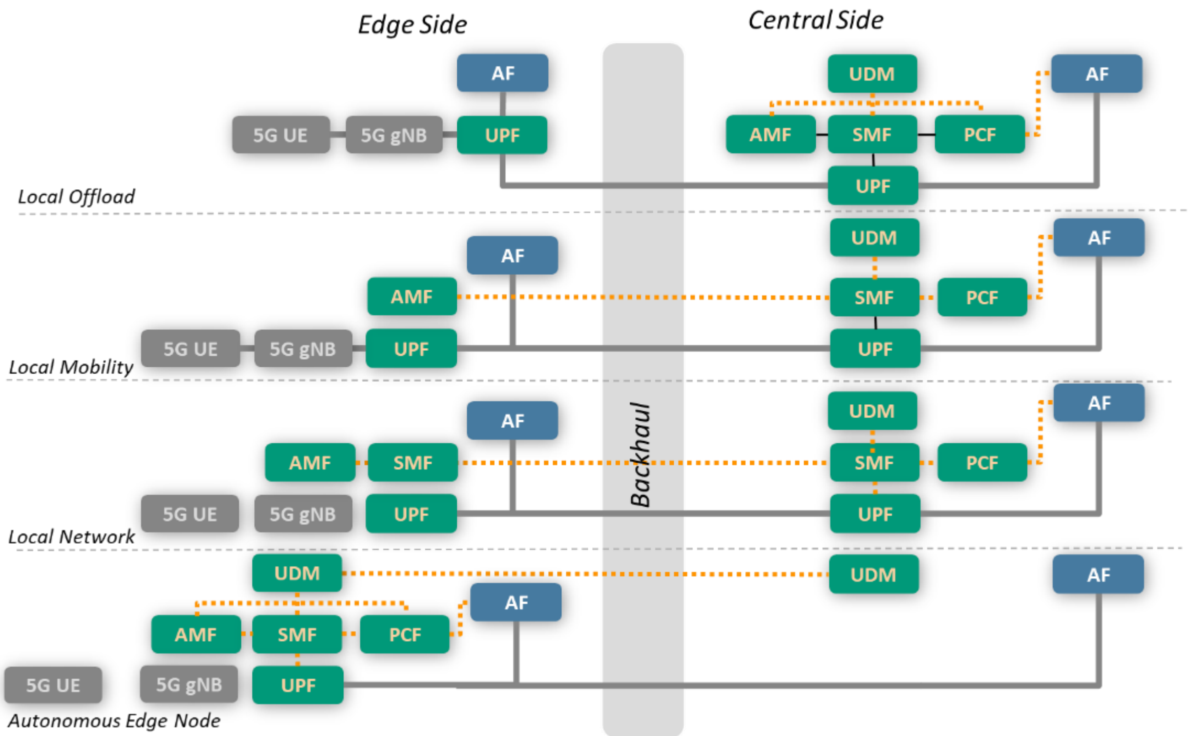

Figure 2-38: Open5GCore Edge and Central Side Deployment Options

2.3.3. Management & Orchestration Layer

As described in the previous deliverable D4.14 [3], the Berlin Platform switched from Open Baton to an industry wide standard – OSM, for its NFV MANO functionality. 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.

As part of this release, OSM Release 8 (in Ubuntu 18.04) was instantiated in the Berlin Platform. The Virtualization Infrastructure Manager (VIM) is provided by OpenStack, the standard de-facto VIM conformant to ETSI NFV specification. OpenStack simplifies the management of virtualized and containerized infrastructure by providing lean and simple process to manage and orchestrate.

The Slice Manager is common to all 5GENESIS platforms and is developed in WP3, specifically within Task 3.2 as described in D3.3 [6]. 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.

Table 2-7 provides an overview of the MANO layer components and associated technologies deployed in the Berlin platform.

Table 2-7: Berlin Platform MANO Components

Component	Product/Technology	Mode of Implementation
Slice Manager	Katana (Opensource implementation)	Custom development of a slice manager supporting 3GPP slicing information model
VIM	OpenStack	OpenStack ("Ussuri" release) at the core and OpenStack at the edge (all-in-one)
NFV Orchestrator	Open-Source MANO	OSM Release 8 supported – 2 instances

2.3.4. Coordination Layer

As described in previous releases (see D4.13 [14] and D4.14 [3]) and in other platform specific deliverables, the Coordination Layer is common to all 5GENESIS platforms. The corresponding software components are only instantiated per platform, i.e., they run independently on different OS / hardware configurations, but functionality-wise they are the same on every platform. The details for each component can be found in D5.4 [19], whereas the details of the integration tests (executed by each platform) can be found in D5.2 [18].

The components instantiated for the 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 Manage**r – Slice Manager provides management service for network slicing for different domains by communicating with South Bound components.
- **Dispatcher** - The 5GENESIS Dispatcher, an implementation based on a NGINX reverse proxy containerized in a Docker environment, is the entry point to the system, offering the functionalities to the Experimenter through OpenAPI interfaces.
- **Analytics Module –** This module provides methods for analyzing and offline learning on the data that is provided by the platform monitoring.

