5G Communication with a Heterogeneous, Agile Mobile network in the Pyeongchang Winter Olympic CompetitioN

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Deliverable D6.4
System level testing of “proof of concept” phase 2

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Abstract

System level testing of “proof of concept” phase2. (Editor: Nokia, ETRI) This deliverable provides the interim results pre-validation demonstration of the whole working system. Contributing tasks: T6.1, T6.2, T6.3, T6.4.

Index terms

5G, mmWave, algorithm, beamforming, etc.

Inputs:4.1 document, WP2.1 and WP2.2 documents, D6.1 and D6.2

Contents

List of Acronyms

3GPP	3rd Generation Partnership Project
5G	5th Generation
5GTN	5G Test network
AGC	automatic gain control
BB	Baseband
BRU	Backhaul Radio Unit
CA	Carrier aggregation
dBi	decibel isotropic
EIRP	Effective isotropic radiated power
EU	European union
GaN	Gallium nitride
GNSS	Global Navigation Satellite System
HW	hardware
IF	intermediate frequency
KPI	Key performance indicator
KR	Korea
LNA	low noise amplifier
LO	local oscillator
LoS	line-of-sight
MANO	Management and Orchestration
MIMO	Multiple-input-multiple-output
MME	Mobility Management Entity
MMIC	monolithic microwave integrated circuit
mmW	millimetre wave
MUX	Multiplexer
OIP	output intercept point
PoP	Point of Presence
PA	Power amplifier
PCB	Printed circuit board
PoC	Proof of Concept
PPP	Precise Point Positioning
QAM	Quadrature amplitude modulation
QPSK	Quadrature Phase Shift Keying
RF-DFE	Radio Frequency Digital Frontend
RSSI	Received signal strength indicator
RTK	Real-Time Kinematic
SDN	Software defined networking
SNR	Signal-to-Noise Ratio
SP	Single Positioning
TDD	Time Division Duplex
WP	Work package

Table of Figures

1 Introduction

This is a document that describes the integration and system testing results of Radio access (WP3), VNF/SDN/EPC for EU and KR (WP4) networks and integration and system results of WP5 Satelite access from EU point of view. Also Olympic 2018 demo results are included into this document.

2 Integration and system level results of Radio access EU

2.1 Key components for system implementation and integration

Main building physical building blocks of EU PoC (Proof of Concept) system are shown in Figure 1. These are described in details in D3.5 document [1]. A generic architecture of the EU PoC system is shown in Figure 2 and the system includes L2 CPU, 10Gbps switch, baseband, digital front end, RF and antenna parts. The antenna unit includes radio frequency parts and actual antenna radiators and those are described in details in [2].

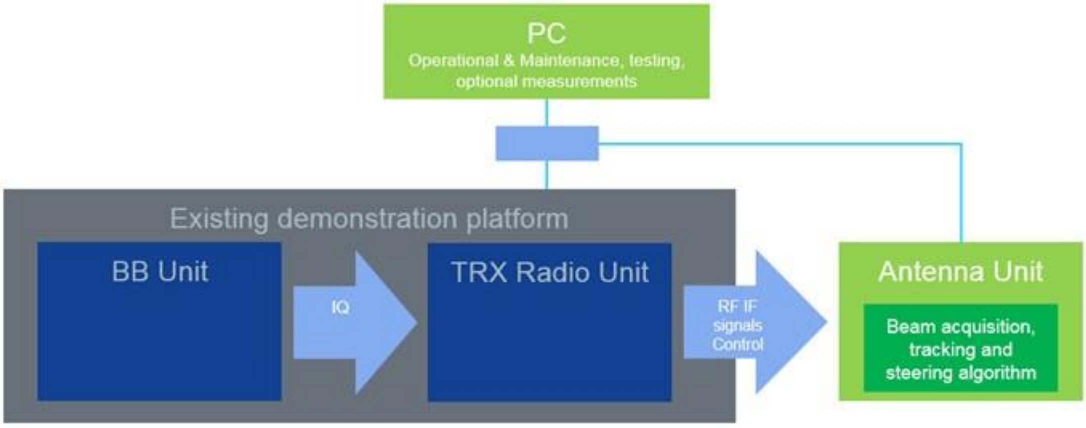

Figure 1. EU POC key components

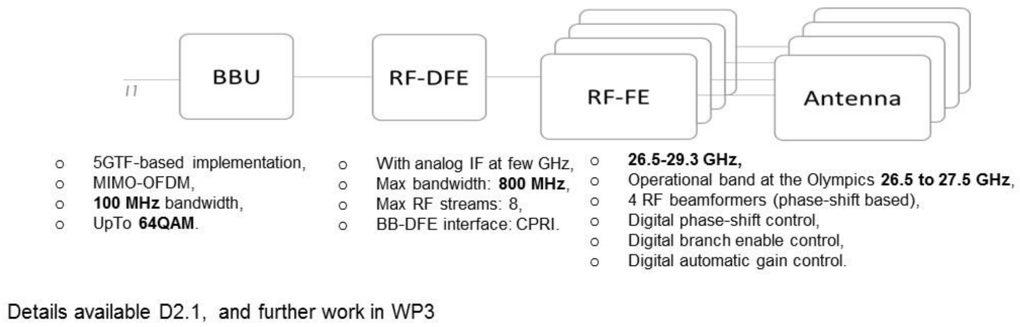

Figure 2. EU POC architecture

Figure 3 shows the block diagram of the system integration [3]. The BB unit implements a 5GTF-like / type physical layer and it is fully developed by NOKIA. It supports up-to 8 MIMO-OFDM channels, with 100MHz Carrier Component and up-to 64QAM modulation. Multiple carrier components can be aggregated in the frequency domain, reaching an overall maximum bandwidth of 800 MHz. In a configuration with 4 BB cards (maximum capacity for the DFE), 20Gbps link can be achieved. Operational frequency at 26.5-29.3 GHz, focus on 26.5 to 27.5 GHz used in the Olympics.

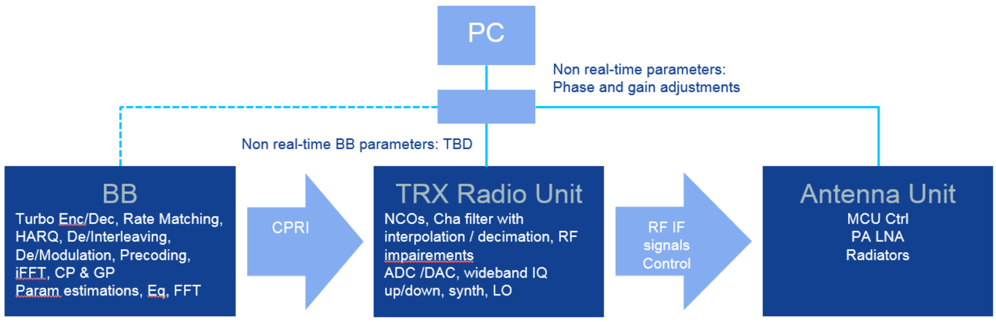

Figure 3 Functional split of different modules in the 5GCHAMPION EU mmW backhaul testbed

A block diagram of the the EU PoC antenna unit is shown in Figure 4 [4]. The block diagram presents main system blocks and interfaces to the antenna unit. The antenna unit includes three main blocks: Two similar radio (RF) boards, one AUX board and one RF digital control unit. In full operational mode, two antenna unit are used. The AUX-board which generates operational voltages of the radio unit, distributes control and clock signals. Additionally the processor board is attached to the AUX-board.

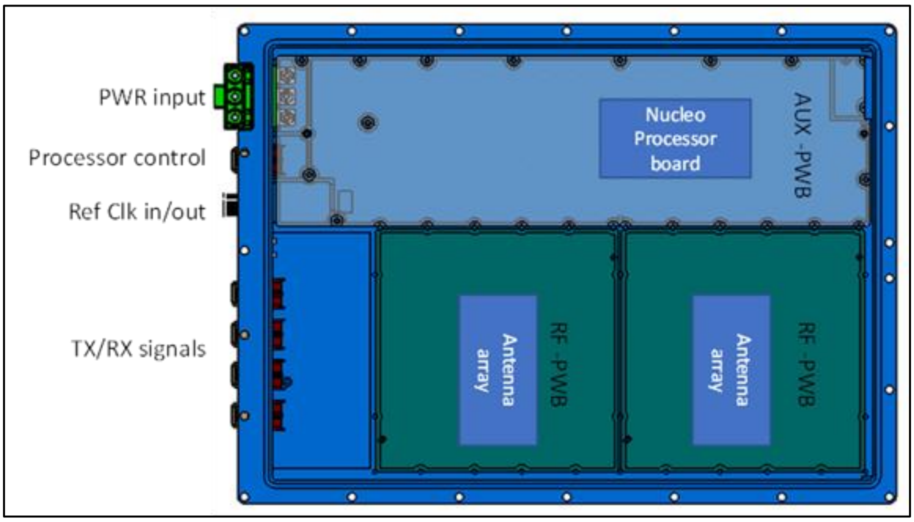

Figure 4. Block diagram of the antenna EU PoC unit

The photographs of the RF board and AUX boards are shown in Figure 5 and Figure 6, respectively [3]. The photograph of the antenna array board is shown in Figure 7 [3].

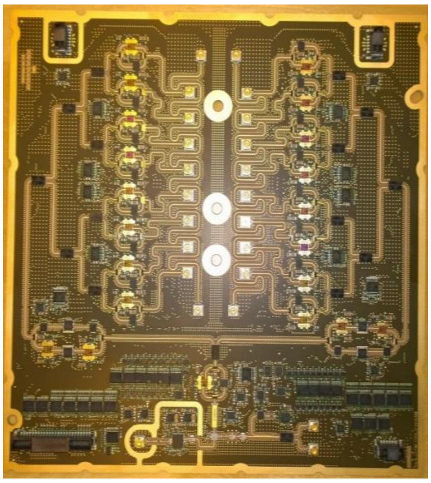

Figure 5. Photograph of RF board prototype

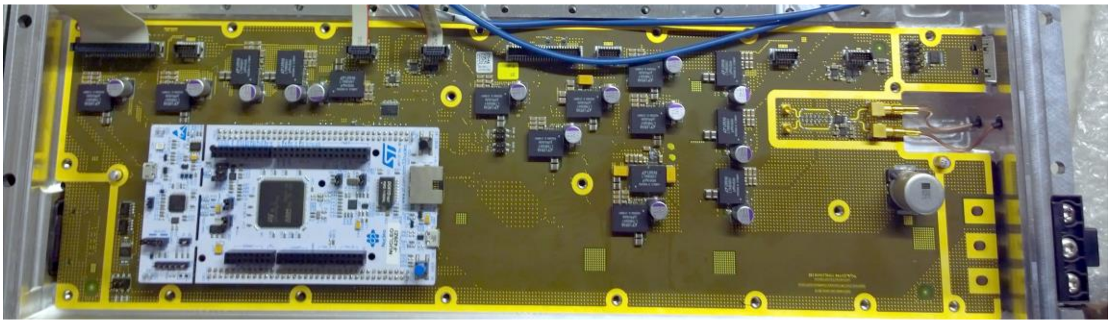

Figure 6. Photograph of the AUX board

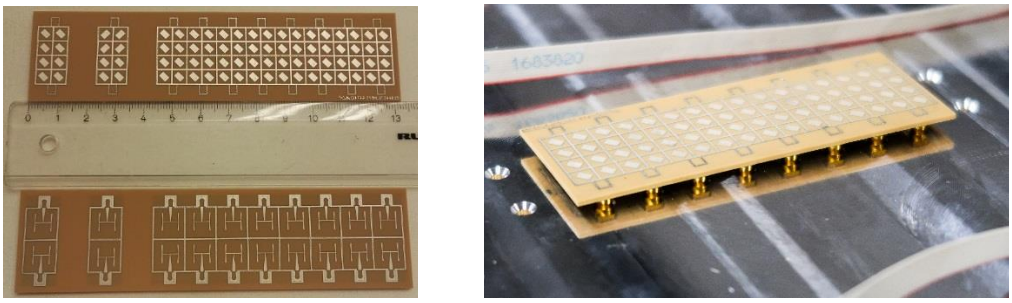

Figure 7. Photograph of the prototype antenna array..(Left) Antenna array with testing subarray. (Right) Antenna mounted on the platform

A complete EU PoC radio unit is shown in Figure 8. The photograph is taken from the front side of the unit and antennas are places behind of the front cover of the radio unit.

Figure 8. Photograph of complete radio unit of EU antenna unit

A complete EU PoC system with two radio units are shown in Figure 9. The unit at the left hand side is a base station unit and the unit at the right hand side is a mobile unit. Both units are implemented with similar hardware and the base station and mobile unit functionalities are implemented with different softwares. Both radio units are controlled with two laptop computers: one controls the base band unit and one controls the antenna unit.

Figure 9. Photograph of complete radio system of EU PoC

2.2 Integration of components and results

All physical interfaces of the radio unit has been tested and more in detail information can be found from document D3.3 [3]. An example spectrum of two carrier 5G signal is shown in Figure 10 which is tested with the antenna unit and the 64QAM constellation diagram of the component carrier is shown in Figure 11.

