Under Trial: Evolved Service-Based Architecture Platform for Mobile Telecommunication Networks

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***Abstract*—5G has brought many system improvements to both the Radio Access Network and Core Network, with the shift towards a Service-Based Architecture for the Core Network as one of the most significant changes. This paper presents the argumentation for this architectural transformation in the Core Network, combined with the capabilities such change entails and a proposition towards the next steps for Service-Based Architectures towards Release 18 and beyond. Most notably, the domain of Private Networks and stronger inclusion of vertical requirements is the key driver for such continuous transformation, which were demonstrated as a live demo at an European conference and presented in this paper.**

***Index Terms*—Service-Based Architecture, 5G, Mobile Networks, Demonstration, Core Network, 3GPP, Cloud-Native**

I. INTRODUCTION

Each generation of the ”Next G” has seen the introduction of novel concepts across the entire communication stack of a mobile telecommunication network; and 5G has been no exception to that. While the Radio Access Network (RAN) has seen the creation of a New Radio to further push towards higher throughput and lower latency, there has been one key trend in both RAN and Core Network (CN): the disintegration of 4G components into a set of functionally smaller components with well-defined (standardised) interfaces. The key argument for this push is the desire from operators to vendor-multiplex their networks without physically separating them. The necessity for operators to demand such vendor and deployment flexibility is driven by a changing requirements landscape.

Over recent years, there has been an attempt in 3GPP to include the verticals in the requirements process, allowing 3GPP to understand the actual needs for verticals. Undeniably, the ultimate attempt is to allow a higher penetration of 3GPP-based deployments and to go beyond the typical nation-wide mobile network deployment. This resulted in a significant interest in - back then - so called ”Campus Networks”. Nowadays, 3GPP defines to them as Non-Public Network (NPN) with the option to operate them as Standalone Non-Public Networks (S-NPNs) or Public Network Integrated Non-Public Networks (PNI-NPNs). As the names imply, the two options allow an operator of a 3GPP network to decide whether it is integrated it with a public network. This requires dedicated SIM cards in all devices that are supposed to be attached to this network. In comparison to that, the PNI-NPN option allows any device to attach and to utilise roaming methods to utilise a local Private Network deployment, as specified in 3GPP.

Utilising a 3GPP-based telecommunication network to provide connectivity to previously wired devices, e.g. robots, cameras, sensors or machines, often requires fine-tuned networks to serve the exact need of a specific use case. While this refers to the Quality of Service (QoS) characteristics of the data plane, such flexible deployment also requires the 5G control plane to scale easily. The concepts behind the ability to scale are adopted from the cloud community, where services seamlessly breath based on the load of incoming requests and are also always operational. The key enabler for such behaviour is an underlying Service-Based Architecture (SBA), which adopts architectural concepts of how the cloud allows to offer such system behaviour. These concepts combine modern software design patterns (aka microservices), stateless application layer protocols (e.g. Hypertext Transfer Protocol (HTTP)), cloud-native deployment and operational procedures (aka orchestration) combined with a flexible system architecture that specifies procedures allowing to pick what control plane functionality is required. For instance, for a Private Network for an Industry 4.0 deployment, machines do not require billing support. Consequently, 3GPP's system architecture should allow for such flexibility without any change in how a vendor chose to implement a 5G Core (5GC) Network Function (NF).

The remainder of this paper is structured as follows: Section II presents the current state of the art of 3GPP's Release 17 system architecture and the advances SBA offers. This is followed by FUDGE-5G's proposition around evolving 3GPP's concepts of SBA with architectural changes. This demonstration of FUDGE-5G's evolved SBA is then described in Section IV and V providing details on the testbed used for the actual demonstration. The paper is concluded in Section VI.

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II. SERVICE-BASED ARCHITECTURE AND ITS ADVANCES

This section presents the 5G system architecture as defined by 3GPP and provides insights into how the advances of a SBA fosters cloud-native orchestration of 5GCs.

