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Final document of 5G-ALLSTAR architecture, API, interface specifications and KPIs for PoC

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Abstract

This deliverable has been created as part of the work in the project Work Package 2 (WP2) and represents its third output. According to the Grant Agreement, the goal of this document is to provide system architectures that are the basis for the research of WP3 and WP4 and to provide the technical specification necessary for the development of testbed and trial platforms for proof of concept (PoC) in WP5. This deliverable also defines a set of key performance indicators (KPIs) to be validated through the PoC. The associated services scenarios and applications will be described in deliverable D2.4.

Keywords

System architecture; Multi-connectivity; System design; System component; Key enabling technology; Proof of concept; Key performance indicator

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Executive Summary

This deliverable provides the specification of 5G-ALLSTAR system describing a set of architectures and associated interfaces. More specifically, it first presents a high-level system architecture with basic required interfaces for 5G-ALLSTAR system. Then, in order to provide other technical work packages (WPs) with architecture for their study, two detailed architectures that originate from the high-level system architecture – WP4-specific architecture and WP5-specific architecture – are described. In close collaboration with WP4, a set of architectures and associated interfaces are defined for WP4's study on Multi-Connectivity (MC) technologies and summarized in this deliverable. This deliverable also specifies the detailed architecture and interface design of testbeds and trial platforms for proof of concept (PoC), particularly focusing on key components, functionalities, application programming interfaces (APIs), interfaces and key technologies to be implemented, and defines target Key Performance Indicators (KPIs) to be fulfilled by the PoC. The system architectures and interfaces specified in this deliverable may be subject to change depending on the final decision on the location of the key event or on the needs of studies in each WP during the remaining period of the project. The possible modifications will be included in deliverables of each concerned WP or in an annual report.

The deliverable is structured as follow:

- In Chapter 2, we describe the 5G-ALLSTAR architectures. More specifically, the basic high-level system architecture of 5G-ALLSTAR system is presented first. Then, a set of MC architectures that can efficiently integrate 5G cellular access network and satellite access network are described and the WP4-specific architecture dedicated for study on MC technologies is also summarized. Finally, the architecture design of Korean (KR) PoC system, European (EU) PoC system and an integrated KR-EU PoC system is provided.
- In Chapter 3, based on the PoC system architecture defined in Chapter 2, the final specification for system components, interfaces, and key functionalities/technologies to be implemented on the testbeds and trial platforms is provided.
- In Chapter 4, we summarize target KPIs to be validated through PoC (testbed or field trial) for different PoC scenarios/applications to be defined in deliverable D2.4.
- In Chapter 5, we draw the conclusions of the deliverable and briefly discuss future activities.

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List of Abbreviations

3D	3 Dimensions / 3-Dimensional
3GPP	3rd Generation Partnership Project
5G	5th Generation
5G-ALLSTAR	5G AgiLe and fLexible integration of SaTellite And cellulaR
5GC	5G Core
5GMM	5G Mobility Management
5GSM	5G Session Management
ADC	Analog-to-Digital Converter
AF	Application Function
AFC	Automatic Frequency Control
AGC	Automatic Gain Control
AM	Acknowledged Mode
AMF	Access and Mobility Management Function
AP	Access Point
API	Application Programming Interface
AR	Augmented Reality
AS	Access Stratum
ASIC	Application-Specific Integrated Circuit
AUSF	Authentication Server Function
BS	Base Station
CN	Core Network
CNS	Core Network Subsystem
CP	Control Plane
CP	Cyclic Prefix
C-RAN	Cloud/Centralized Radio Access Network
CRC	Cyclic Redundancy Check
cRRM	Centralized RRM
CSI-RS	Channel State Information Reference Signal
CU	Centralized Unit
DAC	Digital-to-Analog Converter
DM	Diagnostic Monitoring
DMRS	Demodulation Reference Signal
DN	Data Network
DRA	Dynamic Resources Allocation

DRB	Data Radio Bearer
dRRM	Distributed RRM
DU	Distributed Unit
E2E	End-to-End
ECM	EPS Connection Management
eICIC	enhanced Inter-Cell Interference Coordination
EIRP	Effective Isotropic Radiated Power
ES	Earth Station
FACS	Flexible Access Common Spectrum
GBR	Guaranteed Bit Rate
GEO	Geostationary Orbit / Geostationary Orbit Satellite
gNB	Next Generation Node B
GPRS	General Packet Radio Service
GTP	GPRS Tunnelling Protocol
GUI	Graphic User Interface
HARQ	Hybrid Automatic Repeat Request
IF	Intermediate Frequency
IoT	Internet of Things
IP	Internet Protocol
JSON	JavaScript Object Notation
KISTI	Korea Institute of Science and Technology Information
KPI	Key Performance Indicator
KREONET	Korea Research Environment Open Network
L1C	L1 Controller
LAN	Local Area Network
LDPC	Low-Density Parity-Check
LEO	Low Earth Orbit / Low Earth Orbit Satellite
LLC	Logical Link Control
LoS	Line-of-Sight
MAC	Media Access Control
MBR	Maximum Bit Rate
MC	Multi-Connectivity
MM	Mobility Management

mmWave	Millimeter-wave
MN	Moving Network
MNS	Moving Network System
MNS-CNS	MNS CN Subsystem
MNS-RAS	MNS Radio Access Subsystem
MNS-VES	MNS Vehicular Equipment Sub-system
MT	Mobile Terminal
MTU	Maximum Transfer Unit
MTU	Maximum Transfer Unit
NAS	Non-Access Stratum
NAT	Network Address Translation
NG	Next Generation
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
PCF	Policy Control Function
PDCP	Packet Data Convergence Proto-col
PDU	Protocol Data Unit
PHY	Physical layer
PoC	Proof of Concept
PoP	Point of Presence
PT-RS	Phase Tracking Reference Signal
QCI	QoS Class Identifier
QFI	QoS Flow ID
QoE	Quality of Experience
QoS	Quality of Service
R&E	Research & Experiment
RA	Random Access
RAC	Radio Admission Control
RAN	Radio Access Network
RAS	Radio Access Subsystem
RAT	Radio Access Technology
RB	Radio Bearer
RBC	Radio Bearer Control
RF	Radio Frequency
RLC	Radio Link Control

ROHC	Robust Header Compression
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Signals Received Power
SDAP	Service Data Adaptation Protocol
SDU	Service Data Unit
SE	Satellite Equipment
SI	System Information
SM	Session Management
SMF	Session Management Function
SN	Sequence Number
SNR	Signal-to-Noise Ratio
SQL	Structured Query Language
TAL	Tracking Area List
TB	Transport Block
TC	Traffic Controller
TCP	Transmission Control Protocol
TE	Terminal Equipment
TM	Transparent Mode
TR	Technical Report
TrCH	Transport Channel
TS	Technical Specification / Traffic Scheduler
TX.X	Task X.X
UDM	Unified Data Management
UE	User Equipment
UHD	Ultra High Definition
UI	User Interface
UM	Unacknowledged Mode
UP	User Plane
UPF	User Plane Function
VES	Vehicular Equipment Subsystem
VR	Virtual Reality
V-UE	Vehicle UE
WLAN	Wireless LAN
WP	Work Package

1 Introduction

As outlined in Figure 1-1 of deliverable D2.2 [1], the WP2 “Scenarios for Multiple access in 5G” is divided into four main tasks, which generate five deliverables.

Table 1-1: List of WP2 deliverables

Deliverable	Description	Associated Task	Editor	MoD
D2.1	**5G-ALLSTAR vision document: Vision, Scope and Goals.** This deliverable provides the vision, scope and goals of the project focusing on potential use-cases with KPIs. It also defines preliminary service scenarios/applications and KPIs for PoC.	Task 2.1, Task 2.3	FhG	M04
D2.2	**Preliminary document of 5G- ALLSTAR architecture, API and interface specifications.** This deliverable provides preliminary inputs for studies in WP3, WP4 and WP5.	Task 2.2	ETRI/ CRAT	M10
D2.3	**Final document of 5G-ALLSTAR architecture, API, interface specifications and KPIs for PoC.** This deliverable provides final inputs for WP3, WP4 and WP5.	Task 2.2, Task 2.3	ETRI/ CRAT	M19
D2.4	**Final document of service scenarios/applications for PoC.** This report details the scenarios, applications for the design of the PoC as specified in Task 2.3.	Task 2.3	CEA/ ETRI	M20
D2.5	**Business assessment for vertical markets empowerment.** This report details the business plan developed in Task 2.4. To allow industrial partners to exploit this business plan, this report is confidential.	Task 2.4	GEM	M24

The work of WP2 is divided into two phases as illustrated in Figure 1-1. During the first phase, the potential use cases with associated KPIs that can benefit from the 5G-ALLSTAR system with MC support are identified. Based on such use cases, we designed the first preliminary architecture of 5G-ALLSTAR as reported in deliverable D2.2. Deliverable D2.2 defines a preliminary design of the high-level architecture and functionalities, summarizes several possible architectures identified for MC support and differentiates the preliminary architecture specification for PoCs by testbeds or trial platforms.

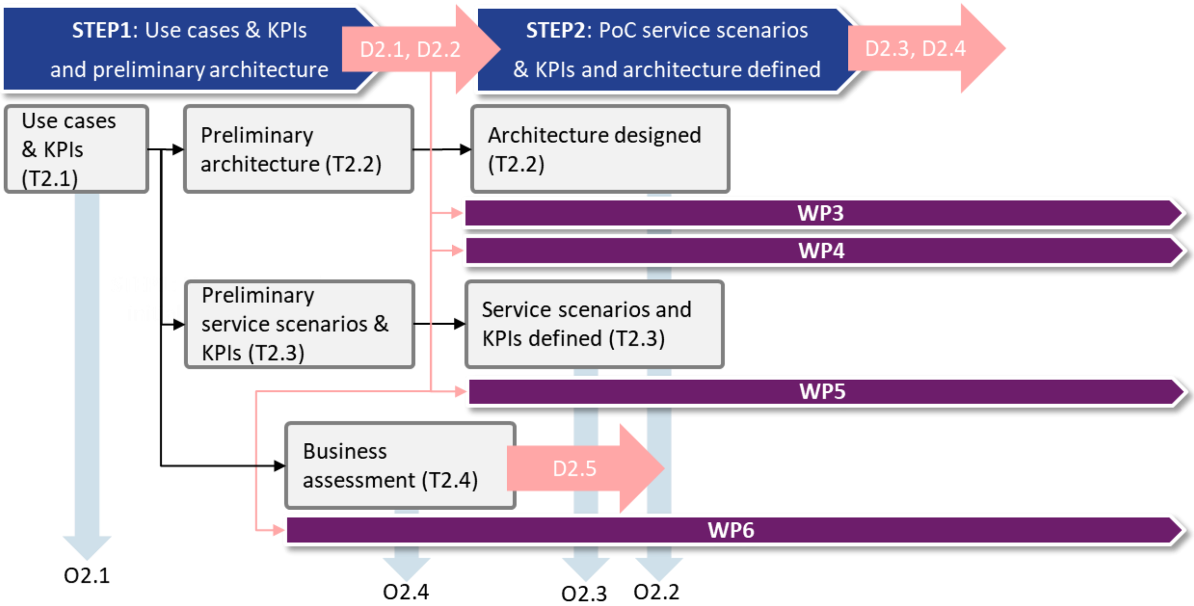


Figure 1-1: WP2 methodology adopted.

As described in Table 1-1, this deliverable (D2.3), which is a key deliverable of WP2, reports the final 5G-ALLSTAR architecture, interface/API specifications and captures the final results of Task 2.2 which aims to deliver [2]:

(i) overall system architecture of 5G-ALLSTAR system,

(ii) network architectures of 5G cellular access and satellite access systems,

(iii) architecture and interfaces for MC,

(iv) description of key components for each access system (e.g., baseband module, RF, and antenna module), and key enabling technologies needed for the target use-cases of the project (e.g., beamforming algorithms),

(v) the overall architecture and interface for intercontinental interoperability between KR and EU systems.

As part of Task 2.3, deliverable D2.3 also reports the final KPIs defined for PoC, the associated service scenarios/applications of which will be described in deliverable D2.4 [7].

Therefore, based on the preliminary specification provided in deliverable D2.2 and on the results of the preliminary study on use cases/PoC service scenarios and associated KPIs captured in deliverable D2.1 [3], deliverable D2.3 provides:

(i) the final high-level 5G-ALLSTAR system architecture and required interfaces as well as the basic supported functionalities,

(ii) a set of 5G-ALLSTAR MC architectures for supporting the flexible integration between cellular and satellite access networks including the WP4-specific architectures for studying MC technologies,

(iii) WP5-specific architectures and interface specification of testbeds and trial platforms, describing key components, APIs/interfaces, and key functionalities/technologies.

2 5G-ALLSTAR system architecture

This chapter provides a general overview of high-level 5G-ALLSTAR system architecture (see §2.1), a set of 5G-ALLSTAR MC architectures (see §2.2), and the PoC architectures (see §2.3).

2.1 General high-level architecture

The high-level basic 5G-ALLSTAR architecture is depicted in Figure 2-1. By combining the current vision of 5G architectures [4] with the 5G-ALLSTAR project needs, it is designed to support a flexible integration between 5G cellular access and satellite access networks with particular focus on the channel and traffic flow optimizations. Same as the preliminary architecture described in [1], as depicted in Figure 2-1, the final high-level system architecture is composed of four main parts, as typically presented in 5G networks:

(i) Data Network (DN),

(ii) Core Network (CN),

(iii) Cloud Radio Access Network (C-RAN), sometimes referred to as centralized RAN,

(iv) User Equipment (UE).

