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

[H2020 - Grant Agreement No. 815178]

Deliverable D3.9

5G Core Network Functions (Release A)

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Version 1.0

Date October 15th, 2019

Distribution PUBLIC (PU)

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Version History

Rev. N	Description	Author	Date
1.0	Release of D3.9	ATH, UNIS, UMA, FhG	15/10/2019

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
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
MME	Mobility Management Entity
NFV	Network Function Virtualisation
NR	New Radio
NSA	Non-Standalone
ONAP	Open Network Automation Platform
OSM	Open Source MANO
PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
PDU	Packet Data Unit
SA	Standalone
SMF	Session Management Function
S/PGW	Serving/Packet data network 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

EXECUTIVE SUMMARY

The deliverable D3.9 has the scope of midterm report on the activities around the 4G and 5G core network functions to support the use cases of the project. The deliverable describes Release A of the core networks in the 5GENESIS architecture (as show in Figure 0-1), and also touches the integration progress with the other components of the network chain.

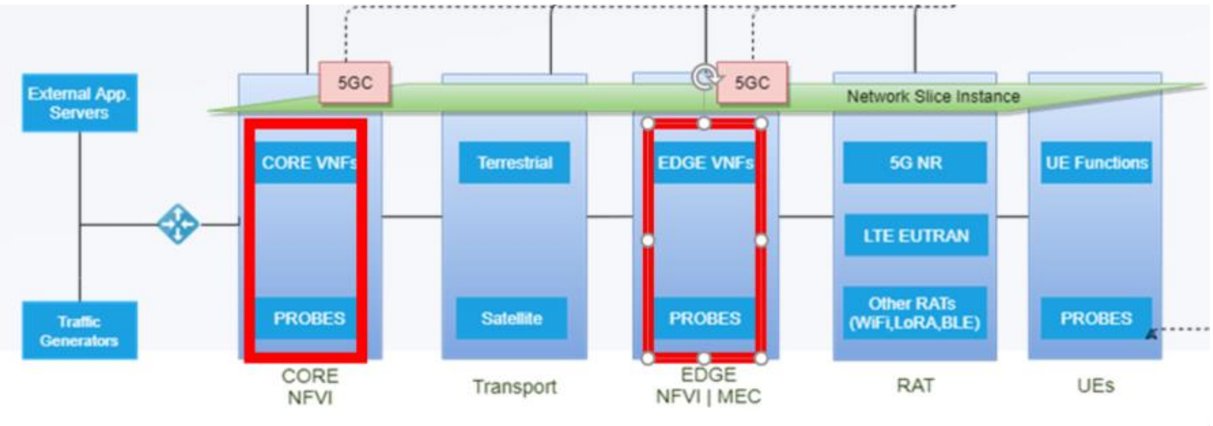

Figure 0-1 Core networks in the 5GENESIS architecture

The key activity carried out during the first year has been the provisioning of the 4G EPC to all platforms in order to build the phase 1 demonstrators, which leverage on LTE access. The 4G EPC solutions are provided by 3 different project partners, Athonet, Fraunhofer FhG and University of Surrey, with the addition of Fon for support of non-3GPP access. This activity feeds WP4, which is in charge of the deployment and integration of the solutions in the 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.

In addition, the core network solution providers have been involved in the design and implementation of the core network functions to support 5G, in both the Non-Standalone (NSA) and Standalone (SA) flavours. For what concerns the NSA solution, most 4G EPC components can be re-used, whereas for 5GC, it is envisioned to upgrade the 4G elements with the protocol stack and functionalities demanded by the 5GC architecture.

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1. INTRODUCTION

1.1. Purpose of the document

One of the key components of the 5Genesis platforms consists of the core network functionalities to support the radio access, with particular focus on 5G New Radio (5G NR). As with previous radio access technologies generations, such as the Universal Terrestrial Radio Access Network (UTRAN - 3G) and Evolved UTRAN (4G), core network functionalities are fundamental to properly execute subscriber authentication, manage user sessions, user mobility and QoS. Not less important, the core network is where business critical functions are executed, such as charging and lawful intercept.

In the context of 5Genesis, the platforms are meant to support use cases based on LTE and 5G NR access, hence the Evolved Packet Core (EPC) and the 5G Core (5GC) are planned for deployment. The present document reports the current progress and plan for developing 5G core network functions within the 5GENESIS project.

1.1.1. Document Dependencies

The infrastructure elements here described belong to the 5GENESIS Infrastructure Layer and belong to the core part of the infrastructure. These elements will be part of several platforms, as indicated in the deliverables of WP4. Table 1 summarizes the relevance towards the deliverables produced by WP2.

Table 1 Document dependencies

id	Document title	Relevance
D2.1	Requirements of the Facility	The document sets the ground for the first set of requirements related to supported features at the testbed for the facilitation of the Use Cases.
D2.2	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	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.

1.2. Structure of the document

The document illustrates in Section 2 the State-of-the-Art core network solutions which has been defined by the telco industry. In particular, the 4G and 5G core networks are described, as defined in the 3GPP standards, but also some key findings from IETF and the research community are shown.

Section 3 is the main part the deliverable and describes the key core network-related activities carried within the project. 5Genesis precisely involves the implementation of several enhancements inside the 5G core network that requires use case-specific optimizations to support 5G NR. Thus, a summary of the platforms in which the 5G core network will be deployed (Athonet, FhG and Surrey) as well as the different addressed challenges have been detailed. 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. 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. It is important to mention that for each solution, all information is structured in three main subsections: a brief introduction of the particularities of each implementation, the first-year contributions (including the changes introduced in the management system) and the planned future steps.

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

1.3. Target Audience

This document aims at providing information to developers and researchers about the capabilities and characteristics of the 5G core network functions used in the 5Genesis platforms. 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

The concept of a packet core network has been introduced between the second (2G) and third generation (3G) of mobile network systems with the General Packet Radio Service (GPRS). The objective was to bring data communications over a packet-switched mobile network, which were then designed only to carry voice over a circuit-switched network.

Since then, further system refinements took place, until a full IP mobile network system was designed around 2007 and 2008, named the Evolved Packet System (EPS), depicted in Figure 2-1, which comprises the Long-Term Evolution (LTE/LTE-A) radio access and the Evolved Packet Core (EPC). This is also known as the 4G mobile system, and it is still today the state-of-the-art technology for large-scale commercial deployments of cellular networks, as its successor, the 5G system, is still in a preliminary phase and deployed at few sites in a handful of countries[1]. The primary community for the core network design is the SA2 working group in 3GPP, that publishes the system architecture specifications in the TS 23.000 series. In particular, TS 23.401 [1] and TS 23.501 [2] are the primary reference documents for the 4G and 5G systems respectively. As such specifications have been evolving, they have addressed a number of enhancements and use case-specific optimizations, as for example for IoT and V2X. The result is a complex system which lends itself to be profiled and implemented by each manufacturer according to its own technical and business needs.

