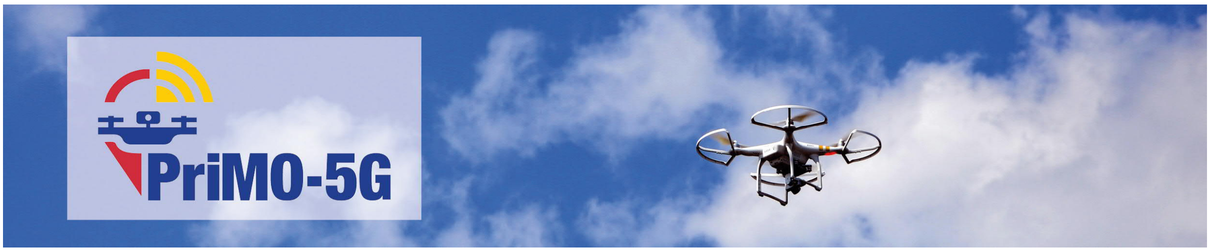

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Instrument	Research and Innovation Action
Topic	The PriMO-5G project addresses the area of “a) Focus on mmWave and super broadband services” in the call “EUK-02-2018: 5G” of the Horizon 2020 Work Program 2018-2020.
Start Date of Project	01.07.2018
Duration of Project	36 Months
Project Website	https://primo-5g.eu/

D2.4 – PRIMO-5G NETWORK SLICE MANAGER-VERTICAL INTEGRATION REPORT

Work Package	WP2, 5G Core network
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Dissemination Level

X	PU: Public
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Executive Summary

This document aims to present the capabilities and characteristics of 5G communication systems within the end-to-end system infrastructure as well as details on the system deployment and results that validate the integration of application verticals within the PriMO-5G 5G infrastructure.

The document is organized as follows:

- Section 2 presents an overview of how network slicing can be enabled within the 5G end-to-end architecture and examines the relevant 3GPP specifications for the 5G Core as well as network slicing within the Cloud-RAN.
- Section 3 focuses on UE registration procedures with respect to network slicing. This includes the UE registration with and without pre-configured NSSAI as well as the PDU session establishment.
- Section 4 provides a description of the Network Management Application Function as part of the PriMO-5G 5G Core design and the necessary procedures for handling and network slice requests from the UE and managing the relevant network slice configurations.
- Section 5 presents the deployment and the validation of a 5G system with network slicing and edge computing capabilities serving a deployed application. An initial experiment is achieved between the testbeds of KCL and Aalto and then extended to work by using the intercontinental 5G Core link for the purpose of remotely controlling a robot in Korea from Finland between YU and CMC.

List of Acronyms

Acronym	Definition
2G	Second Generation Mobile Network
3G	Third Generation Mobile Network
3GPP	3rd Generation Partnership Project
5G	Fifth Generation Mobile Network
5GC	5G Core Network
5GS	5G System
AMF	Access & Mobility Management Function
AN	Access Network
BBU	Base Band Unit
CAPEX	Capital Expenditure
CU	Central Unit
DB	Database
DL	Downlink
DNN	Data Network Name
DNS	Domain Name System
DU	Distributed Unit
eNB	Evolved Node B
FFT	Fast Fourier Transform
gNB	gNodeB
GSMA	Global System for Mobile Communications Association
GUI	Graphical User Interface
HPC	High Performance Computing
HPLMN	Home Public Land Mobile Network
ID	Identity
KOREN	Korea Advanced Research Network
MAC	Medium Access Control
MEC	Multi-Access Edge Computing
NAS	Non-Access Stratum
NF	Network Function
NG	Next Generation
NR	New Radio
NRF	Network Repository Function
NSI	Network Slice Instance
NSSAA	Network Slice-Specific Authentication and Authorization
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
PDCP	Packet Data Convergence Protocol
PDU	Packet Data Unit
PHY	Physical Layer
PLMN	Public Land Mobile Network
PON	Passive Optical Network
RAN	Radio Access Network
RLC	Radio Link Control
RRH	Remote Radio Head
RU	Radio Unit
SD	Slice Differentiator
SLA	Service-Level Agreement
SMF	Session Management Function
S-NSSAI	Single-Network Slice Selection Assistance Information

Acronym	Definition
SNPN	Stand-alone Non-Public Network
SST	Slice/Service Type
TEIN	Trans-Eurasia Information Network
TR	Technical Report
TS	Technical Specification
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function
VLAN	Virtual Local Area Network
WP	Work Package

1 Introduction

1.1 Purpose and Scope of the document

The main aim of the PriMO-5G project is to demonstrate an end-to-end 5G system providing immersive video services for moving objects, showcasing application-driven algorithms for autonomous networking with distributed learning-based computations from AI-assisted networking and edge computing research. The title of deliverable 2.4 is "PriMO-5G Network Slice Manager – Vertical Integration Report" and its purpose is to describe the capabilities and characteristics of 5G communication systems as well as to deploy and validate application verticals integrated within the 5G end-to-end infrastructure. This deliverable builds upon the initial design of the architecture proposed in D2.1.

Deliverable D2.4 is also aligned with Task 2.2 which concerns the implementation and testing of the network slice manager that delivers the network slices for the PriMO-5G applications as well as with Task 2.3 which is related to the implementation and testing of the MEC and the supported PriMO-5G applications.

1.2 Structure of the document

Deliverable 2.4 consists of four main sections regarding management of network slicing within 5G end-to-end communication systems and the deployment and performance validation of application verticals of PriMO-5G. Section 2 investigates the end-to-end 5G infrastructure focusing on network slicing capabilities and characteristics of 5GC and Cloud-RAN. Section 3 focuses on UE registration procedures with respect to network slicing, describing the UE registration with and without pre-configured NSSAI as well as the PDU session establishment. Section 4 provides a description of the Network Management Application Function as part of the PriMO-5G 5GC design and the necessary procedures for handling and network slice requests from the UE and managing the relevant network slice configurations. Finally, Section 5 presents the deployment and the validation of a 5G system with network slicing and edge computing capabilities serving a deployed application. The experiment is also extended to work by using the intercontinental 5GC link for the purpose of remotely controlling a robot in Korea from Finland.

1.3 Relationship to other project outcomes

The overall work structure of PriMO-5G project is illustrated in Figure 1.1. In this work structure, WP1 specifies the PriMO-5G firefighting use cases that inspired research and technology developments in WP2, WP3, and WP4. Deliverable 2.4 includes input related to the interaction with WP1 regarding the Primo-5G use cases, with WP5 regarding the demos for the different use cases and WP4 regarding the implementation of the network slice manager and its integrated machine learning capabilities.

