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D5.1 - DEMONSTRATION PLAN

Work Package	WP5, Testbed and Demonstration
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	PP: Restricted to other programme participants (including the Commission)
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Executive Summary

The PriMO-5G EU aims to demonstrate an end-to-end 5G system providing immersive video services for moving objects. This is achieved by both local and cross-continental testbeds that integrate radio access and core networks developed by different project partners to showcase end-to-end operations of envisaged use cases, specifically those related to firefighting.

To that end, the experimentation activities planned in PriMO-5G project will occur in multiple phases. In the initial phase, the focus is on testing and demonstrating the key enabling radio, edge and core network components and applications. The primary goal of the component testing and demonstration activities is to provide insights on the capabilities of these components from the perspective of the end-to-end operations of the PriMO-5G use cases. Moreover, these activities enable the consortium members to identify and/or enhance the components needed for the subsequent system integration phase. The system integration phase is envisioned to occur over selected partner sites on European and Korean sides. Finally, in the third phase the testbeds on the European and Korean sides will be interconnected to demonstrate global applicability and feasibility of end-to-end operations of PriMO-5G use cases.

This deliverable report *D5.1 Demonstration Plan* focuses on the first phase by providing an overview of the PriMO-5G components contributed by different partners for the PriMO-5G experimentation activities and eventual end-to-end system implementations. To that end, each component, platform or partially integrated system contributed by the partners is described in how it could support testing and demonstration of key 5G developments in radio, edge and/or core networks in the context of PriMO-5G firefighting use cases. Furthermore, this deliverable outlines the demonstration plans associated with each the 12 components or partially integrated systems, as well as, the appropriate evaluation approaches within each demonstrator. These demonstrations will be conducted in partner sites and/or high-profile external dissemination events previously identified in deliverable *D6.2 Dissemination and Exploitation Plan*.

List of Acronyms

Acronym	Definition
3GPP	Third Generation Partnership Project
5G	Fifth-Generation Mobile Network
5GC	5G Core Network
5G-NR	5G New Radio
AF	Application Function
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
BM-SC	Broadcast Multicast Service Centre
BS	Base Station
CIoT	Cellular IoT
CRPI	Common Public Radio Interface
CSCF	Call Session Control Function
DL	Downlink
E2E	End to End
eNB	Evolved Node B
EPC	Evolved Packet Core
FUNET	Finnish University and Research Network
GCS	Ground Control Station
gNB	Next Generation Node B
GRE	Generic Routing Encapsulation
GTP-U	GPRS Tunnelling Protocol User Plane
GW	Gateway
HSS	Home Subscriber Service
IAP	IP Announcement Point
IoT	Internet of Things
IP	Internet Protocol

Acronym	Definition
KOREN	Korea Advanced Research Network
KPI	Key Performance Indicator
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control Layer
MBMS	Multimedia Broadcast/Multimedia Service
MCPTT	Mission Critical PTT
MEC	Multi-access Edge Computing
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MPLS	Multiprotocol Label Switching
NB IoT	Narrowband IoT
NIB	Network-In-a-Box
NREN	National Research and Education Network
NRF	Network Repository Function
NSSF	Network Slice Selection Function
Nxxx	Corresponding service interface of the 5G network function, e.g., Nausf, Nnsf, Nnrf, Npcf, Nsmf, Nudm
ONAP	Open Network Automation Platform
OSM	Open Source MANO
PBCH	Physical Broadcast Channel
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
PMCH	Physical Multicast Channel
PRACH	Physical Random Access Channel
PTT	Push-To-Talk
PxCCH	Physical Control Channel, x=uplink(u)/downlink(d)
PxSCH	Physical Shared Channel, x=uplink(u)/downlink(d)
QCI	QoS Class Identifier
QoE	Quality of Experience

Acronym	Definition
QoS	Quality of Service
QSFP	Quad Small Form-Factor Pluggable Transceiver
RAN	Radio Access Network
RLC	Radio Link Control
RTP	Real Time Protocol
SCEF	Service Capability Exposure Function
SDN	Software Defined Networking
SFP	Small Form-factor Pluggable Transceiver
SMF	Session Management Function
SRT	Secure Reliable Transport
SSB	Synchronization Signal Block
TEIN	The Trans-Eurasia Information Network,
TRP	Transmission Reception Point
UAV	Unmanned Aerial Vehicle
UDM	Unified Data Management
UDN	Ultra Dense Network
UE	User Equipment
UL	Uplink
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle-to-Everything Communications
vEPC	Virtual Evolved Packet Core
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtual Network Function
VoLTE	Voice Over LTE
VR	Virtual Reality
WP	Work Package

1 Introduction

1.1 Scope of the document

The EU-KR PriMO-5G project involves partners from several countries from Europe and a number of partners from South Korea, who together will be addressing objectives of the 'EUK-02-2018:5G' call in the area "*a) Focus on mmWave and super broadband services*". Specifically, the PriMO-5G aims to demonstrate an end-to-end 5G system providing immersive video services for moving objects. This is achieved by both local and cross-continental testbeds that integrate radio access and core networks developed by different project partners to showcase end-to-end operations of envisaged use cases, particularly those related to firefighting.

The experimentation activities planned in PriMO-5G project will occur in multiple phases. In the initial phase, the focus is on testing and demonstrating the key enabling radio, edge and core network components and applications. The objective is to identify and demonstrate the capabilities of these sub-systems. The component demonstrations are essentially building on the existing commercial equipment, demonstration platforms and testbeds that the have been contributed by different European and Korean project partners. To that end, the component testing and demonstration activities provide insights on the capabilities of these components from the perspective of the end-to-end operations of the PriMO-5G use cases. Moreover, these activities enables the consortium members to identify and/or enhance the components needed for the subsequent system integration phase. The system integration phase is envisioned to occur over selected partner sites on European and Korean sides. Finally, in the third phase the testbeds on the European and Korean sides will be interconnected demonstrate global applicability and feasibility of end-to-end operations of PriMO-5G use cases.

The purpose of this deliverable report *D5.1 Demonstration Plan* is to provide a profile of PriMO-5G components, as well as, outline the respective demonstration plans and evaluation approaches for each component.

1.2 Structure of the document

This deliverable document is organised as follows. Section 2 presents an overview of the PriMO-5G radio, edge and core network components and applications developed and/or contributed by the different PriMO-5G project partners. This descriptions also include some of the end user devices (drones) targeted for the PriMO-5G firefighting use cases. In Section 3, the planned demonstrations for each the components are described, including the evaluation approach for each component. Furthermore, Section 3 also documents some of the demonstrations which have already achieved some level of integration of different partner components, as well as, describing demos that have been executed in advance (at the time of preparation of this report). Finally, in Section 4 , the conclusions are presented including an early preview of the project's future ambitions for system integration and cross-continental demo plans, which will be elaborated in further detail in the follow-up deliverable D5.2.

1.3 Relationship to other project outcomes

The overall work structure of PriMO-5G is illustrated in Figure 1. In this work structure, WP1 specifies the PriMO-5G firefighting use cases that inspired research and technology developments in WP2, WP3, and WP4. These WP1-WP4 outcomes shape the establishment of the WP5 component, local and cross-continental testbeds to demonstrate end-to-end operations of 5G system for PriMO-5G use cases. To that end, deliverable D5.1 builds on the specifications and developments of preceding deliverables D1.1 [1] on use cases completed in M8 (Feb 2019) and technology development deliverables of D2.1 [2], D3.1 [3] and D4.1 [4] all due in M10 (Apr 2019). The demonstration plans outlined in this deliverable D5.1 will feed into the reporting of the dissemination and exploitation activities in WP1. Moreover, D5.1 also informs the eventual architectural specifications in WP1.

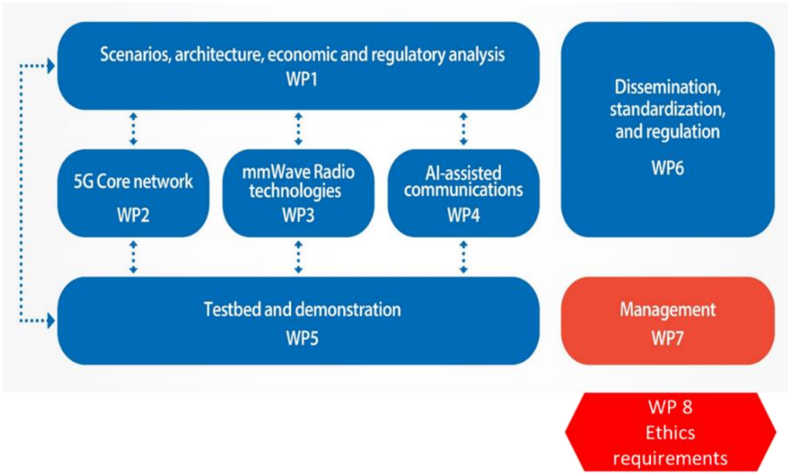

Figure 1 PriMO-5G work structure.

2 Component description

2.1 Overview

The components provided by partners were initially described in the project plan as given below in Figure 2. In the figure, the left part shows the components of the European partners and the right side the corresponding components from the Korean side. In this section, we provide more detailed and up-to-date information about the various components available from each partner.

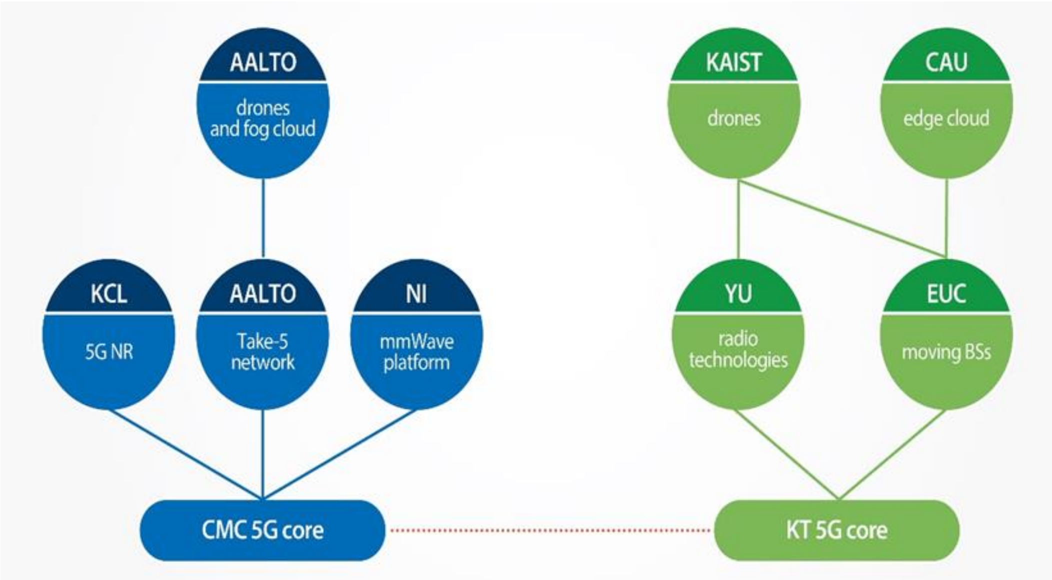

Figure 2 Overview of components from PriMO-5G partners

The components are categorized according to which part of the architecture they belong. As indicated by Figure 2, at the bottom level there are components related to core networks. At the next level, we have components for the radio access networks. Finally, at the highest level there are components related to drones, as well as, edge computing platforms and applications. Each of these are described separately in their own subsections below.

2.2 Core networks

The core network consists of several modules that are listed below together with the supported interfaces, services and performance features.

The core network should include the following network functions as mandatory elements; Access Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF) and Home Subscriber Server (HSS). In 5G networks the HSS is enhanced with Unified Data Management (UDM) and AUSF functions. In addition to these modules 3GPP defined 5G Service Based Architecture (SBA) which requires additional network functions compared to 4G architecture. The new modules to support the discovery of new network functions and to enable network slicing are Network Repository Function (NRF) and Network Slice Selection Function (NSSF).

5G network might include features such as NB-IOT for which modules such as SCF are required. If 5G includes media broadcast features, then BM-SC and MBMS-GW should be added to the architecture.

The aforementioned functions and interfaces are summarised in Figure 3, which depicts the 5G core network architecture. For more information on the architecture, please refer, to e.g., [5].