All above mentioned components are deployed into dedicated virtual machines (VMs), where for two components a co-location had to be used. The VM infrastructure (vSphere) is outlined in Section 2.3.2. It should be noted that in comparison to prior descriptions in D4.14 [3], the Phase 3 setup was adjusted to run all coordination layer components in a Linux-based operating system environment – including OpenTAP. Here, Ubuntu 18.04 was used for compatibility reasons. Each of the provided VMs were instantiated manually, with nearly the same configuration (of provided CPU, memory, and storage; as networking configuration).

The deployment of Coordination Layer components into the VM environment was executed using Ansible, an open-source software for Configuration Management (CM). To make this work, the installation procedures, as given by the integration tests documentation, were transferred into Ansible scripts. Since Ansible allows to separate installation procedures from actual deployment configurations (like into which VM a component should be installed in), each component can use dedicated Ansible scripts. That is: the co-location of two components can be achieved by adjusting the deployment configuration, not the component's installation scripts (refer Table 2-8).

Table 2-8. Installation Details of Coordination and Orchestration Layer Component

Component	Host	Environment	Notes
ELCM + OpenTAP	5genesis_elcmtap	Ubuntu 18.04	OpenTAP 9.12 ELCM v2.4.3
Portal	5genesis_portal	Ubuntu 18.04	-
Dispatcher	5genesis_dispatcher	Ubuntu 18.04	Release B
Slice Manager	5genesis_slicemanager	Ubuntu 18.04	v2.3.0
Analytics	5genesis_analytics	Ubuntu 18.04	Commit ID: 6cee1ea8d71e8ee11d
IperfAgent	(IP used only)	Ubuntu 18.04	Compatible to 5Genesis OpenTAP Plugins v2.0.2
PingAgent	(IP used only)	Ubuntu 18.04	-
MonroeVNAgent	(IP used only)	Ubuntu 18.04	Release A (due to stability issues)
OSM	(IP used only)	Ubuntu 18.04	Release 8

Additional components needed to be instantiated that are not specific components of the Open5Genesis Suite. For storing measurements, an InfluxDB database server was provided. To allow the ELCM executing deployment test an OSM (Open Source Mano) instance was provided. Furthermore, to allow for the execution of measurements, various measurement agents had to be provided.

Please note that while for a newer version of OSM Ansible scripts were provided, due to incompatibilities of provided integration tests, an older version of OSM was installed manually into the dedicated VM.

Not explicitly mentioned in the table but part of the Coordination Layer as well is a VM that is used for centralized control of the above-mentioned components (named "5genesis_ansible"). This VM allows for the Ansible-based deployments, as also acts as main DHCP server and entry point for management.

To validate the installation, the test cases are defined in D5.4 [19]. The executed test results from the Berlin Platform are provided in deliverable D5.2, Section ANNEX 1 [18].

2.3.5. Platform multi-tenant support

A key requirement when implementing Release C of the Berlin Platform was to simultaneously support multiple R&D projects making use of the platform's features. Despite the shared usage of the environment, the need to fully isolate each project in its own "walled garden" environment become obvious, mainly to satisfy security and legal requirements.

As such, the Berlin Platform utilizes the multi-tenant feature of the CISCO ACI core network infrastructure, which can provide fully isolated tenants.

While having the ability to use the virtualization features of the core network for multi-tenancy, the design of the platform had to consider that the 5G infrastructure needs to be accessible from all tenants, while preventing communication between tenants.

As a result, the following approach was taken:

Shared bare metal hardware, i.e., amongst others, the 5G SA RAN components, are placed in a dedicated tenant (named "pg330-admin"). In addition to those shared RAN components, this tenant includes as well means to connect to the external firewall and via that, access the internet.

If a tenant requires access to either the shared RAN equipment or Internet access, the owner (i.e., testbed operator) must explicitly export access rules from the administrative domain into a project tenant. Thus, the full and sole control for such access is solely by the testbed operator.

All other components of a project testbed are placed with the project tenant, hence providing a fully isolated and secured infrastructure for each project.

Figure 2-39 shows a blueprint of such a deployment. Though only one project tenant is depicted, it should be noted that multiple project tenants can be instantiated with the same generic tenant layout; and all tenants can be connected, if required, to the admin tenant for shared access to bare metal components; or reside in full isolation if only emulated RAN components satisfy the project tenant's need. For that, each tenant can deploy within its own administrative domain a dedicated deployment of a 5G core, mimicking an individual operator. Each core would then have its unique operator id, which would allow multiple core networks to attach to a single 5G radio baseband units, which as of today can support up to eight operators in parallel.

As shown in Figure 2-39, each tenant has its own "tenant network", which is used to attach any (application) servers to. The latter can be either bare metal machines provided by the project or virtualized machines. In addition to the tenant network, a full 5G network deployment is instantiated within a tenant. The realized architecture follows the design published by 3GPP to attach the 5G stratum to outside networks. For that, the UPF connect towards the outside networks to the Data / N6 network, which is gain routed towards the tenant network through a NATed data-network-gateway. This already represents a deployment as found in commercial telco network deployments: the tenant network represents the "outside world" (i.e., the Internet) where application servers are located. The N6 network connections within the operator's administrative domain one or several, potentially geographically distributed UPFs, and the NATed DN-gateway separates those administrative domains via NAT.