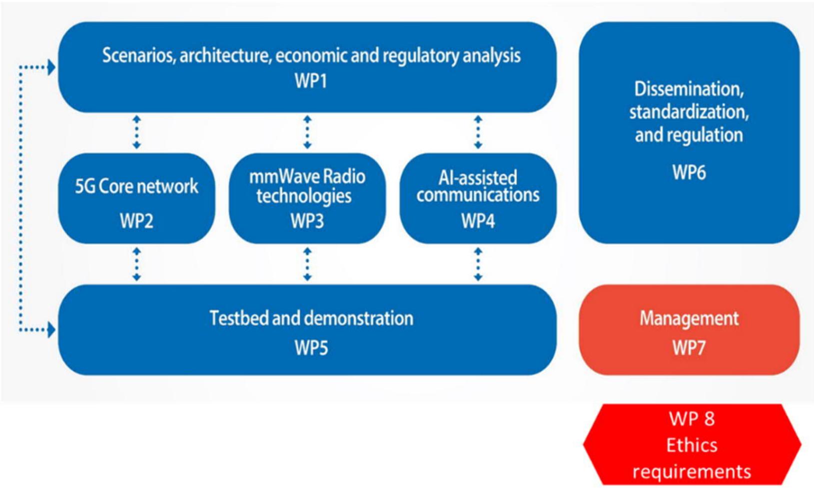
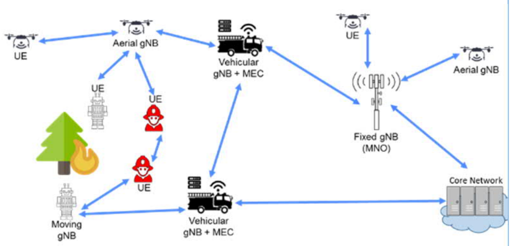
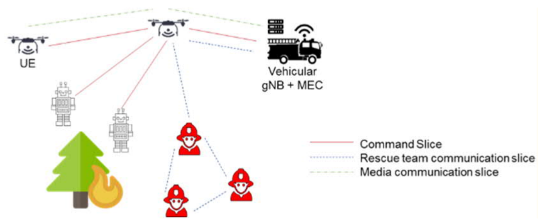
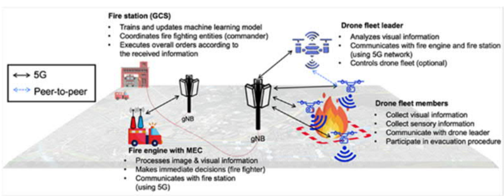
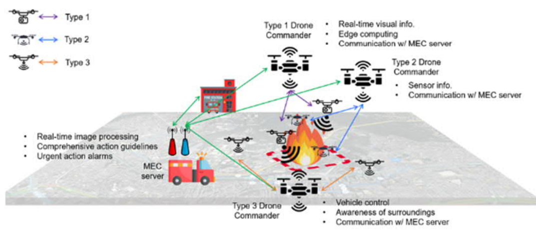


Figure 1.1 PriMO-5G work structure

As noted previously, this present and discuss frameworks and architectural components that expose network services and capabilities to external network users and application developers, focusing on the PriMO-5G firefighting scenarios and use cases described in *D1.1 PriMO-5G Use Case Scenarios* [PRIMO-D11]. These include two scenarios, namely, forest firefighting in rural areas and firefighting in urban areas, with each of these scenarios having two associated use cases. Table 1.1 provides a summary description of the use cases.

Table 1.1 PriMO-5G scenarios and use cases

<table>
<tr><th>Scenarios</th><th colspan="2">Use cases</th></tr>
<tr><td>Scenario A: Forest firefighting with robots and UAVs</td><td>Use case A1. Placement of communication and computing for forest firefighting

</td><td>Use case A2. Network slice management for forest firefighting

</td></tr>
<tr><td>Scenario B: Smart firefighting with UAVs in urban area</td><td>Use case B1. UAV-assisted preparatory measures for smart urban firefighting

</td><td>Use Case B2. Differentiated UAV fleet management for smart urban firefighting

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</table>

2 End-to-end Network Slicing

2.1 Introduction

Within the end-to-end communication infrastructure, both the 5G Core and Access architectures and their supportive technologies act as enablers of a network able to dynamically share its resources according to the requirements of demanding use cases. This can be achieved with network slicing, which 3GPP defines as a logical network that provides specific network capabilities and network characteristics that can be dynamically created.

2.2 3GPP Specifications for 5G Core network slicing

A given User Equipment (UE) may have access to multiple slices over the same Access Network (AN), e.g., over the same radio interface. Each slice may serve a particular service type with agreed upon Service-level Agreement (SLA). A Network Slice is defined within a Public Land Mobile Network (PLMN) and includes the Core Network Control Plane and User Plane Network Functions as well as the 5G AN.

The network can have multiple instances of the same type of slices. Thus, a network slice instance consists on a set of Network Function instances and the required resources (e.g. compute, storage and networking resources) which form a deployed Network Slice.

An introduction of network slicing is defined in GSMA [GSMA-17]. From a mobile operator's point of view, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated service quality. The technology enabling network slicing is transparent to business customers.

A network slice can span across multiple parts of the network (e.g. terminal, access network, core network and transport network) and can also be deployed across multiple operators. A network slice comprises of dedicated and/or shared resources, e.g., in terms of processing power, storage, and bandwidth and has isolation from the other deployed network slices. The Next Generation Mobile Networks (NGMN) alliance also refers to network slice concept as follows [NGMN-18]: "A network slice instance may be fully or partly, logically and/or physically, isolated from another network slice instance".

Network slicing has been defined as part of the 5G architecture in 3GPP [3GPP-23501]. The network slice architecture is shown Figure 2.1. A network slice is considered as a logical end-to-end network that can be allocated to several User Equipment (UE) units and it can be dynamically created and modified. A Network Slice is defined within a Public Land Mobile Network (PLMN) and shall include the Core Network Control Plane and User Plane Network Functions as well as the NG Radio Access Network. A UE may access multiple slices that are linked to a PLMN where each UE is registered. The slices are associated to a given Service-level Agreement (SLA) based on bit rate, latency and packet loss.