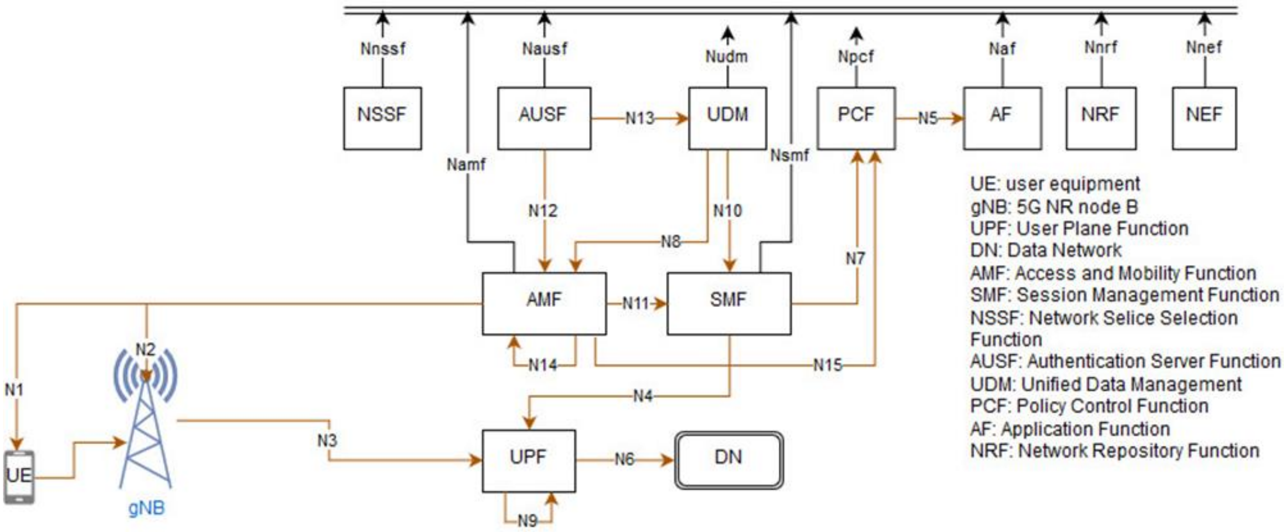

Figure 3 5G core network architecture.

2.2.1 CMC core

The CMC core includes the following components including the services and performance listed in Table 1.

Table 1 Description of capabilities of the 5G core network from CMC

Network Functions	Supported interfaces	Supported Services
AMF	S1-MME, S10, S11, M3, Sm, S6a N1, N2, Namf	5G non-standalone, 5G standalone, CIoT, eMBMS, Network slicing, MEC
SMF	S11, Sm N4, Nsmf	Network slicing, MEC
UPF	S1-U, SGi N3, N4, N6	GTP-U, GRE, VLAN, MPLS
NRF	Nnrf	
NSSF	eMBB, URLLC, mIoT Nnssf	Network slicing SST:1,2,3
HSS	S6a	
UDM	S6a Nudm	Network slicing, MEC
SCEF	T6a	CIoT
MBMS-GW	M1, Sm	eMBMS
BM-SC	xMB	eMBMS

The CMC mobile core is described in Figure 4 where basic modules can be extended with additional network functions to support NB-IOT or eMBMS depending on the required services.

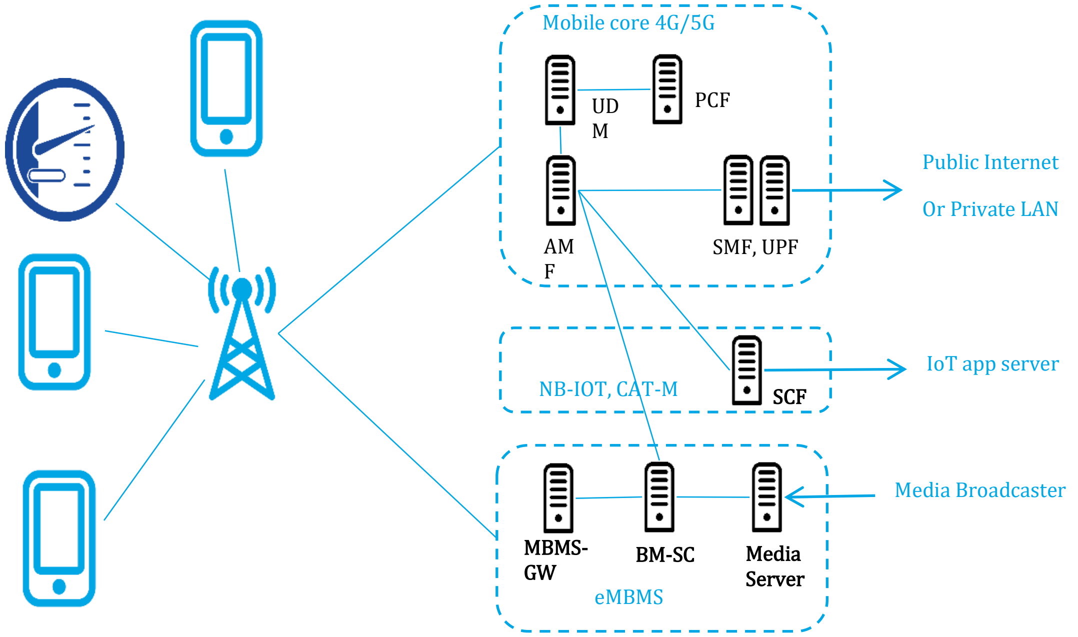

Figure 4 CMC core network illustration

2.2.2 KCL core

KCL core network includes high quality 5G and components supplied by Ericsson. Core functions are virtualised versions of the 4G core with partial implementation of 5G functions (pre-Rel15 spec). The latest version of OAI vEPC is hosted in Openstack [6] as available images to be instantiated by the orchestrator. Several OAI eNB are available in the 5G lab for experimentation. Several vEPC instances can be hosted at once in dedicated vLANs and connected to eNBs in the lab. The OAI core bundle consists of HSS, MME and SPGW. Interfaces between the VNFs are provided over a dedicated 10GbE private overlay network within Openstack while S1-MME and S1-U are exposed over 10GbE to the physical infrastructure. Figure 5 illustrates the KCL core network architecture.

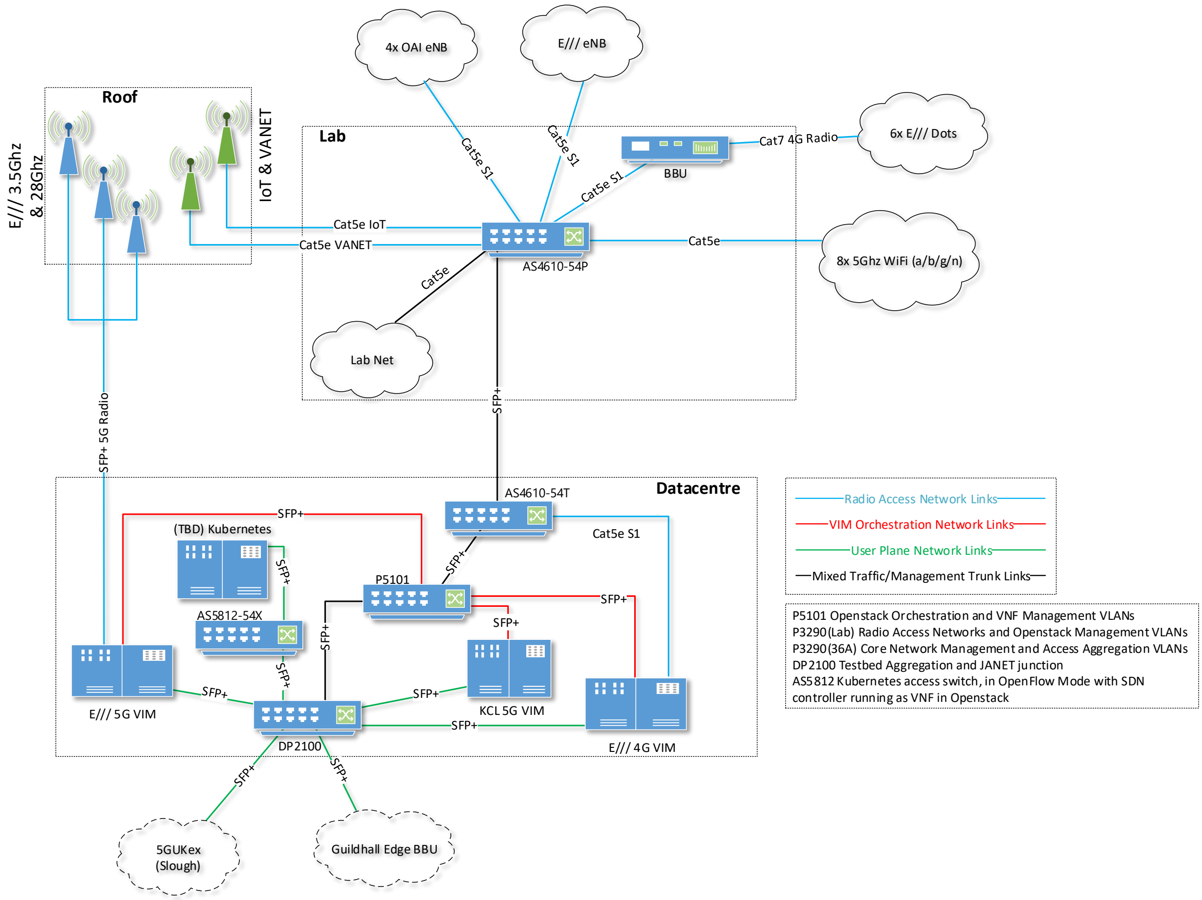

Figure 5 KCL core network

Openstack Capabilities

KCL maintains its own private cloud infrastructure optimized for VNF hosting built on commodity servers and Openstack [6]. The testbed infrastructure uses 10GbE backbone connections with 1GbE access interfaces. There are additional 10GbE interfaces as well as 40GbE interfaces for applications requiring dedicated high-bandwidth links. The entire infrastructure is architected to resemble a production network with a distinct core, distribution and access devices and subnets. Openstack nodes are connected in the core with 10GbE connections per compute host shared by VNFs running on the host. There is a total of seven hosts in Openstack, five of which are configured for general purpose VNF hosting and two hosts configured for ultra-low-latency VNFs. The low-latency hosts also feature dedicated network interfaces for SRIOV for VNFs requiring their own dedicated network interface. Figure 6 depicts measured latencies in the KCL network.

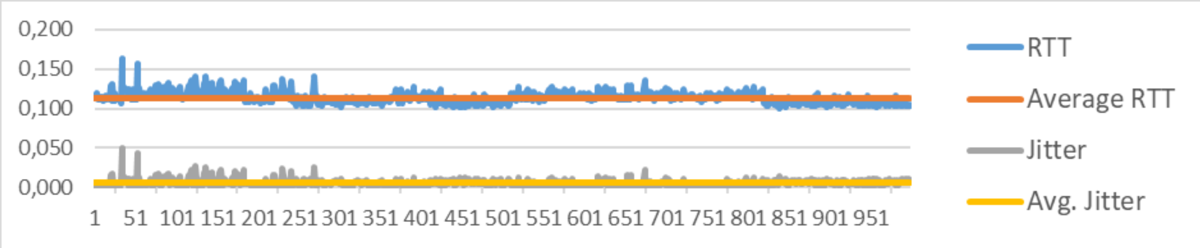

Figure 6 Openstack network latency between VMs on different hosts

There is a total of 600 virtual cores and over 2TB of memory available for VNF hosting. Each host also features 1TB of persistent storage for VNFs. Network traffic for Openstack control, overlay networks and storage is physically separated on different interfaces to optimize performance and minimize impact on VNF network access. User traffic is carried by Openflow-enabled switches running in hybrid mode to provide routing functions between vLANs.

Infrastructure and Orchestration

Testbed orchestration is provided by OSM and ONAP. OSM is currently the primary orchestrator of the infrastructure and is interfaced with the 5GUK Exchange facility in Slough where a cross-domain orchestrator controls the testbed. The link to Slough supports up to 10GbE for orchestration and VNF traffic and is connected directly at the core switch. OSM currently manages Openstack via a private API interface for security and work is carried out to include the Ericsson vRANs in the automation. Remote orchestration is also possible in our system using public Openstack APIs exposed on individual network interfaces for remote partners accessing either via VPN or direct connection to the core. Any remote orchestration that supports Openstack API can be used by our partners to deploy their own services in Openstack.

ONAP is also available for orchestration, deployed within Openstack and independently manages VNFs; however, ONAP is not part of the cross-domain orchestration and is only used for internal testing.

The interfaces of the 5G core network are summarised in Table 2. Note that since the core network is not a standard compliant 5G core, most of the standard 5G interfaces are not available.

Table 2 Description of capabilities of the 5G core network from KCL

Network Functions	Supported interfaces	Supported Services
AMF	NA	None
SMF	NA	None
UPF	NA	None
NRF	NA	None
NSSF	NA	None
HSS	NA	None
UDM	Non-standard	MEC, Network Slicing
SCEF	NA	None
MBMS-GW	Ethernet	eMBMS
BM-SC	NA	

2.2.3 KT core

The KT core includes the following components including the supported services listed in the following Table 3. The supported interfaces that have already been applied or are scheduled to be applied are marked in black text, and those that have not been fixed are marked with blue text.

Table 3 Description of capabilities of the 5G core network from KT

Network Functions	Supported interfaces	Supported Services
AMF	N1, N2, N8, N14, N15, N26, N8, N22	5G NSA, SA, MEC
SMF	N11, N4, N7, N10	MEC
UPF	N3, N4, N6, N9	-
NRF	Nnrf, N27	-
NSSF	Nssf	-
UDM	Nudm	MEC, Location
PCF	N5, N7, N15	-

The 5G edge is one of the biggest features of the 5G core network. The 5G edge core is a network infrastructure that ensures realisation of 5G services, especially “URLLC”, thus brings new revenue generation to telecom operators.

