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D5.2 - INTERMEDIATE REPORT - COMPONENT DEMONSTRATIONS & SYSTEM INTEGRATION PLAN

Work Package	WP5, Testbed and Demonstration
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Dissemination Level

☒ PU: Public
☐ PP: Restricted to other programme participants (including the Commission)
☐ RE: Restricted to a group specified by the consortium (including the Commission)
☐ CO: Confidential, only for members of the consortium (including the Commission)

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Disclaimer

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Executive Summary

The PriMO-5G project 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, namely: initial component and early (sub)system demonstrations. This is then followed by demonstration of systems based on integrated components from different partners, and finally intercontinental demonstrations based on end-to-end systems deployed between Europe and Korea.

This deliverable *D5.2 Intermediate Report – Component Demonstrations & System Integration Plan* reports on the component demonstrations, as well as, some of the demonstrations from testbeds with early system integration. The goal of these experimentation activities was to test and demonstrate key 5G developments in radio, edge and core networks in the context of PriMO-5G firefighting use cases according to the plan of preceding deliverable *D5.1 Demonstration Plan* [PRIMO-D51]. To that end, the deliverable D5.2 has provided the description of the demo for each component or partially integrated system, as well as, the evaluation results obtained from each demonstrator. These component demonstrations are carried out in either partner sites or high-profile external dissemination events mostly within the months M12 (June 2019) to M23 (May 2020). In some cases, the deliverable also described further developments of the components (beyond M23) to further enhance the components prior to system integration or redeploy the components for standalone demos.

Furthermore, deliverable D5.2 provides plans for system integration and demonstrations within the final year of the project, that is, from month M24 (Jun 2020) to M36 (Jun 2021). In this context, system integration planned may occur within confines of testbed sites in either Europe or Korea, connecting testbeds between two European countries (intracontinental integration) or then will target interconnection of PriMO-5G testbeds between Europe and Korea. In all cases, the end-to-end system demo scenarios have been specified and mapped to PriMO-5G firefighting scenarios and use cases of deliverable *D1.1 PriMO-5G Use Case Scenarios* [PRIMO-D11]. For each system integration and demo plan, the deliverable describes system components to be used, the timeline for the key integration and demo activities, and the description of individual demo scenarios. The reporting of the aforementioned system integration activities and demo scenarios will be provided in deliverable *D5.3 Final report – End-to-End Immersive Demonstrations* that is due at the end of the project in M36.

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 several partners from South Korea, who together are addressing objectives of the 'EUK-02-2018:5G' call in the area "a) Focus on mmWave and super broadband services". Specifically, the PriMO-5G project 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 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 Europe and Korea. 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.

The first phase, described above, was documented in the deliverable *D5.1 Demonstration Plan* [PRIMO-D51] in June 2019. Presently, the project is in the second phase. The purpose of this deliverable *D5.2 Intermediate Report - Component Demonstrations and Integration Plan* is threefold: (i) to provide documentation of the results of component demonstrations, (ii) to describe and showcase the demonstration activities resulting from on-going integration of continental demonstrations spanning multiple European partners or Korean partners, and finally (iii) to present a plan for an intercontinental system integration activity between Korean and European partners.

1.2 Structure of the document

Section 2 documents the component-level demonstration activities since D5.1 [PRIMO-D51]. In Section 3, we provide descriptions of the continental integration activities between multiple European partners and Korean partners. Finally, Section 4 presents our plans for the integration of the intercontinental PriMO-5G demonstration.

1.3 Relationship to other project outcomes

The overall work structure of PriMO-5G project 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. Thereafter, WP5 builds on outcomes of WP1-WP4 to develop component, local and cross-continental testbeds to demonstrate end-to-end operations of 5G system for PriMO-5G WP1 use cases.

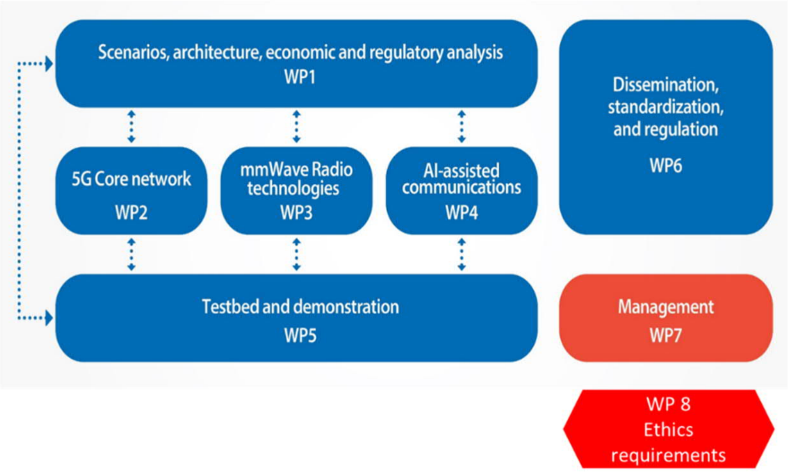
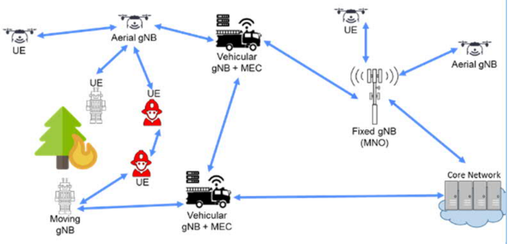
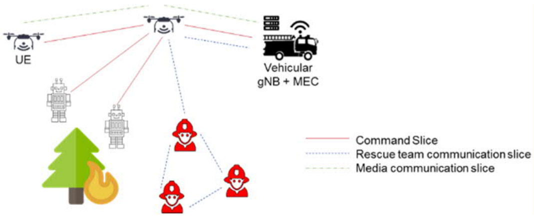
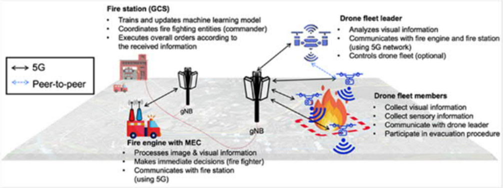
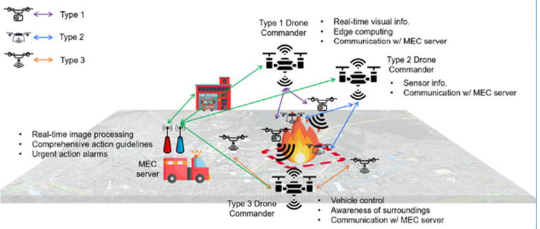


Figure 1: PriMO-5G work structure.

As noted previously, this deliverable presents a plan for end-to-end system demonstrations derived from 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 provides a summary description of the use cases that will be considered in the system and intercontinental demonstrators in Sections 3 and 4.

Table 1 PriMO-5G scenarios and use cases

Scenarios	Use cases	
Scenario A: Forest firefighting with robots and UAVs	*Use case A1. Placement of communication and computing for forest firefighting*  	*Use case A2. Network slice management for forest firefighting* 
Scenario B: Smart firefighting with UAVs in urban area	*Use case B1. UAV-assisted preparatory measures for smart urban firefighting*  	*Use Case B2. Differentiated UAV fleet management for smart urban firefighting* 

2 Review of Component and Initial System Demos

2.1 Overview

In this section, we provide documentation of the results from the component-level demonstrations that were described in detail in Section 3 of D5.1 [PRIMO-D51]. Therefore, also the structure of the Section 2 here follows the structuring in D5.1 [PRIMO-D51], i.e., demonstrations are categorized as European/Korean and underneath there are the individual demos. The section heading of each demonstration is identical to the one each partner had in Section 3 of D5.1 [PRIMO-D51] to facilitate comparison.

For each demonstration, a brief description is given (more details can be found in D5.1 [PRIMO-D51]) and the focus is on describing the continued evolution and obtained results of the demonstration since submission of D5.1 [PRIMO-D51], i.e., during project months M13-M23.

2.2 Demos from European partners

This section presents the results from the component-level demonstration activities from the European partners. Altogether, there are 8 demonstrations, and the section numbering below follows the one in Section 3.2 in D5.1 [PRIMO-D51].

2.2.1 Cell-free Ultra Dense Networks (UDN) demo by Aalto

Description of the demo

The Aalto demonstrator aims to study the feasibility of serving both aerial and ground UEs simultaneously. In the envisaged scenario, users are served by an ultra-dense user-centric network. Contrary to traditional architectures, user-centric networks do not require UEs to periodically interrupt data transmissions in order to perform neighbouring BS measurements, which are then reported to the serving BS. Instead, the network estimates the physical position of each user. Positioning relies on the UEs transmitting beacons for angle-of-arrival estimation. In the considered ultra-dense network scenario, it is assumed that line-of-sight conditions are prevalent between UEs and BSs. Serving drones requires tracking the position of both aerial and ground UEs simultaneously. Further information can be found in D5.1 [PRIMO-D51], Section 3.2.1.

The planned measurement campaign will assess the performance of receive-side 3D beamforming to estimate the position of both an aerial and a ground UE. The experiments will take place outdoors in an LoS environment. Comparing physical measurements of the UEs' locations with the computed estimates will help quantify the location tracking performance of the system. The measurement campaign is scheduled for the summer of 2020 for weather reasons.

Continued developments of the demo

Testbed development has continued since D5.1 [PRIMO-D51] to prepare for the measurement campaign. On the hardware side, platform capabilities have been expanded by increasing the antenna count from 4 in the pre-project proof-of-concept version to 16. Additionally, a networked control system has been developed to enable quasi-simultaneous recording from two or more receivers. Initial testing has taken place indoors. On the algorithmic side, work has been ongoing to extend a previous beamforming approach to support elevation estimation in addition to azimuthal estimation.

Evaluation report

Functional evaluation and integration of the new 16 antenna hardware has been completed. Figure 2 provides an illustration of the measurements carried out. It should be noted that these measurements were carried out indoors and are therefore not representative of the final measurement scenario.

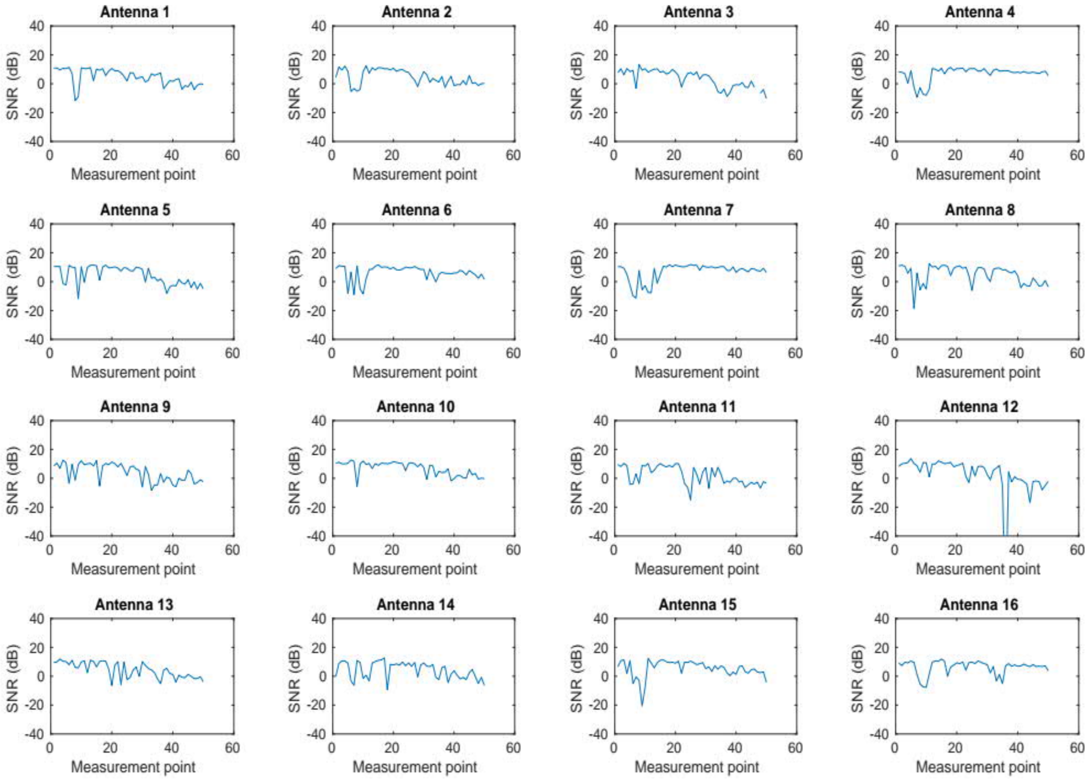


Figure 2: Per-antenna link SNR from preliminary channel measurements.

2.2.2 Real-time video broadcast demo by CMC

Description of the demo

The real-time broadcast demonstrates the streaming of live video from UAVs to mobile devices located in the same service area. The use case as shown in Figure 3 consists of UAV that streams live video uplink to the mobile packet core from where the video can be broadcasted downlink through the eMBMS system to all the mobile devices to receive live video and monitor the progress of the emergency situation.

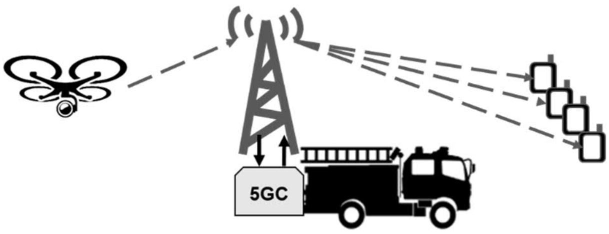


Figure 3: UAV-UE real time video broadcast.

The current demo uses 4G LTE radio for the uplink video streaming and 4G LTE radio for the downlink broadcast since eMBMS service specified in 5GC is still based on the 3GPP specifications Rel 13 that uses LTE radio. 3GPP has specified a new work item for media broadcast in next Rel 17. The UAV, as shown in Figure 3, consists of off the shelf drone with rPI (Raspberry Pi) that has video camera connected and LTE USB dongle for the video streaming to the mobile packet core.

Figure 4: UAV with rPI, LTE USB dongle and video camera.

The radio access consists of commercial base station operating Band 7, 2.6GHz configured with eMBMS service and using a single service area for broadcasting the uplink stream from the UAV.

Figure 5: Base station with eMBMS configuration.

The system includes a packet core by Cumucore (CMC), which runs in Linux Ubuntu 18.04, AMD Quad Core, 3 NICs 1Gbs, 2MB Ram, 1TB HDD and supports 4G and 5G both NSA and SA shown Figure 6. The packet core and base station use Trimble Grand Master for phase synchronization that is required for eMBMS service as shown in Figure 6.

Figure 6: Linux server running 4G/5G core and Trimble Grand Master.

The broadcast session will be received in commercial devices that include eMBMS support such as Bittium mobile phones as shown in Figure 7 that complies with MIL-STD-810G shock,drop resistant and IP67 water and dust resistant specifications.

Figure 7: Mobile device broadcast video playback.

The demo was successful and demoed in EuCNC 19 as well as for other customers that require eMBMS for critical communications.

Continued developments of the demo

The demo will include 5G NR for the uplink video streaming from the UAV to the eMBMS system in order to improve the quality of the live video.

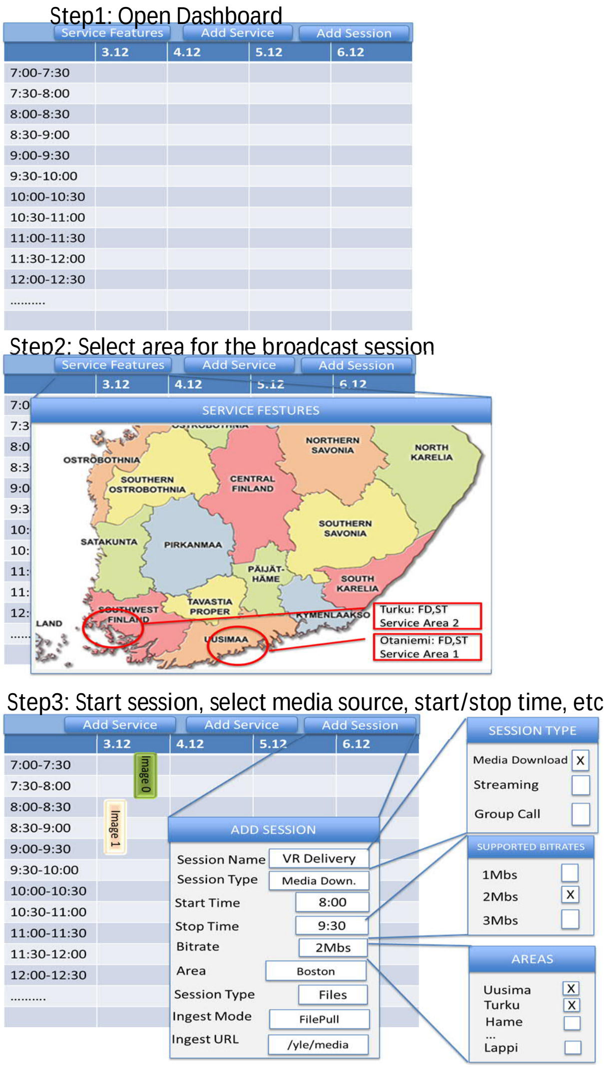
Evaluation report

The measurements of packet delay from the media source to the playback varies between 0.5-1sec and most of the delay is added by the eMBMS GW which has to buffer the incoming packets before can be broadcasted by the base station.

2.2.3 UAV-UE video broadcast demo by CMC

Description of the demo

This demo uses similar equipment as the real-time video broadcast, but streaming is not real time. Instead this demo uses the new xMB interface defined in 3GPP that allow broadcasters to schedule the session, select the service area and the content for broadcasting. In this demo we select static file as media source for the broadcast. This use case, as depicted in Figure 8, uses the xMB interface with graphical interface as shown in for managing the broadcast session. With the xMB the media broadcaster can schedule a session as shows step 1 and the service area or geographical scope for the broadcast, as Figure 8 shows in step 2. Finally, the broadcaster selects the source for the broadcast session in step 3 and the bandwidth required as well as the start-stop time when the broadcasting will take place.



Step1: Open Dashboard

Step2: Select area for the broadcast session

Turku: FD,ST Service Area 2

Otaniemi: FD,ST Service Area 1

Step3: Start session, select media source, start/stop time, etc

ADD SESSION
Session Name: VR Delivery
Session Type: Media Down.
Start Time: 8:00
Stop Time: 9:30
Bitrate: 2Mbs
Area: Boston
Session Type: Files
Ingest Mode: FilePull
Ingest URL: /yle/media

SESSION TYPE
Media Download ☒
Streaming ☐
Group Call ☐

SUPPORTED BITRATES
1Mbs ☐
2Mbs ☒
3Mbs ☐

AREAS
Uusima ☒
Turku ☒
Hame ☐
...
Lappi ☐

Figure 8: Graphical interface on xMB for media broadcast.

Continued developments of the demo

No further enhancements will be added to this demo since 3GPP Rel 17 has included a new work item for incorporating media broadcast as part of 5G system. Thus, after 3GPP Rel 17 is completed we will investigate the new technology and components required for extending current system to become 3GPP compliant with 5G.

Evaluation report

The current eMBMS system when used for streaming non-real time video file results in 4-5 seconds delay.

2.2.4 5G network slicing demo by CMC

Description of the demo

The network slicing demo was performed for separating traffic from NB-IOT devices. NB-IOT traffic is unpredictable, which might cause a collapse of the mobile network. The motivation for using network slicing in specific cases like IoT sensors is because traffic would be unpredictable due to burst communication from large number of sensors. Thus, there is no effective network solution which ensures communication dynamic traffic isolation. Currently there is no comprehensive solution that allows dynamically manage network slicing in mobile networks. In this demo we deployed network slicing based on the integration of SDN in the mobile backhaul. SDN will be integrated in the network edge to deliver network slicing and isolate traffic from various applications and allows sharing existing mobile infrastructure with different service providers. The demo setup consists of Linux server with Ubuntu 16.04 or later with 8GB RAM and 20GB Disk running a 4G/5G packet core by CMC together with SDN switches connected to the eNBs with OpenFLOW support as shown in Figure 9.

Figure 9: Linux servers with packet core in red and SDN switches in blue and gray boxes.

We use commercial eNB with NB-IOT support on 1800MHz as shown in Figure 10.

Figure 10: Commercial eNB with NB-IOT configuration in 1.8GHz

As end devices we use 10 Arduino 10+ NB-IOT sensors with slot for inserting nano-SIM, provided by CMC, as shown in Figure 11.

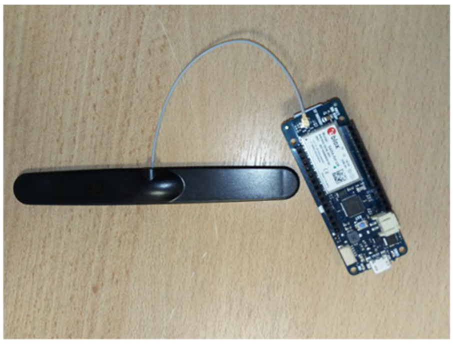


Figure 11: NB-IOT devices.

Continued developments of the demo

This demo will not be developed further since 3GPP Rel 17 has included a new work item related to enhancements of NB-IOT for 5G systems. Thus, we will evaluated the required new modules defined in Rel 17 in order to continue supporting NB-IOT in our 5G system.

Evaluation report

In the demo we defined three network slices with different bandwidth and the results show that devices were assigned to different network slices based on the SIM information. The measurements are captured in real time showing that devices assigned to slice with low bandwidth do not have a reliable data communication. The graphs show that the sensors that have been allocated to a low priority slice have higher packet loss and longer delays than sensors allocated to high priority slice, as shown Figure 12.

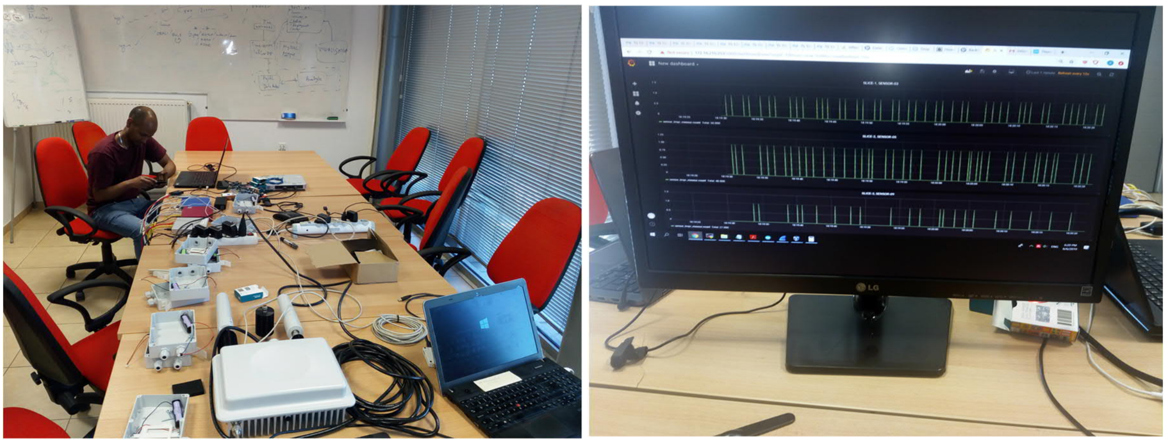


Figure 12: Demo setup and performance results.

2.2.5 MEC orchestrator demo by CMC

Description of the demo

This demo demonstrates the usage of Service Based Architecture (SBA) defined in 3GPP for 5G networks. The SBA allows to deploy different network functions in separate locations if they are connected through IP network. In this demo we deploy different instances of the UPF network function in different location. This demo was deployed as part of the intercontinental setup. It showed that, despite the long connection between Finland and Korea, network functions can be deployed in separate countries, which showcases the usage of Service Based Architecture (SBA) defined in 3GPP for 5G.