A. *5G System Architecture*

With the introduction of Service-based Interface (SBI) in 3GPP's Core Network design, Release 15 has been a ground breaker due to the flexibility this change introduced. The resulting Service-Based Architecture [2] for a 5G System is illustrated in Figure 1 and depicts the majority of the 5G Core Network Functions (in orange) and the change in interface naming conventions. SBIs named with N followed by the name of the NF that offers a service (called Producer). This reveals a core improvement in the system architecture, i.e. there is no strict enforcement on which NF can communicate on an interface. This resulting flexibility allows any new functionality of a Producer to be standardised without the necessity to create a new interface name if the requesting entity has changed. Also, NFs with SBIs enable the reporting of monitoring data into the Network Data Analytics Function (NWDAF) as well as the functionality for other NFs to subscribe to events from an NF.

Release 16 then introduces the Service Communication Proxy (SCP) which routes messages between 5GC NFs. Note, the SCP is not offering an SBI and therefore does not carry an interface name in Fig. 1. Also, the SCP is only an optional component and the 5GC can operate in four Models (A through D), with A and B referred to as “direct communication”, as no SCP is in use and Model C and D as indirect communication.

For Model C, referred to as ”SCP without delegated discovery“, any Consumer (the requesting NF) will communicate with the NRF to determine which Producer (the NF responding to the request) to use and obtain the identifier of the SCP (Fully Qualified Domain Name (FQDN) or IP address). For Model D, referred to as ”SCP with delegated discovery“, the Consumer has the SCP identifier pre-configured or retrieved its addressed from the NRF. All communication towards any Producer will use this address. The SCP then communicates with the NRF to obtain which NF is supposed to be used.

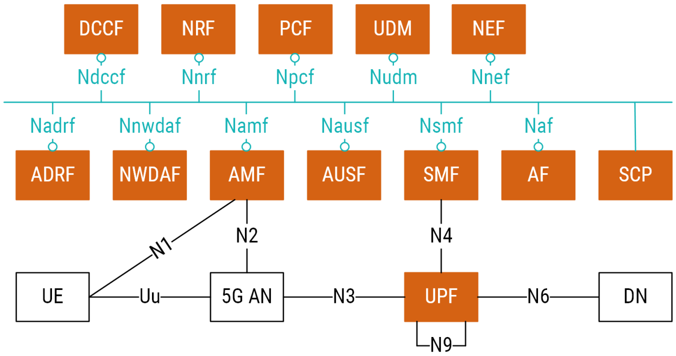

Fig. 1. 3GPP's Release 17 5G System Architecture [2].

TABLE I
A SIMPLE EXAMPLE TABLE

Model	Communication	NRF/SCP	Description
A	Direct	—	No NRF or SCP is used by NFs
B	Direct	NRF	The NRF is used by NFs to obtain the identifier for a Producer. No SCP is used to route the traffic.
C	Indirect	SCP+NRF	The SCP is deployed without delegated discovery, meaning Consumers request the identifier for Producers and SCP from the Network Repository Function (NRF). Packets towards the Producer are then sent to the SCP identifier.
D	Indirect	SCP+NRF	The SCP is deployed with delegated discovery capabilities, meaning the Consumers obtain the SCP from the NRF or have it pre-configured. Once a packet arrives at the SCP, the SCP consults the NRF on the identifier it should use to route the Consumer packet to.

As mentioned before, each SBI-enabled NFs may utilise the SCP to communicate with another NF. However, it can be observed that not all NFs are SBI-enabled, namely the User Plane Function (UPF) resulting in a point to point interface between the UPF and the Session Management Function (SMF). Also, the interfaces between RAN and CN, i.e. N1 and N2, are non-SBI-enabled resulting the Access and Mobility Management Function (AMF) to operate as a peer to the User Equipment (UE) and Access Network (AN).

B. *Impact of Service-Based Architecture on Cloud-Native Procedures*

Modern software design patterns to realise a 5GC NF follow the 12 factor app methodology, which is commonly referred to as implementing an application as a microservice. The 12-factor app methodology [3] essentially provides guidelines on how to decompose a monolithic application into individual software components and let them communicate via an IP-based protocol, e.g. HTTP. Such separation ultimately aims at realising an application that can scale based on demand where microservices that cause a bottleneck can be instantiated as multiple instances and let them handle more overall requests.