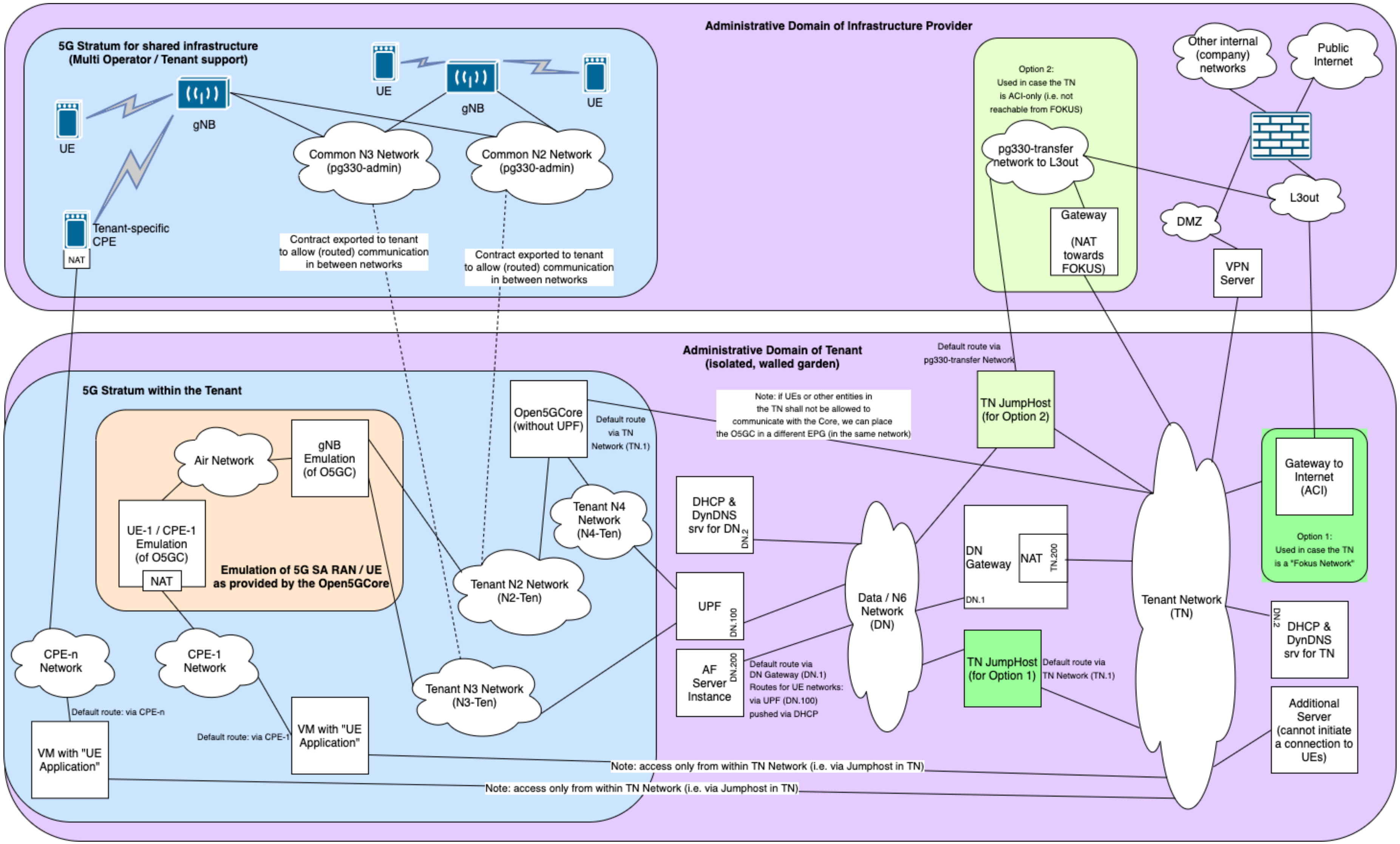

Figure 2-39 Network-centric view of the Platform's Multi-Tenancy Support

The main difference between the N6 network and the data network is that a server-side application cannot establish a connection towards UEs in the 5G stratum due to the NATing at the DN gateway, which is occasionally required, e.g., for industrial UCs. On the other hand, an application server placed within the N6 network may establish a connection to UEs; this can be achieved by dynamically pushing routes to the UEs IP addresses from the DynDNS server in the N6 network towards the application server. As such, the blueprint support two flavors of edge deployments of application servers: those residing close to the operator's gateway outside the operator's administrative domain, and those within the operator's administrative domain within the N6 network. For either of the two cases, UEs can always establish an initial connection towards the application server in either of the two networks.

Looking at the 5G stratum, each tenant has its own 5G core deployment. The core is connected towards the N4 network towards the UPF and towards the N2 network towards the shared radio infrastructure. For the latter, communication between the tenants N2 network and the N2 network in the administrative domain of the (testbed) infrastructure provider, i.e., the admin-tenant, is enabled. Besides the connection to real RAN components, the blueprint includes for each tenant as well instances of emulated gNBs and UEs, which are both provided as part of the Fraunhofer FOKUS Open5GCore. That allows each tenant to choose to use real radio components for experiments and/or emulated radio entities. This approach allows projects to test within their own, isolated tenant deployed services on the emulated radio infrastructure before migrating to real radio system. This feature is useful, as parallel usage of the physical RAN components becomes a bottleneck if more than eight users use the testbed infrastructure.

