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

[H2020 - Grant Agreement No. 815178]

Deliverable D3.10

5G Core Network Functions (Release B)

Editor ATH (Athonet Srl)

Contributors ATH (Athonet Srl), FhG (Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.), UNIS (University of Surrey), FON (FON Technology SL), UMA (Universidad de Malaga)

Version 1.0

Date June 30th, 2021

Distribution PUBLIC (PU)

List of Authors

ATH	Athonet Srl
Daniele Munaretto, Marco Centenaro, Nanda Menon, Stefano Cocco, Nicola di Pietro	
FhG	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
Marc Emmelmann, Fabian Eichhorn, Arun Prakash, Oliver Keil	
UNIS	UNIVERSITY OF SURREY
D. Triantafyllopoulou and Y. Rahulan	
FON	FON TECHNOLOGY SL
Iván Pretel, Iñaki Etxebarria, Alberto Pineda	
UMA	UNIVERSIDAD DE MALAGA
Pedro Merino, Iván González	

Disclaimer

Copyright

The 5GENESIS Consortium consists of:

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 D3.10	ATH	30/06/2021

LIST OF ACRONYMS

Acronym	Meaning
3GPP	3rd Generation Partnership Project
4G, 5G	4th, 5th Generation of mobile broadband systems
5G NR	5G New Radio
5GC	5G Core
AAA	Authentication, Authorization and Accounting
AMF	Access Management Function
ANDSF	Access Network Discovery and Selection Function
API	Application programming interface
APN	Access Point Name
CUPS	Control and User Plane Separation
DÉCOR	Dedicated Core Networks
eNB	eNodeB
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
ETSI	European Telecommunications Standardization Institute
EUTRAN	Evolved Universal Terrestrial Radio Access
HSS	Home Subscriber Service
IMS	IP Multimedia Subsystem
LTE, LTE-A	Long Term Evolution, Long Term Evolution-Advanced
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MME	Mobility Management Entity
MNO	Mobile Network Operator
MVP	Model View Presenter
N3IWF	Non-3GPP Interworking Function
NAS	Non-Access Stratum
NCSRD	NATIONAL CENTER FOR SCIENTIFIC RESEARCH “DEMOKRITOS”
NF	Network Function
NFV	Network Function Virtualisation
NOC	Network Operation Centre
NR	New Radio

NSA	Non-Standalone
NSSF	Network Slice Selection Function
ONAP	Open Network Automation Platform
OSM	Open Source MANO
PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
PDU	Packet Data Unit
PFCP	Packet Forwarding Control Protocol
PGW	Packet Data Network Gateway
RAN	Radio Access Network
REST	Representational State Transfer
SA	Standalone
SBA	Service-Based Architecture
SMF	Session Management Function
S/PGW	Serving/Packet data network Gateway
SUPI	Subscription Permanent Identifier
SUT	System Under Test
TLS	Transport Layer Security
TNGW	Trusted non-3GPP gateway
UE	User Equipment
UPF	User Plane Function
UTRAN	Universal Terrestrial Radio Access
VDU	Virtual Deployable Unit
vEPC	virtual EPC
VM	Virtual Machine
VNF	Virtual Network Function
VNF-C	Virtual Network Function Component
VNFD	Virtual Network Function Descriptor
VoLTE	Voice over LTE

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The scope of this deliverable (D3.10) is to report activities and technical advanvements about the 4G and 5G core network functions utilised in the support of the use cases of the 5GENESIS project. More precisely the deliverable describes the Release B of the core network technologies that were adopted or developed in 5GENESIS, and briefly touches the integration progress with the other components of the network chain, for instance the radio access components from Task T3.6.

The key activity carried out during the second part of the project has been the provisioning of the 5G core networks to all platforms in order to build the demonstrations of the final phase of the project, which leverage the 5G access. The 4G and 5G core network solutions are provided by 3 different project partners, Athonet, Fraunhofer FhG and University of Surrey, with the addition of FON for the support of non-3GPP access in the testbed of the University of Surrey. This activity feeds WP4, WP5 and WP6, which are in charge of the deployment, integration, verification and experimentation of the solutions in all the involved platforms.

In parallel, the core network providers have worked on enhancing the virtualization capabilities of the components, by providing compatibility to the ETSI Management and Orchestration (MANO) framework and the corresponding most popular open-source implementations, such as Open Source Mano (OSM), Open Network Automation Platform (ONAP) and Open Baton. This enhancement enables the testing platforms to automate the instantiation, configuration and termination of a network service built upon virtualized network elements.

To summarize, the core network solution providers have been involved in the design and implementation of the core network functions to support from the very beginning of the project the 4G, then followed progressively by the Non-Standalone (NSA) and finally the Standalone (SA) 5G core technologies. Moreover, selected partners have also contributed to the deployment of enhanced MEC-based solutions in support of the 5G ecosystem, leveraging the separation of user and control planes as suggested by the 3GPP standards.

Table of Contents

1. INTRODUCTION

1.1. Purpose of the document

This deliverable is the second and last release of Task 3.5, which runs within the Work Package 3, focusing on the core network-related developments and progress made during the last period of the 5GENESIS project.

The work described in this document corresponds to the activities performed by the different core network technology providers to enhance the solutions provided to the selected 5GENESIS platforms. This work is specially focused on the integration of 5G SA core networks into the platforms, in order to allow them to support the corresponding use cases, run experiments and measure the associated KPIs.

The contributions and improvements outlined in this deliverable will be integrated into the corresponding platforms as part of 5GENESIS Release B.

1.2. Structure of the document

The document is structured as follows. A short introduction of the Deliverable is provided in Section 1, while an overview of the mobile core networks entailed by 5GENESIS is provided in Section 2. The main technical chapter, Section 3, describes the core network solutions of the technology providers involved in the platforms. Section 4 concludes the document.

As aforementioned, Section 2 is devoted to the State-of-the-Art core network solutions, as considered by the telco industry. In particular, the 4G and 5G core networks are described, as defined in the 3GPP standards, but also in the IETF and the research community.

The key section of the document, Section 3, describes the key core network-related activities carried within the project in its last period (M16-M36). 5GENESIS has targeted the implementation of several enhancements inside the 5G core network that requires use case-specific optimizations to support 5G NR and UEs. Thus, a summary of the platforms in which the 5G core networks from the different core network technology providers (Athonet, FhG and Surrey) have been deployed is given as introduction of this section.

Then, different subsections detail the specific challenges addressed by the different core network solutions. In particular, Athonet Core Network focuses on making effective the separation of the user and control planes to ease flexible and agile developments as required by specific 5G use cases, with special emphasis on virtualization and distribution to the edge of the core network functionalities, i.e., enabling the use of MEC-based solutions.