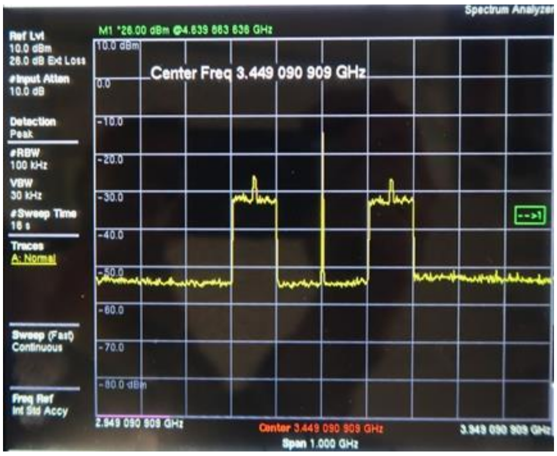

Figure 10. Two carrier component radio signal

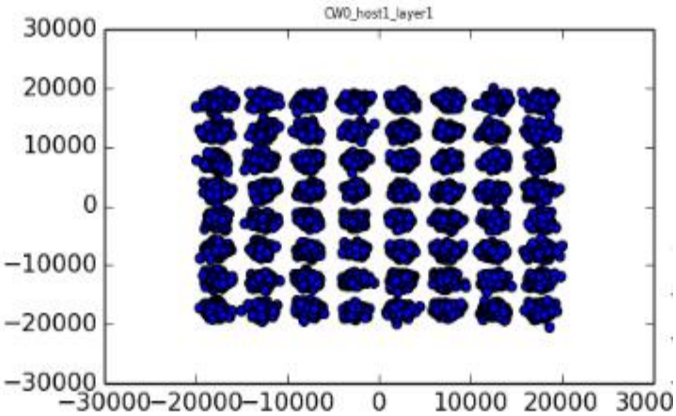

Figure 11. 64QAM signal constellation of the component carrier

The EU PoC was shown in the Winter Olympic Games in Korea and the photograph of the complete EU PoC system at the demonstration booth is shown in Figure 12.

Figure 12. EU PoC at the demonstration booth during the Olympic Games

3 Integration and system level results of Radio access Korea

Integrations for a mobile wireless backhaul system have been conducted. The integrated mobile wireless backhaul system will be used in the Olympic demonstration. The integrations are as follows:

- Integration of baseband modem, RF transceivers and antennas for a base station
- Integration of baseband modem, RF transceivers and antennas for a terminal

First, key components of baseband modems, RF transceivers and antennas are outlined. Second, the integtraions of them and testing results of the system are described.

3.1 Key components for system implementation and integration

Key components of Korean radio access system are described. It includes baseband modem, RF and antenna implementations for both MHN digital unit (mDU) and MHN terminal unit (mTE).

3.1.1 Baseband modem implementation

General baseband modem designs are depicted in Figure 13 for mDU and in Figure 14 for mTE, respectively. Both mDU and mTE modems commonly contains transport channel (TrCH) encoder and decoder, modulator and demodulator, and front-end controller. Turbo coding/encoding and cyclic-buffer rate matching/recovery are implemented at the TrCH encoder and decoder. Front-end controller is responsible for controlling and monitoring the operation of the RF front-end. In the mTE modem, cell searcher is implemented, which acquires time and frequency synchronization, frame timing, and cell identity. For both mDU and mTE modems, interfaces to the corresponding L1 controller are configured.

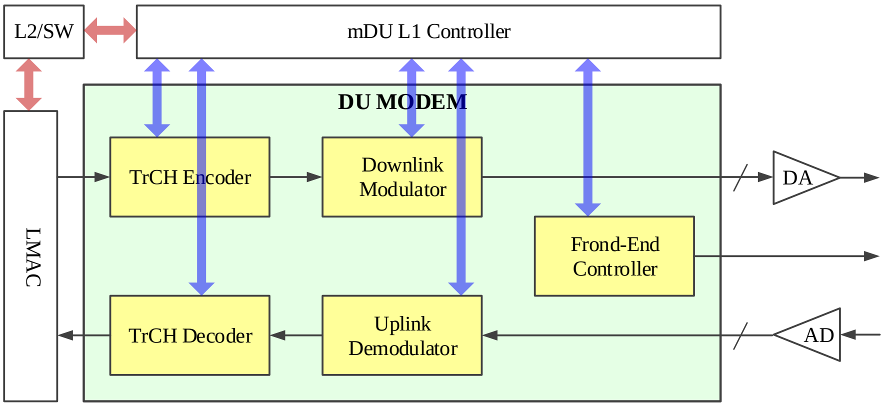

Figure 13 mDU baseband modem diagram

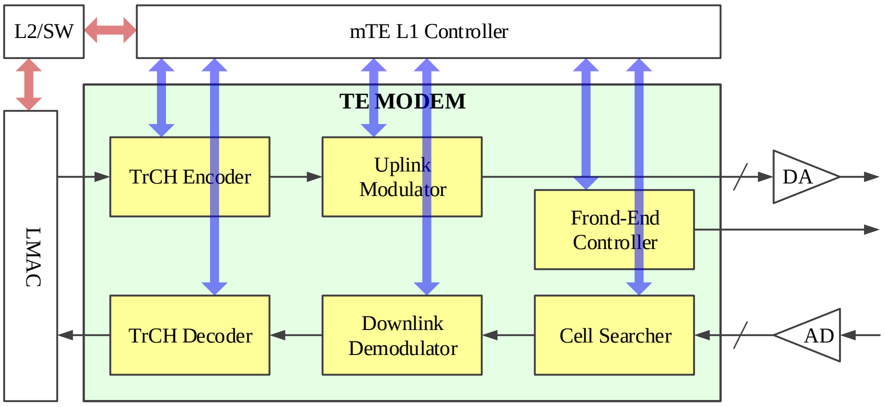

Figure 14 mTE baseband modem diagram

Figure 15 shows implemented mDU baseband modem board. Main modem funtionalities such as modulation/demodulation modules are implemented using field-programmable gate array (FPGA) (Xilinx Kintex7 UltraScale). Analog-to-digital (AD) and digital-to-analog (DA) converters operating with frequency of 1843.2 MHz is used. Micro controller unit (MCU) chip (STM32F746NGH6) is employed for L1 control. The PCIe interface is used between L2/L3 and mDU. The radio-over-fiber (RoF) is used to connect between mDU and mRU.

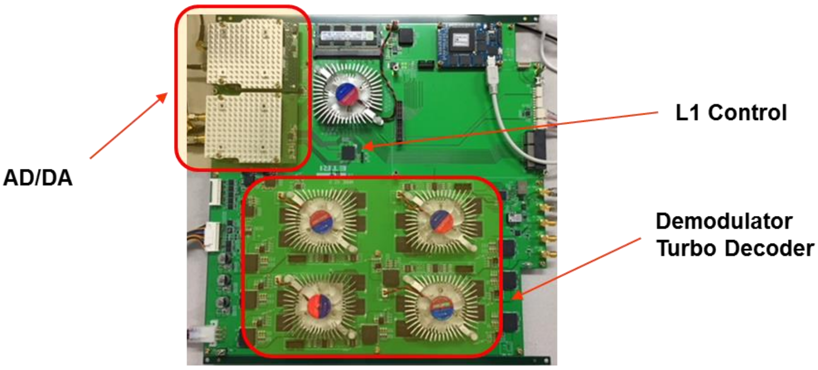

Figure 15 mDU baseband modem implementation

3.1.2 RF and antenna implementation

The RF design target is quite challenging: support for carrier aggregation of 8 component carriers (CCs) with the overall bandwidth of 1 GHz at the carrier frequency band of 25 GHz. The detailed RF design parameters are summarized in Table 1.

Table 1 RF design parameters

Common	Operating frequency	25.1432 ~ 26.1432GHz
	Band Width	1GHz
	DIF Frequency	1.3432 ~ 2.3432GHz
	TDD Switching Time	< 5usec
	TRX Isolation	≥ 55dB
TX	Output Power	> +17dBm(Avg)
	Gain	> 27dB
	Gain Flatness	± 3.0dB(TBD)
	TX Spurious	< -40dBc
	TX DIF Input	-15dBm(Total)
	TX EVM	< 4%(TBD)
RX	Noise Figure	< 8dB
	Input Level	-20dBm (Max.) ~ -57dBm (Min.)
	Gain	> 43dB
	Gain Flatness	± 3.0dB(TBD)
	Gain Control	≥ 0.5/31.5dB , ≥15dB
	DIF Output	-10dBm(Total)

The exterior and interior of mRU is depicted in Figure 16 and in Figure 17, respectively. There are 2 TX and 2 RX RF paths at the mRU. A power supply module, local oscillator module and radio-over-fiber (RoF) interface module are also included.

Figure 16 mRU exterior

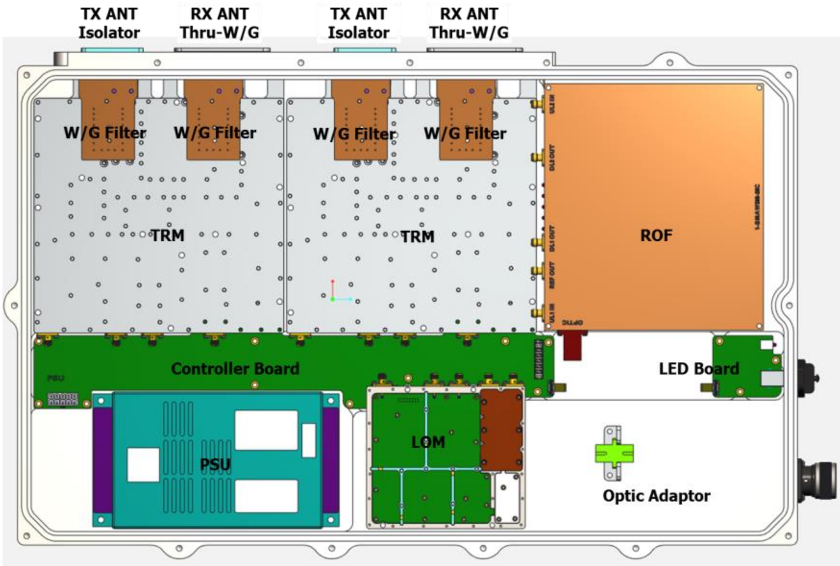

Figure 17 mRU interior

Slotted waveguide array antennas are employed as seen in Figure 18 for mRU and Figure 19 for mTE, respectively. Each TX antenna has 4x4 radiating elements with an array gain of 19 dBi. Each RX antenna has 6x6 radiating elements with an array gain of 22 dBi. The TX antenna should keep the regulatory output power in terms of equivalent isotropic radiated power (EIRP), i.e., the sum of the maximum output power and the array gain should be lower than 36 dBm. Dual-polarized transmission and reception is supported at the mRU TX and mTE RX, allowing 2x2 polarized MIMO transmission.

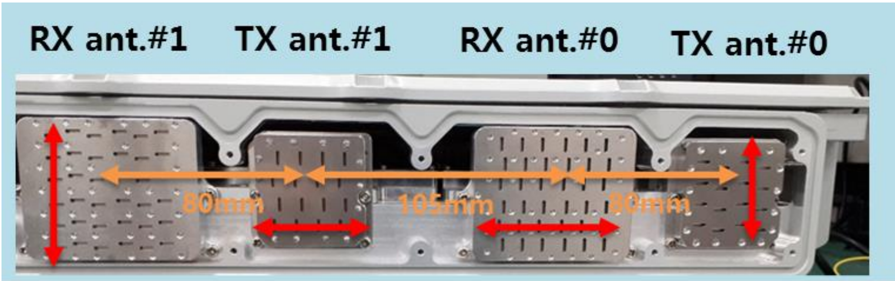

Figure 18 mRU antenna configuration

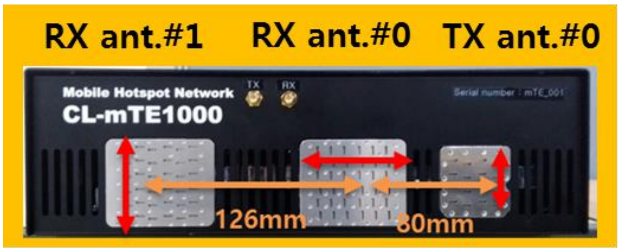

Figure 19 mTE antenna configuration

3.2 Integration of components and results

The mobile wireless backhaul system or MHN system is comprised of mDU, mRU and mTE. A base station includes one mDU and mRU pair connected through optical fiber. A terminal equipment includes a baseband modem, RF and antenna.This section describes the integration for the base station and terminal, respectively, and test results of the integrated systems.

3.2.1 Integration of baseband modem and RF for a base station

An mDU and mRU are wired through an optical fiber spool with radio-over-fiber interface to set up a base station. The mDU is normally located indoor whereas the mRU is deployed along trackside. Figure 20 shows components for the base station including an mDU, mRU and a computer for control and monitoring. The computer controls a baseband modem in the mDU and RF parts in the mRU based on the universal asynchronous receiver/transmitter (UART) protocol.

mDU Layer 1 or physical layer control software incorporates a series of functionalities as shown in Figure 21. It checks 5 FPGAs of Xilinx XCKU115 that are used for modulation and demodulation covering 1-GHz bandwidth. Then, it initializes digital to analog converters (DACs) and analog-to-digital converters (ADCs). After that it invokes RF control functions such as TDD switching, transmit/receive gain control and RoF settings. It also initializes the baseband modem by setting cell-specific transmitter/receiver parameters such as cell identities, cell types, frame structure related numbers, and etc. If these processes are done successfully, the

L1 controller awakes every 250 us to set parameters for modulation, demodulation, encoding and decoding.