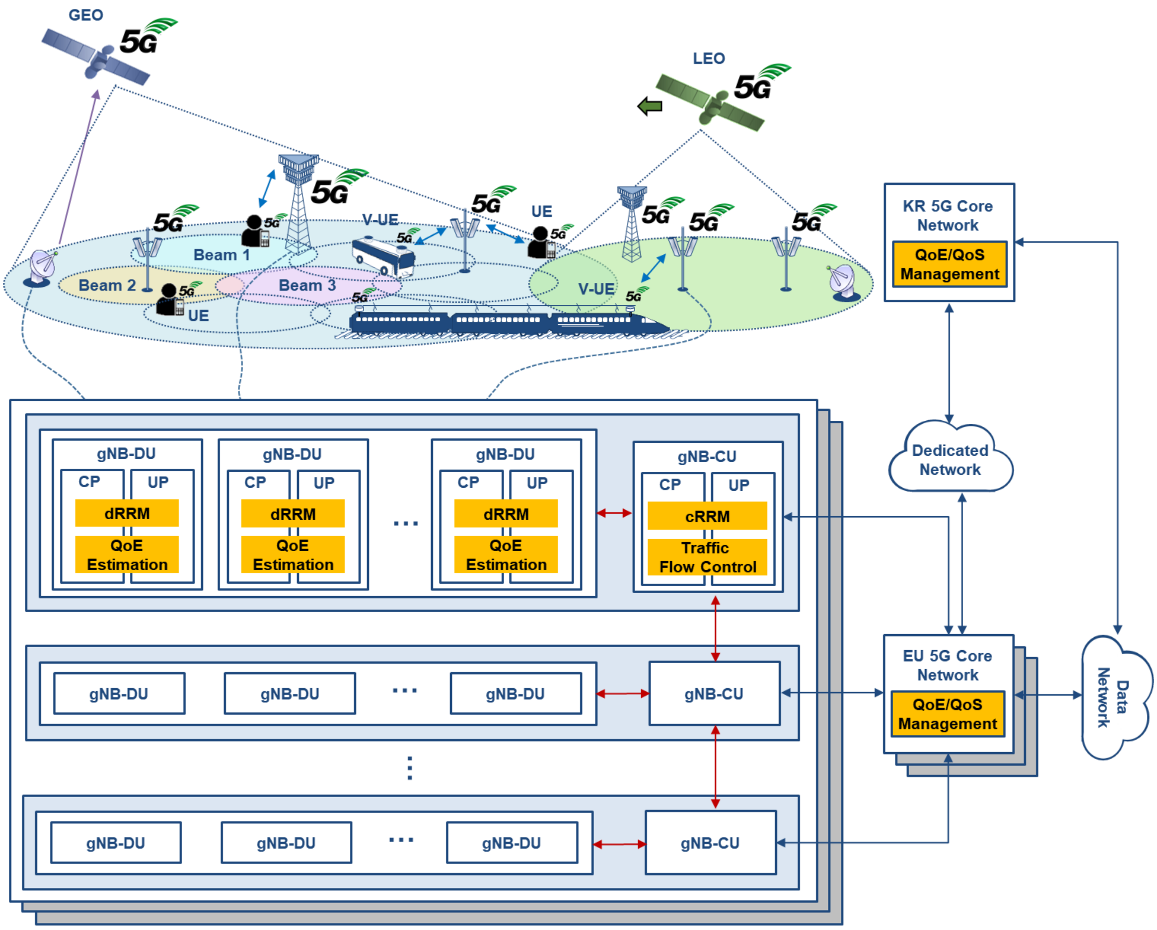


Figure 2-1: Overall 5G-ALLSTAR architecture and functionality.

In general, the DN is perceived as a data container, from which the network can get the service data (e.g., documents, movie contents, etc…), and the DN of both public and private data providers can be considered. This entity enables the transmission of data between UE and data providers.

In the 5G-ALLSTAR system, we add advanced Quality of Experience/Service (QoE/QoS) management functionalities in addition to the already implemented CN functionalities.

The RAN is designed to be composed of two different parts, as suggested in [5], both of them based on the software-defined paradigm with the aim of being dynamically configured, generated/destroyed with the objective of providing network flexibility for satisfying the users' service needs. More specifically, considering [6], the RAN is designed to be composed by:

- A centralized unit (CU) with coordination capabilities and technology independent functionalities. The C-RAN is implemented by using cloud-based technologies to allow resources flexibility and high computing performances. It contains
    - ✓ Control plane (CP) functionalities, e.g. Interferences Management, Radio Bearer Control (RBC), Radio Admission Control (RAC), Dynamic Resources Allocation (DRA), Measurement Configuration, T3S, etc., implemented in a single logical entity, i.e., the gNB-CU-CP (Figure 2-1);
    - ✓ User plane (UP) functionalities, e.g., higher layers of the protocol stack, implemented in different logical entities, i.e., the gNB-CU-UPs (Figure 2-1).
- A distributed unit (DU) with distributed and technology-dependent functionalities that is composed of gNB-DU-CP and the gNB-DU-UP as depicted in Figure 2-1. The D-RAN is implemented as close as possible to the radio technologies and includes
    - ✓ CP functionalities, implemented in the logical entity, called gNB-DU-CP (e.g., Measurement Collection and Provision, Media Access Control (MAC) and Physical Layer (PHY) configuration, QoE/QoS Management …);
    - ✓ UP functionalities, implemented in the logical entity called gNB-DU-UP (e.g. lower layers of the protocol stack as for instance MAC, PHY, etc.)

The UE is considered to be any device which communicates by connecting to the access network (e.g., mobile devices carried by human being, vehicles, Internet of Things (IoT) devices, artificial intelligence-based robots, etc…).

Based on the general architecture in Figure 2-1, the 5G-ALLSTAR project implements additional advanced functionalities at both CN side and RAN side that are essential to fulfill the objectives of the project. Those functionalities will be developed, implemented and tested through the PoC of the project. Among them, MC-related functionalities, placed on the general architecture, for MC enabling flexible integration of cellular and satellite networks include:

- ***Advanced Radio Resource Management (RRM)*** functionalities for the multi-Radio Access Technology (RAT) spectrum sharing scenario, where algorithms for interference analysis and mitigation will be developed. RRM functionalities are conceived to be in the Centralized RRM (cRRM) and Distributed RRM (dRRM) blocks in Figure 2-1.

- ***Traffic switching, steering and splitting***. In fact, in the 5G-ALLSTAR project, the traffic management will be performed taking into account the network status and the QoE requirements for each user.
  - ✓ ***The QoE/QoS Management***, designed to be logically located in the CN, is in charge of assigning a set of personalized parameters (in addition to the QFI [8]) for each traffic flow depending on the learned UE needs and expectations. The Traffic Flow Control, managed by the RAN, performs switching, steering and splitting decisions for the traffic on the basis of the personalized parameters and considering the actual performances of the radio access technologies. The RATs performances are directly provided by the cRRM.
  - ✓ ***QoE Estimation*** provides the estimation of the individual perceived QoS on the basis of the information provided by the user via explicit or implicit feedbacks and on the measurements provided by the dRRM.
- The ***Traffic Flow Controller*** needs to be placed in the CU for several reasons, for example, to guarantee the fast and lossless traffic switching among different RATs, and to have complete information from RANs. The QoE Estimation is placed on the DUs since it relies – for each UE – on a large amount of information (such as RRM measures, UE feedbacks, etc.) available within the DU itself. Finally, we note that, on the one hand, it is fundamental to have a set of RRM functionalities in the CU for the coordination of the radio resources of each RAT, in order to avoid interferences and to reach the optimal performance. On the other hand, it is necessary to have a set of RRM functionalities directly placed on the different RATs, since, in some cases, these functionalities are technology-dependent and needs to collect measurements of the radio system in real-time to perform configuration.

2.2 MC architecture

2.2.1 General MC architecture

In this section, we present a detailed description of MC architectures that arise from the general architecture described in the previous section. The MC architectures include a basic high-level MC architecture that pursues the aims of the project and a detailed MC architecture for the scope of WP4 study.

Figure 2-2 illustrates the high-level MC architecture and shows how a split gNB is inserted into the NG RAN architecture, which is inspired by [6]. In this MC architecture, a set of gNBs is connected to the 5G Core (5GC) network through the NG interface (NG-C and NG-U interfaces), and they can be interconnected through the Xn interface. As described previously, in the 5G-ALLSTAR system, a gNB is implemented by C-RAN technology to consist of a gNB-CU and one or multiple gNB-DUs, and as shown in Figure 2-1, a gNB-DU can be connected with an entity responsible for cellular communication (e.g., a DU of base station) or satellite communication (e.g., an earth station (ES)). The interface between the gNB-CU and the gNB-DUs is called F1.

The NG and Xn-C interfaces for a gNB terminate in the gNB-CU. The maximum number of gNB-DUs connected to a gNB-CU is only limited by implementation choice. In the 3GPP standard, one gNB-DU connects only to one gNB-CU, but implementations that allow multiple gNB-CUs to connect to a single gNB-DU, e.g., for additional resiliency, are not precluded. One gNB-DU may support one or more cells. The internal structure of the gNB is not visible to the CN and other RAN nodes, so the gNB-CU and connected gNB-DUs are only visible to other gNBs and the 5GC as a gNB.

In addition, as can be seen from Figure 2-2, a Packet Data Convergence Protocol (PDCP)-level MC architecture is the basic starting point of research for other technical WPs, which, however, is an exception for the KR PoC system. The KR PoC system introduces an Internet Protocol (IP)-level MC, and the architecture and system components/interfaces are described in §2.3.1 and §3.1, respectively.

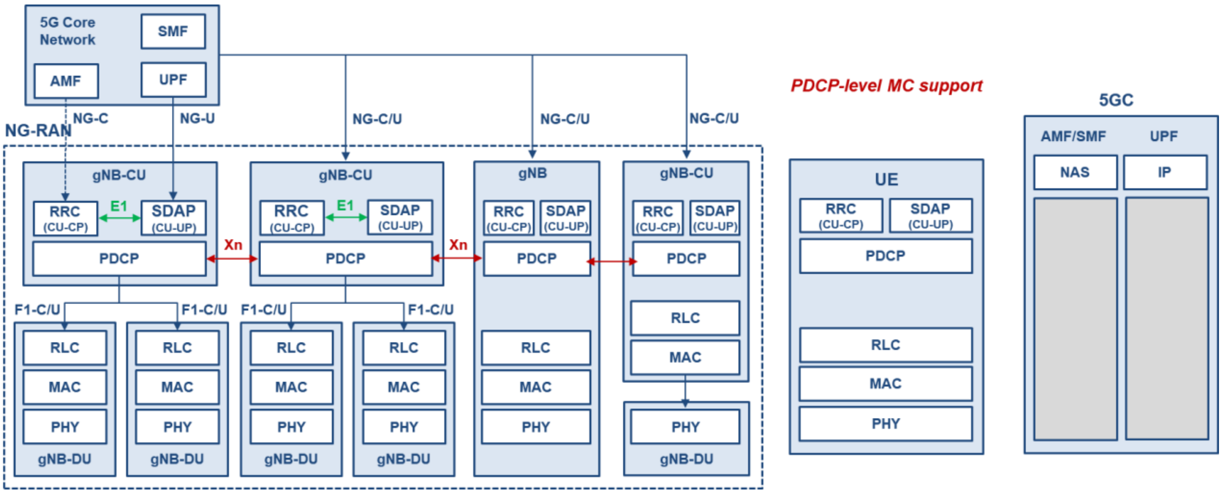


Figure 2-2: Architectures for MC support.

2.2.2 WP4-specific MC architecture

Figure 2-3 reports the architecture for MC introduced in deliverable D4.2 [16].

In the depicted scenario, the functionalities of the architecture are illustrated with the aim of two Protocol Data Unit (PDU) sessions:

- the first PDU session (the green line in the figure) is duplicated over two different Access Points (APs) belonging to different RATs, so that the connection resiliency is increased;
- the second PDU session is made up by two different QoS flows (red and yellow lines in the figure) that, based on the analysis of the network state, can be routed independently from one another, in order to satisfy their QoS requirements accordingly.

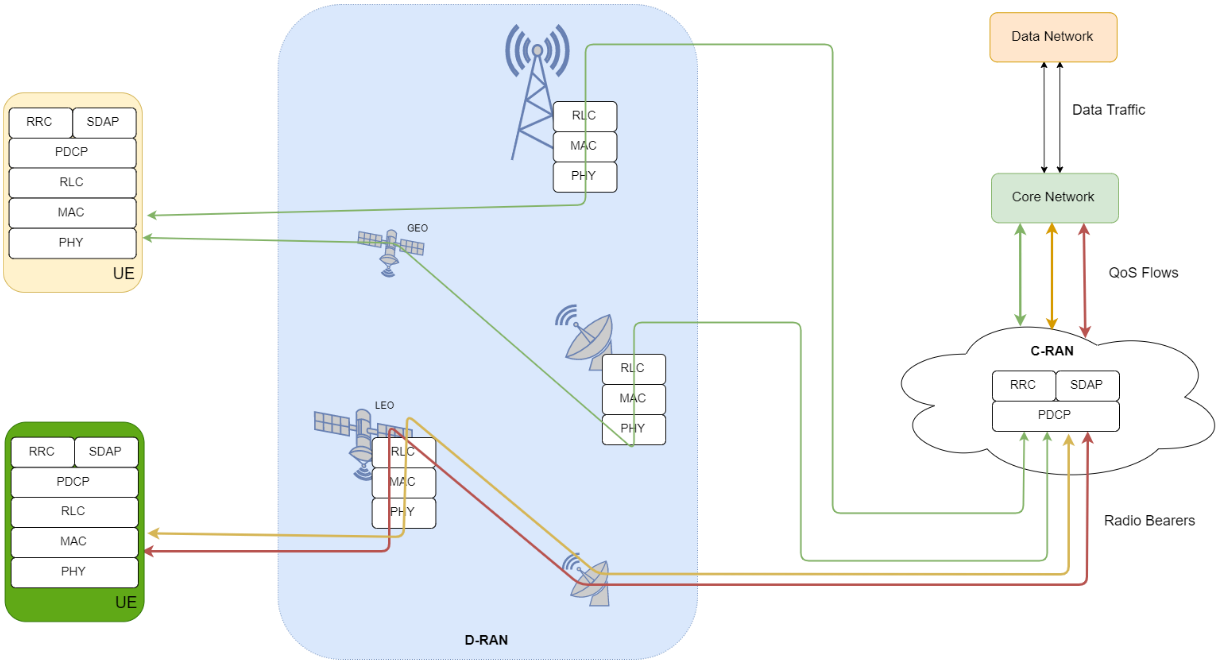


Figure 2-3: MC target physical architecture.