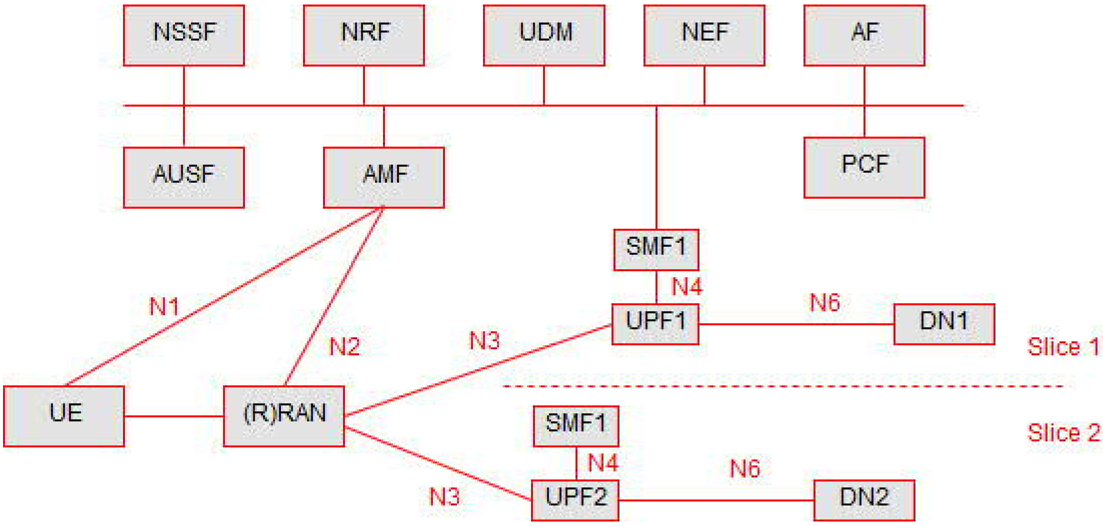


Figure 2.1. Network slice architecture

Each slice is identified by the Single Network Slice Selection Assistance Information (S-NSSAI). 3GPP has defined eight (8) S-NSSAIs in the NSSAI which is the group of S-NSSAI that is sent between the UE and the network during the registration and signalling procedure. The UE provides to the network the NSSAI which then must allocate the required resources at radio, network and mobile core network functions.

The S-NSSAI consists of following elements:

- A Slice/Service type (SST), defined the expected requirements in terms of features and services associated to the network slice.
- A Slice Differentiator (SD), is optional and provides additional information to differentiate each slice amongst multiple Slices with the same SST to e.g. isolate traffic to different services into different slices.

Figure 2.2 shows the process for assigning an AMF for the UE that requires only a URLLC slice. However, if a UE requires several slices simultaneously, the process will assign a single AMF capable of handling all the requested slices.

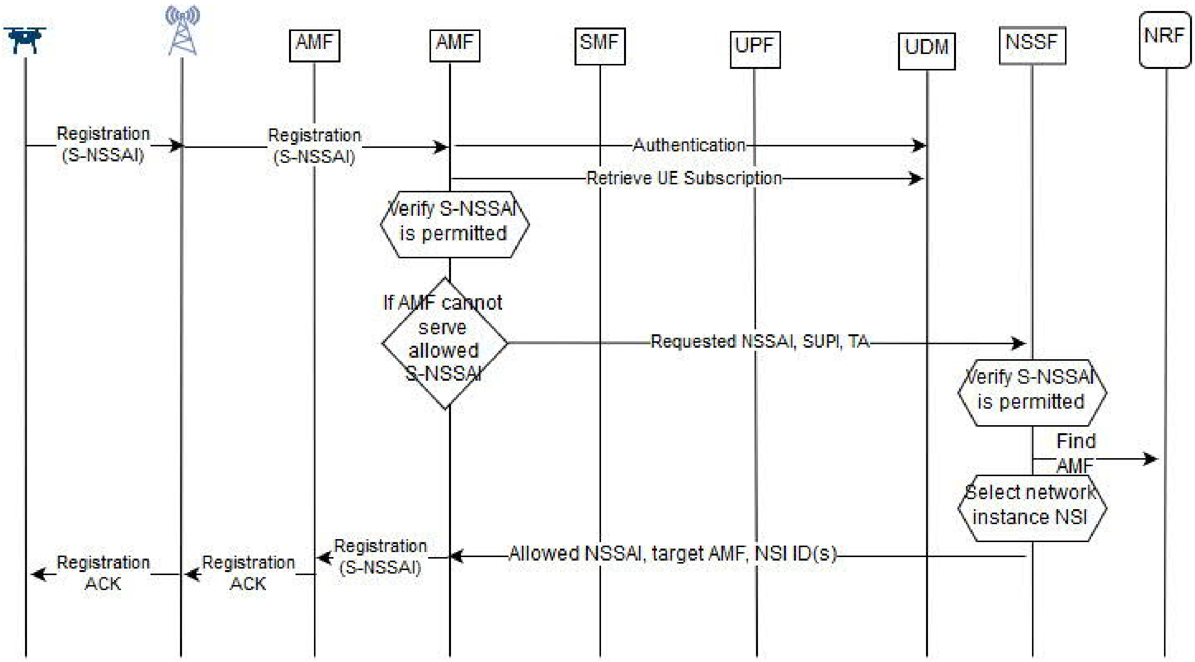


Figure 2.2 Flow for slice allocation

2.3 RAN slicing with flexible function split

The cloudification of RAN, i.e., Cloud-RAN, enables the splitting of the layers of the NR radio stack to function in the form of cascaded functional splits. Each of the split options enable network slicing within RAN by distributing the RAN functions to accommodate different use case requirements. The two main components that share the distributed RAN functions are two:

- The distributed unit (DU), also known as the Remote Radio Head (RRH), which holds analogue and radio frequency functions.
- The central unit (CU), also known as the Baseband Unit (BBU), which holds baseband functionalities.

2.3.1 Functional splits

One view to the RAN network slicing is the ability to run each slice with potentially different split. Figure 2.3 Function Split between CU and DU [3GPP-TR38.801]Figure 2.3 shows the cascaded functional split options between the CU which corresponds to the left side of the split and the and the DU which corresponds to the right side of the split.