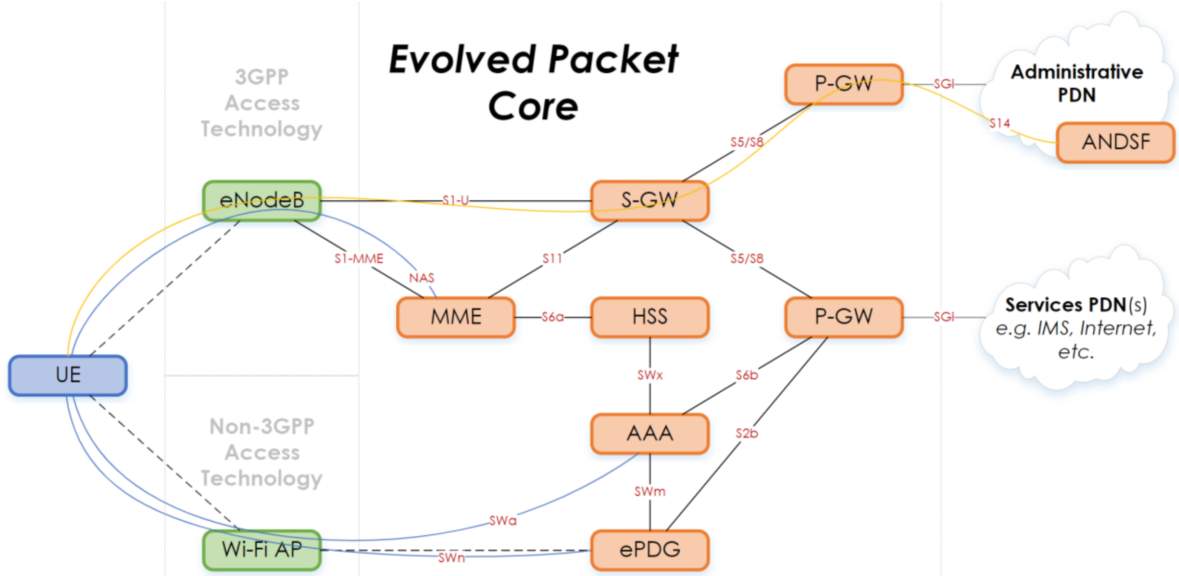

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Figure 2-1. The Evolved Packet System (RAN + core) architecture, showing LTE and WiFi access (Author: Joe Deu-Ngoc, license: CC, URL: https://fr.wikipedia.org/wiki/Fichier:Evolved_Packet_Core.svg)

In the EPC architecture, user data packets are transported by means of *bearers*, which consist on a chain of tunnels built with the GPRS Tunneling Protocol for User Plane (GTP-U) [4] between a Packet Data Network Gateway (PDN-GW, PGW) and a Serving Gateway (SGW) and between the SGW and the radio base station (eNB), which the User Equipment (UE) is currently connected to. Simply put, a bearer is a point to point connection between a UE and the PGW

[1] A table summarizing the 5G deployments in Europe is available from Light Reading at [3].

associated to the PDN (e.g., Internet) that the UE aims at connecting to. In order to gain access to additional PDNs, a new bearer for each PDN is set up, and other PGWs are associated to the user. A unique IP address is assigned to the UE for each bearer, and the corresponding PGW acts as the *IP anchor* for such address, thus creating a 1-to-1-to-1 mapping between the PDN to be accessed, the PGW for such PDN, and the UE's IP address to be used. The Mobility Management Entity (MME) is the control plane elements responsible for establishing the bearers and to modify them to support user mobility. Together with Home Subscriber Service (HSS), the MME performs UE authentication and authorization. Another key element of the EPC architecture is the Policy and Charging Rules Function (PCRF), which defines polices for users' traffic and exposes control interfaces from the core network to external Application Functions (AFs), such as the IP Multimedia Subsystem (IMS) for Voice over LTE (VoLTE) support. The diagram in Figure 2-1 shows also the support to untrusted non-3GPP access (e.g., a public WiFi hotspot), which control plane and user plane transit respectively through an Authentication, Authorization and Accounting (AAA) server and an evolved Packet Data Gateway (ePDG) before reaching the EPC.

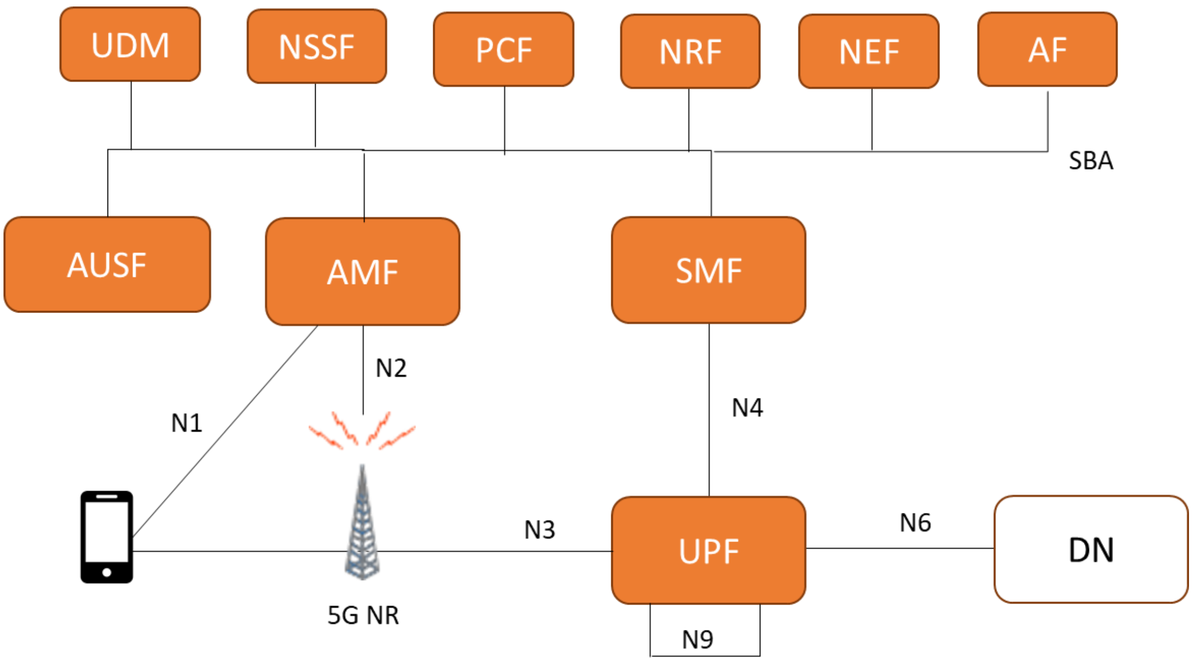

Figure 2-2. 5G system architecture with SBA in the control plane.

The 5G system architecture, illustrated in Figure 2-2, introduces a paradigm shift as it 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 N9 interface. Specifically, session management in 5G allows two methods to bind a Packet Data Unit (PDU) session (i.e., the evolution of a PDN connection) to multiple *PDU session anchors*, i.e., UPFs interfacing the same or different data networks. The first method is through the SMF inserting one additional UPF in the N3 data path, acting as *uplink classifier* able to steer user packets towards multiple PDU session anchors (UPFs). In the second method, a PDU session is associated to multiple IPv6 prefixes (i.e., *multi-homed*), and each prefix is anchored at a different UPF. Also, in this case, an UPF is inserted at a common point where all the data paths branch out, and such UPF is said to support *branching point* functionalities.