As a direct result (and objective) from such approach is to allow automations to deploy and lifecycle manage all microservices that form an application. Such procedures are commonly referred to as cloud-native and are key for an application (such as a 5GC) to be deployed and scaled up or down (e.g. based on incoming control plane requests). The importance of cloud-native procedures to the telecommunication domain were discussed in Next Generation Mobile Network (NGMN)'s cloud-native telco platform project [4]. The published NGMN whitepaper describes in great detail the advances of cloud-native, where it is already utilised in the telco domain and where further efforts are required. One of the key aspects fully acknowledged is the ability to automate the deployment of Virtual NFs (VNFs), cloudified VNFs (cVNFs) and Cloud-Native Network Functions (CNFs), for instance of a 5GC. The key enabler for cloud-native orchestration of 5GCs is the underlying SBA, defined in 3GPP, which defines a set of NFs with well-defined SBIs.

III. EVOLVED SERVICE-BASED ARCHITECTURE

The 5G-PPP ICT-42 project, FUDGE-5G [1], focuses on fully disintegrated private networks and aims to define a unified SBA to improve the operations of a deployed 5G system. FUDGE-5G introduces a dedicated platform layer between the infrastructure and service layer, where 5GC and vertical applications are categorised as an Enterprise Service interfacing via southbound programmable Application Programming Interfaces (APIs) with the platform. Such proposition is illustrated in Fig. 2 with three layers: infrastructure, platform and service.

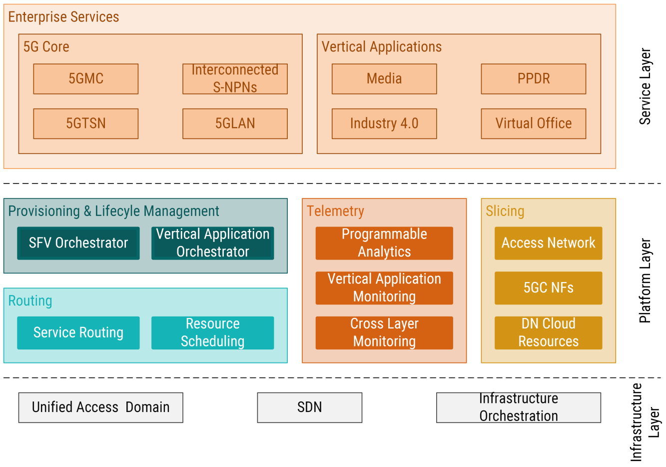

Fig. 2. System Overview of FUDGE-5G's Service-Based Architecture Platform.

The *infrastructure* layer is concerned with components and technologies that are assumed to be available in an operator's infrastructure and exposed through standardised and open APIs. Within the infrastructure layer FUDGE-5G assumes a unified access domain, in the likes of 802.3 as the common denominator as the frame format. If a switching fabric is available in the operator's network, FUDGE-5G assumes it to be fully programmable via Software-defined Networks (SDN) procedures, e.g. OpenFlow. As the FUDGE-5G platform is fully softwarised, all its components can be virtualised and provisioned as VNFs. Thus, the FUDGE-5G platform can either be provisioned on native Commercial off-the-Shelf (COTS) systems without any virtualisation or via an infrastructure orchestrator implementation which follows the ETSI MANO reference architecture [5].

The FUDGE-5G *platform* layer is composed of the three functional blocks: routing, service orchestration and monitoring. The routing block comprises the two functions service routing and resource scheduling. While service routing is concerned about the ability to perform fast and adaptive service routing among CNFs, resource scheduling is performing decisions on which CNF service instance to be chosen from a pool of one or more available instances. These decisions can implement various optimisation criteria in order to meet specific quality of service aspects, such as distributing load equally over a set of CNF instances, limiting the delay of service invocations or similar. The service orchestration block provides location-aware cloud native orchestration for CNFs and an additional vertical application orchestrator for – as the name implies – vertical applications, also utilising the Service Function Virtualisation (SFV) Orchestrator (SFVO). The third block inside the platform layer is concerned with telemetry which is composed of a cross layer and vertical application monitoring as well as an analytics functionality.

The service layer is divided into the two areas 5GC and vertical applications. While the 5GC lists innovations of the FUDGE-5G project around 5G Opportunistic Multicast (OMC), Time Sensitive Networking (TSN), 5G Local Area Network (5GLAN) and interconnected NPNs, the vertical applications range cover four of the five use cases realised by FUDGE-5G to demonstrate the innovations, i.e. media, industry 4.0, Public Protection and Disaster Relief (PPDR), and virtual office.