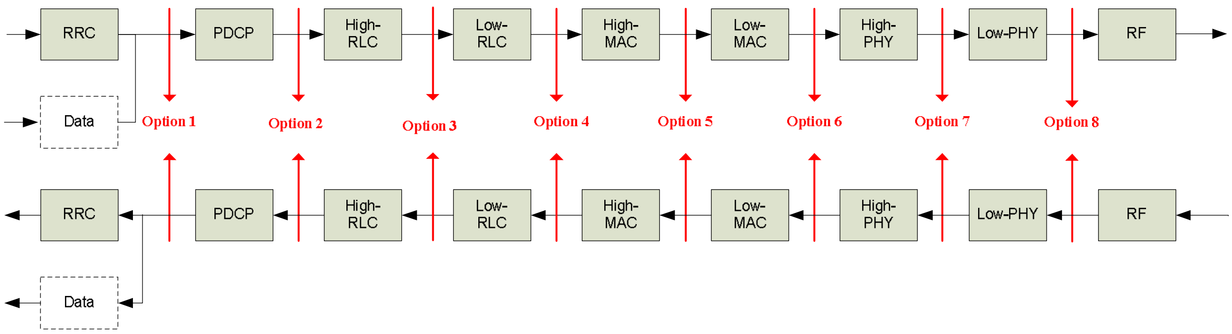


Figure 2.3 Function Split between CU and DU [3GPP-TR38.801]

The options available for the functional splits are:

- Option 1: Only RRC is in CU, PDCP, RLC, MAC, PHY and RF are in DU. The main benefits of this split are that the FH data rate scales flexibly according to the user plane traffic and the interface typically cope with relatively larger latency. Moreover, having all the user plane protocol in DU i.e. closer to the edge, this split is beneficial for low latency use cases. However, because PDCP which performs security is in DU, this split requires the distribution of a security key.

- Option 2: For this split, RRC and PDCP are centralized whereas lower layer functions are distributed. This split point is intensively considered by standard bodies and researchers and it is like split 3C which has been standardized in LTE dual connectivity [5]. Having PDCP in CU, the split is effectively suitable for aggregation at PDCP level because it doesn't necessarily require a strict lower layer synchronization. It's also suitable for mobility and handover as it enables reducing handover failure probability. As in the case of Option 1, FH data rate scales relative to user traffic.

- Option 3: The split is performed within RLC sublayer. From 3GPP point of view, two options are defined in this split. The first option centralizes RLC ARQ which can help to recover from FH interface failure using ARQ end-to-end recover mechanism. The second option separates transmit and receive RLC where transmit RLC is in DU whereas receive RLC is in CU.

- Option 4: RRC, PDCP and RLC are in CU. MAC, PHY and RF are located in DU. The FH interface transports RLC PDUs. Thus, the data rate of the interface is dependent of user activity. The drawback is the split is not simple to implement and might be impractical because of the tight interaction between MAC and RLC. For example, in DL, RLC considers its buffer size along with the scheduling decisions of MAC in terms of resource blocks to generate the RLC PDUs. This mechanism should not take long time.

- Option 5: The split is within MAC, where part of MAC functionality for instance scheduling decision are in CU whereas time critical MAC processing is located in DU.

- Option 6: For this option, the split is between MAC and PHY wherein only PHY and RF are in DU. The split offers a high level of centralization and pooling gain compared to options above. Transport blocks are transmitted over the FH interface, hence the data rate of the FH scales with user traffic.

- Option 7: This is intra-PHY split whereby part of PHY functions are in CU. The other part of PHY and RF are in DU. Key advantage of this option is high degree of centralization with a significant reduction on the FH data rate requirement compared to CPRI by moving antenna related operations to the CU (e.g., DL antenna mapping, FFT, etc.). However, the DU in this option is more complex than the one in Option 8.

- Option 8: This corresponds to a fully centralized RAN architecture. FH transports IQ data in time domain. While this option benefits from the advantages of full centralization, it has very high data rate requirement. Nevertheless, each of this envisioned split has its own requirement. In general, the lower the split point, the greater the level of centralization, the higher is the required interface data rate and the more stringent is the latency requirement.

RAN slices with different split options run on the same infrastructure and hence share the same interconnectivity between RU and the DU/CU; this interconnectivity is referred to as Fronthaul. Sharing the fronthaul among RAN slices is hence an important aspect of the RAN slicing.

2.3.2 Slicing Fronthaul

Fronthaul resources can be sliced orthogonal or non-orthogonal with advantages and disadvantages in terms of efficiency in resource usage and isolation of different slices. Economic solutions for fronthaul include the Ethernet protocol and Passive Optical Network (PON). Either of these two solutions face challenge in meeting the requirements of RAN function split, and need integration of various techniques to accommodate those; feasibility of Ethernet and PON for fronthaul in the case of option 6 is studies in [MRMD17] and [LSMRM21]. Slicing of ethernet is studied in [MMS18] and of PON is studied in [DSKR20].

3 Backhaul and MEC

3.1 Introduction

The network slice assignment process depends on whether the UE already has preconfigured an NSSAI from previous registrations. If the UE does not have specific or default NSSAI available during the registration the Network Slice Selection Function (NSSF) is used to discover slices assigned to the UE.

3.2 UE registration with preconfigured NSSAI

The slice selection is determined by the NSSAI which can be provided by the UE during the registration process. The Radio Access Network (RAN) is the first component to look into the NSSAI requested by the UE to select the appropriate AMF (TS 23.501 [3GPP-23501] clause 6.3.5). The UE should use the S-NSSAI assigned to the given PLMN. The requested NSSAI provided by the UE allows the network to select the appropriate AMF, Network Slice(s) and Network Slice instance(s) for the UE (TS 23.501 [3GPP-23501] clause 5.15.5).

The UE will initiate the registration and provide the assigned NSSAI from previous connections in the registration message. The AMF may query the UDM to retrieve the UE subscription which includes the Subscribed S-NSSAIs (TS 23.502 [3GPP-23502], clause 4.2.2.2.2). The AMF will confirm that the requested NSSAI is included in the list of allowed NSSAIs which the operator has previously registered in the User Data Management (UDM) function as part of the UE subscription profile. If the UE subscription does not include the list of allowed NSSAIs the AMF will fetch it from the NSSF.

After checking that the requested NSSAI is allowed, the AMF must check whether it can serve the NSSAI that the UE has been assigned. If the current AMF cannot handle the NSSAI requested by the UE, the AMF will query the NSSF for the allowed NSSAI.