The concept of leveraging multiple anchors based on different UE IPv6 prefixes is the baseline for the Distributed Mobility Management (DMM) solution in [5]. The DMM working group within the Internet Engineering Task Force (IETF) has pioneered the work towards evolving the architecture for mobile networks, as documented in [6][7].

Beyond those from 3GPP and IETF, many other ideas have been proposed, mainly targeting the 4G architecture but still meaningful towards the definition of 5G. The key point of such proposals is the implementation of the already mentioned CUPS and the introduction of Software-Defined Networking (SDN) and Network Function Virtualisation (NFV) technologies, in order to obtain a flexible data plane programmed by the control plane. In this way, new scenarios are enabled in the core network (e.g. data packet routing optimization). Nevertheless, SDN technologies typically lack native support to GTP-U tunnelling in the mobile core. SBI (South Bound interface) protocols (e.g. OpenFlow) then need to be extended in order to be able to define forwarding rules for GTP-U encapsulated data packets. Despite some proposals go in this direction (such as [13], [12] and [8]), many other works argue for the advantages given by a GTP-less data plane [10]. In [9] a multi-dimensional aggregation solution for routing and classifying packets without GTP-U (and any other tunnelling protocol) is also presented. A more 5G oriented approach is considered in [15] and [16], where in the proposed solutions suggest GTP-less enhancements to the 3GPP's 5G system architecture.

3. CORE NETWORK ACTIVITIES

The design and implementation activities carried out in 5Genesis to produce Release A of the core network components will be described in the following sections. Table 2 summarizes the core network technology providers for each 5Genesis platform.

Table 2. Platforms, contributors and planned activities.

Platform	Contributor	Planned role/activity
Athens	Athonet	4G/5G Core network 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

Athonet 5G core network will bring, starting already in 4G technology along with the NSA architecture and then in 5G technology when the SA will come, the separation of the user and control planes to ease flexible and agile deployments as required by specific 5G use cases (e.g., URLLC). Furthermore, virtualisation and distribution to the edge of core network functionalities, such as the user plane functions, will allow running applications as close as possible to the users, improving service delivery and quality of experience. As defined in 3GPP TS 23.501 [2], control plane and user planes are architecturally separated from the (R)AN between the interfaces N2 towards the Access and Mobility Management Function (AMF) and N3 towards the User Plane Function (UPF). This will ease the deployment of the 5G network starting from the edge. In addition, the already rich set of APIs exposed by the Athonet Mobile Core is planned to be enhanced and harmonized in order to reflect Common API Framework (CAPIF) envisioned by Rel. 16 of the 5G specifications.

3.1.1. First year contribution towards release A

The activities carried out during the project's year one address both the 4G and 5G core functions, with different objectives. In fact, whereas the 4G implementation is a fully commercial product, the 5G one is at its design stage, thus they achieved different milestones.

The 4G implementation has been mostly enhanced with the functions required to run in the 5Genesis platforms, which mostly imply the support to the NFV MANO and automation tools envisaged by the project. Conversely, the work on the 5G solution dealt with upgrading the 4G vEPC to support the 5G New Radio (NR) in Non Standalone (NSA) mode, and the design of a 5G system as per the 3GPP TS 23.501 specifications [2].

3.1.1.1. Management system

The 4G vEPC has been upgraded to support the network functions management 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.

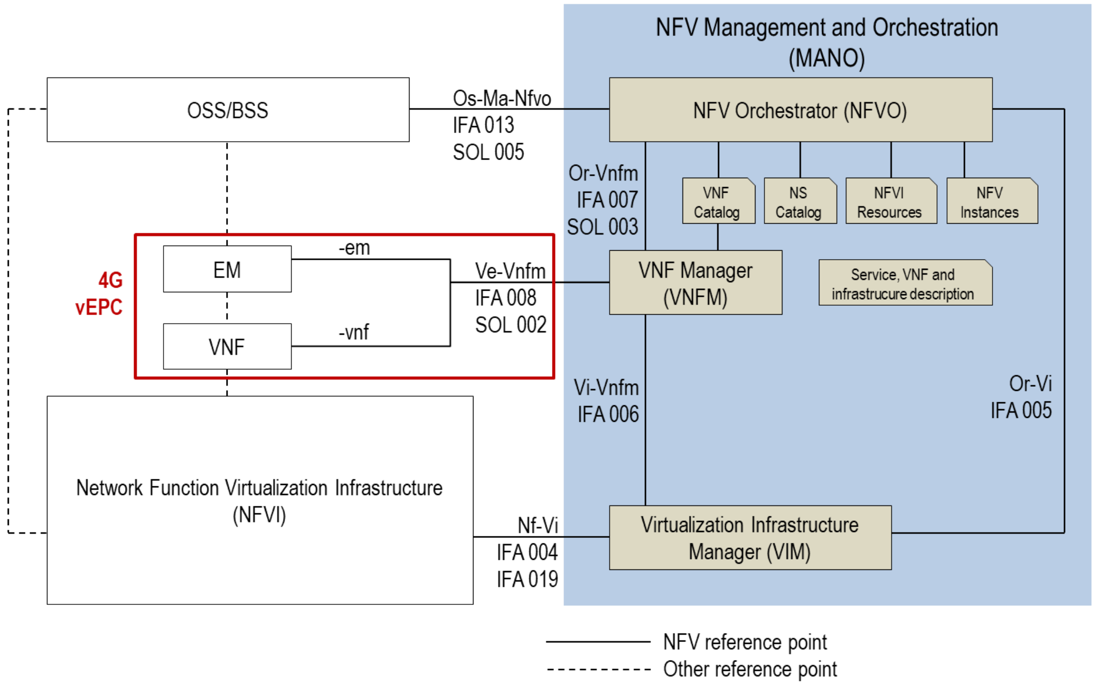

Figure 3-1. 4G vEPC in the ETSI NFV architecture.

The 4G vEPC is hence implemented as one VNF+EM entity. The diagram in Figure 3-1 shows how the 4G vEPC fits in the overall ETSI NFV architecture, with all the related interfaces and specification documents, whereas the diagram in Figure 3-2 depicts the VNF specific architecture.

As illustrated in Figure 3-1, 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 [17] and ETS GS NFV-SOL 002 [18][2]. Among others, the specifications define interfaces for VNF instantiation, VNF configuration and VNF termination.

[2] 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.

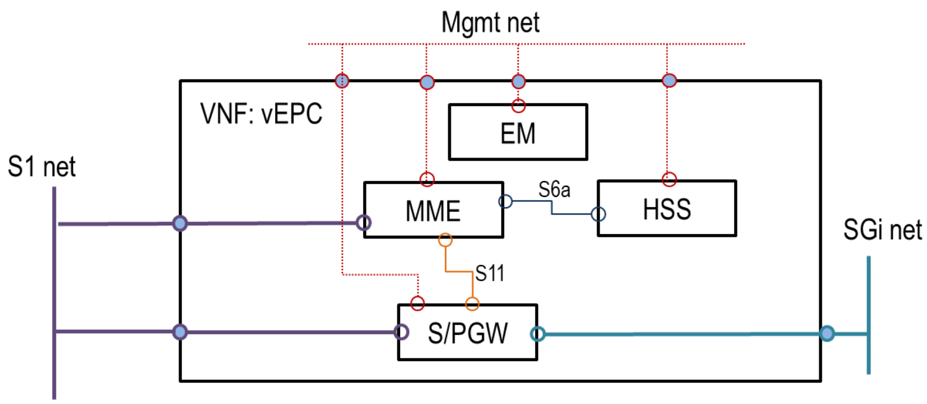

Figure 3-2. VNF architecture of the vEPC.

