5G Testbed Development for Network Slicing Evaluation

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***Abstract*—5G networks supposed to be a solution for providing the ubiquity connectivity of wireless devices. Network slicing is one of the major enablers of 5G networks. Network slice is a logical network with specific network and security capabilities. To provide a tool for a research study of network slicing, the 5G testbed is being developed. The testbed utilizes the LTE architecture and adds 5G elements to LTE testbed by OpenAirInterface. UE and AN are simulated with help of OAI Simulator. Core Network presented by openair-cn. To enable slice selection function, a UE contains NSSAI. eNB extracts NSSAI which is used for slice selection and relays NSSAI to AMF/MME for further processing. Network slices presented as Docker containers. The 5G testbed allows to study performance issues and attacks on network slices from different angles e.g. protocol, slice selection function in AN, processing NSSAI in core networks.**

Keywords—5G; network slicing; testbed; OpenAirInterface

I. Introduction

5th generation (5G) of mobile networks should be officially presented in 2020 to be a successor of commonly used LTE networks. 5G networks are being designed to solve problems with a lack of bandwidth, provide support for new devices that would be developed under the Internet-of-Things (IoT), Vehicle-to-Everything (V2X) etc.

Network slicing is one of the key technologies for 5G networks. As a network slice, the technical specification 23.501 of 3GPP defines a logical network that provides specific network capabilities and network characteristics.

Many research groups propose solutions on network slicing general architecture and security. Evaluation of these solutions is very important to avoid security, privacy, and performance issues. To analyze this kind of issues and potential solutions, researches need a tool that helps to study the NS technology. Take into account the mentioned reasons, the 5G testbed with NS support is being developed. The developing 5G testbed improves LTE testbed by OpenAirInterface (OAI) and involves 5G elements and procedures. The conception of the testbed based on implementation non-roaming architecture for interworking between the 5G and LTE systems. A user equipment (UE) and access network (AN) are simulated with help of OAI Simulator (OAISIM). Core Network presented by OAI Core Network (OAI-CN). To enable slice selection function a UE contains a network slice selection assistance information (NSSAI). An Evolved Node B (eNB) relays NSSAI to modified Mobility Management Entity (MME) while UE's attach request. NSSAI can be read from a configuration file for each UE. Up to eight Single NSSAIs (S-NSSAI) can be added. Each S-NSSAI has Slice Service Type (SST) and Slice Differentiator (SD) parameters. Modified MME decodes attach request and extracts NSSAI which is used for slice selection. The core network can decode NSSAI for further processing.

NSs presented as Docker containers with preconfigured core networks. Containers allow to run, to select, and to access the network slice that has different performance and security configurations at the same time. Multiple containers can be run on the same host to imitate different NS.

The contribution can be summarized as follows:

- Presented architecture of 5G testbed involves simulation approach allows to implement 5G functions on the access network side without using expensive hardware. Containerization helps to imitate network slicing by multiple core networks that can be run on the same machine.
- Proposed approach that implements the Registration procedure described in Fig. 4.2.2.2.2-1 of [1]. The approach allows selecting network slice by eNB. To involve NS selection function the registration request includes NSSAI. To satisfy NS specification presented in section 5.15.2 of [2], the NSSAI and S-NSSAI (incl. SST and SD) were added to the UE.
- Implemented the method of decoding NSSAI by AMF/MME element. The method allows to decode attach request of 5G UEs and to save backward compatibility with regular LTE UEs.

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II. 5G NETWORKS CONCEPTION

Unlike of previous generations (3G or 4G), the 5G network will have the native supporting of the technologies provided significant speed and connectivity improvements [3].

To identify the requirements for 5G networks, organizations are working on the development of the 5G networks, proposed many possible use cases. For example, the METIS project proposed at least four groups of scenarios that are covering 21 use cases regarding the future user's needs [4].

The main performance requirements for 5G networks, as opposed to 4G networks, were presented by the METIS project [5]:

- 1000 times higher mobile data volume per area.
- 10 to 100 times higher number of connected devices.
- 10 to 100 times higher user data rate.
- 10 times longer battery life for low-power massive machine communication.
- 5 times reduced end-to-end latency.