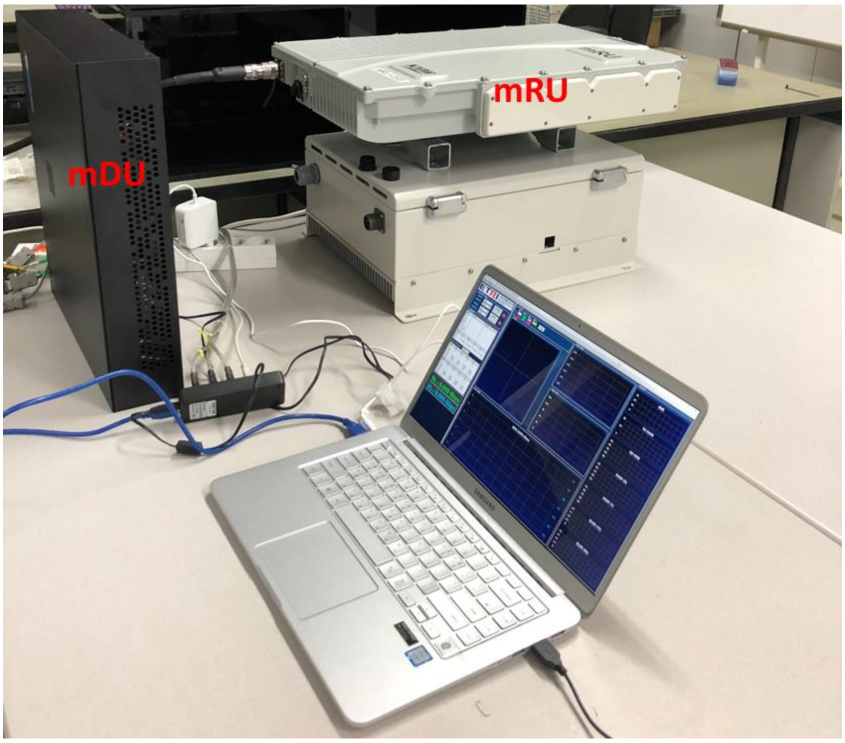

Figure 20 Equipments for a base station

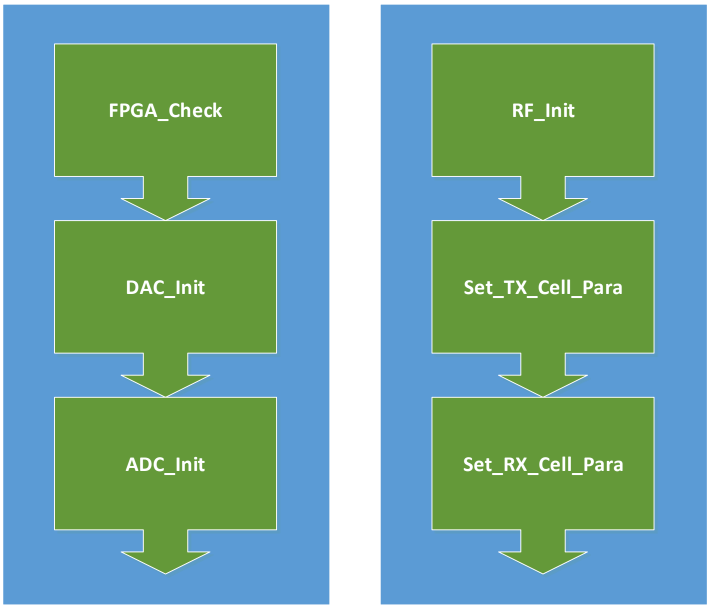

Figure 21 mDU L1 control SW functionalities

The integrated base station has the maximum capability of 5.2 Gbps and 400 Mbps for transmission and reception, respectively.

3.2.2 Integration of baseband modem and RF for a terminal equipment

Vehicles like trains and buses need to load an mTE to communicate with base stations. Figure 22 shows an mTE and a controling/monitoring laptop. Unlike the base station, the terminal equipment puts together a baseband modem, radio transceiver and antennas into a single platform. The control functions in Figure 21 also work in the mTE. Additionally, the mTE needs more routines for a terminal, e.g. automatic frequency control (AFC), automatic gain control (AGC) and cell searching. The AFC is to set the sampling frequency of the terminal to that of the base station. The AGC is to set the amplifier gain for the received signal to appropriate ranges of demodulation. The cell searching is to get an cell identifier and time synchroization. Figure 23 shows two categories of mTE L1 control functions. Initial step functions are listed in the left. An initial cell search is the first step to acquire an cell identifier and time synchronization. After the initial cell search, the L1 control software conduct AFC and AGC routines. This step is followed by time tracking and decoding of the broadcasting channel (BCH) and system information blocks (SIBs) with periodic AFC. If the decoding of BCH and SIBs are failed, the whole process repeats with different initial AFC set values.

The integrated terminal equipment has the maximum capability of 5.2 Gbps and 400 Mbps for reception and transmission, respectively. These match well with those of the base station.

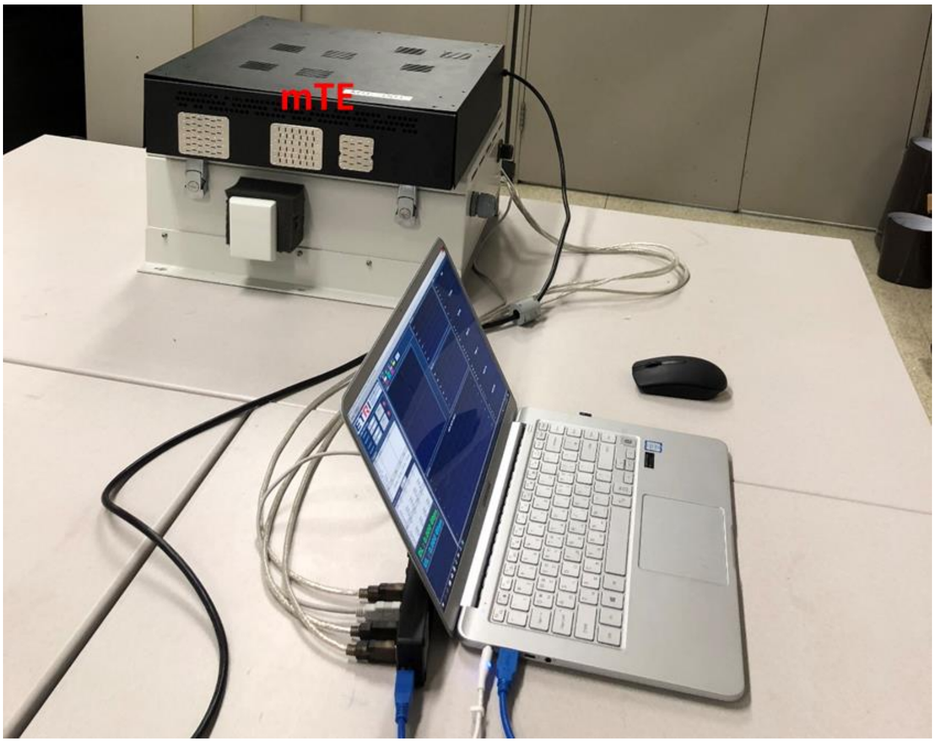

Figure 22 An mTE and a control laptop

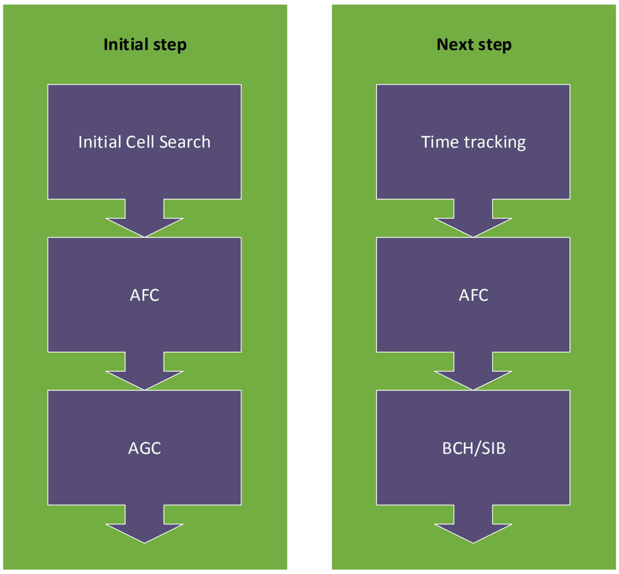

Figure 23 mTE L1 control SW functions

3.2.3 System level testing results

The integrated systems for a base staion and a terminal were tested at a laboratory as shown in Figure 24. The setup shows the mRU and mDU in the left and mTE in the right side on 1.5m x 3.7m table. Layer 1 level link between the two sides have been tested. The result can be monitored with dognostic monitoring (DM) software. An exemplary captured screen is shown in Figure 25. Four out of sixteen frequency bands are selected in the upper check boxes. Constellations, data rates, and time/frequency-domain impulse responses of received signals are drawn and updated periodically per 0.5 seconds. Transmitted signal data rates as well as received signal data rates can also be expressed in case that a feedback channel conveying ACK/NACK of the transmitted signal functions properly. In the figure, instantaneous downlink data rate of 5 Gbps and uplink data rate of 270 Mbps are shown. The green/blue line indicate downlink/uplink data rate and they are very stable since the channel doesn’t vary much under the inddor environment. Additionaly, information including block error rates, receved powers, and signal-to-noise ratios can also be expressed and updated in numerical formats in the left table.

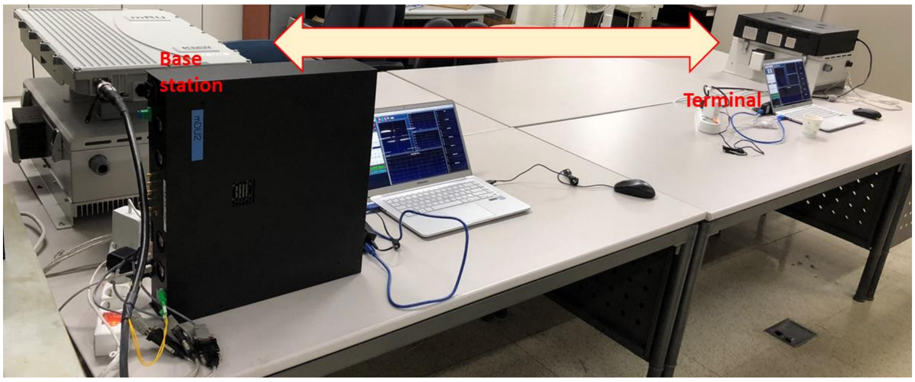

Figure 24 Indoor test setup

Figure 25 Captured screen of test results

4 Integration and system level results of VNF/SDN/EPC of EU

During the first year of the project a 1Gbps L2VPN intercontinental interconnectivity between EU 5GTN and Korea was implemented. The interconnectivity is described in details in Deliverable document D6.2 [5].

The D6.2 contains also VNF/SDN/EPC integration and system testing results. The section 2.1 of D6.2 gives a short overview of EU 5GTN test platform. EU 5GTN platform is based on Nokia commercial products.

The section 3 of D6.2 contains EU – Korean interconnectivity, integration and system test results. It contains internal testing results within EU platform, and also interconnectivity test results between EU – Korea platforms.

Interoperability of EU – Korea networks was not demonstrated in D6.2 as MANO (Management and Orchestration). The orchestration functionalities were not implemented in EU side. Also Korean MANO and Orchestration functionalities were still under development.

For interoperability demonstration and testing instead of using existing Nokia commercial based EPC, an isolated EPC test environment will be used. Reasons for this are:

- The need of SW upgrade to get existing 5GTN EPC to support MANO and Orchestration functionalities (SW upgrade is not scheduled yet),
- Lack of HW to scale out VNFs in existing environment. There is not any budget for HW investments for EU testbed in 5G Champion project.

- 5GTN EPC is used by industrial partners, which makes it not possible to tear down HW temporarily to support interoperability demonstrations.

Instead, 5GTN will offer OpenEPC for interoperability between the EU and Korean testbed as part of 5G champion project to demonstrate the dynamic life cycle management of VNFs, showcasing scalable VNF deployments. Interoperability demonstration between EU-Korean networks involves the Lifecycle management of virtual network functions (instantiate VNF, Scale VNF, upgrade/update VNF, Terminate VNF). It will make use of the Or-Vnfm interface dealing with the exchanges between NFV Orchestrator in Korean testbed and VNF Manager in EU network.