KT edge cloud is built in eight central offices in Korea nationwide (Guro, Hyehwa, Daejeon, Daegu, Gwangju, Busan, Jeju and Wonju). The edge cloud is the place where the 5G Core UP (GW-U / UPF) and 5G RAN CU are located. This edge cloud also includes MEC servers that perform data processing for 5G devices in the vicinity of the devices. The Central Cloud is located in Guro, where the 5G Core CP (GW-C / UDR, UDM, PCF, SMF, AMF, etc.) functions are hosted.

In the 5G era, the edge cloud that is built in the operator network allows to provide ultra-low latency and high-capacity services efficiently (by terminating the GTP mobile session at a close distance from the user and providing IP services such as AR / VR and V2X services).

2.3 Radio access networks

In the PriMO-5G project, multiple different RAN technologies are considered and being explored by the partners. The RAN technologies include the following: cell free data transmission in UDNs, mmWave communications, 5G NR platform supporting FR1 (below 7.125 GHz frequencies) and FR2 (above 24 GHz frequencies) transmission, lens-antenna based communications system, haptic communications and moving base stations. In this subsection, we provide detailed information on these.

2.3.1 AALTO UDN

Future radio access networks (RAN) are going to be characterised by densely deployed transmission-reception points (TRP) with a relatively small coverage area and being deployed on street/building-furniture. In line with this, the Aalto UDN testbed deployment scenario adopts a cell-free RAN implementation that enables seamless service in user-centric manner.

In a cell-free UDN architecture, multiple multi-antenna TRPs are controlled by a common gNB, which creates a virtual cell for every user anchored to it. This architecture allows for efficient implementation of mobility management by allowing seamless handover of a drone from one TRP to another as it moves along its trajectory. This seamless handover is enabled by precise 3D localization and tracking of the flying drone in a user-centric manner. In this scheme, a given user (be it ground or aerial ones) periodically transmits UL pilot signal (e.g., SRS) to connected TRPs. These pilot signals are used for channel parameter estimation, which forms the basis for user positioning. In the Aalto UDN testbed, acquisition of users' location is based on the angle-of-arrival (AoA) estimate of the line-of-sight (LoS) path between the user and multiple TRPs under the serving gNB. The AoA estimates from multiple TRPs are fused into position estimates at the gNB. Figure 7 shows the Aalto SDR-based testbed in the cell-free UDN scenario. The properties of the testbed are summarised in Table 4.

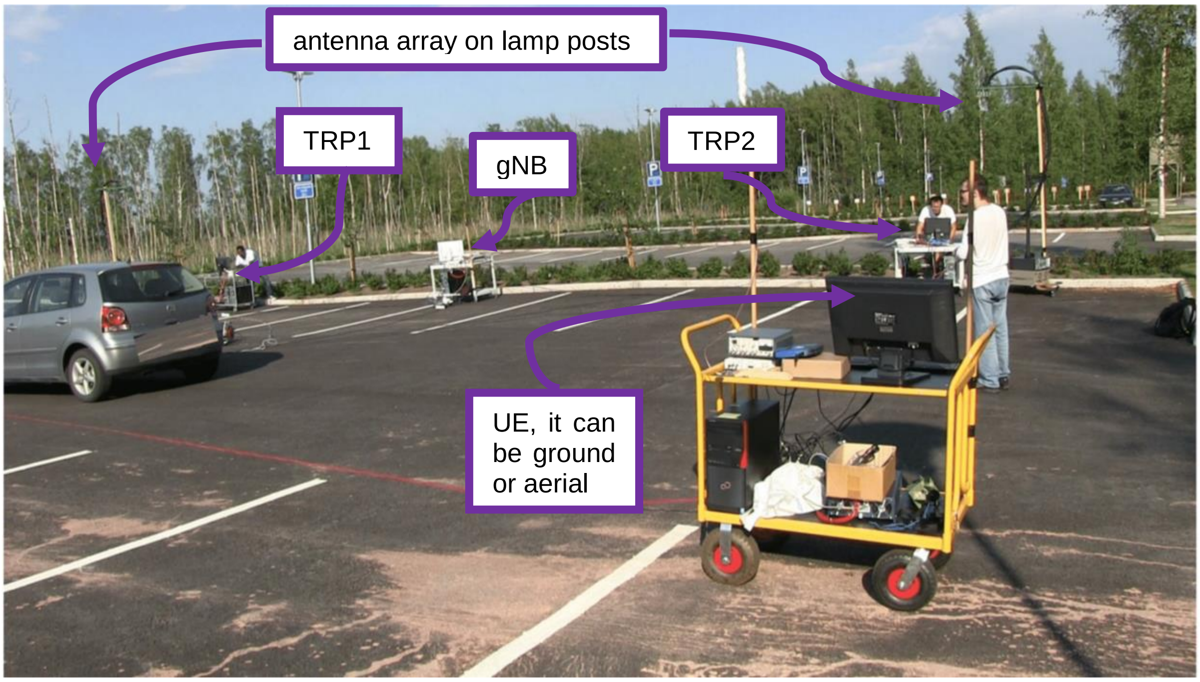

Figure 7 Aalto SDR-based testbed in cell-free UDN scenario

A properly designed and dimensioned cell-free network provides greater flexibility than previous generations of cellular systems by retaining the advantage of network densification and alleviating the signalling overhead problem. Moreover, it enables location-aware dynamic beam steering to flying drones in 3D. This component demonstration aims to study the feasibility of seamless connectivity for drones in cell-free UDN architecture.

Table 4 Description of capabilities of the RAN UDN from AALTO

Capabilities of Aalto Cell-free UDN	
RF capabilities	Sub-6 GHz, support MIMO mode at TRP, TDD
PHY capabilities	Azimuth and elevation angle estimation of drones, positioning, channel coding (LDPC)
L2 capabilities	No
Cell-free network support	Yes, support for seamless mobility
QoS support	No

Capabilities of Aalto Cell-free UDN	
Network slicing support	No
Supported physical interfaces	No
Supported logical interfaces	No

2.3.2 NI mmWave transceiver system

NI provides a mmWave transceiver system based on the 3GPP 5G-NR specification. The transceiver system operates at a frequency range of 24 GHz to 29 GHz and offers a channel bandwidth of up to 100MHz. More capabilities are listed in Table 5. It comprises gNB and UE functionality. NI develops the PHY layer, based on LabVIEW FPGA and LabVIEW Realtime, while layer 2 and 3 utilize the OpenAirInterface software stack. Interfaces for the 5G Core network allow the integration into PriMo-5G testbeds.

Development starts with a below 6 GHz PHY layer. The following functionality is added gradually:

- Interfaces between PHY and L2/L3 features including integration of both subsystems,
- Support of mmWave frequency range: This includes integration of mmWave radio heads and beam-steering-capable antennas w/ baseband processing and support of beam management on PHY and L2/L3 layers.
- Support of network slicing
- Interfaces between L2/L3 and 5G Core network including integration of both subsystems.

Table 5 Description of capabilities of the mmWave transceiver system from NI

Capabilities	
RF capabilities	24 – 29.5 GHz, up to 2x2 MIMO, beam steering antennas, TX output power = 15 dBm CW, TX antenna gain = 15 dBi
PHY capabilities	Up to 100MHz channel bandwidth, PxSCH, PxCCH, PBCH, SSB, PRACH
L2 capabilities	beam management support
Cell-free network support	No
QoS support	Limited
Network slicing support	Yes
Supported physical interfaces	10 GbE, 1GbE
Supported logical interfaces	N1 (UE-AMF), N2 (gNB-AMF), N3 (gNB-UPF), control and debug interfaces

2.3.3 KCL RAN

Ericsson offers high quality connectivity for FR1 (below 7.125 GHz) and FR2 (above 24 GHz) at King’s Strand campus, providing line of sight coverage on the quadrangle area and Somerset House, see Figure 8. More specifically, connectivity at 3.5 GHz is supported by an antenna array with 128 ports with wide beam-steering coverage, 16 beams in DL/UL. In the FR2, KCL testbed can provide access at 28GHz for a signal bandwidth up-to 800 MHz. The coverage is delivered by an antenna with 50 dBm EIRP, 23 dBi antenna gain and 256 radio chains. Fronthaul infrastructure runs on several 10GbE fibre pairs between antennas and baseband units, carrying CPRI signalling. There are two 28GHz and two 3.5GHz antennas available along with baseband units for each antenna. Furthermore, KCL runs independent vRAN platforms for 3.5GHz and 28GHz systems, supporting up to 10GbE bandwidth between vRAN and baseband units for S1.

Additionally, the testbed runs OAI-based RAN using SFF PCs and Ettus USRP B210 [7] that can easily be transported and deployed on any location. The S1 traffic between the OAI eNB and the core is provided over VPN from remote locations and 1GbE on Strand campus.

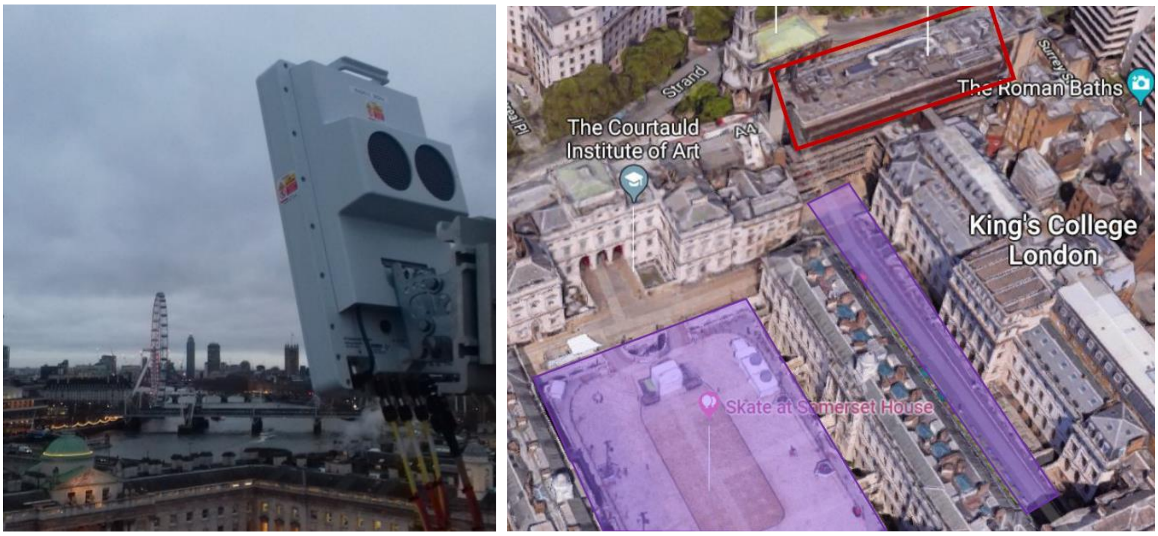

Figure 8 RAN network at KCL

The features of the KCL RAN are summarised in Table 6.

Table 6 Description of capabilities of the RAN from KCL

Capabilities	
RF capabilities	carrier frequency: 3.5GHz (FR1) and 28 GHz (FR2)
PHY capabilities	Beamforming and MIMO: • FR1: 16x8 dual polarized antenna, 120deg x 30deg coverage, 16 beams, grid-of-beams technology • FR2: 800 MHz BW, 128 dual-polarized antennas, 120deg x 120deg coverage, 4 beams
L2 capabilities	MAC address learning functionality for connected nodes
Cell-free network support	No
QoS support	Yes
Network slicing support	Yes IEEE802.11q
Supported physical interfaces	SFP+, RJ45, QSFP
Supported logical interfaces	CRPI, S1-MME, S1-U

Edge infrastructure and miscellaneous hosting

Independent hosts are available for miscellaneous services that can be hosted outside of Openstack in the core and also serves as edge nodes. The hosts reside in the core and distribution networks with a mix of 10GbE and 1GbE network interfaces. There are currently two Kubernetes deployments running on the independent hosts, with a total of 120 virtual cores and 512GB of memory. Several of the hosts also feature GPUs for accelerated VR and AI applications. There is a total of 15 GPUs available in the testbed, including nVidia Titan V, GTX 1080 Ti and GTX 1080 models.

2.3.4 YU lens antenna-based mm-wave communications system

YU's testbeds will demonstrate advanced radio technologies. Novel 5G mmWave radio transceiver and lens antenna array designs are investigated in PriMO-5G. Furthermore, selected waveform designs in both frequency and spatial domains, as well as beam steering and tracking algorithms, and hybrid beamforming algorithms using a lens antenna array will be implemented using NI's hardware platform to prove the feasibility of supporting high data-rate mmWave connectivity with various QoS in latency and reliability to fast moving objects.

Figure 9 Lens antenna-based NI hardware platform used at YU.

A picture of the mm-wave communication system used at YU is shown in Figure 9. The capabilities of the system are summarised in Table 7.