FhG Core Network focuses on the integration of the Open5GCore with commercial, off-the-shelf vendor 5G SA base stations and with 5G RAT developed in the 5GENESIS project, supporting the current need to have a genuine 5G Core Network in addition to the evolved EPC.

Surrey Core Network works towards the integration of WiFi and 5GC, complementing 4G and other non-3GPP access technologies.

Finally, Section 4 collects the conclusions, as well as a brief evaluation of the pending steps and foresight compliance.

1.3. Target Audience

This second iteration of the document aims at providing updated information to developers and researchers about the new capabilities and characteristics of the 5G core network functions used in the 5GENESIS platforms for Release B. Such information is meant to provide valuable insight also to experimenters who are interested in understanding and testing the technology used in the demonstrators.

2. Overview on Mobile Core Networks

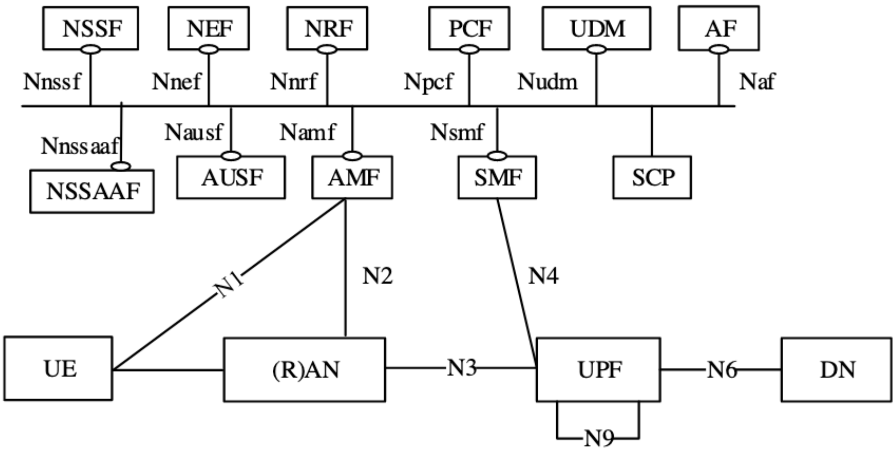

Figure 1. 5G system architecture with SBA in the control plane.

The 5G SA system architecture, illustrated in Figure 1, introduces a paradigm shift compared to the previous 4G and 5G NSA systems. For the interested reader, 3GPP TS 23.401 [1] and TS 23.501 [2] are the primary reference documents for the 4G and 5G systems respectively.

The new 5G system natively supports more flexibility both in the control plane with the Service Based Architecture (SBA), as well as in the data plane, with an enhanced Control/User Plane Separation (CUPS) of the gateways, which was first introduced in 4G Rel. 14. SBA aims at replacing the traditional reference point model through the use of (ideally state-less) text-based APIs among each control plane function instead of stateful binary protocols.

In the SBA, each network function can advertise and discover services by notifying and querying the Network Repository Function (NRF), which makes such services available also to external Application Functions (AFs) through the Network Exposure Function (NEF). User authentication and other user-related information are handled respectively by the Authentication Server Function (AUSF) and the Unified Data Management (UDM), whereas rules and policy are handled by the Policy Control Function (PCF). The Access Management Function (AMF) terminates the control plane signalling with the UE and 5G NR elements (respectively N1 and N2 interfaces), but it also routes the special control messages to the Network Slicing Selection Function (NSSF) for network slicing support. The Session Management Function (SMF) uses the N4 interface to control and program the User Plane Function (UPF), which is ultimately responsible for user packet forwarding between the radio access elements and the Data Networks (DNs) using respectively the N3 (based GTP-U) and N6 interface.

Looking at the state of the art, 5G SA core network solutions have been proposed at 3 different levels:

- Open Source implementations, such as OpenAirInterface (OAI-CN) [3], Open5GS [4], free5GC [5];
- Mid-Size Commercial Vendors, such as the core network providers of this project;
- Tier-1 Vendors, such as Nokia and Ericsson.

Clearly, when applying the core network solutions to the private network arena, that is the target of 5GENESIS as it enables specific vertical services across the deployed platforms, some key advantages and disadvantages can be highlighted for the interested reader:

- Open Source:
  - Pros: license free, good fit for basic lab testing
  - Cons: no support, no roadmap, no guaranteed quality of service, lack of robustness/reliability, unfit for market
- Mid-size Commercial Vendors:
  - Pros: flexible, tailored to customer and verticals
  - Cons: unfit for large nation-wide MNOs
- Tier-1 Vendors:
  - Pros: end-to-end chain all in one
  - Cons: lack of flexibility, vendor locked, not customizable to customer needs and verticals

3. 5G KEY CORE NETWORK ACTIVITIES

The design and implementation activities carried out in 5GENESIS to produce Release B of the core network components are described in the following sections. Table 1 summarizes the core network technology providers for each 5GENESIS platform.

Table 1. Platforms, contributors and planned activities.

Platform	Contributor	Planned role/activity
Athens	Athonet	4G/5G Core network and MEC provider.
Berlin	FhG	4G/5G Core network provider.
Limassol	Athonet	4G/5G Core network provider.
Málaga	Athonet	4G/5G Core network provider.
Surrey	University of Surrey	4G/5G Core network provider.
	FON	Non-3GPP access integration.

3.1. Athonet Core Network

3.1.1. Release B Contributions

Athonet has been evolving its 4G/5G-NSA Software Mobile Core towards a full-fledged 5G SA core network. The 5G-SA Software Mobile Core by Athonet is compliant to 3GPP Rel-15 and newer technical specifications from Rel-16. The apparatus is based on an extremely flexible software architecture on top of which the 3GPP network functions (NFs) are implemented. The new 5G core network brings, among the other functionalities, the separation of the user and control planes to ease flexible and agile deployments as required by specific 5G use cases (e.g., URLLC and TSN). Furthermore, virtualisation and distribution to the edge of the core network functionalities allows running networks with applications as close as possible to the users, improving service delivery and quality of experience.

The 5G-SA Software Mobile Core encompasses the fundamental NFs that are inherited (and evolved) from the 4G/5G-NSA Software Mobile Core (that are AMF, SMF, UPF, UDM/AUSF/UDR) and needed for the scope of 5GENESIS, while more NFs are provided along with the project activities and advances, such as PCF, NSSF.