Finally, the testbed aims at fully supporting remote experiments. For that, a bare metal machine or VM may be attached behind either the emulated (CPE-1) or real (CPE-n) user equipment. That host can then run the user application; access to that host is possible from the tenant network to allow remote administration. It should be noted that in this set-up, the default routes on the CPE-side application machines are always set to go through the 5G stratum to guarantee that experiments run on the machines use the 5G-based communication path.

This network-centric view of the blueprint was transferred into an application-centric design employing virtual router functions (VRFs) to separate routing domains, bridging domains to separate broadcasting domains, and end-point groups containing communication end-points (here the VMs or bare metal servers). The special aspect of that application-centric view is that communication between any end-point group (and hence the servers within an end-point group) can be tightly controlled by communication contracts. Only servers can communicate with each other if they are with EPGs between which an explicit contract exists. This allows full separation of tenants even though two tenants have each a communication contract towards the shared infrastructure in the administrative domain. Communication between two tenants is prohibited as a direct communication contract does not exist between project tenants. The following figure illustrates the application-centric design derived from the network-centric view given in Figure 2-40.

The complete instantiation of communication components is fully automated in the Berlin Platform using CISCO UCS Director and allows to deploy a new project tenant on the Berlin Platform within less than five minutes.

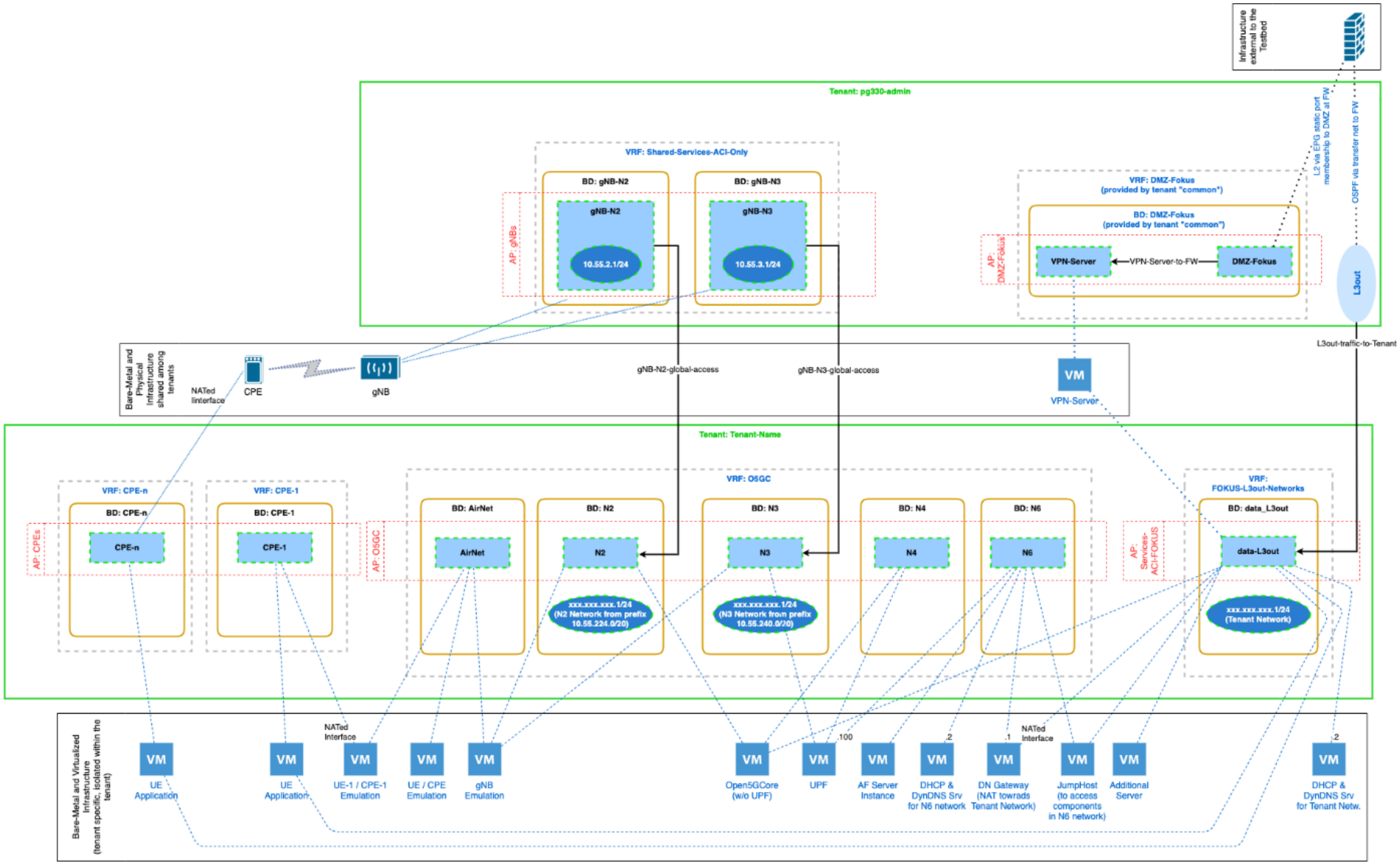

Figure 2-40: Application-centric view of the Platform's Multi-Tenancy Support

3. Use Cases-Specific Extensions

3.1. Use Cases Target Deployment: 360º video service

Over the duration of the 5GENESIS project, the Berlin Platform has addressed 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 360-degree video resources (i.e., live feed) during Festival of Lights event in Berlin.