The research project called METIS-II based on the analysis of the needs and requirements of the METIS-I project, Next Generation Mobile Network (NGMN) Alliance and ITU-R identify three main 5G service types [4]:

- Extreme Mobile BroadBand (xMBB or eMBB), with requirements to the extremely high data rates and low latency.
- Massive Machine-Type Communications (mMTC), providing wireless connectivity for up to tens of billions of network-enabled devices.
- Ultra-reliable Machine-Type Communications (uMTC), requiring ultra-reliable low-latency and/or resilient communication links.

These types of services should fulfill the needs of five general use cases [4]:

- Dense urban information society.
- Virtual reality office.
- Broadband access everywhere.
- Massive distribution of sensors and actuators.
- Connected cars.

To fulfill the users and performance requirements, 5G networks will include many new technologies. However, the main driver will be a software. Network functions (NFs) are expected to run over a unified operating system and rely on technologies such as Software-Defined Networking (SDN), Network Functions Virtualization (NFV), Mobile Edge Computing (MEC) and Fog Computing (FC) **Error! Reference source not found.**.

The SA1 FS_SMARTER [6] consolidates the potential requirements for network operation [7]. If going through the requirements, we can see that the NG networks should be able to support the various type of UEs simultaneously. Moreover, 5G networks should be flexible to provide computing and network capabilities for a third party like logical or virtual networks. One of the main enablers of this feature is a network slicing.

III. NETWORK SLICING FOR 5G NETWORKS

The NS concept is very popular in the 5G community today. One of the first mentions of the NS was made by Ericsson at Broadband World Forum 2013 [8]. The conception of NS is providing the parallel network functions running on the same chip [9]. In 2015, Ericsson proposed the NS for NG networks [10].

Network slicing is one of the key technologies provided by NG networks. The [7] define NS as "dedicated logical networks with customer-specific functionality, without losing the economies of scale of a common infrastructure".

The NS is kind of the virtual network and proposes the third party to create the virtual network infrastructure based on mobile network operator (MNO) physical and logical infrastructure for providing the different services to the customers. The idea based not only on isolation of the one group of devices from others but in the assumption of diverse requirements of the devices e.g. in the areas of functionality, performance, and isolation [11]. The idea comes from the necessity to support UEs whose goals differ from the classical device in terms of the mobile operator. The examples of these UEs could be IoT devices or connected vehicles.

From the third party point of view, the NS provides the channel from an approved UE to the third party's services, data networks (DN) etc.

From MNO point of view, an NS is a virtual network over AN and slice-related virtual network functions (VNF) in the core network that is connected to third party's DN. The MNO should provide a secure access to the NS with certain performance capabilities.

The [2] defines NS as a logical network that provides specific network capabilities and network characteristics. We can extend this definition and guess that an NS is an end-to-end virtual network between UE and DN with certain performance and security capabilities.

IV. ARCHITECTURE OF 5G NETWORKS

To present architecture of NS over 5G networks, the architecture of 5G networks should be introduced as well.

The architecture of 5G network presented by 3GPP in TS23.501: "System Architecture for the 5G System". Regarding [2], the 5G system (5GS) consists of UE, 5G Access Network (5G-AN), and 5G Core Network (5GC). As a 5G network, we can understand the network where UE, 5G-AN, and 5GC are the parts of the same network.

The 5G networks based on virtualization technology to provide flexibility for on-demand network creation and configuration. To provide the independent scalability and evolution, the 5G network separates Control Plane (CP) and User Plane (UP) functions. The basic element of the 5G network is Network Function (NF). NF is some processing network element with defined interfaces and behavior.

The [2] specifies two ways of representation of 5GS: a service-based representation and reference point representation. In addition, the documents present non-roaming and roaming 5G architectures.

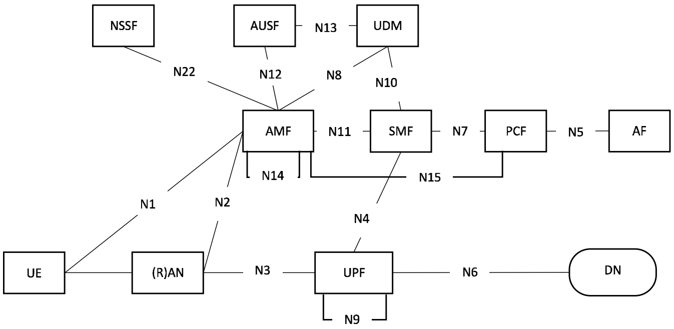

Fig. 1. Non-Roaming 5GS Architecture in reference point representation

Fig. 1 shows non-roaming 5GS Architecture in reference point representation regarding the current version of [2]. The following NF are presented:

- User Equipment (UE)
- (Radio) Access Network ((R)AN)
- Access and Mobility Management Function (AMF)
- Authentication Server Function (AUSF)
- Data Network (DN), e.g. operator services, Internet access or 3rd party services
- Network Slice Selection Function (NSSF)
- Policy Control Function (PCF)
- Session Management Function (SMF)
- Unified Data Management (UDM)
- User Plane Function (UPF)
- Application Function (AF)

The interaction between the NFs (e.g. RAN and AMF) presented by point-to-point reference point (e.g. N2) between any two network functions.