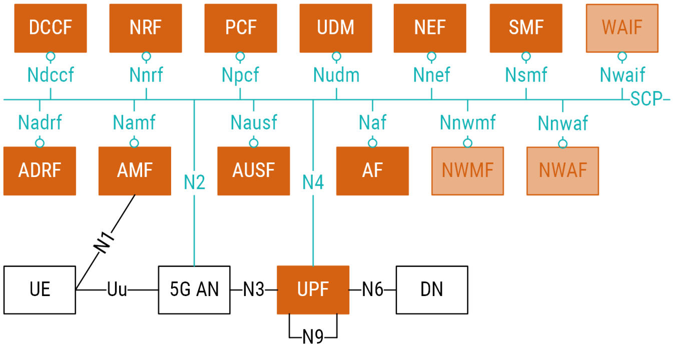

Fig. 3. Applied Beyond Release 17 System Architecture to FUDGE-5G's Service-Based Architecture platform overview.

The result of this unification is provided in Fig. 3, which illustrates a beyond Release 17 5G system architecture with the following improvements:

- The SCP becomes a mandatory component and operates in a new model, Model E, which removes the ability to address the SCP directly and removes the necessity for the SCP to communicate with the NRF. Additionally, the SCP receives resource scheduling capabilities on top of the actual service routing capabilities.

- The N2 and N4 interfaces also use the SCP without any changes to the IP-based protocols they rely on. All endpoints on N2 and N4 are identified through an FQDN, enabling cloud-native orchestration of 5G Cores.
- The NWDAF is split into a Network Monitoring Function (NWMF) and Network Analytics Functions (NWAF). While the NWMF is solely responsible for gathering data points for short-term analytics (1 hour or less). The NWAF offers analytical capabilities based on the data available in the NWMF; similar to the current NWDAF specification. The reason for this is to allow different vendors to realise the NWMF and NWAF, given the growing importance of AI/ML.
- The introduction of a new 5G NF, the Who Am I Function (WAIF), which offers the ability to any NF to request information about itself, e.g. the parent domain under which the entire 5GC operates or the NF type it serves. This is mainly to support cloud-native procedures where NFs are packaged as containers or Virtual Machines (VMs) and can be deployed numerous times.
- The last change to the 5G system architecture partially follows 3GPP's Rel-18 Work Item SP-220417 on "Study on UPF enhancement for Exposure And SBA" [6]. This study introduces an Nupf interface for monitoring purposes and event notifications. FUDGE-5G already implements the key issue on UPF monitoring, indicated by the Nupf interface in Fig. 3.

As illustrated in Fig. 4 and a result of the unification effort, the 5GC NFs WAIF, NWMF, Analytics Data Repository Function (ADRF), Data Collection and Coordination Function (DCCF) and SCP are located in the platform layer. The WAIF is offered as a service endpoint by the SFVO, as the SFVO has all the information about each NF. The SCP combines actual service routing capabilities with the required resource scheduling to make conscious decisions about which Consumer and Producer instances shall communicate with each other. The monitoring and analytics capabilities of the 5GC from Fig. 3, NWMF, ADRF and DCCF, are offered as unified capabilities by the telemetry component of the SBA platform layer.

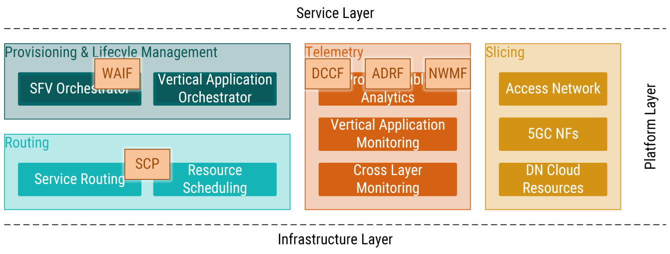

Fig. 4. System Overview of the Service-Based Architecture.