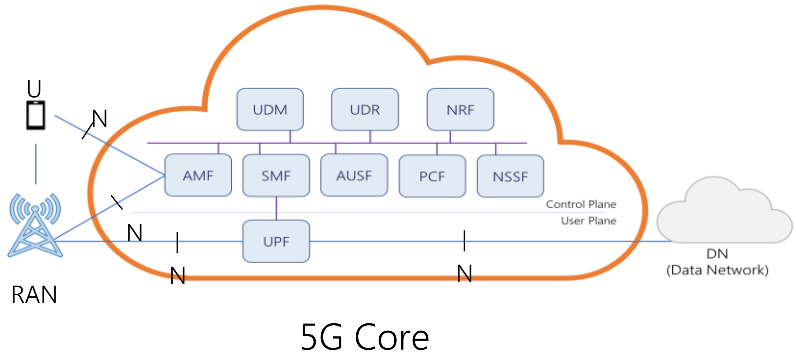

Figure 2 Athonet 5G Core Main Network Functions Overview

Athonet's 5G core network is an easy plug&play solution offered in 5GENESIS as compact (i.e., in-a-box) or as a cloud-based solution (AWS cloud service). The three platforms hosting already the 5G-NSA core network can run separately the 5G-SA private network in order to keep running the tests and integrations performed in 5G-NSA.

Athonet has offered (see http://www.open5g.cloud/) the opportunity to all partners of the consortium to integrate and test their own 5G-SA radios and UEs, for a fast 5G adoption across the world.

Figure 3 Athonet's 5G core in AWS for free integration.

3.1.2. Experimental 5G Architecture with MEC Extension Across Sites

Besides the deployment of the 5G CN in the city testbeds of Malaga and Limassol, either as a core network in a box or as a cloud-based service from AWS, in this deliverable we would highlight and report an innovative 5G architecture that was implemented and tested on the field in the city of Athens, Greece, to run a full 5G architecture with MEC-based traffic local breakout capabilities.

Athonet's 5G core network functions are installed at both the Greek Mobile Operator COSMOTE's site and the academic partner Demokritos' site, in addition a MEC site was implemented in COSMOTE's lab.

Athonet, as an active ETSI ISG MEC member, has authored and edited two white papers that describe new 5G ready MEC architectures in the evolution from 4G to 5G: [3][6][7].

Among the solutions proposed in the above white papers, Athonet provided the SGW-LBO solution to be deployed at the COSMOTE's lab premises. Thus, the main 5G core in the NCRSD site (i.e., Athens platform of 5GENESIS) is connected to the MEC solution in the COSMOTE site, in the same metropolitan area of Athens.

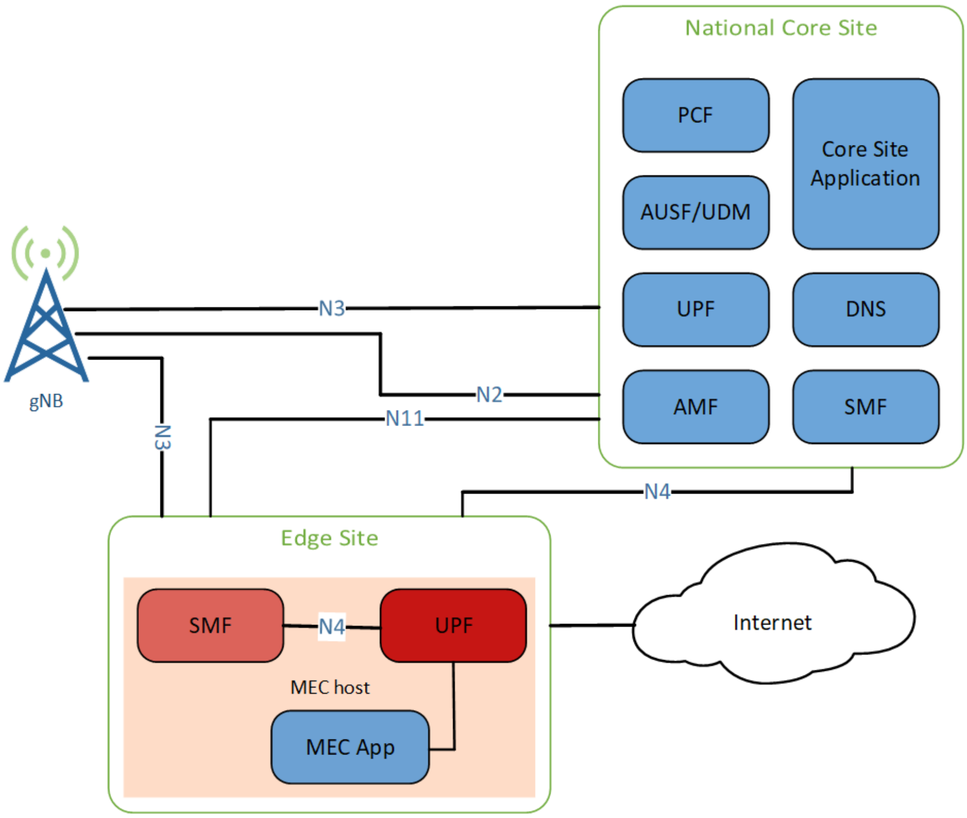

Figure 4 Athonet MEC-based Solution Overview

The above design summarizes the logical architecture deployed, with the full core network in NCSRD, on the right side, and the edge node (MEC) below in the OTE's lab.

3.1.3. Management System

The 5G core has been upgraded to support the network management functions in an NFV environment, in order to onboard, instantiate and run the product as a Virtual Network Function (VNF). This is achieved by exposing the ETSI MANO interfaces, which are required by the MANO functions to execute management operations such as instantiation, configuration and termination in an automatic fashion. A VNF is connected to the MANO system by means of the Ve-Vnfm reference point, which interfaces are defined in ETSI GS NFV-IFA 008 [8] and ETS GS NFV-SOL 002 [9][1]. Among others, the specifications define interfaces for VNF instantiation, VNF configuration and VNF termination.

Using the Athonet VNF descriptors, it was possible to integrate our solution with MANO implementations derived from OSM and from ONAP, provided by different vendors including Nokia, Cisco, Huawei, Whitestack, etc.

3.1.4. Release Summary

In summary, Athonet has provided in the last release of the project, aligned to the original timelines, the 5G SA functionalities along with the previously deployed 4G and 5G NSA functionalities in 3 out of 5 city testbeds of 5GENESIS. Athonet has also provided a MEC-based solution in support of the 5G ecosystem deployed in the platform of Athens to best fit with the requirements of the specific use cases.

Depending on the use cases to be showcased in each platform, either a network in a box or a cloud-based service was selected to support the 5G testing, with additionally also ETSI MEC compliant solutions for performing traffic breakout locally as aforementioned.

The variety of 5G solutions provided to the project are appealing for supporting a wide range of business and use cases raising in the 5G market and promising for future research towards the 6th generation of mobile networks, with focus on the private mobile network domain.