Table 7 Description of capabilities of lens antenna-based mm-wave communication system from YU

Capabilities	
RF capabilities	Carrier frequency: 28.5 GHz
Bandwidth	Up to 800MHz channel bandwidth,
antenna	Up to 1x1, Two lens antennas
Beamforming	Hybrid beamforming

Capabilities	
Beam-steering method	Backplane antenna switching
constellation	QPSK to 64QAM
Throughput	Up to 2.8Gbps

2.3.5 YU haptic communications for robotic arm control

Yonsei University conducts a haptic communication demo. This demo conveys motion vector information to the haptic device (robotic arm) as shown in Figure 9 below, to the user's haptic device via a commercial 5G network. Make sure to imitate the movement of master Haptic equipment with low latency and ultra-reliability. Low-latency and ultra-reliability are essential when the user's haptic equipment simulates the behaviour of the master's haptic equipment. Therefore, this demonstration shows that quality of experience (QoE) is maximized by reflecting compression methods that take into account the characteristics of the Haptic signal. This system will be carried out via KT's commercial 5G network. The capabilities of the haptic communication system are summarised in Table 8.

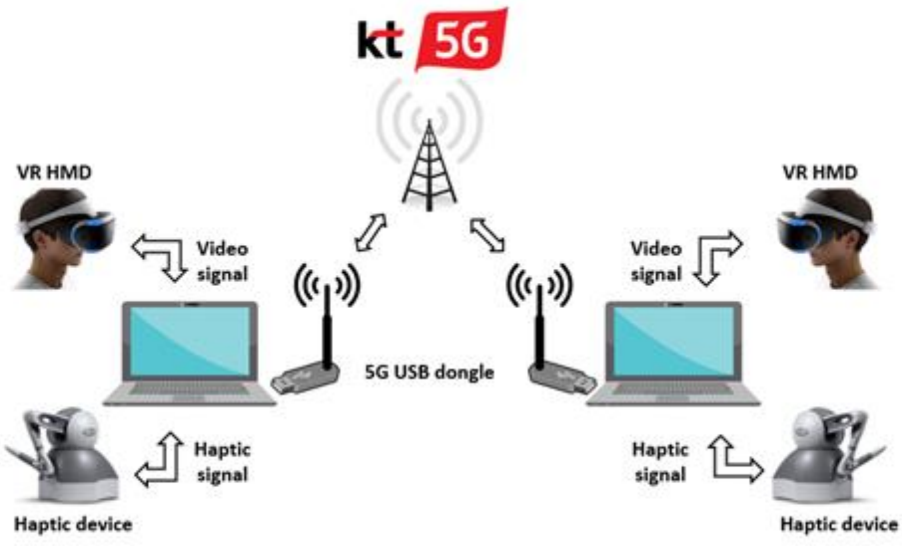

Figure 10 Wireless haptic communication through commercial 5G networks

Table 8 Description of capabilities of haptic communication system from YU

Capabilities	
Networks	Commercial KT 5G network
Carrier frequency	TBD
Bandwidth	TBD
Robotic arms	One Master, Two Slave
QoE support	Yes
Network slicing support	TBD

2.3.6 EUCAST moving base stations

Eucast has two different type of portable base stations [8] – actually they are more than base stations because they have not only eNodeB but also compact EPC and CSCF/PTT Server in it.

EPL2000 is a backpack type base station that weighs less than 10kg (it is still less than 15kg including four cells batteries and backpack frame) and transmits up to 4W+4W. EPL4000 is a vehicular (or vessel) type base station that is rack mountable and transmission power is up to 20W+20W. These are illustrated in Figure 11. The demo(s) to be developed will be mainly based on the use of EPL2000. The capabilities of the base stations are summarised in Table 9.

Figure 11 EUCAST base stations, EPL2000 backpack BS (left) and EPL4000 vehicular BS (right)

Table 9 Description of capabilities of the moving base station components from EUCAST

Capabilities	
RF capabilities	Meets Korean PS-LTE specification - LTE Band 28 (DL: 773 ~ 783MHz, UL: 718~ 728MHz) - 10MHz DL, 10MHz UL - 2x2 MIMO
PHY capabilities	Supports PMCH for eMBMS
L2 capabilities	
Cell-free network support	
QoS support	Default bearer (QCI 9) VoLTE support (dedicated bearer with QCI 1) LTE QCI support (including QCI 65, 66, 69, 70 for MCPTT)

Capabilities	
Network slicing support	Supports local routing for specific service such as MCPTT
Supported physical interfaces	Available physical interfaces for RAN/core network integration. RJ-45
Supported logical interfaces	Available logical interfaces for RAN/core network integration.

2.4 Drones

Drone technology is an important part in the project plan and, e.g., the use cases A1 and B1 envisioned in D1.1 [1]. In this subsection, we provide details on the different types of drones being experimented with at Aalto in Europe and at KAIST and YU in Korea.

2.4.1 AALTO drones

AALTO drone platform compromises H frame and X frame models. The former is equipped with Pixracer [9] flight controllers, while the latter has Pixhawk [10] flight controllers. The used batteries have a capacity of 2200 mAh, providing a flight time of around 20 minutes. More specifications are given in Table 10, while picture of the drone models are show in Figure 12.

Table 10 Basic specifications of the drone models from AALTO

Key features	H frame	X frame
Weight (w/ battery)	2.5 kg	2.5 kg
Max Takeoff Weight	3 kg	3 kg
Max Speed (no wind)	15 m/s	20 m/s
Hovering time[1]	Around 20 minutes	Around 20 minutes
Flight controller	Pixracer	Pixhawk
Companion computer	Raspberry pi 3	Raspberry pi 3
On board sensors	Gas sensor, Humidity & Temperature sensor, camera	Gas sensor, Humidity & Temperature sensor, camera

1 Varies depending on the type of battery.

Figure 12 H frame drone (left) and X frame drone (right) from AALTO

Each drone is equipped with an onboard companion computer, which is a raspberry pi 3 [11]. The latter is connected to the flight controller and has a LTE dongle for Internet connection. Several HATs (Hardware on the top) are considered to enable sensing the environment. A HAT includes different sensors such gas sensor, flame sensor, temperature and humidity sensors. Figure 13 shows a picture of companion computer with HAT.

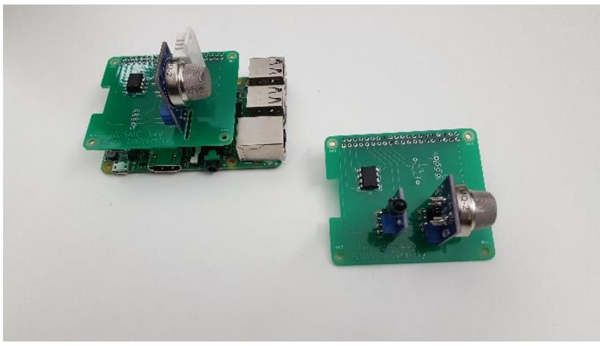

Figure 13 Companion computer with HAT in AALTO drones

2.4.2 KAIST drones

KAIST utilizes two drone models: (1) DJI Matrice 100 [12] and (2) DJI Matrice 600 [13], both of which are controlled by DJI N1 flight controller. Images of the drones are in Figure 14 and basic specifications are in Table 11.

Table 11 Basic specifications of the drone models from KAIST

Key features	Matrice 100	Matrice 600
Weight (w/ battery)	2.4 kg	10 kg
Max Takeoff Weight	3.6 kg	15.5 kg
Max Speed (no wind)	22 m/s	65 kph
Hovering time[2]	22 min (no payload); 13 min (1kg payload)	32 min (no payload); 16 min (6kg payload)

2 Varies depending on the type of battery.

On-board computers are typically attached to the drones to control them via a program. We use Raspberry Pi 3 [11] and NVIDIA Jetson TX2 [14], depending on the need. Raspberry Pi 3 is cheap and suitable for lighter applications, while the NVIDIA Jetson TX2 is GPU enabled, allowing the developers to use more computing-intensive applications. However, NVIDIA TX2's weight may be too heavy for the drone to carry during long runs.

Figure 14 DJI Matrice 100 drone (left) and DJI Matrice 600 drone (right) from KAIST

2.4.3 YU drones

Multi-tiered drones

For multi-tier drone fleet management, YU uses two types of drones with different capabilities. Intel Aero RTF drone [15] is a light-weight programmable drone with minimal capabilities for heavy processing. Although it cannot process over-the-top image processing and other computationally heavy tasks, it is a good candidate for executing various programmed tasks. DJI Matrice 100 [12] (with on-board computer mounted) shows higher overall performance level than Intel Aero RTF. Thus, it is a candidate for a leader drone in a two-tier scenario, or a higher-level member in a three-tier scenario. The basic specifications for each drone is shown in Table 12.

Table 12 Basic specifications of the drone models from YU

Key features	Matrice 100	Intel Aero RTF
Weight (w/ battery)	2.4 kg	865 g
Max Take-off Weight	3.6 kg	1.9 kg
Max Speed (no wind)	22 m/s	15 m/s
Hovering time	22 min (no payload); 13 min (1kg payload)	20 min (max)

Possible Add-ons

Various modules including but not limited to cameras, sensors, antennas, and on-board computers can be added to the drones when necessary. For LTE connection, YU uses Huawei E3372 [16] dongle with 4G router external antenna. For 5G connection, YU uses Galaxy S10 5G [17] (Apr. 2019 Model) as an AP. For the drones' vision, YU uses Intel Realsense 200 [18], See3Cam USB camera [19], Omnivision OV8858 [20]. Lastly, Intel Aero RTF [21] has an inbuilt integrated on-board computer (Atom x7-Z8750 processor) and flight controller; and Nvidia Jetson Nano [22], TX2 [14], and Xavier [23] will be used for the higher tier drones. Drones are illustrated Figure 15.

Figure 15 Intel Aero RTF drone fleet members (left) and DJI Matrice 100 drone (right) at YU

2.5 Edge computing platforms and cloud applications

Finally, to realize the use cases, e.g., A1 and B1 depicted in D1.1 [1], applications and edge computing platforms will be required. In this, subsection we provide details of these.

2.5.1 AALTO edge cloud

For the edge cloud, AALTO utilizes Intel FOG Reference Design (FRD) [15], which is shown in Figure 16. FRD is equipped with CPU Intel XEON (4 physical cores) and has 32 GB of RAM. The edge server is used to host the flight controller services of the drones, and other complementary services. FRD also comes with two Intel Arria 10 GX1150 FPGAs, which can be used to support specific applications.

Figure 16 Intel FOG Reference Design for Aalto edge cloud

2.5.2 CAU edge cloud

At edge cloud around the incidental site, CAU conducts super-resolution (SR) to improve the real-time images collected and transmitted by drones. Especially, CAU proposed the depth-controllable very deep SR (DCVDSR) technique. For SR imaging based on the DCVDSR framework, CPU of Intel i5-8400 [24] (2.8GHz) and GPU of NVIDIA GTX 1060 3GB [25] were used. In addition, the processing computer was equipped with the RAM of DDR4 16GB and the storage of SSD memory 128 GB. This is illustrated in Figure 17.

Figure 17 NVIDIA GTX 1060 3GB in CAU edge cloud.

2.5.3 CAU cloud apps

For cloud applications, CAU utilizes a vehicle to collect and process the real-time images collected and transmitted by drones at the incidental site. The vehicle which carries the image processing unit explained in Section 2.5.2 can be also moving and represent the fleet leader, the firefighter or the fire engine. The vehicle is shown in Figure 18.

Figure 18 CAU vehicle

3 Demonstration plans and scenarios

3.1 Overview

During the initial phase of the project, the partners have been developing demos mostly independently in Europe and Korea. In particular, in Europe partners have developed demos showcasing the various components they are developing, while in Korea demos have already been presented demonstrating integration of various system components. In the following two subsections, we first describe the demo activities from the European partners in Section 3.2 and the demos from the Korean partners are detailed in Section 3.3.

3.2 Demos from European partners

In this section, the demos from the European partners are described. These include the cell-free UDN from Aalto, a series of 5G core network demos from CMC, followed by a mmWave 5G NR demo from NI, a 5G testbed demo from KCL and an optimal routing demo from Ericsson.

3.2.1 Cell-free UDN demo by Aalto

Description of the demo

Aalto Radio Framework (ARF) is a software-defined radio platform designed to enable experimental research with off-the-shelf hardware, namely Ettus USRP X310 [26] and Fairwaves XTRX [27]. The ARF platform is used to develop a testbed that can demonstrate a proof-of-concept user-centric positioning-based cell-free ultra-dense network (UDN). The cell-free UDN testbed consists of an emulated aerial UE, multiple TRPs placed on lampposts and one gNB.