In the 5Genesis implementation of the vEPC as a VNF, the VNF contains its own **Element Manager (EM)** and a variable number of **VNF Components (VNF-C).** The EM terminates the IFA 008/SOL 002 interfaces and is connected to all the others VNF-Cs of the VNF for management and configuration purposes. The VNF may contain a variable number of additional VNF-Cs, according to the desired association between a network element and its Virtual Deployable Unit (VDU). In this implementation, a VDU is a Virtual Machine (VM), and thence a VNF-C is a VM too. For instance, only one additional VNF-C, i.e., one VM, can be used to run all the main EPC components (MME, HSS, SGW and PGW), or, as illustrated in the Figure 3-2, one VNF-C is deployed for each of the MME, HSS and a combined S/PGW.

The 4G vEPC lends itself to different VNF-C configurations, which are collected into the **VNF Descriptor (VNFD)** that is used to feed the MANO system. The VNFD contains the number and flavours of VNF-Cs that make up the VNF, along with the internal and external connection points. The former represents the virtual links among the VNF-Cs, whereas the latter are the links to other VNFs. In addition, the VNFD contains all the VNF-specific configuration data that need to be pushed to the VNF in order to execute the EPC functions. Such specific data range from 3GPP parameters and identifiers, like the PLMN ID, to vendor-specific items, e.g., logging behaviour. The VNFD is available in both the TOSCA and YANG models, as specified respectively in ETSI GS NFV-SOL 001 [19] and ETSI GS NFV-SOL 006 [20].

The system described above has been successfully tested for compatibility against a few MANO implementations during the 4th NFV Plugtests event, held in Sophia Antipolis at the beginning of June 2019[3]. 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.

3.1.1.2. Support for 5G NSA

The Athonet 4G vEPC is a software only solution that undergoes a continuous improvement process, in order to enrich it with new features and functionalities. One of latest enhancements is the addition of the support to 5G NR in NSA mode.

[3] Press release and report available at https://www.etsi.org/newsroom/news/1630-2019-07-etsi-s-4th-nfv-plugtests-event-broadens-its-scope-with-edge-computing-testing.

In the 5G NSA mode, both the control plane and data plane interfaces between the RAN and the core network leverage the EPC architecture: the control plane interfaces are based on S1-AP and NAS signalling; in the data plane, GTP-U is still the encapsulation protocol chosen to transport the user protocol data units.

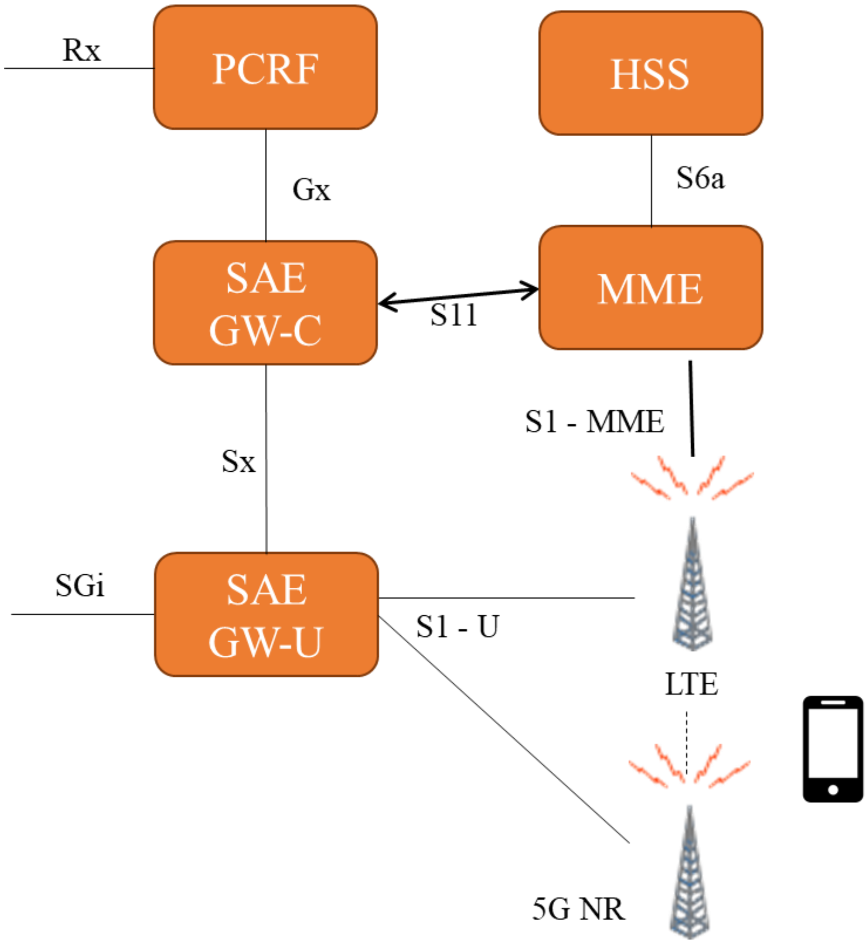

Figure 3-3. Support for 5G NR in NSA mode

This approach does not imply any dramatic change on the legacy core network, and it was actually envisioned by 3GPP precisely to let operators roll out 5G radio without major upgrade of the core infrastructure.

3.2. FhG Core Network

Fraunhofer Fokus' Open5GCore implements the new 5G components as standalone i.e. capable of operating without the 4G EPC functionality. Through this, Open5GCore enables a fast and targeted 5G, hands-on fast implementation and realistic evaluation and demonstration of new concepts and use case opportunities.

Open5GCore integrates with 5G New Radio SA prototypes and off-the-shelf LTE access networks enabling immediate demonstration of different features and applications and supporting the current need to have a genuine 5G Core Network in addition to the evolved EPC one.