OpenEPC, a prototype implementation of the Evolved Packet Core (EPC) in compliance with 3GPP release 11/12, is developed by Core Network Dynamics. The European testbed (5GTN) offers OpenEPC, deployed at University of Oulu, as a service for research purposes to its partners. Though the current setup around OpenEPC at the University of Oulu does not have MANO support, yet the MANO platform is under development in which OpenEPC will be integrated with OpenStack using either OpenBaton or Openstack Tacker as VNFM and NFVO. The adaptation scripts build around OpenEPC, makes the dynamic deployment and re-configuration possible. OpenEPC has VNFDs and VNFC scripts for both Open Baton and Tacker. Both has NFVO, VNFM and EMS components which helps to deploy OpenEPC on cloud infrastructures. The Initial plan is to use Open Baton as a VNFM/NFVO (local). OpenBaton has a generic VNFM and a JuJu VNFM, both could be utilized but for OpenEPC VNF deployment, the generic VNFM will be used. The package management will be based on either CSAR archive following TOSCA (Topology and orchestration specification for cloud application) or TAR archive following the ETSI NFV specification for VNF descriptors and packages. OpenBaton supports additional network service descriptors (NSD) which allows to deploy the whole EPC including all the relations associated with it in a simple move and it implements a full set of lifecycle events that allows dynamic scaling implementations. Yet, currently it is impossible to reference a VNFD that has not been on boarded.

4.1 Overview

Network Function Virtualization, an amalgamation of IT virtualization techniques with communication networks, has changed the conventional networking approaches. The abstraction of network functions from the physical hardware enables network components to operate as software instances. This is achieved by decoupling network functions from the underlying hardware using a hypervisor. Such an approach makes the management of network components very flexible, scalable and dynamic. The virtualization techniques when applied to cellular networks helps reducing the capital and operation expenditures. Apart from improvement in performance, it makes a network pretty independent of proprietary hardware and make it more open for research and innovations. Management and Network Orchestration (MANO), dealing with lifecycle management and orchestration of virtual network functions, is a crucial aspect of ETSI NFV. MANO primarily consists of the Orchestrator (NFVO), the virtual network function manager (VNFM) and the virtualized infrastructure manager (VIM). NVF MANO makes the dynamic management and orchestration of VNF, possible. Network management includes fault management, configuration management, accounting management, performance management, security management, creation and life cycle management of the required virtual resources for the VNF. Whereas, network orchestration includes network service life cycle management operations such as On-board, Instantiate, scale, update, create, terminate etc. The virtualized infrastructure manager(VIM), controls and manages the interaction of a VNF with computing, storage and network resources.[1] [2]

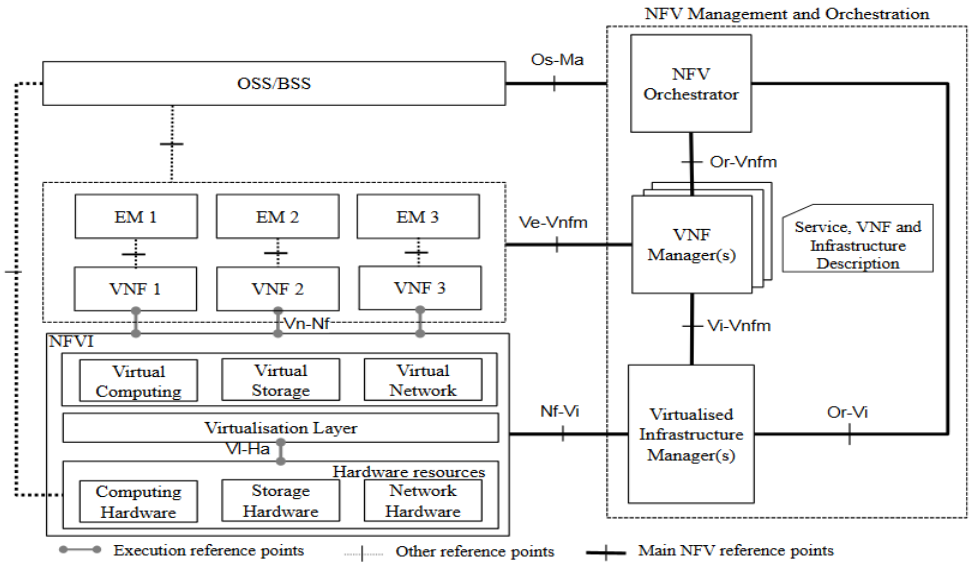

Figure 26. MANO Architectural framework[1]

4.2 NFV MANO platform in University of Oulu Testbed

5G test network at the University of Oulu, is an open network providing an infrastructure to its consortium partners which could be used for building a platform for 5G and beyond.[3] The network includes radio access network (RAN) and multiple core networks (EPC). Open EPC, a virtual 3GPP based prototype evolved packet core developed by core network dynamics (CND)[4], is one of the core element used for different research activities. 5GTN with OpenEPC as a core component provides LTE data service along with voice over LTE (VoLTE) and IMS functionalities. Also, Policy control and charging capability ensures a better quality of service (QoS). To make the network highly scalable and dynamic, MANO platform is built around Open EPC in 5GTN using OpenBaton and OpenStack. Open EPC is integrated with Open stack by making use of the OpenBaton MANO platform which provides with an NFVO and a VNFM whereas, Open Stack serves as a VIM. OpenStack VIM driver in OpenBaton ensures the integration by making a Point of Presence referring to the OpenStack endpoints. The platform is illustrated in Figure 27 where OpenEPC network components i.e. EPC-Enablers, mme, SPGW. eNodeB and EPC-Client serves as virtual network components. OpenBaton is running in a hardware locally at University of Oulu and OpenStack is used from a cloud service. For each OpenEPC VNFs, which are five in number (of which 2 are optional as they are emulation

[1] ETSI GS NFV 002 V1.2.1 (2014-12)

[2] ETSI GS NFV-MAN 001 v1.1.1 (2014-12)

[3] http://www.5gtn.fi
[4] https://www.corenetdynamics.com/products

of LTE eNodeB and UE), at least two vCPUs and 2GB RAM is required (6 Floating IPs). The choice of flavour is optional yet we used 'standard. small' flavour in the descriptor for each VNF package. Heat Orchestration within OpenStack takes care of creating the required topology for OpenEPC network functions. The NFVO and generic VNFM communicates using RabbitMQ but it could also be done using REST APIs[8]. Since, passing an image file inside the VNF package is not supported currently in OpenBaton[6] so an OpenEPC cloud image is uploaded on OpenStack prior to on boarding the VNF packages and required descriptors. Moreover, the NFVO is open to any RESTFUL API requests [5] to manage the lifecycle of network functions from outside the network.

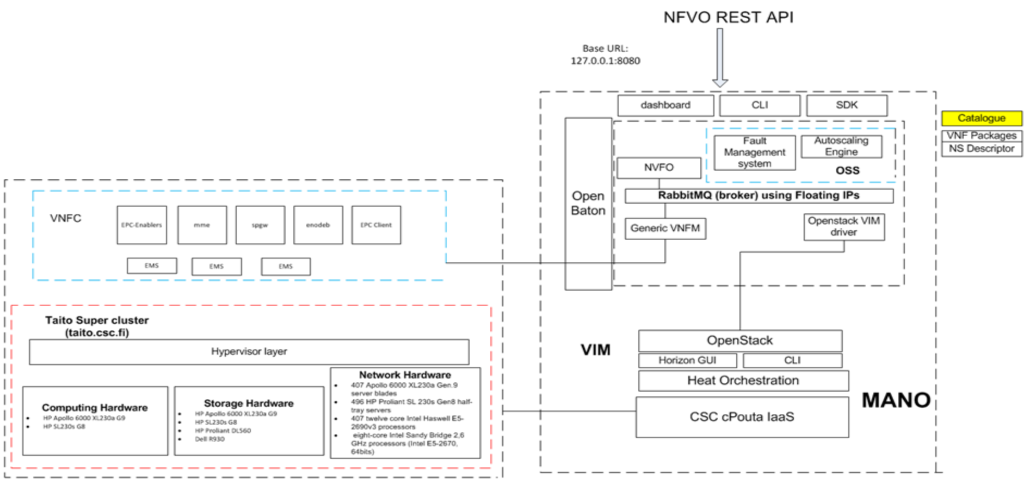

Figure 27. MANO platform in 5G Test Network, University of Oulu

4.2.1 OpenBaton: An ETSI complaint MANO platform

OpenBaton is an open source platform which is an implementation of ETSI NFV Management and Orchestration specifications. It comprises of an NVFO for network orchestration, a generic VNFM and a generic element management system (EMS) to manage lifecycle of VNFs based on their descriptors. There are driver mechanism leveraging different types of VIMs e.g. OpenStack. It also has a monitoring plugin, auto scaling engine and a fault management system.[6] The architectural layout of OpenBaton MANO is illustrated in Figure 28 which depicts all the functional blocks within the framework.

[5] http://get.openbaton.org/api/ApiDoc.pdf
[6] http://openbaton.github.io/documentation/

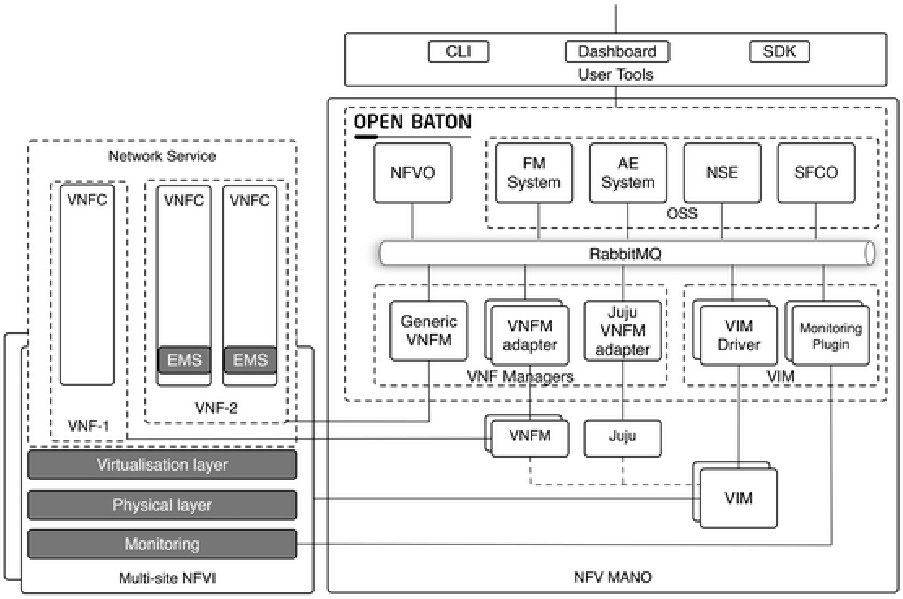

Figure 28. OpenBaton architectural framework[6]

4.2.1.1 NFVO Architecture

The NVFO is a modular software implemented in java using the spring.io framework. Every module inside it is based on the Spring Framework and the communication between NFVI and other external modules is mostly based on RabbitMQ messaging system.[7]

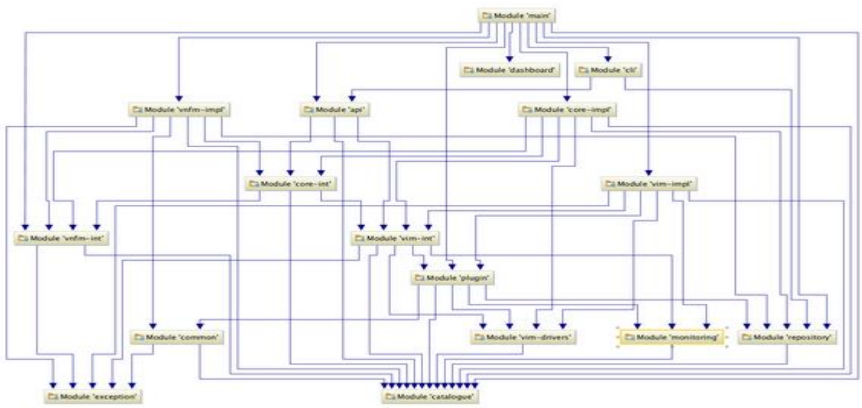

Figure 29. OpenBaton NVO architecture[7]

[7] http://openbaton.github.io/documentation/nfvo-architecture/

The modules, along with their functionalities, within OpenBaton's NFVO are listed in Table 2

Components	Functionality
API	Contains requisite classes for exposing APIs as REST server
MAIN	Contains classes which takes care of the startup of the whole system and gathering configurations
COMMON	contains classes common to the NFVO
VNFM-INT	Contains the interfaces of the core functionalities regarding NVFO interfaces to the VNFM
VNFM-IMPL	Contains the beans implementing vnfm-int interfaces
CORE-INT	Contains the interfaces of core functionalities regarding the NVO internal interfaces only
CORE-IMPL	Contains the beans implementing core-int interfaces
CATALOGUE	Contains the complete NFVO model in the OpenBaton libraries
PLUGIN	Contains the utility classes for the OpenBaton plugins interface
VIM-DRIVERS	Contains the interface for the VIM plugins
EXCEPTION	Contains the exception classes common to projects containing OpenBaton libraries
MONITORING	Contains the interface for monitoring OpenBaton plugins
SECURITY	Configures the security mechanisms used in NFVO
VIM-INT	Contains the interfaces of the core functionalities regarding NVFO interfaces to the VIM
VIM-IMPL	Contains the beans implementing the vim-int interfaces

Table 2. Modules within OpenBaton's NFVO[7]

4.2.1.2 Generic VNFM

Working as an intermediate component between the NFVO and the VNFs, the generic VNFM is an implementation of ETSI GS NFV-MAN 001 V1.1.1 (2014-12). It interoperates with the Element Management System (EMS) to complete the lifecycle of a VNF. The EMS is actually an agent inside the VMs which executes scripts contained in a VNF package or defined through scripts-link inside the descriptor for each package. Communication between the NFVO and EMS is handled by the VNFM using the AMQP protocol over RabbitMQ.[8]

The VNFM sends commands to the EMS and the EMS executes commands locally in the VNFC.[8] Figure 30 illustrates the flow of messages while instantiating virtual network functions.