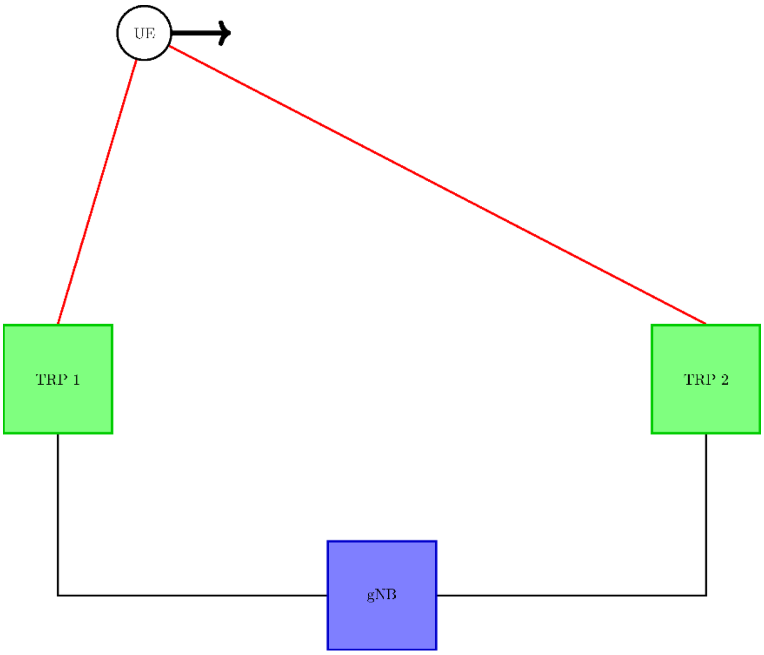

Figure 19 Measurement setup illustration with two TRPs tracking a mobile UE under a gNB's control

The gNB continuously tracks the 3D movement of the aerial UE and then provides seamless service to it based on position information, as illustrated in Figure 19.

Precise position information:

- provides efficient mobility management,

- provides a basis for seamless connectivity (see section 3.3 of D3.1 [3] in WP3) and
- is a functional requirement for use case A1 and use case B2 in WP1 (see D1.1 [1]).

Therefore, the cell-free UDN testbed will be used as a tool to demonstrate, by experimentation,

- the achievable positioning accuracy,
- control plane handover/switchover between TRPs with seamless mobility from the UE perspective.

Development of the cell-free UDN testbed proceeds as a multi-phase activity with increasing complexity. It includes software component development for each node (UE, TRP and gNB), identifying practical impairments of real world system during development and testing phase, and developing solutions as well as performance improvement approaches. This component demonstration (with cell-free UDN testbed) is a standalone RAN level demo.

Evaluation plan

Evaluation of the demonstrator will cover two aspects: positioning and mobility management. Positioning accuracy affects beam-steering, which in turn affects SINR and therefore the quality of the link between the network and the UE. Furthermore, the location data has value beyond its use in the operation of the wireless communication system (see D1.1 [1] KPI *Position accuracy* defined in Section *Operational and functional KPIs*). Performance assessment will be done by comparing the estimated position at the TRP or gNB to a physical measurement (for example, with a tape measure). The achieved accuracy will also be compared to the theoretical performance bound. The quantities measured will be:

- Azimuth angle estimation accuracy
- Elevation angle estimation accuracy
- 3D positioning accuracy
- Positioning accuracy degradation due to latency and skew in TRP-to-gNB report timing

The second aspect assessed is mobility management. Evaluation will be performed by recording the time during which the UE does not receive a usable signal while a handover is taking place. Enabling seamless mobility requires this time to be minimised since during the interruption, the UE cannot receive or transmit data. Communication latency will consequently increase and may degrade application end-to-end performance (D1.1 [1] KPI *E2E latency* defined in Section 5.2.1 *Technical KPIs*).

Further evolution of the demo

The testbed evolution plan includes adding support for more TRPs and multi-UE (both ground and aerial). Plans also include demonstrating and validating seamless mobility with multi-UE support and extended gNB coverage (while UEs are traversing more TRPs).

Time and location of the demo(s)

The measurement campaign will take place on the Otaniemi campus during the spring of 2020. The exact timing is subject to weather conditions being favourable to outdoor measurements. Since testbed development is a continuous, lengthy process, data will be captured in phases, as functionality becomes ready. Tests done at each step will be compiled together to showcase the evolution of the project. This compiled data will be used to produce a video as the extended duration of the measurement campaign prohibits a more traditional demonstration.

3.2.2 *Real-time video broadcast demo by CMC*

Description of the demo

This demo by CMC consist of streaming video from UAV uplink to the mobile core from where it will be broadcasted to the UEs of the firefighters. This demo is related to use case A1 and B1 and is illustrated in Figure 20.

This demo and the subsequent demos from CMC use the following off-the-shelf products: Nokia Flexi Zone eNB [28], Huawei E3372H Dongle [16] and Bittium Tough Mobile GMS Release MR18 [29].

Figure 20 Real-time video broadcast demo by CMC

Evaluation plan

The demo will be evaluated considering technical KPIs such as Data rate and E2E latency. The demo will measure the delay for the live streaming which message flow is described in Figure 20.

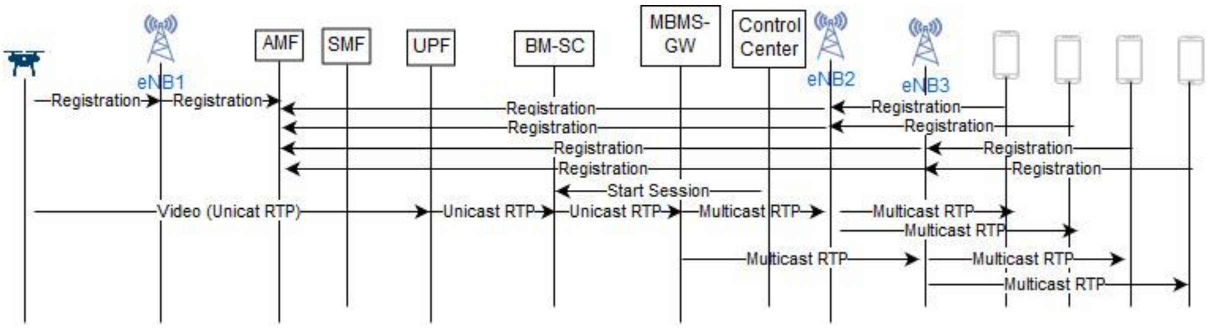

Figure 21 Message flow for real-time video broadcast demo by CMC

The message flow of the demo will be as follows. The UAV and the mobile devices will register to the mobile core according to normal procedure. The UAV and the mobile devices as shown in Figure 21 might send their Registration message to different base stations depending on the dimensions of the scenario. If the area is not so large, both the UAV and the mobile devices to the same base station.

In Figure 21, most of the registration messages are not shown to keep it simple. After the registration the Control Centre will start an eMBMS session defining what is the source and what is the area to cover with the broadcast. The session will consider the uplink media coming from the UAV as the source for the content. The area to be covered will be defined by the base stations that cover the area for the broadcasting. In this example we show that UAV is connected to one base station close the source of the media while the area for broadcast is much wider and is covered by two different base stations.

After the eMBMS session is started the UAV will stream live video using RTP for the uplink communication. The destination IP for the RTP unicast stream is the BM-SC IP address, which then send to the MBMS-GW, which will multicast the RTP stream to all the base stations selected for the broadcast. The base stations will then broadcast the live RTP stream to all the mobile devices.

Further evolution of the demo

This demo will evolve to include uplink with higher bitrate using mmWave connection from the UAV to the gNB.

Time and location of the demo(s)

This demonstration was presented at EuCNC 2019 in June 18-21, 2019.

3.2.3 UAV-UE video broadcast demo by CMC

Description of the demo

This demo by CMC consist of streaming video from UAV uplink to the mobile core from where will be broadcasted to the UEs of the firefighters with will have some delay to additional video processing. This demo is related to use case A1 and B1 and is illustrated in Figure 22.

Figure 22 UAV-UE video broadcast demo by CMC

Evaluation plan

The demo will be evaluated considering technical KPIs such as Data rate and E2E latency. This demo is similar to the previous one with the different of having extra component between the mobile core and the BM-SC. This component will receive the video stream directly to from the UAV and will process it before sending to the BM-SC and follow the flow described in Figure 21. In this demo, the evaluation should measure the additional delay after including the video processing.

Further evolution of the demo

This demo will be evolved to include MEC and reduce the latency due to video processing happening in the cloud.

Time and location of the demo(s)

This demonstration was presented at EuCNC 2019 in June 18-21, 2019.

3.2.4 5G network slicing demo by CMC

Description of the demo

In this demo by CMC, the control centre will request different network slices to different UAV, so each slice delivers different E2E latency depending on the needs of the traffic.

Evaluation plan

The demo will be evaluated considering technical KPIs such as Data rate and E2E latency for each network slice. Figure 23 shows the overall system for the demo where the SDN backhaul is based on OpenVswitch [30] that supports Openflow to manage the switch. The Mobile Backhaul Orchestrator (MBO) will receive information from the mobile core to determine which devices will be assigned to different network slice i.e. red or green line in Figure 23. In this demo besides different network resources, each slice might be assigned a different core or UPF to handle the user plane differently based on the traffic requirements.

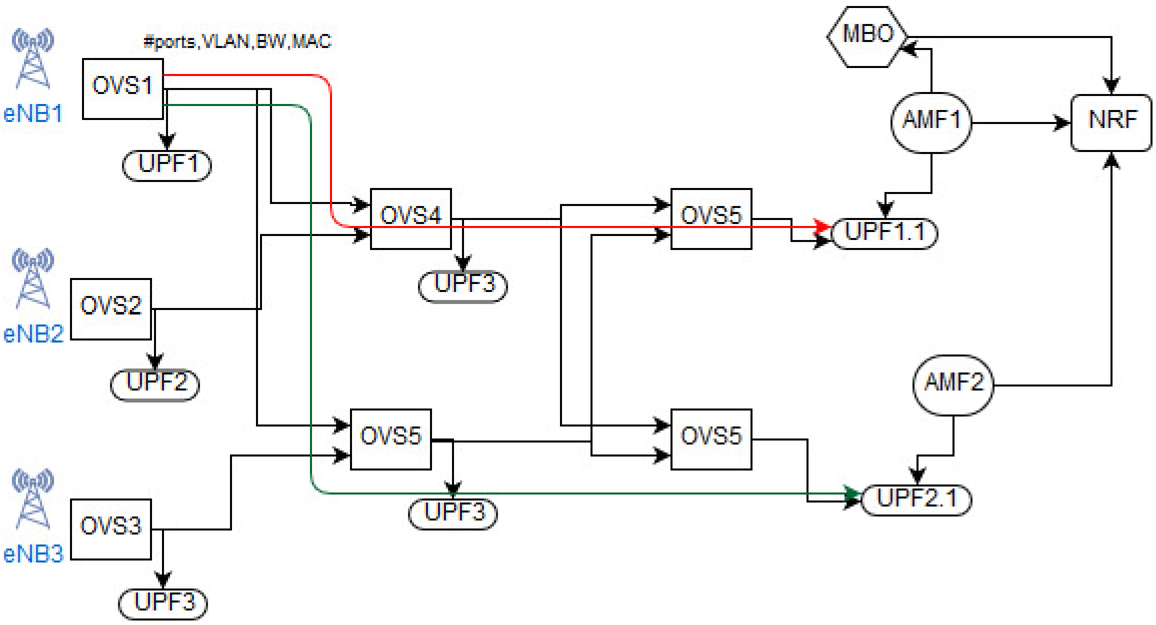

Figure 23 Network slicing demo by CMC

Further evolution of the demo

This demo can evolve to include MEC in addition to network slicing. The demo as shown in Figure 24 allows to select the UPF in different part of the network which facilitates running MEC together with the selected UPF.

Time and location of the demo(s)

This demo was presented at ITS Europe Conference 2019 in Otaniemi, Espoo, on June 16-19, 2019.

3.2.5 MEC orchestrator demo by CMC

Description of the demo

In this demo by CMC, the control centre will request a MEC platform for running video processing application and the network functions to perform the video broadcast closer to the UEs. This is illustrated in Figure 24.

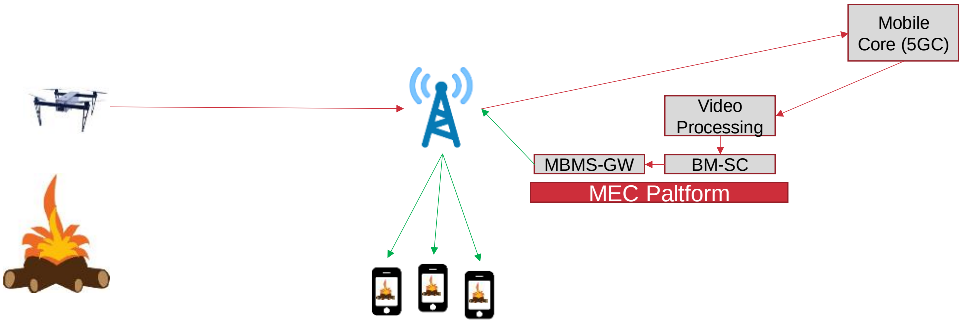

Figure 24 MEC orchestrator demo by CMC

Evaluation plan

The demo will be evaluated considering technical KPIs such as Data rate and E2E latency. This demo is based on network slicing that allows the deployment of UPF in different parts of the network as shown in Figure 23. This demo will be evaluated by measuring the delay when selecting different UPF where MEC can run to reduce the latency for selected traffic. Similar evaluation has been done for network slicing and different UPF for NB-IOT traffic. Figure 25 and Figure 26 show the deployment for NB-IOT and the results of packet delay and packet loss depending on the network slice assigned to different sensors.

