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

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5G CHAMPION architecture, API- and interface document

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Abstract

This deliverable provides a description of the Core and Access Network architecture for 5G CHAMPION. The objective of this document is to provide: i) an overview of the requirements for the 5G CHAMPION architecture, ii) architectures guidelines for both European and Korean networks and testbeds, iii) assessment and specification of the impact of SDN and NFV on the resulting 5G architectures at European and Korean side, iv) RAN architectures for very accurate positioning, integrating Satellite communication, mmWave, multi-RAT in the backhaul with the vEPCs, and v) architectures for interoperability. The mobile core architectures described here are going to be elaborated in WP4. The report is guided by the use-cases document (D2.2).

Index terms

vEPC, MANO, mmW backhaul links, SDN/NFV, interoperability, Satellite Positioning, Satellite integration, RF Bands, Multi-RAT, security, mobility management

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List of Acronyms

3GPP	3rd Generation Partnership Project
5G	5th Generation
5GTN	5G Test network
API	Application programming interface
APN	Access point name
BBU	Base band unit
BRU	Backhaul radio unit
BSS	Business Supports Systems
BTS	Base Transceiver System
CA	Carrier aggregation
CC	Carrier components
CN	Core Network
C-RAN	Centralized radio access networks
CP	Control Plane
D-RAN	Distributed radio access networks
EPC	Evolved packet core
ETSI	European Telecommunications Standards Institute
EU	European union
GNSS	Global navigation satellite system
IGS	International GNSS service
KPI	Key performance indicator
KR	Korea
LoS	line-of-sight
MBS	Macro base stations
MIMO	Multiple-input-multiple-output
MME	Mobility Management Entity
mmW	millimetre wave
MUX	Multiplexer
NFV	Network function virtualization
NGMN	Next Generation Mobile Networks
OSS	Operations Support System
PCRF	Policy Charging and Rule Function
PPP	Point precise positioning
QAM	Quadrature amplitude modulation
QPSK	Quadrature Phase Shift Keying
RAT	Radio access technology
RRH	Remote radio head
RTK	Real Time Kinematic
SDN	Software defined networking
SNR	Signal-to-Noise Ratio
UE	User Equipment
UHD	ultra-high definition
UP	User Plane
VNF	Virtual Network Function
WP	Work package

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1 Introduction

5G networks are expected to support a diverse and conflicting set of use cases. The 5G system targets the support of a wide variety of use cases: ultra-reliable communications for mission critical services, Real Time Vehicle Control, Mobile Health Care, Virtual Presence, Tactile Internet etc. To support such a wide variety of use cases, the network must be highly flexible and controllable. Current generation networks don't provide the adequate set of control tools to the operators and service providers necessary to achieve this level of flexibility.

The objective of this section is to provide design principles which would shape the architecture of both the European and the Korean mobile core network. For this, we need to clarify the role of the different WP's in the project, and the impact they have on the different reference point and corresponding interfaces.

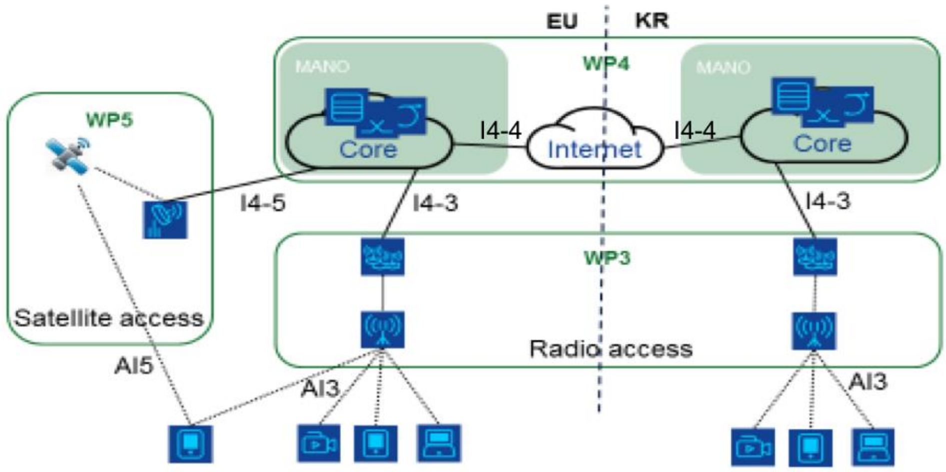

Figure 1 - Split between EU and KR architecture.

The 5GCHAMPION Work Package split divides the 5GCHAMPION network architecture to following domains:

- WP3: Radio access network, including high-capacity wireless backhaul channel and mobility.
- WP4: Virtualized Mobile Core network and the related management and control functions
- WP5: 5G Satellite communication component, providing satellite access between 5G UE and Mobile Core network

Between these domains, the following reference points are identified:

- I4-3: Reference point between Radio access network and Mobile Core network. (responsibility for definition: WP4)
- I4-5: Reference point between Satellite access network and Mobile Core network. (responsibility for definition: WP5)

The following reference points are identified towards user equipment:

- AI3: Reference point between Radio access network and UEs. Responsible: WP3
- AI5: Reference point between Satellite access network and UEs. Responsible: WP5

Expected functional components per domain and internal interfaces are:

- EU Radio access network:
  - mmW backhaul radio unit (BRU): operates as IP pipe from the core network to multi-RAT unit. Beamforming will be supported. It includes mmW air interface (AI0) and L1/L2 interface (I1) for IP traffic
  - multi-RAT radio unit operates as traffic aggregator/multiplexer from the wireless backhaul to other radio technologies
- KR Radio access network
  - mmW with mobility
- Mobile Core network
  - I4-4: Interworking interface between EU and KR core networks. Defined in WP4.

This deliverable will also further refine the architecture of the involved mobile core networks, the potential trade-offs, and potential interoperability architectures. The document is structured further as follows. Section 2 identifies the general requirements for a 5G architecture to be covered by both the European and Korean architectures individually. It gives a general architectural overview of how these requirements can be achieved followed by a view of how Management and Orchestration may be implemented for both the cores. The section ends with the integration multi-RATs with the proposed Core Network architecture.

Section 3 gives an architectural overview of the different radio-access technologies considered in the project. This involves satellite technology, mmWave connectivity, positioning solutions and radio frequency band systems.

Section 4 details the global architecture of the Core Network from the European side also known as the 5GTN architecture. It delves into the Security, MANO and Mobility Managements aspects as well as gives an initial idea of the APIs of the architecture in subsequent subsections. Section 5 follows a similar structure as Section 4, and gives the Korean Core Network architecture.

Section 6 details the architectural aspects of the interoperability between the EU and KR core networks of the project. The document is concluded in Section 7 providing a short overview and recap of the main architectural principles.

2 Common mobile core architecture

This section will detail the 5G mobile core architecture by subsequently discussing the main drivers and requirements, the existing LTE-based architecture, and the impact of Software-Defined Networking and Network Function Virtualization on the resulting mobile core. These sections serve as a common basis for the specific mobile core architectures of the European and Korean setups.

2.1 Requirements

2.1.1 Key Drivers

Although many of the features supported by the architecture will be dependent on the finalized use cases, the main/salient features of the architecture should be driven by the following aspects:

a) Business Needs or Industry verticals – Wide variety of business needs will arise like automation of vehicles, IoT, Tactile internet, smart grids etc. and this should provide strong motivation.

b) Need to integrate multi-RATs – 5G networks should be able to handle efficiently heterogeneity of devices and deployed access networks, providing connectivity exploiting the most convenient access technology.

c) Providing more personalized and tailored services – Users will want more and more personalized services with respect to their usage habits and interests.

d) Enabling elasticity in the architecture, enabling efficient use of network and compute resources, depending on the involved load of the network.

2.1.2 Key Enablers

a) Virtualization of core and radio access network functions will optimize the use of network resources, add scalability and agility.
This will might require data centres with Software Defined Networking (SDN) capabilities.

b) SDN technologies will enable transport network resources, including front-haul and backhaul, to become virtually programmable.

c) End-to-end management and orchestration – architecture should be able to dynamically manage and operate network functions that exploits the best of SDN and NFV.

2.2 Architecture overview

2.2.1 Mobile Core Network Architecture

The Third Generation Partnership Project (3GPP) Long Term Evolution/Evolved Packet Core (LTE/EPC) architecture has been designed to provide seamless IP connectivity between user equipment (UE) and external packet data networks. The core elements of this EPC architecture are depicted in Figure 2.

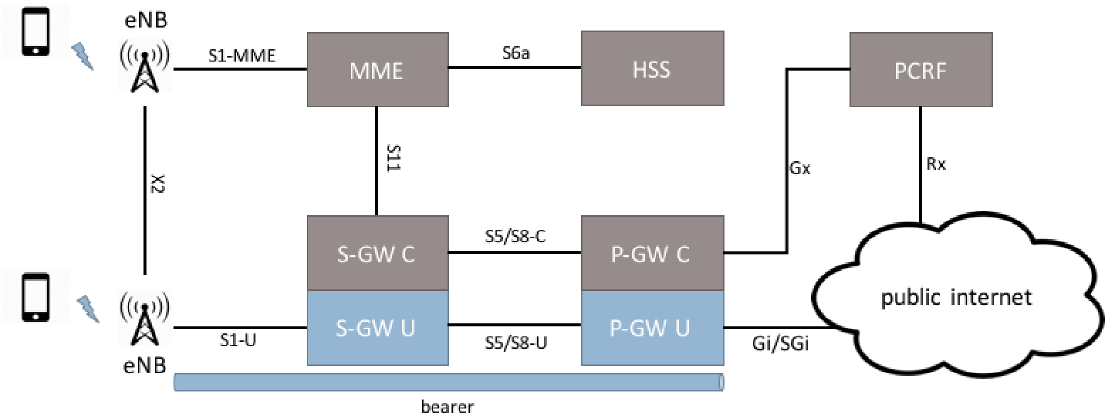

Figure 2 - 3GPP LTE/EPC architecture.

The EPC follows an all-IP architecture composed of several control plane and user plane entities. The user plane is in charge of handling user traffic (data packets), the control plane steers the configuration and operation of the user plane. Here, we will shortly recapitulate the role of the main EPC entities. A more in-depth coverage of these components can be found in [1]:

- The MME acts as the manager of network connectivity, and for UE authentication and authorization, UE session setup, and intra-3GPP mobility management.
- The S-GW routes data packets through the access network and is the local mobility anchor point for inter- eNB handover. The SGW consists of a control part referred as the S-GW C, responsible for the interaction with the MME and PGW, as well as a user plane part S-GW U, in charge of handling of data packets.
- The P-GW is responsible for user plane quality of service (QoS) management and is the anchor point for external PDN Networks. Similar to the S-GW, the P-GW is split into a control (P-GW C) and user plane part (P-GW-U).

The GPRS Tunnelling Protocol (GTP) is the main communication protocol within the LTE/EPC architecture. GTP is the defining IP-based protocol of the EPC. It enables end users of the mobile network to move while continuing to connect to the Internet as if from one location at the P-GW (using a connection tunnel or bearer). This is achieved via carrying the subscriber's data from the subscriber's current S-GW to the P-GW which is handling the subscriber's session.

The given LTE/EPC architecture is currently the de facto standard. However, with respect to the envisioned 5G requirements and objectives, the proposed architecture has some main shortcomings:

- The existing LTE/EPC architecture was not designed with elasticity in mind. Functionality is deployed on dedicated network entities, which execute specific functions. Potentially resulting in inefficient use of resources.
- Involved network entities are prone to vendor locking, resulting in vendor-customized (management) interfaces.
- Because of vendor-lockin, the existing EPC is complicated to manage, hard to change in behaviour, and difficult to scale.

2.2.2 Software-Defined Networking

Software-Defined Networking (SDN) introduces an open interface between the forwarding hardware (responsible for packet switching) of routers and switches and its control component (responsible for instructing the switches). The OpenFlow protocol [2] is currently considered as the de facto standard for a south-bound SDN-interface (SBI). As depicted in Figure 3, traditional routers consist of three main components: i) data or user plane functionality for forwarding packets, ii) a control plane or operating system in charge of interconnecting the local data plane with routing functionality, and iii) control applications in charge of routing and information distribution between routers (e.g., using BGP or OSPF). In SDN, these three functionalities are decoupled, and a network node is mainly reduced to forwarding device, with a thin layer of control functionality (control agent) which can communicate with external control plane logic using an open interface like OpenFlow. Control functionality responsible for routing, can now be executed at a (logically) centralized control entity (SDN controller). SDN control functionality usually consists of a network operating system (NetOS) running a collection of application modules, such as topology discovery, path computation, resource management, and load balancing. The network control applications interact with the NetOS using a north-bound interface (NBI). As an in-depth discussion of SDN technology and research is out of scope of this document, we forward the interested reader to [3].

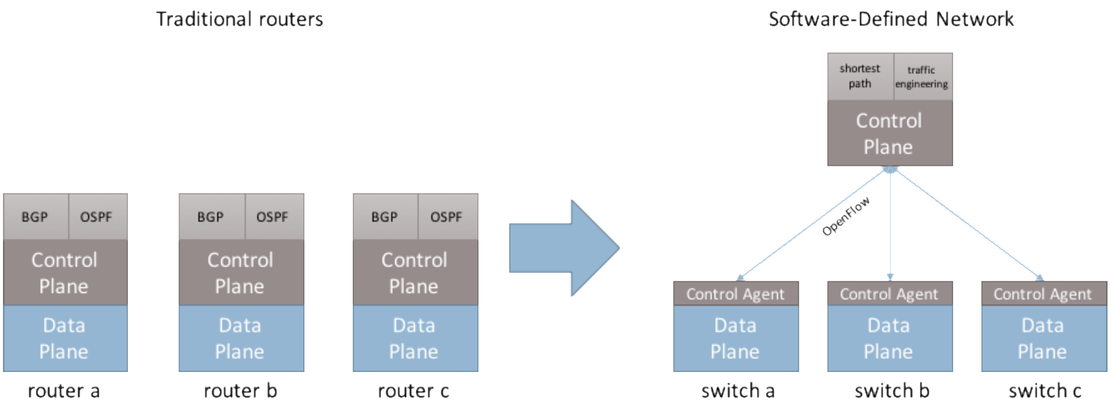

Figure 3 - SDN conceptual architecture

By using SDN capabilities, dynamic control of traffic flows can be performed, redirecting the traffic to gateways according to, say, workloads. Extensions to OpenFlow [5] might support an SDN/NFV-based Mobile Packet Core. This concept is illustrated in Figure 4.

Forwarding abstractions for PDN connections in a split or combined gateway (SGW and PGW combination) may be defined. These abstractions may model the PDN connection segments using ports, tables, and control signalling in. The architecture should be such that minimum changes will be necessary to standard 3GPP defined interfaces. For this purpose, one might re-use OpenFlow-based SGW and PGW devices, augmented with an SDN controller and OpenFlow channel extensions to control the switches. The S5 interface must be implemented for roaming cases as the UE will need to connect to the roaming SGW and the home PGW. GTP tunnels may only be used between the eNB and the first OpenFlow switch. In the OpenFlow switches, ports may be used for the interface to the eNB (S1). Similarly, ports may be used at the SGi interface as well. Forwarding of packets in the OpenFlow switch network may be done through a chain of flow tables which will direct packets from the point of entry to the point of exit. Packet manipulation, encapsulation and decapsulation rules will be installed by the SDN controller. Functions like rate control, event reporting, bearer binding, handovers etc. may be implemented through the OpenFlow interfaces from the SDN controller towards the OpenFlow switches containing the flow tables.