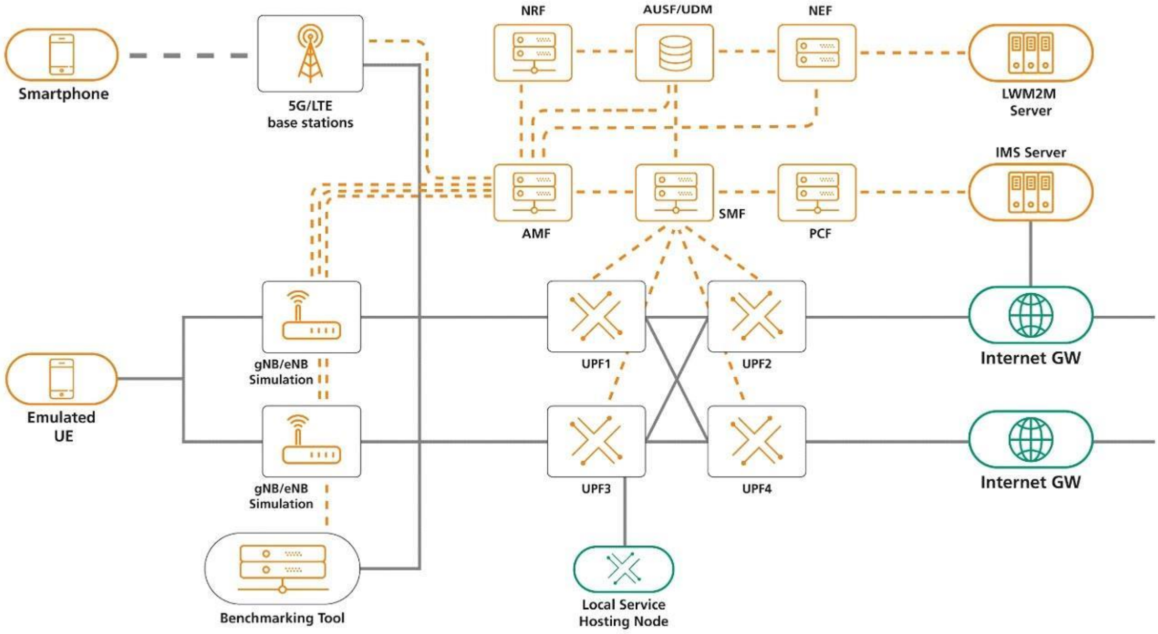

Figure 3-4 Open5GCore Architecture © Fraunhofer FhG.

3.2.1. First year contribution towards release A

3.2.1.1. Management system

The FhG Open 5GCore is running as a network service in an NFV environment. The FhG site uses Open Baton as an NFV MANO orchestrator. For managing the Open 5GCore VNFs, a management system is used which is part of Open Baton and is called Element Management System (EMS).

The EMS is a Python agent which is installed on the virtual machines involved in a VNF deployment when it is launched. In Open Baton, each VNF component inside a Virtual Deployment Unit (VDU), is deployed to a separate virtual machine.

The EMS is a general management system and not tied to a specific type of VNF. The main responsibility of the EMS is the actual execution of the lifecycle operations triggered by the Virtual Network Function Manager (VNFM). The Advanced Message Queuing Protocol (AMQP) is used for the communication between the EMS and the VNFM. The communication runs over Open Baton's RabbitMQ broker. The setup can be seen in Figure 3-5.

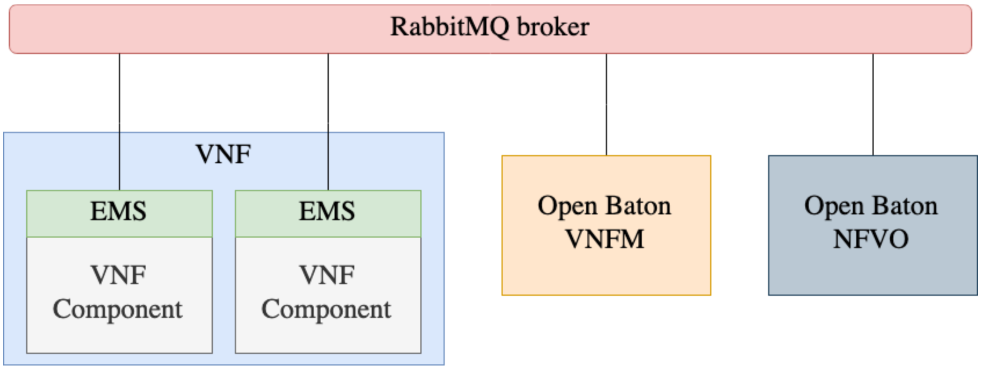

Figure 3-5: EMS in Open Baton

The EMS provides an interface towards the VNFM which can be used to manage the VNF lifecycle operations. The possible commands which can be sent by the VNFM to the EMS via AMQP messages are listed in Table 3. Each message has a JSON payload for sending the needed information and distinguishing the commands.

Table 3: Commands accepted by EMS

Command	Description
Save scripts	Save a transmitted script in a specific directory on the virtual machine. The sent script is part of the command.
Clone scripts	Clone a script from a specified Git repository into the virtual machine.
Execute	Execute a certain script which has been stored before on the virtual machine. The command can also include environment variables which should be usable by the script during execution.
Update script	Replace scripts with new versions sent in the command.
Update script from Git	Replace scripts by cloning new versions from a Git repository.
Save VNF dependency	Save configuration and dependency parameters so that they can be used in scripts during execution.

The lifecycle operations are managed by the VNFM which sends commands to the EMS on the virtual machines and requests the storing of scripts necessary for the execution of certain lifecycles and the script execution. The EMS notifies the VNFM then if the execution has been successful or not.

3.2.1.2. Packaging of Open5GCore for 5Genesis

To support the 5Genesis project, the Open5Gcore required a project-specific packaging and configuration to run with the available access technologies.

In order to allow with integration and testing of pre-commercial 5G cells, a current developer snap-shot of the Open5GCore was required for 5Genesis. Packaging included the creation of an intermediate stable release of the core, which included splitting of functional components into several VMs for automatic deployment via OpenBaton. Dependencies of the latter had to be specified and tested for OpenBaton. Besides, some adaptations of internal networks used for communication between 5G Core components had to be adjusted for the deployment.

3.3. Surrey Core Network

As release A, the surrey core network solution (developed in-house), provides a hybrid core network that supports both 4G & 5G radios and UEs. The 4G core is Rel-15 CUPS compliant as is the Rel-15/16 of 5G core network. However, current Radio access network supports only non-standalone architecture (NSA) and standalone architecture (SA) will be supported in Q1 2020. 5GIC hybrid core is much more flexible and agile deployments as required by specific 5G use cases (e.g., eMBB, MTC/MIoT, URLLC). Furthermore, it has deployed multiple virtualization platform and distribution to the edge of core network functionalities, such as the user plane functions, will allow running applications as close as possible to the users, improving service delivery and quality of experience. As defined in 3GPP TS 23.501 [2], 5GIC hybrid core developed based on service based architecture with control plane and user planes are architecturally separated from the (R)AN between the interfaces S1-AP/N2 towards the Access and Mobility Management Function (AMF) and S1-UP/N3 towards the User Plane Function (UPF). This will ease the deployment of the 5G network starting from the edge. The 5G core uses Kubernetes docker container cluster-based network integration within the Network virtual function as shown in Figure 3-6.