The comprehensive description of all NFs can be found in [2].

A. *Network Slicing Presentation within 5G Networks*

To define which NS the UE would like to connect the NSSAI is used [2]. The NSSAI consist up to eight S-NSSAI. That means 5G UE is able to connect up to eight different NSs. Nevertheless, the current version of [2] standard describes three NS right now. The S-NSSAI contains information concerning SST and optionally SD. The SST is used to connect the UE to a certain type of NS (e.g. IoT slice). In case if MNO has several NS instances (NSI) that provide same NS type but specific for different UEs, the UE can select particular NSI with help of SD (e.g. IoT slice of some company).

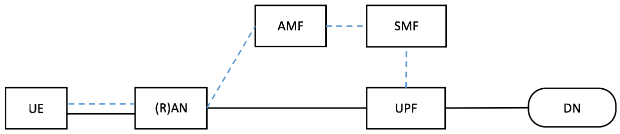

Fig. 2. The simplified NS representation over 5G network architecture from UE's point of view

Fig. 2 shows the simplified NS structure over 5G network elements. The dash lines present Control Plane (CP) connections and solid lines present end-to-end (E2E) User Plane (UP) connection between UE and DN. NS uses the CP layer to establish and configure the connection between UE and DN and UP layer to exchange user data between UE and DN. On the CP layer, UE communicates only with MNO's NFs. If additional, or secondary authentication the DN uses the 5GS to transmit the authentication data between UE and DN. In this case, the DN provides the authentication server and SMF takes the authenticator role [12].

There are several options to connect UE to specific NS. One of them when AN can map SST/SD to specific AMF. Other options assume that AN redirect the NS registration to default AMF which find the proper NS with help of other CN elements like NSSF, UDM etc [2].

V. 5G Testbed Components

As mentioned before, there are no open sourced 5G testbeds in open access right now. Because of that, the LTE testbed is being modified by involving 5G NS procedures to it.

The testbed divided into two parts: (1) the radio part consists of UEs and AN, and core part consists of core network elements.

To have the possibility of implementation 5G procedures like the NS, we should both the radio and the core network allowing modification. The LTE core network part available as an open source software and allows making modifications we need. However, the radio part consists of a hardware that is not allowed to make modification easily. Because of this, the simulation of AN is needed to imitate the radio part and implement 5G procedures.

This kind of requirements could be satisfied by OpenAirInterface software.

A. *OpenAirInterface*

OpenAirinterface (OAI) is an emulation platform that for modeling LTE and 5G (in future) environment [13].

OAI helps to analyze the CP and UP of LTE protocol stack. OAI can trace system information, MAC, and RRC in the control plane, and packet segmentation and reassembly in the user plane. The OAI implements 3GPP stack: the radio access network (including eNB 4G, UE, and gNB, 5G UE in future) as well as the core network (Evolved Packed Core - EPC, 5G-Core Network in future) [13].

The OAI source code is split into two projects:

- OAI Radio Access Network (OAI-RAN)
- OAI Core Network (OAI-CN)

OAI-RAN emulates LTE UE and eNB. To emulate UE and eNB, the OAI-RAN needs OAI-supported hardware. In addition, OAI-RAN includes OAI simulator (OAISIM) that allows imitating LTE UE and eNB functioning without specific hardware support.

OAISIM provides simulation with full physical (PHY) and synthetic radio channels. In PHY mode, the full protocol stack is executed as is the case of use OAI hardware. Several eNB and UE can be virtualized in the same process. Support for Ethernet-based emulation is also provided so that nodes can be distributed on a local network [14]. OAISIM was selected to simulate UE and eNB. OAISIM is open sourced and imitates LTE protocol stack including imitation of the radio connection. As a core network, the OAI-CN was used [13].