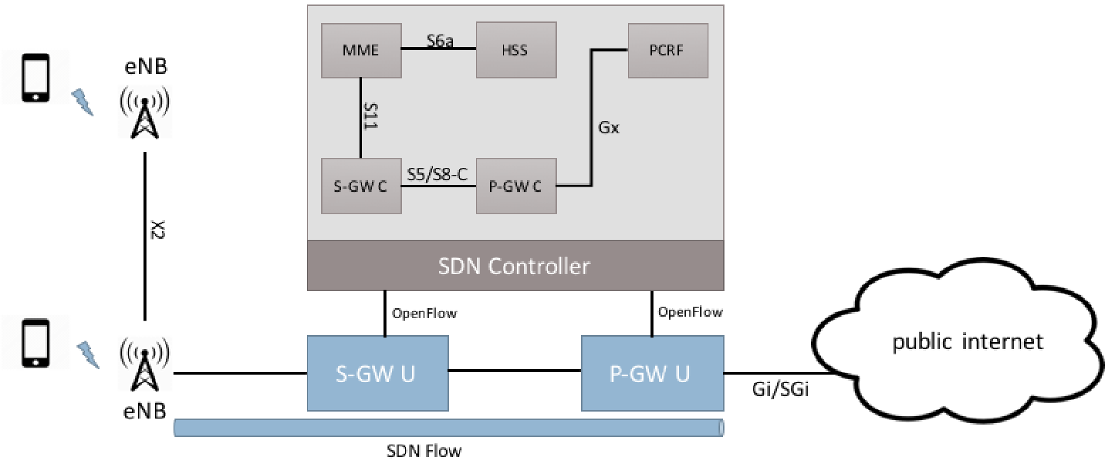

Figure 4 - SDN-enabled mobile core network.

A logically centralized EPC control plane may be defined, running as a group of control applications on top of the considered SDN controller. It will consist of control components of the mobile core network like the MME, PCRF, HSS and a software entity, as well as the control components of the SDN switches introduced into the architecture:

1) SGW/PGW-C - This software/control plane entity may act as the interface between the combined GW and the various other control components like the MME, PCRF, HSS etc. This software entity will also talk to the SDN controller through NBIs. These control plane entities may be implemented as applications allocating the tunnel ids for UE flows, acting as a mobility anchor for inter-eNB communication.
2) Interfaces – SGW/PGW-C will also have the various interfaces to other control elements –
    a) The S11 (MME link) will be realized using GTP-C.
    b) The Northbound interfaces connecting it to the SDN controller may be realized using APIs which will translate the GTP-C messages coming from the MME into

OpenFlow messages which will be in turn used to populate the flow tables with flow rules. These NBIs will be essential in translating the QoS requirements to the OpenFlow enabled transport layer.

2.2.3 Network Function Virtualization

NFV logically partitions the resources from underlying physical hardware resources. NFV management and orchestration (MANO) involves the life cycle management of network service and the virtual network function (VNF) instance. A VNF is responsible for handling specific network functions part of a service that run in one or more VMs (or containers) on top of the virtualized network, compute and storage hardware infrastructure. The NFV architecture is heavily steered by the ETSI standardisation body in the ETSI NFV ISG [4]. A high-level overview of the ETSI NFV architecture is given in Figure 6.

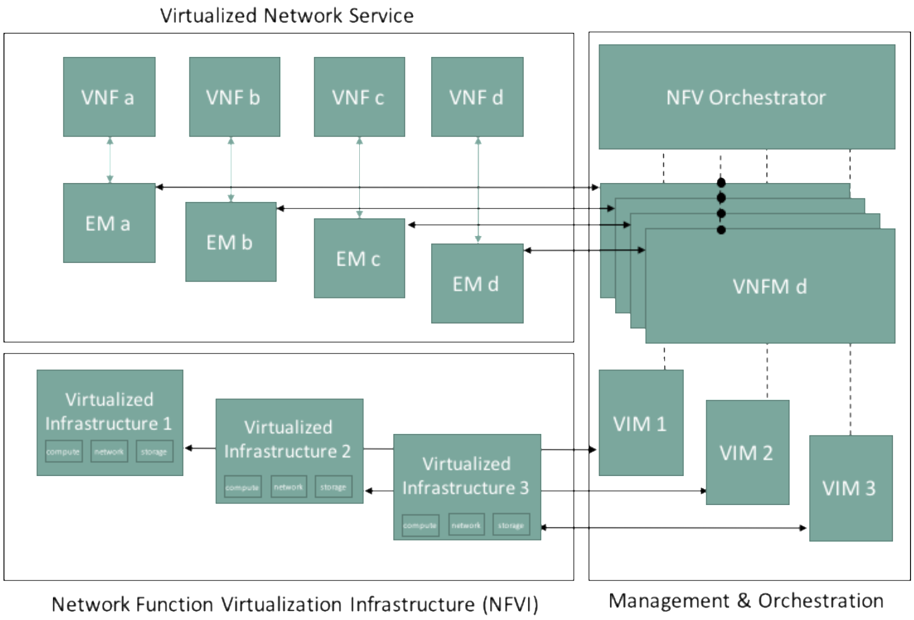

Figure 5 – ETSI NFV architecture.

We will shortly describe the main components and interfaces as described in Figure 6. More detailed coverage can be found at multiple places in academic [5] and standardization literature [4].

- Virtualized Network Service

The NFV service consists of a graph of interconnected Virtualized Network Functions (VNFs), potentially chained using a particular forwarding behaviour. The service is described using descriptors for the VNFs (VNFDs) and the Network Service (NSD) and deployed on the NFVI using the MANO framework. One might distinguish between the service graph, which refers to the network topology of the interconnected NFs, from the network function forwarding graph, which refers to the enforced forwarding logic enforced on top of the service graph. Each of the VNFs is managed by an Element Manager (EM), responsible for FCAPS (Fault, Configuration, Accounting, Performance and Security management).

- Network Function Virtualization Infrastructure (NFVI)

The NFVI consists of the hardware on which Virtualized Network Services are deployed. This involves the actual networking, compute and storage hardware, as well as the virtualization technology (e.g., Xen, KVM) to enable instantiation of VNFs on top of it. Infrastructure is usually organized in locations which group hardware devices (e.g. datacentres) and are referred as Points of Presence (PoPs). In case, these datacentres/cloud resources are close the edge of the mobile network, they are referred as the Mobile Edge Cloud. Virtualized Infrastructure is managed by Virtual Infrastructure Managers, part of the NFV MANO component (next part).

- Management and Orchestration (MANO)

NFV Management and Orchestration (MANO) functionality is responsible for deploying Virtual Network Service requests on infrastructure which might be distributed over multiple PoPs. Therefore, requests are handled by the Network Function Virtualization Orchestrator (NFVO) and delegated (orchestrated) to one or multiple Virtual Infrastructure Managers (VIMs), in charge of controlling and managing network or compute/storage resources in given PoPs. VIMS involve network control systems like SDN controllers (WIM, in case of wide area networks) or cloud infrastructure management solutions (e.g., OpenStack). These instruct the involved NFVI for deploying services. Once deployed, Virtual Network Function Managers (VNFMs) are in charge of instantiating and controlling the virtualized network functions. They are responsible for interacting with the EMs, and handling their lifecycle – instantiation, maintenance etc., as well as the interaction with operations support system (OSS)/base station subsystem (BSS).

Note that the NFV architecture does not necessarily enforce all NFs to be implemented in software. As indicated in [4], one or more NFs might be implement as physical NFs (PNFs). This might, for example be the case for network functions involving switching. Rather than virtualization the switch in software (e.g., using an optimized OpenFlow switch such as open vSwitch), they might rely on a (virtualized slice of) a physical switch.

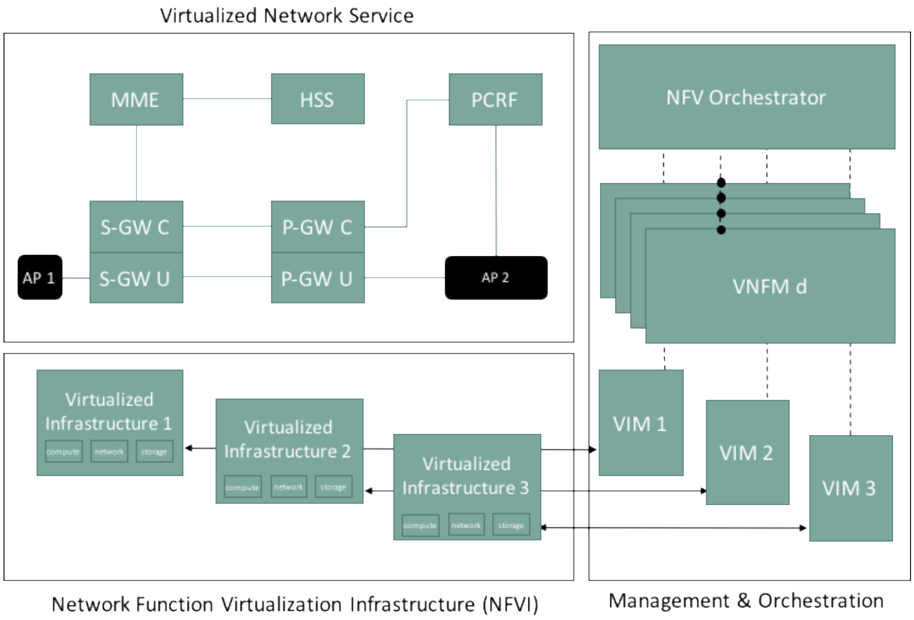

Figure 6 - NFV-based mobile core network.

A direct virtualization of the introduced EPC architecture in NFV context is illustrated in Figure 6. In this case, a subset of the EPC Network Functions might be executed in software on generic purpose hardware in on considered PoPs. The resulting EPC is deployed as a service graph of VNFs implementing MME, HSS and PCRF functionality, together with one or multiple S-GWs and P-GWs. The S-GWs connect to the eNBs or base stations and the P-GWs connect to the external packet network using attachment points which encode the external interconnection points. One of the main advantages of an NFV-based EPC, is the support for scaling in each of the involved core entities, like the MME, S-GW and P-GW. Vertical scaling, enables to attach more resources on the local compute, network or storage device. For example, one might increase the number of used cores to enable handling of a higher number of hand-overs in each MME NF. Horizontal scaling, enables to instantiate more (distributed) instances of a given NF over the network. This enables to balance the load over the pool of NFs. This principle underpins the concept of the distribute MME presented later in this document. On the other hand, in case resources are under-used, a (horizontal or vertical) scale-out operation can reduce the required resources for certain NFs.

2.2.4 Combined SDN- and NFV-enabled mobile core network

SDN increases the programmability of the network, by decoupling the control and the data plane of the components, while NFV increases the resource efficiency of network functionality, by decoupling the data plane from (dedicated) hardware and enabling functionality to be implemented in software. As both paradigms are orthogonal to each other, 5G CHAMPION considers a combined SDN/NFV architecture as depicted in Figure 7.

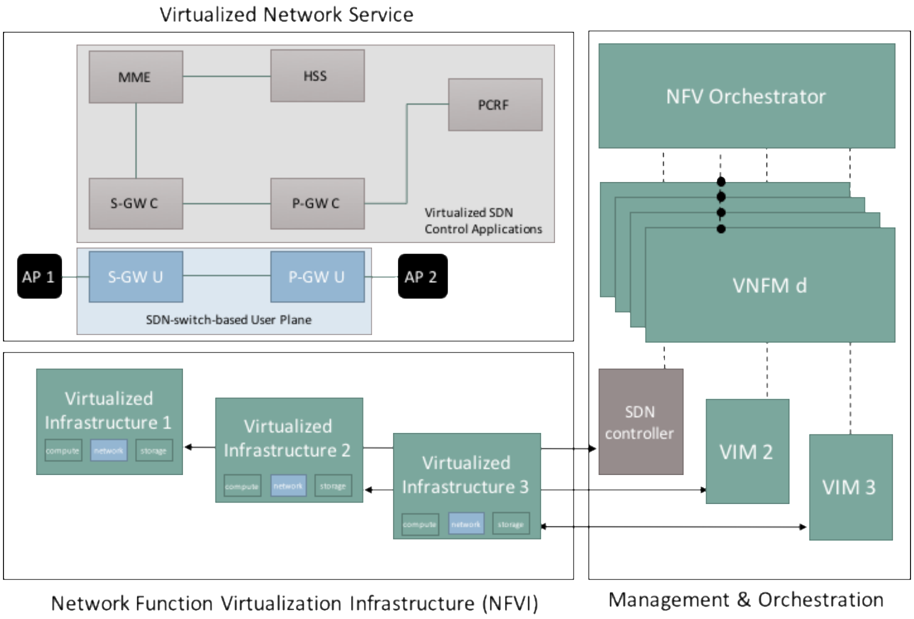

Figure 7 - Combined SDN-NFV mobile core architecture.

In the considered combined SDN/NFV architecture for the mobile core network, the NFs in charge of the control of the mobile core network, might be implemented as control applications on top of a SDN control framework (a VIMs deployed in the global 5G CHAMPION MANO functionality), which are deployed as software-based VNFs. As VNFs, they support elastic operation as required by some of the envisioned use cases. Data/user plane, i.e. S-GW and P-GW functionality might be implemented as either software or hardware-based (PNFs) Network Functions. The latter might be implemented as SDN switches.

An example of how the MANO will manage both the Infrastructure as well as the VNFs - when a new VNF MME is switched on in a data centre, the MANO will notify and configure this new MME with the corresponding association of other virtual functions such as the SGW/PGW-C, HSS, and other MMEs. In addition, the MANO will interact with the referred SDN controllers for setting up the required connectivity. The MANO gives the pool of eNBs of interest and the information details to be configured to the MME. Based on this information, the new MME will start an initial handshake procedure and establish the S1-AP interface.

3 Common radio-access architecture

In this section, we give a short overview of how radio-access technology fits into the 5G CHAMPION architecture. We focus on the integration of satellite – and mmWave communication, as well as on integration positioning technology. The selected frequency ranges and breakdown in bands is further detailed in deliverable D2.2.

3.1 Integrating satellite communication

Key Drivers

Key drivers of the targeted architecture depend on the considered use case. A common requirement includes however a global coverage for low data rates and/or voice services and a huge system capacity in terms of number of served terminals. At least for mobile scenarios, it is required to maximize the battery life time of the terminals. Besides, use cases related to IoT communications may require extremely long battery life time of the terminals up to several years. For use cases related to service and context continuity and to back-up service to the terrestrial network, terminals must be able to seamlessly handover between the terrestrial and satellite systems.

Key Enablers

The satellite is a natural candidate to provide global coverage for M2M communications and voice services. While a single GEO satellite enables to cover one third of the globe, a constellation of several satellites is required for global coverage when considering non-GEO satellites.