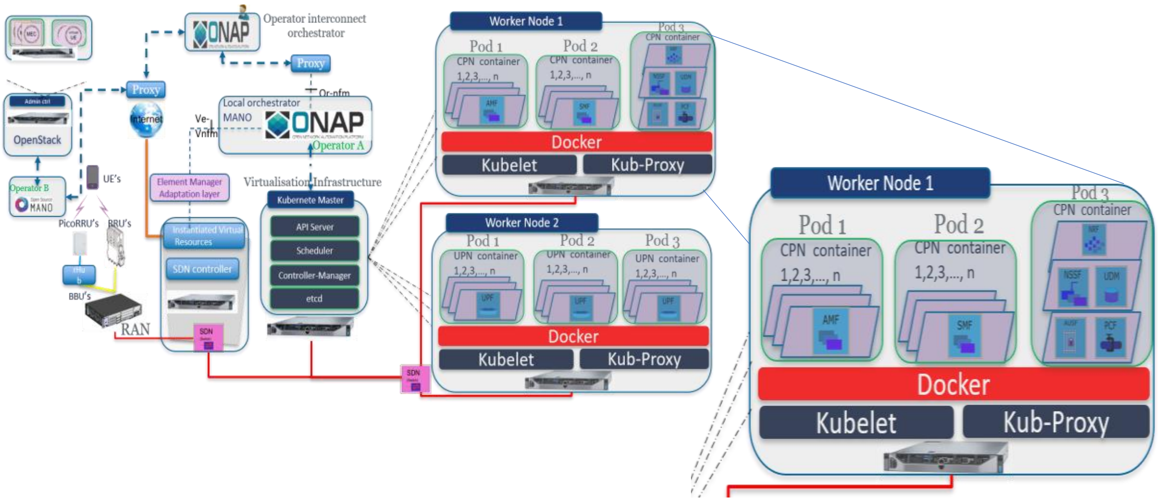

Figure 3-6: Deployment of the 5GENESIS system components at 5GIC testbed

3.3.1. First year contribution towards Release A

On the core side, the focus of activities carried out during the project's year one to produce release A include development of both the 4G and 5G core functions. Both the 4G and 5G core implementations are of commercial grade in line with first year milestones.

The 4G implementation has been mostly enhanced with the functions required to run in the 5Genesis platforms, i.e. support of the NFV MANO and automation tools envisaged by the project. The work on the 5G solution dealt with implementation of core functions and signalling to support the 5G New Radio (NR) in Non Standalone (NSA) mode, as per the 3GPP TS 23.501 specifications [2].

Focusing on the non-3GPP access unlicensed spectrum technology, the integration between WLAN and 5GC will complement 4G and other non-3GPP access technologies by providing an overlapping coverage and contributing to the maintenance of service continuity at the trial site.

During this year, FON has been assessing and enhancing the technology to integrate WiFi interface following release 15, which considers NSA case for non-3GPP networks. Consequently, the use of 4G EPC as the core of the mobile network should be considered.

The access points (APs) populate a specific SSID for the 5G non-3GPP network. In order to manage them, enterprise-scale deployments typically have a WiFi Access Controller (AC) that exposes via API (normally complemented by an easy-to use dashboard), it allows quick and controlled configurations of the corresponding APs. Using the AC through its API, MANO is able to automatically configure all the corresponding APs. All the user traffic generated with that particular SSID will be tunnelled directly to the EPC. Regarding the authentication, the Radius-based AAA server in the WiFi network finalizes the authentication performed in the mobile networks' HSS. According to the release 15 definition, two interfaces that enable this functionality are exposed by the 3GPP AAA server, acting as a proxy of the HSS.

The configuration for the Surrey platform should follow an architecture which contains the interfaces for the integration of a non-3GPP network in NSA case with a 4G EPC (release 15 compliant). It is important to mention that according to release 15, non-3GPP networks can be considered as trusted or untrusted networks. Although both are viable, depending on the type of network the integration is performed in a different manner. In order to integrate an untrusted non-3GPP network, the Radius server of the WiFi network should use the SWa interface to reach the 3GPP AAA server to finalize the authentication of the users. The Radius server of the WiFi network, is in charge of translating from Radius-to-Diameter protocol to enable 3GPP AAA to process the requests. The user data is redirected to the ePDG using the SWn interface. The ePDG component oversees the routing the user-plane traffic to the PDN GW of the EPC.

In contrast to the untrusted approach, when the non-3GPP network is considered a trusted one, authentication is performed using the STa interface. For the data plane, the user traffic is redirected to the PDN GW using the S2a interface.

3.3.1.1. Management system

The Surrey (5GIC) network management systems currently compromise of a commercial OMC and 5GIC-Exchange integrated to support full end to end network slicing.

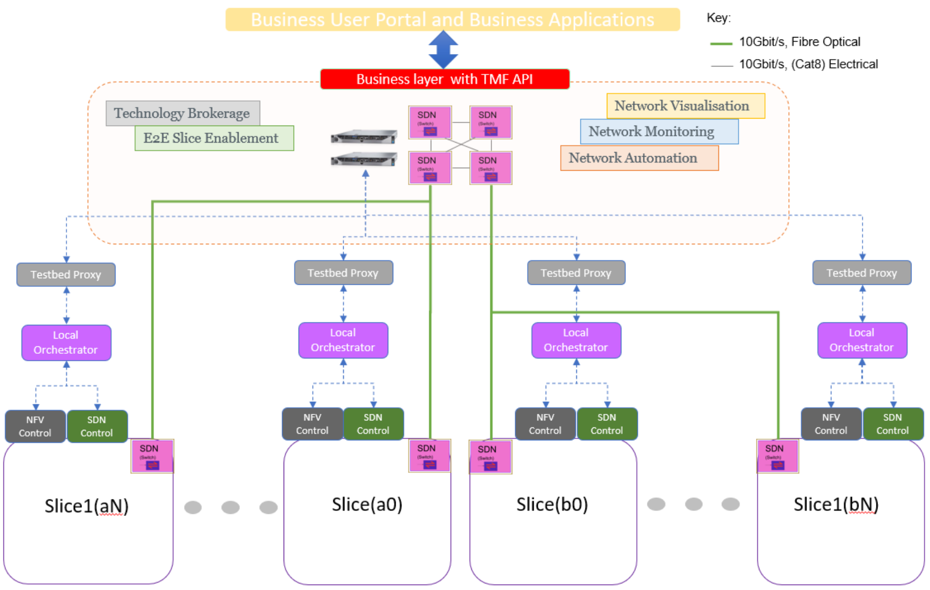

Figure 3-7: Slicing support and components at 5GIC testbed

The figure above illustrates the network connection between multiple technology and each of the network will have their own management systems and 5GIC has implemented the full end-to-end network systems that enables the seamless network slicing. However, the current commercially available radios do not support 5G slicing, hence 5GIC team has implemented network management system that enable the radio slices and integrate with 5G core and transmission slices as shown below.