IV. TESTBED

FUDGE-5G follows an agile component integration process with a dedicated testbed made available outside of the trial sites in Norway. This testbed offers the integration of all platform components and Enterprise Services at Technology Readiness Level (TRL) 4. Fig. 5 depicts the testbed with a hardware-based SDN switching fabric and an Network Function Virtualisation (NFV) framework, i.e. OpenStack. The dotted grey lines represent the OpenStack compute nodes and form a logical three-tier edge compute infrastructure with two OpenStack-based data centre nodes at the top, three OpenStack-based edge nodes in the middle and a bare metal-based far edge at the bottom. The coloured boxed represents the SBA platform components deployed as VNFs in OpenStack and as Linux Container (LXC) at the far edge. Furthermore, the far edge is also equipped with a Release 16-compliant gNB (Amarisoft Mini Callbox [7]) and a Quectel 5G modem [8].

Most importantly to Enterprise Services, the VNFs and LXCs called *-sh are the Service Hosts (SHs) into which the SFVO can instantiate an Enterprise Service. The same applies to the *-dn node, representing the Data Network (DN) of the 5G data plane.

V. DEMONSTRATION

The narrative of the demonstration is to showcase the capabilities of the evolved SBA utilising cloud-native procedures to orchestrate a 5GC and to offer unified service routing and telemetry capabilities to the Enterprise Service, i.e. the 5GC. In order to achieve that, Fraunhofer FOKUS' Open5GCore [9] is used, which had been fully containerised including the UPF. All 5GC NFs are orchestrated via the SFVO which comes with a telco-centric and location-aware cloud-native resource descriptor. While this descriptor borrows a number of objects from Topology and Orchestration Specification for Cloud Applications (TOSCA) for NFV definitions, it is fine-tuned towards telco-centric and location-aware capabilities, removing the vast majority of network- and instance relationships. Furthermore, to demonstrate the flexibility of the SFVO to foster multi-vendor deployments, the UPF is deployed separately into the only available SH which offers N3, N4 and N6 capabilities, i.e. fe1-sh. The resulting resource descriptor describing the 5GC is provided in code block Listing 1 below. The resource descriptor is given to the SFVO of the platform layer and will deploy the 5GC according to the instructions provided.

As described in [10], the resource descriptor is split into three main categories: `meta`, `service_functions` and `provisioning`. While the `meta` object allows to specify the definition version this descriptor follows combined with the name of the service chain (fokus-5gc in the example here), the `service_functions` object allows to define the properties for each service function. In case of a 5GC, a service function is an Network Function, e.g. SMF or AMF. While defining typical cloud resources for each service function, e.g. compute, memory and storage, the identifier must be also provided which is the FQDN under which the service function will be registered against the SCP of the SBA platform. Furthermore, the instance manager must be specified (`lxc` in this case for all