Increased battery life time is achieved by considering energy efficient waveforms using low PAPR modulation schemes. Specific waveforms operating at very low SNR-ranges combined with advanced access techniques will enable to extend the battery life up to several years. Advanced random access techniques shall enable to increase the capacity of the system in terms of number of served terminals.

Agile terminals will be considered to enable seamless handover between terrestrial and satellite systems.

Key Design Features:

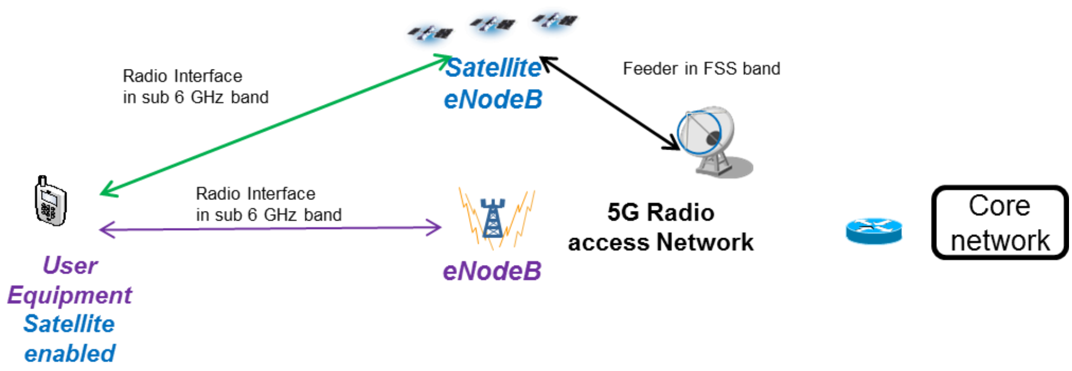

Figure 8 – High-level architecture integrating satellite communication.

The Key Design Features include:

- User terminal with seamless ubiquitous access to the satellite and terrestrial links for low data rate services and energy efficient capabilities. The terminals optionally include software reconfiguration features for improved adaptability to the target framework (based on the recently published ETSI European Norms EN 302 969, EN 303 095, EN 303 146-1/2/3/4).
- Adapted waveform for low PAPR and ultra-low SNR requirements.
- Satellite eNodeB with enhanced MAC capabilities (SIC, interference management…).
- Smart terrestrial-satellite resource management.

3.2 Integration of mmWave radio access

3.2.1 System Overview

Figure 9 shows the integration of the mmW radio with the 5GCHAMPION core network. With a focus on the radio access connectivity, it can be noticed that the mmW links are used as high-capacity wireless backhaul. The backhaul can units are can be connected either to multi-radio access nodes, thus enabling moving or stationary hot-spots, or to UE equipment, thus acting as 5G terminals.

The mmW air-interfaces, denoted by AI0 and AI1, refer to the wireless link developed in European and Korean test-bed, respectively. Key specifications are:

AI0

- 26.5-29.3 GHz band,
- 800 MHz maximum bandwidth,
- 2.5Gbit Minimum data-rate capacity,
- MIMO-OFDM transmission technology,
- 200m minimum coverage.

AI1

- 24.14-26.14 GHz band,
- 1 GHz maximum bandwidth,
- 2.5Gbit Minimum data-rate capacity,
- MIMO-OFDM transmission technology,
- 200m minimum coverage.

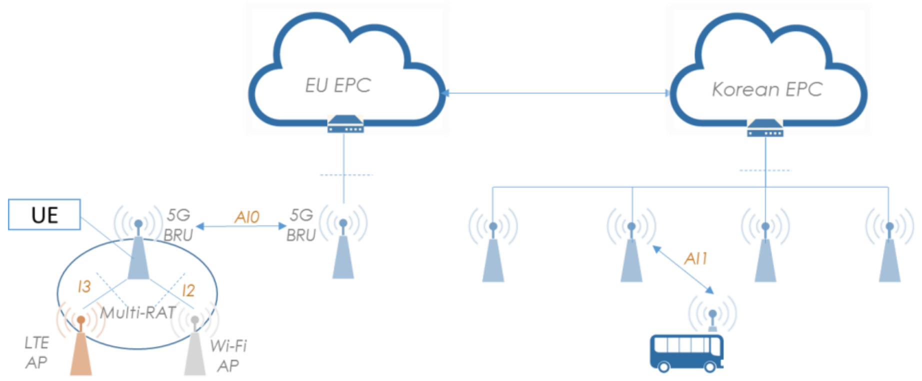

Figure 9 - System overview of mmWave technology in the architecture.

3.2.2 EU Backhaul Radio Unit

3.2.2.1 Specifications

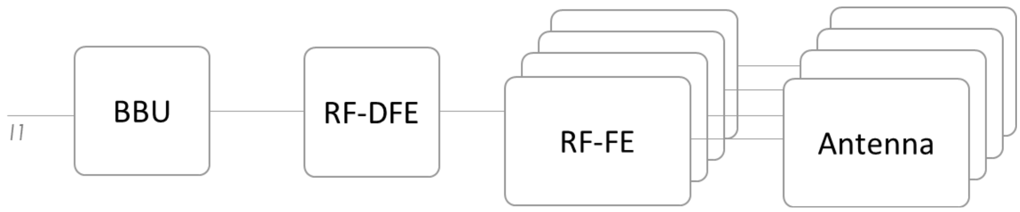

Figure 10 - Overview of the BRU components.

In order to match EU, Korean as well as US and Japan regulations, the EU BRU is developed in the frequency band of 26.5–29.3 GHz. It consists of a baseband unit (BBU), an RF digital front-end (DFE), and the antenna module as depicted in Figure 10.

Key specifications and detail of component architectures are indicated below

- **Antenna**
  - Wideband 1 GHz,
  - Phased-array (16x4 radiators),
  - Structure 8x2 RF beamformer – with 2x2 antenna subarray in each, linearly polarized,
  - Maximum gain 22.7 dBi (simulation based).
- **RF-FE**
  - 26.5-29.3 GHz,
  - Operational band at the Olympics 26.5 to 27.5 GHz,
  - 4 RF beamformers (phase-shift based),
  - Digital phase-shift control,
  - Digital branch enable control,
  - Digital automatic gain control.
- **RF-DFE**

- With analog IF at few GHz,
- Max bandwidth: 800 MHz,
- Max RF streams: 8,
- BB-DFE interface: CPRI.

- **BBU**
  - 5GTF-based implementation,
  - MIMO-OFDM,
  - 100 MHz bandwidth,
  - UpTo 64QAM.

3.2.2.2 Link-budget analysis

The requirements and specifications summarized in the previous section are derived from the following link-budget analysis. To begin with, we consider the elementary study of single-layer OFDM transmission. In Table 1, the link-budget calculation is shown. We include realistic loss figures (however, yet to be verified during the experimental tests) at transmitter and receiver side to account for front-end (RF and digital) non-ideality (e.g., EVM, RX noise figure and TX-FE losses). It can be noticed that under this system model, the range requirements (200m) is likely to be achieved be achieved with 64 QAM modulation (or lower) and array gain of 22.76 dBi.

LINK BUDGET (64 QAM, 0.85 coding-rate, 100MHz, 1280 subcarriers)	
SNRmin [dB]	25,20
SNRmin_coded [dB]	24,49
EVM TX [dB]	-26,00
RX SNR Requirement [dB]	29,83
Noise density [dBm/Hz]	-174,00
Thermal noise [dBm]	-94,17
RX noise figure [dB]	10,00
Sensitivity [dBm]	-54,35
TX power branch for total signal [dBm]	30,00
Antenna gain TX [dBi]	22,76
Antenna gain RX [dBi]	22,76
TX FE losses [dB]	5,00
EIRP (total)	59,80
Link margin [dB]	137,20
Path loss coefficient	2,50
Wavelength [mm]	11,1
Maximum distance [m]	264,8

Table 1 - Link budget calculation based on 64QAM modulation and 100MHz channel bandwidth.

3.2.2.3 Antenna

Based on the link-budget analysis, 23dBi is the maximum array-gain requirement for the antennas of B-RU. Notice, that this value can be fine-tuned based on EIRP regulations. Currently, we assume that EIRP is about 60dB (similar to DL LTE).

In addition to the EIRP, another important requirement for the antenna design is the sector coverage. Since there is not a specific target, we assume that the minimum value is +/- 30 degree.

In light of the above, in the 5GCHAMPION project we pursue two approaches: one is based on planar phased array and the other electronically reconfigurable transmit array technologies. Regarding the planar array model, the structure is a rectangular array of 2x2 subarrays as shown in Figure 11. The 2x2 subarray structure allows a good trade-off between array gain, beam coverage and energy efficiency. The latter is directly connected with the implementation of the RF beamformer, whose specifications are detailed in the next Section.

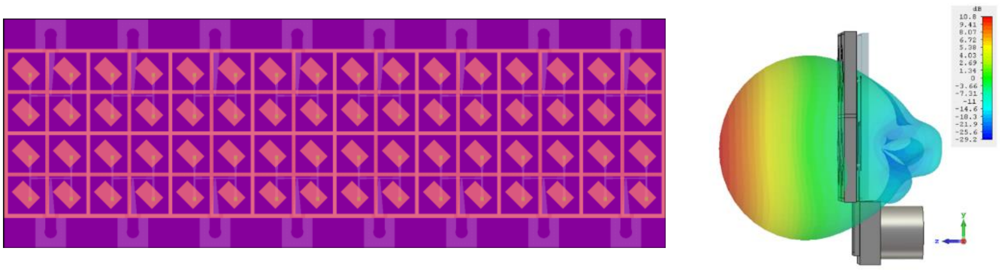

Figure 11 - Phase-array antenna.

An alternative or complementary solution to the phased-array antenna is the configuration shown in Figure 12. In this solution, it is exploited the possibility to phased-array (focal source) and a flat-lens array of unit cells to permit beamsteering and beamforming. The proposed solution is based on a tunable unit cell [14, 15] with p-i-n diodes that are used to locally control the transmission phase on the flat-lens array.

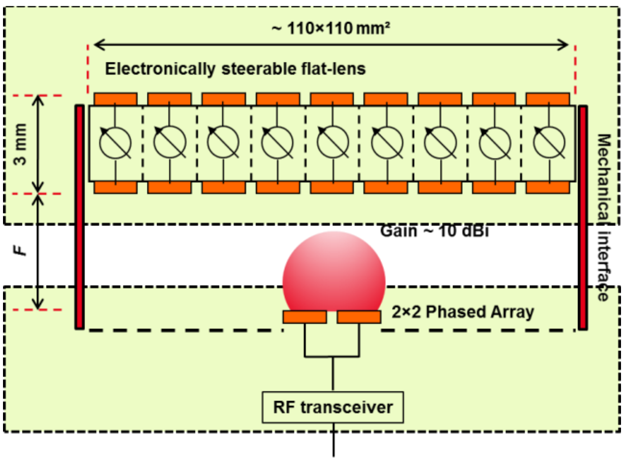

Figure 12 - Reconfigurable transmit array.

For this implementation, key requirements are

- Radiation pattern of the focal source,
- Dimensioning of the distance of the focal source,
- Size of the unit-cell array.

Below, reference performances are provided for 20x20 unit-cell transmit array.

TA performances	
Directivity	26.1 dBi
Gain	23.2 dBi
Gain of focal source	10.0 dBi
Spill-over	-1.64 dB
Reflection loss	-0.77 dB
Emission losses	-1.78 dB
Total efficiency	52.1%
Aperture efficiency	19.8%

3.2.2.4 RF-FE

For the design of the RF-FE [14] the following requirements are taken into account:

- **Operational bandwidth.** Based on the availability of commercial components as well as licence for 5G mmW system testing in EU and Korea, the operational bandwidth of the RF-FE is set in the 26.5 -29.3 GHz band.
- **Time-division-duplex (TDD) communication**: This is a system requirement determined by the fact that mmW communication protocol and frame structure.
- **Power consumption**: Low power consumption is an important criterion in the design of the RF-FE. Key issue it to minimize power consumption with respect to long range and with poor availability of power amplifiers.
- **Beamforming**: this is necessary requirement beamsteering/adaptation. It impacts on performance, capability/limitations, costs and consumption.
- **RF beamformer logic**: this is necessary requirement to allow beamforming. It also considers timing interface with the DFE.
- **Automatic Gain Control**: this is necessary at the receiver side to allow extended dynamic range, thus solving near-far effects in case of mobility.

Based on the above requirements, the following specifications are determined.

One RF-FE is needed for each antenna unit. For instance, in Figure 13, it is illustrated the architecture of the RF-FE unit including two RF beamformers based on digitally controlled phase-shifters. It can be noticed that frequency up/down conversion is used to achieve and tune the desired carrier frequency in the 26.5 -29.3 GHz band. Also, switched are used to separate TX and RX paths, thus, enabling TDD. Finally, to minimize energy consumptions, implementation cost and form-factor, several components are shared between the TX and RX paths.

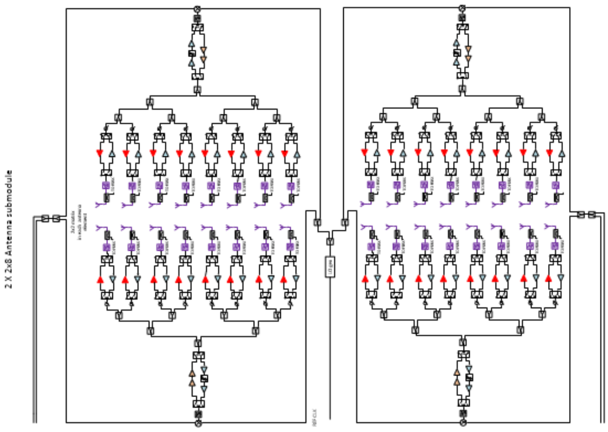

Figure 13 - RF-FE design mode.

3.2.2.5 Data-rate calculation and analysis of the distance-rate-bandwidth trade-off

In order to achieve the target data-rate of 2.5 Gbit/s, we first analyse the required number of streams. Table 2 shows this result based the assumption that BR-U uses OFDM transmissions with inter-carrier spacing 75 KHz, number of subcarriers 2048 and 100 MHz transmission bandwidth, coding-rate 0.85 and 50% UL/DL ratio.

	QPSK	16 QAM	64 QAM	256 QAM
Channel bandwidth [MHz]	100	100	100	100
Subcarrier spacing [kHz]	75	75	75	75
Modulation	4	16	64	256
Coding rate	0.85	0.85	0.85	0.85
UL/DL ratio [%]	50	50	50	50
Achievable-rate per stream [Gbit/s]	0.08	0.16	0.24	0.33
Number of streams	**32**	**16**	**11**	**8**
Target rate [Gbit/s]	2.5	2.5	2.5	2.5

Table 2: Stream and modulation requirements to achieve the (average) target rate of 2.5 Gbit/s.

Next, we derive different base-band configurations that can provide the necessary number of streams. For this, we utilize a combination of carrier aggregation technique and MIMO spatial multiplexing.