The NSSF verifies the requested NSSAI is permitted, selects the Network Slice instance(s) (NSI) and determines the target AMF to be used for serving the UE. The NSSF may also return the NRF(s) to be used to select NFs/services (e.g. SMF, UPF) within the selected Network Slice instance(s).

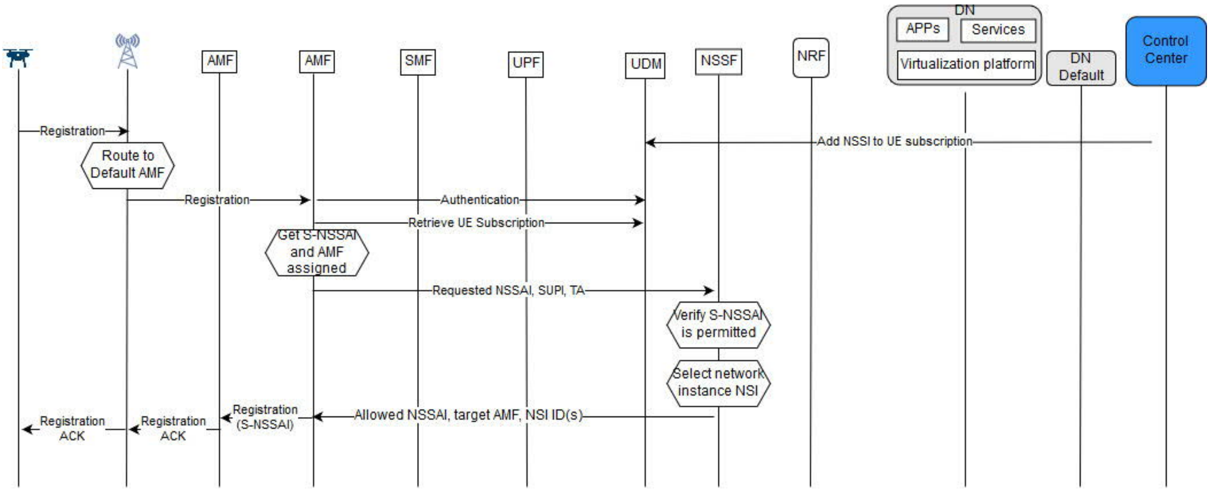


Figure 3.1 Registration with slice selection with NSSAI from UE

3.3 UE registration without pre-configured NSSAI

When a UE registers with a PLMN, if for this PLMN the UE has not included a Requested NSSAI nor a Globally Unique AMF ID (GUAMI) while establishing the connection to the (R)AN, the (R)AN shall route all NAS signalling from/to this UE to/from a default AMF. The default AMF will retrieve the UE subscription from the UDM where the subscribed S-NSSAIs are included. The default AMF will contact the NSSF to find the target AMF where the registration will be forwarded and the NSI assigned to the UE.

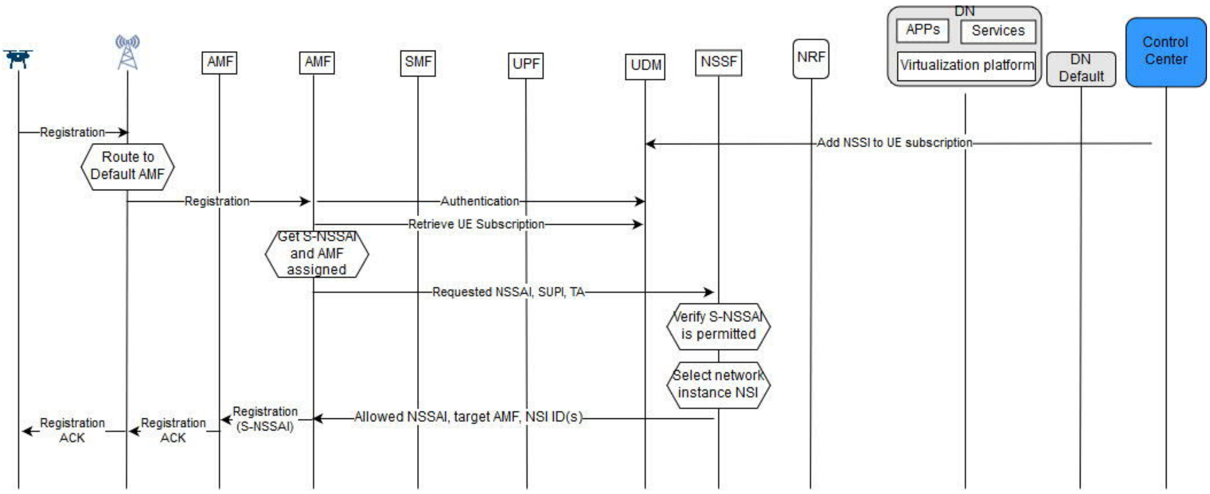


Figure 3.2. Registration with slice selection NSSAI from UDM

Upon successful completion of a UE's registration procedure over an Access Type, the UE obtains from the AMF an Allowed NSSAI for this Access Type, which the UE will keep for the next registration process and at any time, the AMF may provide the UE with a new Configured NSSAI for the Serving PLMN [3GPP-23502] with UE configuration update procedure.

If the UE receives indication from the AMF that the network slicing subscription has changed, the UE locally deletes the network slicing information it has for all PLMNs, except the Default Configured NSSAI (if present). It also updates the current PLMN network slicing configuration information with any received values from the AMF.

3.4 PDU Session establishment

SMF discovery and selection within the selected Network Slice instance is initiated by the AMF when a message to establish a PDU Session is received from the UE. The appropriate NRF is used to assist the discovery and selection tasks of the required network functions for the selected Network Slice instance.

The AMF queries the appropriate NRF to select an SMF in a network slice instance based on S-NSSAI, DNN, NSI-ID (if available) and other information, e.g., UE subscription and local operator policies, when the UE triggers the PDU Session Establishment. The selected SMF establishes a PDU Session based on S-NSSAI and DNN.

After the slice assignment a PDU will be established to the UE according to the slice requirements. A PDU Session belongs to one and only one specific Network Slice instance per PLMN.

4 PriMO-5G Network Management Design

4.1 Network Management Application Function

The Network Slice Management Application Function (NSM-AF) consists of an internal function that allows the network operator to manage the network slices assigned to mobile devices. The network may serve a single UE with one or more network slice instances simultaneously, therefore, the NSM-AF should allow the operator to assign multiple slices (a maximum of eight allowed slices) to the mobile device/UE (3GPP TS 24.501 [3GPP-24501] Section 4.6.2.2). As shown in Figure 4.1 the NSM-AF will store slice information in the internal DB and will update the UE profile in the UDM through the Application Function (AF) Endpoint.