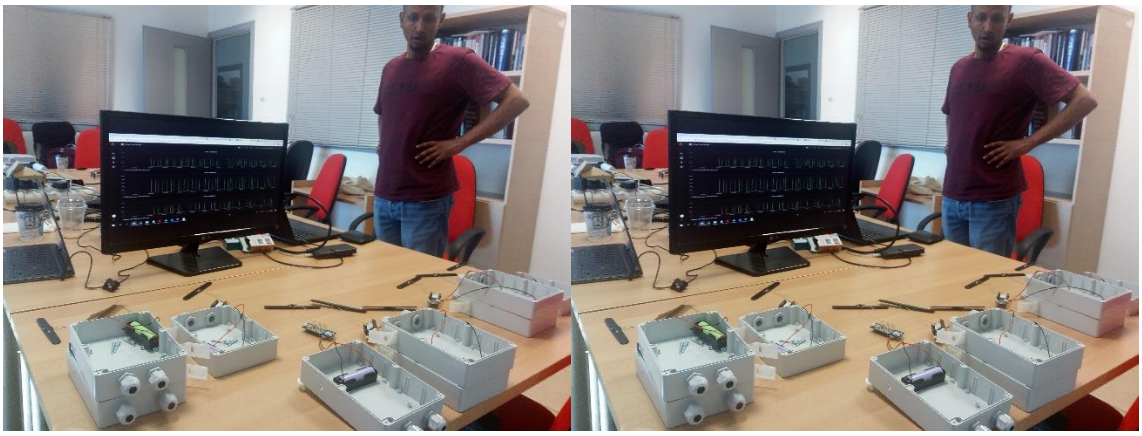

Figure 25 Demo setup for network slices used with NB-IOT demo by CMC

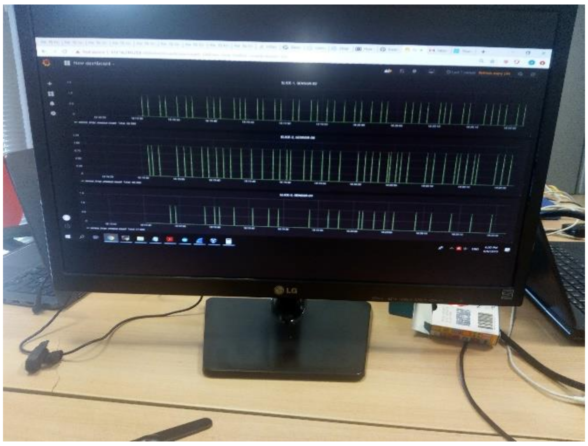

Figure 26 Packet loss and delay measurements for different network slices

Further evolution of the demo

No evolution is currently planned.

Time and location of the demo(s)

The exact timing has not been decided yet, but it will be before M22 (Apr 2020).

3.2.6 5G-NR transceiver demo by NI

Description of the demo

The 5G-NR transceiver demo by NI will consist of two parts:

The 1st part will showcase IP-layer-based data transmission over the 5G-NR link utilizing the 5G-NR gNB and UE developed in WP3. This link can represent the connection between a vehicular gNB and an aerial gNB. The focus of this first component demonstration lies on the integration of NI's FPGA based PHY layer implementation with the Layer 2 and Layer 3 of OpenAirInterface. This integration will enable the demonstration of the random-access procedure, the attach procedure of the UE to the gNB, the signalling and data bearer setup and DL and UL data transmission on IP layer. A block diagram of the system used for the demo is shown in Figure 27. This demo will make usage of frequencies below 6 GHz.

The 2nd part will showcase functionality and performance of the components needed to operate on mmWave frequencies, namely on frequencies in the range of 24.25 – 27.5 GHz. The focus of this part of the component demo is on showing that the mmWave transceiver components are able to get integrated into the overall 5G-NR system.

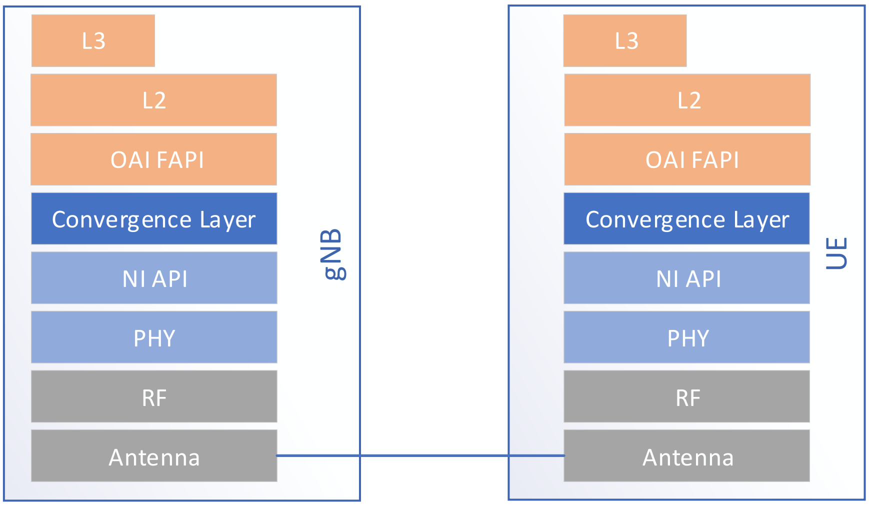

Figure 27 5G-NR transceiver demo by NI

Evaluation plan

For the 1st part of the component demo, the following functionality is evaluated:

- Random access: UE and gNB finish random access procedure
- ATTACH: UE gets attached to the gNB and configures PHY, MAC, RLC and PDCP layer
- Signalling and data bearer setup

Apart from functional evaluation, the following performance evaluations will be carried out on IP layer for the 1st part of the component demo:

- User plane throughput at ingress and egress points of layer2
- User plane latency at ingress and egress points of layer2
- Those performance measurements will be done using iperf or comparable tools.

For the 2nd part of the component demo, transmission and reception of broadband signals on targeted mmWave frequencies is evaluated. Measurements of TX EVM, TX spectral mask, TX output power and RX EVM will be done to evaluate the performance of the mmWave components.

Further evolution of the demo

The functionality of the 5G-NR transceiver will be enhanced during the runtime of the project. Next phases of the demonstration will show:

- Support of beam steering capabilities
- Integration of mmWave components into 5G-NR system
- Integration with 5G Core

Time and location of the demo(s)

The demo will be presented in M21 (Mar 2020) at National Instruments in Dresden.

3.2.7 Cross-Domain demo by KCL

Description of the demo

An important aspect of low latency communication is to be maintained when communication cross over multiple domains over long distances. Succeeding in such cases is only possible via migration of low-latency components to local networks when needed. In the case of PriMO-5G scenarios, the remote control of the flying object, and various functionality on-board, e.g. object recognition, are low-latency component that, if run by the network, should run locally.

This demo by KCL will show feasibility of remotely controlling a moving object from long distance and across a roaming network. To enable this, orchestration of resources for federated network slicing will be necessary. For instance, Figure 28 illustrates a possible use-case, where UE is registered in the Korean domain while it is acting in a different continent (UK).

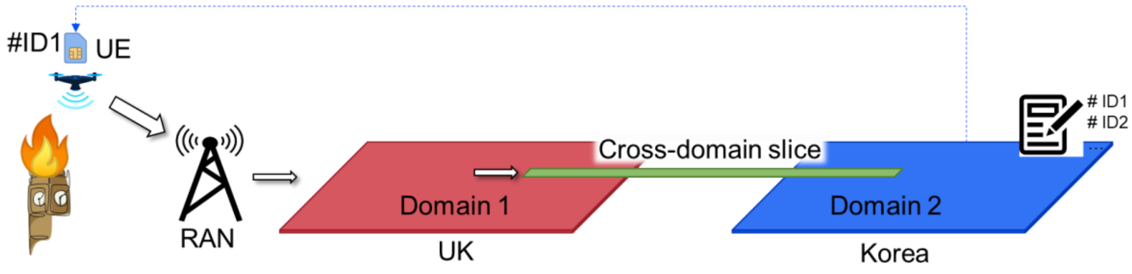

Figure 28: Cross-domain slicing

Evaluation plan

The KPIs to be tested will of course firstly be the acquired latency, but also the low-latency tasks (e.g. remote control or object recognition) to be executed successfully.

Further evolution of the demo

An interesting aspect of this demo will be to connect the two continents, and run over the cross-continental links. Hence, further plan here will be to run the cross-domain demo as a cross-continental scenario between KCL and the Korean partners.

Time and location of the demo(s)

The demo is planned in M21 (Mar 2020), and as part of KCL open days.

3.2.8 Optimal routing demo by Ericsson

Description of the demo

The Optimal Routing demonstration by Ericsson showcases a solution to the following problem: The 3GPP defined 5G Core (5GC) architecture provides a mechanism to have IP address preservation at mobility events. However, this implies that the IP address gets associated with a User Plane Function (UPF) that cannot be changed. This is a disadvantage for edge use cases, where low latency requires that the UPF is close to the UEs. Other solutions allow to change the UPF, but without IP address preservation.

The concept of Optimal Routing provides a solution that allows low latency communication UE-to-server or UE-UE, while keeping service and session continuity (IP address preservation). The objective of the demonstration is to visualize the Optimal Routing prototype.

In the demonstration, two scenarios are shown: 1) a UE communicates simultaneously with central and local servers, and 2) UE-to-UE communication. The components of Optimal Routing run in Virtual Machines in a remote OpenStack-testbed. By triggering handovers, we visualize how the traffic flows via our prototype components in the system in the different scenarios.

The demonstration is applicable to the use cases A1 and B1 in D1.1 [1]. Examples for UE-to-UE communication: drones communicating with each other, drone is controlled by a firefighter; drone sends video traffic to a firefighter, etc.

The demonstration is installed on an OpenStack cluster, where an example core network is deployed, which has 2 central sites and 2 local sites. Each site's all functionality runs in a Virtual Machine (VM).

A central site VM consists the following components:

- Central Server: the VM is running a server that communicates with the UE. This is to simulate a server either in the Internet or in a central operator site.
- IAP (IP Announcement Point): the VM is running an IAP, the user plane component of Optimal Routing

A local site VM consists of the following components:

- Local Server: this VM is running an edge server that communicates with the UE.
- IAP: the VM is running an IAP
- UPF (User Plane Function): the VM is running a simple UPF with functionalities such as GRE and GTP encapsulation/de-encapsulation, bandwidth limiting, etc.

In the setup, there are two more VMs:

- Central Control VM: This VM runs control plane functionalities, such as the Location Register component of Optimal Routing and an emulated Command Line Interface-based SMF
- Access Network VM: this VM runs emulated gNB functions with GTP encapsulation/de-encapsulation and emulated UEs running as containers

The setup is illustrated in the following Figure 29.

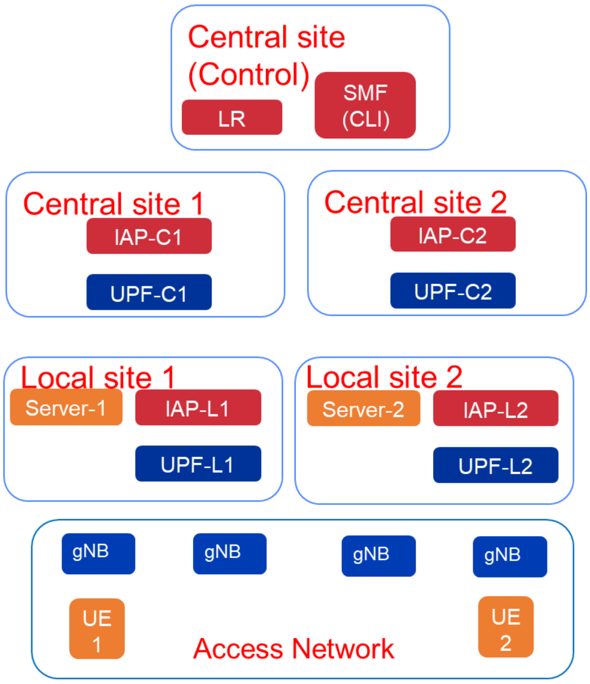

Figure 29 Optimal routing prototype components in OpenStack testbed in Virtual Machines, emulating 2 central and 2 local sites

Evaluation plan

E2E latency is an important KPI for Optimal Routing (both for UE-to-UE communication and when the UE is communicating with edge servers). Service disruption time is another important KPI, measuring how long there is a disruption in the communication, e.g. at mobility events.

Further evolution of the demo

N/A

Time and location of the demo(s)

This demonstration was presented at EuCNC 2019 in June 18-21, 2019.