The idea is to provide an end-to-end (E2E) framework, that once integrated with the standard 5G functionalities (e.g., Session Management Function (SMF), Access and Mobility Management Function (AMF), RRM, etc.) will be able to manage the connections from the higher protocol levels to the lower protocol level and to act based upon the CN and RAN connections and users information (e.g. user and PDU session information from the CN and real-time measurement from the RAN). The knowledge of all these information allows a fast and dynamic control of the connection flows, ensuring the best mapping of the high-level connection flows to the low-level radio resources.

The integration between the standard 3GPP network functionalities and the 5G-ALLSTAR MC system is one of the fundamental aspects to be considered. In this respect, the typical QoS flows handling will be guaranteed and strengthened. Figure 2-4 shows the main steps in the 3GPP connections data handling, where the fundamental steps are:

(i) mapping of application data (PDU Session data) in QoS flows; and

(ii) mapping of QoS flows in the Access Resources.

This approach does not allow the use of users and applications information in the RAN during the assignment of the resources, hampering the possibility to assign lower-level resources in a QoE fashion. The 5G-ALLSTAR improves this aspect by making use of user and application information in the RAN. In this perspective, the providers' connections and users' information typically stored and managed in the CN and used for the PDU Session to QoS flow mapping, accordingly to the 3GPP standard, will be processed and enriched with a specific QoE Management System, to be used with the aim to strongly influence the resource assignment in the RAN. On the other hand, this resource assignment shall be constrained by the QoS of the ongoing connections and the actual status of the network. This implies the needs of the information that are managed at RRM level in 3GPP standard, such as, measurement provision and configuration functionalities.

Further improvements in the 5G-ALLSTAR architecture are the strong cooperation and coordination between the several RATs involved in the connections. In this perspective, a key feature is the load balancing between them and the user-centric RATs selection, i.e. based on the network status the system tries to perform the best associations between QoS flows and RATs from the QoE point of view, but it will be constrained by the RATs congestion and the link performances.

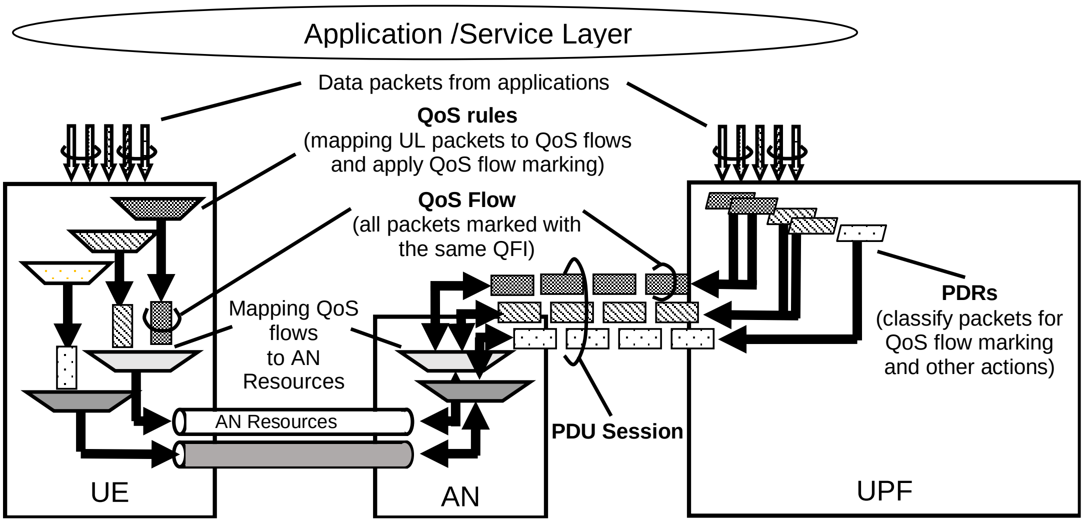


Figure 2-4: The principle for classification and UP marking for QoS flows and mapping to AN Resources.

As detailed in deliverables D4.1 [15] and D4.2 [16], the chosen architecture uses a RAN-Based Integration, to allow the RATs cooperation and coordination, fast reaction to the radio link conditions variations and connection flows anchoring between the RATs to allow UP Aggregation and Fast Switch between them. Furthermore, a RAN-Controlled Approach is used, to avoid suboptimal solutions typical in the case of User-Centric Approach and encouraging the dynamic adaptation of the resources allocation and configuration based on the actual networks' condition.

For the considerations above, the architecture was chosen in order to have a Central Unit (CU) that contains the CP cooperation and coordination functionalities together with the UP integration and switching functionalities, as presented in 3GPP TS 38.401 [12] (see Figure 2-5).

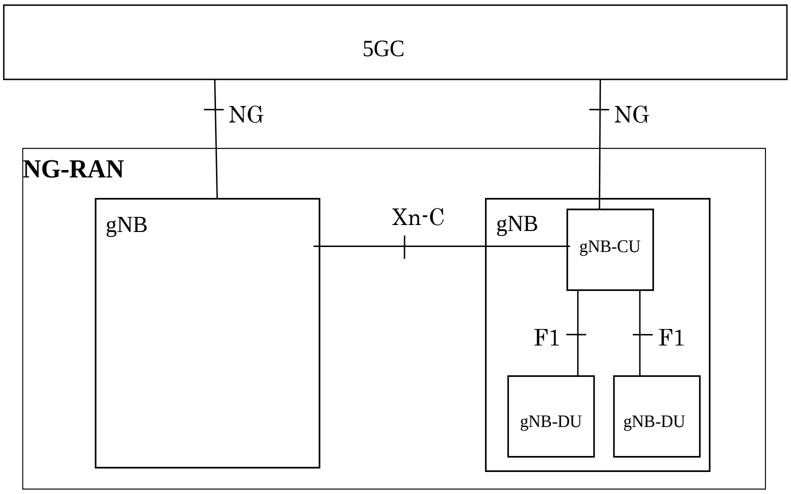


Figure 2-5: Overall RAN architecture.

This solution is further detailed in 3GPP TR 38.801 [11] as Centralized Deployment (see

Figure 2-6) where the need of a decision on the functional split between CUs and DUs is discussed. The first point to consider in this RAN deployment is the transport link performances between the CU and the DUs, a high-performance transport link (e.g., an optical link, high-throughput radio bridge, etc.) enables a high level of cooperation in data transmission and resources scheduling that are key instruments in the MC management. On the other side, low-performance transport link between CU and DUs enable only the placement of higher protocol layers on the CU, since they have lower requirements in terms of bandwidth, delay, synchronization and jitter.

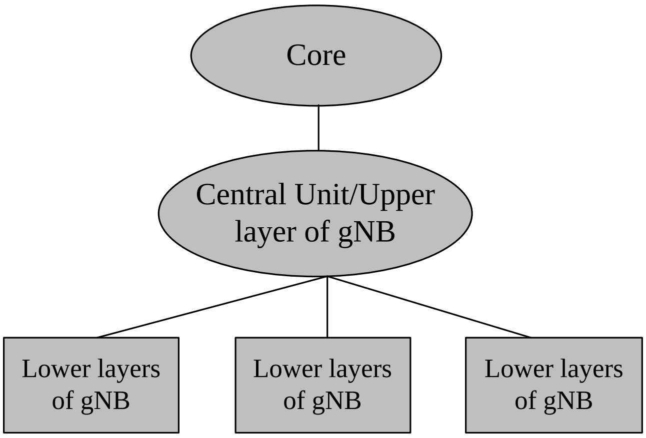


Figure 2-6: Centralized deployment.

The functional split options are presented in 3GPP TR 38.801 (see Figure 2-7) [11]:

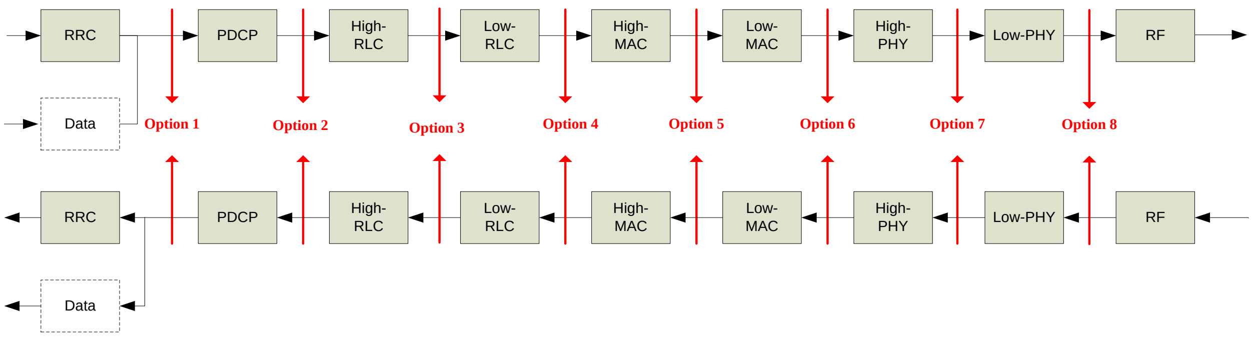


Figure 2-7: Function split between central and DU.

In our architecture, the decision regarding the functional split is mainly driven by power consumption and latency requirements constraints of the functionalities:

- For the CP the technology-independent and asynchronous (non-real-time) functionalities (e.g., Measurements Configuration, RBC, QoS flows to Radio Bearers (RBs) mapping (i.e., Flow Control), Connection Mobility Control, …) are placed in the CU and the technology-dependent and synchronous functionalities (RAC, Beamforming Configuration, …) in the DU.
- For the UP, PDCP split is adopted, that allows the connection switching and aggregation at PDCP level (i.e., in the CU) facilitating the management of traffic load between RATs, without low latency and high throughput requirements that are present in case of Intra-PHY or PHY-MAC split. This split, identified as Option 2 in 3GPP, is the more promising for standardization since it is already

implemented in LTE Dual Connectivity and the incremental effort for the needed functionalities can be minimal.

The considerations above apply for the resource allocation, and, for the QoS flows allocation among the RATs (Flow Control), that shall be performed in Dynamic Real-Time and Measurement-Based fashion.

On the other hand, the personalization system introduced does not require Real-Time capabilities and needs very high storage and processing power capabilities. These characteristics caused the personalization-related functionalities placement in the CN. The overall personalization system is composed by a repository of the historical connections data for each user, and a processing block that, based on the stored information, is able to synthesize for each user, or a homogeneous group of users (cluster), a set of user characteristics in terms of user's Connection Preferences.

These Connection Preferences specify the user's needs not in terms of additional QoS constraints, but in terms of personal user's preferences expressed over a set of non-standardized parameters as battery consumption, connection cost, mobility, etc… The stored information is updated based on user's feedback at the end of each connection and is used for Traffic Flow Control as described in deliverable D4.2 [16].

In 5G-ALLSTAR, the Traffic Flow Controller performs its choices based on the QoS constraints and network status, trying to satisfy in the best possible way the Connection Preferences of each user, in a multi-objective fashion. The final building block needed to allow an MC architecture with a personalization system is a measurement of the actual users' experience (QoE). This measurement links QoS and user experience, considering additional attributes that are specific to the user (or cluster). The QoE level can be used by the Flow Control as an additional input for the selection of its AP and traffic steering decisions.

The resulting functional architecture is depicted in Figure 2-8, which represents a functional overview of the modules developed in WP4 and detailed in deliverable D4.2 [16]:

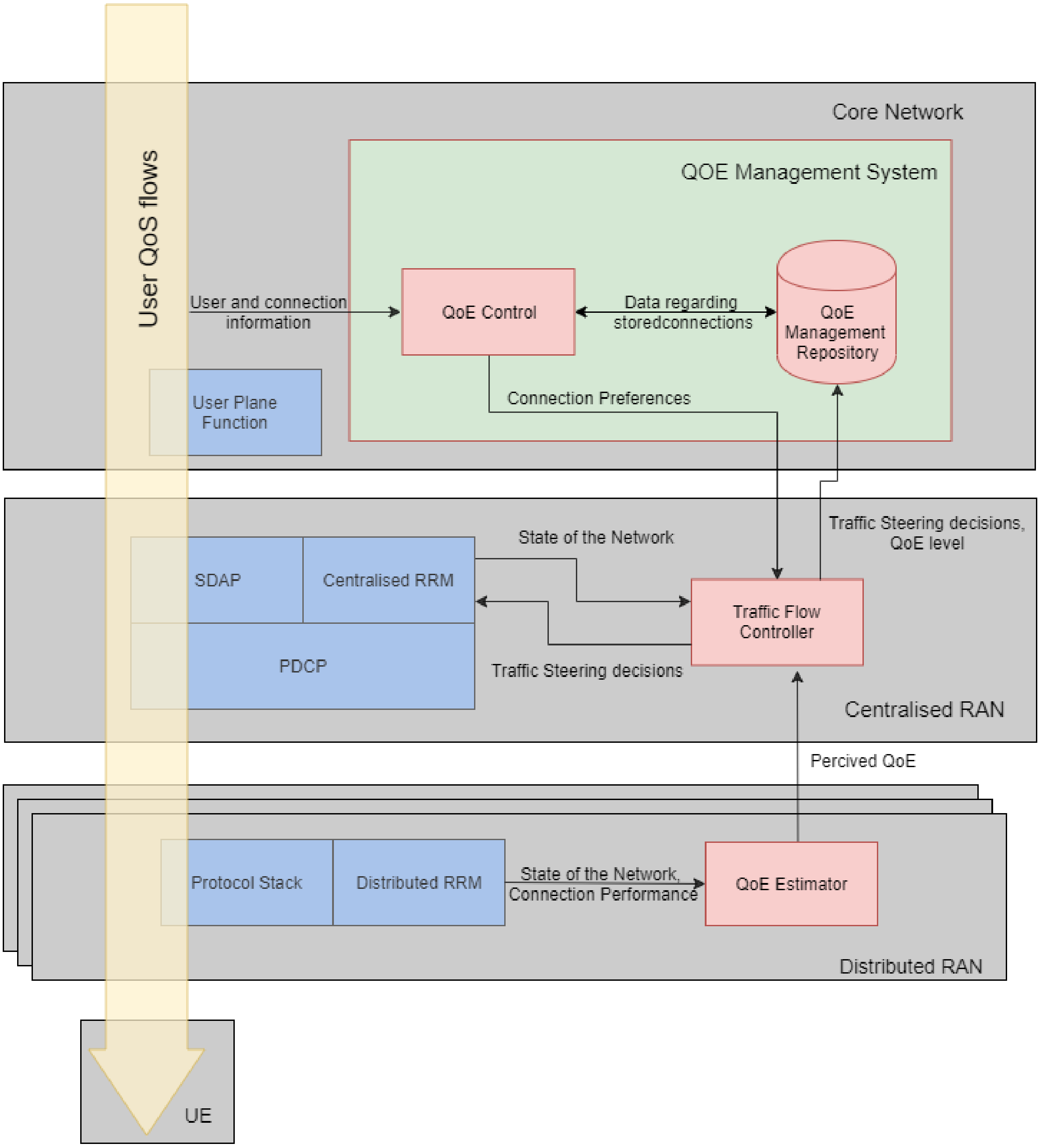


Figure 2-8: WP4 functional architecture.