[8] http://openbaton.github.io/documentation/vnfm-generic/

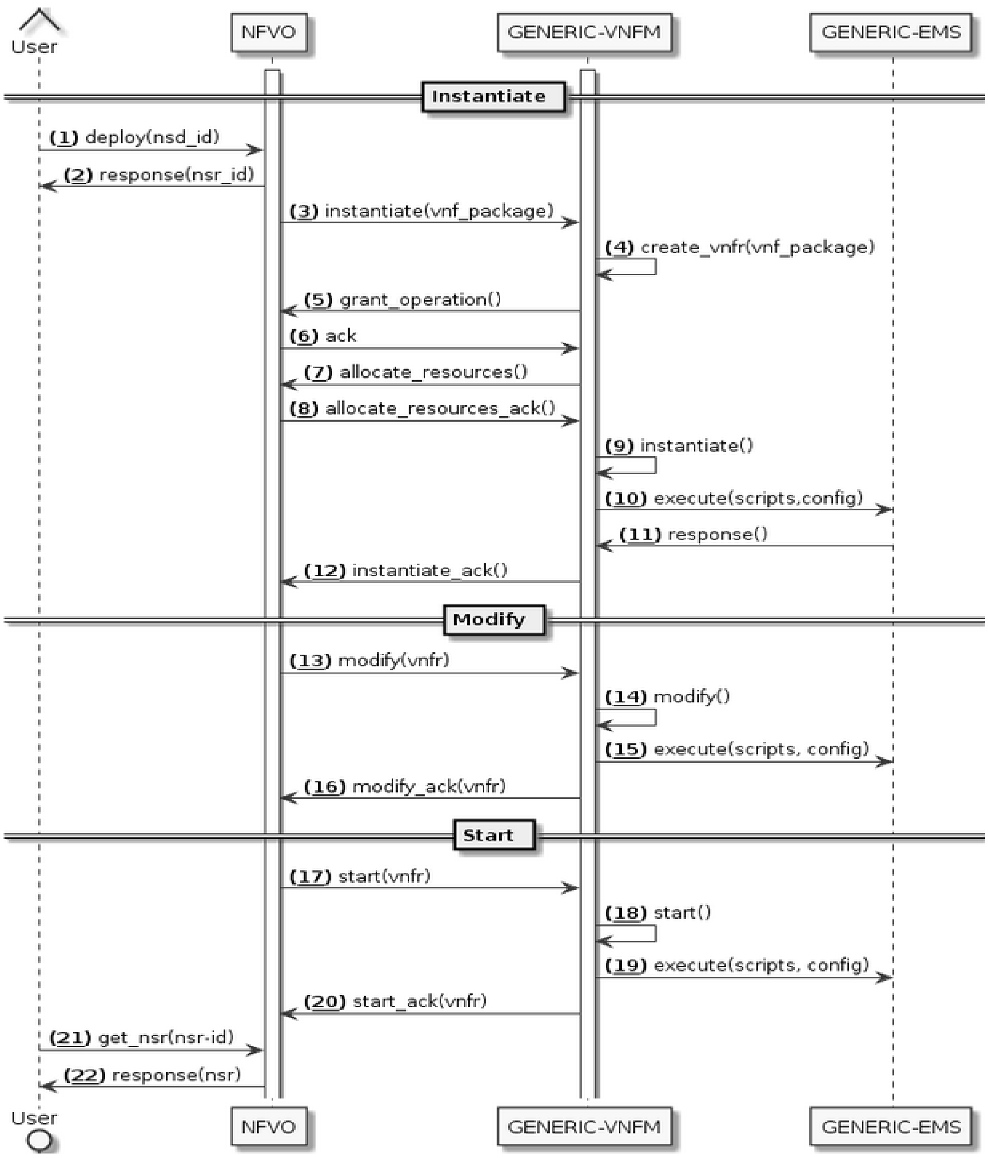

Figure 30. Instantiation flows[8]

The 'INSTANTIATE' message typically comprises of VNF Descriptor and some other parameters requisite to create VNF Records like Virtual Link Records. The message is directed towards the Generic VNFM for Virtual Network Function Record creation which is then sent back to the NFVO into a 'GrantOperation' message which triggers NFVO to check availability of resources. If there are enough resources of that VNF Record, 'GrantOperation' message with the updated VNF Record is sent back to the Generic VNFM. The Generic VNFM then forms an 'AllocateResources' message with the received VNF Record and sends it to the NFVO. Having created the VMs, the NFVO sends back the 'AllocateResources' message to the VNFM. Now, the scripts contained in the VNF Package is sent to the EMS and the Generic VNFM will call for the execution of each script defined in the VNF Descriptor. Once all scripts are executed without an error, the VNFM sends 'Instantiate' message back to the NFVO.[8] The modify and start messages inside the flow as shown in Figure 30 again follows the same steps as explained earlier where the NFVO sends a message to the VNFM (modify/start/stop in this case). The VNFM then executes scripts in the VNF descriptor and returns it back to NFVO[8]. Since, VNF instantiation can either be done with resource allocation done by NFVO or with resource allocation done by VNF manager so the generic VNFM uses the former approach for VNF instantiation flows[8]. The following two types of messages will be sent to the NFVO:

GRANT_OPERATION message: It checks the availability of resources on a selected PoP. If the message is returned, then it is an indication of enough resources unless otherwise, an ERROR message will be sent.[8]

ALLOCATE_RESOURCE message: It directs the NFVO to create all the resources. If no errors occurred, allocate_resource message will be returned to the VNF manager.[8]

4.2.1.3 OpenBaton Catalogue

4.2.1.3.1 NS Descriptor

The network service descriptor (NSD) in OpenBaton is in compliance with ETSI GS NFV-MAN 001 V1.1.1 (2014-12) and is used by the NFVO for deploying network services. It supports both JSON file representation and TOSCA template. name, vendor, version, vnfd, vld and vnf_dependancy are some requisite parameters while making an NSD. The virtual link descriptor (VLD) depicts the virtual links required for inter VNF connectivity. The VNFD uses the network description defined in the VLD while creating network.[9]

4.2.1.3.2 VNF Descriptor

Each VNF package has a virtual network function descriptor (VNFD) which the NSD will also have as part of description for each package. name, vendor, version, type and endpoint are the requisite parameters inside a VNFD. Also, it has virtual deployment unit (VDU) which comprises of image list, PoP list, scale_in_out, vnfc. When a network service is launched, each VNFC will run on a different virtual machine. Apart from that, there are also other parameters like virtual link (pointing to a VLD defined in the NSD), Lifecycle events (INTANTIATE, CONFIGURE, START, TERMINATE; SCALE_IN), Deployment Flavour and inter-VNF dependencies.[10]

4.2.1.3.3 Network Service Record

Initially, the network service record (NSR) created upon launching the network service descriptor is in NULL state. Once, the instantiation is finished in the VNFM, the virtual network function records (VNFR) will set to 'INSTANTIATED'. The NSR will also change to INSTANTIATED state when all the VNFR are in INSTANTIATED state. Now, when the START

[9] http://openbaton.github.io/documentation/ns-descriptor/
[10] http://openbaton.github.io/documentation/vnf-descriptor/

message is sent to the VNFM and returned, the NFVO sets the VNFR state to ACTIVE. When all the VNFR are in ACTIVE state, the NSR will also change its state to ACTIVE. The similar change of state will be followed in case of MODIFY and TERMINATE states.[11] The VNF record states is illustrated in Figure 31.

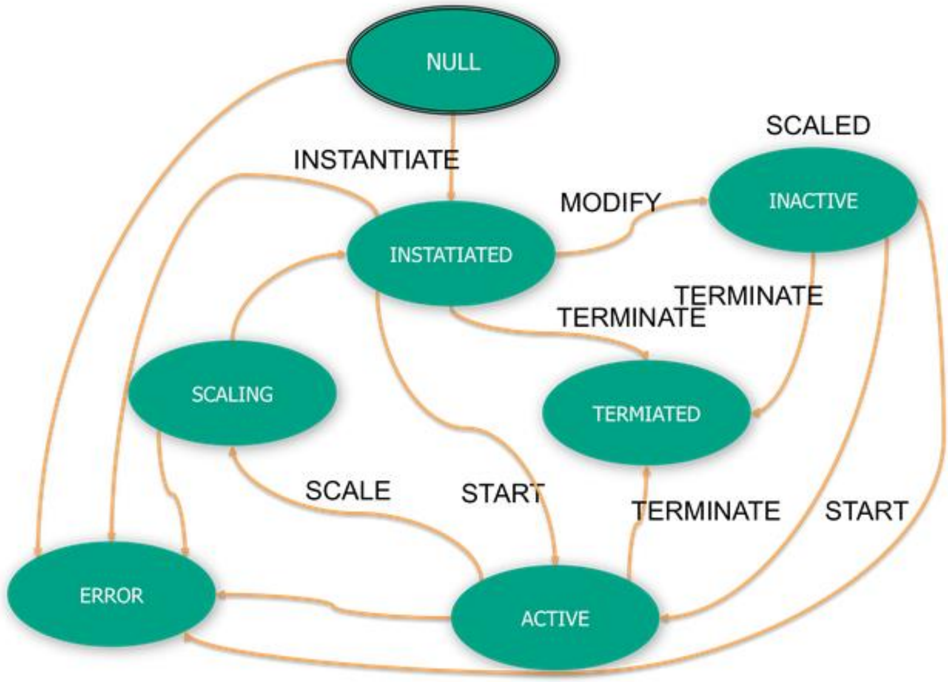

Figure 31. VNF Record States[11]

4.2.2 OpenStack as a VIM

The controlling and managing NFVI compute, storage and network resources within a Point of Presence (PoP) is handled by the virtualized infrastructure manager (VIM)[12]. Before instantiating any resources on a PoP, we should inform the NFVO. Depending on the choice of VIM, different drivers are required. In our case we need an OpenStack VIM driver to integrate our OpenStack instance with OpenBaton, as they are running in different hosts. So, initially installation of OpenStack VIM driver is requisite. We can then register a PoP by writing a JSON script containing the details of the PoP. We can either use the CLI or the dashboard for this purpose. name, auth-url, tenant/project ID, username, password and type are the parameters, mandatory while registering a PoP. It could be all added inside a JSON file or manually added while registering a PoP.

[11] http://openbaton.github.io/documentation/vnfr-states/
[12] http://openbaton.github.io/documentation/pop-registration/

4.2.3 Open EPC virtual machines as VNFs

EPC Enablers, mme, spgw, enodeb and epc-client are OpenEPC virtual machines which would be used as VNFs on OpenStack. Initially, we created the network topology by using heat orchestration on OpenStack. For that we need to write a script in heat template for OpenEPC and launch a new stack. Once, the creation of stack is accomplished then we can see the created network on OpenStack. The created network topology and graph from OpenStack is illustrated in Figure 32 and Figure 33, respectively.

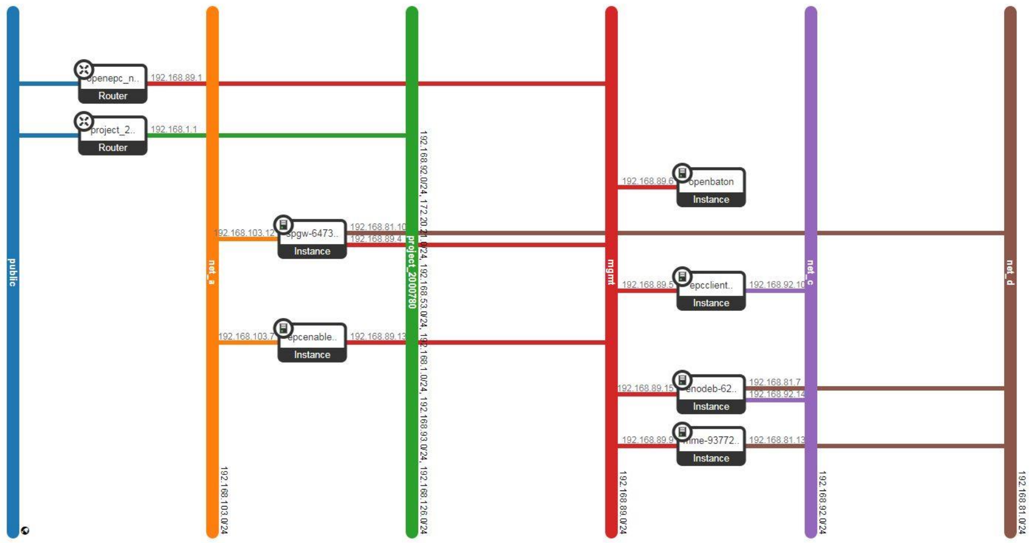

Figure 32. Network Topology (copyrights corenetwork dynamics)

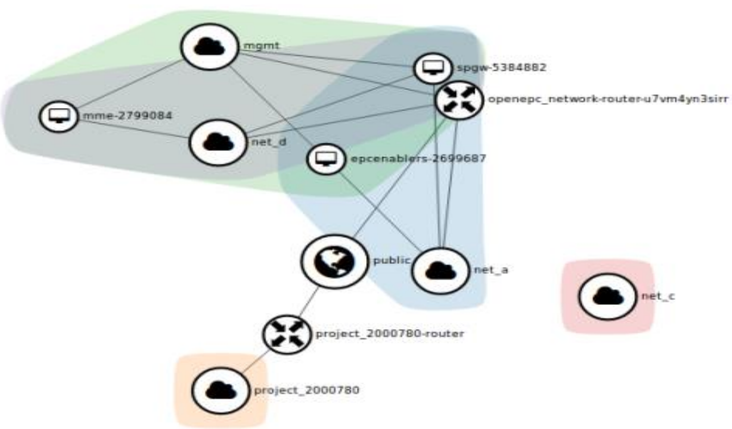

Figure 33. OpenEPC network graph (copy right corenetwork dynamics)

4.3 Multi-vim NFVO-VIM based Interoperability

The interoperability between different virtual EPCs is approached by instantiating EPC nodes of OpenEPC and OpenAirInterface corenetwork (OAICN) in different VIMs. The idea is to instantiate, modify and scale VNFs from NSDs in OpenBaton which is created based on the VNF packages created for each EPC.