3.2. FhG Core Network

The Fraunhofer Institute for Open Communication Systems (FOKUS) develops a prototypical implementation of a 3GPP standard aligned 4G/5G core network, the Open5GCore. It is a software-based core network oriented towards research and development, which supports 4G, 5G non-standalone and standalone architectures. It also includes UE and gNodeB simulator software for testing. Open5GCore is deployed and used for experimentation in the Berlin platform of the 5GENESIS project.

3.2.1. Release B Contributions

As the 5GENESIS project progressed, FOKUS continued to develop the Open5GCore following the 3GPP releases 15 and 16. These developments culminated in the release 6 of the

[1] Both ETSI GS NFV-IFA 008 and ETSI GS NFV-SOL 002 specify the same interfaces and are to be considered companion documents. The former contains the interface requirements and the definition of the functionalities, whereas the latter defines the data model and the RESTful binding.

Open5GCore, which is deployed in the Berlin platform for the final phase of 5GENESIS. Figure 5 depicts an architectural overview of the 5G SA VNFs of the Open5GCore. New Features include improved support for idle mode, data path diversity, advanced session management, network slicing and non-3GPP access support. For testing and evaluation purposes, 5G data path load generation for the Open5GCore benchmarking tool was implemented. Additional work was conducted to integrate Open5GCore with open source technologies such as OSM and kubernetes.

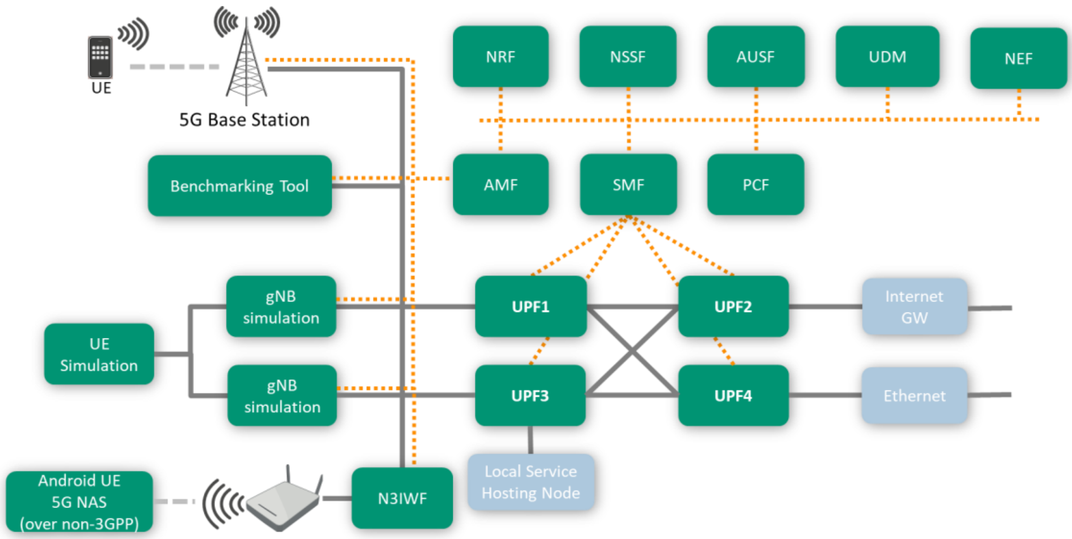

Figure 5 Open5GCore 5G Core Network Functions Overview

When the Berlin platform deployed commercial, off-the-shelf vendor 5G SA base stations, they were integrated with the standalone 5G core network components. Integrated devices include products by vendors such as AmariSoft, Huawei and Nokia. During these integrations, compatibility and functionality of the Open5GCore components were improved and extended.

In collaboration with KeySight Technologies, Fraunhofer FOKUS integrated the Open5GCore with their 5G Core Network testing tool, LoadCore [10]. LoadCore is a software system aimed at conformity and performance tests for 5G core networks. It supports the whole core network as a SUT, but also supports the service-based architecture for testing individual components in isolation. This allows the test and validation of different interfaces between core network functions, as well as towards the RAN. The integration resulted in benefits similar to those from integrations with vendor products. Furthermore, LoadCore provides a comprehensive REST API for integration with OpenTAP via a respective plugin, allowing its use within the Open5GENESIS framework [11].

3.2.2. Idle Mode Support

FOKUS improved the 5G Core VNFs with support for UE idle mode [12], which is essential for compatibility with many commercial off-the-shelf end devices. The improvements target various procedures and components involved when changing the UE state to & from IDLE mode. The affected components are the AMF, SMF, UPF and the gNodeB/UE simulators for 5G.

3.2.3. Data Path Diversity

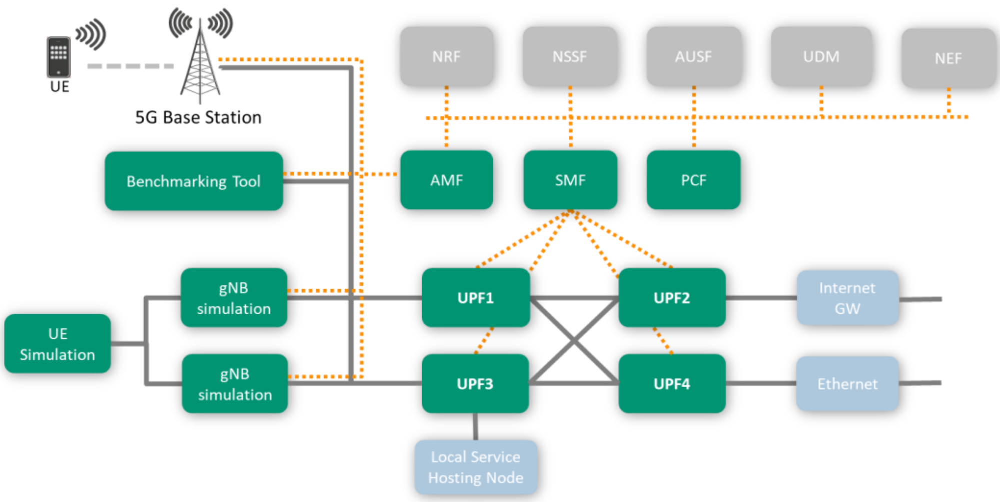

Figure 6 Open5GCore Data Path Diversity

Data Path Diversity refers to the ability of the core network to steer traffic through the data plane in diverse ways. Based on the separation of control and user plane (CUPS [13]), it is possible to deploy multiple UPFs in the data plane of a core network. To better meet the traffic demands of user equipment, redundant deployments can improve overall capacity and geographically diverse deployments can shorten data paths of individual connections. Network utilization and the latency of connections can be optimized. Using the CUPS feature and Packet Forwarding Control Protocol (PFCP) [14], Open5GCore implements a large number of deployment scenarios for data path diversity.