QAM			
Carrier components	8	4	2
Spatial layers	4	8	16
Channel bandwidth [MHz]	800	400	200
Distance [m]	**736**	**972**	**1283**

16QAM			
Carrier components	8	4	2
Spatial layers	2	4	8
Channel bandwidth [MHz]	800	400	200
Distance [m]	**295**	**389**	**514**

64QAM			
Carrier components	8	4	2
Spatial layers	2	4	8
Channel bandwidth [MHz]	800	400	200
Distance [m]	115	152	**200**

256QAM			
Carrier components	8	2	1
Spatial layers	1	4	8
Channel bandwidth [MHz]	800	200	100
Distance [m]	58	102	134

Based on the above, it is shown that high-order modulations are not suitable for the target range. On the other hand, lower modulations can meet the distance and rate requirements, however a trade-off between bandwidth (carrier aggregation) and MIMO processing complexity must be found.

3.2.2.6 Frame structure and numerology

The frame structure and numerology are based on [12] and [13], respectively. On the one hand the presence of DL and UL control messages at the being of each subframe aids the management of the UL and DL traffic. On the other hand, the numerology enables compatibility with LTE, flexibility to cope with low latency applications, reduced complexity, and power consumption [13]. For instance, the numerology based on the 75 KHz OFDM subcarrier spacing is compatible with LTE timing as well as a good trade-off for high-data rate and low-latency applications.

Figure 14 - Superframe structure.

Subcarrier spacing	15 kHz	75 kHz	375 kHz
Sampling clock rate (MHz)	30.72	153.6	768
OFDM symbol duration, no CP (us)	66.67	13.33	2.67
CP duration (us)	4.7	0.95	0.19
CP overhead (%)	7	7	7
Symbols per TTI	14	14	35
TTI duration (ms)	1	0.2	0.1
Frame duration (ms)	10	10	10

Table 3 - Candidate numerology for EU mmW BR-U.

3.2.2.7 Transceiver functionality & interfaces

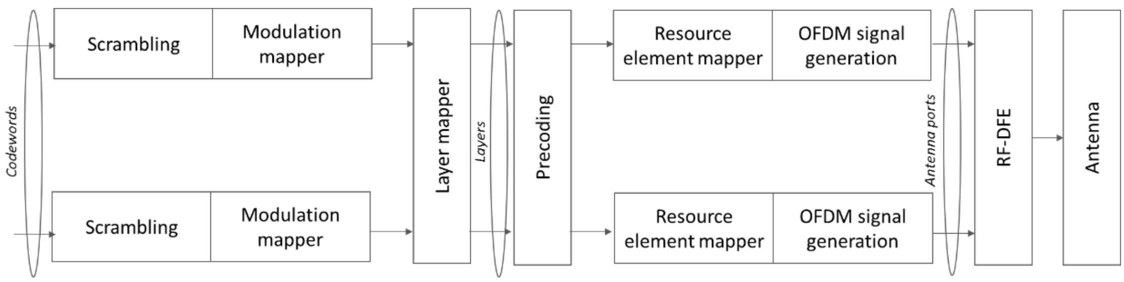

Figure 15 - Overview of the BB processing and interface to RF-DFE.

The BB is defined in terms of the following steps:

- Scrambling of coded bits in each of the code words to be transmitted,
- Modulation of the scrambled bits to generates complex-values symbols,
- Mapping of the complex-valued modulation symbols onto one or several transmission layers,
- Precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports,
- Mapping to antenna ports,
- Generation of the complex-valued time-domain OFDM signal.

Additionally, the BB provides control signalling for the antenna submodule. These include:

- TX/RX timing,
- Power measurements.

The RF-DFE unit provides:

- Complex Numerically Controlled Oscillator (NCOs),
- Interpolation/decimation filter,
- RF impairment correction,
- ADC/DAC,
- Wideband IQ up/down,
- Synthesizer,
- LO.

Antenna module provide

- Phase-shift control,
- Automatic gain control,
- Up/down frequency conversion,
- (Optional) carrier aggregation,
- Calibration,
- Power measurements.

3.2.3 EU Multi-RAT Radio Unit

3.2.3.1 System overview

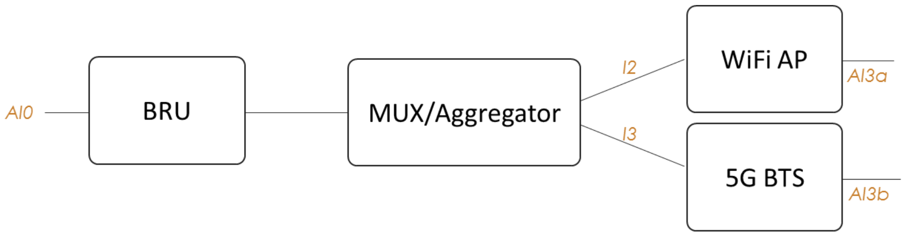

Figure 16 - Overview of the multi-RAT unit.

The EU multi-RAT consists of a backhaul radio unit connected to multiple access points, e.g, Wi-Fi and 5G BTS (if available) via switch. The BRU follows the requirements defined in the previous sections. The other components are off-the-shelf devices with the following requirements.

MUX/Aggregator

- A switch that can work up to 10 Gbps per port,
- Can have fibre or Ethernet connections,
- Up to 48 ports.

WiFi AP

- Can work as a bridge, router, switch for WiFi traffic,
- Can be used to control number of 5G use cases where low latency is needed.

5G BTS

- Can work as a 5G BTS,
- Specifications not known.

Inter-technology interfaces

- I2=100/1000/10000MBps fibre or Ethernet, IP –protocol on top,
- I3=100/1000/10000MBps fibre or Ethernet, S1(assumed) –protocol on top,
- AI3a= IEEE Wi-Fi 2.4Ghz/5Ghz connection,
- AI3b= Assumed 5G air interface connection, functionality not known yet.

3.2.3.2 High level functionalities

For the multi-RAR BRU, the following functionalities have been identified

- Works as an TX/RX interface towards another BRU,
- Identical data pipes towards network and from network,
- L1 and L2 capability,
- Multi-technology switch capabilities,

3.2.4 KR Backhaul Radio Unit

3.2.4.1 System overview

The Korean BRU is an enhancement of the mobile hotspot network (MHN) system [11] , and the testbeds of the Korean BRU will be developed to show Giga bits per second (Gbps) moving hotspot service using millimeter-wave, which is one of the major service scenarios of the project. Basically, the basic architecture of the testbed, as illustrated in Figure 17, is similar to that of the MHN in [11]. It consists of MHN NodeB (mNB) and MHN terminal equipment (mTE) mounted on a vehicle, which is mainly responsible for mobile wireless backhauling between them, and onboard access link (e.g. Wi-Fi) installed inside the vehicle is interconnected with the mTE testbed. The mNB testbed consists of multiple MHN digital units (mDUs) and multiple MHN radio units (mRUs), and the mDUs, each of which is mapped to the corresponding mRU consisting of RF and antennas, are co-located to provide baseband (BB)/L1 functionalities. Similarly, the mTE testbed consists of processing units for both physical and upper layers, RF and antennas units.

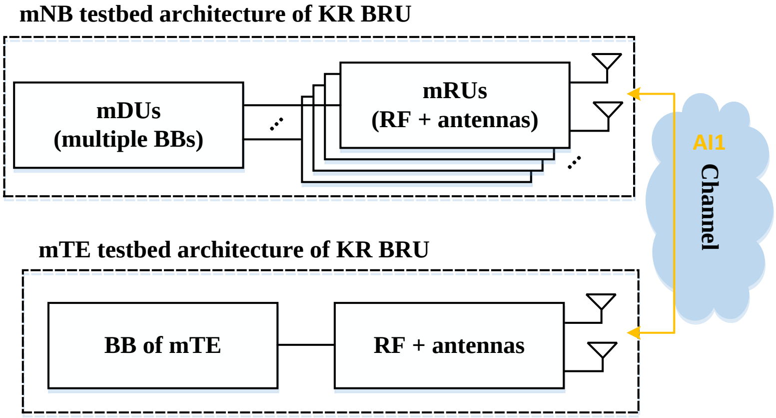

Figure 17 - Overview of the BRU components.

For Korean BRU link, which is a broadband dynamic mmWave backhaul link, the air interface relies on the following key requirements:

- Radio interface operated in the frequency bands of 25.14 ~ 26.14 GHz (FACS)
- Carrier aggregation of multiple component carriers to attain a total transmission bandwidth of up to 1GHz (500MHz ~ 1GHz bandwidth)
- Bandwidth of each component carrier is 125MHz
- Subcarrier spacing of 180 KHz robust to high-mobility up to 500km/h
- FFT size of 1024
- Pre-coded data transmission for digital MIMO techniques such as transmit diversity scheme (SFBC) and open-loop MIMO scheme

3.2.4.2 Antenna Module Functionality & Interfaces & Requirements

To support a digital MIMO technology for further improving spectral efficiency, dual-polarized array antennas will be implemented for both mNB and mTE testbeds. More specifically, as illustrated in Figure 18, the mNB(mRU) is equipped with 2 transmit (TX) antennas and 2 receive (RX) antennas, and the mTE is equipped with 1 TX antenna and 2 RX antennas. 4x4 and 8x8 vertical/horizontal arrays are configured for TX and RX antennas respectively.

Since the Korean BRU is design to operate in unlicensed frequency bands in the range of 25.14 ~ 26.14 GHz, called Flexible Access Common Spectrum (FACS) in Korea, it is mandatory to meet Effective Isotropic Radiated Power (EIRP) requirement regulated by Korean government, where the maximum EIRP allowed is 36dBm. That’s the main reason why the different antenna configurations are considered for TX and RX antennas, and the maximum antenna gains of which are approximately 16 dBi and 21 dBi respectively considering the maximum transmit power of 20 dBm. The simulation results of radiation patterns for TX and RX antennas are shown in Figure 19.

Additionally, only a fixed RF beamforming is considered for each array antenna, and the RF is required to support several indispensable functionalities such as automatic gain control (AGC) and automatic frequency control (AFC) for compensation of frequency offset due to local oscillator frequency offset and Doppler effect. The following table shows the details of the specification of RF, antenna and interface.

Cat.	Item	Specification	Remarks
T/RX	Operating frequency	East-to-West: 25.1056 ~ 25.5376 GHz	West-to-East: 25.9056 ~ 26.3376 GHz
	Bandwidth	432MHz	
	DIF Frequency	705.6~1137.6MHz	RF: 2305.6MHz ~ 2737.6MHz
	TDD Switching Time	< 5usec	
	TRX Isolation	> 55dB	
TX	Output Power	> +17dBm(Avg.)	PAPR : 10dB, Amp. : +20dBm output
	Gain	> 37dB	
	Gain Flatness	± 2.0dB	
	TX Spurious	< -40dBc	LO Leakage
	TX DIF Input	-20dBm (Total)	ATT : 0dB
	TX EVM	< 4%	For 64QAM(Target : 3%)
RX	Noise Figure	< 8dB	
	Input Level	-20dBm Max. ~ -61dBm Min.	
	Gain	> 51dB	Max. gain, -35dBm input, RX Fix att.
	Gain Flatness	± 2.0dB	
	Gain Control	≥ 0.5/31.5dB , ≥15dB	
	DIF Output	-10dBm (Total)	
Interface	Power	+12V / +6.5V	mRU : +12V(10W) , +6.5V(80W)
	LED	USB 1-PORT , 2-Color LED	Alarm(PLL/POWER) / Normal
	Power /RoF	AC 220V / Analog Optic	Electro-Optic Mixed Cable

Table 4 - Details of the specification of RF, antenna and interface.

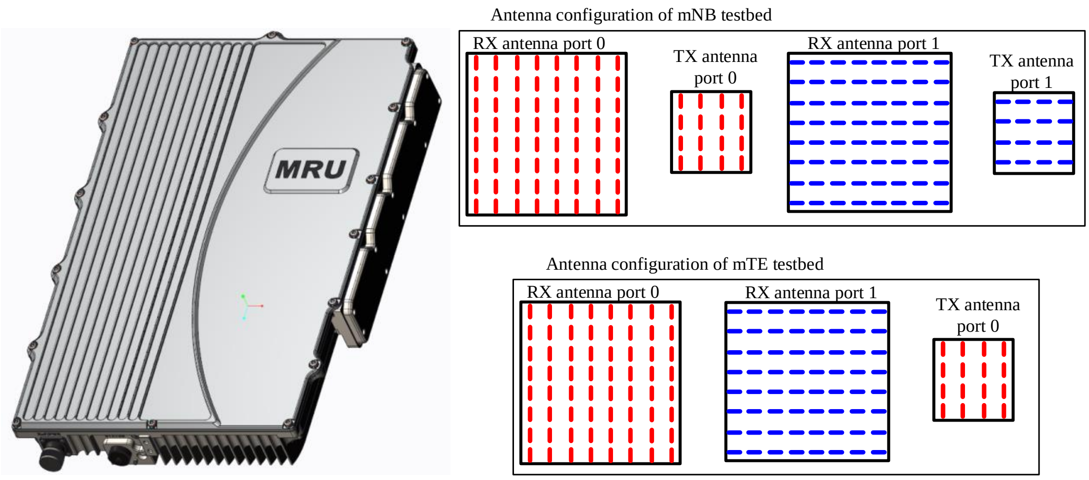

Figure 18 - Antenna configuration of mNB(mRU) and mTE.

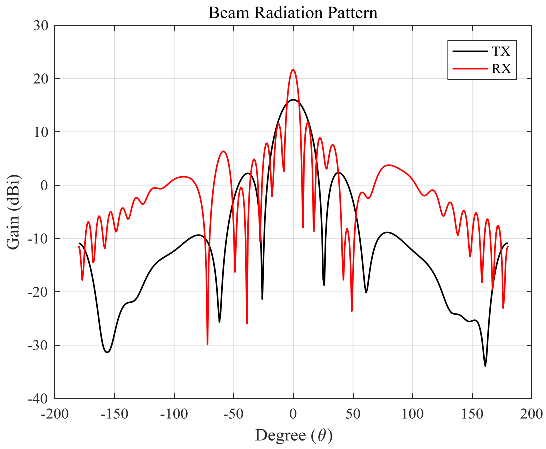

Figure 19 - Antenna radiation pattern of TX and RX.

3.2.4.3 RF-DFE Functionality & Interfaces

The RF-DFE unit provides:

- RF baseband receiver/transmitter functionality
- IF down/up converter functionality to the mmWave carrier frequency (25.14 ~ 26.14GHz)
- TDD switch time of less than 5us

3.2.4.4 Frame structure and numerology

The Korean BRU testbeds aim to allow the aggregation of a maximum of eight component carriers (CCs) to attain a total transmission bandwidth of up to 1GHz as illustrated in **Erreur ! Source du renvoi introuvable.**. Each configured CC in the BRU employs orthogonal frequency division multiplexing (OFDM) for both uplink (UL) and downlink (DL) transmissions. The system only supports time-division duplex (TDD) as uplink-downlink duplexing and the BBs of both mDU and mTE testbeds will be implemented on Xilinx FPGAs capable of providing a maximum data-rate exceeding 2.5 Gbps.