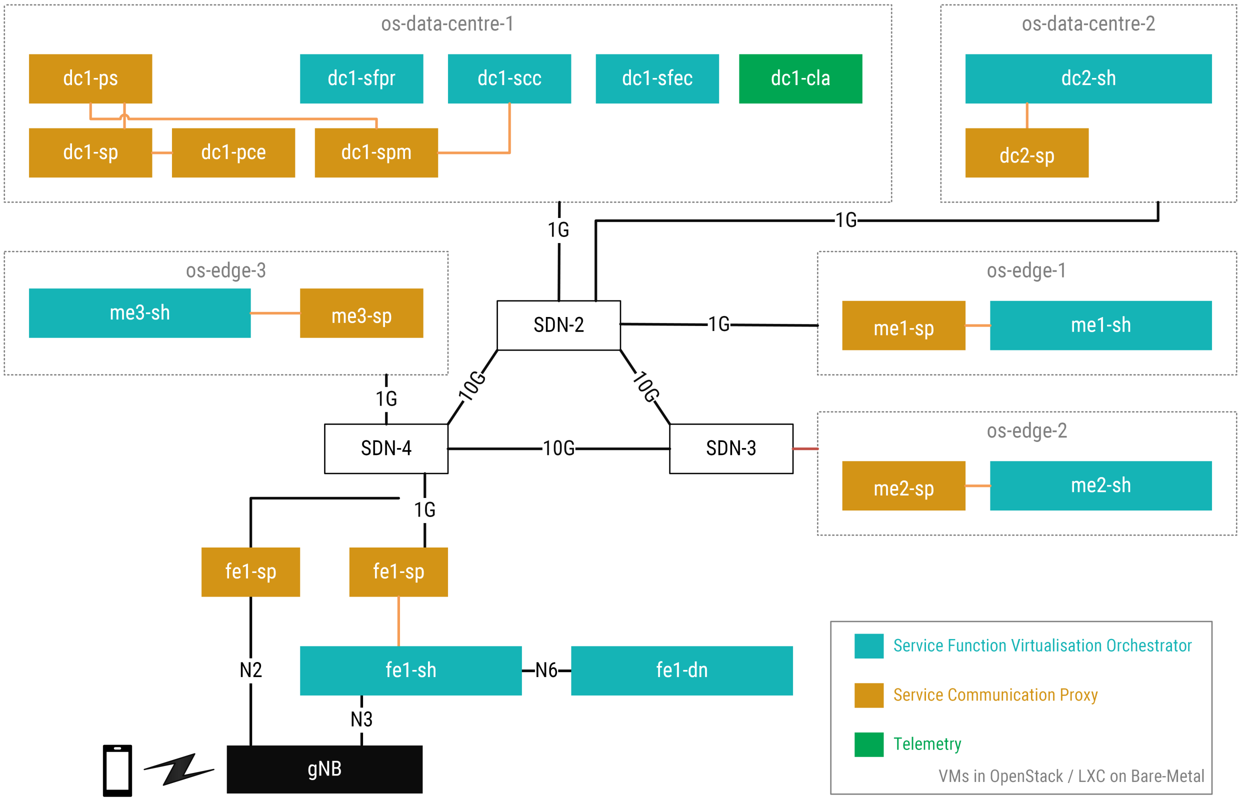

Fig. 5. FUDGE-5G Testbed for Component Integration and Technology Demonstration.

service functions). The last object in the resource descriptor is `provisioning`, allowing to specify which service function is deployed into which SH, how many instances and into which lifecycle management state. In case of the demo described herein, all service functions were set to `connected`, meaning they are imported to by local LXC manager, started and registered against the SCP.

Listing 1. Resource Descriptor for off-premise 5G Core Network Functions

```
meta:
    definition_version: "1.0"
    service_chain: "fokus-5gc-off-premise"

service_functions:
  - name: "db"
    identifiers: ["db.5gc"]
    sfp_url: "http://sfpr/fhg/db.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
  - name: "nrf"
    identifiers: ["nrf.5gc"]
    sfp_url: "http://sfpr/fhg/nrf.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
  - name: "udm"
    identifiers: ["udm.5gc"]
    sfp_url: "http://sfpr/fhg/udm.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
  - name: "ausf"
    identifiers: ["ausf.5gc"]
    sfp_url: "http://sfpr/fhg/ausf.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
  - name: "amf"
    identifiers: ["amf.5gc"]
    sfp_url: "http://sfpr/fhg/amf.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
  - name: "smf"
    identifiers: ["smf.5gc"]
    sfp_url: "http://sfpr/fhg/smf.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000

provisioning:
  - service_function: db
    service_host: dc2-sh
    state: "connected"
    instances: 1
  - service_function: nrf
    service_host: dc2-sh
    state: "connected"
    instances: 1
  - service_function: udm
    service_host: dc2-sh
    state: "connected"
    instances: 1
```

```
  - service_function: ausf
    service_host: dc2-sh
    state: "connected"
    instances: 1
  - service_function: amf
    service_host: dc2-sh
    state: "connected"
    instances: 1
  - service_function: smf
    service_host: dc2-sh
    state: "connected"
    instances: 1
```

As mentioned earlier in this paper, the UPF is deployed separately to demonstrate a permanent on-premise deployed with the 5GC being orchestrated off-premise as part of the demonstration. This is to demonstrate the flexibility introduced by FUDGE-5G's SBA platform to allow gNB (N2) and UPF (N4) to communicate via the SCP via FQDNs. The resource descriptor for the UPF is provided in the code block Listing 2.

In addition to the already introduced fields in the resource descriptor for the object `service_functions`, the UPF has constraints when it comes to installed kernel libraries on the compute host and 3GPP networks that must be available. In the example below, the UPF requires Open vSwitch to be installed in Version 2.5.0 or above and the 3GPP networks N3 and N6 available. These constraints allow the SFVO to ensure the chosen SH has the required libraries and networks.