The implemented functionality in the SMF and PGW-C (control plane part of the PGW) enables support for multiple APNs and dedicated bearers. Data paths for specific bearers can be offloaded according to network policies and QoS demands. In cases of congestion, the core network can trigger network only data path changes and spread the load between different parts of the data plane. The handover between Local Service Hosts (with and without IP address continuity) can be realized faster, as only the local parts of existing data flows need to be adjusted.

3.2.4. Advanced Session Management

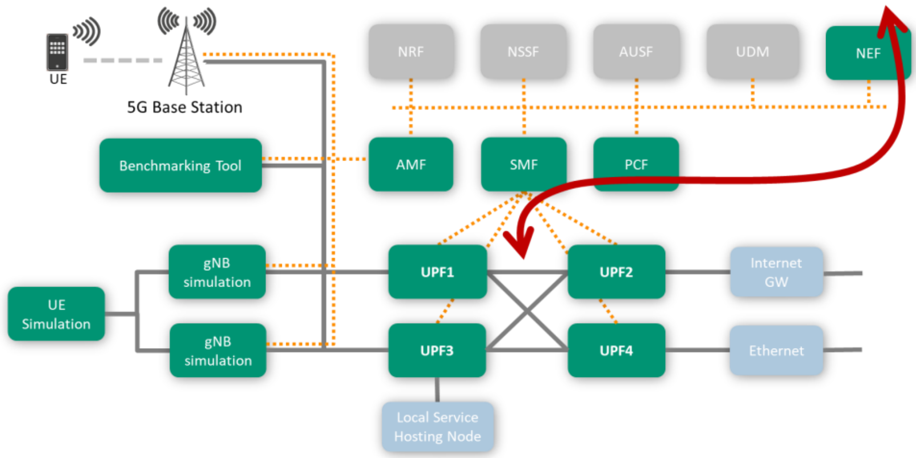

Figure 7 Open5GCore Advanced Session Management: data flow

Open5GCore offers advanced session management through Open APIs and policy-based data plane adaptation for the subscribers. FOKUS implemented the Network Exposure Function (NEF) as well as the Policy Control Function (PCF) to realize this. The NEF exposes an API towards third party application functions (AFs). The PCF implements policy-based decision making for the advanced session management. Additionally, the SMF integration of data path diversity was implemented and the UDR was extended to support subscription profiles. The advanced session management also includes support for subscriber and bearer-oriented data path selection.

Support for establishment of default bearers is realized through policy-based decisions according to the Session Management Policy Control service (*Npcf_SMPolicyControl)* in the PCF and communication between SMF, UPF and PCF. Figure 7 depicts the way in which the NEF and PCF expose this functionality.

3.2.5. Network Slicing Support

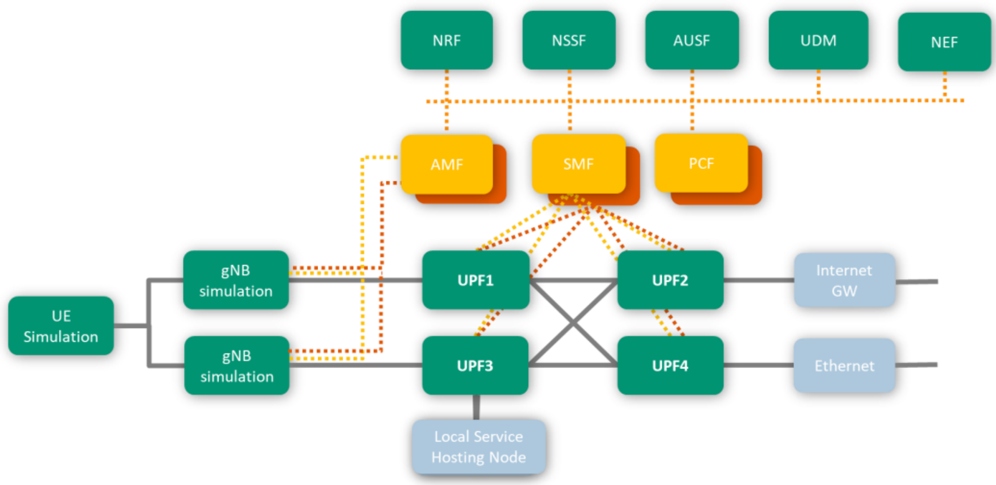

Figure 8 Open5GCore network slicing support

Open5GCore supports network slicing through the implementation of the Network Slice Selection Function (NSSF) along with the required functionality in other VNFs, as listed in the following:

- The AMF supports the slice selection in a way similar to dedicated core networks (DECOR [12]), by querying the NSSF for slice identity and supporting reallocation as part of the registration procedures.
- The NRF operates as a single entity with multiple visibility domains and slice-awareness.
- The UDM stores slice information in the access and mobility subscription data.
- The SMF and PCF can be deployed as independent entities for each slice.
- One or more UPFs can be split or shared among multiple slices.
- The gNodeB emulator supports AMF reallocation as part of the registration.

Figure 8 illustrates the slicing of the Open5GCore VNFs into two slices. With the slice-specific components highlighted in yellow and orange respectively. The shared VNFs are kept in green.

3.2.6. Non-3GPP Access

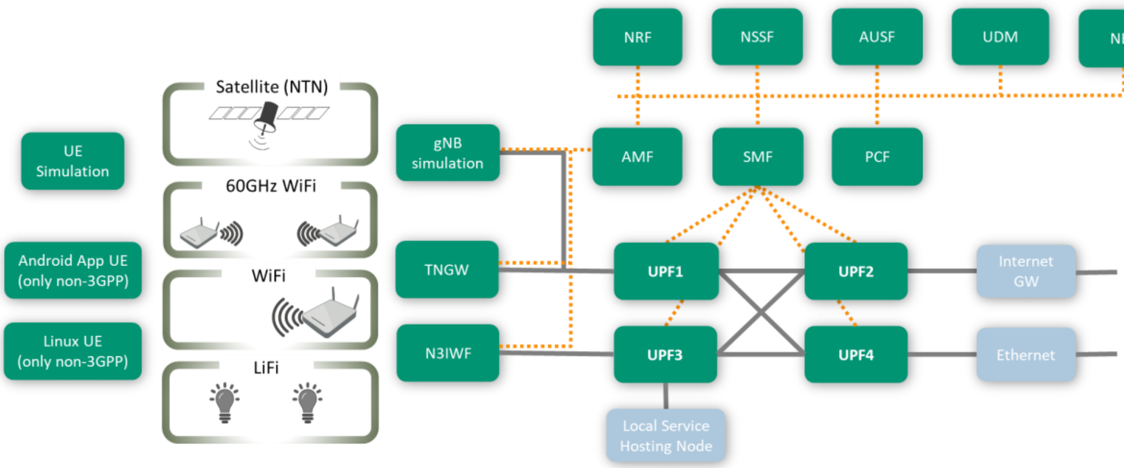

Figure 9 Open5GCore: N3GPP Access

The 3GPP specifications of the 5G core network include support for non-3GPP access technologies [2]. Here 3GPP differentiates between trusted and untrusted non-3GPP access networks.