Back in 2019, the 5GENESIS Berlin Platform did provide the eMBB 5G service by deploying several hardware/software core and edge components at different sites of the Berlin Platform (Fraunhofer FOKUS and HU) [3].

As explained in Section 2.1, the COVID-19 Pandemic and related social distancing has entailed the inability for the Berlin Platform members to have access and demonstrate the final UC co-located with the Festival of Lights 2021. Therefore, the location for the final demonstration needed to be reassessed and we finally agreed to provide it at a site (IHP) that is less prone to contacts among people.

3.1.1. Set up @ FOKUS Laboratory

360º videos allow a user to control the viewing direction in a scene. It has been selected as a target UC for the Berlin testbed as transfer of 360º videos over mobile networks are particularly challenging due to high bandwidth demand and risk of stalling. In addition to the final live demonstration at IHP (see Section 3.1.2), we use a setup at the FOKUS Laboratory to perform controlled experiments, allowing us to evaluate the video quality under different network settings and assessing the scalability of the solution. For the setup at FOKUS Laboratory we will use the MONROE measurement probe called 360-dash (described in Deliverable 3.6 [9]) that works as a 360º video client emulator.

The probe also measures the viewing quality of the video. For measurements, a video server will be connected to the testbed through Tenant network, seen as the pink box located at the right corner of Figure 3-1. Several 360º video files will be hosted at the server (running nginx). The client, 360-dash, runs within MONROE VN and will be connected in parallel both through the real 5G network via CPE-n network using the CPE (pink box to the far right in Figure 3-1) and to the emulated gNB provided by Open5GCore via CPE-1 network (pink box to the middle right in Figure 3-1). 360º videos hosted at the server will be streamed to the 360-dash clients. After each viewing of the video files, several performance metrics such as startup delay, quality switch, number of stalls will be recorded to measure the achieved viewing quality. The two data paths between the clients and the server are illustrated by the red lines in Figure 3-1. The parallel use of the two data paths will allow to increase the load on the 5G core part of the network. Several 360-dash clients may be run within each MONROE VN to increase the load and we may also use iPerf probes in parallel to further congest the network.