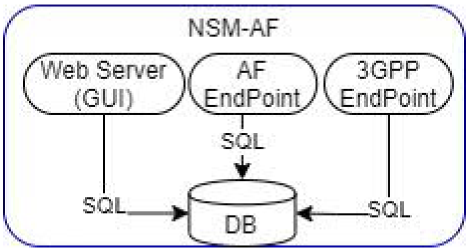


Figure 4.1. Network Slice Manager Application Function Design

A PDU Session belongs to one and only one specific Network Slice instance per PLMN. Different Network Slice instances do not share a PDU Session, though different Network Slice instances may have slice-specific PDU Sessions using the same DNN.

It needs to be mentioned that there can be at most eight S-NSSAIs in Allowed and Requested NSSAIs sent in signalling messages between the UE and the Network (3GPP TS 23.501 [3GPP-23501] Section 5.15.2.1). A network slice instance can be associated with one or more S-NSSAIs, and an S-NSSAI can be associated with one or more network slice instances.

The network may have a pre-configured UE profile with allowed NSSAIs in the UDM and the network can send changes in the assigned NSSAI to the UE during registration. Furthermore, the UE can receive the new configured NSSAI for this PLMN or SNPN and the Configuration update indication IE with the Registration requested bit set to "registration requested", in the same CONFIGURATION UPDATE COMMAND message.

Moreover, the network can request additional authentication from the UE for accessing NSSAI. The REGISTRATION ACCEPT message, during a registration procedure for mobility and periodic registration area updating, is received with the "NSSAA to be performed" indicator of the 5GS registration result IE set to "Network slice-specific authentication and authorization is to be performed. 24.501 section 4.6.2.4

Additionally, a UE can receive an S-NSSAI associated with a PLMN ID from the network during the PDN connection establishment procedure in EPS as specified in 3GPP TS 24.301. Also, the UE might have the NSSAI information stored locally from previous registrations and will request those slices during the registration process. Based on the Requested NSSAI (if any) and the Subscription Information, the 5GC is responsible for selection of a Network Slice instance(s) to serve a UE including the 5GC Control Plane and User Plane Network Functions corresponding to this Network Slice instance(s).

Also, the Subscription Information shall contain one or more S-NSSAIs i.e. Subscribed S-NSSAIs. Based on operator's policy, one or more Subscribed S-NSSAIs can be marked as a default S-NSSAI. If an S-NSSAI is marked as default, then the network is expected to serve the UE with a related applicable Network Slice instance when the UE does not send any permitted S-NSSAI to the network in a Registration Request message as part of the Requested NSSAI. At any time, the AMF may provide the UE with a new Configured NSSAI for the Serving PLMN, associated with mapping of the Configured NSSAI to HPLMN.

Furthermore, the NSM-AF allows operator to assign new slices or change existing slices. When the subscribed S-NSSAIs change, a UDR flag is set in the HPLMN to make sure the current PLMN (or, if the UE was not reachable, the next serving PLMN) is informed by the UDM that the subscription data for network slicing has changed. The AMF, when it receives the indication from the UDM subscription has changed, indicates the UE that subscription has changed and uses any updated subscription information from the UDM to update the UE. Once the AMF updates the UE and obtains an acknowledgment from the UE, the AMF informs the UDM that the configuration update was successful and the UDM clears the flag in the UDR.

Finally, the AMF queries the NSSF with Requested NSSAI, Default Configured NSSAI Indication, mapping of Requested NSSAI to HPLMN S-NSSAIs, the Subscribed S-NSSAIs, PLMN ID of the SUPI and UE's current Tracking Area. Based on this information, local configuration, and other locally available information including RAN capabilities in the current tracking area for the UE, or load level information for a network slice instance provided by the NWDAF (the NWDAF can read RAN and network resource available from the DB which previously were stored by the MBO), the NSSF does the following:

- It verifies which S-NSSAI(s) in the Requested NSSAI are permitted based on comparing the Subscribed S-NSSAIs with the S-NSSAIs in the mapping of Requested NSSAI to HPLMN S-NSSAIs. It considers the S-NSSAI(s) marked as default in the Subscribed S-NSSAIs in the case that no Requested NSSAI was provided or no S-NSSAI from the Requested NSSAI are permitted i.e. are not present in the Subscribed S-NSSAIs or not available e.g. at the current UE's Tracking Area.

- The NSM-AF will interact with network functions to assign network slices and the required slices to different devices or UE. The NSM-AF will include a GUI to configuration of the network slice configuration using e/gNB pre-configured slice information stored in DB. The NSM-AF will associate devices to network slices and VLANs that will be stored in DB.

5 System Deployment and Validation

5.1 Introduction

In this section, we present the deployment of a 5G system across different PriMO-5G partner testbeds, with network slicing and edge computing capabilities in a field test and show the performance results to validate the usage of the deployed application.

5.2 CMC

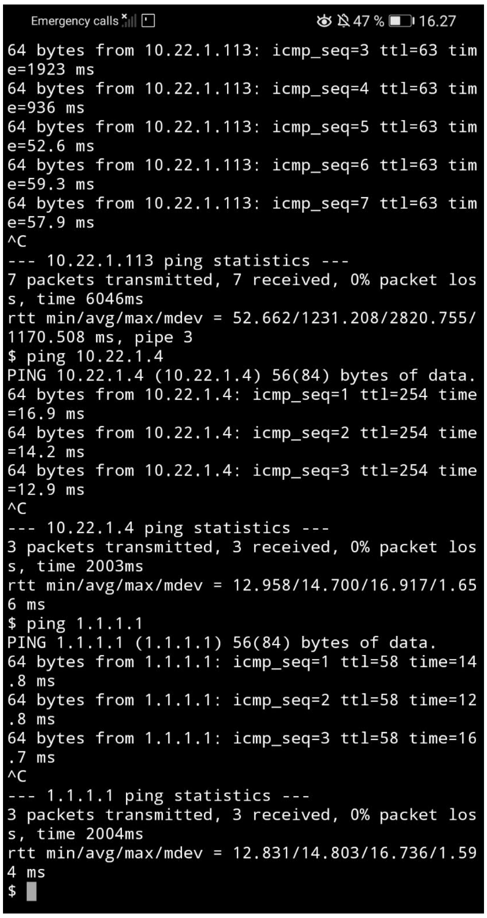
The deployment of different slice based on application requirements is managed by assigning different Data Network Name (DNN) to be used by different applications in the mobile device. Each application will select the DNN which is more convenient based on the requirements in terms of delay or bandwidth.