To support trusted non-3GPP access, FOKUS provides the trusted non-3GPP gateway (TNGW). The UE can connect to the TNGW without additional NWt security. In the untrusted case, a Non-3GPP Interworking Function (N3IWF) serves as intermediary between these non-3GPP RANs and the core network. Providing the N3 interface towards the AMF and enabling the Non-Access Stratum (NAS) communication with the UE, the TNGW and N3IWF would be placed in the “(R)AN” block of Figure 9, together with the respective non-3GPP access NFs. Open5GCore implements an N3IWF and the existing UE simulator gained non-3GPP signalling extensions. Support for untrusted non-3GPP access was tested over WiFi and LiFi transmission technologies.

The new N3IWF supports secure connectivity with the UE (NWu) and the interconnection with the core network through the N2 (NGAP) and N3 (GTP-U) interfaces. The AMF (N1 and N2 interfaces) and the SMF were extended to support concurrent 3GPP and non-3GPP access. 5G UE simulator's N1 interface now also supports concurrent 3GPP and non-3GPP access, as well as PDU session handover. Furthermore, FOKUS developed an Android user space application simulating a UE and enabling non-3GPP UE registration.

In addition, Open5GCore supports over the top integration, using its UE and gNB simulation, which were tested over 60 GHz WiFi and Satellite connections.

3.2.7. Data Path Load Generation

The Open5GCore 5G benchmarking tool simulates 3GPP compatible RAN components. It combines the signaling of UE and gNodeB, for the purpose of testing the core network's performance and conformance. In addition to the 5G signaling, it now implements a traffic generator for the data path. This enables the assessment of the data path's capacity, delay and packet loss.

3.2.8. Management System

To ease the integration with the Open5GENESIS suite and as an alternative to OpenBaton [16], FOKUS implemented an Open Source MANO (OSM) [17] compatible VNF package for the Open5GCore. The creation of the VNF package followed standard on-boarding guidelines.

State-of-the-art 5G mobile core networks aim to support various deployment environments. One type of environment, relevant to both central and edge VNF deployment scenarios, are container orchestration platforms. To support these kinds of platforms with the Open5GCore, FOKUS worked on the containerization of the 5G VNFs and deployed them on Kubernetes (k8s). Kubernetes is a popular, open source, state-of-the-art container orchestration platform. To facilitate the orchestration of such a complex application, the Helm [18] tool was chosen. Helm allows the developer of a Kubernetes based service, to express the deployment of and relationships between containers, through the definition of helm charts. These helm charts are a collection of files expressing the structure of the application stack. By default, Kubernetes services all share a single network. Certain core network functions like the UPF however participate in both control and data plane or need to forward traffic between networks. In order to avoid transmitting control and data plane traffic over the same network and enable forwarding, Open5GCore VNFs need multiple network interfaces. In Kubernetes this can be achieved, only through utilization of certain container network interface (CNI) plugins. For Open5GCore, Fraunhofer FOKUS chose the flannel[2] and multus[3] plugins. While flannel provides the overlay network between pods, multus enables the creation of multiple network interfaces as the VNFs require.

FOKUS also developed a new web-based GUI for the management of subscriber information. It was implemented as a Node.js web application based on the Vue.js[4] MVP (Model-View-Presenter) framework. The form for SUPI provisioning of the web UI is shown in Figure 10. It can be used to provision the potentially numerous users required for experimentation.

[2] https://github.com/coreos/flannel
[3] https://github.com/Intel-Corp/multus-cni
[4] https://vuejs.org/

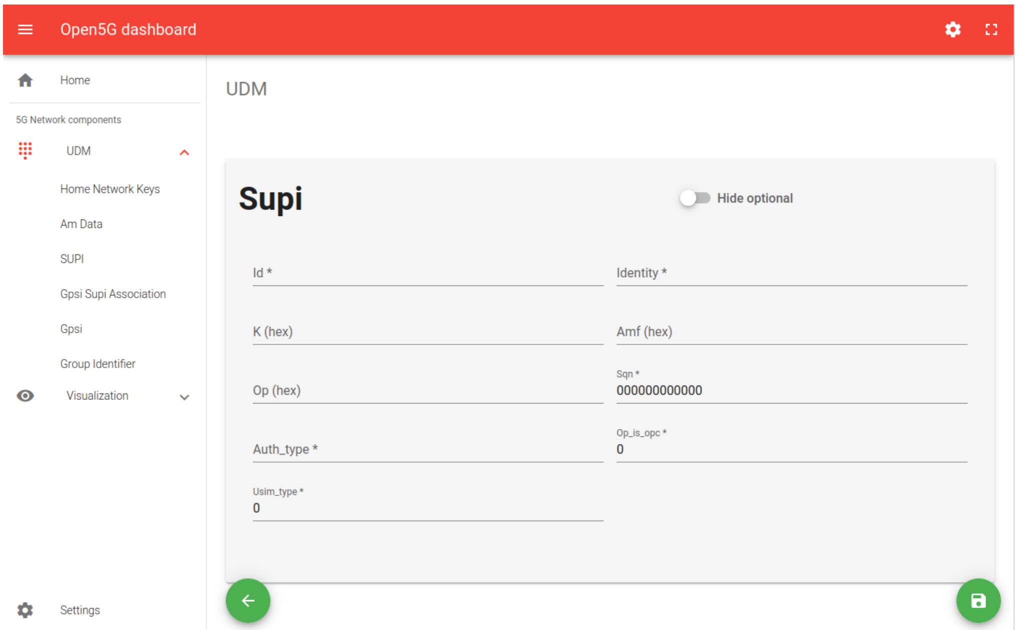

Figure 10 Open5GCore web UI: SUPI provisioning form

3.2.9. Release Summary

Since 5GENESIS release A, FOKUS has extended the Open5GCore with various features to enable a broadening of the scope of experiments for the final phase of 5GENESIS. The new deployment options will enable better integration with the Open5GENESIS framework in WP5 and streamline experimentation in WP6. The conformance and performance improvements will strengthen further the Berlin platform's capabilities, with regards to the testing and evaluation of current as well as future commercial off-the-shelf user devices and mobile network equipment, exploiting further the 5GENESIS Berlin facility as an experimentation platform.