OAI-CN is an implementation of EPC and 5G-CN (in future) that is used in real LTE deployments for research and commercial purposes. In OAI-CN implementation, the Serving Gateway (SGW) and the Public Data Network Gateway (PGW) are merged together. The Mobility Management Entity (MME) is a network entity that can be deployed on its own host or can be co-located with any other LTE network entity (SPGW, HSS). The SPGW is a network entity that can be deployed on its own host or can be co-located with the MME or/and with the HSS [13].

B. 5G Testbed Architecture

With help of OAI, the developing 5G testbed based on a combination the simulation and "in-situ" modeling principles that provide a high level of accuracy of experiments. The initial architecture of LTE testbed that is used for implementation of the 5G testbed is presented on Fig. 3.

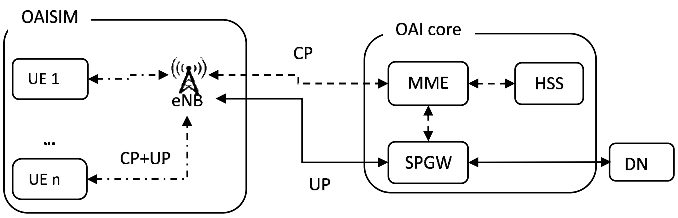

Fig. 3. Initial testbed architecture

In Fig. 3 the radio part consists of UEs and eNB. The CN contains MME, HSS, and SPGW that combines SGW and PGW. The CN is connected to DN that is Internet access in our case. By the dash lines presented CP, by solid lines UP, and by dash-dot lines the CP and UP together.

As it showed in Fig. 3, the initial testbed consists of LTE elements. The initial testbed provides a capability to connect and serve LTE UEs only.

5G elements were added to LTE testbed to provide the interworking with E-UTRAN connected to EPC [TS23.501, 4.3]. As a first step, the part of the non-roaming architecture for interworking between 5GS and EPC/E-UTRAN was implemented regarding Figure 4.3.1-1 of [2] (Fig. 4).

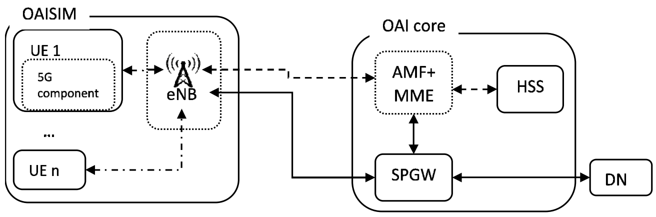

Fig. 4. Current 5G Testbed architecture

In Fig. 4, the elements lined by solid are the LTE entities, elements lined by dots including both functions of 5G and LTE networks regarding Figure 4.3.1-1 of [2]. UE attach function was modified by including NSSAI to UE configuration and encoding the NSSAI into attach message. CN selection function of eNB take into account provided NSSAI. AMF/MME has the decode function of NSSAI.

The architecture presented in Fig. 4 allows implementing the NS conception and providing internetworking with LTE.

VI. 5G Testbed Implementation

In the section, the 5G testbed setup and new implemented functions are described.

In the current development stage, a UE registration procedure to the NS was implemented with an option where eNB selects proper NS based on provided NSSAI [1, Figure 4.2.2.2.2-1].

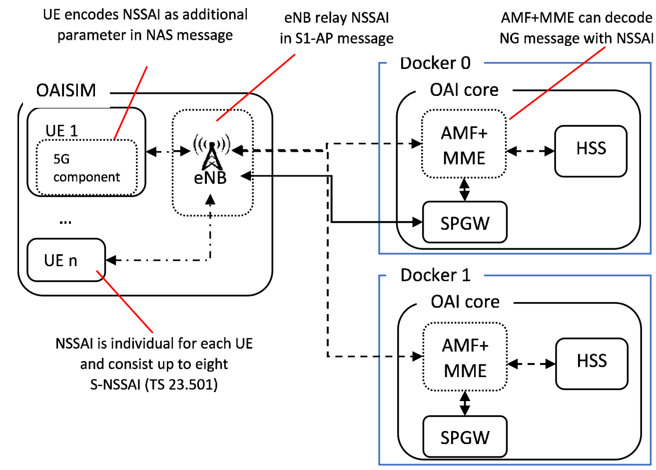

Fig. 5. The structure of 5G Testbed with NS support

Fig. 5 shows implemented 5G testbed with the shortcut of components functionality. The NSs were imitated by Docker containers. Each Docker container has installed OAI-CN with specific IP address. HSSs' databases are identical and contain all necessary UE credentials. The isolation of CNs relies on Docker.