To validate the usage of different slice for each application an intercontinental scenario has been deployed and two DNNs have been assigned to different network slice. Thus, DNN = “Internet” will assign the applications in the mobile a UPF located in King’s College London with longer delay but higher MEC processing capabilities. When the application in the mobile selects DNN = “RemoteInternet” will be assigned a UPF located in Aalto University with lower delay but lower MEC processing capabilities.

In Figure 5.1 we present the ping test results for three different connection (from top to bottom):

- The UE pings IP 10.22.1.113 which is the 5GC at King’s College London
- The UE pings IP 10.22.1.4 which is the gNB
- The UE pings 1.1.1.1 a DNS server on the Internet.

Then in Figure 5.2, we present the results of a speed test using speedtest.net. Last but not least, we also present the results of a ping test from the remote UPF at KCL to the UE at Aalto in Figure 5.3. In this case the RTT min/average/max is 58.1/61.65/111 ms.



```
Emergency calls                    47 %  16.27
64 bytes from 10.22.1.113: icmp_seq=3 ttl=63 tim
e=1923 ms
64 bytes from 10.22.1.113: icmp_seq=4 ttl=63 tim
e=936 ms
64 bytes from 10.22.1.113: icmp_seq=5 ttl=63 tim
e=52.6 ms
64 bytes from 10.22.1.113: icmp_seq=6 ttl=63 tim
e=59.3 ms
64 bytes from 10.22.1.113: icmp_seq=7 ttl=63 tim
e=57.9 ms
^C
--- 10.22.1.113 ping statistics ---
7 packets transmitted, 7 received, 0% packet los
s, time 6046ms
rtt min/avg/max/mdev = 52.662/1231.208/2820.755/
1170.508 ms, pipe 3
$ ping 10.22.1.4
PING 10.22.1.4 (10.22.1.4) 56(84) bytes of data.
64 bytes from 10.22.1.4: icmp_seq=1 ttl=254 time
=16.9 ms
64 bytes from 10.22.1.4: icmp_seq=2 ttl=254 time
=14.2 ms
64 bytes from 10.22.1.4: icmp_seq=3 ttl=254 time
=12.9 ms
^C
--- 10.22.1.4 ping statistics ---
3 packets transmitted, 3 received, 0% packet los
s, time 2003ms
rtt min/avg/max/mdev = 12.958/14.700/16.917/1.65
6 ms
$ ping 1.1.1.1
PING 1.1.1.1 (1.1.1.1) 56(84) bytes of data.
64 bytes from 1.1.1.1: icmp_seq=1 ttl=58 time=14
.8 ms
64 bytes from 1.1.1.1: icmp_seq=2 ttl=58 time=12
.8 ms
64 bytes from 1.1.1.1: icmp_seq=3 ttl=58 time=16
.7 ms
^C
--- 1.1.1.1 ping statistics ---
3 packets transmitted, 3 received, 0% packet los
s, time 2004ms
rtt min/avg/max/mdev = 12.831/14.803/16.736/1.59
4 ms
$
```

Figure 5.1 Ping tests from UE (in Aalto) to the remote UPF (at KCL), gNB and the Internet (from top to bottom)

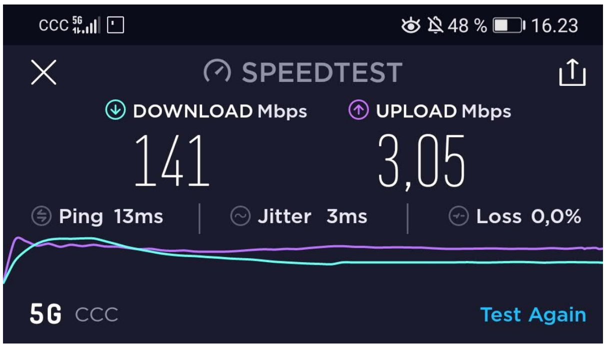
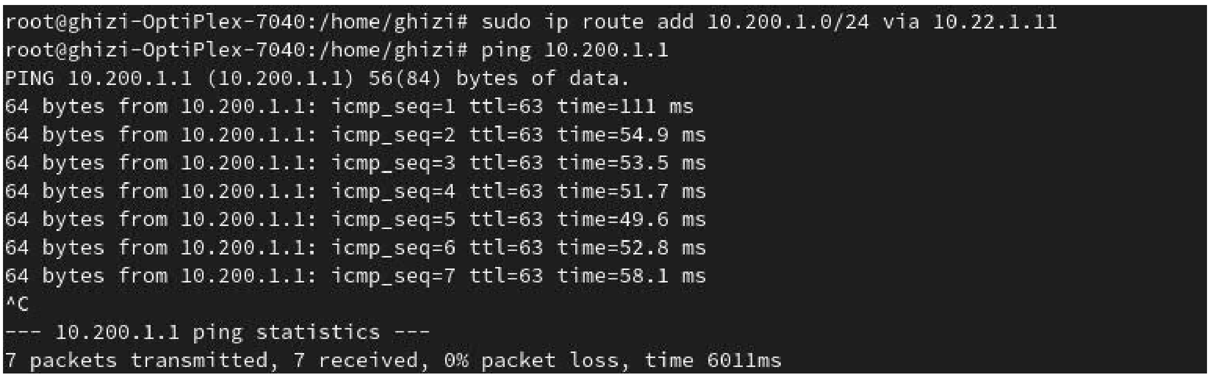


Figure 5.2 Internet connection speed test from the UE in Aalto



```
root@ghizi-OptiPlex-7040:/home/ghizi# sudo ip route add 10.200.1.0/24 via 10.22.1.11
root@ghizi-OptiPlex-7040:/home/ghizi# ping 10.200.1.1
PING 10.200.1.1 (10.200.1.1) 56(84) bytes of data.
64 bytes from 10.200.1.1: icmp_seq=1 ttl=63 time=111 ms
64 bytes from 10.200.1.1: icmp_seq=2 ttl=63 time=54.9 ms
64 bytes from 10.200.1.1: icmp_seq=3 ttl=63 time=53.5 ms
64 bytes from 10.200.1.1: icmp_seq=4 ttl=63 time=51.7 ms
64 bytes from 10.200.1.1: icmp_seq=5 ttl=63 time=49.6 ms
64 bytes from 10.200.1.1: icmp_seq=6 ttl=63 time=52.8 ms
64 bytes from 10.200.1.1: icmp_seq=7 ttl=63 time=58.1 ms
^C
--- 10.200.1.1 ping statistics ---
7 packets transmitted, 7 received, 0% packet loss, time 6011ms
```