Listing 2. Resource Descriptor for on-premise 5G Core Network Functions

```
meta:
    definition_version: "1.0"
    service_chain: "fokus-5gc-on-premise"

service_functions:
  - name: "upf"
    identifiers: ["upf.5gc"]
    sfp_url: "http://sfpr/fhg/upf.lxc.tar.gz"
    instance_manager: "lxc"
    compute: 1
    memory: 500
    storage: 1000
    constraints:
      kernel_libraries:
        - name: openvswitch-switch
          min_version: 2.5.0
      interfaces: [n3, n6]

provisioning:
  - service_function: upf
    service_host: fe1-sh
    state: "connected"
    instances: 1
```

The demonstration at European Conference on Networks and Communications (EuCNC) [11] saw the orchestration of the off-premise NFs for each visitor of the booth, including the usage of a health monitoring vertical application pre-deployed in the DN (fe1-dn). Once the resource descriptor for the off-premise service chain `fokus-5gc` was submitted to the SFVO via curl, the deployment took around 2min and the first data points started to arrive in the dashboard (Fig. 6). Once all 5GC NFs started reporting data points to the dashboard, the gNB's software stack was restarted allowing to resolve the FQDN amf.fokus to the IP address assigned to the AMF. Note that, every time the 5GC is redeployed the IP address for each NF is provided by a Dynamic Host Configuration Protocol (DHCP) server that comes with the SBA platform. The IP address assignment is based upon the MAC address of DHCP clients, i.e. the MAC address of each LXC-based NF. As the MAC address changes with each deployment, the IP address is also a different one for each NF. While the routing component of the SBA platform implements Name-based Routing [12] which routes packets solely on the basis of FQDNs instead of IP addresses (Deployment Option 3 for an SCP, as defined in 3GPP's 23.501 [2]), this does not pose any issue to SBI-enabled NFs. However, for the endpoints of non-SBI-enabled interfaces, i.e. N2 and N4, the requesting entity (Next Generation NodeB (gNB) and UPF), must implement logic to resolve FQDNs via Domain Name System (DNS) every time they lose the connection. Amarisoft's gNB implementation only resolves the FQDN for the AMF once the software is started. Thus, if the 5GC has been re-orchestrated, it loses the connection to the AMF and does not trigger a new DNS request for the configured FQDN (i.e. amf.fokus). Consequently, the gNB software must be restarted once the new 5GC has been orchestrated. Within a matter of a couple of seconds, the gNB is attached to the AMF and is ready to serve UEs to attach to the 5GC.

The 5G modem was controlled through AT commands with pre-written Minicom [13] scripts to attach and detach. Instead of a command line, the Minicom commands were executed via system commands from a python-based web interface, making it more appealing to the visitor. Once the modem attached to the 5GC and had its Packet Data Unit (PDU) session of type IPv4 established, the sensory health-related data collection agents on the UE were able to reach the vertical application which visualised the incoming data. Most importantly, the dashboard started to show packets being processed by the UPF on the data plane at the bottom right graph in Fig. 6. A full video of the demonstration can be watched online on FUDGE-5G's YouTube channel [14].

To visualise the orchestration of all on- and off-premise NFs of the 5GC, the dashboard of the telemetry component of the SBA platform was used, which is provided as a screen shot in Fig. 6. The dashboard visualises real-time information about all deployed 5GC NFs and was configured prior to the demo. All NFs are configured to periodically report aggregated data points from Linux' /proc directory including CPU and RAM utilisation along with packet counts. In addition to these data points illustrated as value-over-time graphs in Fig. 6, the number of deployed service functions per location is reported by all SHs. As off-premise NFs are deployed in dc2-sh and on-premise ones on fe1-sh, the dashboard shows the total count of 6 for dc2-sh and 1 for fe1-sh (i.e. upf).

During the course of the three day exhibition, the demo was given around 30 times in total to a mix of technologist, researchers and consultants. In particular the evolution of SBA triggered numerous discussions around reasoning, security concerns and the impact on vendors to take cloud-native orchestration methodologies and microservice design patterns stronger into account.