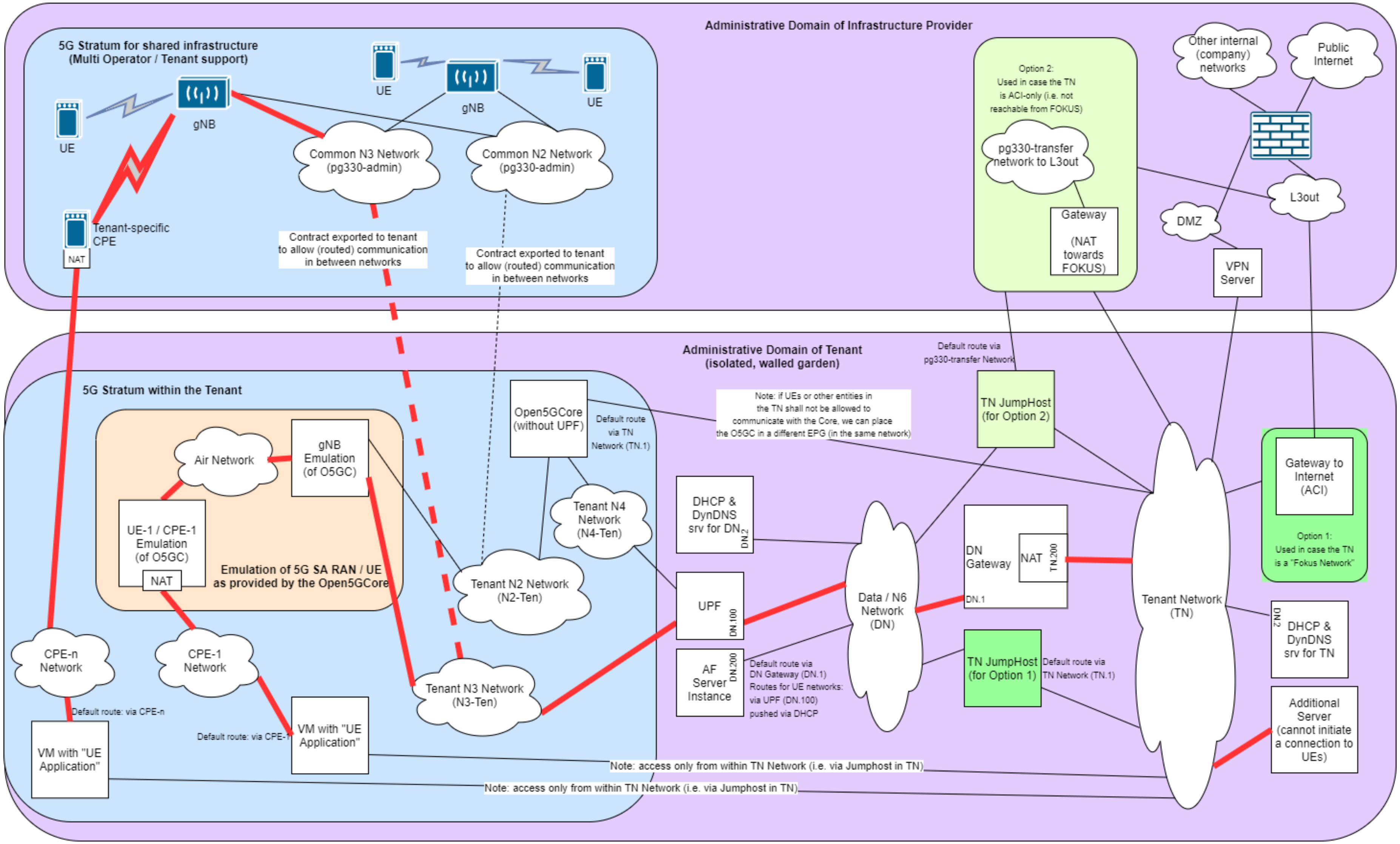

Figure 3-1: Communication path between User applications and Server application for 360' Video Use case

3.1.2. UC1: Set up @IHP

For the setup at IHP we will utilize the 360º video framework that has been described in detail in D4.14 [3]. The 360º video camera will be installed at a traverse gate that will be deployed at the parking deck. 5G connectivity (uplink) will be provided from the 5G CPE installed at the gate for providing the live feed of the camera. Downlink traffic will be provided by the 5G NR antenna at the rooftop to the various number of users witnessing the event at the parking deck.

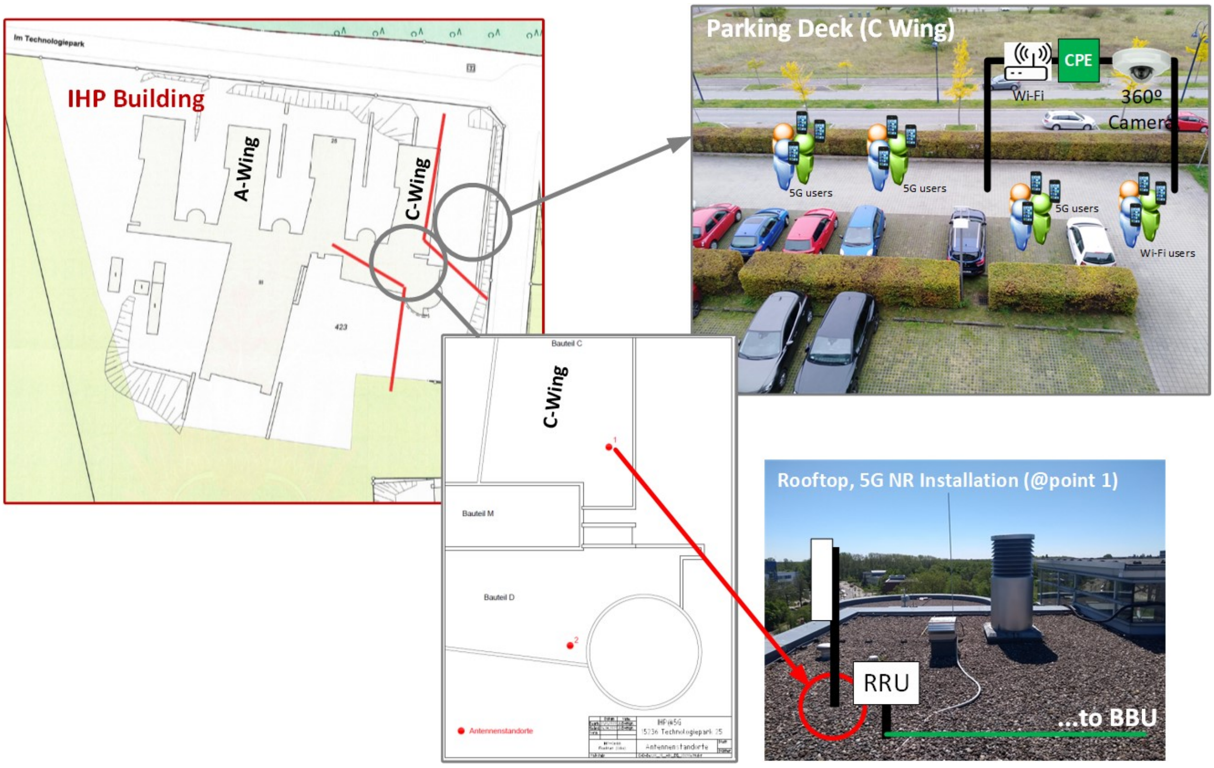

Figure 3-2 Deployment of the 5G NR at the rooftop and at the parking deck

To realize this framework, we will use a media server and a 360º camera with the following hardware configuration.