3.3 Demos from Korean partners

In this section, presents the demos by the Korean partners. On the Korean side, the partners have already started integrating system components together, which will be evident from the following descriptions. Consequently, the demos are typically collaborations between multiple Korean partners. The demos to be presented include the aerial video streaming demo with YU, CAU and KT, and streaming aerial video demo with NIB approach from EUCAST, which focuses on achieving video streaming also over LTE networks. Finally, there are two demos from YU: lens based mm-wave communications demo and haptic communications demo.

3.3.1 Aerial video streaming system with real-time object detection and super-resolution demo by YU, CAU and KT

Description of the demo

Yonsei University 5G enabled drone testbed platform is designed to showcase different missions using programmable drones equipped with various network modules including 4G LTE and 5G. The platform has three primary operational locations, see also Figure 29:

- Sinchon Ground Control Station (YU) in Yonsei University Seoul Campus,
- MEC enabled automobile (CAU) in between Seoul and Incheon,
- Songdo drone fleet station (YU and KAIST) in Yonsei University International Campus, which is located 40 km from Sinchon.

We hope to demonstrate the possibility of near-zero latency mission involvement (in a firefighting scenario) by introducing 5G-enabled immersive video streaming. One of the enabling factors, which we will show, is the leveraging of different computing and communicating resources provided by the overall system, e.g. multi-tiered drones, MEC, and a server.

In order to do so, we primarily showcase the capability of 5G networks by juxtaposing three video feeds simultaneously. Furthermore, to illustrate the trade-off between computation and communication in a multi-tiered 5G system, we display three videos in a parallel manner:

1) direct display of the video from the UAV with lower-accuracy detection,

2) streamed high-quality video, via 5G, on the server with a moderate-accuracy detection, and

3) streamed and processed (super resolution) video with high-accuracy detection.

By showcasing the system, we expect to revisit the communication-computation trade-off relationship as depicted in D1.1 Section 4.2.2.3 [1].

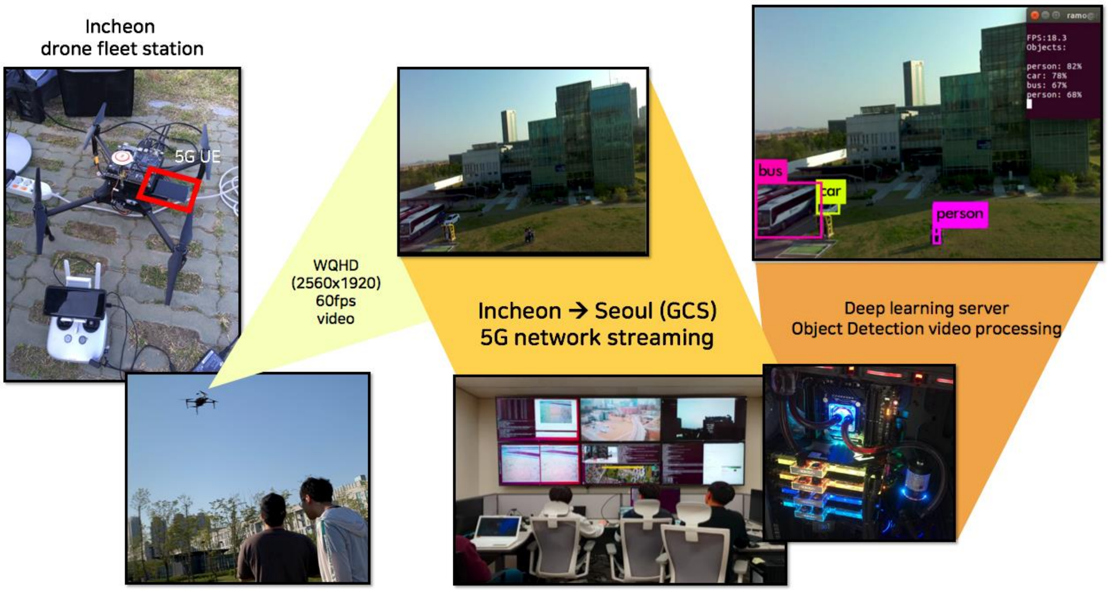

Figure 30 5G-equipped drone testbed in M10 (Apr 2019)

Evaluation plan

The demonstration will be mainly evaluated in two aspects: data rate and latency. Data rate corresponding to the technical KPIs (depicted in D1.1 Section 5.2.1 [1]) and determines the quality of the video streamed by the communication link. Although the firefighters in the MEC and the incident commander in the GCS are the end users in this demonstration, they experience the output video processed by each server in their location. For this reason, the computing servers in the intermediate step are real users who experience data rate of the communication link. Consequently, as a key KPI, the data rate determines the resolution and the frame rate of the streamed video, and it will finally affect the accuracy of the object detection as well as the quality of the image, which is processed by the end server running super-resolution technique. Since it is the primary source of information, the uplink data rate of 5G enabled drone is our primary concern. Consequently, uplink data rate will be monitored constantly, and severe data congestion at the node will be alleviated by utilizing the network capabilities of the drone fleet and its environment. The data and transmission offloading scheme will be evaluated by monitoring the level of alleviation of data congestion.

The second aspect to be evaluated is latency. The latency between two operational points can be measured by using the system timestamp or by using a synchronized global time displayed on the video. The capability of the system to maintain a low latency is critical to a firefighting system where real time interaction between actors are directly related to the result of the mission. Firstly, latency can be classified into E2E latency corresponding to the technical KPIs (in D1.1 Section 5.2.1 [1]), and operation delay corresponding to the operational KPIs (in D1.1 Section 5.2.2 [1]). Emphasizing the former would focus on the timely transmission of data, whereas emphasizing the latter would focus more on how quickly the system responds to the generated data. Secondly, E2E latency can be further divided into components according to the resource level latencies caused by different layers, e.g. communication, transportation, and computation. As explained above in the demo description, usage of resources should be leveraged appropriately to shorten the E2E and operational latencies.

To add, the results from the demonstration testbed will illustrate how the research issues pointed out in D1.1 (Sec. 4.2.1.3) [1] can be leveraged:

- Trade-off between communication latency and computing power: real-time resource identification and allocation schemes will be topics of further research.

- Simultaneous video transmission of live streaming and high-quality and reliable streaming: Secure Reliable Transport (SRT) will be integrated with 5G network.

Shown below in Figure 31 and Figure 32 is an initial view on the testbed designed to illustrate such difficulties in M12 (Jun 2019) Seoul-Incheon 5G enabled drone AI computing testbed.

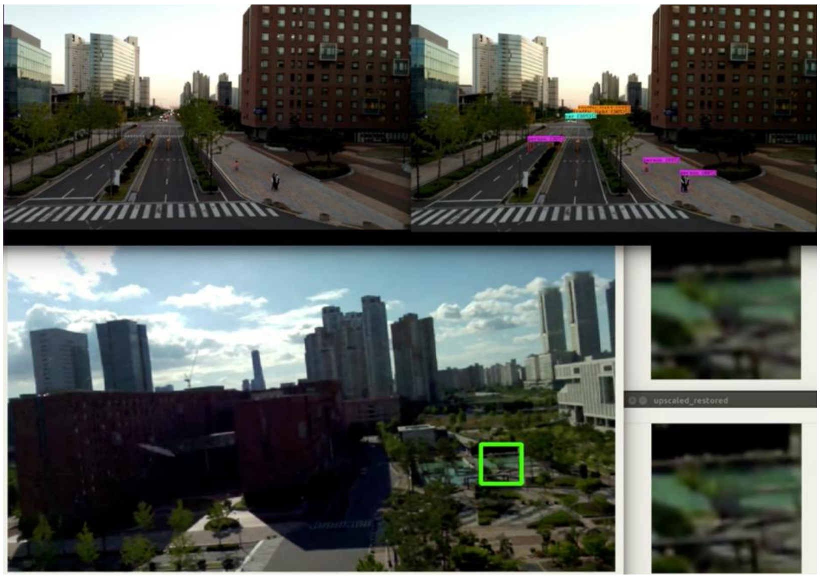

Figure 31 Initial testbed demonstrating MEC and GCS server that are using footage from a drone to detect objects (using YOLOv3 [31]) and run super resolution (using advanced convolutional neural networks) in real-time

Figure 32 Initial testbed showing aerial computation-communication trade-off. Image on the top right is processed on an MEC server, while the images in the bottom are processed on drone. Even with accelerated computing, on drone processing suffers from tremendous delay or frame drop.

Further evolution of the demo

Real time virtual reality videos will be provided for the firefighters and the incident commander so that they can have a chance to take proper action faster. Alongside, the actors receiving VR videos will be able to control their vision by moving the gimbal camera, which is in sync with their goggles, by rotating and tilting his/her head. In the control side, further technical development will enable the control of a drone or a fleet of drones remotely (from a long distance, e.g., Seoul to Incheon). On-device image processing will be performed while drones are traveling. Various combinations of these techniques will increase the diversity of demonstrations. This is illustrated in Figure 33.

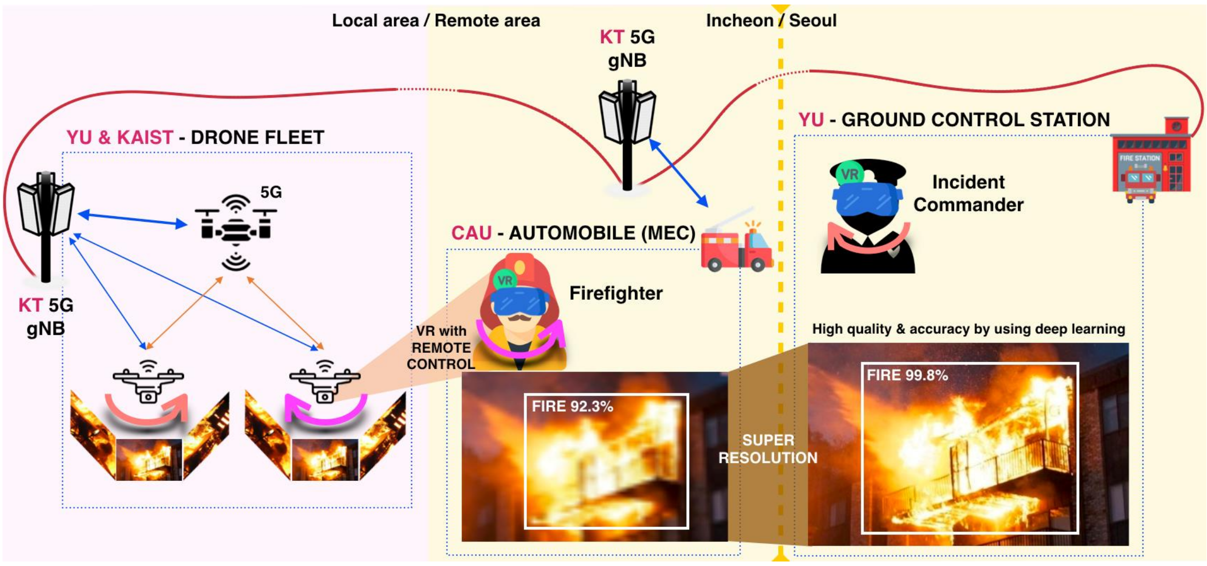

Figure 33 Overall illustration of aerial video streaming system with real-time object detection and super-resolution demo

Time and location of the demo(s)

This demo will be gradually evolved by the spring of 2020 (M22, Apr 2020). As the first step, high-definition video was streamed from a drone in Incheon to GCS in Seoul through the commercial 5G network of KT in the winter of 2018 (M6, Dec 2018). Based on this experiment, real-time object detection with FHD streamed video through 5G network is demonstrated by using deep learning algorithm in GCS until June 2019 (M12). This result was showcased at EuCNC 2019 Valencia, Spain. This demo will be further enhanced until the winter of 2019 (M18, Dec 2019) in terms of its scale by adding the 5G-enabled MEC capable of super-resolution and object detection. It will also be followed by improvements in GCS performance (video resolution, video frame rate, and detection accuracy). Finally, implementation of technical components like constructing drone fleet, streaming VR videos and remotely controlling drones and/or gimbal camera in real-time will be added to the testbed up to the spring of 2020 (before M22, Apr 2020).

3.3.2 Streaming aerial video system through LTE NIB demo by EUCAST

Description of the demo

Even though 5G commercial service is launched in Korea and US, and field trials are actively ongoing in many countries, it’s certain that 4G LTE would be the most widely used service at least for next few years. Especially LTE deployment is in its very early stage in vertical markets such as Public Safety (PS-LTE), railway service (LTE-R), maritime service (LTE-M), and so on.

So it would be better if we can support not only 5G NR but also LTE in our firefighting demo scenario illustrated in Figure 33, and it’s possible by collocating Eucast Portable LTE system – or Network In a Box (NIB) – together with MEC server at MEC enabled automobile in Figure 33.

It could be a good solution because we can support legacy LTE UEs (drones) while utilizing the benefit of MEC and 5G backhaul to guarantee sufficient capacity and short delay in backhaul. The EUCAST NIB solution is illustrated in Figure 34. For 5G backhaul link in Figure 34, KT 5G gNB will be used.