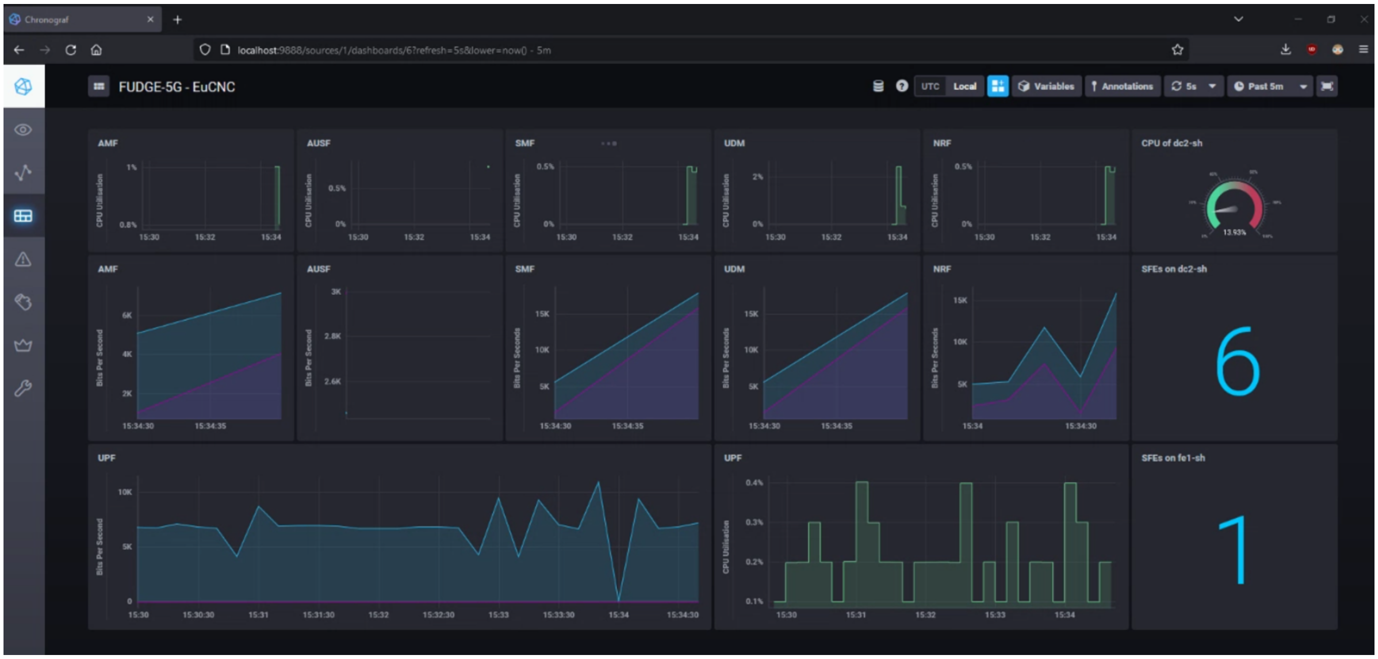

Fig. 6. Dashboard of the Platform's Telemetry Component.

VI. CONCLUSION

This paper presented an evolved Service-Based Architecture platform targeted at both Public and Private Network deployments. In particular the required flexibility to deploy feature-specific 5G networks demands a system architecture that permits that technically. The platform's architectural propositions beyond, what Release 17 offers, range from a new Model E Service Communication Proxy deployment options, over a newly introduced Network Function, the Who Am I Function, and the split of the NWDAF into Network Monitoring Function and NWAF. The components 5GC Network Functions Service Communication Proxy, Who Am I Function and Network Monitoring Function have been then moved into a dedicated Service-Based Architecture platform layer, which offer their functionality to the upper service layer enforcing functionality upon them. The architectural propositions have been then validated in a live demonstration for EuCNC 2022. Using an integration testbed at Technology Readiness Level 4, the live demo entailed the orchestration of a 5G Core within two minutes while walking the visitor to the booth through the architectural concepts. The demo was then concluded with a health monitoring application on the User Equipment (client application) and Data Network (server application), demonstrating the readiness of the data plane.

The demonstrated evolved Service-Based Architecture platform is going to be trailed as part of the 5G-PPP project FUDGE-5G at Telenor, Norway. This will include four different vertical stakeholders form different domains, demonstrating the flexibility of the proposed architecture and the readiness of Service-Based Architecture and multi-vendor 5G Cores.

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