Media server

- Intel Core i7-7700K CPU
- 32 GB DDR3-SDRAM
- 1TB NVMe SSD
- Nvidia GeForce GTX 1080 graphics card
- 3×1000 Mbps Ethernet NICs

Media server

GPU (Nvidia GeForce GTX 1080p)

Vivotek FE9391-EV panoramic camera

- 12-megapixel CMOS sensor
- 30 fps frame rate
- (2816 pixels) resolution
- requires active PoE (802.3at Class 4)

For the tests at IHP, the goal is to assess the limits of the 5G network infrastructure. To achieve this, we plan to encode the videos at high quality resulting in high bitrates. We will further use a combination of 5G phones directly connected to the 5G network as well as some other phones that are connected to a Wi-Fi AP (installed at the gate as depicted in Figure 3-2), which will in turn be connected to the 5G Core. Apart from making available some 5G phones to connect to the 5G network, we also plan to generate some background traffic using open source tools such as iPerf or D-ITG to congest the network. More information on the setup and on the actual results stemming from the trial will be made available in deliverable D6.3.

3.2. 5GENESIS Berlin Platform future Use Cases

The 5GENESIS Berlin Platform is a key asset for those partners building up the main sites, i.e. Fraunhofer FOKUS and IHP. The work in 5GENESIS has given the opportunity to these partners of participating in successful project proposals that have led to the following R&I Projects:

- **H2020 ICT-19 5G-VICTORI**: the 5GENESIS Berlin Platform will be further extended towards Berlin Central Station (*Berlin Hauptbahnhof*), where three different trials will be executed concurrently targeting services like digital mobility, rail critical services and CDN services in static and mobile scenarios.
- **BMBF 6G SENTINEL**: the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung or BMBF) has funded this project, where Fraunhofer FOKUS is involved in this project in the development of a software-based, 6G-ready core network. More information can be found in https://www.fokus.fraunhofer.de/en/ngni/projects/sentinel-6g
- **BMBF 6G Hubs for Germany**: BMBF is funding the establishment of four hubs for research into the future technology 6G with up to 250 million euros. Fraunhofer FOKUS and IHP will be involved in two of them over the next four years:
  - the "6G Research and Innovation Cluster" (6G-RIC), pwhich ursues the goal of developing mobile radio systems with open interfaces across all technological boundaries. In addition to the actual technology development, the focus is on setting up a high-performance test infrastructure
  - and the Open6GHub, which is designing a holistic 6G system that will be resource-saving and energy-efficient, ensure the protection of personal data and guarantee high network availability.

4. BERLIN PLATFORM EVOLUTION IN 5GENESIS

4.1. Evolution Timeline for Phase 3 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 for the Berlin Platform is shown in Figure 4-1. It shows the functional blocks implemented and integrated in Phase 1, Phase 2 and Phase 3. The RAN and other radio components were not managed by 5GENESIS Framework due to security and IT infrastructure policies.