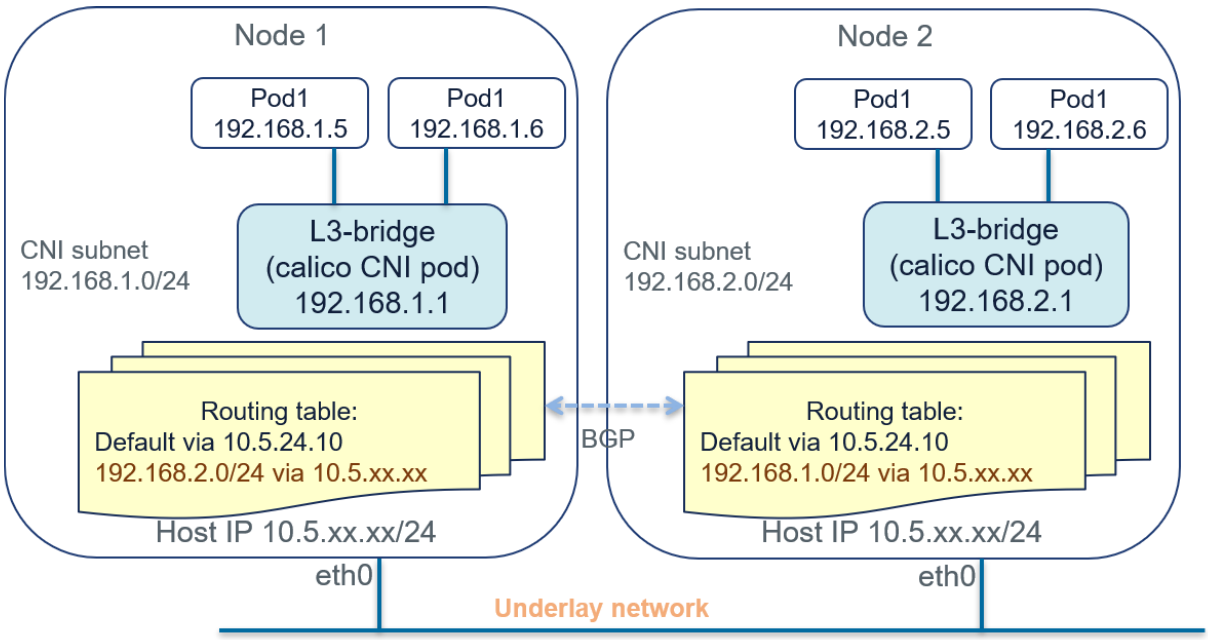

Figure 3-8: 5GIC network management setup in support of 5G slicing

4. Release A summary and future plans

4.1. ATH Core Network

In light of the activities carried out during the project's first year, the Release A core network supports 4G and 5G NSA radio access. Moreover, it provides an enhanced programmability framework with advanced APIs to facilitate automatic configuration, management and monitoring, supporting also the interaction with ETSI NFV MANO implementations.
The key activity that will be carried out by Athonet towards release B of the core network is the realization of a 5G core network to support the NR in SA mode. The preliminary design stage has already produced a transition phase from current 4G implementation to 5G according to the evolution of the network elements as illustrated in Figure 4-1.

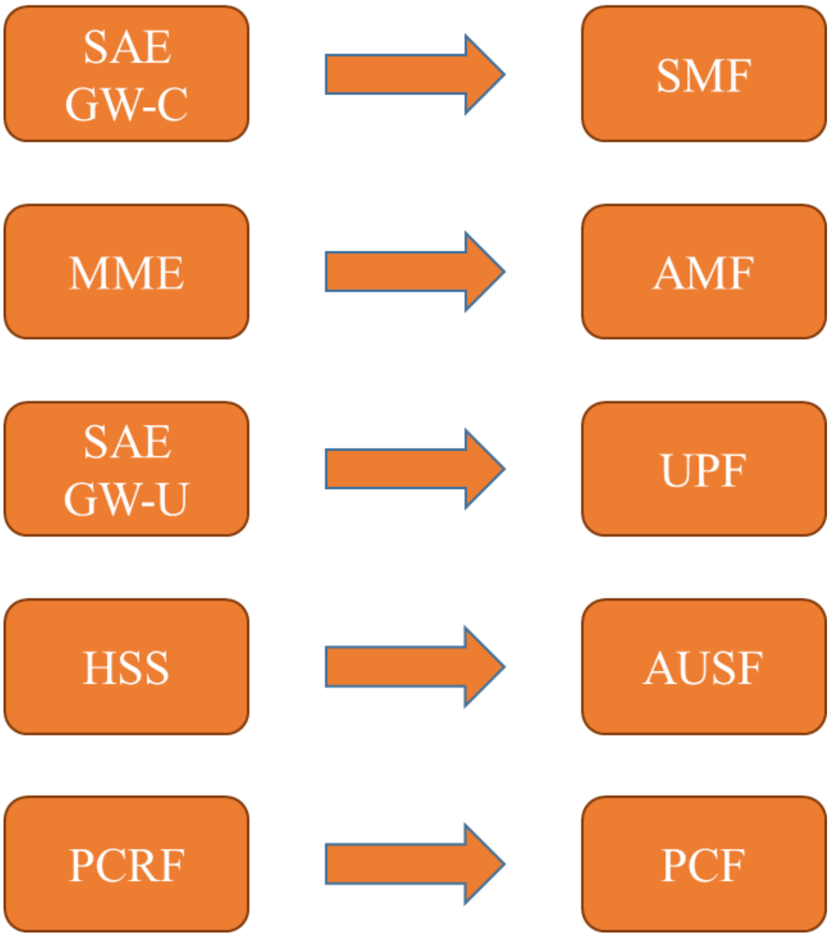

Figure 4-1. Evolution of 4G network elements into 5G ones.

The key enabler of such evolution is Athonet's early design choice of splitting the implementation of control plane elements and user plane elements, which has been further improved with the introduction by 3GPP of Control/User Plane Separation of the EPC Gateways (CUPS). With CUPS, the SGW and PGW were divided into a Control plane element and User plane element, interconnected by the standard Sx interface. Such split was maintained in the

5G design, with the gateway control plane component restructured in the Session Management Function (SMF) and the gateway user plane elements restructured as the User Plane Function (UPF).

The most dramatic change introduced by the 5G core network architecture is the so-called Service Based Architecture, by which the binary protocols traditionally used in the telco industry are replaced by text-based protocols based on RESTful APIs. This profound paradigm shift brings a number of engineering challenges that will lead to extremely different implementations depending on the use case, dimensioning, deployment, infrastructure and runtime environment, that belong to the IT and Cloud computing areas, but have never been really solved in the telco industry.

Figure 4-2. illustrates a combined 4G and 5G deployment as envisioned with Athonet core network technology. The diagram depicts the logical architecture, but it is worth noting that in terms of implementation, similar functions, like the AMF and MME, can be actually part of the same software instance.