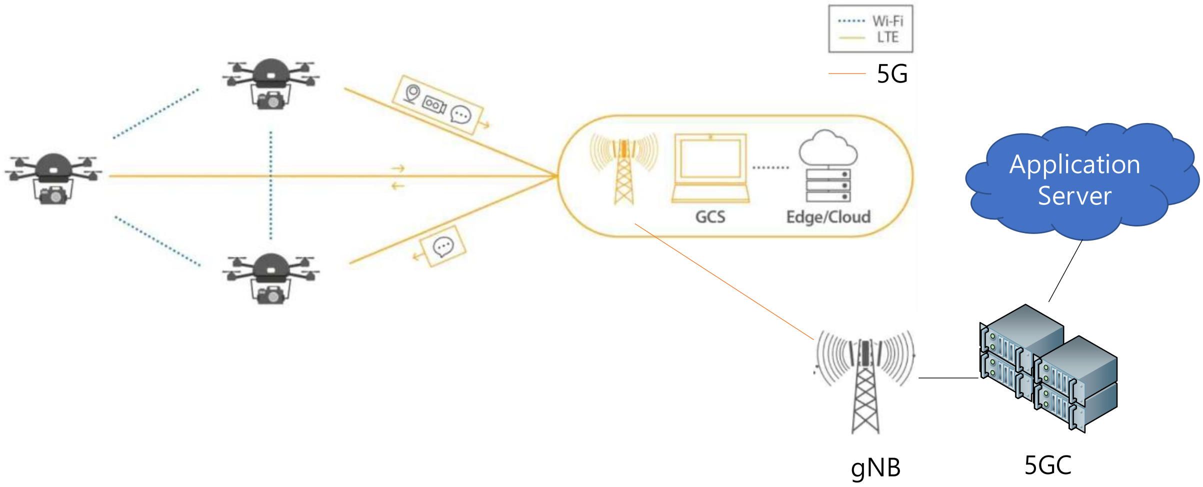

Figure 34 EUCAST NIB solution

Another demo scenario which can be showcased with above setup is eMBMS/MCPTT. When LTE network is applied for PS-LTE service like firefighting scenario, it's inefficient to deliver the audio/video contents from one source to multiple destinations by unicast. It would be better if the contents is multicast to multiple destinations simultaneously (1:n communication), for example the video contents of drone can be multicast to the firefighters and the local command centres. This is shown in Figure 35.

Figure 35 EUCAST demo scenario

This scenario is similar with Sections 3.2.2 – 3.2.5. Difference is that in the setup here the MCE (Multicast Coordination Entity) is located at core network side, while it is at eNB in Sections 3.2.2 - 3.2.5.

Evaluation plan

The evaluation points of this demo are almost the same with those of Section 3.3.1. So the data rate and latency of this demo will be used as a comparison purpose to understand the benefit of 5G network in time critical services such as firefighting.

Also when adaptive determination of resolution and frame rate is supported by application, they will be monitored/compared between unicast and multicast in LTE network.

In operational viewpoints, Operational deployment time and Operation durability (depicted Section 5.2.1 of D1.1 [1]) of portable NIB will be evaluated.

Further evolution of the demo

Eucast NIB will be eMBMS/MCPTT ready by 1st half of 2019, and then the interoperability test with 3rd party EPC, BM-SC, MBMS-GW, MCE and UE will be done before 2nd half of 2019.

Since initial deployment of 5G-NR is NSA (Non Standalone Architecture) based, the gNB cannot run without help of legacy LTE network, for example the dual connectivity with LTE eNB is needed for control message exchange with core network. Eucast NIB will be enhanced to support dual connectivity with gNB (3GPP release 15 feature) to provide emergency service even when fixed LTE eNB is destroyed while still neighbour 5G gNB is available.

Time and location of the demo(s)

The time and location of this demo is exactly same with Section 3.3.1, i.e. this demo will be done as a part of the demo described in Section 3.3.1.

3.3.3 Lens based mmWave communications demo by YU

Description of the demo

This demonstration is conducted by YU to achieve the connectivity of gNB and UAV reliably in the use case of WP1 D1.1 [1]. To keep the connection between the fast-moving object drone and gNB, stable and accurate beam-tracking must be supported. In addition, accurate beamforming and beam tracking are essential as narrow beams are formed due to characteristics of the mmWave band. The demo introduces the hybrid beamforming system with a lens antenna so that the fast beam switching method show lower complexity compared to the existing method using phased array. Furthermore, both curved and planar lenses are considered, and hybrid beamforming is performed. Planar and curved lenses are illustrated in Figure 36. All of these are implemented in the NI hardware and have high throughput, and high received power in mind. The system operating frequency will support wide bandwidth of up to 800MHz at 28.5 GHz.

Figure 36 Illustration of lens antennas with planar and curved shapes

Evaluation plan

Demonstrations will be evaluated in two aspects. The first is the data rate, and the other is reliability. Both perspectives follow the technical KPIs specified in D1.1 section 5.2.1 [1]. With the first phase, our demo aims to achieve a high-data rate through the lens. In the demonstrations, the configuration may be considered in one of two situations where only the Tx antenna uses the lens antenna, and both Tx & Rx use the lens antenna. The second phase will then conduct the beamforming & beam tracking view with lens antenna. The main evaluation KPI for the second phase is expected to be ultra-reliability and data rate. This assessment can show throughput and received power in various constellations.

Further evolution of the demo

The second phase demonstration after phase 1 aims to achieve the beamforming & beam-tracking of with the lens antenna. Along with the hybrid beamforming algorithm, it is going to establish a system that supports scenarios that reliably achieve data rate for drones as UEs, a fast-moving object. In this demo, the beam-tracking method is performed using the backplane antenna switching method, unlike the traditional phased array antenna method.

Time and location of the demo(s)

The demonstration will be held in Songdo, Korea, and phase 1 will be completed in M18 (Dec 2019) and phase 2 will be completed in M22 (Apr 2020).

3.3.4 Haptic communications demo by YU

Description of the demo

Yonsei University implements a system that transmits haptic information. This demonstration can be added to the existing firefighting scenario A, rural firefighting scenario. In the scenario of WP1 D1.1 [1], drones and robots are used as supplementary means to help put out fires. In this scenario, master robotic arm controlled by the control centre directly controls the arm of the slave robots as UEs at the fire site. In this proposed scenario, a robotic arm is used to pick up or remove obstacles and to rescue people. For the connection of this haptic communication, the haptic information is compressed and delivered in a compressed method which takes account of haptic communication characteristics. The network of this demonstration is based on the use of a 5G commercial network. The test set up is shown in Figure 37.

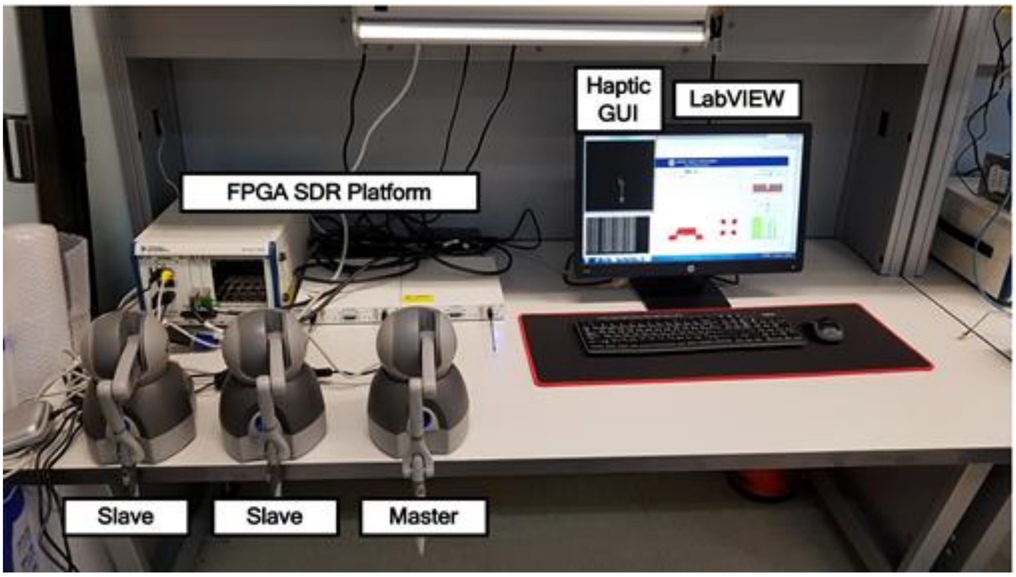

Figure 37 SDR platform for controlling haptic robotic arms

Evaluation plan

Haptic communication demo uses quality of experience (QoE) as a measure of performance evaluation, and studies techniques to model QoE and maximize it through self-learning. Yonsei University proposes techniques to analyse and compress the characteristics of the haptic signal by using the robotic arm equipment and conducts research that is implemented in actual wireless communication on the SDR platform. This is expected to be possible to optimize the haptic signals proposed in this study through learning and to implement them in the KT commercial 5G mobile communication environment.

Further evolution of the demo

A technique for analysing and compressing the characteristics of the haptic signal is proposed. Furthermore, QoE can be maximized in various environments of 5G by studying self-learning-based transmission algorithms. This research will likely be able to expand into real commercial 5G mobile telecommunication environment.

Time and location of the demo(s)

The demonstration will be held in Songdo, Korea, and will be completed in M18 (Dec 2019).

4 Conclusions and future steps

This deliverable report D5.1 Demonstration Plan provided an overview of the PriMO-5G components contributed by different partners for the PriMO-5G experimentation activities and eventual end-to-end system implementations. The goal of these experimentation activities is to test and demonstrate key 5G developments in radio, edge and core networks in the context of PriMO-5G firefighting use cases. Furthermore, the deliverable has outlined the demonstration plans associated with each component or partially integrated system, as well as, the appropriate evaluation approaches within each demonstrator. These component demonstrations are carried out in either partner sites or high-profile external dissemination events identified in deliverable D6.2 Dissemination and exploitation plan [32].

The earlier project plans had envisioned the planning of the component demonstrations as the initial phase of the WP5 overall objectives, roughly corresponding to project months M4 (Oct 2018) - M12 (Jun 2019). The execution of these component testing and demonstration activities would then occur in the next phase, corresponding to months M13 (Jul 2019) - M23 (May 2020) to provide a foundation for planning for system integration. However, as noted in this report some of the project partners have succeeded in achieving some level of integration from components of different partners and the demonstrations over these testbeds will continue over the next few months of this second phase.

The follow-up deliverable D5.2 Intermediate report – Component demonstrations & System integration plan will report on the component demonstrations, as well as, some of the demonstrations from testbeds with early system integration. In cases where the partner components required further development and testing prior to system integration, the planning for those integration processes will also be described in deliverable D5.2. It is noted that the system integration referred to here is still confined to testbed sites in either Europe or Korea.

Finally, the third phase, corresponding to months M24 (Jun 2020) - M36 (Jun 2021) will target interconnection of PriMO-5G testbeds across the two continents and the demonstration of end-to-end immersive video services over this federated 5G network. This demo intends to showcase (i) the integration of radio access and core, and (ii) the core networks interoperability between 5G testbeds in EU and Korea. To that end, initial work has been carried out to setup a direct high-capacity connection between the testbed at Aalto University 5G network and the YU – KT 5G Open network. This cross-continental connection (see Figure 38) leverages a number of national research and education networks (NRENs) to meet the QoS and security requirements needed in cross-continental testbed experimentation.

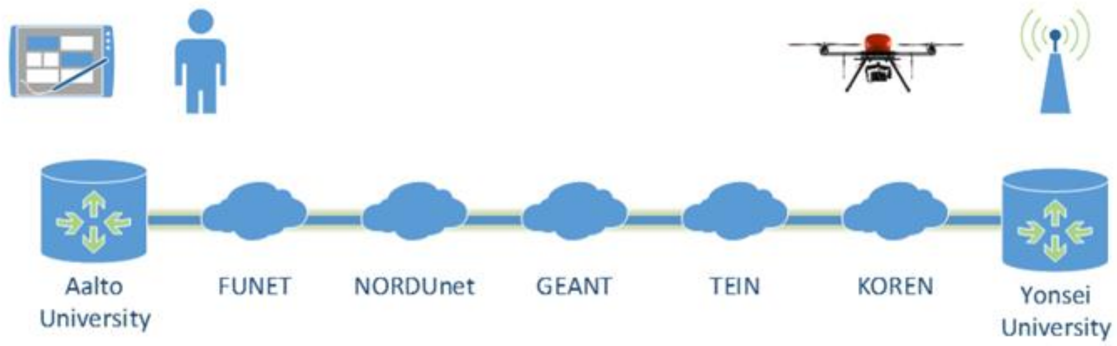

Figure 38 Cross-continental connection setup between Aalto University and Yonsei University (Note: FUNET – Finnish University and Research Network, TEIN - The Trans-Eurasia Information Network, KOREN - Korea Advanced Research Network)

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