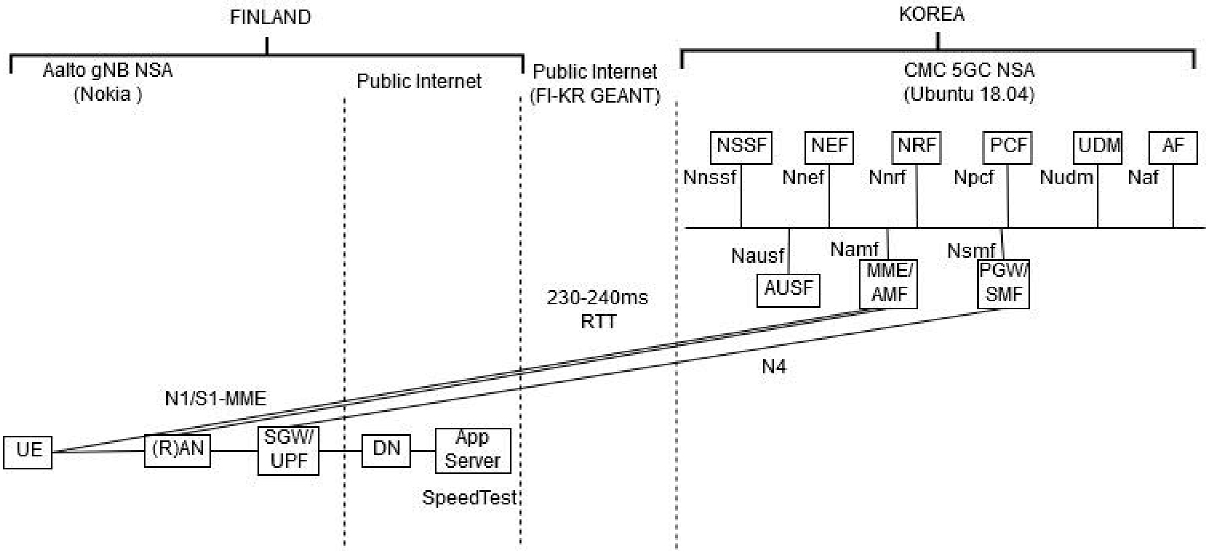


Figure 13: Setup to demo MEC based on 5G SBA.

Continued developments of the demo

This demo will continue in order to test other network functions that in addition to MEC can deploy network slices.

Evaluation report

The results of the intercontinental testing showed that the delay for the control plane between the 5G base station and the core in Korea was about 250ms but the delay for the data plane from the mobile device to the public Internet through the local gateway was 6ms. Thus, the signaling was performed between the base station and the mobile core in Korea separated over 7.000km and 230ms delay. However, the user plane was handled between the base station and the UPF deployed close to the base station resulting in 6ms delay and 284Mbps for 60MHz bandwidth used in the 5G base station as shown in Figure 14.

03/12/19, 11.55

DOWNLOAD
284
Mbps
Data used
464 MB

UPLOAD
11,6
Mbps
Data used
15,1 MB

PING
6
ms

JITTER
3
ms

PACKET LOSS
0,3
%

Connections
Multi

Elisa Oyj
Helsinki

CMCC

User Location
Lat: 60,1864 Lon: 24,8163

Internal IP: 10.200.1.1
External IP: 195.148.124.248

Figure 14: Speed test measurements with local UPF.

2.2.6 5G NR transceiver demo by NI

NI has been working with three demos: (i) Vertical 5G NR UE stack integration demo, (ii) IP data transmission over 5G NR gNB + UE PAL (PHY abstraction layer) setup , and (iii) mmWave Component Demo. These are described each in their own subsection.

Vertical 5G NR UE stack integration demo

Description of the demo

Scope of this component demo is to demonstrate the vertical stack integration of NI's FPGA-based 5G NR PHY layer with the 3rd party 5G NR protocol layer. Testing the vertically integrated NI 5G NR UE stack against a gNB emulator is the main idea of this component demo. Figure 15 shows how the setup for this component demo looks like. The gNB emulator consists of a real-time playback of 5G NR DL signals with pre-generated content. Those 5G NR DL signals are received, demodulated and decoded in real-time by the NI 5G NR UE stack, which has been configured via 3GPP-compliant RRC test vector injection. In the component demo, the random access procedure is executed according to the methodology described above and data transmission/reception is shown at the UE while in RRC_CONNECTED state.

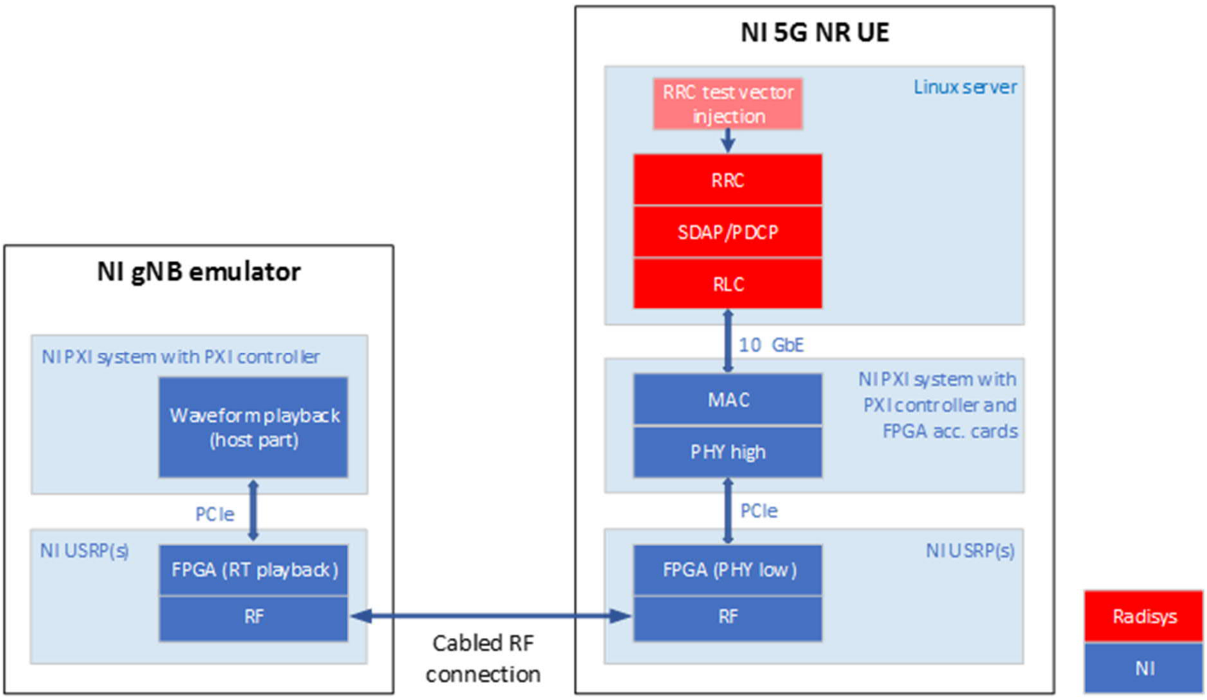


Figure 15: Setup for vertical 5G NR UE stack integration demo

Continued developments of the demo

During the reporting period, all the hardware and software components became available and are functional. Integration of the components started and first integration tests passed. The outcome of this demo serves as baseline for further enhancements of the system towards a complete system consisting of RF, physical layer and protocol stack (MAC, RLC, PDCP, RRC) components and will lead into final mmWave transceiver demo together with the outcome of the component demo described in the mmWave Component Demo section.

Evaluation report

Figure 16 shows a screenshot of the GUI for the 5GNR test UE once the integration has been finished and the system is in RRC_CONNECTED state and ready for data transfer. The current system for this component demo is based on frequencies below 6 GHz.

5GNR Test UE

UE connection
IPv4 169.254.134.2
state Connected

Cell ID 0
E-ARFCN 0

L1 Measurements

RSSI	RSRP	SINR
-72.08 dBm	-72.08 dBm	38.88 dB

Throughput

PDCP	MAC	PHY CRC	PHY grant
0.00bit/s	0.00bit/s	13.2Mbit/s	0.00bit/s

BLER 0.00000

RX constellation 0 CC 0 Antenna port 17 slot 2 symbol PDSCH channel

EVM -34.42 dB
EVM 0.00 dB
EVM 0.00 dB
EVM 0.00 dB

☑ show reference

System state Connected
NR RRC state Connected

Figure 16: 5G NR Test UE in connected mode reaching PDSCH throughput of 13.2 Mbit/s

IP data transmission over 5G NR gNB + UE PAL setup

Description of the demo

Scope of this demo is to demonstrate an end-to-end IP-layer based data transmission over horizontally integrated 5G NR gNB and 5G NR UE protocol stacks. For this demo the higher layer protocol components of the selected 3rd party protocol provider are used and integrated. The physical layer is abstracted by a so-called PHY abstraction layer (PAL). A simple 5G core network (5GC) from the 3rd party protocol stack provider is used to setup and control the connection through gNB and UE stack. The overall demo setup is shown in Figure 17. The system used consists of the 5G core network (5GC) components “User Plane Function” (UPF), “Session Management Function” (SMF) and “Access and Mobility Management Function” (AMF) running on a server machine. The gNB consists of a Supermicro server machine running the Central Unit (CU) and another Supermicro server machine running the Distributed Unit (DU). All these machines are connected via 1Gbps ethernet to control the components, and via 10Gbps ethernet for traffic. The UE stack is running on the same machine as the DU. An application server connected to the 5GC machine is used which acts as the counterpart of the UE for the IP data transmission. Initially the data transmissions are performed with iperf running in server and client mode on the application server and the UE respectively and vice versa for demonstrating uplink and downlink. The demo is configured to demonstrate a 5G NR mmWave mode using a downlink centric TDD scheme.

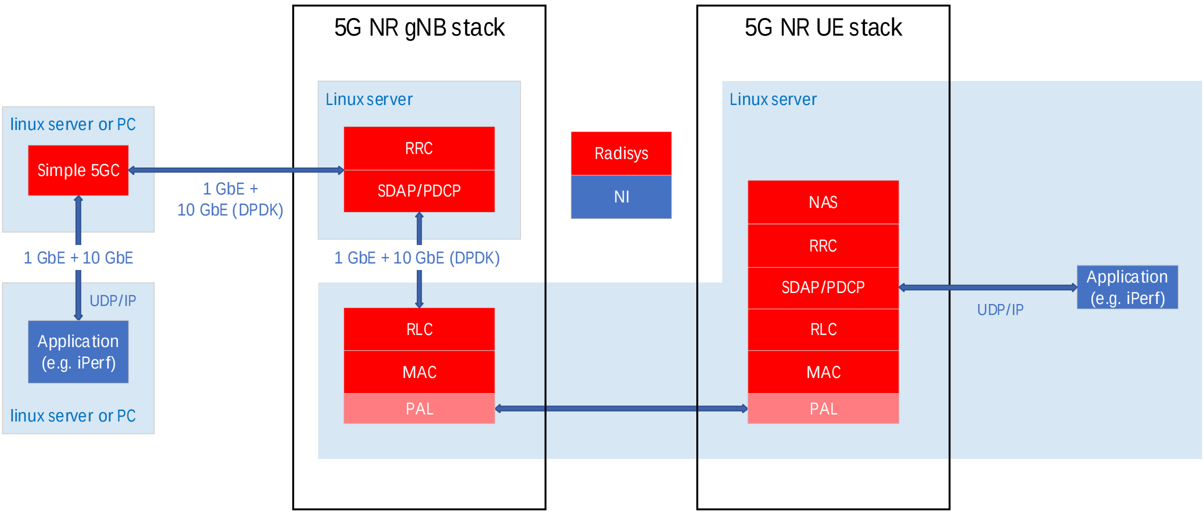


Figure 17: Overview of 5G NR gNB + UE PAL setup

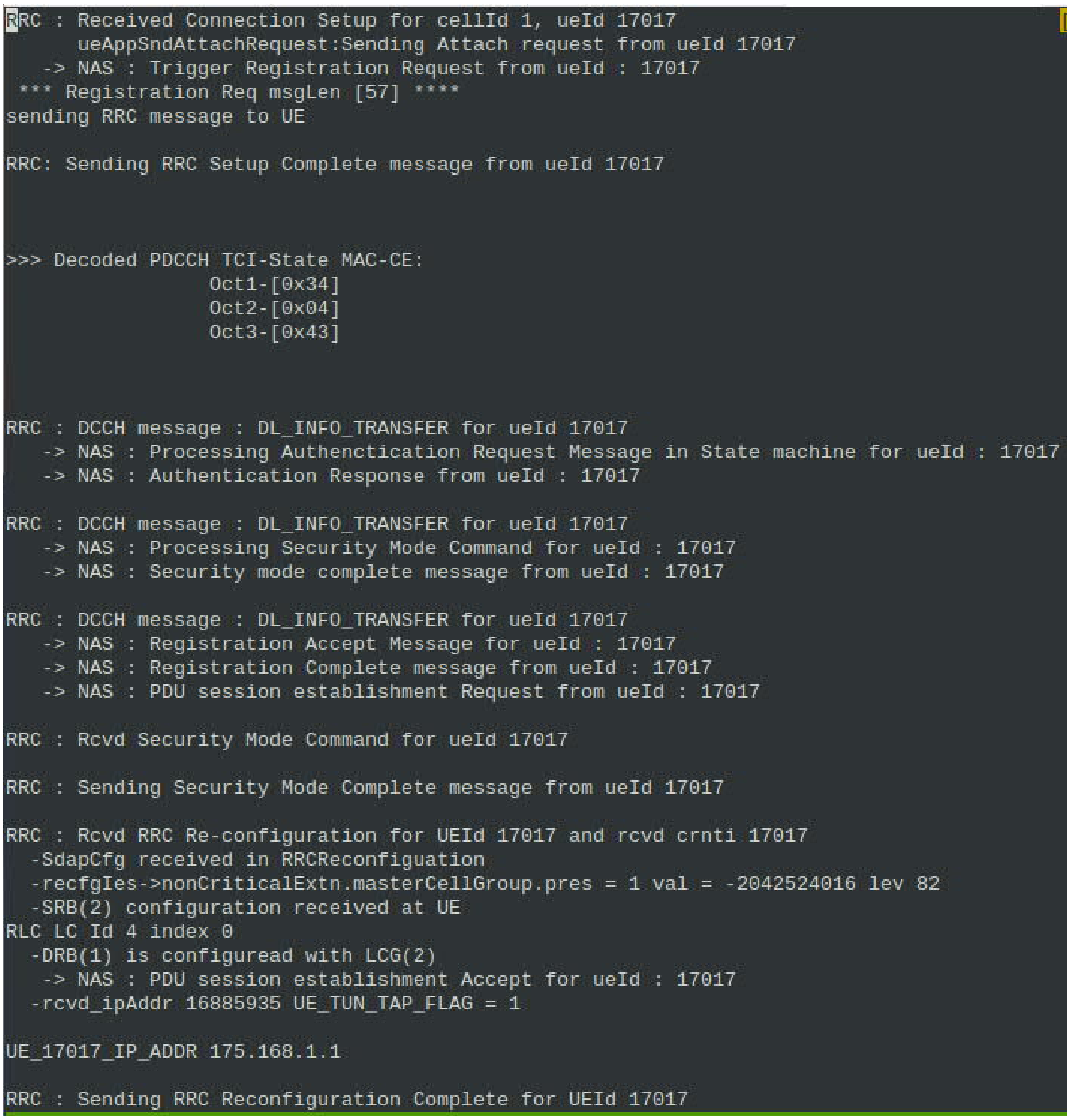
Continued developments of the demo

During the reporting period, the hardware and software components became available and are functional. NI finished the hardware setup and the overall software integration and test.

The outcome of this demo serves as baseline system for the integration with the 5G core network from partner CMC.

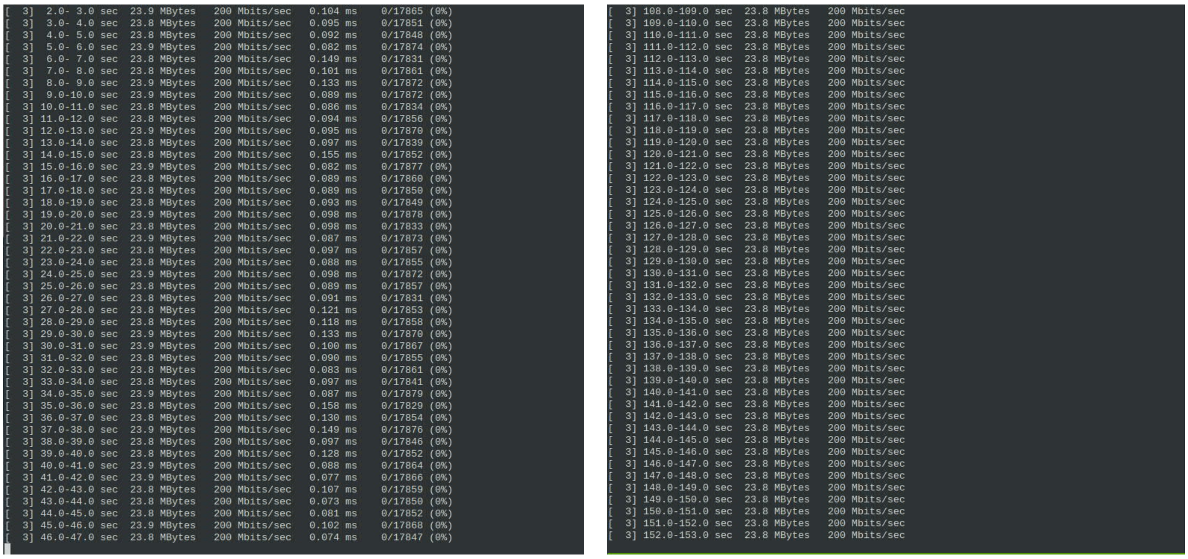
Evaluation report

The UE simulator can attach to the gNB as visible in Figure 18. IP traffic from the application server towards the UE and vice versa works with a throughput of approximately 1.1Gbps in the downlink and about 200Mbps in the uplink. Figure 19 and Figure 20 show the uplink and downlink performance measured with iperf.



```
RRC : Received Connection Setup for cellId 1, ueId 17017
      ueAppSndAttachRequest:Sending Attach request from ueId 17017
   -> NAS : Trigger Registration Request from ueId : 17017
 *** Registration Req msgLen [57] ****
sending RRC message to UE

RRC: Sending RRC Setup Complete message from ueId 17017



>>> Decoded PDCCH TCI-State MAC-CE:
                 Oct1-[0x34]
                 Oct2-[0x04]
                 Oct3-[0x43]



RRC : DCCH message : DL_INFO_TRANSFER for ueId 17017
   -> NAS : Processing Authenctication Request Message in State machine for ueId : 17017
   -> NAS : Authentication Response from ueId : 17017

RRC : DCCH message : DL_INFO_TRANSFER for ueId 17017
   -> NAS : Processing Security Mode Command for ueId : 17017
   -> NAS : Security mode complete message from ueId : 17017

RRC : DCCH message : DL_INFO_TRANSFER for ueId 17017
   -> NAS : Registration Accept Message for ueId : 17017
   -> NAS : Registration Complete message from ueId : 17017
   -> NAS : PDU session establishment Request from ueId : 17017

RRC : Rcvd Security Mode Command for ueId 17017

RRC : Sending Security Mode Complete message from ueId 17017

RRC : Rcvd RRC Re-configuration for UEId 17017 and rcvd crnti 17017
  -SdapCfg received in RRCReconfiguation
  -recfgIes->nonCriticalExtn.masterCellGroup.pres = 1 val = -2042524016 lev 82
  -SRB(2) configuration received at UE
RLC LC Id 4 index 0
  -DRB(1) is configuread with LCG(2)
   -> NAS : PDU session establishment Accept for ueId : 17017
  -rcvd_ipAddr 16885935 UE_TUN_TAP_FLAG = 1

UE_17017_IP_ADDR 175.168.1.1

RRC : Sending RRC Reconfiguration Complete for UEId 17017
```