Although Option 2 (i.e. PDCP split) is the reference split option for the 5G-ALLSTAR architecture, it is worth mentioning that the architecture of Figure 2-1 does not explicitly detail how the protocol stack was split to enable MC. The reason is the non-applicability of this solution for some scenarios, (e.g., MC between some non-terrestrial and terrestrial networks) that for implementation reasons enable only different splits. With this in mind, three split options are considered and reported in Figure 2-9, the ideal architecture shall be flexible to dynamic change among these different split at the same time, using the software-defined solution as already discussed in 3GPP TR 38.801 [11].

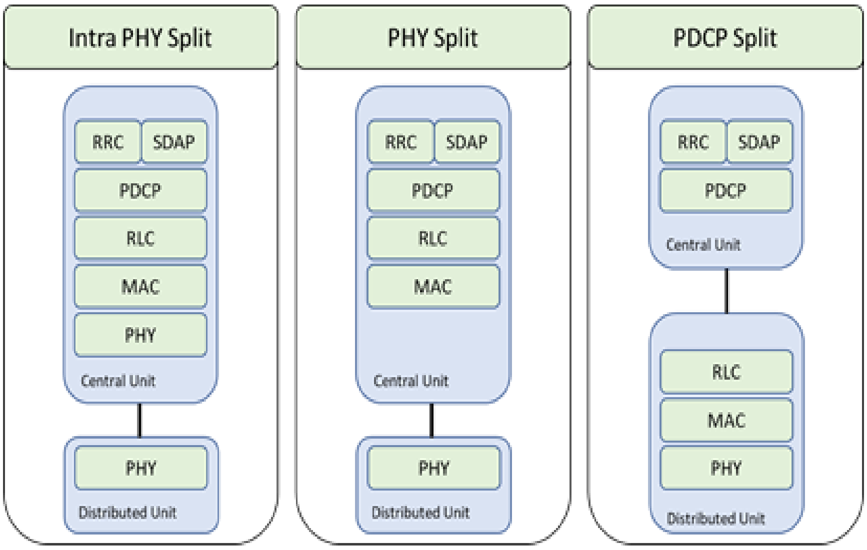


Figure 2-9: MC protocol split options.

In 3GPP TR 38.811 [13] this discussion is presented, where the approach is the consideration of three options (see Figure 2-10, Figure 2-11, Figure 2-12). These options show how the RAN functionalities are moved between CU and DU depending on the network capabilities: for a bent-pipe satellite the functionalities are fully deployed in the CU; in case of regenerative satellite a set of (or all) the functionalities can be placed in the DU (the satellite its self) taking into account mass and power budget.

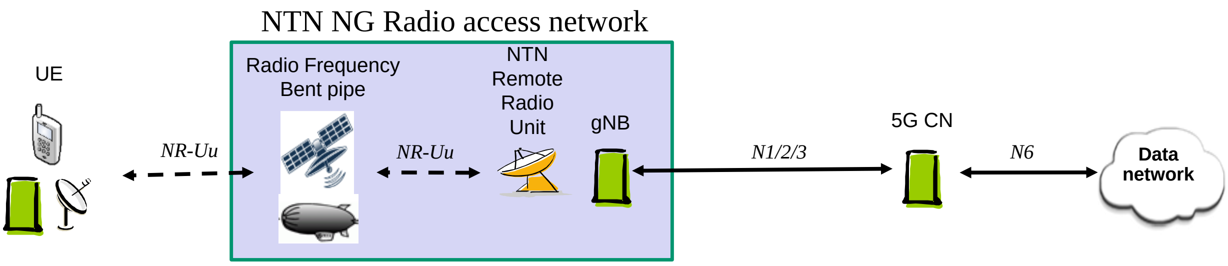


Figure 2-10: Mapping option 1 - NG RAN architecture in non-terrestrial network with bent pipe payload.

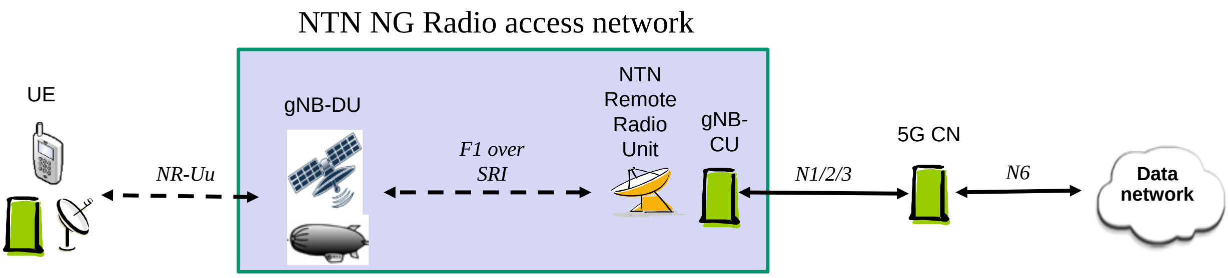


Figure 2-11: Mapping option 2 - NG RAN architecture in non-terrestrial network with gNB-DU processed payload (SRI refers to Satellite Radio Interface).

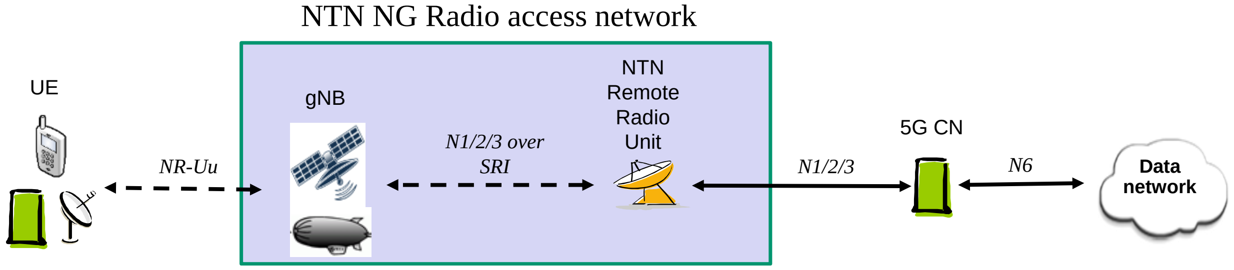


Figure 2-12: Mapping option 3 - NG RAN architecture in non-terrestrial network with gNB processed payload.

Several considerations can be done: the PDCP split configuration is advantageous since PDCP and RRC are not subject to the same constraints required for the first two solutions, allowing the usage of LEO satellites for MC. Regarding the inclusion of GEO satellites in the MC framework of the project, we highlighted in Figure 2-1 how they act as a transparent mean of communication, as their DU protocol stack is deployed on a dedicated ground equipment. In general, the inclusion of satellites as potential RAT for MC poses several other challenges ranging from spectrum sharing (addressed in the scope of WP3) to optimal radio resource usage.

In general, satellites cover extremely wide areas, usually beyond the reasonable scope of a single ground C-RAN. Having a satellite dedicated to a controller deployed in a C-RAN that does not have an adequate coverage would lead to the loss of one of the key advantages of satellite connections, i.e., their wide area availability. On the other hand, the same connection resources cannot be controlled by multiple C-RANs, as they may make decisions that may be in conflict (e.g., cumulatively allocating more resources than available).

Two different solutions to this issue have been identified, namely:

- The slicing of the satellite resources, so that each C-RAN that has access to it oversees only a portion of resources so that no conflict on their usage may arise;
- The deployment of a wide-area C-RAN in the CP, that oversees the functioning of multiple C-RANs of the UP taking their traffic flow control decision without requiring to directly interact with the QoS flows.

Both solutions are transparent to the algorithms for traffic control of WP4, and they do not impose particular modifications to the architecture of Figure 2-3.

2.3 PoC architecture

This chapter describes the architecture of KR PoC system, EU PoC system, and joint KR-EU PoC system. Korea and Europe construct different types of PoC systems and use them to demonstrate target 5G services/applications under different PoC service scenarios to be defined in deliverable D2.4 [7]. In particular, for the EU PoC, two different types of PoC systems, implemented as testbed and trial platform, respectively, are used to perform technical demonstrations over two PoC stages, while a single trial platform is developed for the KR PoC to perform the final outdoor demonstration after completion of sufficient indoor preliminary tests. After the completion of two independent demonstrations with KR and EU systems, the final joint PoC demonstration using an integrated KR-EU PoC system will be conducted at a key event (possibly Roland Garros 2021) to showcase several potential 5G services/applications to the visitors.

2.3.1 KR PoC system architecture

KR PoC system is a communication system that provides a mobile wireless backhaul link to a moving vehicle in an integrated cellular and satellite network. In general, the moving vehicle is a vehicle with a large number of passengers, such a bus, but the system design does not preclude the application to the other vehicles.

Meanwhile, KR PoC system focuses on public transportations like express buses or city buses, and these buses travel on various types of roads (straight road, curves, intersection and so on), which has a direct impact on communication performance. In addition, when buses go from one lane to another, communication performance may be degraded due to the misalignment between Tx and Rx beams, which is critical in communication systems like mmWave-band Moving Network (MN) system.

KR PoC system is mainly composed of two systems:

- MN system (MNS),
- Satellite system (hereinafter referred to as SAT),

which are integrated by MC technology to provide a broadband and reliable mobile wireless backhaul link to the vehicles as described above.

As shown in Figure 2-13, various services are provided to passengers on the bus through a wireless data connection through a Wi-Fi AP in the vehicle. A device that connects to the KR PoC system is a device having a Wi-Fi communication chip, for example, a smartphone, a notebook computer, a tablet, and so on, and through the KR PoC system, a number of Wi-Fi devices are connected to the DN by accessing to the KR PoC system.

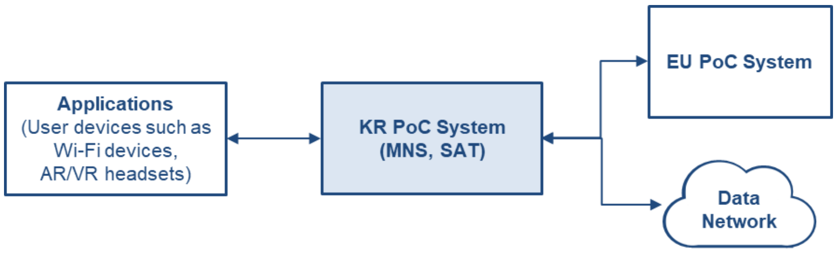


Figure 2-13: Target services/applications provided by KR PoC system.

As depicted in Figure 2-14 and listed in Table 2-1, the KR PoC system is composed of a number of system components. It mainly includes five subsystems

- MNS CN Subsystem (MNS-CNS),
- MNS Radio Access Subsystem (MNS-RAS) composed of MNS-RAS-CU and MNS-RAS-DU,
- MNS Vehicular Equipment Subsystem (MNS-VES),
- SAT-RAS composed of SAT-RAS-GEO and SAT-RAS-ES,
- SAT-VES,

and system component called Traffic Controller (TC) as well as other system components for diagnostic and demonstration purposes. In this deliverable, system components, MNS-VES, SAT-VES, and TC are collectively called Vehicle UE (V-UE).

Inside the KR PoC system, downlink data is sent in the following order:

- For broadband onboard Wi-Fi service, MNS-CNS → MNS-RAS → MNS-VES → Wi-Fi-AP → UE (e.g., smartphones, Virtual Reality (VR) headsets),
- For 4K/8K video streaming service, MNS-CNS → MNS-RAS+SAT-RAS → MNS-VES+SAT-VES → TC → Display Screen (DS),

and uplink data is sent in the following order:

- UE → Wi-Fi-AP → MNS-VES → MNS-RAS → MNS-CNS.

From the point of view of a user using a Wi-Fi device, the intermediate MNS is invisible and the service is provided through a server in the final DN.

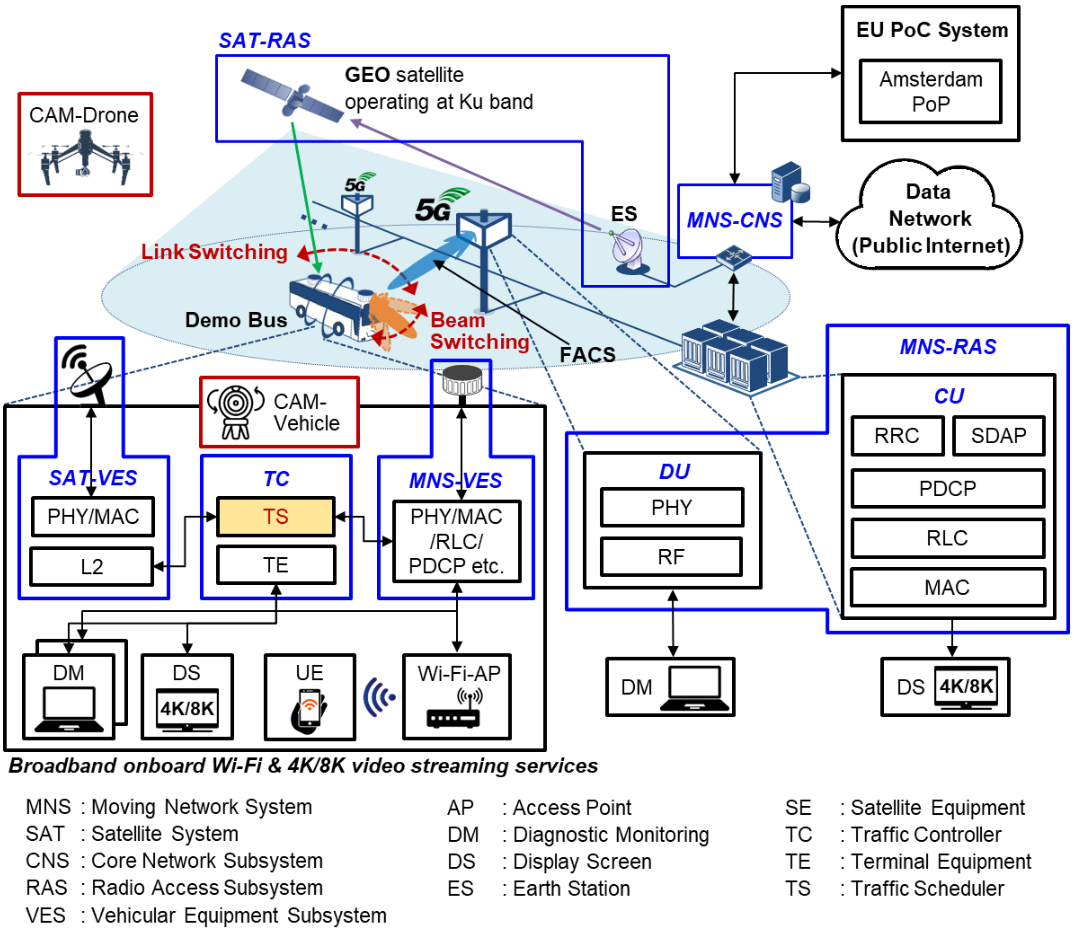


Figure 2-14: Overall architecture of KR PoC system.