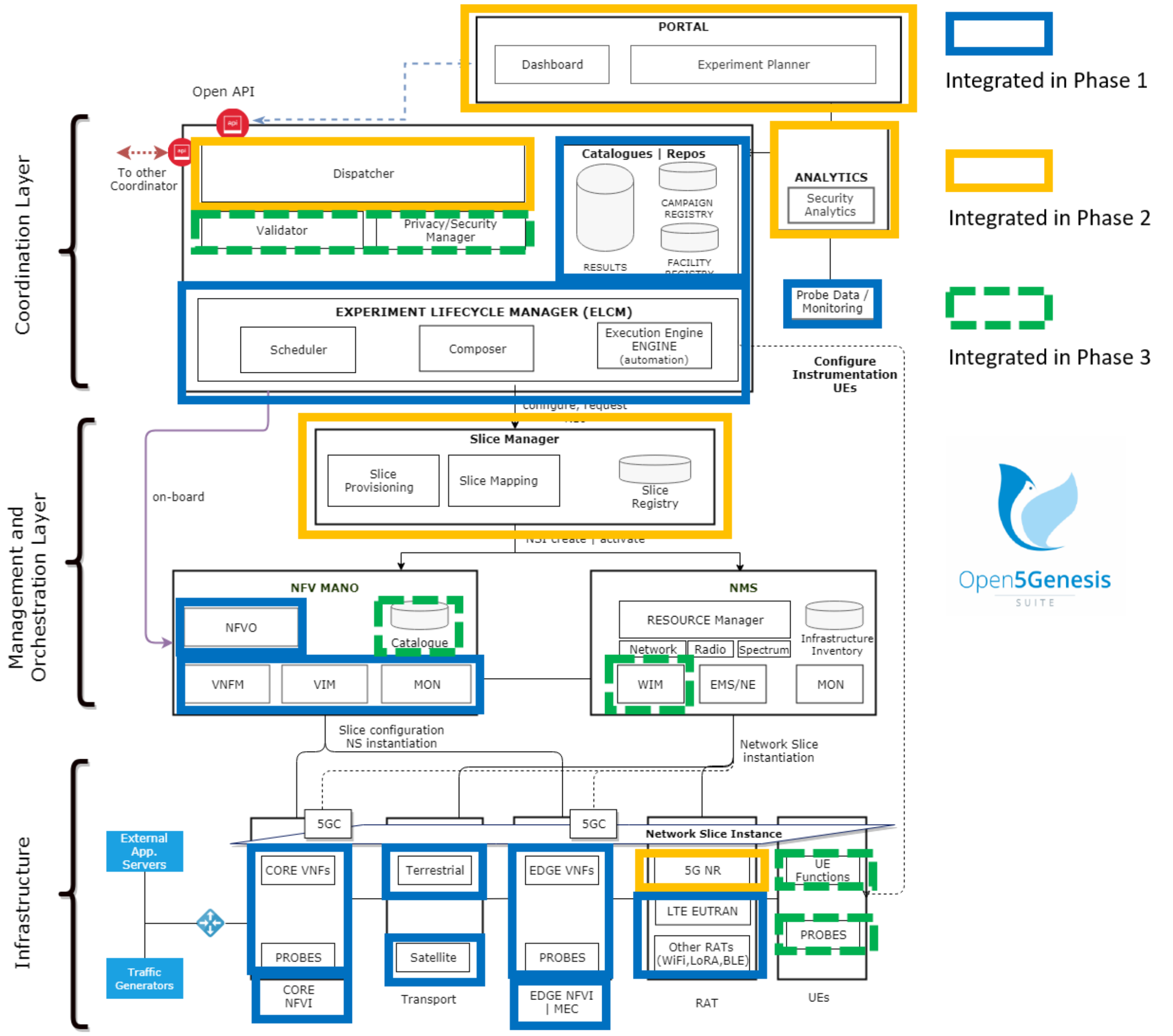

Figure 4-1 Instantiation of the 5GENESIS Architecture for the Berlin Platform

The Phase 3 exhibited the complete flavour of E2E 5G deployments with the integration of Open5GCore including network slicing, 5G radio units and other software components from the Coordination Layer that were integrated into the Berlin Platform. This allowed us to be able to do full E2E experimentation trials at the designated sites, so to realize the UC as described in D2.1 [1] (and in detail in Section 3.1) and validate the proposed E2E KPIs.

4.2. Phase 3 Accomplishments

For Phase 3 of the Berlin 5G Platform development, we achieved the following activities as planned during the previous Phase 2:

- Deployment of 100 Gbps Spine-Leaf-based switching infrastructure at the Fraunhofer FOKUS site.
- Deployment of Huawei- and Nokia-based 5G SA RAN in the parking decks, laboratories, and roof of the Fraunhofer FOKUS site.
- Deployment of additional compute and storage (Cisco UCS and NetApp storage cluster) supporting multi-tendency at FOKUS site.
- Extension of the non-3GPP access technology deployment at FOKUS site: addition of WiFi-based non3GPP access network.
- Deployment of IHP mmWave nodes outdoors in IHP.
- Extension of the Berlin Platform and the 5G capabilities to the IHP site. Deployment of 5G SA RAN at the rooftop of IHP.
- Continuous operation and maintenance of the Berlin site, including support for external users (projects) such as the 5G-VICTORI project.

5. CONCLUSIONS

This document presents the final release of the Berlin Platform in the 5GENESIS project. The platform consists of two main sites, one at Fraunhofer FOKUS and one at IHP. The entire platform architecture, as planned and documented in the previous two platform deliverables, was put into operation during this phase by installing a 100Gbps core network, 5G SA RAN of two manufacturers, a new compute and storage cluster, DWDM-based long haul connectivity, as well as Wi-Fi-based non3GPP access technology. With those upgrades, the Berlin Platform features an "operator-like" environment, which fully supports multi-tenancy to address the need of parallel usage of the platform by different users / research projects, each existing in a an isolated "walled garden" virtualized platform environment. Added automation – existing in surplus of the 5GENESIS testbed framework – allows within approx. five minutes to deploy isolated testbed environments for new projects using the platform.

In addition to those upgrades of the Berlin Site, the network architecture and components were specified to further extend 5G SA capabilities at the IHP site, to be used for the final large-scale experiments. By these extensions, the Berlin Platform added in Phase 3 the capability for extensive tests occurring at one location and involving advanced 60 GHz backhaul technology developed by IHP and 5G SA commercial off-the-shelf RANs.

Along with those fundamental advancements of the platform's infrastructure, the Berlin Platform fully instantiated for the 5GENESIS tenant the project's testing and automation framework used to execute Phase 3 experiments of the project.

The outcome of the final phase of the Berlin Platform upgrade allows for automated KPI validation. Besides, the platform's architecture provides a blue-print for designing 5G SA testbeds, which acted in part as a baseline for additional testbed deployments that occurred outside the scope of the 5GENESIS project.

The remaining phase of the project will be dedicated towards extensive testing of the new components and functionalities added to the platform, which will occur as part of WP6 activities.

As the Berlin Platform will be used in the future for ongoing ICT-19 projects, industry projects, and Lighthouse projects of the German Federal Ministry for Education and Research and of the German Federal Ministry for Economic Affairs and Energy, the operation of the Berlin Platform will continue.

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