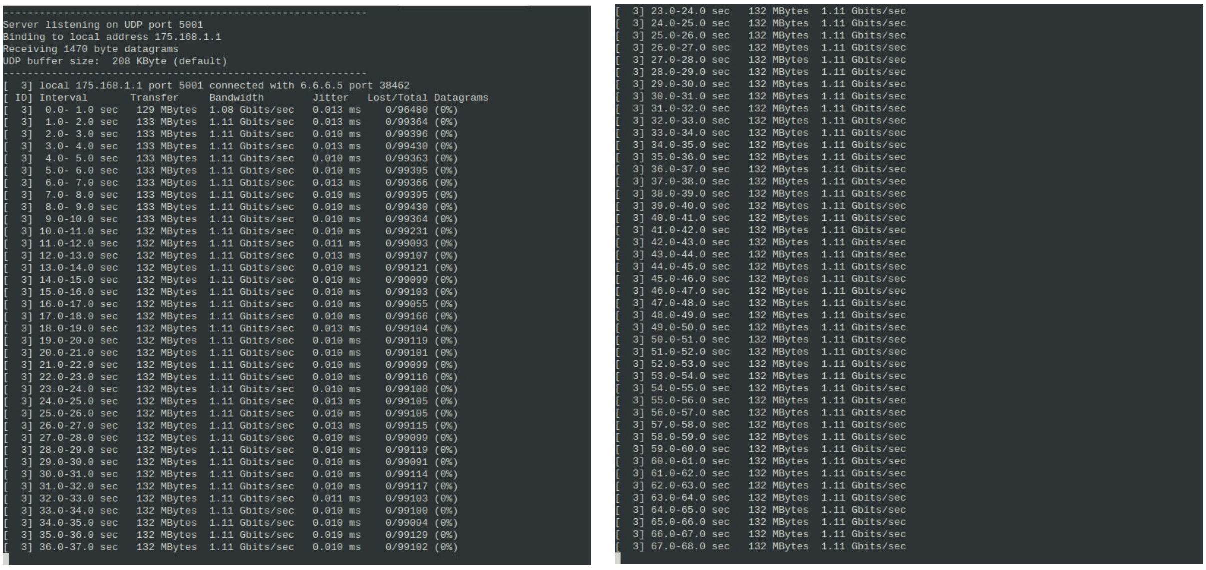
Figure 18: UE simulator attach procedure console output



```
[  3]  2.0- 3.0 sec  23.9 MBytes   200 Mbits/sec   0.104 ms    0/17865 (0%)
[  3]  3.0- 4.0 sec  23.8 MBytes   200 Mbits/sec   0.095 ms    0/17851 (0%)
[  3]  4.0- 5.0 sec  23.8 MBytes   200 Mbits/sec   0.092 ms    0/17848 (0%)
[  3]  5.0- 6.0 sec  23.9 MBytes   200 Mbits/sec   0.082 ms    0/17874 (0%)
[  3]  6.0- 7.0 sec  23.8 MBytes   200 Mbits/sec   0.149 ms    0/17831 (0%)
[  3]  7.0- 8.0 sec  23.8 MBytes   200 Mbits/sec   0.101 ms    0/17861 (0%)
[  3]  8.0- 9.0 sec  23.9 MBytes   200 Mbits/sec   0.133 ms    0/17872 (0%)
[  3]  9.0-10.0 sec  23.9 MBytes   200 Mbits/sec   0.089 ms    0/17872 (0%)
[  3] 10.0-11.0 sec  23.8 MBytes   200 Mbits/sec   0.086 ms    0/17834 (0%)
[  3] 11.0-12.0 sec  23.8 MBytes   200 Mbits/sec   0.094 ms    0/17856 (0%)
[  3] 12.0-13.0 sec  23.9 MBytes   200 Mbits/sec   0.095 ms    0/17870 (0%)
[  3] 13.0-14.0 sec  23.8 MBytes   200 Mbits/sec   0.097 ms    0/17839 (0%)
[  3] 14.0-15.0 sec  23.8 MBytes   200 Mbits/sec   0.155 ms    0/17852 (0%)
[  3] 15.0-16.0 sec  23.9 MBytes   200 Mbits/sec   0.082 ms    0/17877 (0%)
[  3] 16.0-17.0 sec  23.8 MBytes   200 Mbits/sec   0.089 ms    0/17860 (0%)
[  3] 17.0-18.0 sec  23.8 MBytes   200 Mbits/sec   0.089 ms    0/17850 (0%)
[  3] 18.0-19.0 sec  23.8 MBytes   200 Mbits/sec   0.093 ms    0/17849 (0%)
[  3] 19.0-20.0 sec  23.9 MBytes   200 Mbits/sec   0.098 ms    0/17878 (0%)
[  3] 20.0-21.0 sec  23.8 MBytes   200 Mbits/sec   0.098 ms    0/17833 (0%)
[  3] 21.0-22.0 sec  23.9 MBytes   200 Mbits/sec   0.087 ms    0/17873 (0%)
[  3] 22.0-23.0 sec  23.8 MBytes   200 Mbits/sec   0.097 ms    0/17857 (0%)
[  3] 23.0-24.0 sec  23.8 MBytes   200 Mbits/sec   0.088 ms    0/17855 (0%)
[  3] 24.0-25.0 sec  23.9 MBytes   200 Mbits/sec   0.098 ms    0/17872 (0%)
[  3] 25.0-26.0 sec  23.8 MBytes   200 Mbits/sec   0.089 ms    0/17857 (0%)
[  3] 26.0-27.0 sec  23.8 MBytes   200 Mbits/sec   0.091 ms    0/17831 (0%)
[  3] 27.0-28.0 sec  23.8 MBytes   200 Mbits/sec   0.121 ms    0/17853 (0%)
[  3] 28.0-29.0 sec  23.8 MBytes   200 Mbits/sec   0.118 ms    0/17858 (0%)
[  3] 29.0-30.0 sec  23.9 MBytes   200 Mbits/sec   0.133 ms    0/17870 (0%)
[  3] 30.0-31.0 sec  23.9 MBytes   200 Mbits/sec   0.100 ms    0/17867 (0%)
[  3] 31.0-32.0 sec  23.8 MBytes   200 Mbits/sec   0.090 ms    0/17855 (0%)
[  3] 32.0-33.0 sec  23.8 MBytes   200 Mbits/sec   0.083 ms    0/17861 (0%)
[  3] 33.0-34.0 sec  23.8 MBytes   200 Mbits/sec   0.097 ms    0/17841 (0%)
[  3] 34.0-35.0 sec  23.9 MBytes   200 Mbits/sec   0.087 ms    0/17879 (0%)
[  3] 35.0-36.0 sec  23.8 MBytes   200 Mbits/sec   0.158 ms    0/17829 (0%)
[  3] 36.0-37.0 sec  23.8 MBytes   200 Mbits/sec   0.130 ms    0/17854 (0%)
[  3] 37.0-38.0 sec  23.9 MBytes   200 Mbits/sec   0.149 ms    0/17876 (0%)
[  3] 38.0-39.0 sec  23.8 MBytes   200 Mbits/sec   0.097 ms    0/17846 (0%)
[  3] 39.0-40.0 sec  23.8 MBytes   200 Mbits/sec   0.128 ms    0/17852 (0%)
[  3] 40.0-41.0 sec  23.9 MBytes   200 Mbits/sec   0.088 ms    0/17864 (0%)
[  3] 41.0-42.0 sec  23.9 MBytes   200 Mbits/sec   0.077 ms    0/17866 (0%)
[  3] 42.0-43.0 sec  23.8 MBytes   200 Mbits/sec   0.107 ms    0/17859 (0%)
[  3] 43.0-44.0 sec  23.8 MBytes   200 Mbits/sec   0.073 ms    0/17850 (0%)
[  3] 44.0-45.0 sec  23.8 MBytes   200 Mbits/sec   0.081 ms    0/17852 (0%)
[  3] 45.0-46.0 sec  23.9 MBytes   200 Mbits/sec   0.102 ms    0/17868 (0%)
[  3] 46.0-47.0 sec  23.8 MBytes   200 Mbits/sec   0.074 ms    0/17847 (0%)
```

```
[  3] 108.0-109.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 109.0-110.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 110.0-111.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 111.0-112.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 112.0-113.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 113.0-114.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 114.0-115.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 115.0-116.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 116.0-117.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 117.0-118.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 118.0-119.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 119.0-120.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 120.0-121.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 121.0-122.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 122.0-123.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 123.0-124.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 124.0-125.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 125.0-126.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 126.0-127.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 127.0-128.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 128.0-129.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 129.0-130.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 130.0-131.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 131.0-132.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 132.0-133.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 133.0-134.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 134.0-135.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 135.0-136.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 136.0-137.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 137.0-138.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 138.0-139.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 139.0-140.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 140.0-141.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 141.0-142.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 142.0-143.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 143.0-144.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 144.0-145.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 145.0-146.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 146.0-147.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 147.0-148.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 148.0-149.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 149.0-150.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 150.0-151.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 151.0-152.0 sec  23.8 MBytes   200 Mbits/sec
[  3] 152.0-153.0 sec  23.8 MBytes   200 Mbits/sec
```

Figure 19: Uplink traffic with iperf on the application server (left) and the UE (right)



```
------------------------------------------------------------
Server listening on UDP port 5001
Binding to local address 175.168.1.1
Receiving 1470 byte datagrams
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 175.168.1.1 port 5001 connected with 6.6.6.5 port 38462
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  3]  0.0- 1.0 sec   129 MBytes  1.08 Gbits/sec   0.013 ms    0/96480 (0%)
[  3]  1.0- 2.0 sec   133 MBytes  1.11 Gbits/sec   0.013 ms    0/99364 (0%)
[  3]  2.0- 3.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99396 (0%)
[  3]  3.0- 4.0 sec   133 MBytes  1.11 Gbits/sec   0.013 ms    0/99430 (0%)
[  3]  4.0- 5.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99363 (0%)
[  3]  5.0- 6.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99395 (0%)
[  3]  6.0- 7.0 sec   133 MBytes  1.11 Gbits/sec   0.013 ms    0/99366 (0%)
[  3]  7.0- 8.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99395 (0%)
[  3]  8.0- 9.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99430 (0%)
[  3]  9.0-10.0 sec   133 MBytes  1.11 Gbits/sec   0.010 ms    0/99364 (0%)
[  3] 10.0-11.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99231 (0%)
[  3] 11.0-12.0 sec   132 MBytes  1.11 Gbits/sec   0.011 ms    0/99093 (0%)
[  3] 12.0-13.0 sec   132 MBytes  1.11 Gbits/sec   0.013 ms    0/99107 (0%)
[  3] 13.0-14.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99121 (0%)
[  3] 14.0-15.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99099 (0%)
[  3] 15.0-16.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99103 (0%)
[  3] 16.0-17.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99055 (0%)
[  3] 17.0-18.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99166 (0%)
[  3] 18.0-19.0 sec   132 MBytes  1.11 Gbits/sec   0.013 ms    0/99104 (0%)
[  3] 19.0-20.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99119 (0%)
[  3] 20.0-21.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99101 (0%)
[  3] 21.0-22.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99099 (0%)
[  3] 22.0-23.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99116 (0%)
[  3] 23.0-24.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99108 (0%)
[  3] 24.0-25.0 sec   132 MBytes  1.11 Gbits/sec   0.013 ms    0/99105 (0%)
[  3] 25.0-26.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99105 (0%)
[  3] 26.0-27.0 sec   132 MBytes  1.11 Gbits/sec   0.013 ms    0/99115 (0%)
[  3] 27.0-28.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99099 (0%)
[  3] 28.0-29.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99119 (0%)
[  3] 29.0-30.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99091 (0%)
[  3] 30.0-31.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99114 (0%)
[  3] 31.0-32.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99117 (0%)
[  3] 32.0-33.0 sec   132 MBytes  1.11 Gbits/sec   0.011 ms    0/99103 (0%)
[  3] 33.0-34.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99100 (0%)
[  3] 34.0-35.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99094 (0%)
[  3] 35.0-36.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99129 (0%)
[  3] 36.0-37.0 sec   132 MBytes  1.11 Gbits/sec   0.010 ms    0/99102 (0%)
```

```
[  3] 23.0-24.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 24.0-25.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 25.0-26.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 26.0-27.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 27.0-28.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 28.0-29.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 29.0-30.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 30.0-31.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 31.0-32.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 32.0-33.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 33.0-34.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 34.0-35.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 35.0-36.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 36.0-37.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 37.0-38.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 38.0-39.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 39.0-40.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 40.0-41.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 41.0-42.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 42.0-43.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 43.0-44.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 44.0-45.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 45.0-46.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 46.0-47.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 47.0-48.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 48.0-49.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 49.0-50.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 50.0-51.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 51.0-52.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 52.0-53.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 53.0-54.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 54.0-55.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 55.0-56.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 56.0-57.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 57.0-58.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 58.0-59.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 59.0-60.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 60.0-61.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 61.0-62.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 62.0-63.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 63.0-64.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 64.0-65.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 65.0-66.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 66.0-67.0 sec   132 MBytes  1.11 Gbits/sec
[  3] 67.0-68.0 sec   132 MBytes  1.11 Gbits/sec
```

Figure 20: Downlink traffic with iperf on the UE (left) and the application server (right)

mmWave Component Demo

Description of the demo

The purpose of this demo is to show the performance of the individual mmWave components. This separated performance analysis will give insight into which overall system performance to be expected. Figure 21 shows the underlaying RF architecture consisting of a Universal Software Radio Peripheral (USRP), a separate mixer that can be used as upconverter as well as downconverter and an active antenna array.

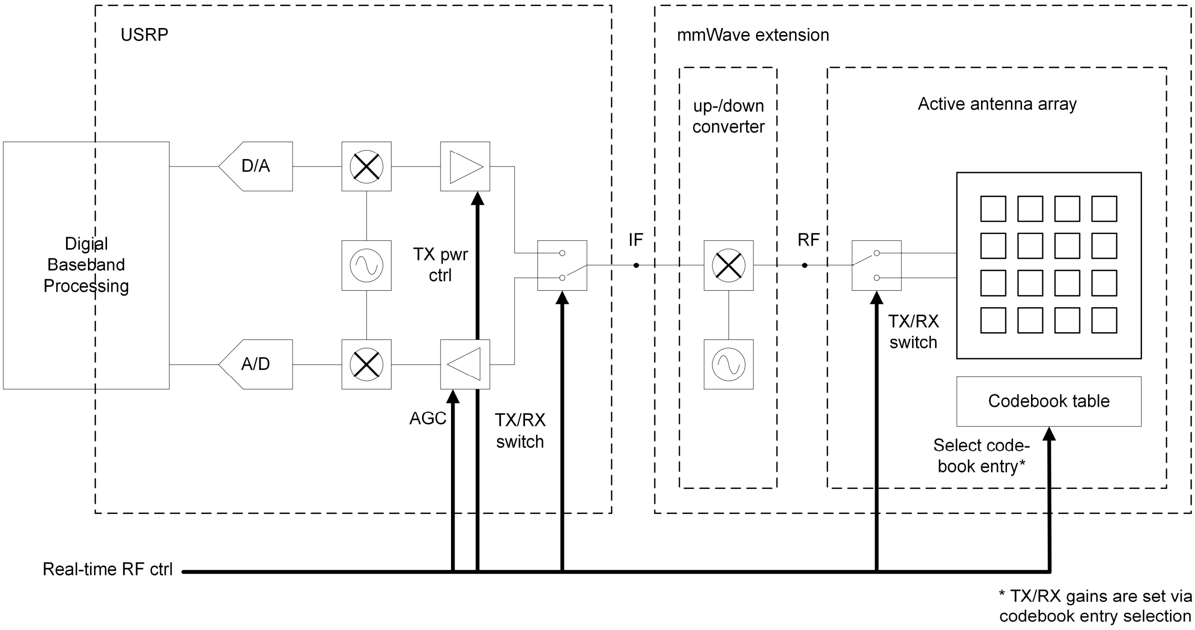


Figure 21: RF architecture in NI mmWave demo

Figure 21 shows the setup used to conduct performance measurements such as EVM, SEM measurements. All RF measurements have been taken while radiating signals over the air

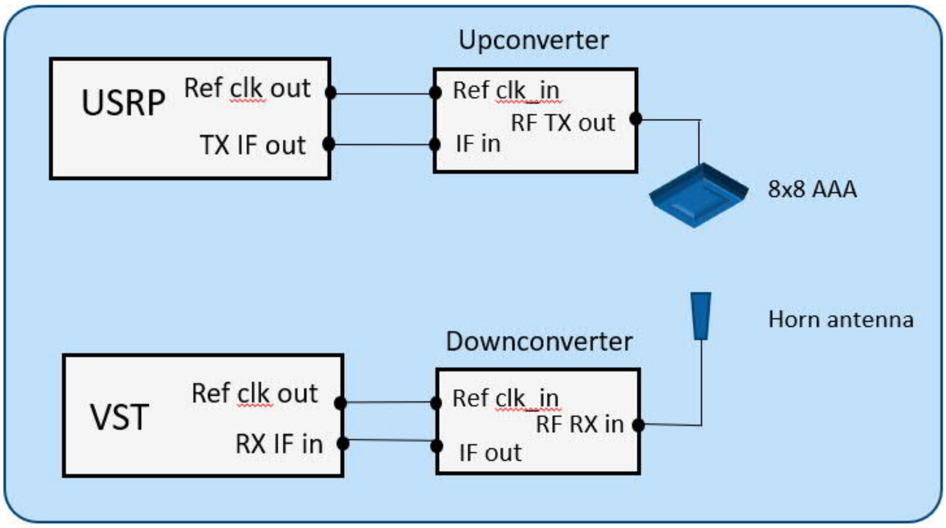


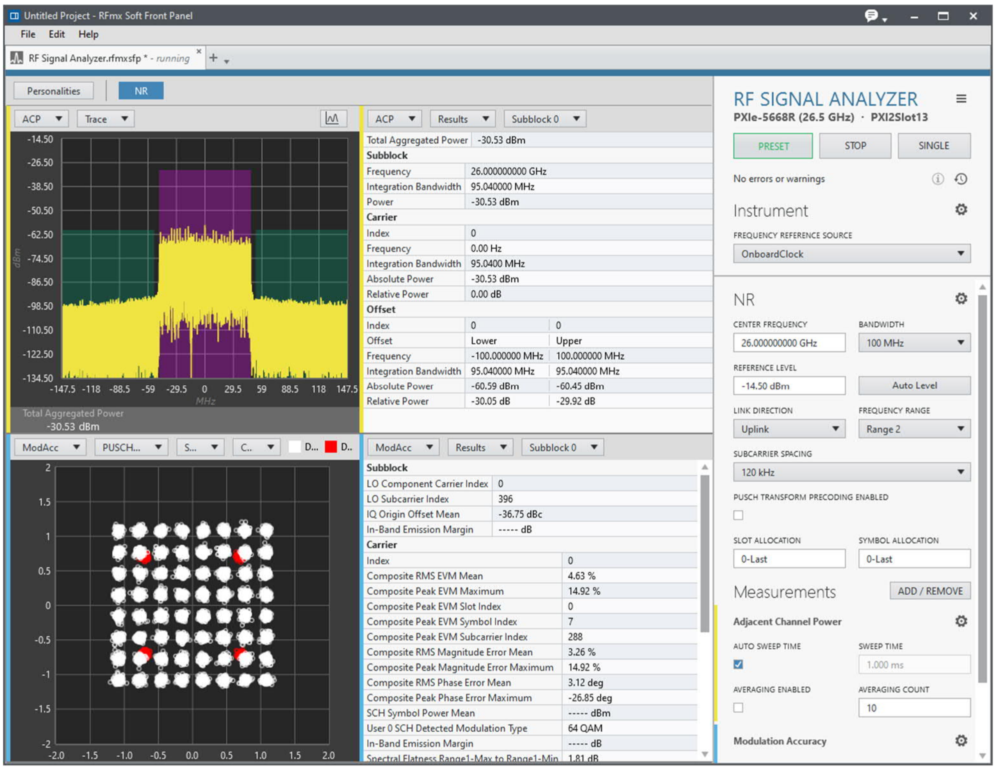
Figure 22: Measurement setup in NI mmWave demo

Continued developments of the demo

Since the last reporting period, considerable amount of progress has been made: All the necessary mmWave components became available, the measurement setup has been established and the integration of the mmWave components into the PHY subsystem has been started. The current component demo can be seen as a development snapshot. The outcome of this demo serves as baseline for further enhancements of the system towards a complete system consisting of RF, physical layer, and protocol stack (MAC, RLC, PDCP, RRC) components and will lead into final mmWave transceiver demo.

Evaluation report

Figure 23 shows the EVM performance measured over the air. The system has been parametrized as follows: IF = 2 GHz, RF = 26 GHz, component carrier bandwidth = 100 MHz, subcarrier spacing = 120 kHz, 64QAM as modulation scheme and the usage of PTRS has been enabled. A measured averaged EVM of approximately 4% would allow the usage of 64QAM as modulation scheme.



Total Aggregated Power	-30.53 dBm	
Subblock		
Frequency	26.000000000 GHz	
Integration Bandwidth	95.040000 MHz	
Power	-30.53 dBm	
Carrier		
Index	0	
Frequency	0.00 Hz	
Integration Bandwidth	95.0400 MHz	
Absolute Power	-30.53 dBm	
Relative Power	0.00 dB	
Offset		
Index	0	0
Offset	Lower	Upper
Frequency	-100.000000 MHz	100.000000 MHz
Integration Bandwidth	95.040000 MHz	95.040000 MHz
Absolute Power	-60.59 dBm	-60.45 dBm
Relative Power	-30.05 dB	-29.92 dB

Subblock	
LO Component Carrier Index	0
LO Subcarrier Index	396
IQ Origin Offset Mean	-36.75 dBc
In-Band Emission Margin	----- dB
Carrier	
Index	0
Composite RMS EVM Mean	4.63 %
Composite Peak EVM Maximum	14.92 %
Composite Peak EVM Slot Index	0
Composite Peak EVM Symbol Index	7
Composite Peak EVM Subcarrier Index	288
Composite RMS Magnitude Error Mean	3.26 %
Composite Peak Magnitude Error Maximum	14.92 %
Composite RMS Phase Error Mean	3.12 deg
Composite Peak Phase Error Maximum	-26.85 deg
SCH Symbol Power Mean	----- dBm
User 0 SCH Detected Modulation Type	64 QAM
In-Band Emission Margin	----- dB
Spectral Flatness Range1-Max to Range1-Min	1.81 dB

RF SIGNAL ANALYZER
PXIe-5668R (26.5 GHz) · PXI2Slot13
No errors or warnings

Instrument
FREQUENCY REFERENCE SOURCE: OnboardClock

NR
CENTER FREQUENCY: 26.000000000 GHz
BANDWIDTH: 100 MHz
REFERENCE LEVEL: -14.50 dBm
LINK DIRECTION: Uplink
FREQUENCY RANGE: Range 2
SUBCARRIER SPACING: 120 kHz
PUSCH TRANSFORM PRECODING ENABLED: ☐
SLOT ALLOCATION: 0-Last
SYMBOL ALLOCATION: 0-Last

Measurements
Adjacent Channel Power
AUTO SWEEP TIME: ☑
SWEEP TIME: 1.000 ms
AVERAGING ENABLED: ☐
AVERAGING COUNT: 10
Modulation Accuracy

Figure 23: Snapshot of EVM measurement having IF = 2 GHz and RF = 26 GHz

2.2.7 Cross-Domain demo by KCL

Description of the demo

The test consists of CMC 5G core located in Finland and eNB located in KCL. The eNB is based on Open Air Interface (OAI) software. The eNB, running on a Linux PC at KCL, supports NSA functionality with a full software implementation of LTE standards. Figure 24 shows the setup of the demo whereby the CN is CMC 5G running in a linux server, eNB and UE are based on OAI. The eNB is configured for FDD band 7.

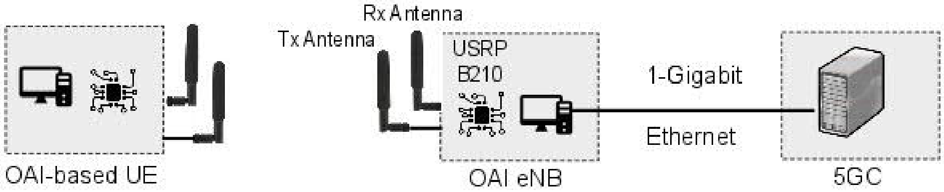


Figure 24: Experimental setup of CMC 5G core and KCL gNB.

Continued developments of the demo

The experimental testing of the setup shown in Figure 24 consists of three steps:

- Running 5GC to set network interfaces and get ready listening at the configured ports
- Running OAI-based eNB which establishes an NG connection with the 5GC
- Once the NG link is established, the OAI-based UE is invoked which initiates RRC connection to the eNB.

The setup didn’t work as OAI-based UE stopped running when trying to setup a connection with eNB. Therefore, we couldn’t perform an end-to-end testing as there weren’t any data transfer between eNB and UE. The problem couldn’t be fixed, and we couldn’t try a newer OAI software version as it is not compatible to Ubuntu 14.04.

As KCL could not progress on setup shown in Figure 24, then there is a plan to replace the OAI-based UE by COTS UE. Figure 25 shows that COTS UE will be used instead of OAI-BASED UE. However, this will need some reworking.

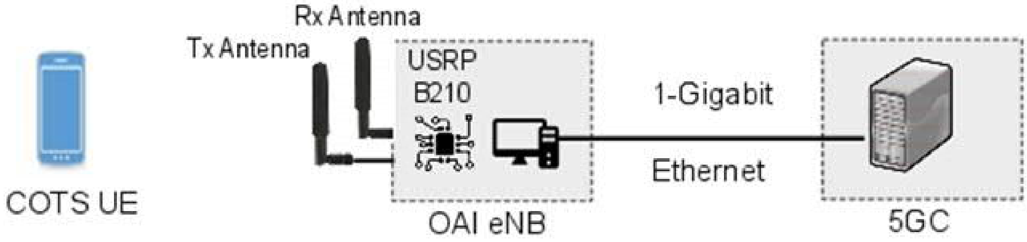
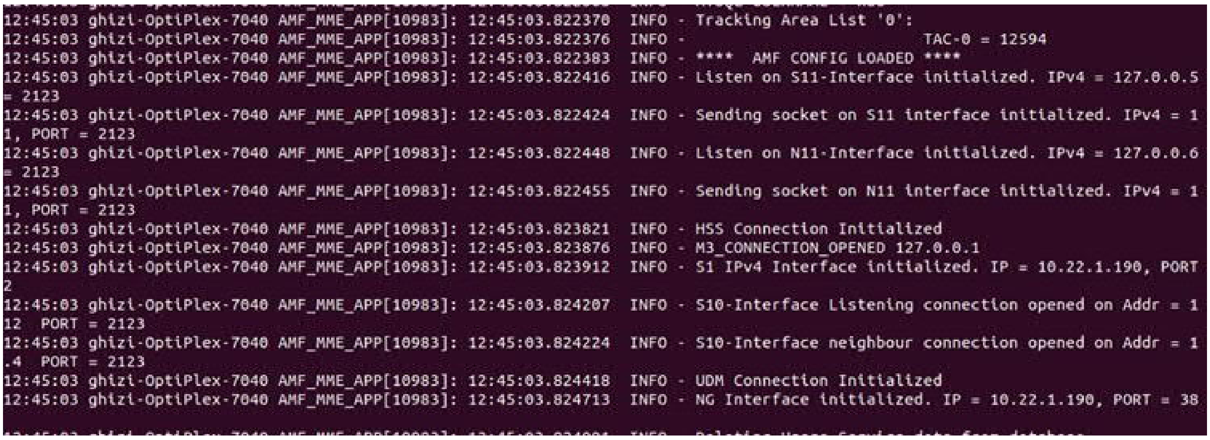


Figure 25: Experimental setup of CMC 5G core and KCL gNB using COTS UE.