Table 2-1: List of system components in KR PoC system

Label	Component	Description of the main features	Commercial device or not (Yes/No)
K-C0100	MNS-CNS	• AMF: registration management, connection management, Mobility Management (MM), access authentication and authorization • SMF: session management (session establishment, modification, release) • User Plane Function (UPF): packet routing & forwarding, packet inspection, QoS handling • Policy Control Function (PCF): unified policy framework, providing policy rules to CP functions, access subscription information for policy decisions in UDR	No (see details in §3.1.1.1)

		• Authentication Server Function (AUSF): acts as an authentication server • Unified Data Management (UDM): User identification handling, access authorization, subscription management	
K-C0200	MNS-RAS-CU	• Centralized 5G New Radio (NR) gNB-CU interconnected with gateway/MNS-CNS • RRM functions such as RB control, RAC, connection mobility control, dynamic resource allocation • AMF selection • User data forwarding to UPF • System Information (SI) broadcasting • Measurement and measurement reporting configuration for mobility and scheduling	No (see details in §3.1.1.2)
K-C0300	MNS-RAS-DU	• 5G NR gNB-DU distributed along the roadside and interconnected with MNS-RAS-CU • RRM functions such as RBC, RAC, connection mobility control, dynamic resource allocation • Baseband processing • Transmission and reception of radio signals	No (see details in §3.1.1.2)
K-C0400	MNS-VES	• MNS User Interface (UI) functionality • Non-Access Stratum (NAS) protocol functionality: SM, MM • AS protocol functionalities including Radio Resource Control (RRC), Service Data Adaptation Protocol (SDAP), Radio Link Control (RLC), MAC, PHY layers • Uplink scheduling • Measurement reporting	No (see details in §3.1.1.3)
K-C0500	SAT-RAS	• Composed of SAT-RAS-GEO and SAT-RAS-ES	Yes (see details in §3.1.1.4)
K-C0501	SAT-RAS-GEO	• Ku-band bent-pipe GEO satellite (KOREASAT 6)	Yes (see details in §3.1.1.4)
K-C0502	SAT-RAS-ES	• Earth station	Yes (see details in §3.1.1.4)
K-C0600	SAT-VES	• Satellite MODEM	Yes (see details in §3.1.1.5)
K-C0700	TC	• TC for traffic switching/selection, but the detailed design of this block will be described in deliverable D4.3NOTE1	No (see details in §3.1.1.6)
K-C0800	DM	• Diagnostic monitoring (DM) • Visualization of target KPIs (uplink/downlink data rate etc.)	No (see details in §3.1.1.7)
K-C0900	DS	• Display screen for 4K/8K video streaming or DM screen display	No (see details in §3.1.1.8)
K-C1000	Wi-Fi-AP	• Wi-Fi AP	No (see details in §3.1.1.9)
K-C1100	UE	• Passengers' mobile devices such as smartphones, tablets, and Augmented Reality (AR)/VR headsets.	No (see details in §3.1.1.10)

NOTE1: 5G-ALLSTAR D4.3, "Implementation of multi-RAT load balancing algorithms and technical specifications of the relevant interfaces," will be delivered in M30 (Dec. 2020).

The CP protocol stack of MNS is shown in Figure 2-15 and the UP protocol stack is shown in Figure 2-16. Functioning as a router, Wi-Fi-AP supports IEEE 802.11, and the

Terminal Equipment (TE) of MNS-VES (MNS-VES-TE) supports the Transmission Control Protocol/IP (TCP/IP) protocol for user applications. MNS-VES supports the 3GPP 5G NR radio protocol and the IEEE 802.11 protocol. The 3GPP 5G NR radio protocol consists of a CP protocol and a UP protocol.

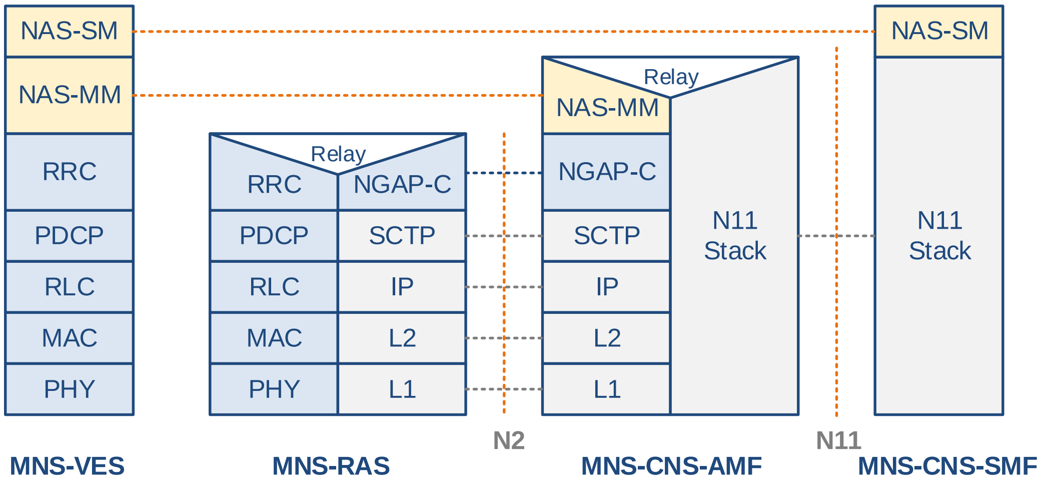


Figure 2-15: CP protocol stack of MNS.

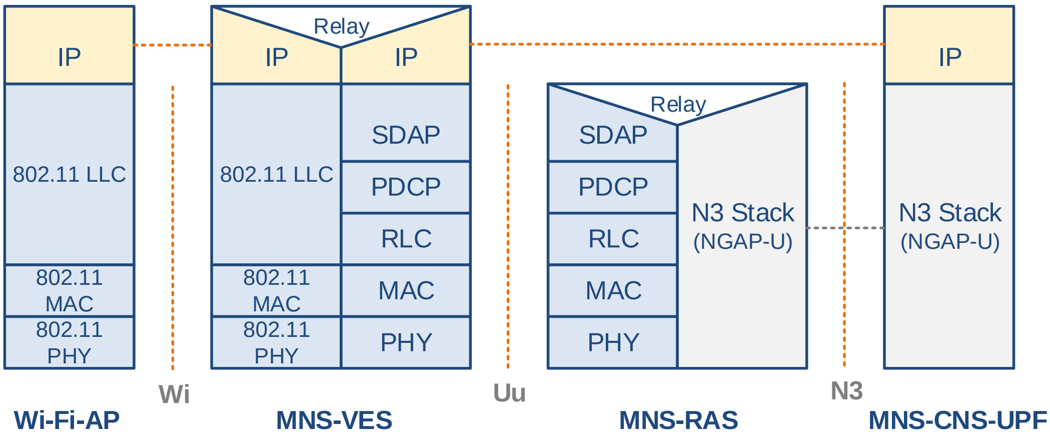


Figure 2-16: UP protocol stack of MNS.

The CP protocol includes Session Management (SM), MM, RRC, Packet Data Convergence Protocol (PDCP), RLC, MAC, and PHY protocol and the UP protocol is composed of IP, SDAP, PDCP, RLC, MAC, and PHY layer protocols. Meanwhile, the IEEE 802.11 protocol is composed of Logical Link Control (LLC), MAC, and PHY layer protocols.

The 5G NR protocol stack is divided into an Access Stratum (AS) protocol responsible for transmitting control signals between the terminal and the base station and a NAS protocol layer for transmitting control signals between the terminal and the CN. The AS protocol layer includes the SDAP, PDCP, RRC, RLC, MAC, and PHY protocols, and the NAS protocol layer includes SM and MM protocols.

2.3.2 EU PoC system architecture

EU PoC consists of two platforms:

- the EU testbed: it will be mainly used to validate the developed WP3 spectrum sharing functionalities by testing suitably selected KPIs (e.g. related to throughput, latency, and other QoS KPIs) in scenarios related to 5G verticals. It will allow link and system-level evaluations.
- the EU trial platform: it will demonstrate some key resource sharing functionalities both related to spectrum sharing and MC. It will combine satellite and cellular terrestrial accesses.

2.3.2.1 EU testbed

The EU Testbed architecture is built up according to the reference architecture depicted in §2.1. The EU testbed hardware and software architectures have been extensively described in deliverable D5.1 [14]. Figure 2-17 and Figure 2-18 respectively show the functional and the physical architectures.

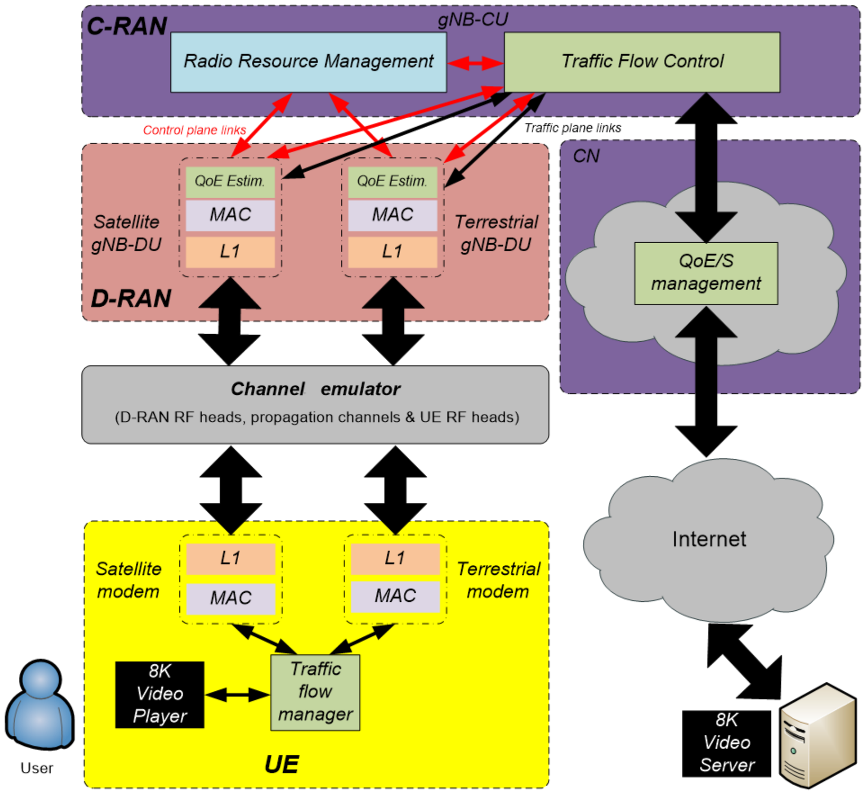


Figure 2-17: EU testbed functional architecture.

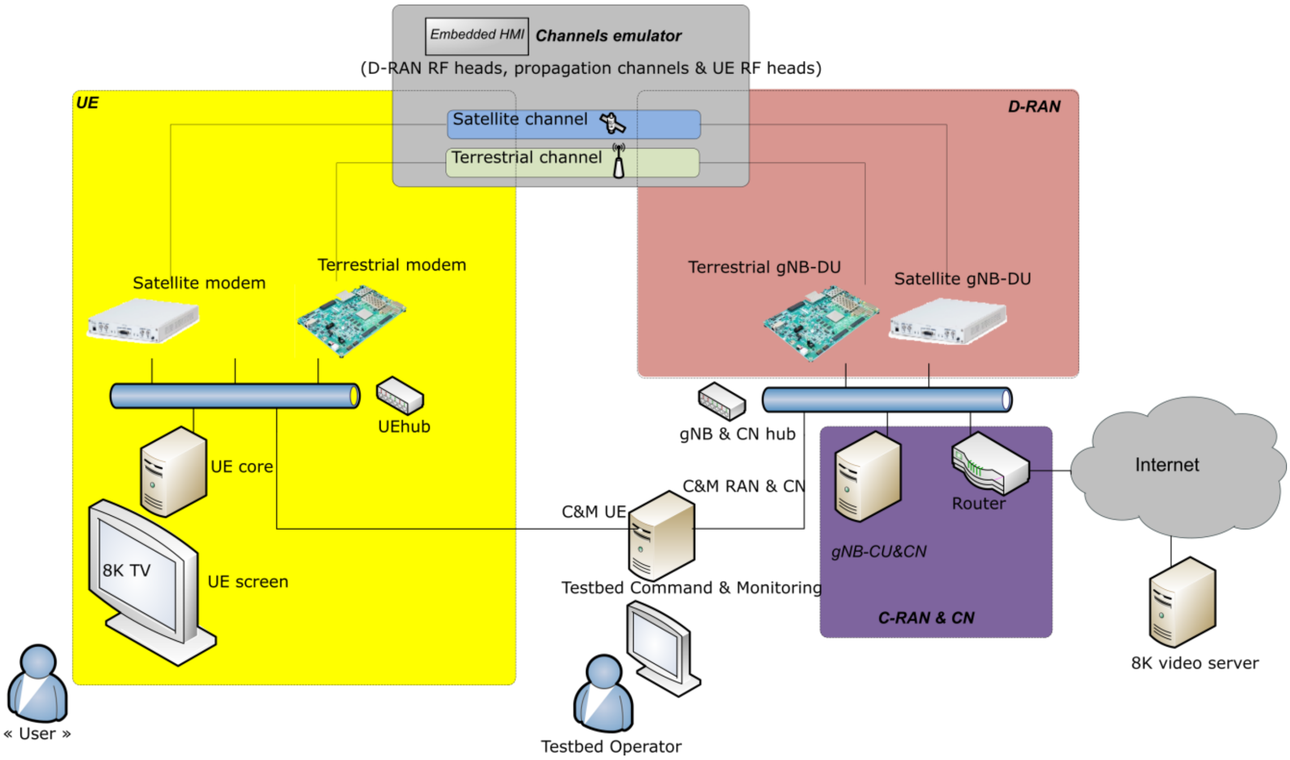


Figure 2-18: EU testbed physical architecture.