3.3. Surrey Core Network

The University of Surrey 3GPP standards Release16 5G core is shown in the figure below.

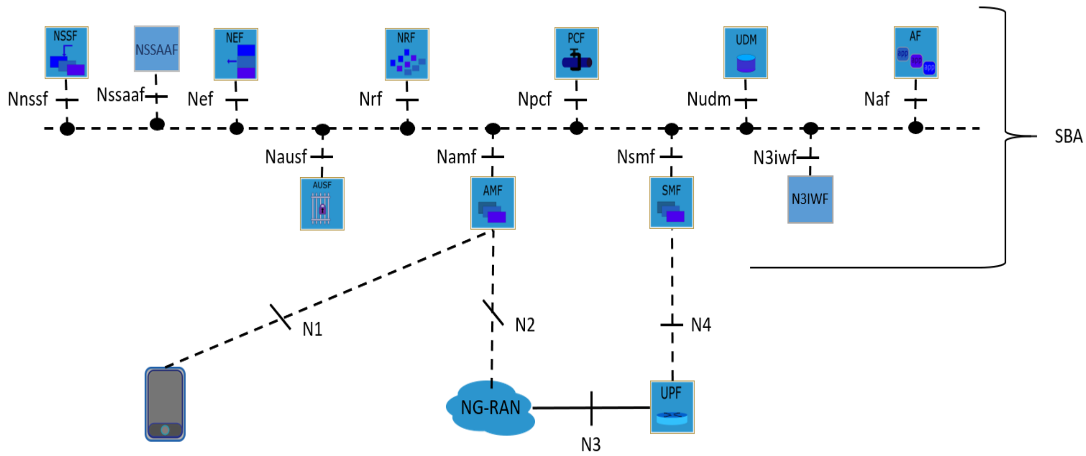

Figure 11. The UNIS core network

This illustrates the protocol interfaces exposed in a 5G network architecture. The functionality of components including AMF. SMF, and UPF, as well as interfaces N1-N4 are highlighted in Section 2.

Starting with the UPF, protocols likely to be employed on the N3 and N9 interfaces would be GTPv2, with appropriate header extensions for 5G5. GTP is a relatively straightforward encapsulation protocol, which is used to tunnel user plane traffic from a UE through to the UPF, from which it can be transferred to an external data network. GTP as a protocol does not incorporate security features, as it was originally designed in the GPRS 2.5G era, where it was assumed that mobile operator networks were secure and ring-fenced from attack. Security in GTP comes from the control plane authorising transfers through the control plane, and that these would not be permitted without appropriate authentication of the user separately – in the architecture outlined above, the SMF would not inform the UPF to allow traffic for a given IMSI to flow unless it had assurance from the AMF that it had authenticated the UE.

3.3.1. Release B Contributions

One of the major differences between 3GPP Rel-15 and Rel-16 was improvements to the service-based architecture (SBA) security specifications[6].

More specifically, in Rel-15 security was considered only for communication directly between two network functions. This was achieved through the use of mutual authentication and transport security (provided by TLS 1.2 or TLS 1.3) between network functions, and token-based authorisation for network function users to consume services, with tokens based on the OAuth 2.0 protocol.

TLS is an internet protocol, widely used for secure HTTP communications by web browsers, and one of the design goals for it is to enable encryption to be terminated on the network function itself, rather than via a separate "appliance". With the move towards software-based virtualised network components, such a move can help to simplify deployments, and reduce the number of physical servers or appliances to be installed.

The token-based authorisation approach allows for dynamic access control to be carried out, with a central authorisation server handing out tokens to other network functions, after they authenticate themselves to it. This approach is highly scalable and helps to secure a virtualised system.

Instances can "scale up" in response to demand, and simply be issued with their own authorisation token to enable connection to a network function. The receiving NF will validate the access token before granting access to services, through the TLS-secured connection.

In the 5G Service Based Architecture (SBA), the Network Repository Function (NRF) acts as the authorisation server and validates requests against rules that the service producers provide when they register with the NRF. Tokens are only issued after mutual authentication with a network function is carried out, and the link to the NRF is secured by TLS.

[5] https://www.metaswitch.com/knowledge-center/reference/what-is-the-5g-user-plane-function-upf

[6] https://www.ericsson.com/en/blog/2020/8/security-for-5g-service-based-architecture

In 3GPP Rel-16 of the SBA, security is specified for indirect communication, which allows for a Service Communication Proxy (SCP) to sit between consumers and providers of network functions, in order to eliminate the need for direct connections between network functions. This introduces changes to the trust model, since the SCP needs to be trusted, as it terminates the TLS connection and re-establishes a new connection to the provider of the network function, allowing it to modify and forward requests arbitrarily. This means that there is no end-to-end security between network functions, as the SCP sits between both. The SCP is able to pass-through the access token provided by the consumer of the network function, in order to allow the end function to validate that the requester is permitted to make a given request. Some deployment models, however, allow the SCP to make its own requests for tokens, and therefore the NRF must ensure that only SCPs which should make such requests do so.

In addition, when securing an SBA configuration, it is important to consider the management plane communications. For example, in the case of satellite backhaul, it is likely that there will be no dedicated separate management plane available. Where a separate link is available, it is likely that this would be used for user plane traffic as well, since it would likely be more economical to use than some satellite services. It should therefore be assumed that management plane traffic will need to be carried over the satellite link as well.

The interconnection of the UNIS 5G core with the non-3GPP networks deployed in the use case has been designed to support releases 16 and 15 of the 3GPP standard. In this way, the network allows the retroactive interconnection of 4G equipment to the 5G network from both the non-3GPP and 3GPP RAN, and the interconnection of 5G equipment to both networks. For the deployment based on release 16, the N3IWF module that manages the interconnection of Fon's WiFi network with the 5G core has been deployed. Fon has designed and developed the WiFi network to fit the requirements of both releases and the deployment has been performed successfully. The interconnection based on both releases allows backward compatibility of the 5G network with all available equipment and will facilitate the offloading from WiFi to 5G/4G radio and 5G/4G radio to WiFi.

3.3.2. Management System

The 5G/6G-IC network operation centre (NOC) is built around the concept of a Service-Oriented Network Architecture where End-to-End network connectivity is achieved via the composition of heterogeneous microservices within each local network technology to form localised network services that are interconnected via the JANET infrastructure. Client applications run on top of these interconnections and are unaware of the component services and the underlying infrastructure configuration.