Evaluation report

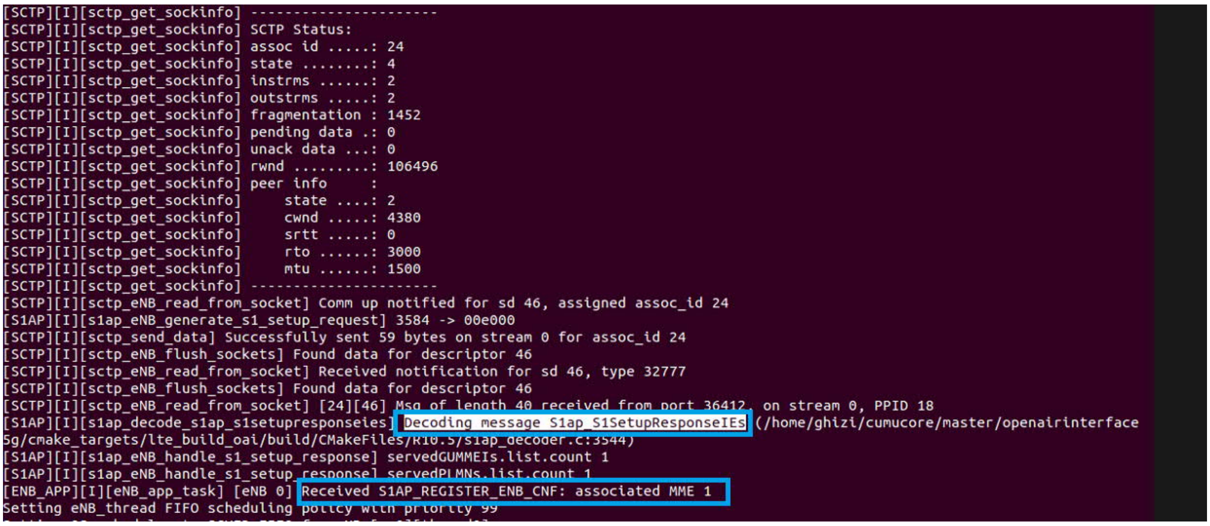
The screenshot in Figure 26 shows the setup of network interfaces successfully in 5GC CMC and the screenshot in Figure 27 shows that S1 setup procedure is established successfully between CMC 5GC and OAI-based eNB in KCL. The received S1 setup response indicates that CMC MME accepted the S1 setup requested by eNB.

However, eNB failed to setup RRC connection with OAI-based UE. Therefore, this test could not progress further.



```
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822370  INFO - Tracking Area List '0':
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822376  INFO -                               TAC-0 = 12594
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822383  INFO - ****  AMF CONFIG LOADED ****
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822416  INFO - Listen on S11-Interface initialized. IPv4 = 127.0.0.5
= 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822424  INFO - Sending socket on S11 interface initialized. IPv4 = 1
1, PORT = 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822448  INFO - Listen on N11-Interface initialized. IPv4 = 127.0.0.6
= 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.822455  INFO - Sending socket on N11 interface initialized. IPv4 = 1
1, PORT = 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.823821  INFO - HSS Connection Initialized
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.823876  INFO - M3_CONNECTION_OPENED 127.0.0.1
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.823912  INFO - S1 IPv4 Interface initialized. IP = 10.22.1.190, PORT
2
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.824207  INFO - S10-Interface Listening connection opened on Addr = 1
12  PORT = 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.824224  INFO - S10-Interface neighbour connection opened on Addr = 1
.4  PORT = 2123
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.824418  INFO - UDM Connection Initialized
12:45:03 ghizi-OptiPlex-7040 AMF_MME_APP[10983]: 12:45:03.824713  INFO - NG Interface initialized. IP = 10.22.1.190, PORT = 38
```

Figure 26: Screenshot of 5GC log illustrating successful interface setup



```
[SCTP][I][sctp_get_sockinfo] ---------------------
[SCTP][I][sctp_get_sockinfo] SCTP Status:
[SCTP][I][sctp_get_sockinfo] assoc id .....: 24
[SCTP][I][sctp_get_sockinfo] state ........: 4
[SCTP][I][sctp_get_sockinfo] instrms ......: 2
[SCTP][I][sctp_get_sockinfo] outstrms .....: 2
[SCTP][I][sctp_get_sockinfo] fragmentation : 1452
[SCTP][I][sctp_get_sockinfo] pending data .: 0
[SCTP][I][sctp_get_sockinfo] unack data ...: 0
[SCTP][I][sctp_get_sockinfo] rwnd .........: 106496
[SCTP][I][sctp_get_sockinfo] peer info     :
[SCTP][I][sctp_get_sockinfo]     state ....: 2
[SCTP][I][sctp_get_sockinfo]     cwnd .....: 4380
[SCTP][I][sctp_get_sockinfo]     srtt .....: 0
[SCTP][I][sctp_get_sockinfo]     rto ......: 3000
[SCTP][I][sctp_get_sockinfo]     mtu ......: 1500
[SCTP][I][sctp_get_sockinfo] ---------------------
[SCTP][I][sctp_eNB_read_from_socket] Comm up notified for sd 46, assigned assoc_id 24
[S1AP][I][s1ap_eNB_generate_s1_setup_request] 3584 -> 00e000
[SCTP][I][sctp_send_data] Successfully sent 59 bytes on stream 0 for assoc_id 24
[SCTP][I][sctp_eNB_flush_sockets] Found data for descriptor 46
[SCTP][I][sctp_eNB_read_from_socket] Received notification for sd 46, type 32777
[SCTP][I][sctp_eNB_flush_sockets] Found data for descriptor 46
[SCTP][I][sctp_eNB_read_from_socket] [24][46] Msg of length 40 received from port 36412, on stream 0, PPID 18
[S1AP][I][s1ap_decode_s1ap_s1setupresponseies] Decoding message S1ap_S1SetupResponseIEs (/home/ghizi/cumucore/master/openairinterface
5g/cmake_targets/lte_build_oai/build/CMakeFiles/R10.5/s1ap_decoder.c:3544)
[S1AP][I][s1ap_eNB_handle_s1_setup_response] servedGUMMEIs.list.count 1
[S1AP][I][s1ap_eNB_handle_s1_setup_response] servedPLMNs.list.count 1
[ENB_APP][I][eNB_app_task] [eNB 0] Received S1AP_REGISTER_ENB_CNF: associated MME 1
Setting eNB_thread FIFO scheduling policy with priority 99
```

Figure 27: Sceenshot of eNB log illustrating successful S1 setup procedure

2.2.8 Optimal routing demo by EAB

Description of the demo

The scope of the demo is to visualize and demonstrate the feasibility of Optimal Routing. It is achieved by implementing the main functional entities in the concept:

- IAP (IP Announcement Point): the IAP in the user plane receives plain IP packets from the Data Networks. It determines which User Plane Function (UPF) the packet has to be sent to, either by sending a query to the Location Register, or looking up from its local cache. Then, the packet is encapsulated with GRE and sent to the correct UPF.
- LR (Location Register): it stores the UE IP address -> UPF mappings. These entries are inserted, updated and deleted by the Session Management Function (SMF). The LR replies to queries received from the IAPs, and also keeps a list of IAP instances that asked for the information for a given UE IP address. Using that list, it can push updates to the IAPs whenever it receives a new UPF IP address for the given UE IP address.

As reported in D5.1 [PRIMO-D51], the demonstration is implemented in an OpenStack cluster, by deploying several Ubuntu Virtual Machines. The components running in the different VMs can be seen in Figure 28.

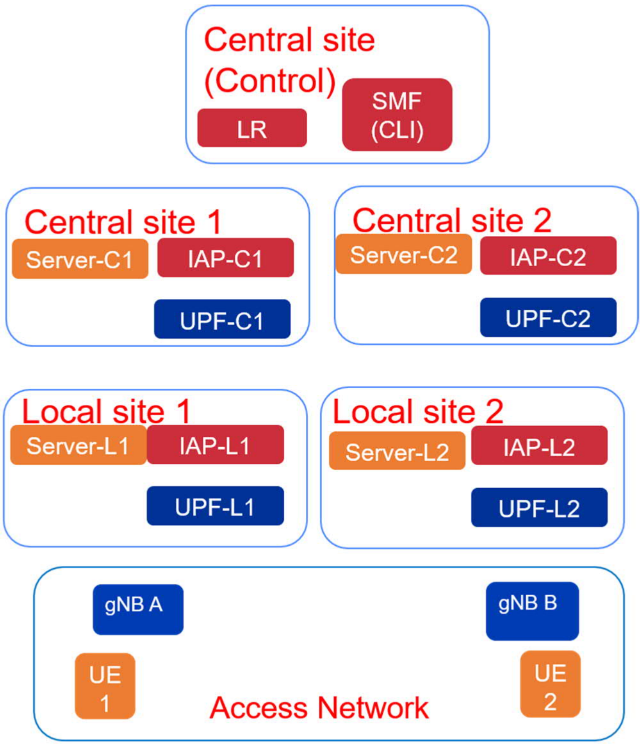


Figure 28: Optimal Routing demo set-up

For further information on the demo setup, please refer to D5.1 [PRIMO-D51], Section 3.11. The Optimal Routing concept is further described in D2.1 [PRIMO-D21].

Continued developments of the demo

The demo is not developed further, as following the earlier plans. However, the Optimal Routing prototype and concept is further enhanced in the context of WP2.

In that work, Optimal Routing is combined with Application Server instance relocation. After a handover happens and the UPF changes, the SMF indicates this to the Application Function, which in turn can decide to relocate the Application Server instance. The relocation involves copying the session context from the source server to the target server. After the relocation is finalized, the communication will now follow the path target server -> target UPF -> target gNB -> UE, thereby reducing the latency by avoiding the possibly longer path from the original server instance to the UE.

Evaluation report

The demonstration has been presented in the PriMO-5G booth at EUCNC in June 2019. As stated previously the goal of the demonstration was to visualize the concept and serve as proof-of-concept.

The demo picture has the following windows, see Figure 29:

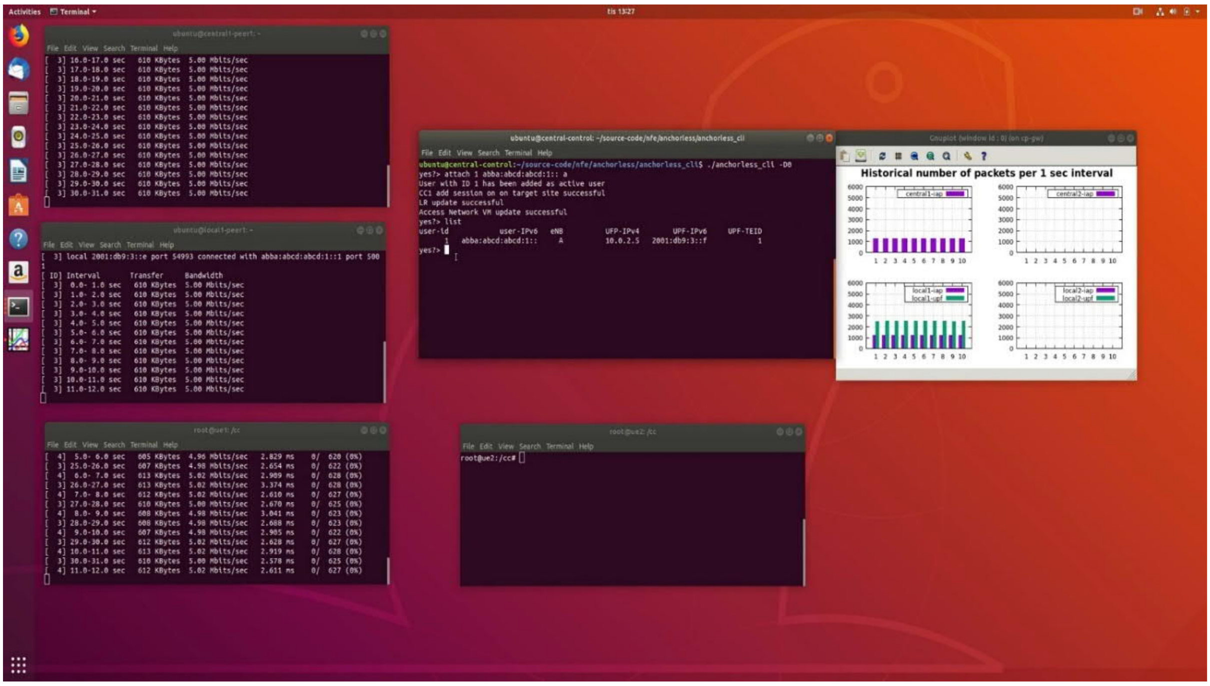
- First (uppermost) window in the 1st column: a server on the central site 1 (Server-C1)
- Second (middle) window in the 1st column: a server on the local site 1 (Server-L1)
- Third (downmost) window in the 1st column: UE1

- First (upper) window in the 2nd column: the CLI window representing the SMF, where attach and handover commands can be given
- Second (lower) window in the 2nd column: UE2
- Window in the 3rd column: statistics collected real-time. Purple bars show packets per second (pps) as seen in the IAP and the green bars show packets per second as seen in the UPF. It is divided into 4 windows:
    - Upper in the left: IAP in Central Site 1 (IAP-C1)
    - Upper in the right: IAP in Central Site 2 (IAP-C2)
    - Lower in the left: IAP and UPF in Local Site 1 (IAP-L1, UPF-L1)
    - Lower in the right: IAP and UPF in Local Site 2 (IAP-L2, UPF-L2)

The demo is run in the following steps:

- The first UE (UE1) is attached, and that is given in the CLI: “attach 1 abba:abcd:abcd:1:: a”, i.e. a prefix is allocated and it is connected to gNB a (therefore UPF-L1 will be selected)
- We start to send traffic to the UE1, both from a central (Server-C1) and a local server (Server-L1). The traffic sent is 5 Mbit/s UDP stream from each server.

At this point, the following can be seen in the screen, see Figure 29:



```
[  3] 16.0-17.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 17.0-18.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 18.0-19.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 19.0-20.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 20.0-21.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 21.0-22.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 22.0-23.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 23.0-24.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 24.0-25.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 25.0-26.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 26.0-27.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 27.0-28.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 28.0-29.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 29.0-30.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 30.0-31.0 sec   610 KBytes  5.00 Mbits/sec
```

```
[  3] local 2001:db9:3::e port 54993 connected with abba:abcd:abcd:1::1 port 500
1
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0- 1.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  1.0- 2.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  2.0- 3.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  3.0- 4.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  4.0- 5.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  5.0- 6.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  6.0- 7.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  7.0- 8.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  8.0- 9.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  9.0-10.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 10.0-11.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 11.0-12.0 sec   610 KBytes  5.00 Mbits/sec
```

```
[  4]  5.0- 6.0 sec   605 KBytes  4.96 Mbits/sec   2.829 ms    0/  620 (0%)
[  3] 25.0-26.0 sec   607 KBytes  4.98 Mbits/sec   2.654 ms    0/  622 (0%)
[  4]  6.0- 7.0 sec   613 KBytes  5.02 Mbits/sec   2.909 ms    0/  628 (0%)
[  3] 26.0-27.0 sec   613 KBytes  5.02 Mbits/sec   3.374 ms    0/  628 (0%)
[  4]  7.0- 8.0 sec   612 KBytes  5.02 Mbits/sec   2.610 ms    0/  627 (0%)
[  3] 27.0-28.0 sec   610 KBytes  5.00 Mbits/sec   2.670 ms    0/  625 (0%)
[  4]  8.0- 9.0 sec   608 KBytes  4.98 Mbits/sec   3.041 ms    0/  623 (0%)
[  3] 28.0-29.0 sec   608 KBytes  4.98 Mbits/sec   2.688 ms    0/  623 (0%)
[  4]  9.0-10.0 sec   607 KBytes  4.98 Mbits/sec   2.905 ms    0/  622 (0%)
[  3] 29.0-30.0 sec   612 KBytes  5.02 Mbits/sec   2.628 ms    0/  627 (0%)
[  4] 10.0-11.0 sec   613 KBytes  5.02 Mbits/sec   2.919 ms    0/  628 (0%)
[  3] 30.0-31.0 sec   610 KBytes  5.00 Mbits/sec   2.578 ms    0/  625 (0%)
[  4] 11.0-12.0 sec   612 KBytes  5.02 Mbits/sec   2.611 ms    0/  627 (0%)
```

```
ubuntu@central-control:~/source-code/nfe/anchorless/anchorless_cli$ ./anchorless_cli -D0
yes?> attach 1 abba:abcd:abcd:1:: a
User with ID 1 has been added as active user
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
yes?> list
user-id            user-IPv6   eNB          UFP-IPv4       UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     A          10.0.2.5   2001:db9:3::f            1
yes?>
```

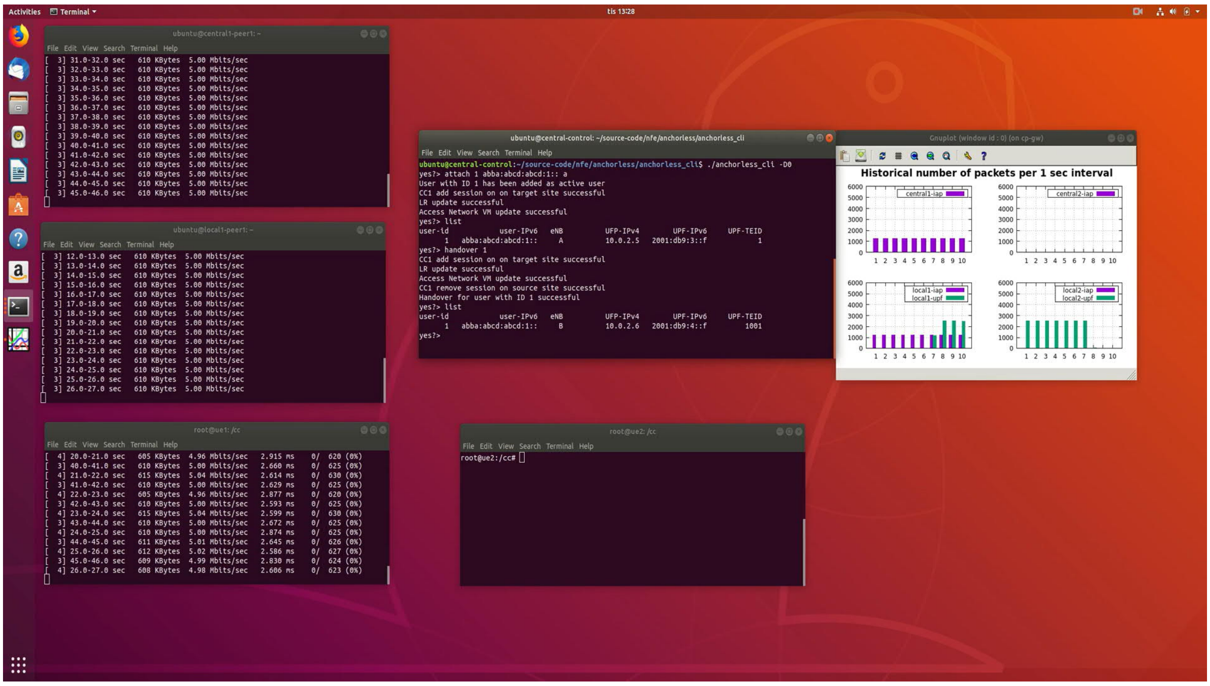
```
root@ue2:/cc#
```

Figure 29: Demonstration screen after UE1 attached and receives traffic from both the central and local server

It can be seen that IAP-C1 and IAP-L1 are receiving processing traffic for UE1, as they are the closest one from the Central Server on Central Site 1 and the Local Server on Local Site 2. The IAPs queried the Location Register (not seen in the figure) and learned that UE1’s packets has to be sent to UPF-L1.

- A handover is performed with the CLI command: “handover 1”. This means that the UE1 will change to a base station (gNB “b”) and that will trigger changing the UPF from UPF-L1 to UPF-L2.

At this point the following is seen in the screen, see Figure 30:



```
[  3] 31.0-32.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 32.0-33.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 33.0-34.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 34.0-35.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 35.0-36.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 36.0-37.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 37.0-38.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 38.0-39.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 39.0-40.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 40.0-41.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 41.0-42.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 42.0-43.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 43.0-44.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 44.0-45.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 45.0-46.0 sec   610 KBytes  5.00 Mbits/sec
```

```
[  3] 12.0-13.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 13.0-14.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 14.0-15.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 15.0-16.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 16.0-17.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 17.0-18.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 18.0-19.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 19.0-20.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 20.0-21.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 21.0-22.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 22.0-23.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 23.0-24.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 24.0-25.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 25.0-26.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 26.0-27.0 sec   610 KBytes  5.00 Mbits/sec
```

```
[  4] 20.0-21.0 sec   605 KBytes  4.96 Mbits/sec   2.915 ms    0/  620 (0%)
[  3] 40.0-41.0 sec   610 KBytes  5.00 Mbits/sec   2.660 ms    0/  625 (0%)
[  4] 21.0-22.0 sec   615 KBytes  5.04 Mbits/sec   2.614 ms    0/  630 (0%)
[  3] 41.0-42.0 sec   610 KBytes  5.00 Mbits/sec   2.629 ms    0/  625 (0%)
[  4] 22.0-23.0 sec   605 KBytes  4.96 Mbits/sec   2.877 ms    0/  620 (0%)
[  3] 42.0-43.0 sec   610 KBytes  5.00 Mbits/sec   2.593 ms    0/  625 (0%)
[  4] 23.0-24.0 sec   615 KBytes  5.04 Mbits/sec   2.599 ms    0/  630 (0%)
[  3] 43.0-44.0 sec   610 KBytes  5.00 Mbits/sec   2.672 ms    0/  625 (0%)
[  4] 24.0-25.0 sec   610 KBytes  5.00 Mbits/sec   2.874 ms    0/  625 (0%)
[  3] 44.0-45.0 sec   611 KBytes  5.01 Mbits/sec   2.645 ms    0/  626 (0%)
[  4] 25.0-26.0 sec   612 KBytes  5.02 Mbits/sec   2.586 ms    0/  627 (0%)
[  3] 45.0-46.0 sec   609 KBytes  4.99 Mbits/sec   2.830 ms    0/  624 (0%)
[  4] 26.0-27.0 sec   608 KBytes  4.98 Mbits/sec   2.606 ms    0/  623 (0%)
```

```
ubuntu@central-control:~/source-code/nfe/anchorless/anchorless_cli$ ./anchorless_cli -D0
yes?> attach 1 abba:abcd:abcd:1:: a
User with ID 1 has been added as active user
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
yes?> list
user-id           user-IPv6   eNB          UFP-IPv4        UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     A         10.0.2.5   2001:db9:3::f            1
yes?> handover 1
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
CC1 remove session on source site successful
Handover for user with ID 1 successful
yes?> list
user-id           user-IPv6   eNB          UFP-IPv4        UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     B         10.0.2.6   2001:db9:4::f         1001
yes?>
```

```
root@ue2:/cc#
```

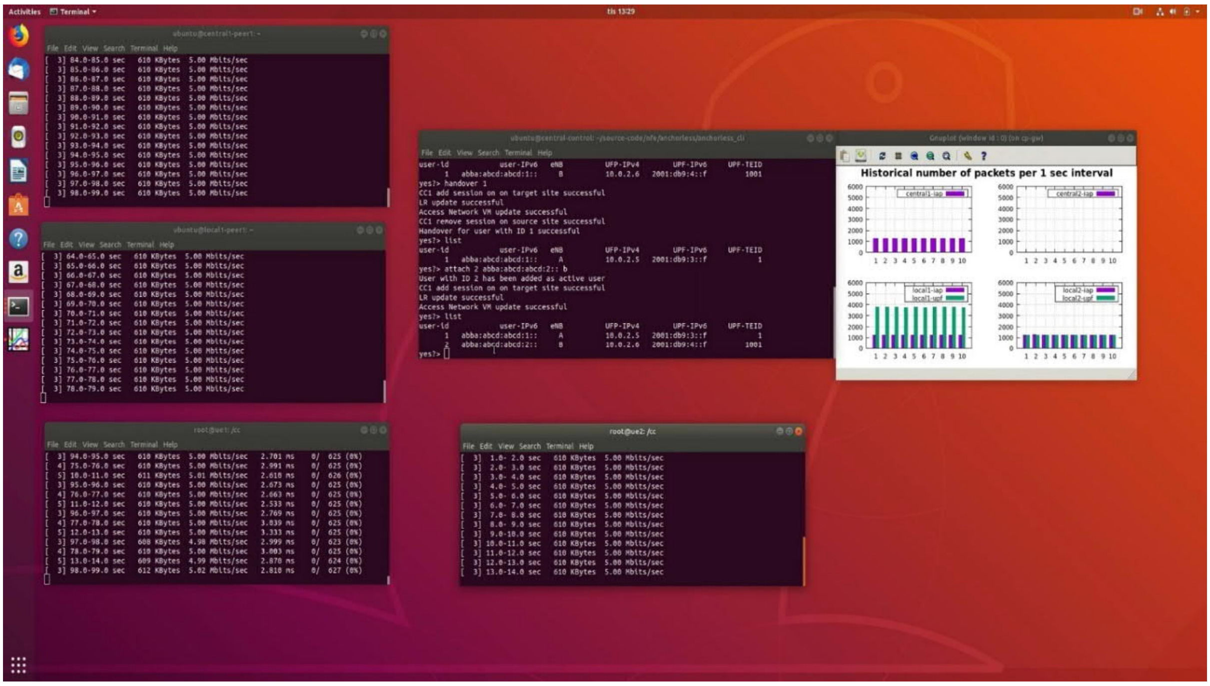
Figure 30: Demonstration screen after UE1 performed a handover

It can be seen in Figure 30 that UPF-L2 processes the packets of the UE1, after IAP-C1 and IAP-L1 was informed by the Location Register about the new UPF IP address for UE1. The amount of traffic at IAP-C1 and IAP-L1 is unchanged. It is also seen that no packet was lost at the iperf sessions.