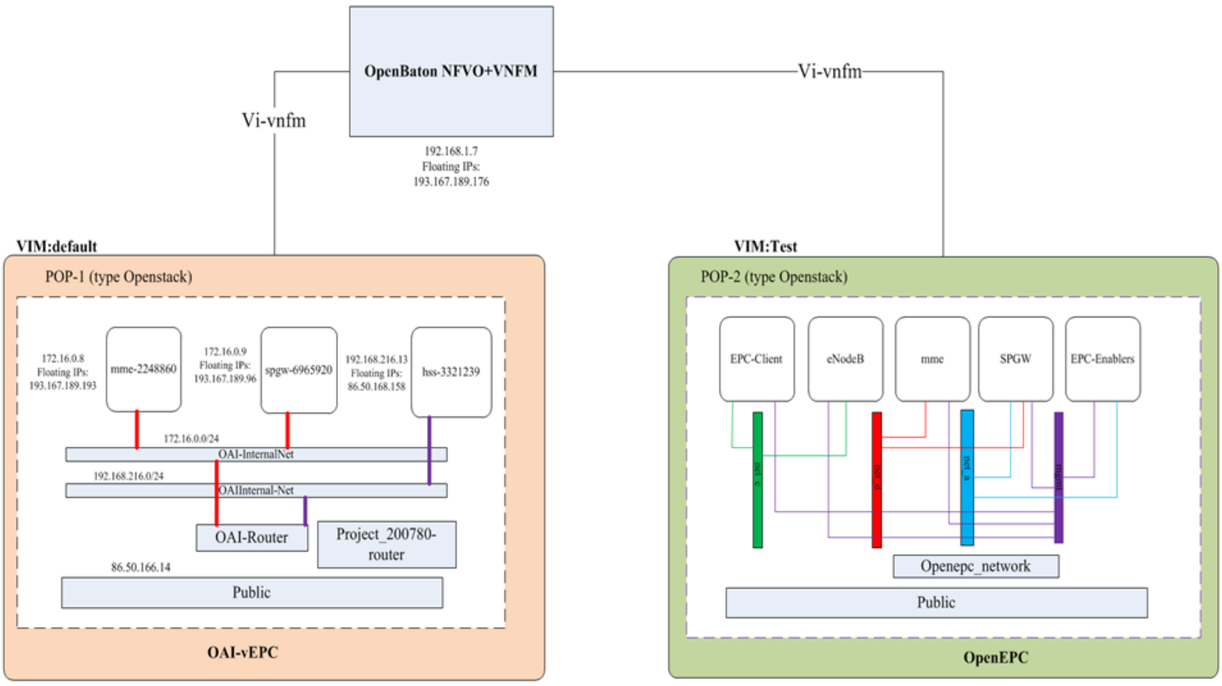

Figure 34. Multi-Vim deployment using OpenBaton NFVO/VNFM

Figure 34 provides with a view of multi EPC deployment in different OpenStack run times utilizing a single orchestartor. The VNF in each VIM i.e default and Test can then be modified, instantiated and scaled dynamically.

5 Integration and system level results of VNF/SDN/EPC of Korea

5.1 System overview

Figure 35 Photograph of the Korean MANO system during the Olympic Games

Korea's 5G mobile core (Evolved Packet Core, EPC) features can be divided into three major.

First, by separating the 5G mobile core function into a control plane and a transmission plane and defining these granular functions as VNF, we have implemented a high agile and flexible 5G mobile core. Secondly, based on NFV MANO, we can deploy 5G mobile core function at any time and provide 5G mobile core service with lifecycle management. Finally, the 5G mobile core is provided with an auto-scaling function that allows real-time monitoring of the state and scale-out of functions as needed to accommodate service requests.

During the PyeongChang Olympic Games, South Korea's NFV MANO system was installed in Daejeon and Gangneung areas and distributed 5G mobile cores in two regions. The MANO system in the Daejeon region is equipped with full functionality of NFV MANO including Orchestrator and acts as a global Orchestrator including management of European 5G mobile core. The MANO system in Gangneung consists of VNFM and VIM and was installed in Gangneung ICT Square in conjunction with the Pyeongchang Olympic Games. On the NFV MANO system in the two regions, the 5G mobile core was operated as a service for the purpose of 5G mobile core PoC demonstration.

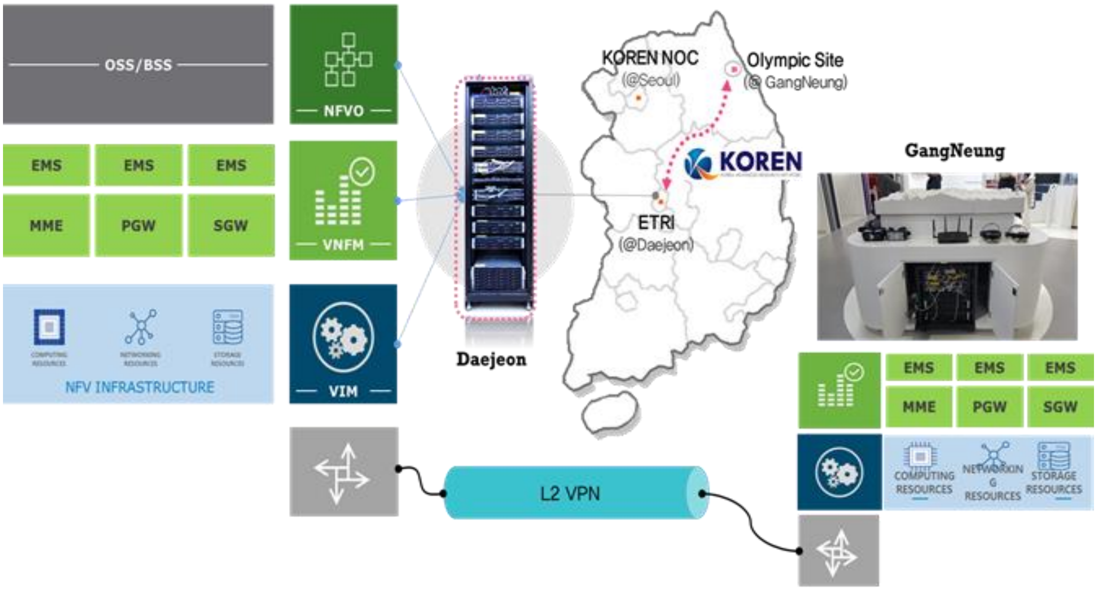

Figure 36 Multi-site 5G Mobile Core Deployment

Especially, mobile terminals connected to 5G mobile core service operated by NFV MANO system in Gangneung area work with European application services. 5G mobile core terminals must be connected to KOREN L2VPN network for interworking between Europe and Korea in order to link with European application servers. On the other hand, in order for 5G mobile core terminals to access the Internet, the 5G mobile core must be connected to the KOREN Public network. For this dynamic configuration, Gateway (GW) was added to the NFV MANO system in Gangneung area.

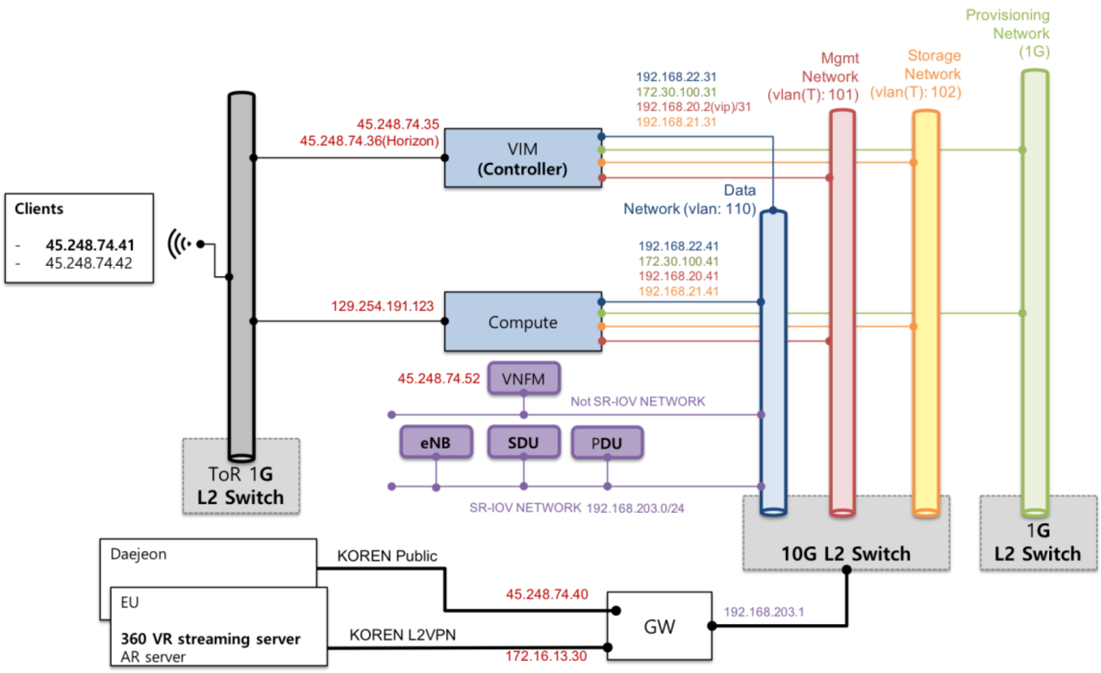

Figure 37 Gangneung site 5G Mobile Core Network Configuration

5.2 Test results

For evaluation of distributed mobility management in vEPC environment, we assume that vEPC components are deployed independently on each edge PoP (Point of Presence). Handover between PoPs means that the PGW of the previous PoP performs as a home anchor and the PGW of the new PoP acts as an access node. Until now, we did not modify current EPC components yetm but adding new components to provide DMM mechanism between two edge PoPs.

5.2.1 Testbed Design

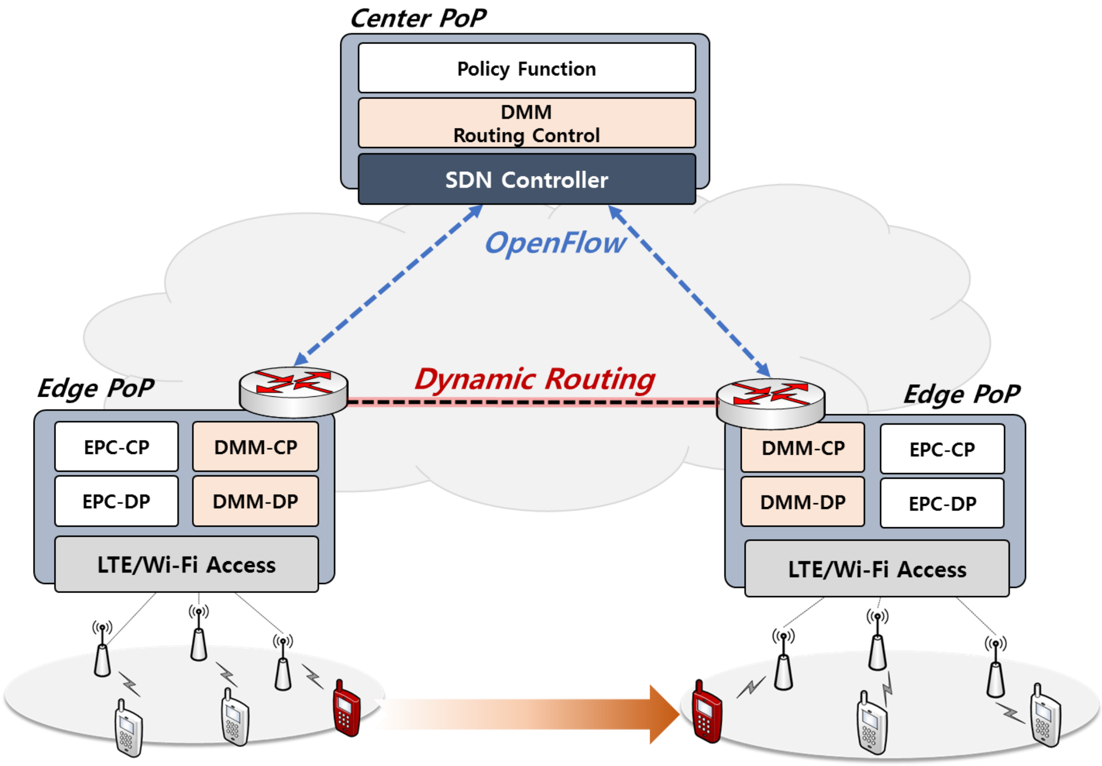

Figure 38 - Testbed for DMM

- DMM CP functions of edge PoP exchange mobility signaling messages with the DMM Routing Control function located in the core PoP to query information of current MN's location, address of anchor node. The DMM CP function also updates location of the MN to the DMM Routing Controller when the MN attaches to its PoP.
- DMM DP function is deployed as a GW of its edge PoP and it forwards traffic of MN between edge PoPs by using dynamic routing configuration based OpenFlow.
- For SDN-based routing, the SDN controller in the center PoP configures forwarding rules based on policy function in the center PoP and movement of MN.