A Service-Oriented Network Architecture will configure the underlying physical infrastructure into several virtual services, which are treated as objects. These objects may share component services or can run in complete isolation to each other. Similarly, they can be used by a single tenant or shared by multiple tenants. These objects are presented through the Local Orchestrator as Network Services that are comprised of Virtual Network Functions/cloud native functions and Physical Network Functions. The Network Operation Centre combines and orchestrates these advertised Network services to create an E2E connection between the local network technologies. As long as the Network Services and their components comply with agreed industry standards (i.e., 3GPP, ETSI), the vendor, version and type (physical/virtual) of these services are completely abstracted. This will allow the experimenters to deploy services across multiple Local networks with minimal input and without the need of any insight or knowledge on the components of the system. However, the system will also give experimenters the opportunity to create their own Network Services by reconfiguring existing component services or deploying new VNFs/CNFs/PNFs into the system.

The design of NOC architecture allows for two different modes for Network Service deployment. A Static Design Composition predefines which component services will be used by a Network Service. Manual Composition relies on the user to select and compose the services as opposed to Automatic Composition which requires no user input. As a future goal, Dynamic Composition can also be considered and will enable a more flexible and efficient use of infrastructure resources. Dynamic Composition uses a set of runtime parameters taken by Network Services to determine which instances are best used for delivering a composite service to a particular client. Such inputs can be the computing cost, network cost, service availability and desired QoS. To evaluate a composite service as proposed, we can use execution time, computing and network cost and composition sustainability in case of component failure. To enable this level of Composition, we first need to enable real-time monitoring of the infrastructure within the Orchestrator of each Island and share the collected data with the NOC. This also implies that some form of intelligence will be implemented in the NOC to support Dynamic Composition and can operate either in the form of a suggestion to the user of how to configure their Network Service Descriptor, or automatically configure Network Service Descriptors submitted by users to use existing running instances of VNFs.

In the first release of NOC, the main purpose is to allow for Automatic and Manual Composition of services, so experimenters have the flexibility to deploy either a preconfigured E2E service and run their Over-The-Top (OTT) applications or create their own services featuring their own components or existing components provided by 5G/6G IC projects or partners. These two options are selected because they are quicker to implement and provide sufficient flexibility for a variety of experimenters that may wish to use the system.

3.3.3. Release Summary

The upgrade of the Surrey Platform Core Network to 3GPP Release 16, supporting SA operation, will play a crucial role in the successful completion of the planned IoT-based use case with the use of the Release B of the Open5GENESIS suite. Provision of concurrent mMTC and eMBB slicing is supported, while the advanced service deployment capabilities of the NOC architecture allows for the dynamic instantiation and provision of the IoT-vGW as a service in a multi-RAT environment.

4. CONCLUSIONS

The activities of this phase were focused on the implementation and evolution towards the 5G SA mode, as well as the implementation of several enhancements inside the 5G core network that require use case-specific optimizations to support 5G NR and UEs. In particular, the following enhancements have been performed:

- Athonet Core Network focused on providing a smooth transition from 4G, 5G NSA to 5G SA solutions in 3 out of 5 platforms of the project, making effective the separation of the user and control planes to ease flexible and agile developments such as MEC-based solutions for traffic offload. Athonet made also available in the public cloud, i.e., AWS, a full version of the 5G CN to accelerate the adoption of UEs and Radio equipment capable of supporting 5G SA for 5GENESIS partners and worldwide. This last release along with the previously deployed 4G and 5G NSA functionalities has been deployed in three city testbeds, and has been integrated with radios provided by project partners and commercial providers such as Nokia and Amarisoft.
- FhG Core Network enables a software-based core network that supports 4G, 5G non-standalone and standalone architectures, the Open5GCore. Open5GCore was extended with various features to enable a broadening of the scope of experiments for the final phase of 5GENESIS, enabling better integration with Open5GENESIS framework and streamline experimentation. Concretely, the Berlin platform has deployed commercial, off-the-shelf vendor 5G SA base stations including AmariSoft, Huawei and Nokia.
- Surrey Core Network, in the context of multiple sensors to support mMTC services, worked towards the integration of WiFi and 5GC, complementing 4G and other non-3GPP access technologies. In particular, the N3IWF module that manages the interconnection of Fon's WiFi network with the 5G core has been deployed, allowing backward compatibility of the 5G network with all available equipment to facilitate the offloading from WiFi to 5G/4G radio and 5G/4G radio to WiFi.

REFERENCES

[1] 3rd Generation Partnership Project (3GPP), "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access", 3GPP TS 23.401.

[2] 3rd Generation Partnership Project (3GPP), "System architecture for the 5G System (5GS)", 3GPP TS 23.501.

[3] OpenAirInterface (https://openairinterface.org/),

[4] Open5GS (https://open5gs.org/),

[5] Free5GC (https://free5gc.org/);

[6] *ETSI White Paper* No. *24*. MEC Deployments in 4G and Evolution Towards 5G: https://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp24_MEC_deployment_in_4G_5G_FINAL.pdf

[7] *ETSI White Paper* No. *28*. MEC in 5G networks: https://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp28_mec_in_5G_FINAL.pdf

[8] ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV), "Network Functions Virtualisation (NFV) Release 3; Management and Orchestration; Ve-Vnfm reference point - Interface and Information Model Specification", ETSI GS NFV-IFA 008.

[9] ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV), "Network Functions Virtualisation (NFV) Release 2; Protocols and Data Models; RESTful protocols specification for the Or-Vnfm Reference Point", ETSI GS NFV-SOL 002.

[10] Keysight Technologies, "LoadCoreTM5G Core Testing", online, https://www.keysight.com/us/en/assets/3120-1180/data-sheets/LoadCore-5G-Core-Testing.pdf

[11] 5GENESIS Consortium, "Open 5GENESIS Suite", online, https://github.com/5GENESIS

[12] 3rd Generation Partnership Project (3GPP), "NR; User Equipment (UE) procedures in idle mode and in RRC Inactive state", 3GPP TS 38.304

[13] 3rd Generation Partnership Project (3GPP), "Architecture enhancements for control and user plane separation of EPC nodes", 3GPP TS 23.214

[14] 3rd Generation Partnership Project (3GPP), "Interface between control plane and user plane nodes", 3GPP TS 29.244

[15] 3rd Generation Partnership Project (3GPP), "Architecture enhancements for dedicated core networks; Stage 2", 3GPP TS 22.707

[16] OpenBaton, "An extensible and customizable NFV MANO-compliant framework", online, https://openbaton.github.io/

[17] ETSI OSM, "Open Source MANO", online, https://osm.etsi.org/

[18] Helm tool: The package manager for Kubernetes https://helm.sh