2.3.2.2 EU trial platform

The EU trial platform will combine satellite and cellular terrestrial accesses. The architecture is depicted in Figure 2-19 and is essentially equivalent to the architecture of the EU testbed with the only exception that the satellite and cellular segments are replacing the channel emulator. To achieve this, the trial platform deploys additional hardware and RF equipment that are listed in Table 2-2 and further detailed in §3.2.4.

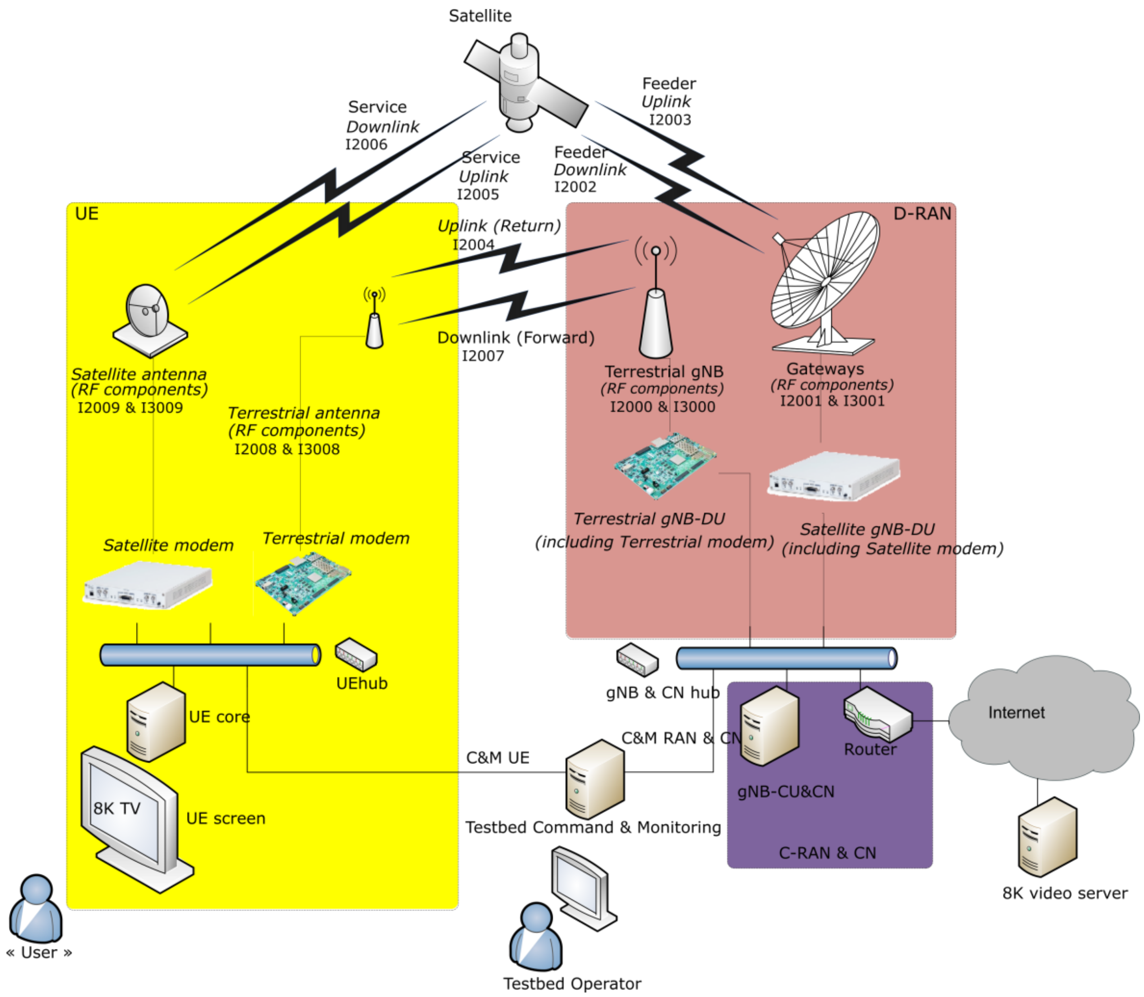


Figure 2-19: EU trial platform architecture.

Table 2-2: EU trial hardware components list (components identical to testbed are not listed)

Label	Component	Description of the main features	Commercial device (Yes/No)
E-C0001	gNB upconverter	For the DL. Upconverter from IF to the target frequency (18.3 – 21.2 GHz) in the K-band.	Yes
E-C0002	gNB transmit antenna	For the DL. K-band antenna.	Yes
E-C0003	UE terrestrial receive antenna	For the DL. K-band antenna.	Yes
E-C0004	UE terrestrial downconverter	For the DL. Downconverter from the receive frequency (18.3 – 21.2 GHz) in the K-band to IF.	Yes
E-C0005	UE terrestrial upconverter	For the UL. Upconverter from IF or baseband to the target frequency (28.45 – 31 GHz) in the Ka-band.	Yes
E-C0006	UE terrestrial transmit antenna	For the UL. Ka-band antenna.	No[NOTE1]
E-C0007	gNB receive antenna	For the UL. Ka-band antenna.	No[NOTE1]
E-C0008	gNB downconverter	For the UL. Downconverter from the receive frequency (28.45 – 31 GHz) in the Ka-band to IF or baseband.	Yes
E-C0009	Gateway	This component is provided by the French Space Agency (CNES). The specification is confidential.	Yes
E-C0010	Satellite	This component is provided by CNES. The specification is confidential.	Yes

Label	Component	Description of the main features	Commercial device (Yes/No)
E-C0011	Satellite antenna	This component is provided by CNES. The specification is confidential.	Yes
E-C0012	Satellite RF	This component is provided by CNES. The specification is confidential.	Yes

NOTE1: antennas developed in CEA for another project

2.3.3 Integrated KR-EU PoC architecture

5G-ALLSTAR is planning a demonstration at the Roland Garros 2021 tennis tournament. At the time this deliverable is written, we are still waiting for the confirmation of such an opportunity. The architecture foreseen for the integrated KR-EU PoC is depicted in Figure 2-21. Joint demonstration with this integrated KR-EU PoC platform will be conducted in three different trial sites

- Trial site 1: Roland Garros booth in Paris, France,
- Trial site 2: Toulouse, France (CNES premises),
- Trial site 3: Automobile proving ground in Yeonggwang or Cheonan, Korea.

In order to make a link between the tennis tournament and the demonstration and to promote our technical achievements of the project by interesting Roland Garros visitors, a VR tennis game will be used. It is one of the main PoC applications being considered for this joint demonstration. However, it is important to note that it may be subject to change depending on whether the permission of our joint demonstration at the Roland Garros 2021 tennis tournament is granted. In other words, in case the location of trial site 1 is changed, the final PoC application may be changed to another application other than the VR tennis game, and this change will be described in another deliverable (e.g., one of WP5 deliverable).

Tennis Kings VR, which is a VR-sport game developed by a KR company called Appnori Inc., is chosen as the primary option for the VR tennis game used in the joint demonstration. Figure 2-20 shows a screenshot of the gameplay. When playing the game, players can experience a life-like tennis play in VR applied realistic physical ball movement and spinning. Following is the features of the game:

- Simple UI and easy control to play.
- Advanced AI divided by 5 difficulty levels.
- Variety of rackets from standard to funny style.
- Applied the basic rules of tennis.
- Optimized with the combination of vive racket sports set and tracker.

Since the VR tennis game is a delay-sensitive application, the VR tennis game server will be located somewhere in EU as illustrated in Figure 2-21, which can minimize the physical distance between two players to avoid the unnecessary communication delay.

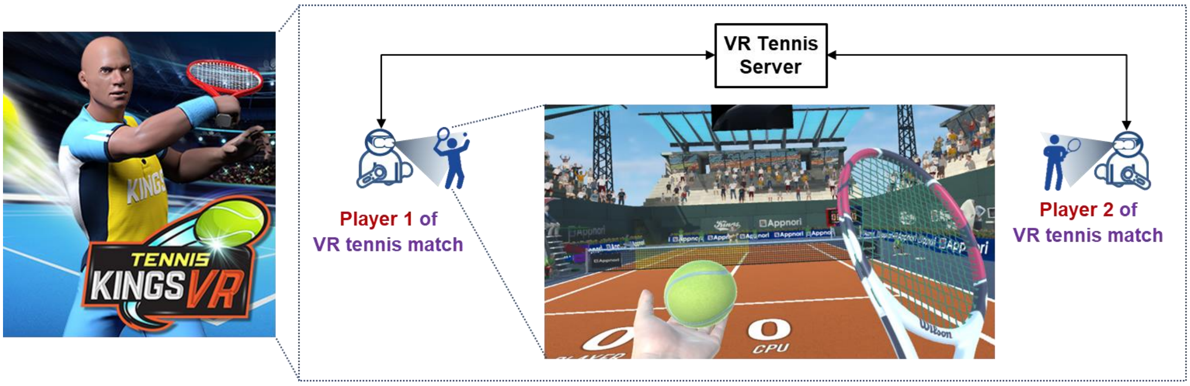


Figure 2-20: Tennis Kings VR developed by Appnori.

The EU part of the demonstration will take place concurrently in the trial sites 1 and 2. In the Toulouse site, the architecture is the same as the one described in §2.3.2.2, Figure 2-19. In this trial site, a VR tennis player is filmed by an 8k camera. The video can be watched in the Roland Garros site and the trial site in Korea. The data stream from the Toulouse site is sent via 5G satellite and/or 5G cellular, depending on required QoS (see deliverable D2.4 [7] for scenarios). The second VR tennis player is located in the Roland Garros site, where the game is recorded with an 8k camera and can be watched in Korea. The connectivity between Toulouse, Roland Garros and Amsterdam is described in §3.3.2.2, and the Amsterdam PoP and KR PoC system are interconnected via an interface called Korea Research Environment Open Network (KREONET), which is described in §3.3.2.1.

The KR part of the demonstration will take place in automobile proving ground located in Yeonggwang or Cheonan, Korea, and the PoC system architecture of KR part is same as the architecture described in §2.3.1. In this trial site, passengers on a moving vehicle can watch VR tennis game match with their VR headsets, and they can also watch live (or recorded) 4K/8K videos through a TV screen (or laptop screen) installed on the vehicle displaying the VR tennis players located in the trial sites 1 and 2. Meanwhile, the demonstration in the KR trial site will be filmed by two cameras, CAM3 and CAM4. CAM3, an 8K/360-degree camera (4K camera is also considered as an option), is installed on the vehicle records the passengers watching the 4K/8K video through TV screen and VR tennis match with their own devices while CAM4 on drone records the trial site in bird view where the demonstration is being conducted using the moving bus. Both videos recorded by CAM3 and CAM4 will be sent through the link described in §3.3.2.

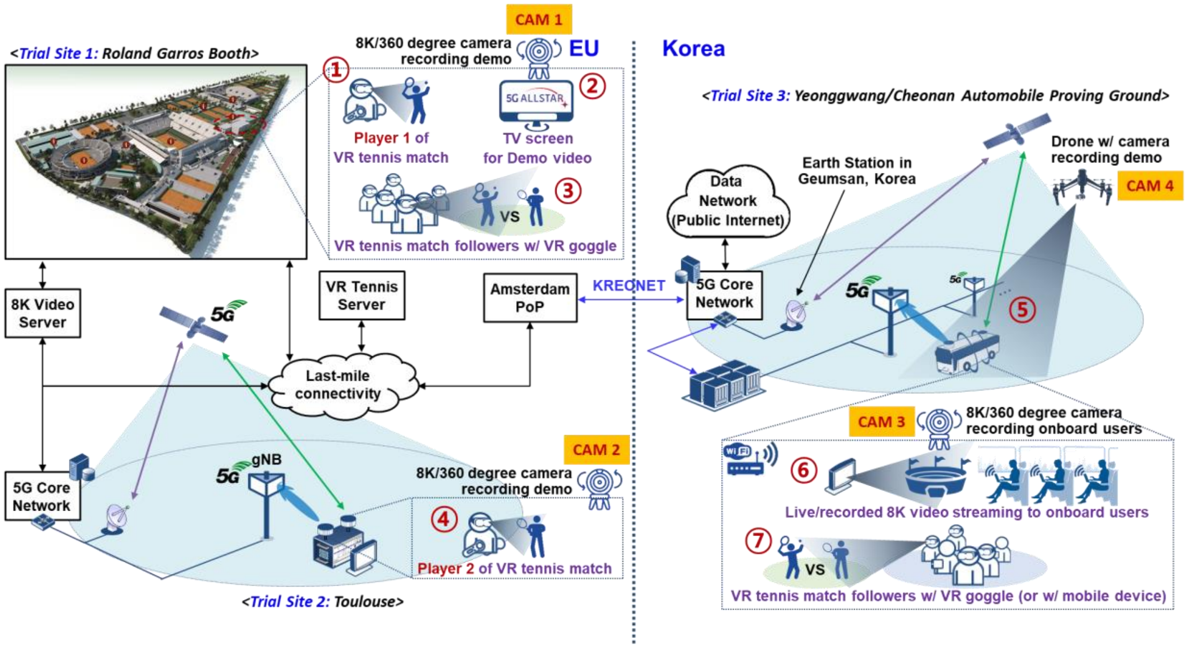


Figure 2-21: High-level architecture for joint PoC for intercontinental interoperability services.