5.2.2 Message flow

5.2.2.1 Initial attachment flow

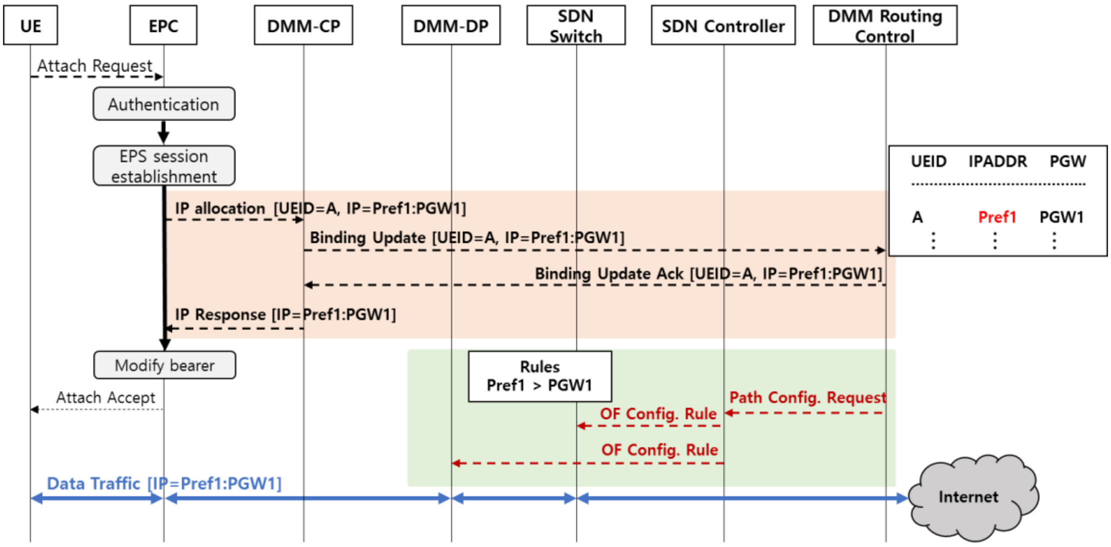

Figure 39 - Initial attachment message flow

- In the edge PoP, authentication procedure and the EPS bearer establishment process are performed in a standardized way
- The DMM routing function in the center PoP, determines that the UE attaches at the first in the network, updates information of the UE in the binding table, and sends the Binding Update Ack message to the DMM-CP.
- When the DMM binding table is updated, the corresponding information is sent to the SDN controller to push the forwarding rules to the DMM-DP at the edge PoP using OpenFlow Config message.

5.2.2.2 Handover flow

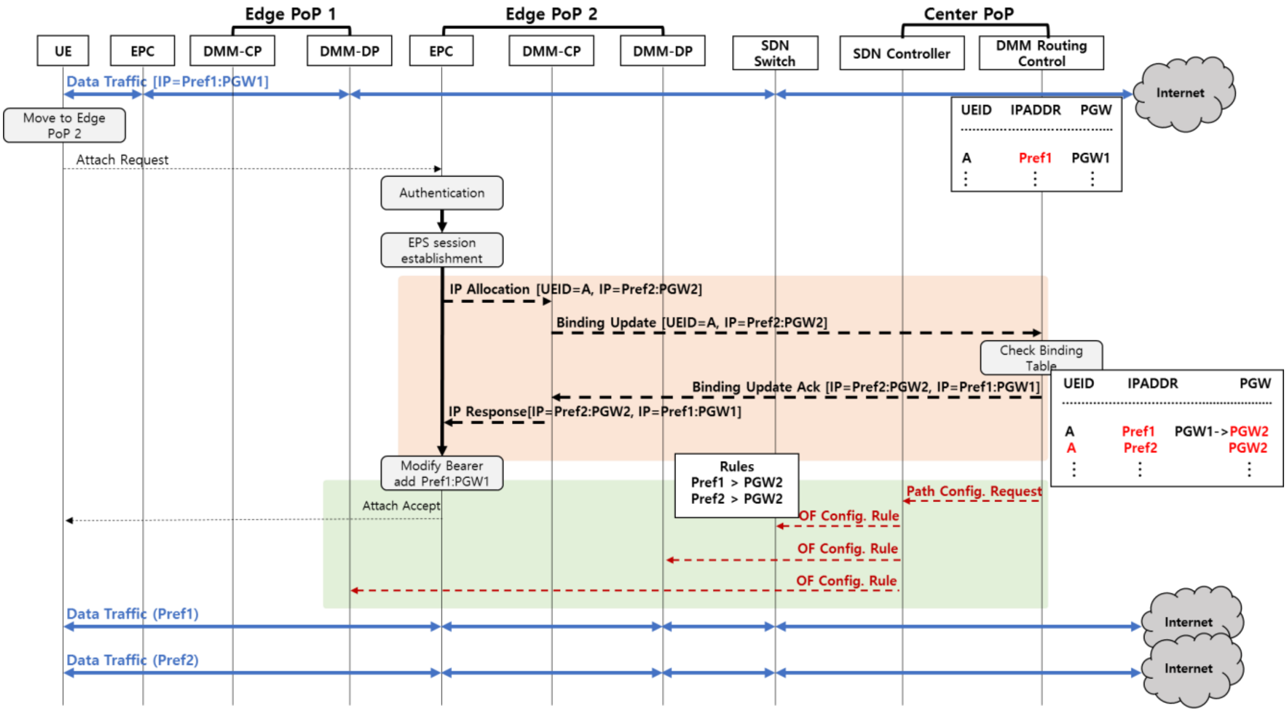

Figure 40 - Handover message flow

- The DMM Routing Control function receives information of the UE included in the Binding Update message from the DMM-CP of edge PoP2 and it can determine that the UE is moved from edge PoP1 to edge PoP2.
- Since that information of UE is already existing in the binding table, the DMM Routing Function updates the current location of the UE and assigns a new IP address to the binding table, and sends the Binding Ack message including IP address assigned at the edge PoP1 to the DMM-CP of the edge PoP2.

6 Olympic demo results

6.1 Background of demos

There were 3 key key performance indicators for demos in 2018 Olympics: Speed, latency and interconnection. All of those 3 areas were met: Speed from 1.2Gbps to 5Gbps, latency from 1.2ms to 2 ms and interconnection between Oulu/Finland and Gangneung/Korea having 14.000km distance and 0.3ms latency.

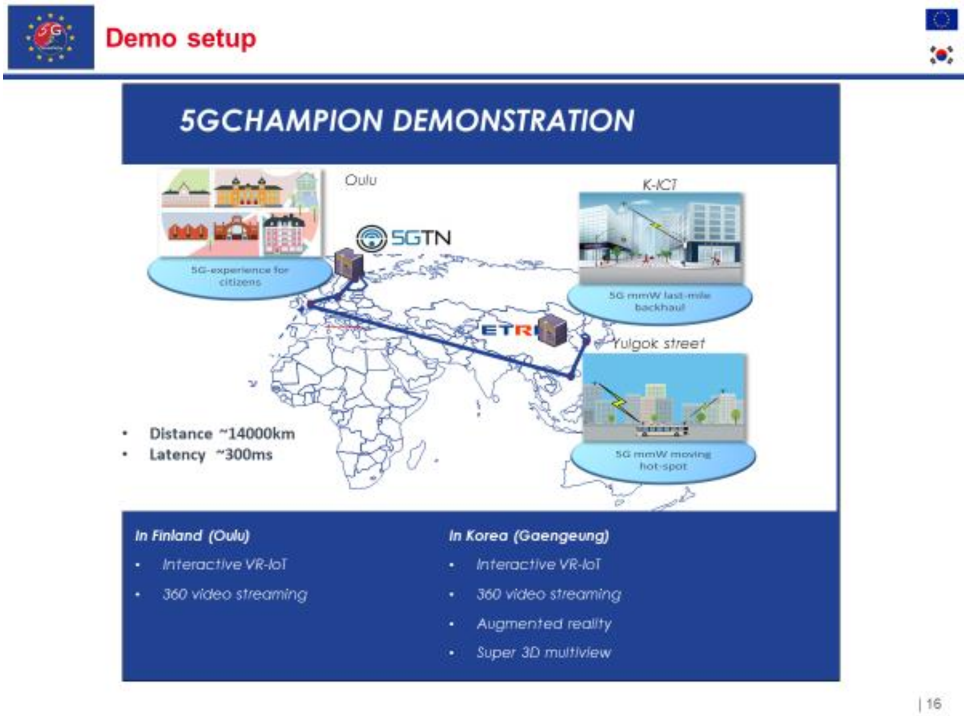

Figure 41: Intercontinental core network setup

Aim of the demos was to tell to public what 5G brings to people´s everyday life. With that we were able to show to demos in 4 different places: Gangneung K-ICT in Figure 42, Gangenung ETRI bus in Figure 43, Oulu City Library and Oulu Kastelli school in Figure 44 during 20-22.2.2108. K-ICT have been open from 1.2.2018 and until 18.3.2018.

Figure 42: ICT-square in Gangneung

Figure 43: Bus demo location in Gangneung

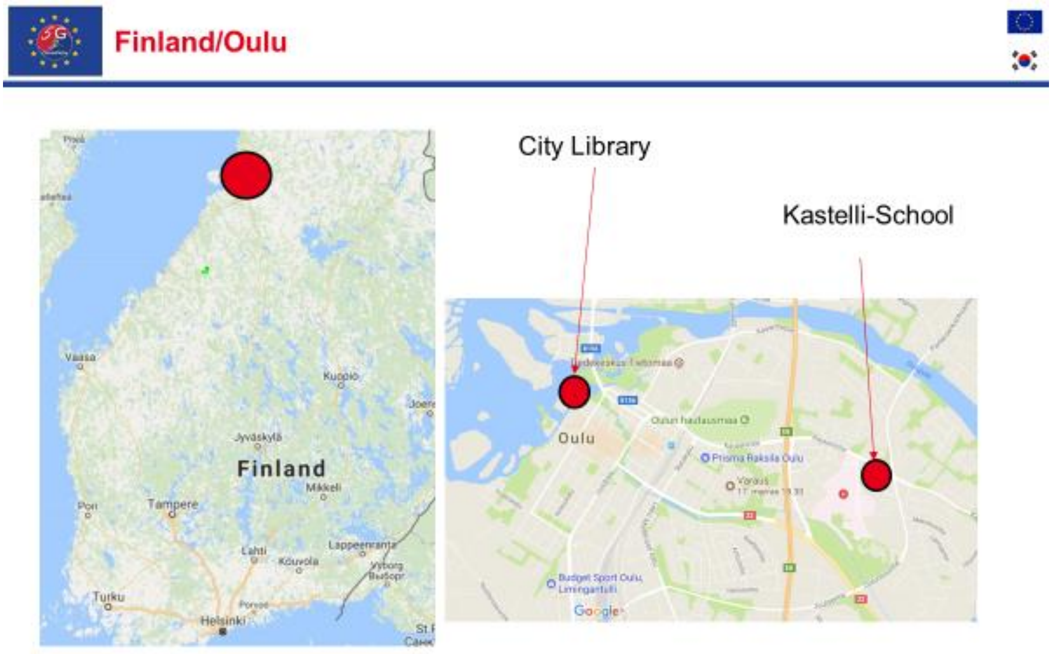

Figure 44: Demo places in Finland/Oulu

Demo items were:

- Augmented reality
    - AR was created using MS Hololens and data was fetched from Koren connection. Data show was about Olympic places infrastructure and game statistics.
- Virtual reality with 360 video
    - 360 raw data was filmed in K-ICT and Kastelli school and feed was able to be seen in all 4 places i.e locally and remotely. 5G EU POC was used in K-ICT to deliver data to other places, locally data speed was >1Gbps and scaled down to other places(note that Koren-5GTN interconnection is <1Gbps)
- Virtual reality with internet of things attached
    - With 360 VR feed IOT data was attached to view. There was many sensors in Kastelli school from snow depth to air quality.
- Virtual reality with remote control
    - In Kastelli school there were aurora borealis lights that were able to control from all 4. Places, i.e high speed data with VR and remote control was being demonstrated.
- Super 3D Multiview
    - On the Youlgok street in Gangeung area, 3D Multiview service was shown in Demo BUS based on Korean mmWave 5G moving wireless backhaul.