After this, the following steps are performed:

- UE1 does another handover, therefore it is again connected to gNB A, and traffic is flowing through again UPF-L1. The situation is similar as in Figure 3.
- UE2 attaches: “attach 2 abba:abcd:abcd:2:: b”. It is connected to gNB B, therefore UPF-L2 will be processing this UE’s traffic
- UE2 starts to send 5Mbit/s to UE1

At this point, the following is seen in the screen, see Figure 31:



```
[  3] 84.0-85.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 85.0-86.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 86.0-87.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 87.0-88.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 88.0-89.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 89.0-90.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 90.0-91.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 91.0-92.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 92.0-93.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 93.0-94.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 94.0-95.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 95.0-96.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 96.0-97.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 97.0-98.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 98.0-99.0 sec   610 KBytes  5.00 Mbits/sec
```

```
[  3] 64.0-65.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 65.0-66.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 66.0-67.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 67.0-68.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 68.0-69.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 69.0-70.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 70.0-71.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 71.0-72.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 72.0-73.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 73.0-74.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 74.0-75.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 75.0-76.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 76.0-77.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 77.0-78.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 78.0-79.0 sec   610 KBytes  5.00 Mbits/sec
```

```
user-id           user-IPv6   eNB          UFP-IPv4        UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     B          10.0.2.6   2001:db9:4::f         1001
yes?> handover 1
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
CC1 remove session on source site successful
Handover for user with ID 1 successful
yes?> list
user-id           user-IPv6   eNB          UFP-IPv4        UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     A          10.0.2.5   2001:db9:3::f            1
yes?> attach 2 abba:abcd:abcd:2:: b
User with ID 2 has been added as active user
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
yes?> list
user-id           user-IPv6   eNB          UFP-IPv4        UPF-IPv6     UPF-TEID
      1   abba:abcd:abcd:1::     A          10.0.2.5   2001:db9:3::f            1
      2   abba:abcd:abcd:2::     B          10.0.2.6   2001:db9:4::f         1001
yes?>
```

```
[  3] 94.0-95.0 sec   610 KBytes  5.00 Mbits/sec   2.701 ms    0/  625 (0%)
[  4] 75.0-76.0 sec   610 KBytes  5.00 Mbits/sec   2.991 ms    0/  625 (0%)
[  5] 10.0-11.0 sec   611 KBytes  5.01 Mbits/sec   2.610 ms    0/  626 (0%)
[  3] 95.0-96.0 sec   610 KBytes  5.00 Mbits/sec   2.673 ms    0/  625 (0%)
[  4] 76.0-77.0 sec   610 KBytes  5.00 Mbits/sec   2.663 ms    0/  625 (0%)
[  5] 11.0-12.0 sec   610 KBytes  5.00 Mbits/sec   2.533 ms    0/  625 (0%)
[  3] 96.0-97.0 sec   610 KBytes  5.00 Mbits/sec   2.769 ms    0/  625 (0%)
[  4] 77.0-78.0 sec   610 KBytes  5.00 Mbits/sec   3.039 ms    0/  625 (0%)
[  5] 12.0-13.0 sec   610 KBytes  5.00 Mbits/sec   3.333 ms    0/  625 (0%)
[  3] 97.0-98.0 sec   608 KBytes  4.98 Mbits/sec   2.999 ms    0/  623 (0%)
[  4] 78.0-79.0 sec   610 KBytes  5.00 Mbits/sec   3.003 ms    0/  625 (0%)
[  5] 13.0-14.0 sec   609 KBytes  4.99 Mbits/sec   2.870 ms    0/  624 (0%)
[  3] 98.0-99.0 sec   612 KBytes  5.02 Mbits/sec   2.810 ms    0/  627 (0%)
```

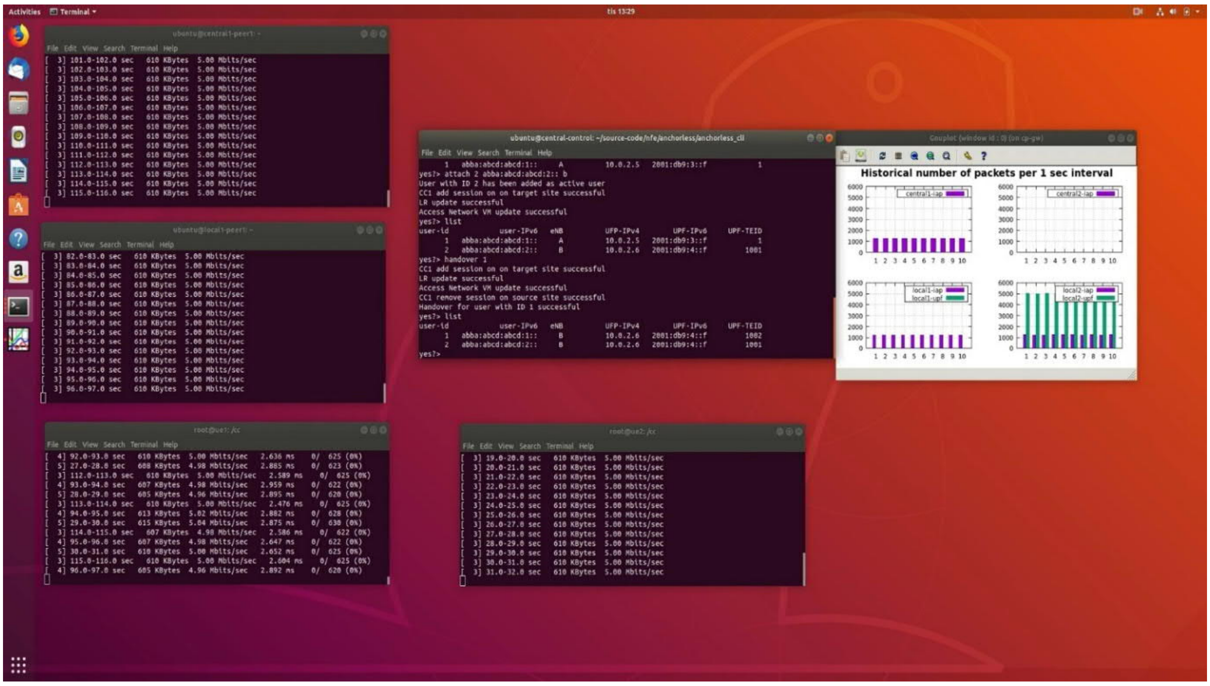
```
[  3]  1.0- 2.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  2.0- 3.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  3.0- 4.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  4.0- 5.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  5.0- 6.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  6.0- 7.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  7.0- 8.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  8.0- 9.0 sec   610 KBytes  5.00 Mbits/sec
[  3]  9.0-10.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 10.0-11.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 11.0-12.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 12.0-13.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 13.0-14.0 sec   610 KBytes  5.00 Mbits/sec
```

Figure 31: Demonstration screen after UE2 attached and started to send traffic to UE1

Now UE1 receives traffic from the central and the local servers and also from the UE2 simultaneously. It can be seen in Figure 31, that now the IAP-L2 is also processing traffic, as this is the closest IAP, after UE2's packets were processed in UPF-L2 (shown also with the green bar on the lower right segment in the statistics window).

- UE1 performs a handover: "handover 1", meaning it will change from gNB A to gNB B, which will mean that from now on UE1's packets are also processed in UPF-L2

At this point, the following can be seen in the screen, see Figure 32:



```
ubuntu@central1-peer1: ~
[  3] 101.0-102.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 102.0-103.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 103.0-104.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 104.0-105.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 105.0-106.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 106.0-107.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 107.0-108.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 108.0-109.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 109.0-110.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 110.0-111.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 111.0-112.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 112.0-113.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 113.0-114.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 114.0-115.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 115.0-116.0 sec   610 KBytes  5.00 Mbits/sec
```

```
ubuntu@local1-peer1: ~
[  3] 82.0-83.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 83.0-84.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 84.0-85.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 85.0-86.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 86.0-87.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 87.0-88.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 88.0-89.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 89.0-90.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 90.0-91.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 91.0-92.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 92.0-93.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 93.0-94.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 94.0-95.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 95.0-96.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 96.0-97.0 sec   610 KBytes  5.00 Mbits/sec
```

```
ubuntu@central-control: ~/source-code/nfe/anchorless/anchorless_cll
      1   abba:abcd:abcd:1::     A          10.0.2.5   2001:db9:3::f          1
yes?> attach 2 abba:abcd:abcd:2:: b
User with ID 2 has been added as active user
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
yes?> list
user-id            user-IPv6   eNB          UFP-IPv4       UPF-IPv6    UPF-TEID
      1   abba:abcd:abcd:1::     A          10.0.2.5   2001:db9:3::f          1
      2   abba:abcd:abcd:2::     B          10.0.2.6   2001:db9:4::f       1001
yes?> handover 1
CC1 add session on on target site successful
LR update successful
Access Network VM update successful
CC1 remove session on source site successful
Handover for user with ID 1 successful
yes?> list
user-id            user-IPv6   eNB          UFP-IPv4       UPF-IPv6    UPF-TEID
      1   abba:abcd:abcd:1::     B          10.0.2.6   2001:db9:4::f       1002
      2   abba:abcd:abcd:2::     B          10.0.2.6   2001:db9:4::f       1001
yes?>
```

```
root@ue1: /cc
[  4] 92.0-93.0 sec   610 KBytes  5.00 Mbits/sec   2.636 ms    0/  625 (0%)
[  5] 27.0-28.0 sec   608 KBytes  4.98 Mbits/sec   2.885 ms    0/  623 (0%)
[  3] 112.0-113.0 sec   610 KBytes  5.00 Mbits/sec   2.589 ms    0/  625 (0%)
[  4] 93.0-94.0 sec   607 KBytes  4.98 Mbits/sec   2.959 ms    0/  622 (0%)
[  5] 28.0-29.0 sec   605 KBytes  4.96 Mbits/sec   2.895 ms    0/  620 (0%)
[  3] 113.0-114.0 sec   610 KBytes  5.00 Mbits/sec   2.476 ms    0/  625 (0%)
[  4] 94.0-95.0 sec   613 KBytes  5.02 Mbits/sec   2.882 ms    0/  628 (0%)
[  5] 29.0-30.0 sec   615 KBytes  5.04 Mbits/sec   2.875 ms    0/  630 (0%)
[  3] 114.0-115.0 sec   607 KBytes  4.98 Mbits/sec   2.586 ms    0/  622 (0%)
[  4] 95.0-96.0 sec   607 KBytes  4.98 Mbits/sec   2.647 ms    0/  622 (0%)
[  5] 30.0-31.0 sec   610 KBytes  5.00 Mbits/sec   2.652 ms    0/  625 (0%)
[  3] 115.0-116.0 sec   610 KBytes  5.00 Mbits/sec   2.604 ms    0/  625 (0%)
[  4] 96.0-97.0 sec   605 KBytes  4.96 Mbits/sec   2.892 ms    0/  620 (0%)
```

```
root@ue2: /cc
[  3] 19.0-20.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 20.0-21.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 21.0-22.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 22.0-23.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 23.0-24.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 24.0-25.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 25.0-26.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 26.0-27.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 27.0-28.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 28.0-29.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 29.0-30.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 30.0-31.0 sec   610 KBytes  5.00 Mbits/sec
[  3] 31.0-32.0 sec   610 KBytes  5.00 Mbits/sec
```

Figure 32: Demonstration screen after UE1 performs another handover: now all traffic turns locally on UPF-L2

As can be seen now in Figure 32, only the UPF-L2 processes traffic. As previously, the IAPs got updated location information for UE1, so now they all send the traffic to UPF-L2. This also means that the traffic from UE2 to UE1 turns also locally on UPF-L2, therefore the latency is minimized, as there is no need to visit the old UPF (UPF-L1 in this case).

With this demonstration steps above the following can be concluded:

- Optimal Routing components are feasible to implement (IAP and LR)
- Optimal Routing can provide low-latency paths for UE-to-UE communication, even after handovers
- Packet losses do not happen after handovers, even after changing UPFs

2.3 Demos from Korean partners

This section presents the results from the component-level demonstration activities from the Korean partners. Altogether, there are 4 demonstrations, and the section numbering below follows the one in Section 3.3 in D5.1 [PRIMO-D51].

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

Description of the demo

This demo is a representative implementation of urban firefighting portrayed in D1.1 [PRIMO-D11] comprising of Yonsei University’s (YU) UAVs and ground control station, KT's 5G gNB and core, and

Korea University's (KU[1]) vehicle capable of edge computing. In this demo, to advance the research and implementation of 5G system using UAVs, the PriMO-5G team implements an end-to-end system that showcases seamless real-time streaming of immersive media through 5G and post-processing using AI techniques for object detection and super resolution. This demo is simultaneously implemented in the following main locations:

- UAV in YU International Campus (Songdo, Incheon): The UAV executes its aerial mission in a virtual accident site, acquiring sensory information around it, including high quality video from a camera sensor. The UAV streams the high quality video to the GCS in a remote location (e.g. fire station) as well as MEC within a moving vehicle (e.g. fire truck), through 5G, in real-time.

- Ground Control Station (GCS) in YU Seoul Campus: The ground server, being located about 30 km away from the UAV, receives the high quality video from the UAV then reprocesses the video with algorithms such as object detection and super resolution. Having a higher computing power than the moving vehicle (e.g. fire truck), it can process the videos immediately, garnering as much information from the streamed video as possible.

- MEC in KU's vehicle moving towards the UAV's location: The computing server in the moving vehicle is much powerful than the computer mounted on the UAV but still less so than the performance of GCS. This limitation is inevitable due to the size and energy constraints inherent in a moving vehicle. However, it has an edge on latency because of its proximity to the accident site, and it is a vital component in the scenario because it is where the fire fighters gain situation awareness while travelling to the accident site.

Continued developments of the demo

The UAV was upgraded from the DJI matrice 100 platform to DJI matrice 600 pro platform. There were three main reasons behind this upgrade. Firstly, UAVs with higher load capacity is required to carry high end cameras that captures and stitches immersive images with resolution starting from 4K. In reality, we have implemented a platform that mounts batteries and 360 camera (insta 360 pro2) that weighs over 2 kg to stream 4K 3D videos in real-time, and to save and upload 12K images and videos that can be processed later for a more precise analysis. Secondly, to fulfill a more stringent requirement for stability when mounting 5G and computing devices. 5G device is needed to access the 5G network, and GPU enabled computing server is needed for forwarding and computing videos in real-time. For this reason, devices required stable source of power, thus adding additional batteries, 5G device (Samsung Galaxy s10 5G), GPU-mounted mini computer (NVidia Jetson AGX Xavier), and video capturing and forwarding device (Magewell Pro Capture HDMI 4K Plus), which weighs over 3 kg in total, to the system. Lastly, to ensure longer and more stable flight missions. To explain, heavier UAVs tend to grant more stability during hovering sessions due to the reduction of microscopic vibrations and movements caused by wind and wing motion. Also, larger battery capacity increased the flight time to around 20 minutes, which is sufficient for anchoring the mission until the fire truck arrives on site. The images in Figure 33 are UAV mounted with the mentioned devices and the image captured in YU International Campus using the UAV platform.

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[1] CAU in the previous report D5.1 [PRIMO-D51]has been replaced by KU.

Figure 33: Implemented UAV platform and the capture image of YU international campus

On the other hand, for the demonstration of image transmission from UAV to its associated MEC vehicle, we implement our software in a computing platform which is located in MEC vehicle. The main components of software are (i) object detection and (ii) depth-controllable super resolution. With the first component, i.e., object detection, when the MEC vehicle receives images in a sequential manner, it determines whether our interesting events (e.g., fire spots in fire fighting scenarios and wrecked people in rescue scenarios) exist or not in each image. If it is determined using object detection that the event exists, the second component, i.e., depth-controllable super resolution algorithm will be conducted in order to enlarge the image to see more details. Note that our super-resolution algorithm is depth controllable in order to maintain stability which is essential in real-time computing systems. If there are a lot of images in a buffer, then the super-resolution algorithm should process them as soon as possible even though certain amounts of performances are sacrificed in order to avoid overflow. Thus, small number of hidden layers are used in our proposed depth-controllable super-resolution algorithm. On the other hand, if there are rare images in a buffer, the super-resolution algorithm can maximize its performance without the consideration of processing time. Thus, entire hidden layers are used in our proposed depth-controllable super-resolution algorithm.

Evaluation report

The throughput performance of aerial 5G communication is shown in the graph below: ensuring the capacity of at least 100 Mbps and 30 Mbps for downlink and uplink transmission, respectively. Specific results and analysis on this matter has been presented in IEEE WCNC 2020 AERCOMM workshop [KK20]. The 5G uplink transmission is capable of streaming videos with over 1K resolution while satisfying low latency, as its average capacity suggests, and the resolution can be further increased to 4K and more accompanied with additional encoding process and delay. Figure 34 shows real-time application of YOLOv3 object detection algorithm on the 1K video being streamed in real-time as well. This result was evaluated and demonstrated in 2019 5G Vertical Summit.

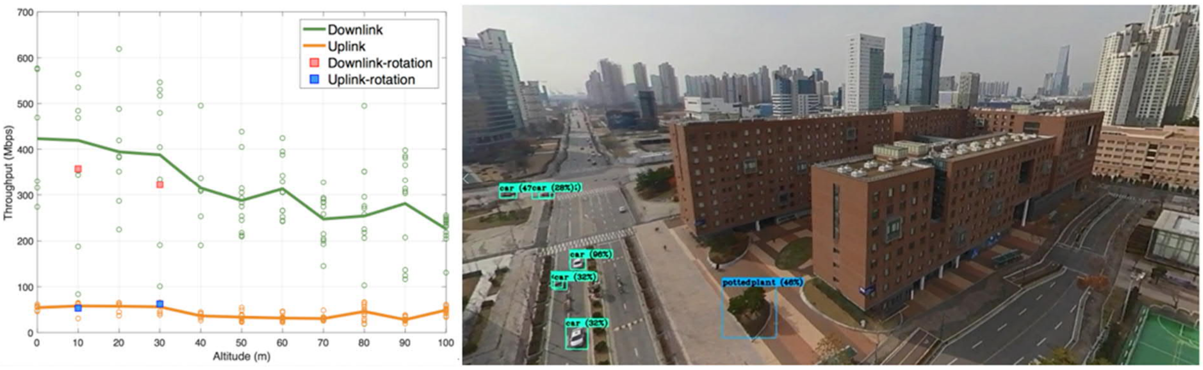


Figure 34: The throughput of KT's 5G network in aerial environments and real-time streaming and

object detection result

Finally, the basic components of the depth-controllable super-resolution algorithm were already implemented when its paper was published in International Joint Conference on Neural Networks (IJCNN) 2019 [KKK+19].

2.3.2 *Streaming aerial video system through LTE NIB demo by EUC*

Description of the demo

This demo is similar with the one introduced in Section 2.2.2 that is it also demonstrates the streaming of live video from UAVs to mobile devices. But in this demo the video streaming is served by MC (Mission Critical) services defined in 3GPP Rel.13. For this, NIB includes LTE eNB, EPC, and MC server as shown in Figure 35. In the demo, UAV uploads live video stream to eNB, and eNB forwards this to MC Server via EPC. MC Server manages group to forward the received video stream.

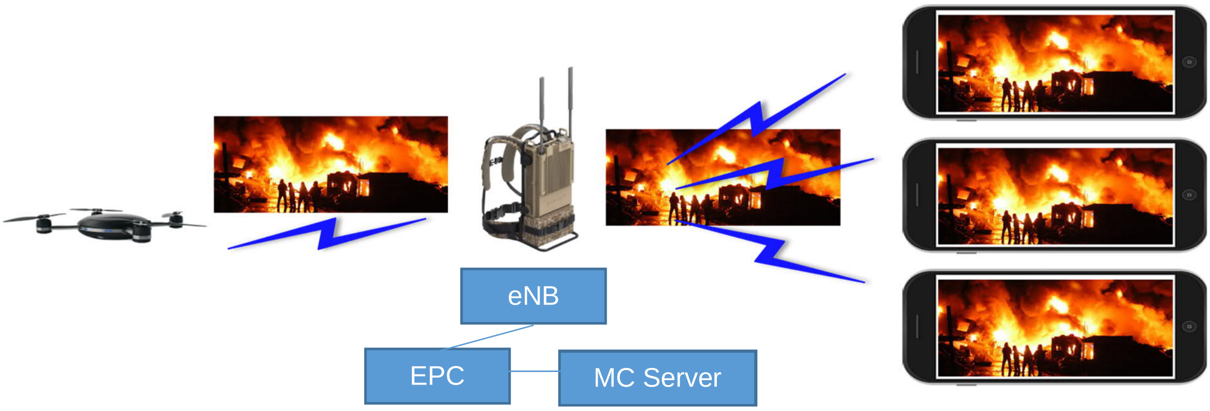


Figure 35: MC service based video streaming

The video stream can be forwarded to the group members through unicast or multicast. The decision whether to send the video stream through unicast or multicast is done by GCS AS (Group Communication Service Application Server) usually depending on the number of group members in MBMS service area.