Table 2-3 lists the hardware components of the joint KR-EU trial platform. Further details are provided in §3.3.1.

Table 2-3: KR-EU PoC hardware components list (components identical to individual EU and KR platforms are not listed)

Label	Component	Description of the main features	Commercial device (Yes/No)
KE-C0001	VR tennis server	See details in §3.3.1.1	Yes
KE-C0002	VR tennis equipment	VR headsets and VR controllers for VR tennis game (Tennis Kings VR) to be provided Appnori	Yes
KE-C0003	CAM1	8k camera	Yes
KE-C0004	CAM2	8k camera	Yes
KE-C0005	CAM3	8K or 360-degree camera recording demonstration inside KR demo bus	Yes
KE-C0006	CAM4	Drone with camera recording bus demonstration in KR trial site (trial site 3: Yeonggwang or Cheonan automobile providing ground)	Yes
KE-C0007	TV screen	8k TV screen located in trial site 1	Yes

3 System component and interface specification

This chapter details the components and the interfaces of the KR PoC system, the EU PoC system, and the joint KR-EU PoC system.

3.1 KR PoC system

This section provides the specification of the KR trial platform describing the detailed design of system components and interfaces and supported functionalities.

3.1.1 System components

In this subsection, a detailed description of system components listed in Table 2-1 and their sub-components is provided.

3.1.1.1 MNS-CNS

As depicted in Figure 3-1, MNS-CNS is composed of CP and UP functional blocks:

- CP functional blocks:
  - ✓ Bearer Controller,
  - ✓ NGAP/NAS Controller,
  - ✓ IP Allocator,
  - ✓ Mobility Controller.
- UP functional blocks:
  - ✓ Session Manager,
  - ✓ TC.

and their functionalities are described in Table 3-1.

Table 3-1: List of sub-components in MNS-CNS

Label	Sub-component	Description of the main features	Commercial device or not (Yes/No)
K-C0101	Bearer Controller	MNS-RAS bearer control (establishment, release): • QoS function for traffic class (QCI: QoS Class Identifier) • QoS function by subscriber session • Guaranteed Bit Rate (GBR) function	No
K-C0102	NGAP/NAS Controller	NAS signaling and NAS signal security: • Registration, deregistration • PDU session establishment • PDU session modification • PDU session deletion • Multiple PDU session management • Initial context setup • UE context release request • UE context release (AMF initiated) • UE context modification	No
K-C0103	IP Allocator	IP allocation and management: • Dynamic IP address allocation based on its local IP pool • Static IP allocation • Tracking Area List (TAL) information management	No

K-C0104	Mobility Controller	Handover management: • Reachability management for UE in ECM (EPS Connection Management)-IDLE state • TAL management • Inter-gateway handover • Inter-RAT handover • X2 handover • Handover preparation • Handover resource allocation • Handover notification • Handover cancellation • Path switch request • Uplink/downlink RAN status transfer	No
K-C0105	Session Manager	MN-RAS session management: • G-PDU • GPRS[1] Tunnelling Protocol (GTP): GTP-C/GTP-U • GTP encapsulation/decapsulation • Maximum Transfer Unit (MTU) setting for IP packet fragmentation • GTP packet routing	No
K-C0106	TC	Packet routing and forwarding: • Packet received from NGAP-U interface • Enqueue ring to worker core • UE IP based load balancer (GTP-U from NGAP-U interface: inner source IP % n_Worker) • Dequeue ring from worker core • Packet sending to SGi interface • Path management message (echo request, echo response) function • Tunnel management message (Error Indication, End Marker) function Traffic QoS control for MNS-RAS: • QoS control function for traffic class (i.e., QCI) • QoS control for subscriber session • Profile management for QoS control • Traffic control for service flow by Maximum Bit Rate (MBR) • GBR function MM point for Inter-MNS-RAS handover: • Echo request/response • Local mobility anchor point for providing UE with service continuity during intra-GW handover • Indirect tunnelling for traffic delivery during inter-GW handover • In case of handover (inter-BS or inter-RAT handover), "End Marker" is delivered to the source node (MNS-RAS) immediately after traffic path is changed • Inter-3GPP Mobility anchor	No

[1] GPRS: General Packet Radio Service

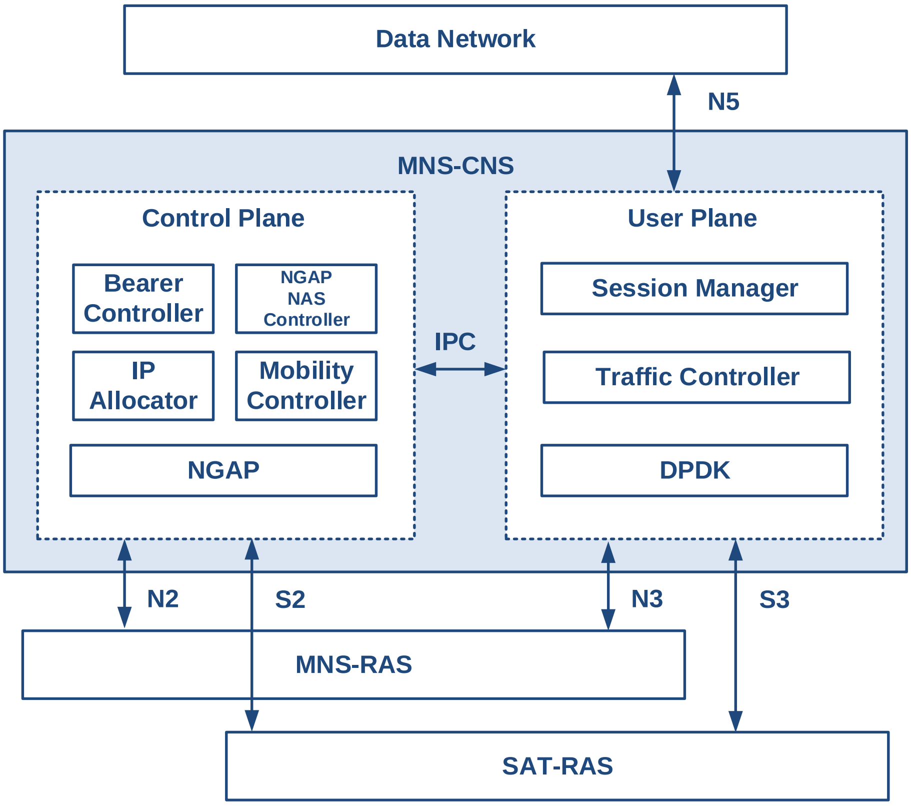


Figure 3-1: Architecture of MNS-CNS.

3.1.1.2 MNS-RAS

The architecture of MNS-RAS is designed as depicted in Figure 3-2, and the MNS-RAS is composed of two system components, MNS-RAS-CU and MNS-RAS-DU.

The functional blocks of MNS-RAS-CU and MNS-RAS-DU are

- MNS-RAS-CU:
  - ✓ SDAP,
  - ✓ RRC,
  - ✓ PDCP,
  - ✓ RLC,
  - ✓ MAC.
- MNS-RAS-DU:
  - ✓ PHY,
  - ✓ RF,
  - ✓ L1 Controller (L1C).

and their functionalities are described in Table 3-2 and Table 3-3, respectively.

Table 3-2: List of sub-components in MNS-RAS-CU

Label	Sub-component	Description of the main features	Commercial device or not (Yes/No)
K-C0201	SDAP	QoS flow management: • A single protocol entity of SDAP is configured for each PDU session (the exception to this is Dual Connectivity) • Map a specific QoS flow within a PDU session to a corresponding Data Radio Bearer (DRB), which has been established with the appropriate level of QoS • Mark the transmitted packets with the correct QoS flow ID (QFI)	No
K-C0202	RRC	Connection control of radio interface between MNS-RAS and MNS-VES: • Broadcast of SI related to AS/NAS • Paging • Establishment, maintenance, and release of an RRC connection between the UE and base station • Signaling for RB management • Security handling • MM (UE measurement report/configuration) • Handover • QoS management • Transfer of NAS message from UE to NAS or vice versa	No
K-C0203	PDCP	Connection between IP layer and RLC layer: • Transfer of UP or CP data • Maintenance of PDCP Sequence Numbers (SNs) • Robust Header Compression (ROHC) function • In-sequence delivery of upper layer PDUs • Duplicate elimination of lower layer SDUs • Ciphering and deciphering of UP data and CP data • Integrity protection and integrity verification of CP data	No
K-C0204	RLC	Connection between PDCP layer and MAC layer: • Operate in 3 modes of operation: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM) • Transfer of upper layer PDUs • Error correction through ARQ (only for AM data transfer) • Concatenation, segmentation and reassembly of RLC SDUs (only for UM and AM data transfer) • Re-segmentation of RLC data PDUs (only for AM data transfer) • Re-ordering of RLC data PDUs (only for UM and AM data transfer) • Duplicate detection (only for UM and AM data transfer) • RLC SDU discard (only for UM and AM data transfer) • RLC re-establishment • Protocol Error Detection (only for AM data transfer)	No
K-C0205	MAC	MAC PDU composing and decomposing: • Mapping between logical channels and transport channels (TrCHs) • Multiplexing/ De-multiplexing of MAC SDUs from one or different logical channels onto transport blocks (TBs) to be delivered to the PHY on TrCHs Hybrid Automatic Repeat Request (HARQ): • Error correction • HARQ transmission / reception	No

		Scheduling: • Scheduling information reporting • Priority handling between UEs by means of dynamic scheduling	

Table 3-3: List of sub-components in MNS-RAS-DU

Label	Sub-component	Description of the main features	Commercial device or not (Yes/No)
K-C0301	PHY	PHY (baseband) communication: • Mapping between TrCHs and physical channels • Encoding and modulation of TrCHs • Demodulation and decoding of received signals • MIMO transmission/reception • Measurement report	No (except for Turbo decoder)
K-C0302	RF	Antenna/RF unit for transmission/reception of mmWave V2I signal (see details below): • Up/down-conversion between baseband signals and mmWave-band RF signals • Local oscillator • Bandpass filtering	No
K-C0303	L1C	PHY control: • Baseband MODEM control • TTI (Transfer Time Interval) control signal generation L2/L3 message transmission/reception: • MAC/RRC control message transmission/reception	No

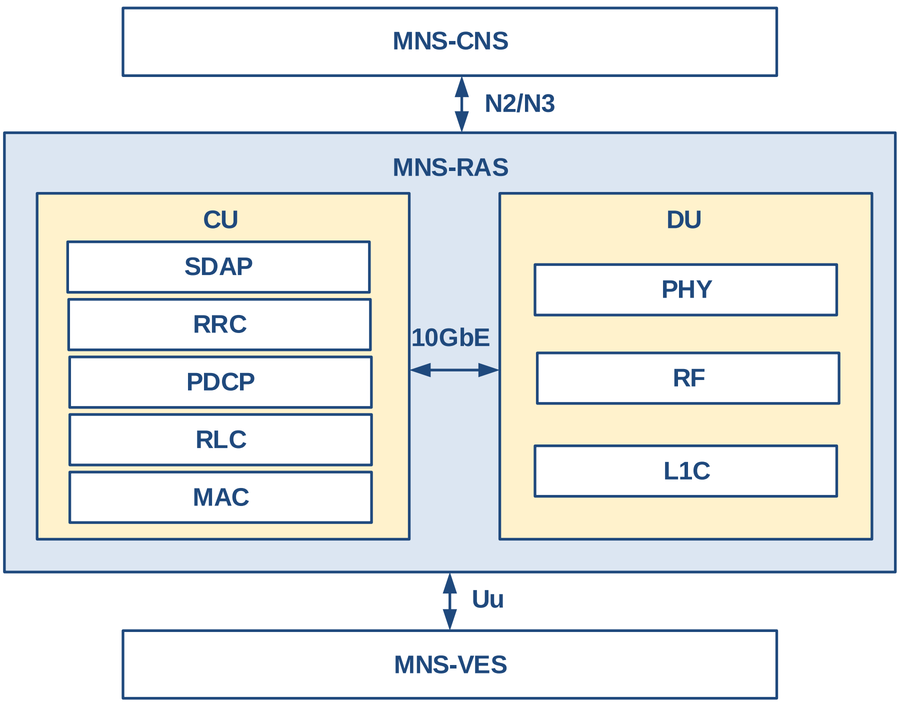


Figure 3-2: Architecture of MNS-RAS.

In addition, the detailed design of sub-components, MNS-RAS-DU-PHY and MNS-RAS-DU-RF, is presented as follows:

- MNS-RAS-DU-PHY

✓ The functional structure and internal/external interface of MNS-RAS-DU-PHY are depicted in Figure 3-3, and key functional blocks include:

- TrCH encoder:
  - TB Cyclic Redundancy Check (CRC) attachment,
  - Code block segmentation and code block CRC attachment,
  - Channel coding using Turbo coding instead of Low-Density Parity-Check (LDPC) coding,
  - PHY HARQ processing,
  - Rate matching.
- TrCH decoder:
  - It is important to notice that commercial products, application-specific integrated circuit (ASIC) chips developed for Turbo decoder, will be used.
- Downlink modulator:
  - As depicted in Figure 3-4, downlink baseband processing includes scrambling, modulation (QPSK, 16QAM, 64QAM), layer mapping (up to 2 spatial layers), precoding, mapping to assigned resources and antenna ports.
- Uplink demodulator:
  - Demodulate uplink signals.
- Front-end controller:
  - The front-end controller is responsible for controlling and monitoring the operation of the RF front-end.

✓ Interface with MNS-RAS-DU-L1C, LMAC of MNS-RAS-CU-MAC, and MNS-RAS-DU-RF (via ADC/DAC).