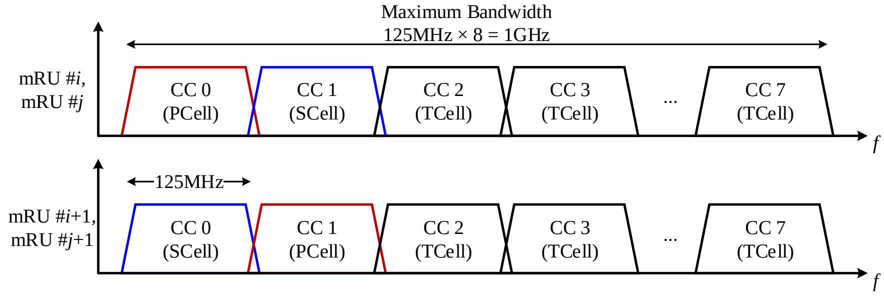

Figure 20 - Contiguous intra-band carrier aggregation.

Figure 21 shows the TDD frame structure of the Korean millimetre-wave-based BRU. The second slot in each subframe of 2*ms*, *l*-th slot (*l*=1,9,17,25,33), is a special slot, which consists of downlink pilot time slot (DwPTS), guard period (GP), and uplink pilot time slot (UpPTS).

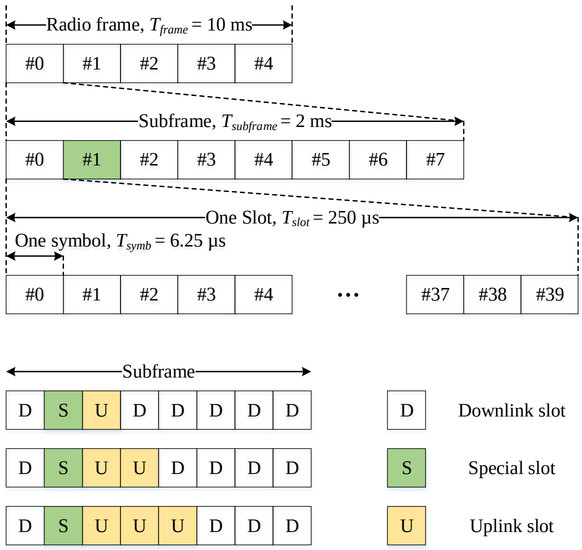

Figure 21 - Frame structure of KR BRU.

A subframe has 8 slots and each slot is 250-us long. Each slot contains 40 OFDM symbols. One symbol is 6.25-us long which is the sum of the reciprocal of a subcarrier spacing of 180 kHz (5.56 us) and a cyclic prefix length of 0.69 us. Figure 21 also shows three different uplink-downlink configurations supported in the system, and their corresponding ratios of downlink to uplink. Following table gives the details of numerology for the Korean BRU.

Subcarrier spacing	180 kHz
Sampling clock rate (MHz)	184.32
OFDM symbol duration, no CP (us)	5.56
CP duration (us)	0.69
CP overhead (%)	12.4
Number of symbols per TTI	40
TTI duration (ms)	0.25
Frame duration (ms)	10
Number of RBs in frequency domain	50
Number of subcarriers per RB	12
FFT size	1024

Table 5 - Numerology for KR mmW BRU.

Due to the characteristics of received signal strength at mTE as shown in Figure 22 where the SNR received from serving mRU is much larger than that received from target mRU most of the time and drastically drops in a very short time, it is highly difficult to obtain cell information and timing synchronization of a target cell prior to handover. This is the main reason why three different cell types are defined in the system, which are primary cell (PCell), secondary cell (SCell), and tertiary cell (TCell) as shown in Figure 23. Each CC can be configured by one of the cell types. The first and second CCs are configured by either PCell or SCell depending on the location of mRU as shown in the Fig. 2 and the remaining CCs are configured by TCell.

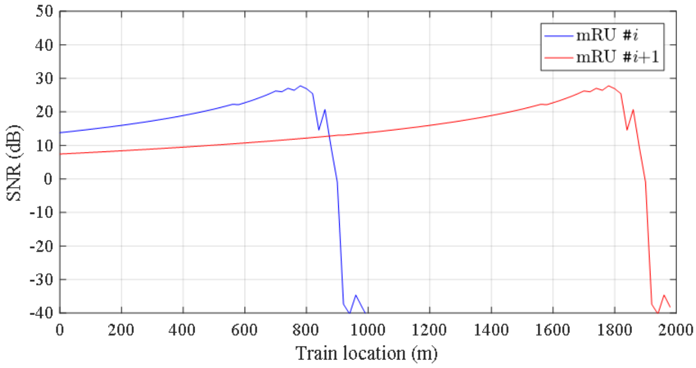

Figure 22 – Received SNR at mTE.

As illustrated in Figure 23, the PCell is not only responsible for sending data and control channels, but also for sending MHN synchronization signal and cell information through MHN broadcast channel (M-BCH). The SCell and TCell, on the other hand, only send data and control information. The main difference between the two is that the SCell vacates the resource location where MHN broadcast channel (M-BCH) or synchronization signal is transmitted in the PCell to detect target cell signal without interference from serving cell.

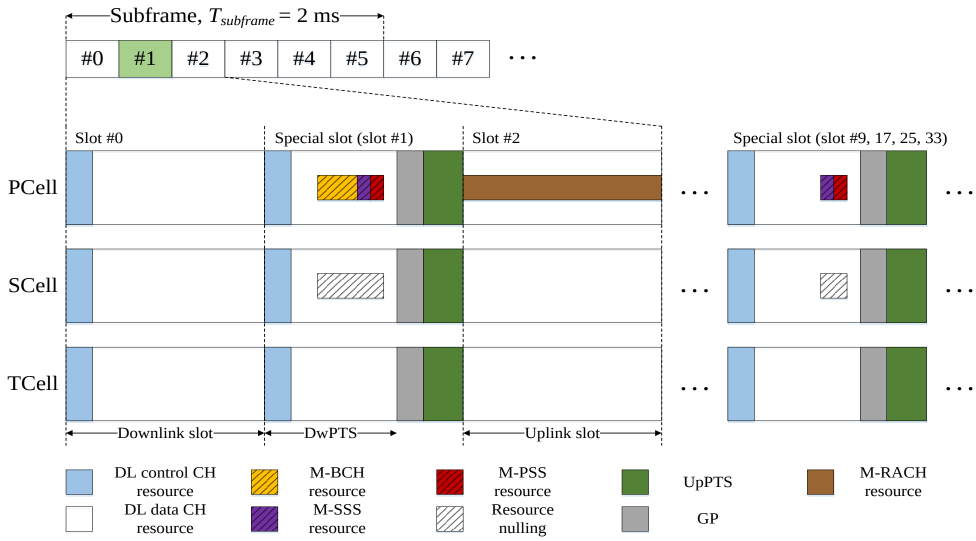

Figure 23 - Frame structure enabling CA, efficient neighbour cell search and fast handover.

Figure 24 shows the pilot structure for the Korean BRU. The pilot signal of the system is designed to use a lattice type allocation, and the allocation of the pilot signals is for a total of two antenna ports. The period in the time domain is four symbols, and the period in the frequency domain is six subcarriers.

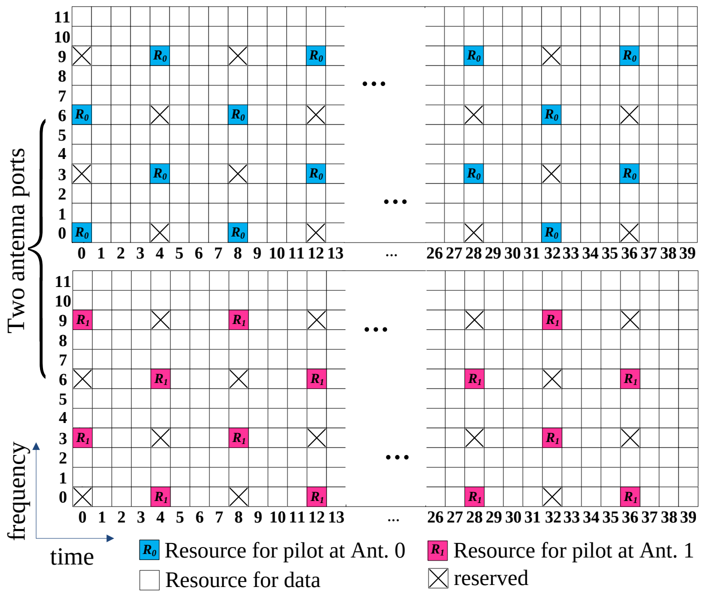

Figure 24 – Pilot structure for KR BRU.

3.2.4.5 Transceiver functionality & interfaces

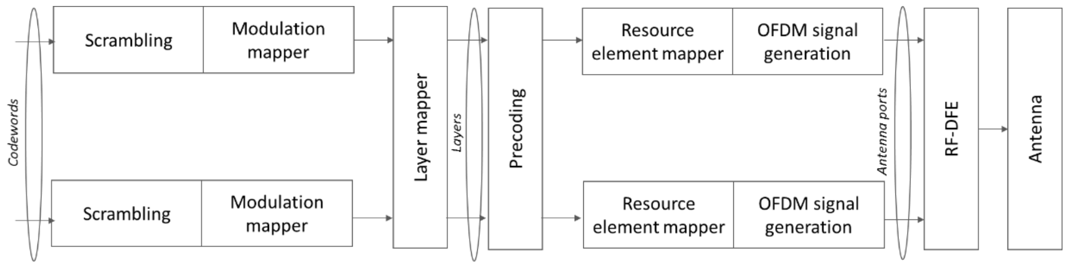

Figure 25 - Overview of the BB processing and interface to RF.

The BB is defined in terms of the following steps:

- Scrambling of coded bits in each of the code-words to be transmitted
- Modulation of the scrambled bits to generates complex-values symbols
- Mapping of the complex-valued modulation symbols onto one or two transmission layers
- Precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- Mapping to complex-valued modulation symbols for each antenna port to resource elements
- Generation of complex-valued time-domain OFDM signal for each antenna port

Additionally, the BB provides control signalling for the antenna submodule. These includes

- TX/RX timing

3.3 Positioning architecture

The figure below shows the overall architecture of the satellite/mm-wave positioning solution:

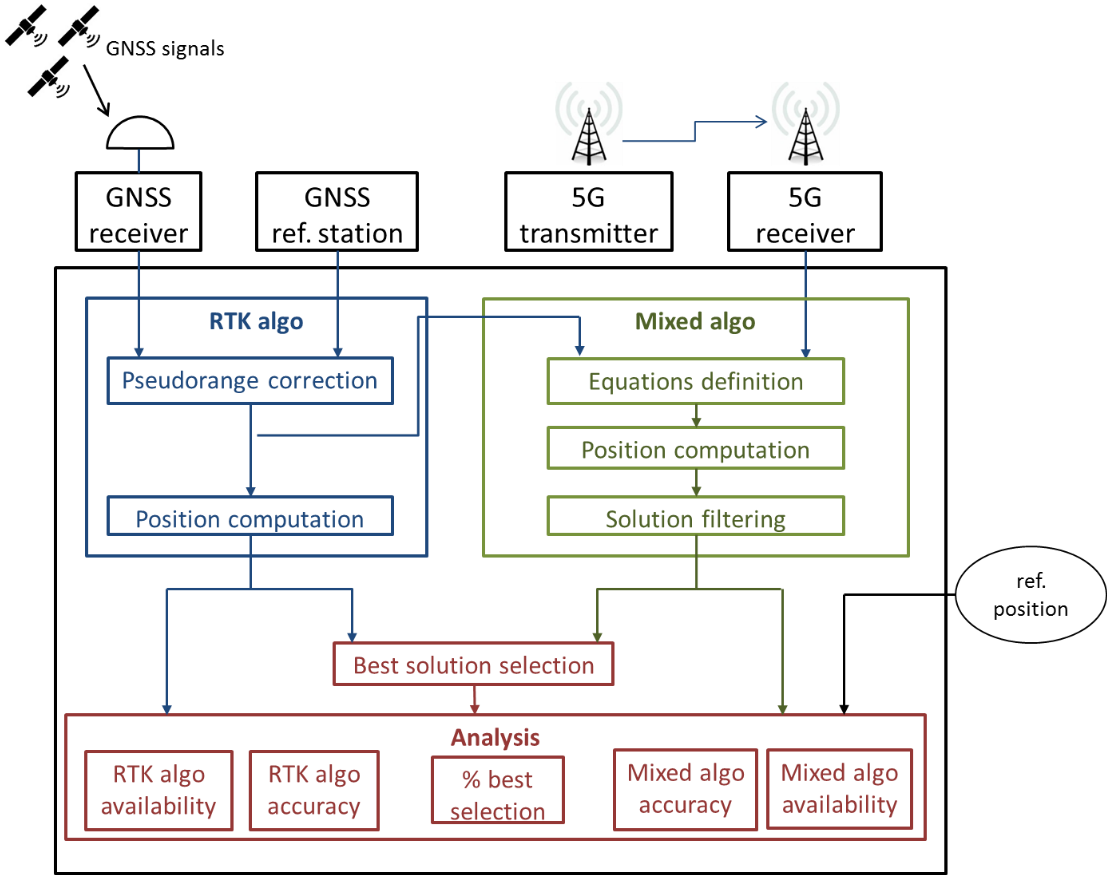

Figure 26 - Overall architecture of satellite/mmWave positioning solution.

The positioning architecture is composed of:

- A single-frequency multi-constellation GNSS receiver, connected to an antenna which collects the signals from the Galileo, GLONASS and GPS satellite constellations
- A GNSS reference station, which transmits in real-time reference GNSS data (RINEX observation and navigation files)
- 5G mm-wave antennas, which provide an angle information between the transmitter and the receiver
- A laptop or a remote server, which is in charge of computing a position from the elements above.

3.3.1 Position computation

The position can be calculated in two different ways:

- With a RTK (Real Time Kinematic) algorithm (blue box in the figure above), which combines exclusively GNSS data from the receiver and the reference station. It generates pseudoranges corrections which are used to compute an accurate position.
- With a mixed mm-wave/GNSS positioning solution (green box in the figure above) : both the GNSS and the 5G antennas provide information that can be translated into geometrical equations. The algorithm computes all possible solutions with various combinations of GNSS satellites, excluding the ones that do not fit with the angle information provided by the 5G antenna.

The algorithms will be detailed in D5.3.

3.3.2 Selection of the best positioning method

The most reliable positioning solution is then chosen by a selective algorithm (red box “best solution selection” in the figure above). To do so, the two positioning algorithms provide not only the positions calculated with the satellite and mm-wave methods, but also *discriminating* data, which are extra information to help the decision algorithm. This discriminating data will be based on the dilution of precision and the accuracy of each positioning technique.

3.3.3 Analysis

During demonstration and tests, the real position of the user will be known and therefore metrics such as accuracy will be calculated. This metric will allow assessing the performances of the selective algorithm.

4 European vEPC architecture (5GTN)

4.1 Planned Architecture overview

The EU vEPC is based on Nokia portfolio that consists of the following VNFs:

- Mobile gateway: The Cloud Mobile Gateway (CMG) provides the SP-GW, GGSN and Traffic Detention Functions (TDFs), evolved packet data gateway (ePDG) and trusted wireless access gateway (TWAG).
- Mobility management: The Nokia Cloud Mobility Manager (CMM) provides the mobility management entity (MME), and SGSN functions.
- Policy control and charging: The Nokia Dynamic Services Controller (DSC), built on the patented Agile Rules Technology (A.R.T) rules engine, provides the Policy and Charging Rules Function (PCRF) and wireline Radius/Change of Authorization.
- Element and network management: The Nokia 5620 Service Aware Manager (SAM) and Nokia NetAct provide end-to-end network management visibility across the entire mobile network.