Figure 5.3 Ping test from remote UPF (in KCL) to UE (in Aalto)

5.3 CMC-Yonsei Robotics Integration and Deployment

The deployment from Section 5.2 has been extended to Yonsei Robotics Testbed. The Yonsei Robotics Testbed consists of different nodes: 5G core, mobile edge computer, and mobile object picker robot. 5G core is the core linked to Finland, as in the multi-DNN configuration of the CMC-YU core switching testbed; mobile edge computer is a computer linked to the 5G core that is capable of advanced processing like GPU acceleration and streaming; and the mobile object picker robot is a multi-joint robot that has a vision sensor and engine. Figure 5.4 shows the network topology that links the nodes explained above.

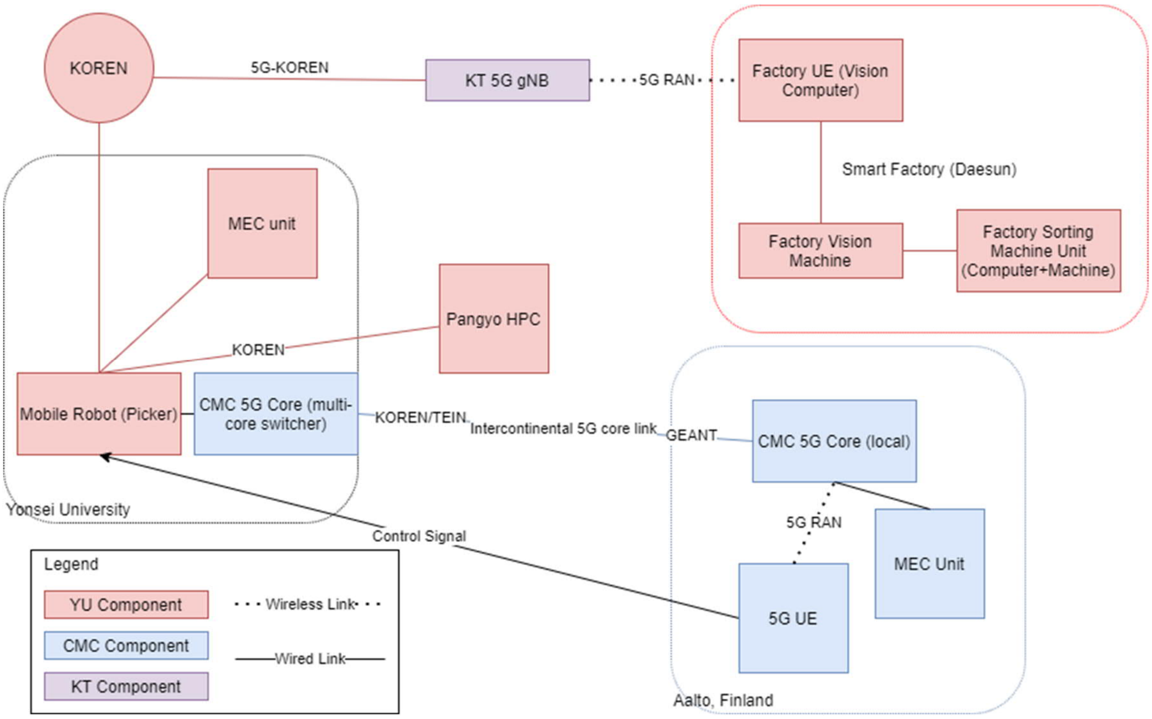


Figure 5.4 CMC-Yonsei core switching testbed extended to the Yonsei Robotics Testbed

As shown in Figure 5.4, 5G cores in Korea and Finland are connected via KOREN, TEIN, and GEANT, which is identical to the topology explained in previous sections. Using the linked cores, Finland controls the robot in Korea remotely. The control signal exploits the optimal routing provided by the closed L2VPN network configuration of the intercontinental testbed. In addition to responding to the control signal from Finland, the mobile robot offloads its processing task, i.e. real-time multi-object detection, to the MEC or HPC, then returns Finland the result.

Finally, as an exploitation of the PriMO-5G network architecture, the deployment can be further extended to the Yonsei industrial testbed, shown in the top portion of Figure 5.4, which consists of a smart factory linked to the Yonsei Robotics Testbed. This is further explained in the deliverables of WP5 and WP6 of the project.

6 Conclusions and Outlooks

This deliverable aims to present the design, capabilities and characteristics of the end-to-end 5G infrastructure with regards to network slicing, within PriMO-5G and builds upon the initial design proposed in deliverable D2.1. We also presented results from the deployment of use case applications that make use of the network slicing capabilities integrated within the PriMO-5G partner testbeds.

The document was divided in four main sections, namely “End-to-end Network Slicing”, “Backhaul and MEC”, “PriMO-5G Network Management Design” and “System Deployment and Validation”. Section 2 presented an overview of how network slicing can be enabled within the 5G end-to-end architecture and examines the relevant 3GPP specifications for the 5G Core as well as network slicing within the Cloud-RAN. Afterwards, Section 3 focused on UE registration procedures with respect to network slicing, including the UE registration with and without pre-configured NSSAI as well as the PDU session establishment. Then, in Section 4 described the Network Management Application Function as part of the PriMO-5G 5G Core design and the necessary procedures for handling and network slice requests from the UE and managing the relevant network slice configurations. Finally, Section 5 presented the deployment and the validation of a 5G system with network slicing and edge computing capabilities serving a deployed application. An initial experiment is achieved between the testbeds of KCL and Aalto and then extended to work by using the intercontinental 5G Core link for the purpose of remotely controlling a robot in Korea from Finland between YU and CMC.

Therefore, it was demonstrated that with the 5G architecture implemented in PriMO-5G it is possible to deploy network slicing while being able to decide what is the optimal location of the network functions to satisfy the requirements of use cases. Furthermore, we demonstrated and validated, the benefits to separate the components of core and access network from the point-of-view of the application.

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