OAISIM has UE configurator that is needed for compilation of UE's parameters and credentials. The configurator takes information from UE's configuration file. The configurator was modified and the functionality to compile the NSSAI was added.

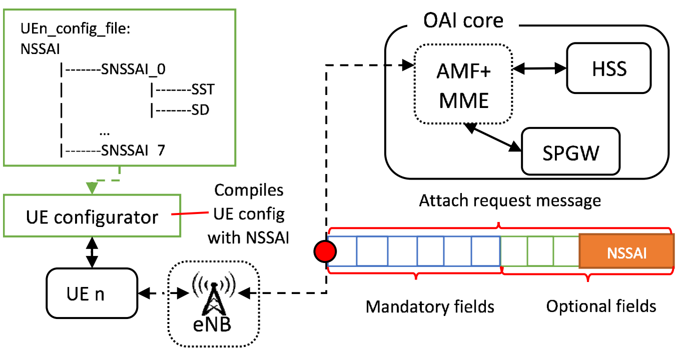

Fig. 6. NSSAI implementation

The example of input NSSAI parameters from the configuration file is shown in Fig. 6. If no NSSAI is presented in the configuration file, the configurator will skip NSSAI field while a compilation of the UE. In this case, the UE will be presented as a regular LTE UE. If the configurator compiled a new UE with NSSAI the UE encodes NSSAI in attach request on NAS layer.

An LTE UE creates a regular attach message which has mandatory and optional fields. The NSSAI is encoded as an optional field to save backward compatibility with regular LTE CNs.

The process of NS selection by eNB is shown in Fig. 7 that presents CP protocol stack of UE, eNB, and AMF/MME.

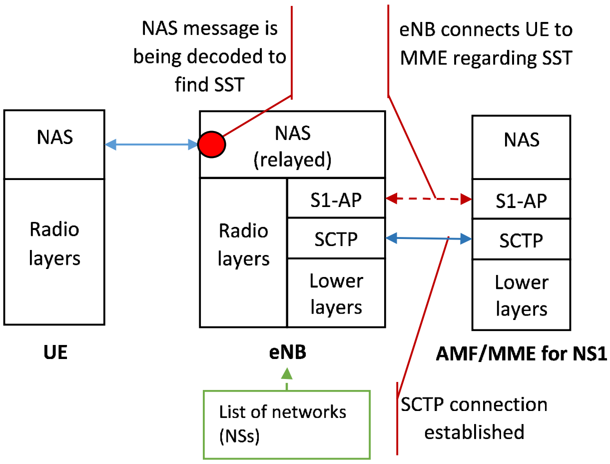

Fig. 7. Attach request modifications

The modified eNB reads a list of networks (NSs) where the available CN are numbered. After the simulation run, the eNB establishes SCTP connection to all available CNs and waits for an attach request from UE.

When eNB gets the attach request from UE, it should select an AMF/MME. The modified eNB will check if NSSAI presented in PDU container. In case if NSSAI is presented, the modified eNB run a loop to compare the number in SST to network number in the list of networks. If the eNB finds the AMF/MME number which is corresponding to SST, it establishes an S1 connection to selected AMF/MME.

If no NSSAI is presented in NAS message the modified eNB working as a regular eNB by default.

When the selected AMF/MME gets modified attach request message, it decodes mandatory fields like the regular ones. After mandatory fields decoded, the AMF/MME check the flag of optional fields by standard decode function. If NSSAI's flag is found, AMF/MME runs NSSAI decode function. This kind of method allows saving backward compatibility with regular LTE UEs.

VII. Conclusion

The paper presents the current state of 5G testbed development for a research study of NS function. The testbed consists of modified LTE UE, eNB, and CN where the 5G procedures implemented to allow using NS selection function.

The 5G testbed provides an environment to study and testing NS related architectural and security solutions from different angles e.g. protocol, NS selection function in AN, processing NSSAI in UE, AN, and CN.

The testbed introducing containers allow to run, select, and access the virtual networks (NS) that have different performance and security configurations simultaneously.

Comprehensive manuals how to install and run OAISIM, OAI-CN, how to get pre-configured Docker containers, as well as the 5G testbed source code, can be found on https://github.com/ashxz47.

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