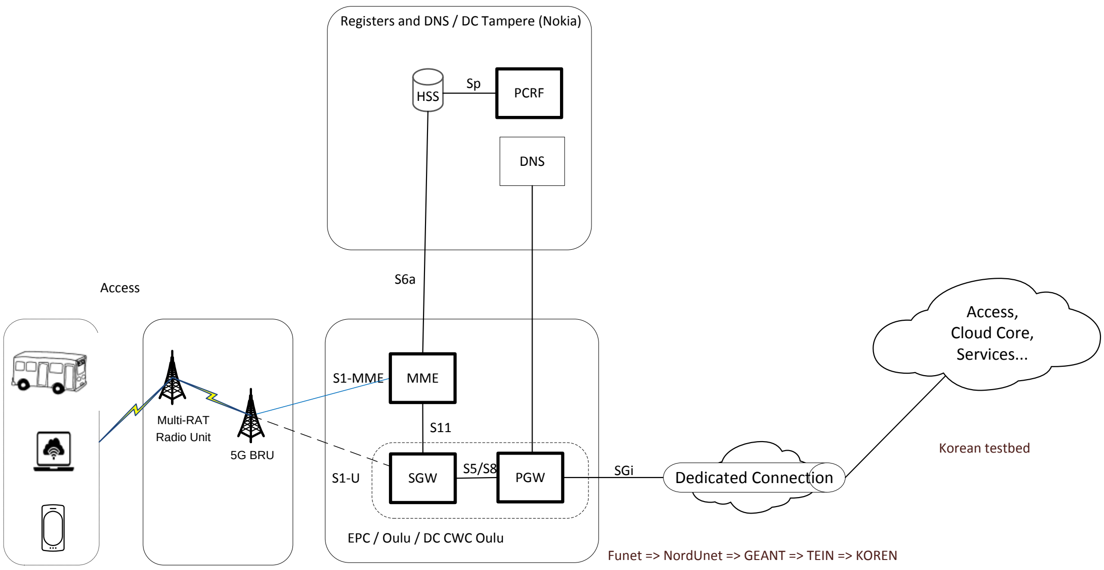

Figure 27 - EU test bed network architecture.

These NFV functions have been deployed on CloudBand's NFV infrastructure (NFVI) and its management and orchestration (MANO) solution. 5GTN project will start by using NCIO (Nokia Cloud Infrastructure OpenStack) as an NFVI which will be then replaced to CloudBand later during the project.

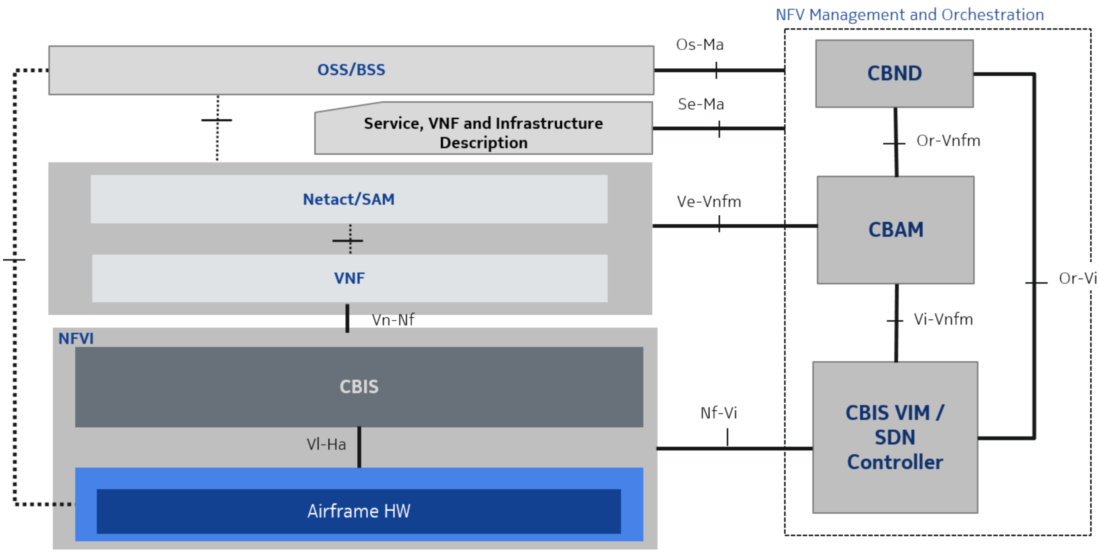

Figure 17 – Cloud infrastructure and management functions in EU testbed.

CloudBand is a portfolio of three products that cover the three ETSI NFV MANO functions. CloudBand Infrastructure Software (CBIS), CloudBand Application Manager (CBAM), and CloudBand Network Director (CBND) are optimized to fit the NFVI and virtualized infrastructure manager (VIM), VNF manager (VNFM) and the NFV orchestrator (NFVO) roles respectively

VNF life cycle management from first deployment to scaling, healing, upgrade and phase out, is done by using two key elements:

- Using CloudBand Application Manager, life-cycle operations are executed with OASIS TOSCA and OpenStack-based Heat orchestration templates as well as Mistral workflows.
- The Nokia 5620 SAM adds VNF monitoring and supervision capabilities with a built-in VNF life-cycle management (LCM) trigger engine for notifying the CBAM when VNF LCM actions need to be taken. The 5620 SAM collects fault and performance monitoring data to give advanced warning of capacity utilization issues through correlation and analysis of the VNF events. It also leverages CBAM integration to collect cloud performance data for calculating key capacity indicators (KCIs) used to trigger VNF scale-outs.

CloudBand has also been integrated with the Nuage Networks™ Virtual Services Platform (VSP)overlay SDN solution.

EU test bed serves 2 different 5G Champion targets:

1. End user (e2e) demo cases
2. NFV/SDN based EPC study

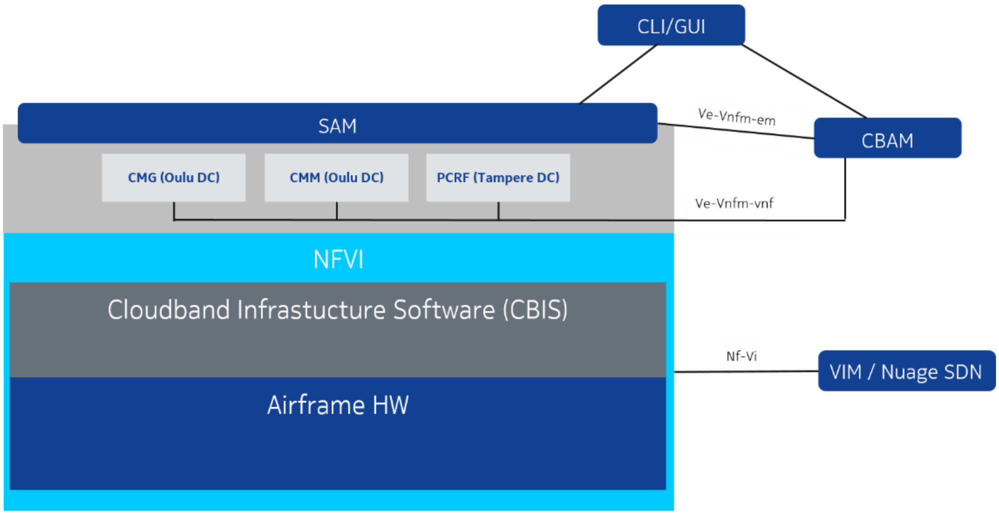

Figure 18 - 5G TN VNF and main management interfaces.

To support the scalability required to meet the expected 4G, 5G and IoT service demands, the EU vEPC VNFs supports following key 5G Core functionalities:

- Packet core VNFs are decomposed into separate control and data plane virtual machine (VM) instances. This enables a distributed architecture where data plane resources can be deployed in edge data centres, closer to the device while control plane resources can be centralized.
- State-efficient VNF processing, which unpins the subscriber/device state information from the VMs, freeing up the underlying compute resources to be reused to process other subscribers/devices.

4.2 Security aspects

CloudBand security design has been hardened with numerous measures, such as encryption of messages between system components. For example, messages between system components are encrypted. CloudBand also provides role-based access control in a multi-tenant environment, allowing different teams to securely share the NFV platform.

The integrated Nuage Networks Virtualized Services Platform provides secure connectivity between the VNFs and their components, both within the data centre and across multiple locations.

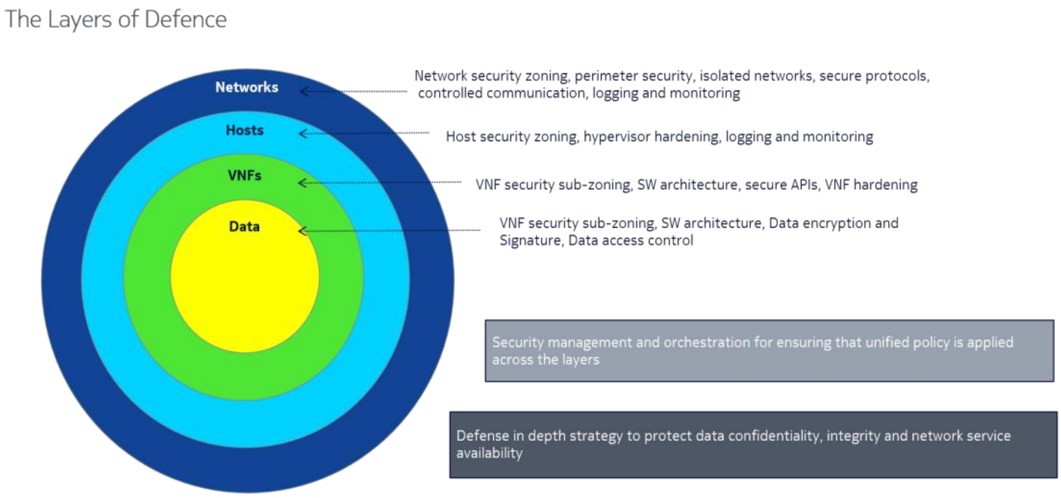

Figure 19 – Layers of Defence in Telco cloud.

5 Korean vEPC architecture

5.1 Architecture overview

The core network of 4G LTE is in charge of mobility, authentication and charging allowing all mobile traffic pass the core network to access services incurring traffic congestion in the core networks. Our plan for 5G is to distribute mobile core functions to the edge nodes. 5G core is generally divided into 5G Core UP (User Plane) in charge of bearer delivery and 5G Core CP (Control Plane) in charge of signalling and control of the 5G core network. One of the deployment options will be centralized CP with distributed UP over the edge nodes. The reason to distribute the 5G core functions could be explained as followings.

- If the core network where bearers are terminated moves down, close to cell sites application servers follow naturally
- 5G will allow users to communicate at the speeds of 1 Gbps eventually and thus traffic generated from Radio Access Network will skyrocket. Once the core is distributed to local areas and a variety of associated application servers are moved down along with them, backhaul traffic will significantly decrease, bringing in cost reduction for continual backhaul enhancement.
- 5G network is supposed to be able to provide ultra-real time services like highly sensitive remote control, auto driving vehicle, etc. These types of services may cause much lesser traffic than video, but require ultra-lower delays other than applications. To this end, it is possible to relocate core functions closest to end users as well as place real-time servers where the core functions are located

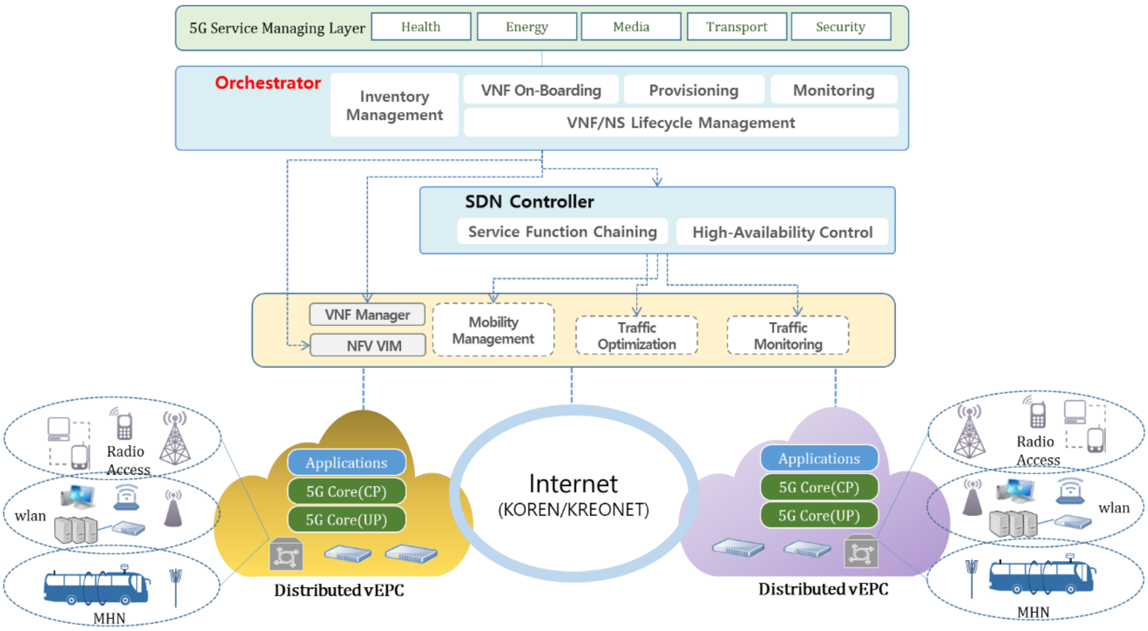

Figure 28 - High level architecture of Korea's Distributed virtualized EPC.

Another outstanding feature of 5G mobile core networks represents the accommodation of diversity. A variety of types of mobile core networks where each networks are defined a set of virtual network functions could be generated and deployed in order to provide designated network service to the end users. HSvEPC and HEvEPC for 5GCHAMPION shows two distinct types of virtualized mobile core networks prove flexibility and agility of mobile core networks in 5G.

5.1.1 Highly Scalable vEPC (HSvEPC)

To provide highly scalable 5G mobile core networks we employed two types of scalability: functional scalability and service scalability. Functional scalability means the capability of expansion of vEPC by separating conventional consolidated functions into user plane and control plane functions by dynamic scaling operations over virtualized network functions while service scalability is about diversification of core networks for end users classified by applications, policy and other context information using network slicing technology.

5.1.1.1 Functional Scalability

HSvEPC is formed with virtual network functions which means that they can be scaled in or out depend on the situation. With scalability, it can be applied to any network functions such as Massive IoT or Mission-critical IoT which requires small amount of resource from hardware but specific functionality. For example, we can have an IoT device that requires single core to run, and then we can scale VNF to meet the requirement of that specific IoT device instead of spending whole EPC hardware such as using non-ip address device.