In this demo, the video stream can be forwarded to the members even they are not in single MBMS service area. Another characteristic of this demo is that the battery powered backpack type NIB enables providing emergency service in disastrous areas where the power system is destroyed.

Continued developments of the demo

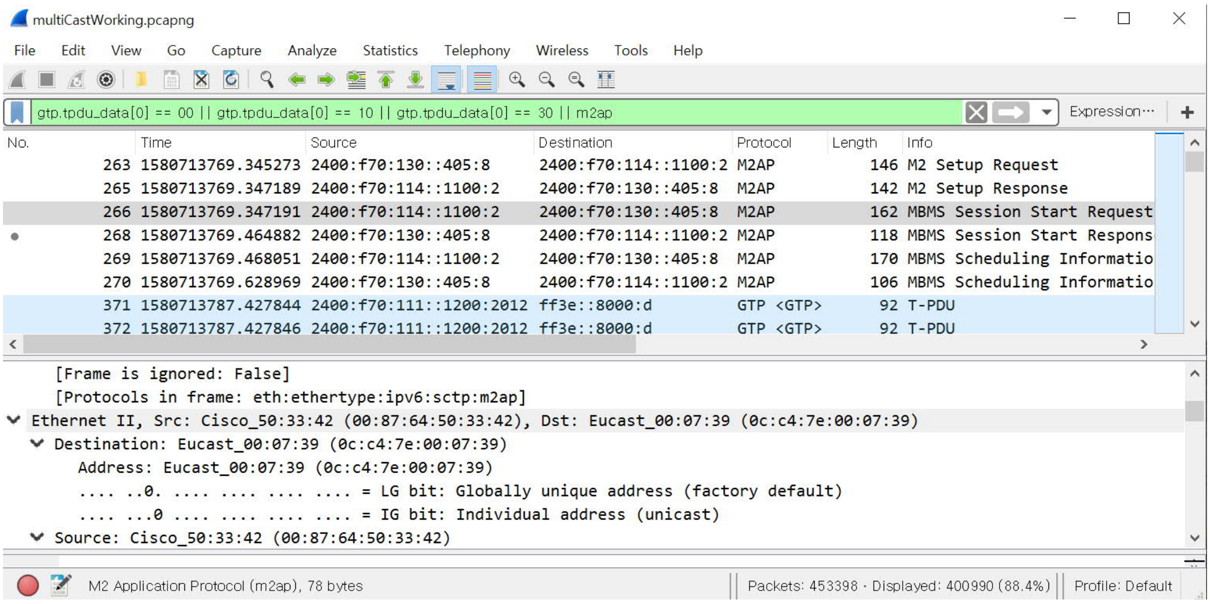
As of now, eNB in NIB is enhanced to support Rel.13 MC (Mission Critical) service specifications that is based on GCSE (Group Communication System Enablers) and eMBMS. So multicast based MC services can be provided only if the necessary modules such as GCS AS, BM-SC, MBMS-GW and MCE is integrated, and it’s done with KT PS-LTE core network servers.

But to support same MC services without backhaul connection, the development and localization of GCS AS, BM-SC, MBMS-GW and MCE modules are ongoing to show demo in 2nd half of 2020.

Evaluation report

Evaluation is done for two scenarios, first scenario is the unicast based video streaming without backhaul, and second one is the multicast based MCPTT service integrated with KT PS-LTE core networks.

Figure 36 and Figure 37 show the captured messages between EUC eNB and KT PS-LTE core network for eMBMS setup and video stream multicast (SYNC PDU), respectively.



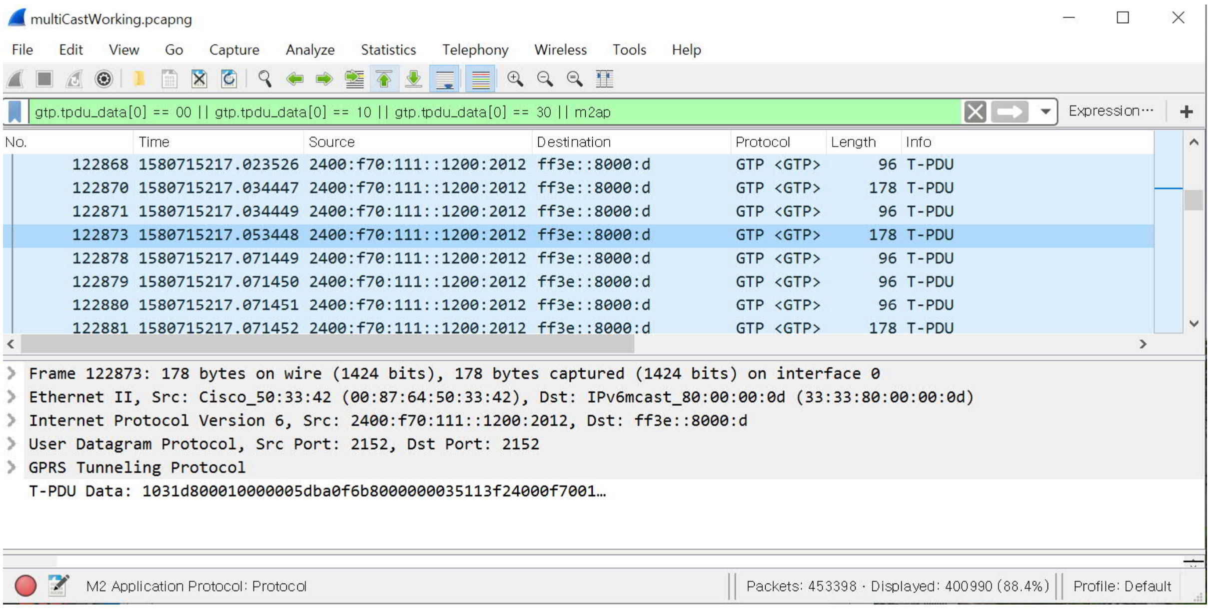
```
gtp.tpdu_data[0] == 00 || gtp.tpdu_data[0] == 10 || gtp.tpdu_data[0] == 30 || m2ap

No.     Time              Source                  Destination         Protocol   Length Info
    263 1580713769.345273 2400:f70:130::405:8     2400:f70:114::1100:2 M2AP         146 M2 Setup Request
    265 1580713769.347189 2400:f70:114::1100:2    2400:f70:130::405:8  M2AP         142 M2 Setup Response
    266 1580713769.347191 2400:f70:114::1100:2    2400:f70:130::405:8  M2AP         162 MBMS Session Start Request
    268 1580713769.464882 2400:f70:130::405:8     2400:f70:114::1100:2 M2AP         118 MBMS Session Start Respons
    269 1580713769.468051 2400:f70:114::1100:2    2400:f70:130::405:8  M2AP         170 MBMS Scheduling Informatio
    270 1580713769.628969 2400:f70:130::405:8     2400:f70:114::1100:2 M2AP         106 MBMS Scheduling Informatio
    371 1580713787.427844 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     92 T-PDU
    372 1580713787.427846 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     92 T-PDU

    [Frame is ignored: False]
    [Protocols in frame: eth:ethertype:ipv6:sctp:m2ap]
Ethernet II, Src: Cisco_50:33:42 (00:87:64:50:33:42), Dst: Eucast_00:07:39 (0c:c4:7e:00:07:39)
  Destination: Eucast_00:07:39 (0c:c4:7e:00:07:39)
    Address: Eucast_00:07:39 (0c:c4:7e:00:07:39)
    .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
    .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
  Source: Cisco_50:33:42 (00:87:64:50:33:42)

M2 Application Protocol (m2ap), 78 bytes || Packets: 453398 · Displayed: 400990 (88.4%) || Profile: Default
```

Figure 36: M2 Setup, MBMS Session Start, and MBMS Scheduling Information messages



```
gtp.tpdu_data[0] == 00 || gtp.tpdu_data[0] == 10 || gtp.tpdu_data[0] == 30 || m2ap

No.     Time              Source                  Destination         Protocol   Length Info
 122868 1580715217.023526 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     96 T-PDU
 122870 1580715217.034447 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>    178 T-PDU
 122871 1580715217.034449 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     96 T-PDU
 122873 1580715217.053448 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>    178 T-PDU
 122878 1580715217.071449 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     96 T-PDU
 122879 1580715217.071450 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     96 T-PDU
 122880 1580715217.071451 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>     96 T-PDU
 122881 1580715217.071452 2400:f70:111::1200:2012 ff3e::8000:d         GTP <GTP>    178 T-PDU

> Frame 122873: 178 bytes on wire (1424 bits), 178 bytes captured (1424 bits) on interface 0
> Ethernet II, Src: Cisco_50:33:42 (00:87:64:50:33:42), Dst: IPv6mcast_80:00:00:0d (33:33:80:00:00:0d)
> Internet Protocol Version 6, Src: 2400:f70:111::1200:2012, Dst: ff3e::8000:d
> User Datagram Protocol, Src Port: 2152, Dst Port: 2152
> GPRS Tunneling Protocol
  T-PDU Data: 1031d800010000005dba0f6b8000000035113f24000f7001…

M2 Application Protocol: Protocol || Packets: 453398 · Displayed: 400990 (88.4%) || Profile: Default
```

Figure 37: SYNC packets to multicast video streams

2.3.3 Lens based mmWave communications demo by YU

Description of the demo

This demonstration is conducted to achieve the connectivity of gNB and UAV reliably in the use case of WP1 D1.1 [PRIMO-D11]. To keep the connection between the fast-moving object drone and gNB, stable and accurate beam-tracking must be supported. Also, 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. Also, both curved and planar lenses are considered, and hybrid beamforming is performed. 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.

Continued developments of the demo

We conducted the demonstration illustrated above for phase 1. To achieve the high throughput of phase 1, we demonstrated a link-level system with an RF lens antenna in an indoor environment. Not only high throughput caused RF lens antenna, but also, we consider high throughput from ultra-wideband. Accordingly, we simultaneously conducted a study on the degradation of throughput from beam-squint in the wideband system.

Evaluation report

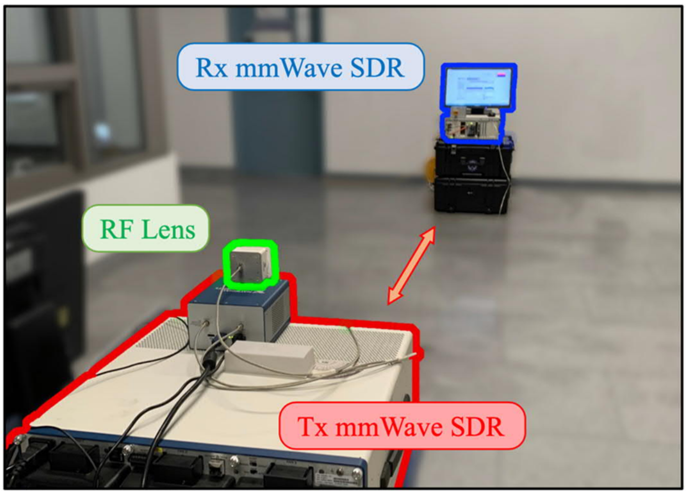
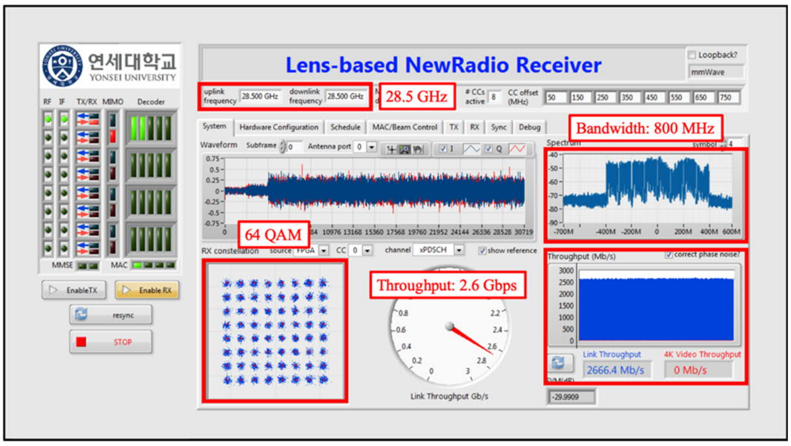


Figure 38: Indoor mmWave software defined radio (SDR) testbed with a fabricated RF lens for assessment


Lens-based NewRadio Receiver

uplink frequency 28.500 GHz
downlink frequency 28.500 GHz
CCs active 8
CC offset (MHz) 50 150 250 350 450 550 650 750
Subframe 0
Antenna port 0
source FPGA
CC 0
channel xPDSCH
☐ Loopback? mmWave
☑ show reference
☑ correct phase noise?
Link Throughput 2666.4 Mb/s
4K Video Throughput 0 Mb/s
EVM(dB) -29.9909

Figure 39: Link-level system throughput at 28.5GHz with 800 MHz bandwidth

To test the performance of the lens antenna as a component of a transmission system, demo setup shown in Figure 38, the link-level performance is evaluated using the mmWave transceiver system SDR platform with an up/downlink frequency of 28.5 GHz and 800 MHz bandwidth. A single data stream is transmitted and received via the modulation and coding scheme (MCS) (i.e., 64-quadrature amplitude modulation (QAM) and 5/6 coding rate). The results in Figure 39 show that the prototyped lens antenna can achieve a maximum throughput of 2.6 Gbps. Note that this high throughput was achieved by a single stream. This is attributed to not only the large bandwidth of the channel but also the high directivity and gain of the lens antenna. Furthermore, the beam-squint phenomena described in the earlier sections are empirically demonstrated to assess performance degradation due to beam-squint in the indoor link-level testbed. In particular, the angle distortion (AD) of the lens antenna caused by the wideband, 27.5–29.5 GHz, is evaluated. As a result, Table 2 illustrates the AD and degraded SNR over beam-squint (DSBQ). The angle changes were 0.26◦ at 27.5 GHz and 0.08◦ at 29.5 GHz. DSBQ imply degraded snr values of each frequency in contrast to it of center frequency.

Table 2: Performance of the fabricated RF lens via mmWave Testbed

Frequency	Beamforming angle [deg]	AD [deg]	DSBQ [%]
27.5 GHz	9.52	0.26	88.03 %
28.5 GHz	9.26	0	[Standard] 100 %
29.5 GHz	9.34	0.08	88.06 %

2.3.4 *Haptic communications demo by YU*

Description of the demo

This demonstration was performed for testing a proof of concept of haptic communications. In firefighting scenario, remote-controlled robots are used to help put out fires and rescue people. The haptic communications enable the control centre to control UEs' haptic equipment remotely with low latency and high reliability. In this demo, we set up a multicast system to test a multi UE scenario as depicted in Figure 40. When the operator manipulates the master robot, a force vector data is transmitted to UEs and the slave robots at UEs regenerate the movements by the force vector data. If there is an unexpected situation such as collision or resistance, the operator can feel haptic feedback helping adjust an input control. The haptic data is compressed and packetized to connected with the wireless link over UDP in real-time.

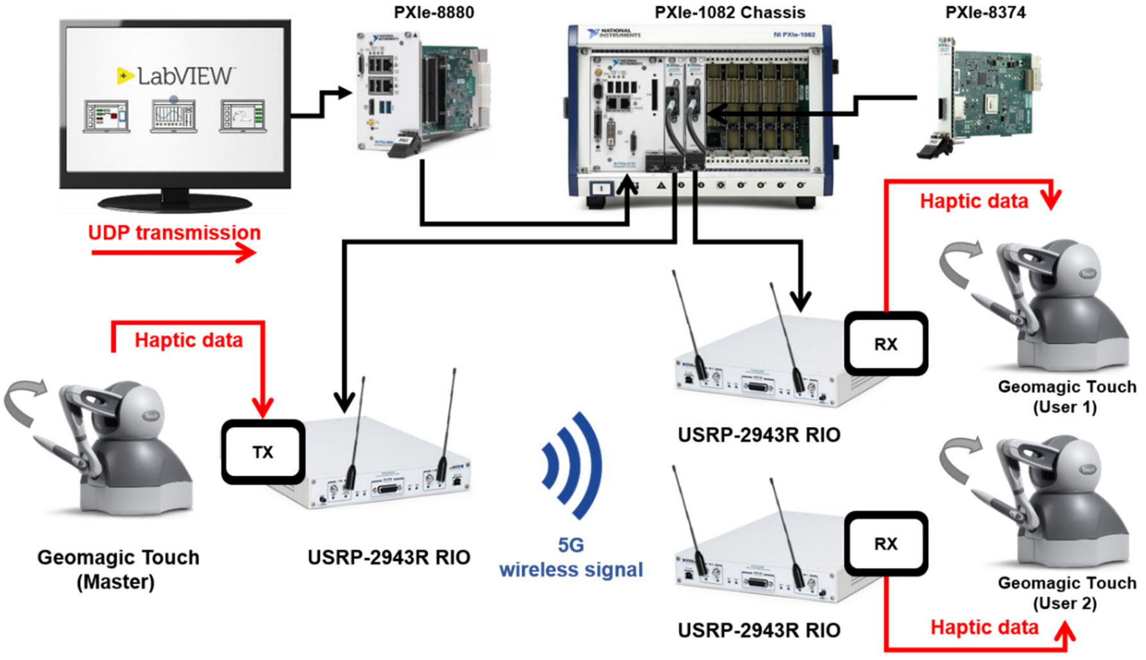


Figure 40: The system description of haptic communication demo at YU.

The demo setup consists of three robotic arms (Geomagic Touch) and software-defined radio (SDR) platform (National Instruments). The six degree-of-freedom (DoF) robotic arms are deployed at master-side and slave-side as shown in Figure 41. The wireless communication link is implemented using LaVIEW system design software on PXIe-8880 controller and the USRP RIOs to construct a network similarly to commercial 4G/5G network.

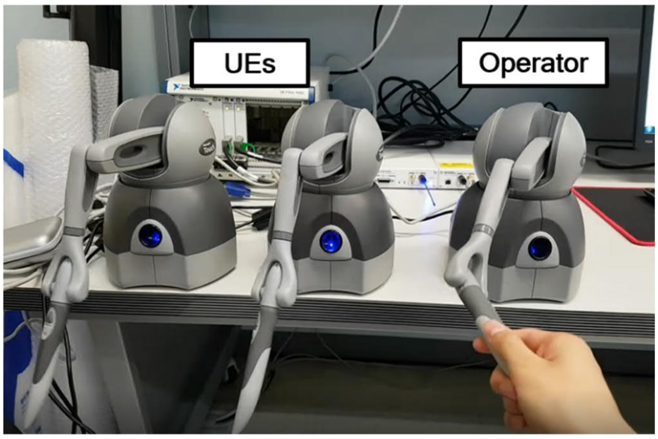


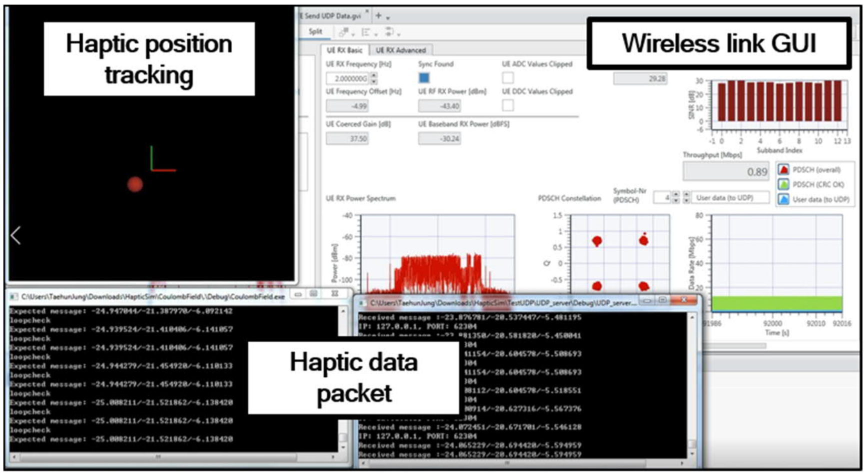
Figure 41: 3D SYSTEMS Geomagic Touch robotic arms at YU

Continued developments of the demo

This demo will continue to test various techniques to reduce the system latency and compare their performances.

Evaluation report

The graphical interface of haptic communication demo is depicted in Figure 42. The haptic positions of operator and UEs are displayed using spheres in a 3D virtual space. The haptic data packets are transmitted and received in real-time as shown at the bottom of the screen. In addition, the wireless link performances are displayed such as power spectrum, constellation, and throughput. The results of the latency tests showed that the delay incurred by wireless link (standard: 4G) was over tens of milliseconds, that means the latency should be reduced to a few milliseconds to satisfy user's quality of experience.



```
C:\Users\TaehunJung\Downloads\HapticSim\CoulombField\.\Debug\CoulombField.exe
Expected message: -24.947044/-21.387970/-6.092142
loopcheck
Expected message: -24.939524/-21.410406/-6.141057
loopcheck
Expected message: -24.939524/-21.410406/-6.141057
loopcheck
Expected message: -24.944279/-21.454920/-6.110133
loopcheck
Expected message: -24.944279/-21.454920/-6.110133
loopcheck
Expected message: -25.008211/-21.521862/-6.138420
loopcheck
Expected message: -25.008211/-21.521862/-6.138420
loopcheck
Expected message: -25.008211/-21.521862/-6.138420
```

```
C:\Users\TaehunJung\Downloads\HapticSim\TestUDP\UDP_server\Debug\UDP_server...
Received message :-23.876781/-20.537447/-5.481195
IP: 127.0.0.1, PORT: 62304
Received message :-23.981350/-20.581820/-5.450041
304
11154/-20.604578/-5.508693
304
11154/-20.604578/-5.508693
304
08112/-20.604578/-5.518551
304
00914/-20.627316/-5.567376
304
Received message :-24.072451/-20.671701/-5.546128
IP: 127.0.0.1, PORT: 62304
Received message :-24.065229/-20.694420/-5.594959
Received message :-24.065229/-20.694420/-5.594959
```

Figure 42: Graphical interface of haptic communications demo.

3 Local and intracontinental system integration plans

3.1 Overview

In this section, we provide information about the on-going activities on intracontinental demonstrations involving multiple partners in Europe or Korea. There are four demonstrations, with two involving European partners and two involving Korean partners, and they are listed below:

- D1: CMC-NI system integration and demonstrations (Section 3.2)
- D2: KCL-CMC system integration and demonstrations (Section 3.3)
- D3: YU-KT-KU system integration and demonstrations (section 3.4)
- D4: EUC-KT-YU system integration and demonstrations (Section 3.5)

The involved partners are indicated in the name of each demonstration. For each demonstration, in the following sections, we provide a short description of the system, integration plans together with a Gantt chart about the implementation timeline and a description of the planned demo scenarios.

Each demonstration, as listed above, is related to one or more use cases listed below:

- A1: Placement of communication and computing for forest firefighting
- A2: Network slice management for forest firefighting
- B1: UAV-assisted preparatory measures for smart urban firefighting
- B2: Differentiated UAV fleet management for smart urban firefighting

The use cases details are summarised in Section 1.3 and described in more detail in D1.1 [PRIMO-D11]. The summary of how each demonstration maps to the use cases is given in Table 3.

Table 3: Mapping of intracontinental demonstrations to PriMO-5G use cases

Demo/Use case	A1	A2	B1	B2
D1	X			
D2			X	
D3			X	X
D4			X	

3.2 CMC-NI system integration and demos

3.2.1 Description of system components to be used

The objective of the overall integration and demo efforts of CMC and NI is to showcase the integration of the CMC 5G core towards the mmWave capable 5G gNB from NI. The following components will be part of this demonstration:

- CMC 5G Core
- NI 5G NR gNB stack with mmWave physical abstraction layer (PAL)
- NI 5G NR UE stack with mmWave physical abstraction layer (PAL)
- NI 5G NR gNB stack with 26 GHz mmWave 8x8 antenna array
- NI 5G NR UE stack with 26 GHz mmWave 2x8 antenna array

These components will be used to integrate and showcase the PriMO-5G objectives in two different setups.