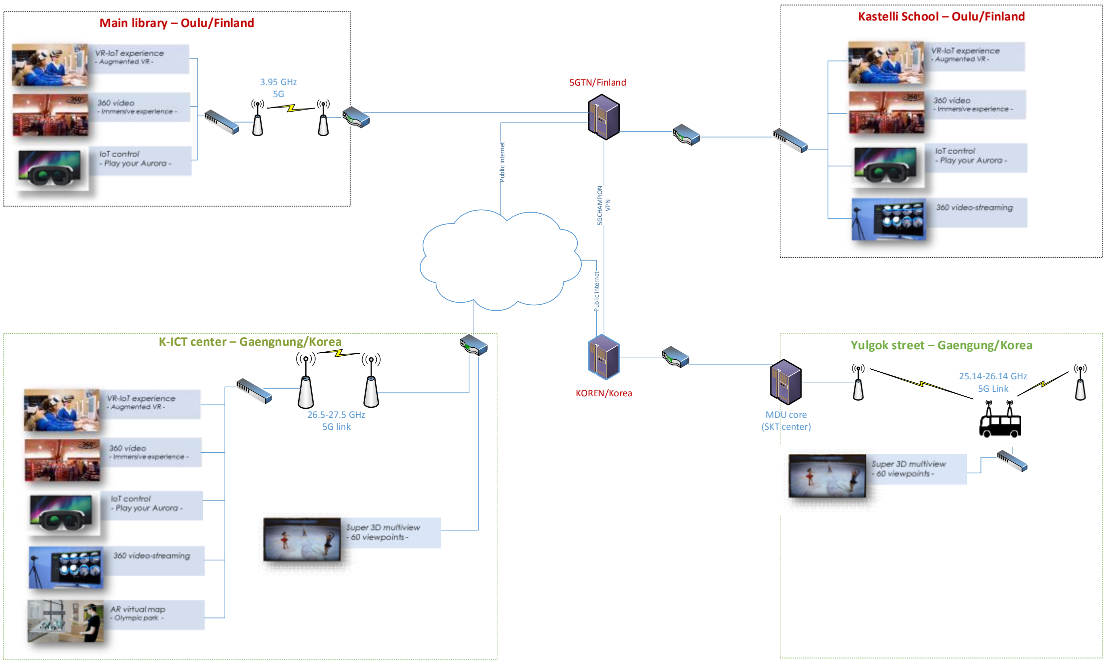

Figure 45: Demonstration architecture.

6.2 Demo results from EU point

During 20 - 22.2.2018 about 400 people were visiting per day at Kastelli school and 100 people per day at Oulu library. There were about 40 people volunteers from Nokia and Oulu University to run the things for school – and library visitors. Every day school kids were doing a show to other viewing places. An example of the show from the school is shown in

Figure 46: Example of "presentations" from Kastelli School.

We had some publicity before the event, having several disseminations in Finnish level press and during the event itself:

- Kaleva(LocalNewspaper):http://www.kaleva.fi/uutiset/kotimaa/5g-muuttaa-penkkiurheilijan-kokemuksen-verkkoa-testataan-oulussa-ja-etela-koreassa/785579/
- Tekniikka ja Talous: https://www.tekniikkatalous.fi/tekniikka/ict/5g-tekniikka-voittaa-pyeongchangin-talviolympialaisissa-oulun-ja-etela-korean-valilla-virtuaalinen-liveyhteys-4-paikassa-6702942
- https://yle.fi/uutiset/3-8851947
- http://www.kaleva.fi/uutiset/oulu/oululainen-5g-osaaminen-paasee-esiin-etela-korean-talviolympiakaupungissa/782817/
- http://www.oulu.fi/yliopisto/node/50698

Also we had a VIP visitor in K-ICT 20.2.2018 when Finnish Prime Minister with Finnish Olympic President visited 5GChampion demos and spend 1 hour to get to know what have we done between Korea and Finland as shown in Figure 47.

Figure 47: VIP visit in K-ICT.

Also EU team did some 360 videos that can be seen until mid May 2018. You can view them with Chrome web browser https://spot.name/5gchampion

6.3 Demo results from Korean point of view

6.3.1 Moving hotspot

Basic demo configuration of KR side is shown in Figure 48. One mRU was deployed SKT's LTE cell site on Youlgok street in Gangneung Area. Which locates near by Gangneung ICT Squire. BUS was used for the demo, i.e., mTE was deployed on the front of the BUS (inside the window). There was two types of demo scenarios, the first one was just to test the mmWave radio link performance and the second one was to provide the 3D multi-view service inside the BUS. The minimum data for the 3D multi-view service was 1.5 Gbps. It was shown that the KR test bed could support that service even in moving environments. From the link performance test, it was also shown that the maximum data rate of the moving backhaul was 5 Gbps and typically the backaul data rate was 2 ~ 4 Gbps. Considering 1 GHz BW and 2x2 MIMO configurations, these results are a little bit expected ones. It was also shown that the coverage of the mRU was less than 500 m (The max transmit power was just 36 dBm).

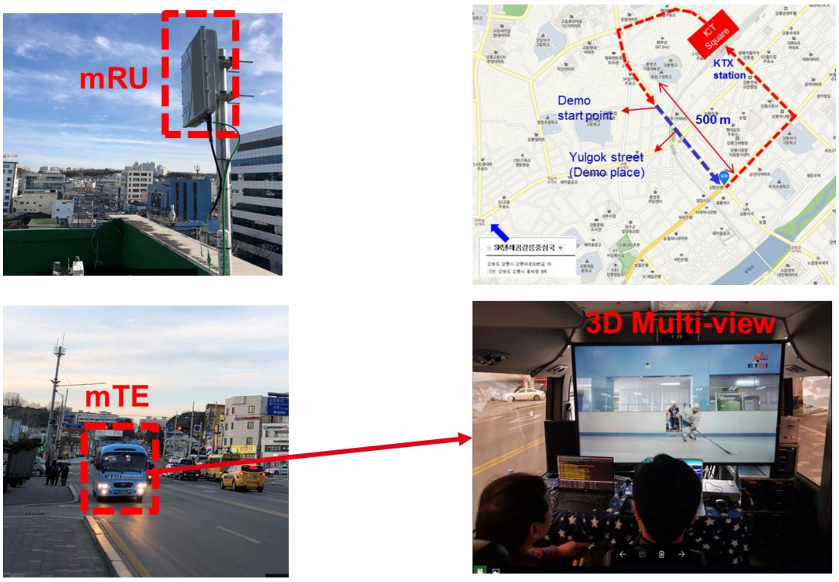

Figure 48. Moving hotspot demo configuration

Figure 49. mTE deployed on demo BUS

6.3.2 Inter-continental interoperability

The interoperability verification between Korea's 5G mobile core and Europe's 5G mobile core has two goals. The first is service-level interoperability verification. This is to confirm that the end-to-end service runs smoothly through 5G mobile core in Korea and Europe. Currently 360 degree VR camera is installed in the library of UOULU in Finland and 360 degree live streaming service is available in Gangnueng, South Korea, where live VR is available. In addition, the AR function is used to verify whether interactive services are available through European servers and Korea's 5G mobile core.

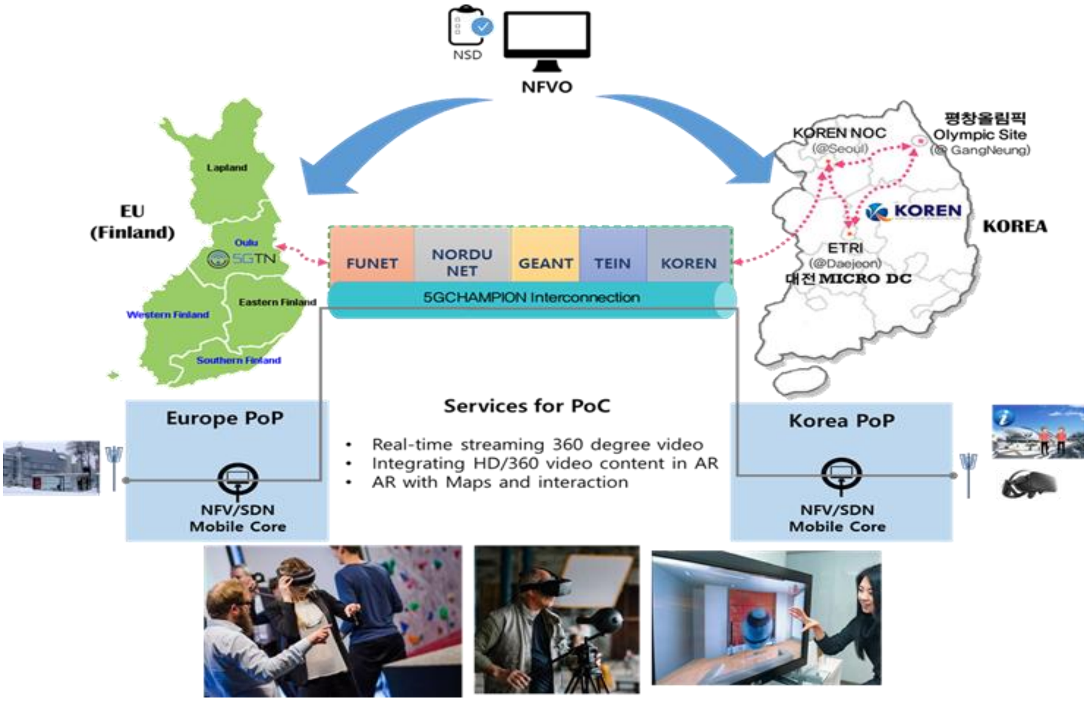

Figure 50. 5G Mobile Core Service Interoperability

The second verification objective is management interoperability. To ensure that the process of creating and operating different 5G mobile cores through the NFV MANO is conducted according to the ETSI NFV SOL003 international standard. Currently, the 5G mobile core network service in Europe and Korea is managed by maintaining the interoperability of the orchestrator installed in Daejeon in Korea as a global orchestrator.

As described above, it has been confirmed that the service is performed properly through the end-to-end service among the heterogeneous 5G mobile cores distributed and arranged.

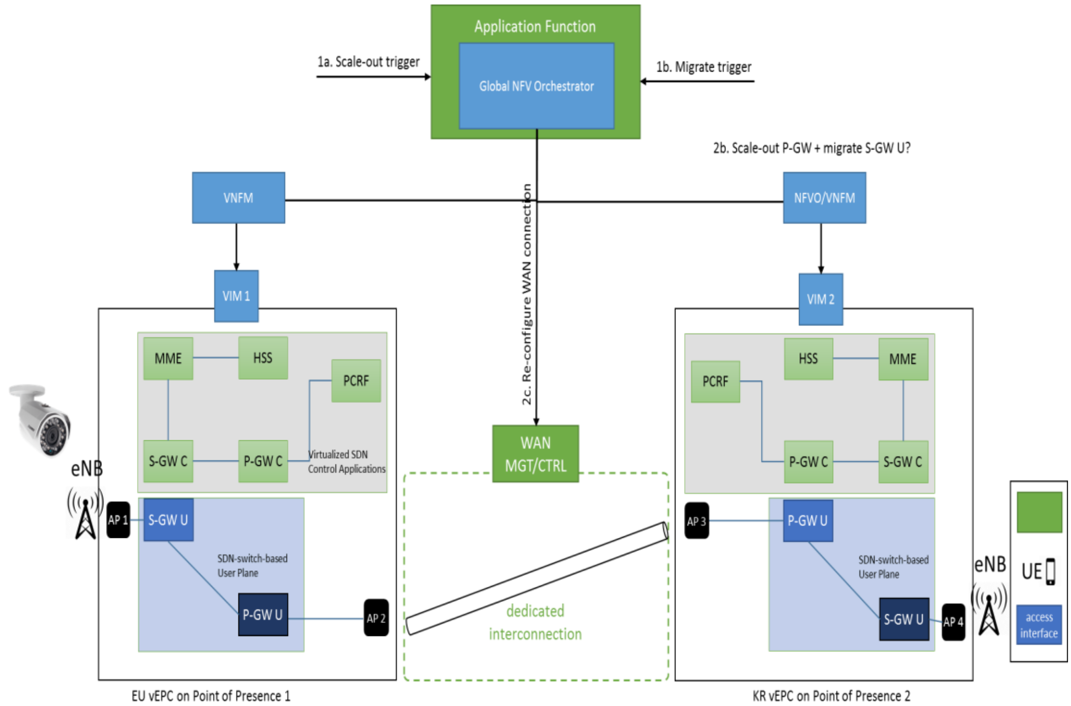

Figure 51. 5G Mobile Core Management Interoperability

7 Summary

Demos in 2018 Olympics were very good showcase of Korean and Finnish knowhow in 5G frontier and 5GChampion project got very good national and international coverage in newspaper and publications.

It was the main goal for whole project and was very successful from dissemination and technical point of view.

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