Main functionality and features of HSvEPC for functional scalability are as follows:

- OpenStack and NFV based EPC function and separation of Control Plane and Data Plane
- Dynamic core network resources management and control management
- Designed from standard to apply any 3rd party platform
- NFV based scalable and dynamic network condition projection

HSvEPC is mainly formed with vMME, vSGW-CU, vPGW-CU, vSGW-DU, and vPGW-DU. CU is control plane which controls device management and DU is user plane which controls data transfer between devices. The main reason why we separated functions by each plane is to have scalability by situation. Since our vEPC is divided into CU and DU functions, they function as VNF, therefore they can be modified and have micro-control on each function.

Node	Description
vMME	Manage mobility of UE and process authentication.
vSGW-CU	vSGW-CU creates a session with vMME and GTP-C, then send it to vSGW-DU with using SDP.
vSGW-DU	vSGW-DU connects with vSGW-CU to get session information, then communicate UE traffic between eNB and PGW-DU with GTP-U.
vPGW-CU	vPGW-CU creates session with vSGW-CU and GTP-C, send related session information to vPGW-DU with using SDP, and apply QoS from PCRF.

vPGW-DU	vPGW-DU gets session information from vPGW-CU, communicate UE traffic between SGW-DU by GTP-U, and communicate traffic between PDN by SGi interface.

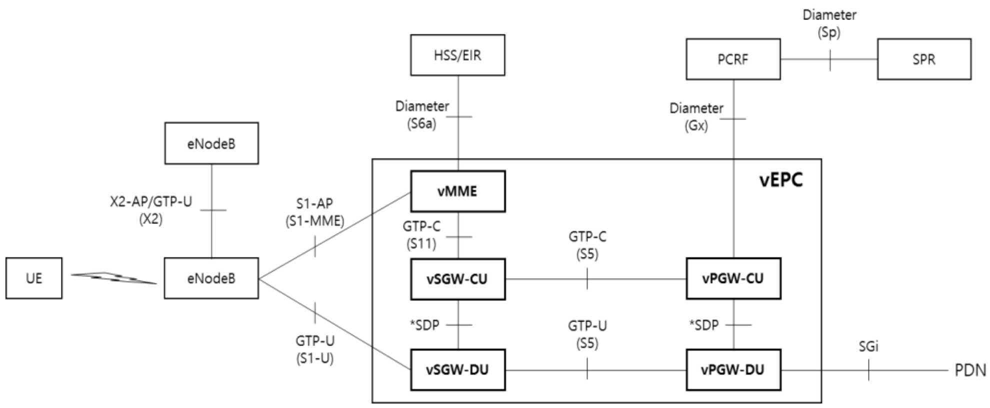

Figure 29 - HSvEPC Network Architecture – CP/UP Separation Model (HS-vEPC).

5.1.1.2 Service Scalability

Network slicing is a trending topic and has an important role for the service scalability. The main concept of network slicing is to divide several functions of network into slices by each role of network functions. For example, current 4G network is mainly focused on mobile device, however in order to accommodate newly employed IoT service in the network, all of new IoT devices and functions should be added in the same networks. In 5G network the service would not depend on which service is being used, it will depend on functionalities it should have and all of them will use same network. HSvEPC is designed to give network operators sufficient elasticity to support heterogeneous service for upcoming 5G era.

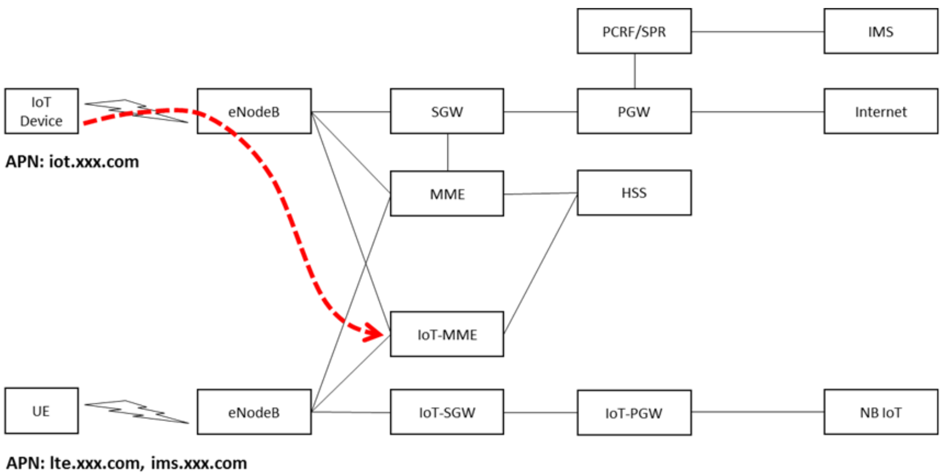

Figure 30 - HSvEPC Core Slicing Use Case.

The figure 20 is showing a use case for APN-based Core Network Slicing. Since IoT devices have different APN from current UE and discrimination of each device occurs at MME. One of the provided functions is to categorize resources for SGW and PGW functions provided by service providers.

The key feature of 5G is network slicing which is based on scalability and flexibility of network function. In 5G network, requirement will be focused on IoT devices which requires small amount of core functions with large number of devices in certain area with less traffic than 4G network. HS-vEPC also can be scaled in or out depend on demand.

5.1.2 Highly Efficient vEPC (HEvEPC)

HEvEPC is the optimized mobile core network for Mobile Hotspot Networks (MHN) to enhance agility of the network. For faster and more dynamic mobility management, S1 interface of the virtual EPC has been modified in terms of user plane and control plane. Main features of HEvEPC are as follows.

- Single-bearer multi-carrier optimization scheme: For channel efficiency in the MHN, single EPS bearer between mTE and mGW will be utilized as multi-carrier data links for connectivity of both sides.
- User Plane interface: Highly flexible interface leveraging legacy transport protocol and minimizing overlaying overhead.
- Control Plane: Reducing configuration overhead for GTP tunnelling for data path setup keeping exchange of indispensable information for both sides.

5.1.2.1 Components of MHN

Mobile Hotspot Networks with HEvEPC consists of 3 components as shown in Figure 21.

- mTE: mTE stands for MHN Terminal Equipment for mobile communications interfacing with mNB to provide high-speed mobile packet service.
- mNB: MHN Node Base station has both wireless interface with mTE and wired interface with mGW. Especially mS1 interface between mGW and mNB supports multiple connectivity between them.
- mGW: MHN Gateway is responsible for control plane functions through mS1 interface such as session management and mobility management of User Equipment as well as establishment of signalling interface with mNB for EPS bearer and handover management. For user plane, mGW performs packet filtering and routing for downlink packet streams while transmits data packets over tunnels between mNB and mGW.

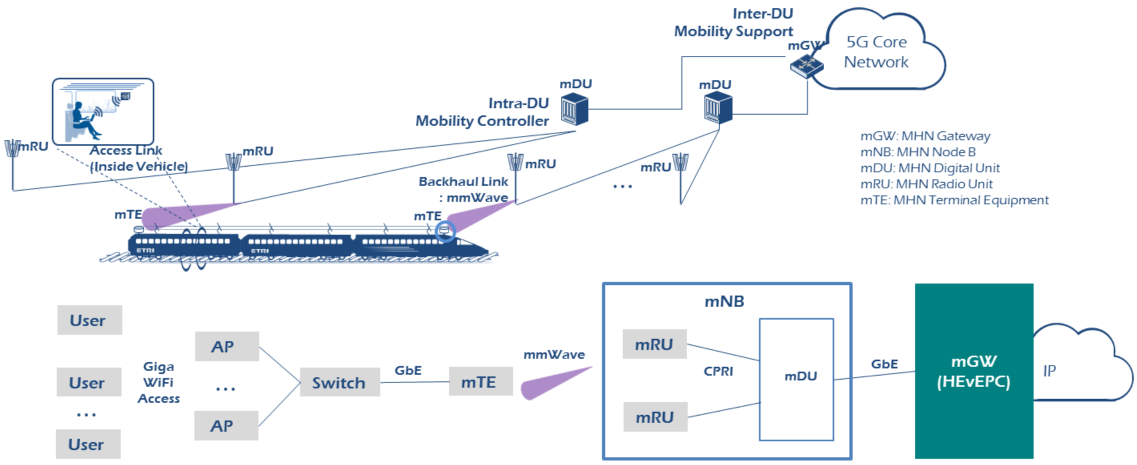

Figure 31 - HSvEPC Network Architecture - MHN Model.

5.1.2.2 Interfaces between components of MHN

Interfaces between components of Mobile Hotspot Networks illustrated in Figure 22 are as follows.

- mUu interface supports air interface for physical signals and channels in order to transmit upstream and downstream traffic between mTE and mNB. mUu interface also supports radio resource control interface for communication in the wireless area.
- mS1 interface supports operation interface between mNB and mGW such as E-RAB management, initial context delivery and NAS signalling. mS1 also supports tunnelling interface for data traffic transmission for both sides upstream and downstream.

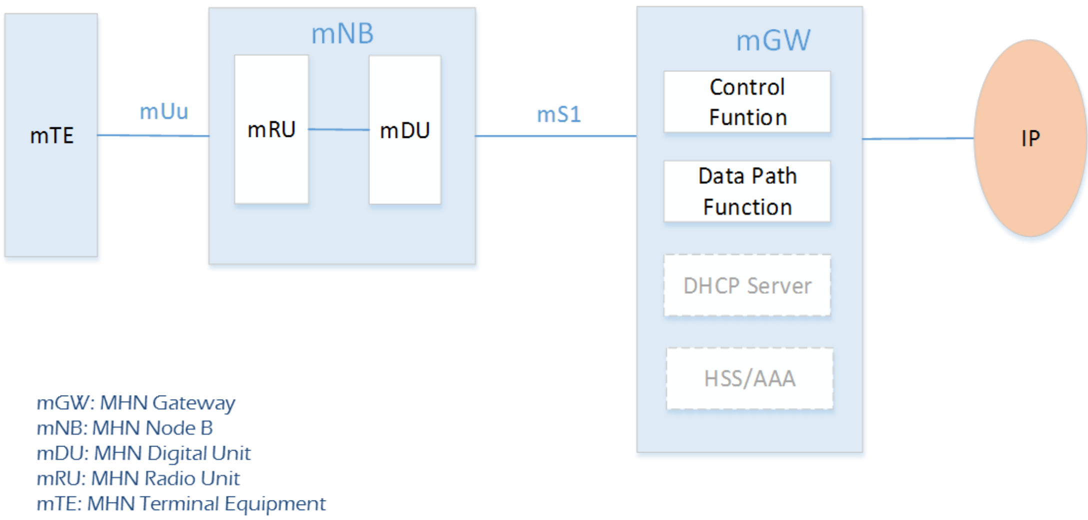

Figure 32 - HEvEPC Network Interface - MHN Model.

5.1.3 Mobility Management

Handover management: Specifically, in the MHN, a fast handover mechanism is required even in high-speed movements keeping user data rate for application service. To this end, designated handover scheme using policy-based SDN technologies is exploited and used for PoC of the mobility management.

In the future functional decomposition & distribution for global service management will span multiple PoP(Point of Presence)s over the network. Anchoring and mobility management tailored to a network slicing instance will be determined at the central node. Composition functions and resource will be orchestrated for dynamic mobility management.

Distributed Mobility Management technology is to distribute and place IP anchoring functions over the network to address issues stemming from conventional centralized single anchoring architecture such as Mobile IP (MIP), Proxy Mobile IP (PMIP). There are 5 DMM architectural models applicable to mobile core networks of 5GCHAMPION.

5.2 Security aspects

Coming from the network slicing perspectives a comprehensive level of security have been discussed.

- Isolation of Network slice instance in terms of resource and components including constituent functions.
- Identification & authentication of the end users in terms of network slicing administration
- Different security & policy rule enforcement depending on the network slice
- Admission control for communications between network slice instances

Distributed 5G core management platform provides secure and trusty network slicing orchestration & management mechanism for various application providers across the distributed networks.

5.3 Management and Orchestration (MANO)

Defined in ETSI ISG NFV architecture, MANO (Management and Network Orchestration) is a layer that manages and orchestrates the cloud infrastructure, resources and services. It is comprised of, mainly, three different entities — NFV Orchestrator, VNF Manager and Virtual Infrastructure Manager (VIM).

NFV Orchestrator is responsible for managing the functions such as network service life-cycle management and the overall resource management. Service management or orchestration deals with the creation and end-to-end management of the services — made possible by composing different virtual network functions (VNFs). Resource management helps in ensuring that the NFV-infrastructure resources are abstracted cleanly (independent of VIM) to support the services that access these resources.

The VNF Manager oversees the lifecycle (typically involves provisioning, scaling, terminating) management of instances of virtual network function (VNF). It is typically assumed that each VNF will be associated with a VNFM that will manage that particular VNF’s lifecycle. A VNFM may manage multiple instances of the same type of VNF or different types of VNFs.

The Virtualized Infrastructure Manager (VIM), controls and manages the NFVI compute, storage, and network resources. The VIM-component has received tremendous focus and various open source solutions such as OpenStack and has been used to realize the virtualized infrastructure management functionality of MANO.

In summary, when MANO is seen as a single entity, the typical functionalities of include (a) Infrastructure automation and providing consistent, accurate and global view of the resources, (b) Network integration, (c) VNF lifecycle management and its placement in in NFVI, (d) service management, (e) Performance monitoring, analysis and governance (auditing, compliance) support.

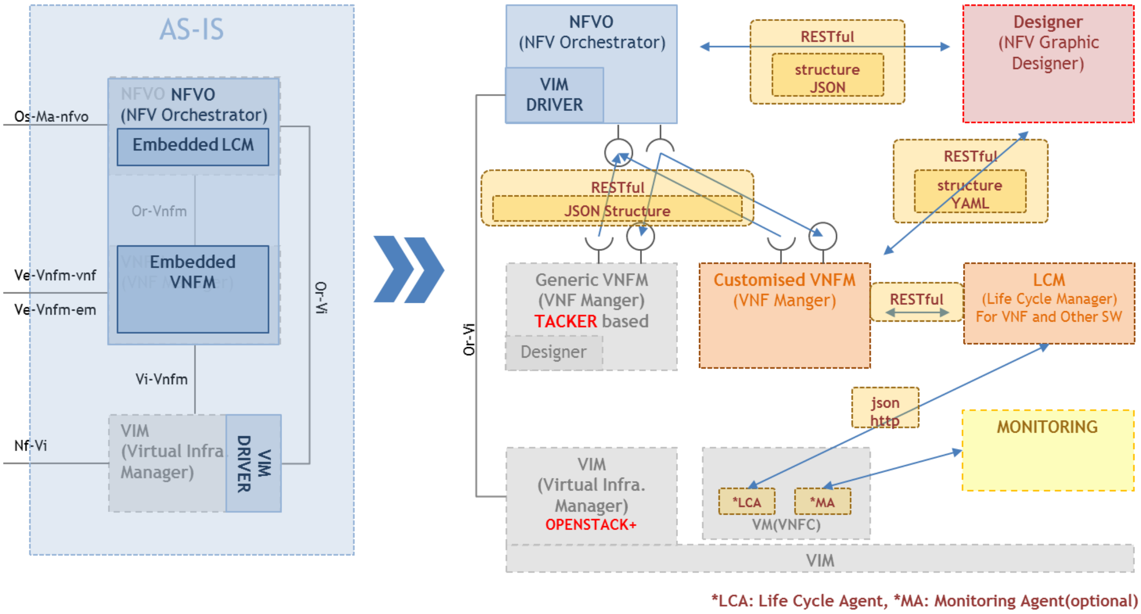

Figure 33 - KR MANO Architecture.