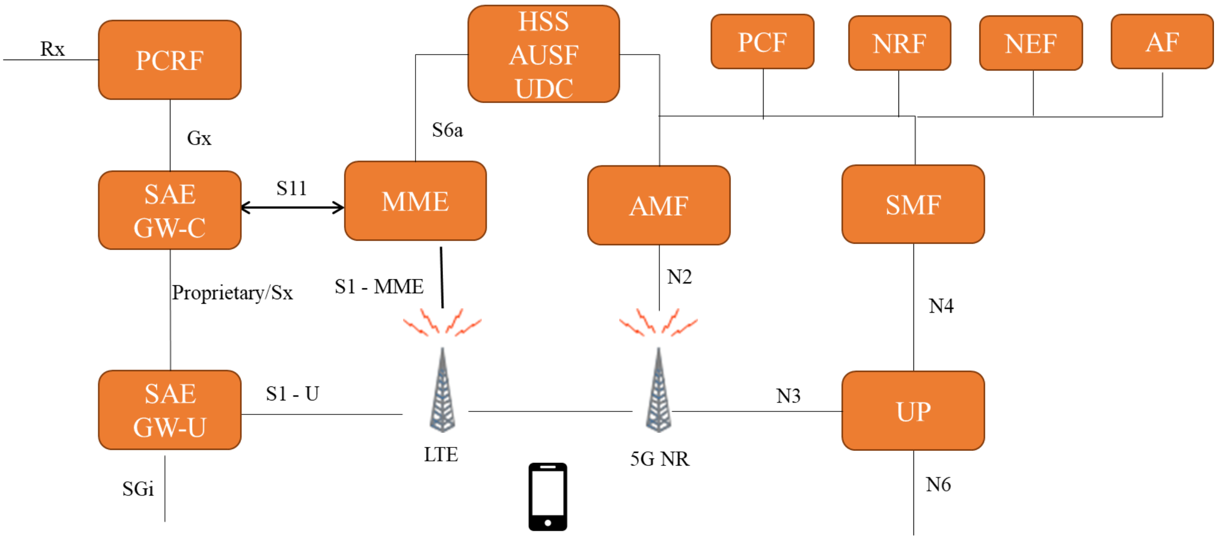

Figure 4-2. Combined 4G and 5G technology

4.2. FhG Core Network

The core network functionalities available from the Open5Gcore Release A support the 4G and 5G radio access, and, from the management perspective, it is compatible with the Open Baton MANO framework.

Main focus of the following project phase will be 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. Equipment vendors as well as telco providers have approached Fraunhofer FhG for such initial integration tests using the Berlin platform, which are expected to occur in Q4-2019.

Besides, additional ways of providing a scalable deployment – apart from using an underlying MANO system – are currently under evaluation according to requirements provided from industry. For example, a Docker-based provisioning of a 5G Core / Testbed is anticipated to be provided within the upcoming project year.

Additionally, an integration of the Open5GCore with commercial test equipment is scheduled.

As part of continuously ongoing developments, the Open5GCore will be enhanced with features of 3GPP Rel. 16

4.3. UNIS Core Network

As part of release A, 4G and 5G core (NSA, Rel.15) have been developed, with work on rel.16 5G core and development of N3IWF interfaces in support of non-3GPP untrusted access, are planned for phase 2 (release B) by Q1-2020. The 3GPP release 16 will specify the details to perform SA cases. Unfortunately, the specifications of this release (w.r.t untrusted non-3GPP network components) have not been formally delivered yet and consequently, the SA cases have not been detailed. Currently, the release-15-compliant EPC deployed on the Surrey Platform does not support the required STa and SWa interfaces. As the main project focus is on 5G functionalities, the integration with the 5G Core, requiring the development of the Y2 and NWu interfaces is planned and aimed for instead. The 3GPP non-roaming architecture for 5GC Network with untrusted non-3GPP network component corresponds to the scenario that is planned to be supported by the Surrey Platform.

5. CONCLUSIONS

In the first year of the project the activities in the core network were focused on the deployment of 4G functionalities towards NSA and initial versions of 5G SA core. The features in the three solutions to be produced in the project include: separation of control and data planes, virtualization of the core components, innovative local break out solutions suitable for MEC, evolution of current EPCs to support NSA and design of the software for SA core, specific configuration of Open5Gcore and integration of WiFi with a 5G Core.

The next steps are oriented to implement or evolve the the SA mode and to evaluate different vEPCs and 5G cores in the context of the outdoor deployments at several platforms:

- At UMA and Malaga City, UMA will evaluate the use of Athonet vEPC extended to release 15 with the NSA mode, and later the use of the SA mode with Athonet 5G core. The 5G and 5G NR equipment to be deployed outdoor is NOKIA AirScale solution provided as response to the open public procurement process by UMA in the context of 5Genesis.
- At Berlin, the Open 5GCORE will be the main solution to test commercial equipment in the area of FhG and Humbold University
- At Surrey, in the context of multiple sensors to support mMTC services.

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] M. Lore, "Trump Is Losing the European War Against Huawei", Light Reading, 9/9/2019 (online) https://www.lightreading.com/trump-is-losing-the-european-war-against-huawei/a/d-id/753980?_mc=RSS_LR_EDT&fbclid=IwAR0k2p4LssIoQXAy2BP1AID5U-J75aqbhL87YdEK-hXaXbicTY5ui82EU60

[4] 3rd Generation Partnership Project (3GPP), "General Packet Radio Service (GPRS) Tunnelling Protocol User Plane (GTPv1-U)", 3GPP TS 29.281.

[5] C. J. Bernardos, A. De La Oliva, F. Giust, J. C. Zuniga, A. Mourad, "Proxy Mobile IPv6 extensions for Distributed Mobility Management", IETF Internet Draft, draft-ietf-dmm-pmipv6-dlif-04, January 2019.

[6] H. Chan, D. Liu, P. Seite, H. Yokota, J. Korhonen, "Requirements for Distributed Mobility Management", IETF RFC 7333, August 2014.

[7] D. Liu, J. C. Zuniga, P. Seite, H. Chan, C. J. Bernardos, "Distributed Mobility Management: Current Practices and Gap Analysis", IETF RFC 7429, January 2015.

[8] M. R. Sama, L. M. Contreras, J. Kaippallimalil, I. Akiyoshi, H. Qian, H. Ni, "Software-defined control of the virtualized mobile packet core", IEEE Communications Magazine, vol. 53, no. 2, pp. 107-115, 2015.

[9] X. Jin, L. E. Li, L. Vanbever, J. Rexford, "Softcell: Scalable and flexible cellular core network architecture", ACM CoNEXT 2013.

[10] S. Chourasia, K. M. Sivalingam, "SDN based Evolved Packet Core architecture for efficient user mobility support", IEEE Network Softwarization (NetSoft), 2015.

[11] A. Basta, W. Kellerer, M. Hoffmann, K. Hoffmann, E.-D. Schmidt, "A virtual SDN-enabled LTE EPC architecture: A case study for S-/P-gateways functions", IEEE Future Networks and Services (SDN4FNS), 2013.

[12] K. Pentikousis, Y. Wang, W. Hu, "Mobileflow: Toward software-defined mobile networks", IEEE Communications magazine, vol. 51, no. 7, pp. 44-53, 2013.

[13] J. Kempf, B. Johansson, S. Pettersson, H. Luning, T. Nilsson, "Moving the mobile evolved packet core to the cloud", IEEE WIMOB 2012.

[14] J. Mueller, Y. Chen, B. Reichel, V. Vlad, T. Magedanz, "Design and implementation of a carrier grade software defined telecommunication switch and controller", IEEE NOMS 2014.

[15] F. Giust, A. Malik, M. Liebsch, "Simplification as design principle for 5G: A native IP data plane for a lean packet system," IEEE PIMRC 2017.

[16] U. Fattore, F. Giust, M. Liebsch, "5GC+: an Experimental Proof of a Programmable Mobile Core for 5G", IEEE CAMAD 2018.

[17] 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.

[18] 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.

[19] ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV), “Network Functions Virtualisation (NFV) Release 2; Protocols and Data Models; NFV descriptors based on TOSCA specification”, ETSI GS NFV-SOL 001.

[20] ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV), “Network Functions Virtualisation (NFV) Release 2; Protocols and Data Models; NFV descriptors based on YANG specification”, ETSI GS NFV-SOL 006.