A first demo/test showcases the integration of the CMC 5G core with the NI 5G gNB. In this test CMC 5G core is running in NI premises with NI gNB running locally in Germany. The objective is to test the interoperability between a 5G core and NI mmWave gNB with PAL.

A second separate demo showcases the integration of the NI 26 GHz mmWave antenna arrays on NIs 5G gNB and UE. A more detailed overview and planning of the setups is given in the following section.

3.2.2 Integration plans

The integrated systems of the two demo setups is shown in the following. Figure 43 shows a visualization of the NI 5G NR gNB stack and the NI 5G NR UE stack.

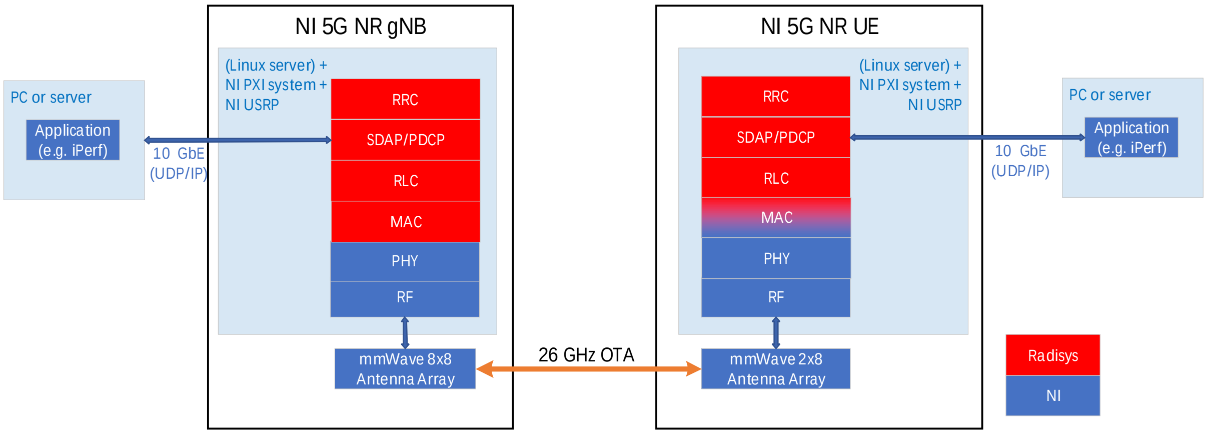


Figure 43: Integration Setup for NI mmWave gNB and UE

The goal of this integration effort is the inclusion of the mmWave antenna arrays on both gNB and UE side. This is depicted as the attachment of the 8x8 antenna array on the gNB side as well as the 2x8 antenna array on the UE side. A full stack implementation will be used on both gNB and UE side and the integration is mainly done on lower layers where control functionality for beam management needs to be integrated into the system. Furthermore, appropriate adaptions of higher layers may also need to be taken into account. The partitioning of components and layers onto different HW platforms such as NI USRP, NI PXI or Linux servers is subject to further investigation.

As the demonstration of this setup includes an over-the-air transmission in the mmWave band, appropriate RF licenses need to be prepared. We plan to use parts of the spectrum in the 5G NR band n258. Besides that, the demonstration of this setup will also incorporate mild mobility according to the use case mentioned in Section 3.2.3. Due to the overall weight of the setup, an attachment to a drone is not possible so a modeling of mobility in the demo setup needs to be achieved by mobile carts at ground level or similar.

The second integration setup is depicted in Figure 44. It shows the full NI 5G gNB and UE stack but without the mmWave PHY layer and active antenna arrays. Instead, a physical abstraction layer is used.

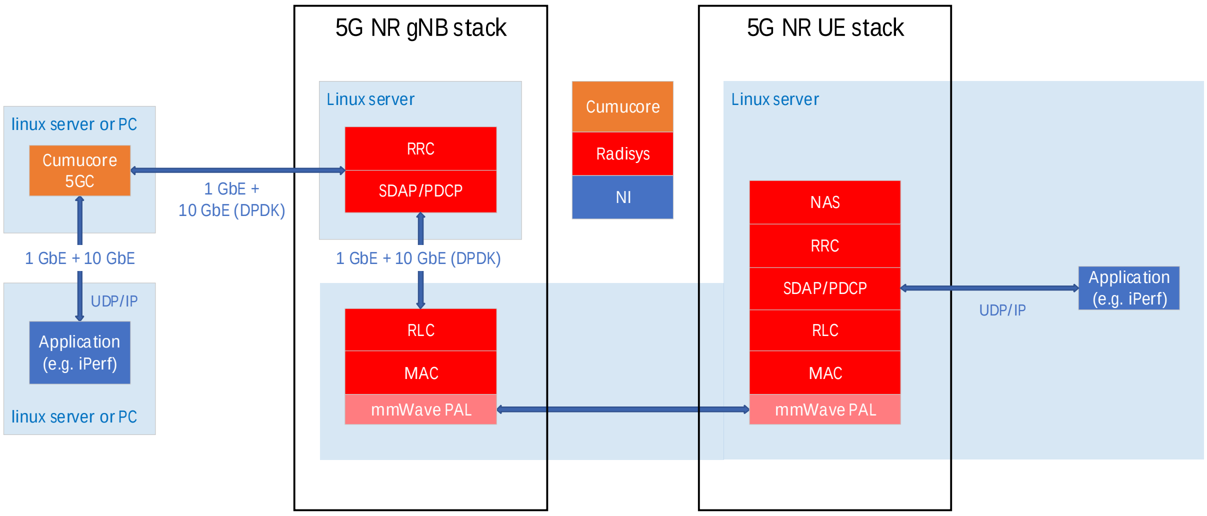


Figure 44: Integration and demo setup for 5G Core integration with NI 5G mmWave gNB and UE

This helps to still work with a complete 5G NR stack for integration but have a setup at hand that does not involve over-the-air transmission and therefore doesn't rely on RF licenses to be used. The 5G core by CMC can then be directly attached to the system. Various possibilities for MEC setups can be envisaged but are subject to a final demonstration according to the use cases considered. The partitioning of components to different server hardware will be investigated and shall suffice the requirements of the final demonstration setup.

The planning for integration of these two demo setups is shown in Table 4.

Table 4: Gantt chart of activities for CMC-NI and mmWave system demonstration

Activity	**Q2 2020**	**Q3 2020**	**Q4 2020**	**Q1 2021**	**Q2 2021**
Preparation (planning, licensing, permits, procurement etc.)	■	■			
CMC – NI 5G stack integration development		■	■		
NI 5G gNB and UE mmWave integration development		■	■	■	
Demonstration development and measurement campaign (KPIs)					■

3.2.3 Planned demo scenarios

With the two aforementioned integrated setups, demonstrations of use cases in the forest fighting scenario A1 (see D1.1 [PRIMO-D11]) are envisaged.

A demo that includes that setup with CMC 5G core and NI 5G gNB and UE can be used to present key functionality of the core network with a full 5G stack implementation. This demo shows the usage of 5G system for local deployment in a remote location without connection to main operator network. This demo will show the setup and usage of local infrastructure deployed in the location of the firefighting; Therefore, this demo is applicable to PriMO-5G scenario A. Forest firefighting with robots and UAVs.

The NI 5G mmWave transceiver system setup will be used to showcase a forest fire fighting scenario as in Scenario A1 from D1.1 [PRIMO-D11]. An incident commander in the fire truck is connected to a stationary access drone that acts as an aggregation point for uplink video streaming of surrounding video capturing drones. These video capturing drones are observing the forest fire scene and produce a video stream in the uplink towards the aggregating stationary access drone. This drone collects the different video streams and forwards the information to the incident commander for further processing. As the aggregation of video streams will require a high bandwidth, the 5G mmWave links properties of high bandwidth are favorable for these requirements. The demonstration will focus on showcasing the mmWave link and beam steering functionality while the link from the stationary access drone to the video capturing drones will be abstracted with video applications.

A final demonstration setup and use case description will be available in D5.3. The possibility to combine the two aforementioned setups for a final demonstration will be assessed during the coming project period.

3.3 KCL-CMC system integration and demos

3.3.1 Description of system components to be used

In this test CMC 5G core is running in KCL, and Aalto gNB running in Finland, see Figure 45. The objective is to test an architecture where network functions are deployed in different locations.

Figure 45 shows the setup for testing whereby KCL and Aalto are connected using a remote connectivity through Virtual Private Network (VPN). The setup consists of CMC 5G with NSA and SA functionalities running on a Linux PC at KCL, which is connected to the Aalto gNB manufactured by Nokia and 5G UE.

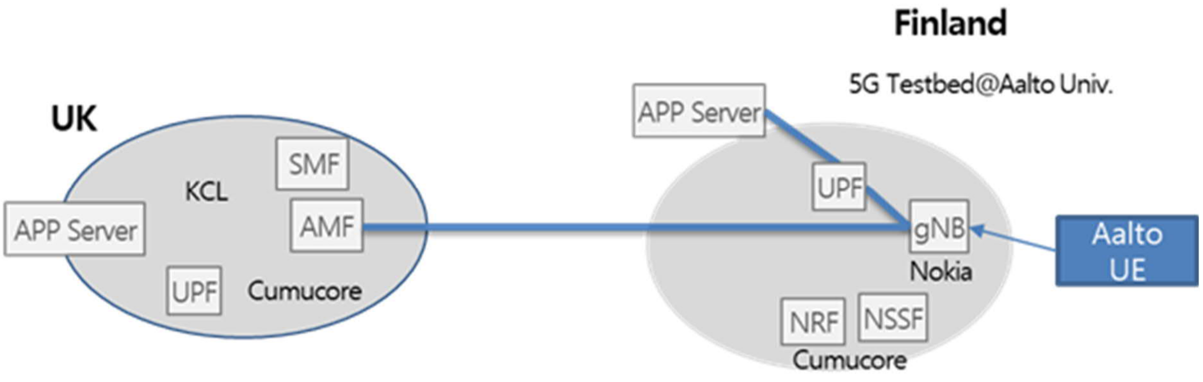


Figure 45: Intercontinental test setup CMC 5GC in KCL- gNB in Aalto

Two deployments are considered. In the first deployment, gNB that is located in Aalto communicates with the CMC core network components, such as, Access and Mobility Management Function (AMF), Session Management Function (SMF) and User Plane Function (UPF), at remote site through the intercontinental connection. While in the second deployment, the gNB will contact the default AMF which is located in KCL as part of the mobile operator but then, the default AMF will allocate a suitable UPF that is located close to the gNB.

3.3.2 Integration plans

KCL setup OpenVPN with Aalto. Aalto needs to use the configuration provided by KCL and ping KCL IP address to check the connection is set successfully.

The planned timeline for implementing the KCL-CMC demo is shown in Table 5.

Table 5: Gantt chart of activities for KCL-CMC system demo

Activity	**Q2 2020**	**Q3 2020**	**Q4 2020**	**Q1 2021**	**Q2 2021**
Preparation (planning, licensing, permits, procurement etc.)	▨	▨			
Deployment, system integration and testing		▨			
Application development and deployment			▨		
Demonstrations, KPI measurement and system evaluation			▨	▨	

3.3.3 Planned demo scenarios

As mentioned in Section 3.3.1 there are two demo scenarios considered. The two demos described in Section 3.3.1 are planned with similar functionality but changing the location of network components. This first demo will show feasibility of remotely controlling a moving object across a remote network. The second demo intends to demonstrate the scenario where mobile operator deploys local network functions in the area of the emergency situation to handle connectivity on-site where low latency is required.

However, in this delivery only the second scenario is considered, whereby the user plane is handled using local instance of the UPF in Aalto data center. This is due to proximity of the event to the gNB in Aalto premises.The KPI to be measured would be user plane latency and available bandwidth.

This demo is related to PriMO-5G scenario B1 in D1.1 [PRIMO-D11] aiming to show feasibility of UAVs in a fire scene through 5G wireless communication technology. Smart firefighting with UAVs in urban area where the mobile operator has coverage. In this situation, it's critical that the firefighters obtain the appropriate information to deal effectively with fire situation. The signaling is handled in the mobile operator cloud to provide reliable communications. However, for data plane, where UAVs need to share the status of the fire spreading among firefighters through live video streaming, the reliability and low latency are required. For this reason, data plane is handled locally where firefighting is taking place. The local deployment of data plane allows to achieve low latency.

3.4 YU-KT-KU-KAIST system integration and demos

3.4.1 Description of system components to be used

This demo is a continuous work described in Section 2.3.1. Although the demo is depicted in a single subsection, there are three main components in terms of their functional operation and the components should be integrated properly to become a representative implementation of urban firefighting portrayed in D1.1 [PRIMO-D11].

Immersive video streaming: The video captured from the UAV's camera is stitched in real-time to produce and encode the raw videos into a single 4K video; then it is captured in the onboard computer through the HDMI 2.0 cable. The captured video is transported and streamed along three routes. The first route is the route from the camera to the onboard camera, processing the video immediately on the UAV, for immediate usage. The second route is from the camera to the 5G device, then from the 5G device to the MEC or GCS through 5G. In the MEC and GCS, the videos are applied to the object detection and depth-controllable super-resolution algorithm explained in the description; and they are also viewable as a VR video using an HMD. The visual information pipeline explained above is implemented as shown in Figure 46.

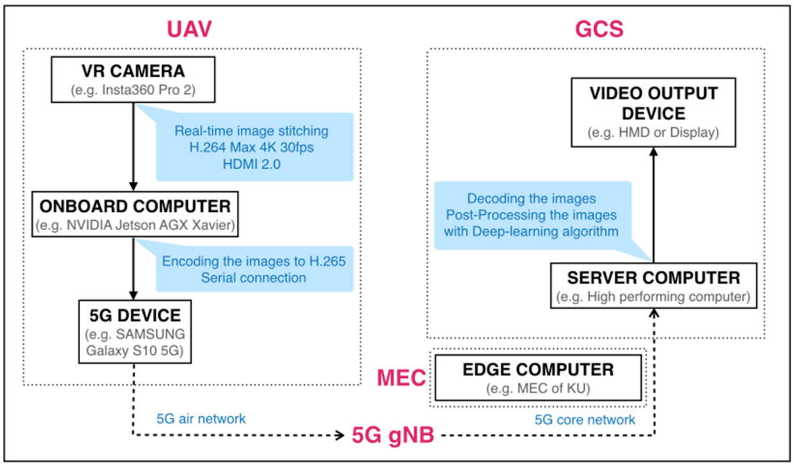


Figure 46: Pipeline of visual information from UAV to GCS and MEC

When the visual information pipeline is composed, various network protocols can be used according to network environments and the users' latency requirements. The most commonly used protocol is SRT (secure reliable transport) [SRT] which outperforms the other protocols in terms of latency performance. SRT supports low latency and high-quality video streaming by utilizing packet loss recovery through advanced low latency retransmission techniques and detecting the network performance between endpoints (packet loss, latency, jitter). On the other hand, when the latency requirement is not tight but the quality of the video should be the first requirement, we can use TCP-based network protocols that guarantee the perfect delivery of the video.

Real-time object detection: For real-time object detection, there are two intriguing points for investigation, thus requiring real-time system optimization. Seen from a distance, this problem is the epitome for two well-known tradeoffs: computation vs. communication and exploration vs. exploitation. Firstly, computation and communication tradeoff is evident from the heterogeneous computing power and latency of each computing entity, including but not limited to the UAV itself, other UAVs within the fleet, mobile edge computers, and the GCS. This tradeoff is well demonstrated in the figure below. One on pipeline, the video is processed and classified within the UAV, then transported to the server with the classification results; and on the other pipeline, the encoded video is streamed to the server then processed and classified with the server computer within the GCS.

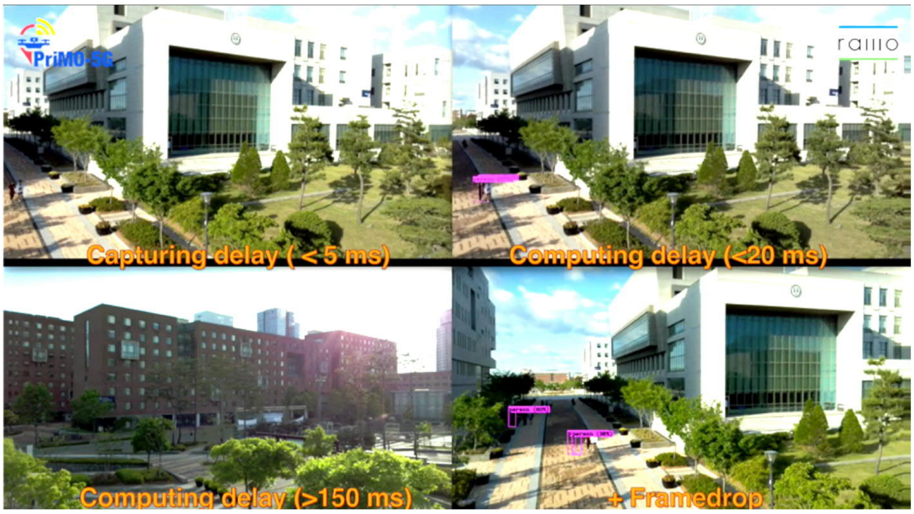


Figure 47: Computation and communication tradeoff arises from the heterogeneity of computation and communication specification of the servers: results from the 5G UAV platform located in YU International Campus, Incheon (left) and results from the GCS located

SR-based virtual bandwidth extension

The main objective of this demonstration is for enabling UAV-to-MEC communications under strict channel limitations. Note that the wireless transmission from UAV can be (i) extremely time-varying and (ii) seriously bandwidth-limited due to the unexpected UAV mobility patterns. Thus, the wireless transmission from UAV should be carefully handled.

In order to handle this problem, the approach in the demonstration is as follows. UAV transmits low-resolution video/image streams to an MEC station. The reason why low-resolution images/video is considered is to accelerate the transmission speed from UAV to MEC in order to combat the issues in the wireless transmission from UAV. The MEC station receives the image/video and then conducts super-resolution in order to increase the resolution on top of the video/image streams. Then, MEC can find target interesting objects on top of high-resolution images.

According to the fact that the streams are consistently arriving at the MEC, the MEC requires queueing systems in order to control the random time-varying arrivals. The MEC observes the queue-backlog and then if the queue-backlog is large, then it starts to control the super-resolution deep learning network to speed up the processing while sacrificing certain amounts of the accuracy for recognizing interesting target objects. On the other hand, if the queue-backlog is idle, then the MEC can control the super-resolution deep learning network in order to increase the accuracy of the recognition while sacrificing certain amounts of delays. Therefore, the demonstration software at MEC should include (i) queueing systems, (ii) super-resolution deep learning network, and (iii) delay-aware control algorithms.

3.4.2 Integration plans

The images from the UAV are provided beforehand to train the object detection and depth-controllable super resolution algorithm. Then, the trained models are implemented in the MEC and the GCS, and the real-time videos are transported to them through the pipeline using gstreamer [GSTR]. In short, the functions run on the onboard computer on the UAV, GCS, and MEC's computing servers are all wrapped up by gstreamer, thus providing a fully functional video and processing pipeline. The planned timeline for implementing the demo is shown in the following Table 6.

Table 6: Gantt chart of activities for YU-KT-KU system demo

Activity	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021
Indoor preparation (object detection and depth-controllable SR algorithm training, UAV, MEC, and GCS SW setup: gstreamer and socket programming)	■				
5G live streaming field test (UAV-GCS, UAV-MEC, UAV-MEC-GCS)	■	■			
Visual information post-processing field test (UAV ondevice, MEC, and GCS)		■	■		
E2E demonstrations including all components, KPI measurement and system evaluation			■	■	■

3.4.3 *Planned demo scenarios*

The integrated demo is closely related to PriMO-5G use case B1 (UAV-assisted preparatory measures for smart urban firefighting) and B2 (Differentiated UAV fleet management for smart urban firefighting) in D1.1 [PRIMO-D11] in that it uses pre-installed infrastructure in the metropolitan area at the urban cities. The implemented system including the intelligent drones equipped with various computational device and AI-based techniques such as object detection and SR could be a representative demo for the use case in B1. Furthermore, in this demo, a firm basis for the use case in B2 could be instantiated with several additional drones included for different classified tiers according to their functional capability.

Specifically, the UAV platform, located in YU International Campus, Incheon, captures videos of the situation from the air. The captured video is transported along the pipeline described above: to the MEC located near the platform (within 5 km radius) and the GCS in Seoul (about 40 km away) through the commercial 5G network in real-time. At the GCS, the video is processed in real-time to run object detection algorithms, then the videos are displayed on the screen or the VR HMD to monitor the remote location's immersive situation in real-time. On the MEC, after object detection is run, depth-controllable super resolution algorithms are run, accordingly to the events, to selectively zoom in to the situation.

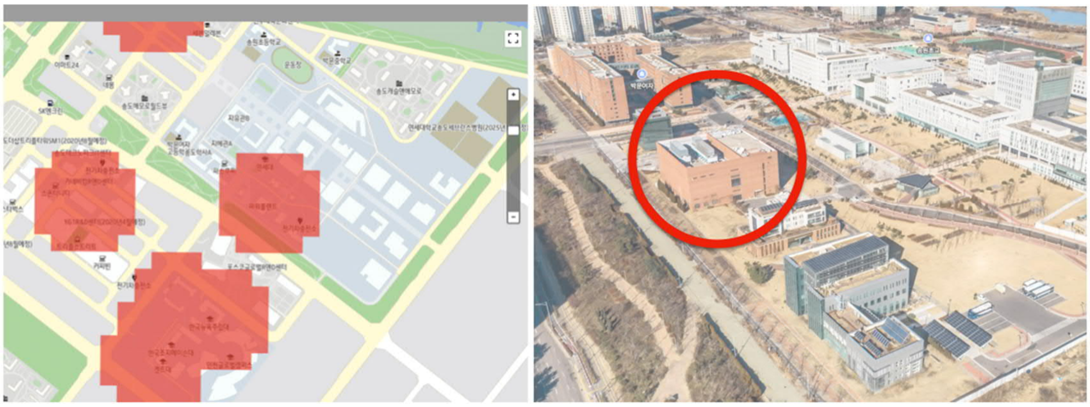


Figure 48: The location of KT 5G gNB (RU-antenna) in YU international campus from KT 5G

coverage map.

As depicted in Figure 48, the commercial 5G network uses the installed gNB in campus, allowing us to run performance tests within the coverage of the 5G network, comparing it with the performance of LTE tested under the same circumstances.

The testbed and the demonstrations are not merely concerned with high quality videos, but with immersive media. Most works and demonstrations on object detection, putting issues related to real-time latency aside, deals with traditional forms of videos. Working with immersive media brings in challenges that were not evident within the scope of traditional videos. For instance, immersive videos are captured with multiple inputs to cover the range of 180 or 360 degrees of vision. These inputs have to be stitched together to provide the user with an immersive experience, however, due to heavy computation required for stitching and more so for object detection, synchronization issue occurs depending on the timing of stitching and object detection within the entire pipeline. Also, the videos are different from traditional videos with higher resolution. Although the required size of data may be the same, the immersive videos are more sensitive to the angle and thus more prone to distortion. This distortion causes difficulties for the user’s experience, but poses further threat on the success of detection, causing rapid performance degradation for missions executed by non-human entities relying on the detection results. The demonstration planned for December 2020 (M30) will demonstrate this issue in a real setting, and a continued demonstration before May 2021 (M35) will showcase the entire system, providing a practical solution for this problem.

3.5 EUC-KT-YU system integration and demos

3.5.1 Description of system components to be used

In 3.3.2 of D5.1 [PRIMO-D51], we proposed a way to use 5G NR as a wireless backhaul of 4G LTE so that the portable base station provides the public safety service even without wired backhaul. In this test, we will try two different scenarios.