6 EU-KR interoperability

The use cases 6 and 7 as documented in D2.2, require interoperability between the European and Korean mobile core networks:

- Scenario 6 – Where there are two users, one connected to the EU EPC and the other to the KR EPC. Content is shared between the two users which is a latency critical application like shared gaming.
- Scenario 7 – In this scenario a mobile UE on the KR side is the content provider and is streaming UHD videos to a receiving UE on the EU side. The aim is to achieve very high data rates across the two EPCs.

This section will detail the requirements of such interoperability and detail potential interoperability architectures. WP4 will further refine the implementation of these interoperability architectures. Interoperability requirements

The different use cases targeted 5G CHAMPION require high end-to-end connectivity quality. End-user experience can be only as good as the weakest link of the connectivity chain. Therefore, functionalities in the transmission path which are causing any delays (L3 routing decisions, security checks, etc.) must be minimized. Next, the routing between both testbeds (EU and KR) needs to be as stable as possible, to keep the end-user service quality sufficiently high.

The 5G CHAMPION use cases are targeting both bandwidth-hungry applications such as streaming 4K video and latency critical applications such as control and gaming. Demonstrations with high transmission need and with 5G radio access both in EU and Korea can be assumed with two systems interworking with each other. On the other hand, it is unrealistic to assume that demos requiring real-time experience, such as remote controls could be arranged between EU and KR, given the physical latency limitations of interconnecting testbeds which are almost at a 7000 km air distance from each other.

The table in Figure 28 gives an overview of the different latency budgets of the use cases formulated in D2.2. The latency details are split into the following parts:

- **E2E delay**: end-to-end delay as required by the global use case
- **RAN delay**: delay budget available for, or enforced from the radio access network
- **Core network delay**: delay budget available for the mobile core network
- **Interconnection delay**: delay budget available for the interconnection network, as deduced from the other delay budgets above

Table 6 - Use case latency budget overview.

Scenario	E2E delay	RAN (radio and backhaul)	Core	Internet
1) Stationary multi-RAT hot-spot connected via mmW backhaul	10 - 50 ms	<30ms (3gpp LTE std based)	<20ms (remaining)	NA
2) Ultra-high data rate over a radio link	1 – 10 ms	<10 ms	<5 ms	NA
3) Indoor-outdoor positioning	> 50 ms	<15 ms	<50 ms	NA
4) Emulation of sub 6GHz satellite access with IoT devices	NA	NA	<50 ms	NA
5) High user-mobility	> 50 ms	--	--	--
6) Short-latency application	1 – 10 ms	<2 ms (There is two RAN -> <1ms on each RAN)	<1 ms (There is two core -> <0.5ms on each Core)	<2 ms
7) Broadband applications	> 50 ms	<2 ms (There is two RAN -> <1ms on each RAN)	<1 ms (There is two core -> <0.5ms on each Core)	<300 ms

As indicated in the table, several cases do not involve a mobile core network, or the interconnection of multiple mobile core networks.

6.1 Interoperability architectures

As documented in the previous sections, the EU and KR testbed involve two independent EPCs, each with their own particular architecture and implementation. Figure 29 illustrates the considered logical architecture for the interoperability of both mobile core networks.

The interconnection of both EPCs, which are located in testbeds at a distance of 7000 km of each other, therefore follows a loose interconnection model with the following salient features:

- **Default SGi PDN interconnection via IP**. This follows the standard 3GPP approach.
- A **dedicated tunnel between the EU and KR testbed** which will provide guaranteed bandwidth and latency. This will ensure that the QoS requirements of the two use-cases involving multiple EPCs are guaranteed.

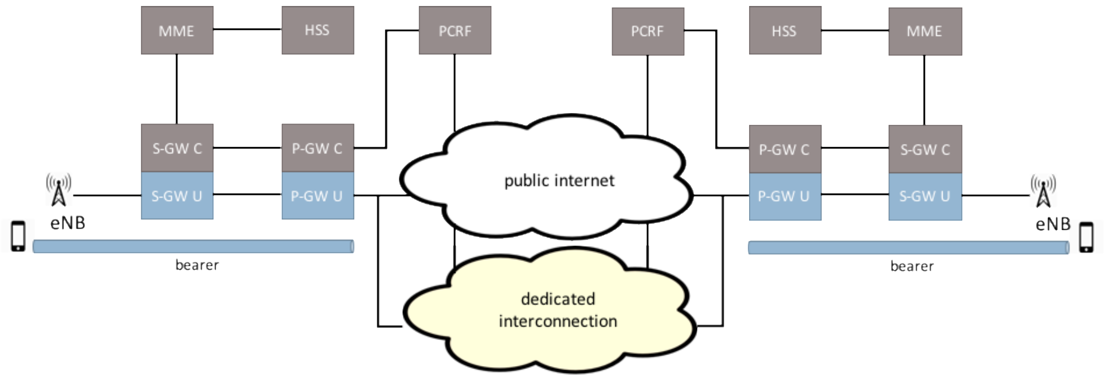

Figure 34 - Logical architecture for mobile core interoperability.

Given, the different requirements, and delay budgets as documented in Figure 28, the following subsections will refine physical interoperability setups as supported by the different use cases.

6.1.1 Physical interoperability architecture for fully remote EPCs

As both the EU and KR mobile core setups are largely developed in an independent way and deployed in the corresponding local testbeds, the preferred way of interconnecting them, is to keep both EPCs locally and interconnect them using either the public internet or the referred dedicated QoS-supportive network connection. This architecture setup is depicted in Figure 30.

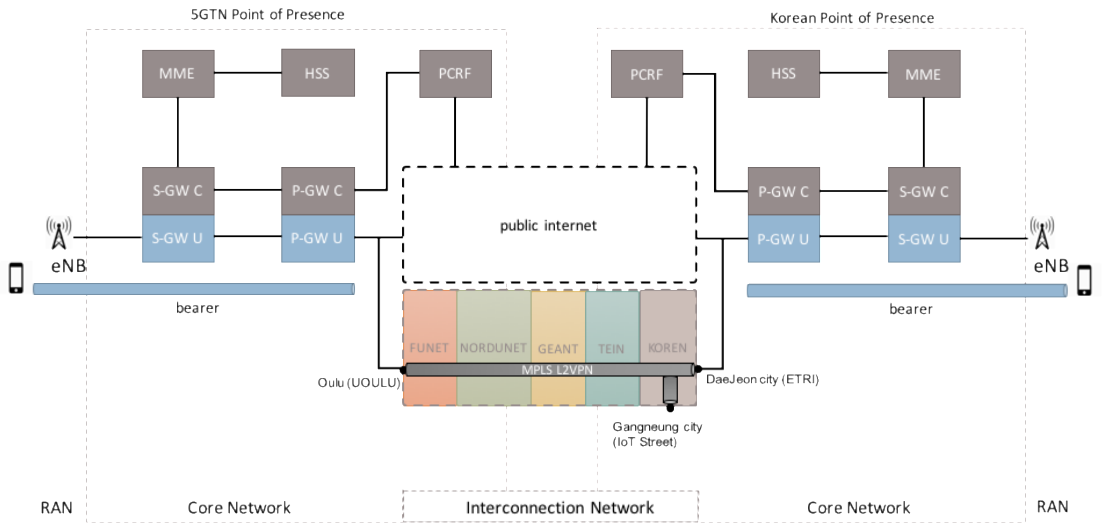

Figure 35 - Physical interoperability architecture with fully remote EPCs.

In the depicted architecture, a dedicated connection is provided as an MPLS-provisioned L2VPN tunnel between the EU and KR testbed (i.e., the Korean side has 2 connection points, one at ETRI in DaeJeon city, and another at IoT Street in Gangneung city). Note that the L2VPN connectivity is more than the required L3 connectivity for the SGI interfaces according to 3GPP standards. The MPLS-based carrier, enables QoS support required for the considered use cases.

As indicated in the picture, the interconnection crosses multiple research networks, and enables

- **FUNET** (Finnish University and Research Network) is a high-speed data communications network serving the Finnish research community. It connects about 80 research organizations and about 370 000 users. CSC maintains and develops the Funet network. (https://www.csc.fi/en/funet-network-services)
- **NORDUNET** operates an optical network backbone interconnecting Oslo, Stockholm, Helsinki, Copenhagen, Hamburg, Amsterdam, and London. This network forms the northern extension of the GÉANT footprint. (https://www.nordu.net)
- **GEANT** is a fundamental element of Europe's e-infrastructure, delivering the pan-European GÉANT network for scientific excellence, research, education and innovation. Through interconnections with its 38 National Research and Education Network (NREN) partners, the GÉANT network is the largest and most advanced R&E network in the world, connecting over 50 million users at 10,000 institutions across Europe and supporting all scientific disciplines. (http://www.geant.org)
- **TEIN** (Trans-Eurasia Information Network) provides a dedicated high-capacity data-communications network for research and education communities across Asia-Pacific. It operates at speeds of up to 10 Gbps. (http://www.tein.asia)
- **KOREN** (Korea Advanced Research Network) is a non-profit testbed network infrastructure established for facilitating research and development and international joint research cooperation. It provides quality broadband network testbed for domestic and international research activities to the industry, academia, and research institutions, enabling testing of future network technologies and supporting R&D on advanced applications. (http://www.koren.kr/)

The above setup enables connectivity between 1 Gbps and 10 Gbps, sufficient to fulfil the bandwidth requirements of targeted use cases. As two routes are available in this setup, a certain reliability and network failure resilience can be guaranteed. With respect to latency, initial measurements indicate that the RTT between both sides of the dedicated interconnection is between 250 and 300 ms, sufficient for use case 7, but not for use case 6.

6.1.2 Physical interoperability architecture for co-located EPCs

As indicated in the above, short-latency applications, such as real-time gaming, as required for use case 6, require network interconnection delay of less than 2 ms. Clearly, this cannot be achieved using an interconnection of remote mobile core networks in Finland and Korea. Therefore, several alternative architectures might be considered.

6.1.2.1 Fully co-located mobile core networks

Keeping the logical integrity of both (EU and KR) mobile core network setups, one possible way to achieve low latency interoperability, is to co-locate both setups. When considering this approach for the targeted PoC of use case 6 at the Olympic games in Korea, one might re-use the connectivity provided by the KOREN network. This enables a range of different PoPs for deploying the EU vEPC. This setup is illustrated in Figure 31.

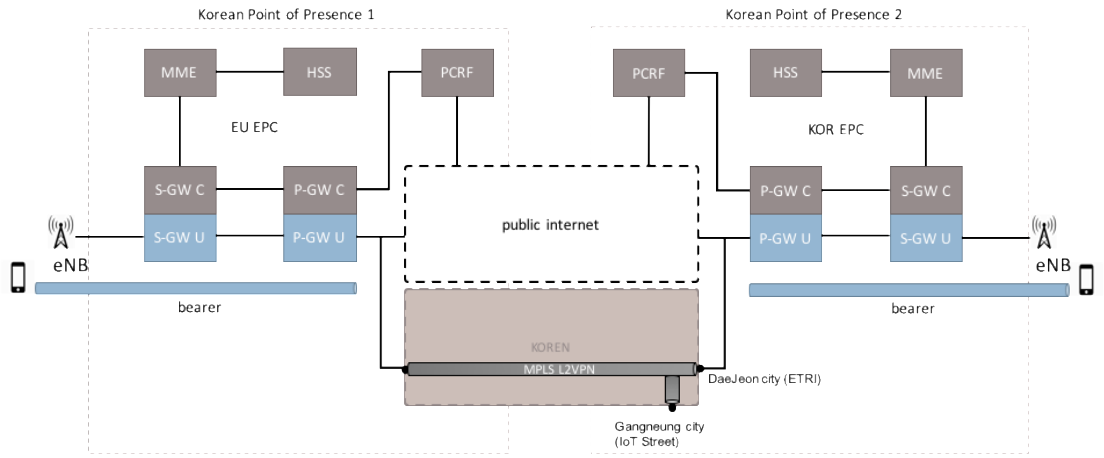

Figure 36 - Co-located vEPCs in different PoPs.

This setup requires the entire EU vEPC implementation to be deployed locally in Korea. However, as the considered use case, requires low latency only for use plane traffic, an alternative architecture might be to keep vEPC control functionality deployed locally in the 5GTN testbed, while deploying user plane NFs of the EU vEPC in the co-located PoP. This scenario is depicted in Figure 32.

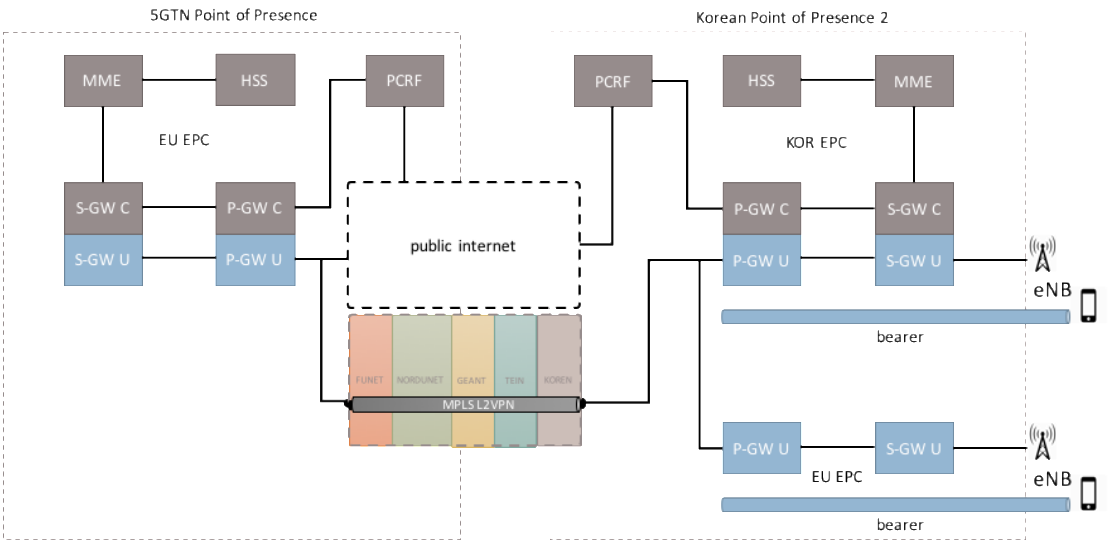

Figure 37 - Partially co-located vEPC interoperability architecture.

7 Conclusion

In this deliverable, we have described the architectural overview from the radio access up to the mobile core network in order to support targeted use cases and PoCs as prescribed by the 5G vision of the project. In the core network part, the architecture has been described and an overview has been given of the Management and Orchestration of the core functionalities and resources. The ETSI MANO framework will be followed in both the architectures. The section on security aspects discusses encryption and secure connections between the various VNFs etc. The various aspects of the RAN have also been discussed – mmWave, Satellite Communication, Positioning using both mmWave and satellite, integrating Multi-RAT technology etc. The last section also discusses the interoperability between the EU-KR testbed with respect to the use-cases which will demonstrate interoperability during the Winter Olympic games in PyeongChang, South Korea.

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