First scenario is to locate eNB in EUC portable base station, and then eNB communicates with the KT core network components at remote site through 5G backhaul. Second scenario is to locate eNB and core network components in EUC portable base station, and then communicate with the MCPTT server at remote site.

Figure 49 shows the network components and the interfaces for MCPTT. In Figure 49, the backhaul and PDN is the point where 5G NR is applied for first and second scenario, respectively.

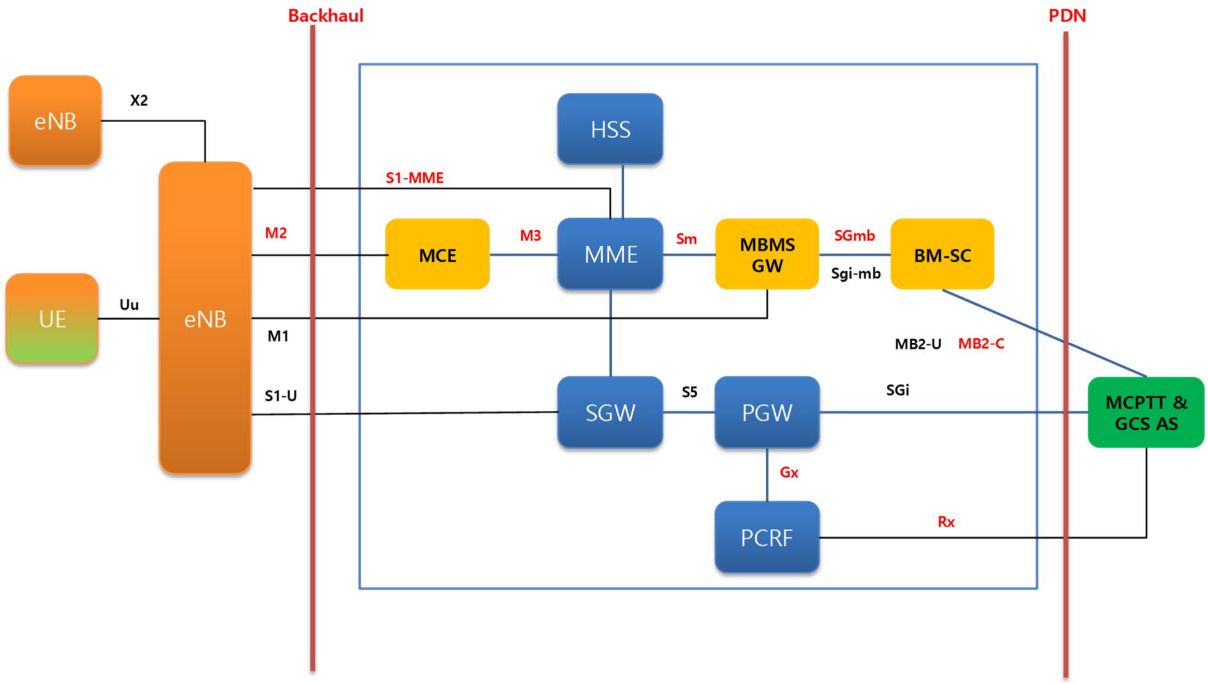


Figure 49: Network Diagram for MCPTT

3.5.2 *Integration plans*

Before the setup of scenario 1 and 2, the interoperability test based on wired backhaul and PDN connection must be done first. The tests in Section 2.3.2, is the wired backhaul based interoperability test for scenario 1.

For scenario 2, localized core network component is needed. EUC already has eNB and EPC, and the eMBMS components such as BM-SC, MBMS-GW, and MCE will be ready by 2nd half or 2020. Then scenario 2 can be tested through wired connection with PDN.

When wired connection based verification is done, then scenario 1 and 2 will be tested through KT 5G NR backhaul and PDN connection.

The overall timeline of the integration activities is summarized in Table 7.

Table 7: Gantt chart of activities for EUC-KT-YU system demo

Activity	**Q2 2020**	**Q3 2020**	**Q4 2020**	**Q1 2021**	**Q2 2021**
eMBMS feature development and verification in eNB	▨				
BM-SC, MBMS-GW, and MCE development	▨	▨	▨		

Activity	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021
Integration test with KT core using 5G backhaul			■	■	
Integration test with EUC local core and PDN connection using 5G				■	■

3.5.3 *Planned demo scenarios*

This demo is related to PriMO-5G scenario B1 in D1.1 [PRIMO-D11]: Smart firefighting with UAVs in urban area where it's critical that the firefighters and incident commander obtain the appropriate information to deal with each unique fire situation. For this purpose, they should be able to communicate with each other and UAVs. These communications are one-to-many rather than one-to-one in many cases, e.g. video streaming from UAV to share the status of the fire spreading among firefighters and incident commander, and eMBMS demonstrated in this setup is the efficient way in one-to-many communication.

As explained in Sections 3.5.1 and 3.5.2, there are two demo scenarios. First one is to demonstrate the interoperability between EUC eNB in portable base station and remote KT core network through KT 5G NR backhaul. And second one is the interoperability between EUC portable base station – including eNB, EPC, and eMBMS components - and remote MCPTT server through KT 5G NR based PDN connection.

For both scenarios, YU streaming software will be used for UE side video uploading and multicasting.

4 Intercontinental PriMO-5G system integration and demo plan(s)

4.1 Overview

The PriMO-5G system integration targets interconnection of PriMO-5G testbeds between Europe and Korea and thereafter demonstration of end-to-end immersive video services for firefighting use cases via the federated 5G network. Preliminary work for intercontinental system integration involved setup a direct high-capacity connection between the testbed at AALTO 5G test network in Espoo, Finland, and the YU – KT 5G Open network in Seoul, South Korea. This cross-continental connection, see Figure 50, utilizes national research and education networks (NRENs) to meet the QoS and security requirements needed in cross-continental testbed experimentation.

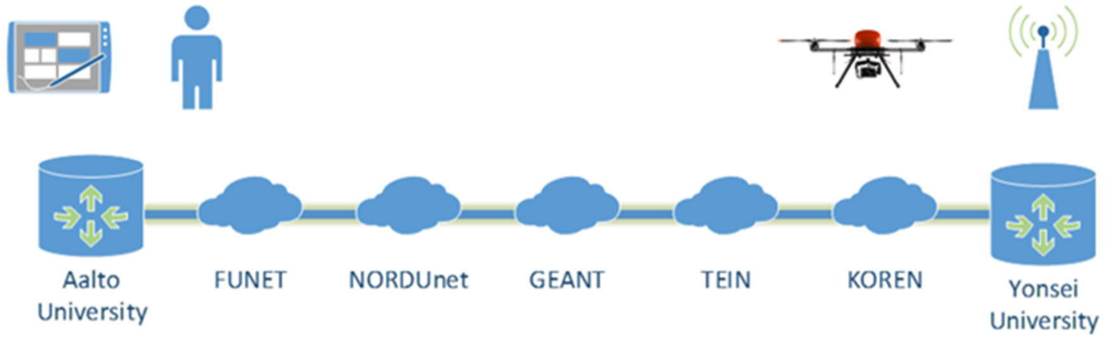


Figure 50 Intercontinental connection setup between Aalto University and Yonsei University (Note: FUNET – Finnish University and Research Network, TEIN - The Trans-Eurasia Information Network, KOREN - Korea Advanced Research Network)

The intercontinental system integration and demo activities bring together partners associated with each 5G testbed, that is, AALTO and CMC from Finland and YU, KT, KAIST and EUC from the Korean side. In terms of the linkages to WP1 use cases, the intercontinental demo links to more than one following use cases as noted in Table 8.

- A1: Placement of communication and computing for forest firefighting
- A2: Network slice management for forest firefighting
- B1: UAV-assisted preparatory measures for smart urban firefighting
- B2: Differentiated UAV fleet management for smart urban firefighting

The use cases details are summarised in Section 1.3 and described in more detail in D1.1 [PRIMO-D11].

Table 8 Mapping of intercontinental demonstrations to PriMO-5G use cases

Demo/Use case	A1	A2	B1	B2
Intercontinental D1	X	X		
Intercontinental D2	X	X		

4.2 Description of system components to be used

As noted, the intercontinental demo will leverage system components and assets provided by the two 5G testbeds in Finland and Korea. Several of these have are also been targeted for the local and intracontinental demos described previously in Section 3. These include:

- CMC 5G Core (see Sections 3.2.1 and 3.3.1) deployed both in Finland and Korea;
- 5G NR base stations (gNBs) deployed in Finland and Korea by AALTO and KT, respectively, operating at 3.5 GHz band;
- 5G connected UAVs available both in Finland and Korea;
- Immersive (VR) video capture and streaming tools (see Section 3.4.1), initially deployed in Korea and later in Finland;
- MEC platforms deployed both in Finland and Korea;
- GCS deployed in Korea (see Section 3.4.1);
- Real-time object detection and super resolution processing software (see Section 3.4.1) to run on aforementioned MECs and GCS.

Additionally, the system upgrades on the Korean testbed are being envisioned with the deployment of mmWave 5G NR base stations by EUC which will enable UAV connectivity with higher capacity mmWave links.

4.3 Integration plans

The work of intercontinental system integration commenced in Q1/Q2 2019 with the setup of the intercontinental link between the 5G testbeds in Finland and Korea as noted previously in Figure 50. The timeline for the remaining intercontinental system integration, upgrade and demo activities is shown in Table 9. This planning assumes end of lockdown restrictions by June 2020 in Finland, allowing unrestricted access to AALTO 5G testbed in Finland for start of deployed, integration and upgrade activities from Q3 2020. Otherwise, at the time of writing, the restrictions are relatively less on the Korean side allowing for full access by researchers to the 5G testbed at YU. The plan will be updated accordingly to ensure that the demo activities are conducted in Year 2021 as envisioned.

Table 9: Gantt chart of activities for intercontinental system integration and demos

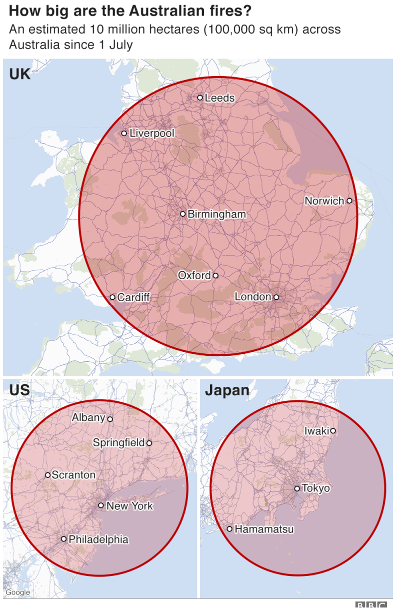
Activity	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021
Specification of the demo plans and scenarios Deployment of the experimental 5GC in Korea	■				
Iterative upgrades, integration and testing between radio and core network components in Finland and Korea (including mmWave upgrade in Korea)		■	■	■	
Deployment and testing of immersive video and MEC applications in Finland			■	■	
Conducting of intercontinental demos and repeated measurement components different scenarios and upgrades				■	■

4.4 Planned demo scenarios

4.4.1 Rationale for intercontinental public safety scenarios

The response to large scale disaster events (e.g. floods, wildfires, hurricanes etc.) may necessitate interventions from multiple first responder groups or agencies in possibly in different locations depending on the needs of the disaster event or organization or the response operation. This necessitates interagency coordination and collaboration to have a common operational picture and guarantee an overall rapid, efficient and safe responses to the event[2] [KS17]. To that end, the incident planning and management processes (e.g. situational analysis, incident assessment, action planning etc.) may be implemented by the collaborating groups at different administrative levels depending on the scale of the disaster event. For relatively small-scale events, Incident Command Post (ICP) may temporarily setup at the disaster area to provide incident identify local objectives and possible courses of action, assigns tasks to group(s) overseen by the ICP and manage resources at the disaster area. Larger scale events (covering wider geographical areas) would usually necessitate setup of multiple strategically distributed ICPs.

A recent major wildfire event in Australia engulfing a land area of 100,000 km^2 between July 2019 and January 2020 (see figure below). The scale of the fire required firefighting assistance from five countries as well as local volunteers.



The ICPs are supported by one or more Emergency Operations Centre (EOC) usually located remotely away from the disaster area. An EOC provides situational awareness and facilitates coordination of resources across different ICPs serving multiple incident areas or types. Depending on the scale of the disaster on emergency response organization in a country, the EOCs may be serving a local region or nationwide. In the cases that the disaster response requires resources beyond what could be mobilized locally, there may international assistance through deployment of emergency first responder groups from other countries. The incident planning and management in such a scenario may include ICP(s) for the international groups and their respective EOCs.

Figure 51 provides high-level example of organization of ICPs and EOCs for a disaster event with a multinational response, whereby, 5G technologies, immersive video services (extended reality) and AI are leveraged to enhance the collaborative response between the assisting country and affected country. This likely scenario provides a backdrop for the specification of the PriMO-5G intercontinental demo scenarios in the next subsection.

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[2] Karagiannis, G., & Synolakis, C. (2017). Twenty Challenges in Incident Planning, Journal of Homeland Security and Emergency Management, 14(2), 20160061. doi: https://doi.org/10.1515/jhsem-2016-0061

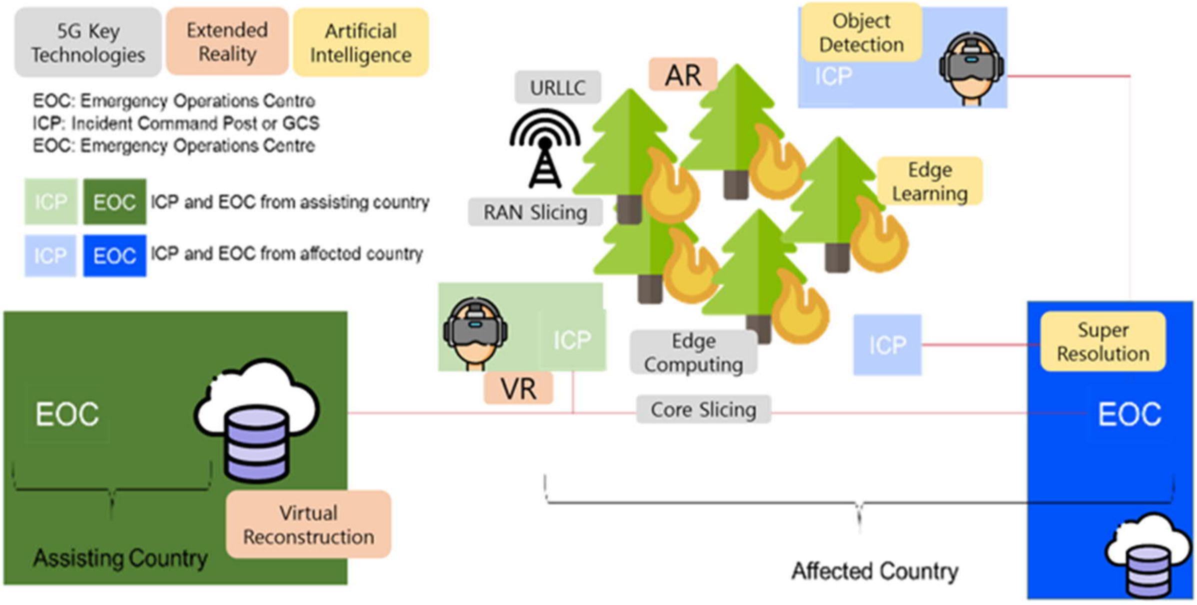

Figure 51 Example illustration of emergency response organized between two countries and leveraging various technologies.

4.4.2 Intercontinental demo scenarios

The intercontinental system demos aim at demonstrating the flexibility of 5G Service Based Architecture (SBA) that allow having different network slices where network functions can be running in different interconnected 5G networks (in this case the 5G testbeds in Finland and Korea). As the 5G SBA suggests, a public safety mission would require the architecture to be constructed in a way that is most fitting to achieve a success in its own criteria, such as, maximum public protection, fast recovery, and so on. Accordingly, an end-to-end network slice should be constructed and allocated to meet the requirements of a specific mission. To that end, in PriMO-5G intercontinental firefighting scenarios, a slice could be allocated to route traffic from UAV to a local MEC platform for processing video collected by the UAVs during firefighting event in an affected country. Furthermore, an intercontinental slice between 5G networks in assisting and affected countries, would allow for support staff at EOC of assisting country to have richer and current situation picture through immersive video transported over the slice.

Two intercontinental demo scenarios are planned with similar functionality but changing the network components. The first demo scenario will test the SBA using Network Repository Function (NRF) and Network Slice Selection Function (NSSF) for AMF re-registration from remote AMF in Korea to local AMF in Finland after discovering it includes MEC functionality as shown in Figure 52. In this demo scenario, it assumed that Finland is the affected country and Korea is the assisting country.

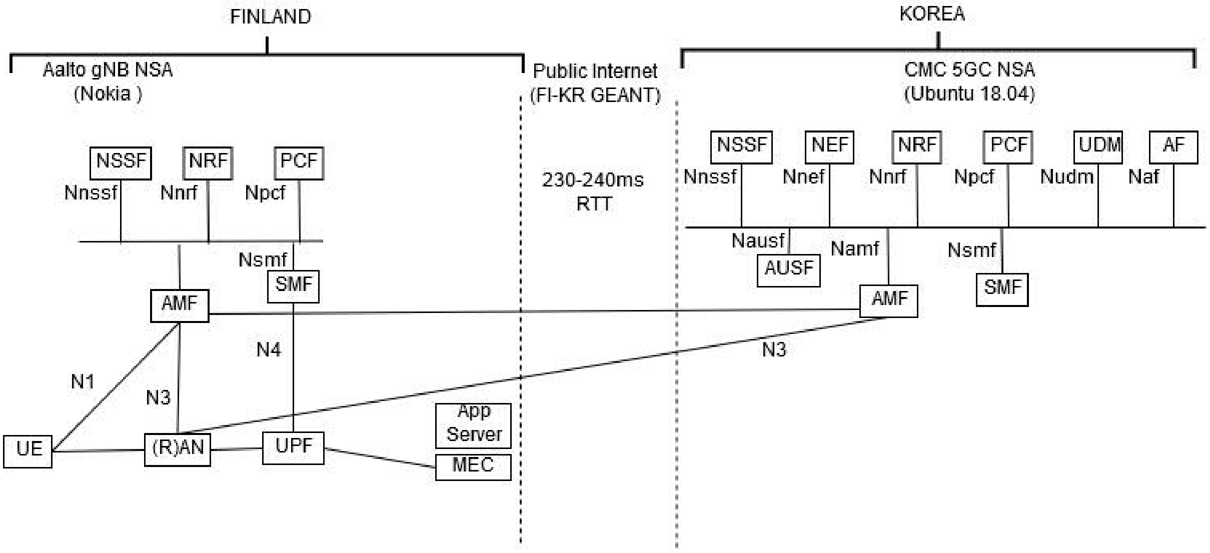

Figure 52: Intercontinental test setup with 5GC in KR and gNB in FI SA mode with SBA functionality.

This second intercontinental demo is similar to the first one, but the main difference being that it will test the 5G core interoperability with YU or KT after changing some of the components either gNB or 5GC from KT and the SBA that uses NRF and NSSF to locate optimal AMF with UPF including MEC functionality as shown in Figure 53. This setup now assumes that Korea is the affected country and Finland is the assisting country.

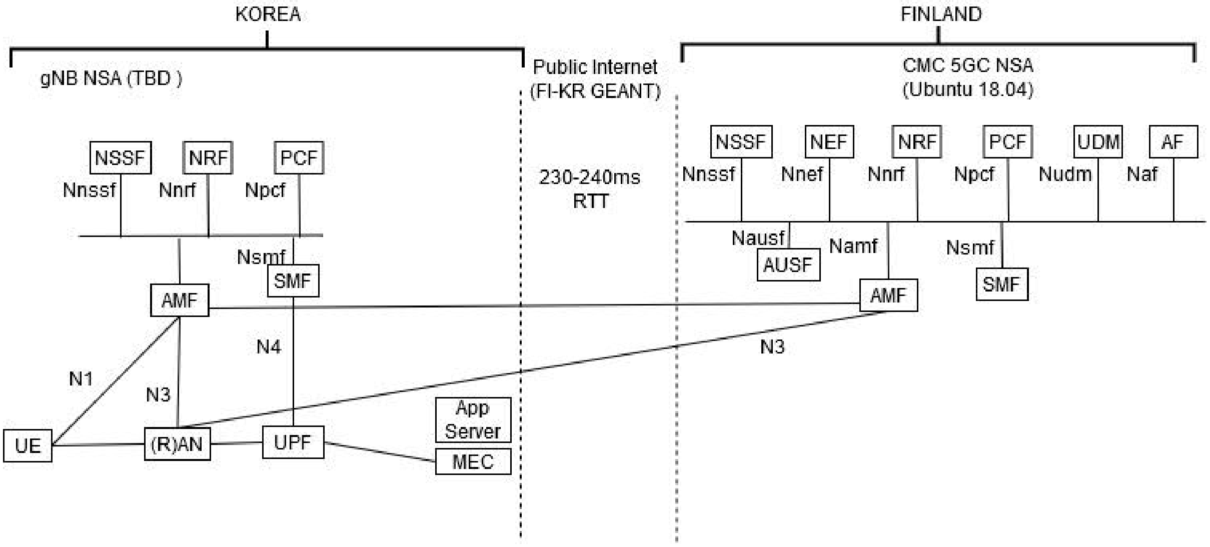

Figure 53: Intercontinental test setup with 5GC in FI and gNB in KR SA mode with SBA functionality

In both intercontinental demos, since the gNB and UE still do not support the possibility of requesting network slices, the UE (that is, 5G connected UAV) will select different APN to request from the network different slice. Thus, UE will use default APN with name e.g. Internet, and will have allocated default network functions with the associated delay. The UE will use a second APN with name e.g. FastInternet, and the default network function will search for local instances of network functions in the current location of the UE with MEC support to provide reliable and low latency communications on the site of the assumed emergency area.

The intercontinental aspect of both demos creates the need to measure and investigate impact of intercontinental connectivity on KPIs associated with PriMO-5G use cases related to these intercontinental demos (see Table 8).

5 Conclusions

This deliverable *D5.2 Intermediate report – Component demonstrations & System integration plan* reports on the component demonstrations, as well as, some of the demonstrations from testbeds with early system integration. The goal of these experimentation activities was to test and demonstrate key 5G developments in radio, edge and core networks in the context of PriMO-5G firefighting use cases according to the plan of D5.1 [PRIMO-D51]. To that end, the deliverable D5.2 has provided the description of the demo for each component or partially integrated system, as well as, the evaluation results obtained from each demonstrator. These component demonstrations are carried out in either partner sites or high-profile external dissemination events mostly within the months M12 (June 2019) to M23 (May 2020). In some cases, the deliverable also described further developments of the components (beyond M23) to further enhance the components prior to system integration or redeploy the components for standalone demos.

Furthermore, deliverable D5.2 provides plans for system integration and demonstrations within the final year of the project, that is, from month M24 (Jun 2020) to M36 (Jun 2021). In this context, system integration planned may occur within confines of testbed sites in either Europe or Korea, connecting testbeds between two European countries (intracontinental integration) or then will target interconnection of PriMO-5G testbeds between Europe and Korea. In all cases, the end-to-end system demo scenarios have been specified and mapped to PriMO-5G firefighting scenarios and use cases of deliverable D1.1 [PRIMO-D51]. For each system integration and demo plan, the deliverable describes system components to be used, the timeline for the key integration and demo activities, and the description of individual demo scenarios. The reporting of the aforementioned system integration activities and demo scenarios will be provided in deliverable *D5.3 Final report – end-to-end immersive demonstrations* that is due at the end of the project in M36.

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