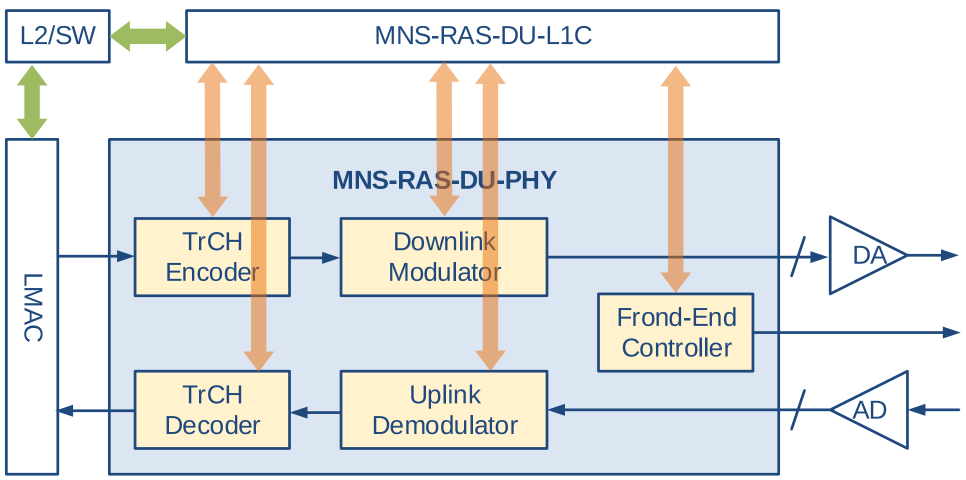


Figure 3-3: Functional architecture and interface design of MNS-RAS-DU-PHY.

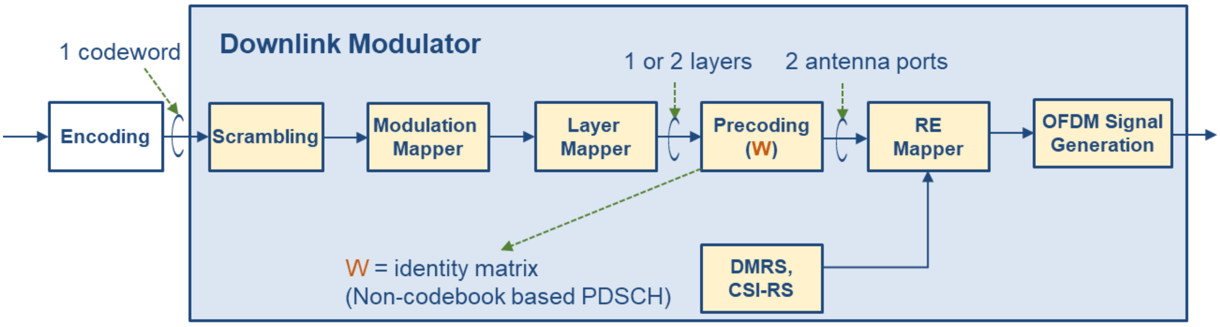


Figure 3-4: Downlink baseband processing.

- ✓ PHY specifications to be implemented (also applied to MNS-VES-PHY in §3.1.1.3):
  - Waveform: only CP-OFDM is supported for both downlink and uplink transmissions.
  - Duplex mode: TDD.
  - Numerology:
    - μ=2 and μ=3, whose parameters are summarized in Table 3-4,
    - Numerology of μ=2 is only implemented in MNS.

Table 3-4: Supported numerology

Parameter / Numerology (μ)	2	3
Max. number of CCs per gNB	10	10
Max. number of CCs per VUE	3	3
Bandwidth per CC (MHz)	100	100
Subcarrier spacing (kHz)	60	120
Number of PRBs per CC	132	66
FFT size	2048	1024
Sampling rate (MHz)	122.88	122.88
TTI (μs)	250	125
OFDM symbol duration (μs)	16.67	8.33
Cyclic Prefix duration (μs)	1.17	0.57
OFDM symbol including CP (μs)	17.84	8.92

  - Transmission scheme:
    - Only non-codebook-based transmission is supported for both downlink and uplink transmissions.

- MNS-RAS-DU-RF
  - ✓ As shown in Figure 3-5, a slotted waveguide array antenna will be employed for each antenna panel for MNS-RAS-DU-RF of the KR PoC system. The array antenna consists of 4x4 radiating elements with an array gain of around 19~20 dBi and it forms a fixed beam in the desired direction. Since the target system will be designed to be operated in Flexible Access Common Spectrum (FACS), it is mandatory to comply with the Effective Isotropic Radiated Power (EIRP) requirement regulated by the KR

government where the maximum allowable RF power emitted by the TX antenna is 36 dBm.

- ✓ Antenna module consists of two antenna panels that have orthogonal polarization angles and are placed with enough distance between one another to obtain spatial diversity gain.

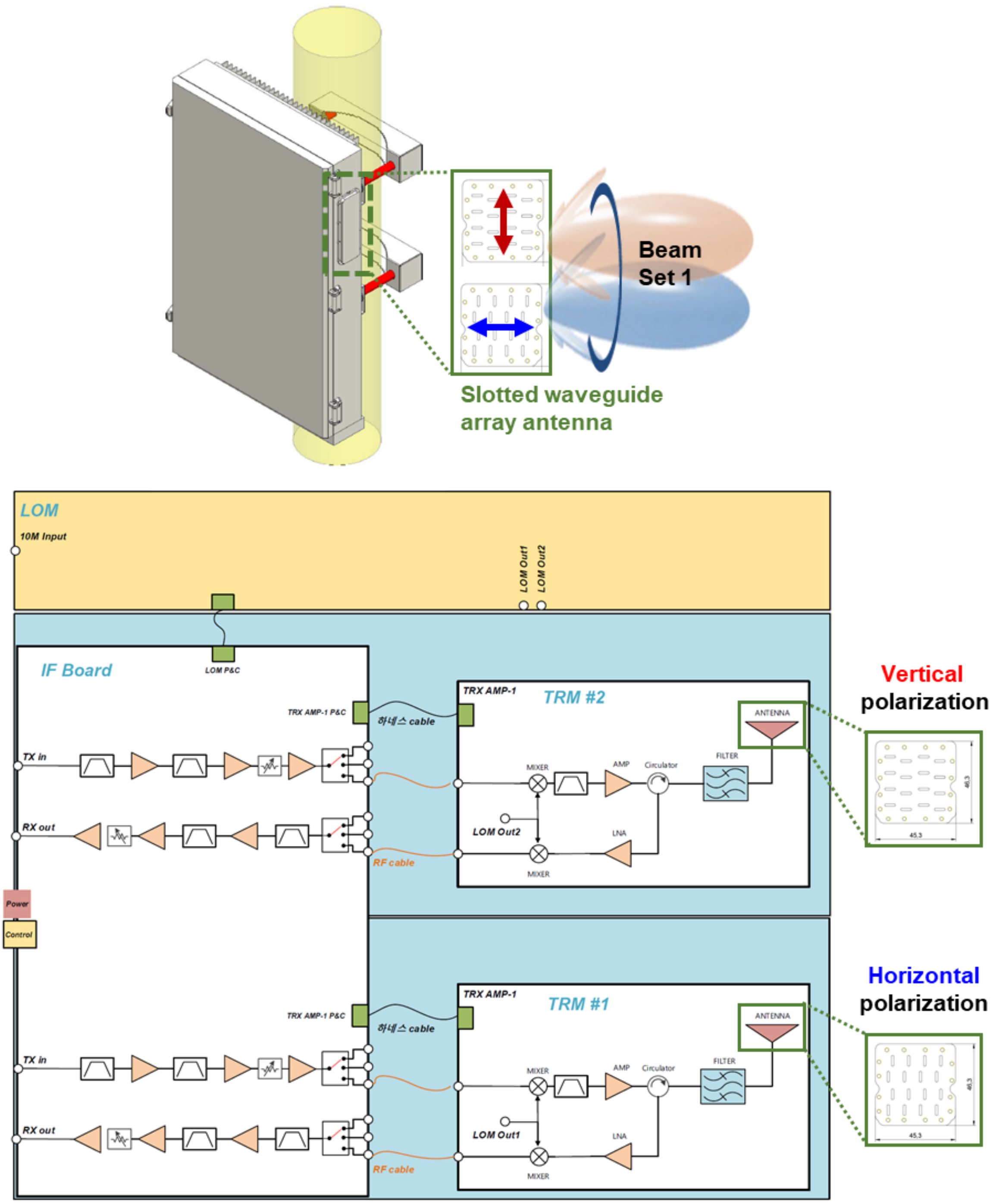


Figure 3-5: Preliminary design of MNS-RAS-DU-RF.

3.1.1.3 MNS-VES

The architecture of MNS-VES is designed as depicted in Figure 3-6, and the MNS-VES is composed of sub-components as follows

- CP functional blocks:
  - ✓ 5G SM (5GSM),
  - ✓ 5G MM (5GMM),
  - ✓ RRC.
- UP functional blocks:
  - ✓ SDAP,
  - ✓ PDCP,
  - ✓ RLC,
  - ✓ MAC,
  - ✓ PHY,
  - ✓ RF,
  - ✓ L1C.

and their functionalities are described in Table 3-5.

Table 3-5: List of sub-components in MNS-VES

Label	Sub-component	Description of the main features	Commercial device or not (Yes/No)
K-C0401	5GSM	5GSM defined in TS 24.301 [9] provides procedures for the handling of 5GS PDU session contexts. Together with the bearer control provided by the AS, this protocol is used for the control of UP bearers: • PDU session creation, release, and management based on service activation or deactivation • After PDU session establishment, receive IP address assigned to UE from DN and send it to TC-TE of V-UE or Wi-Fi-AP. • Access to default DN and PDU session that a user wants to connect • QoS and IP packet filter information forwarding	No
K-C0402	5GMM	5GMM defined in TS 24.301 [9] provides procedures for the control of mobility when the UE is using the NG RAN and/or non-3GPP access network. This protocol also provides control of security for the NAS protocols: • Network registration/de-registration, UE context management • MM based on TA registration and TA tracking • Security and authentication • Service request, UE configuration update, reachability, etc. • Receive and respond to paging messages	No
K-C0403	RRC	• Receive system information broadcasted by the base station • Establishment, maintenance, and release of an RRC connection • Establishment/ modification/ release of RBs carrying user data (DRBs)	No

		• Radio configuration control including assignment/ modification of ARQ configuration, HARQ configuration, DRX configuration • Measurement reporting and control of the reporting • Mobility functions including handover and cell selection/reselection	
K-C0404	SDAP	• Transfer of downlink IP packet received from PDCP to application program and vice versa • Mapping between a QoS flow and a DRB (due to new QoS framework) • Marking QoS flow ID (QFI) in both DL and UL packets (DL: due to reflective QoS and UL: due to new QoS framework)	No
K-C0405	PDCP	• Transfer of UP data (DRB) and CP data (SRB) • Reordering and in-order delivery • Duplicate discarding • PDCP re-establishment for re-establishment of lower layer	No
K-C0416	RLC	• Operate in 3 modes of operation: TM, UM, and AM • Transfer of upper layer PDUs • Error correction through ARQ (only for AM data transfer) • Concatenation, segmentation, and reassembly of RLC SDUs (only for UM and AM data transfer) • Re-segmentation of RLC data PDUs (only for AM data transfer) • Provide an SN different from that is provided by PDCP • Duplicate detection (only for UM and AM data transfer) • RLC SDU discard (only for UM and AM data transfer) • RLC re-establishment	No
K-C0407	MAC	• Mapping between logical channels and TrCHs • Multiplexing/ De-multiplexing of MAC SDUs from one or different logical channels onto TB to be delivered to the PHY on TrCHs • Scheduling information reporting • Error correction through HARQ • Power Headroom reporting	No
K-C0408	PHY	• Baseband processing unit for transmitting/receiving V2I signal (see details below) • Mapping between TrCHs and physical channels • Encoding and modulation of TrCH • Demodulation and decoding of received signals • MIMO transmission/reception • Measurement report	No (except for Turbo decoder)
K-C0409	RF	Antenna/RF unit for transmission/reception of mmWave V2I signal (see details below): • Up/down-conversion between baseband signals and mmWave-band RF signals • Local oscillator • Bandpass filtering • Antenna switching (beam switching)	No
K-C0410	L1C	PHY control: • Baseband MODEM control • Automatic Gain Control (AGC) • Automatic Frequency Control (AFC) L2/L3 message transmission/reception: MAC/RRC control message transmission/reception	No

NOTE1: 5G-ALLSTAR D4.3, “Implementation of multi-RAT load balancing algorithms and technical specifications of the relevant interfaces,” will be delivered in M30 (Dec. 2020).

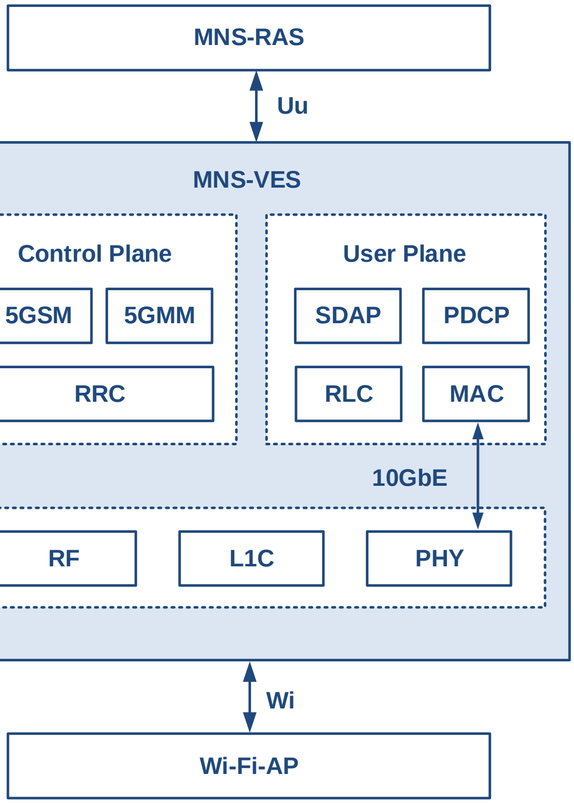


Figure 3-6: Architecture of MNS-VES.

In addition, the detailed design of sub-components, MNS-VES-PHY and MNS-VES-RF, is presented as follows:

- MNS-VES-PHY
  - ✓ The functional structure and internal/external interface of MNS-VES-PHY are depicted in Figure 3-7, and key functional blocks include:
    - ▪ TrCH encoder:
      - TB CRC attachment,
      - Code block segmentation and code block CRC attachment,
      - Channel coding using Turbo coding instead of LDPC coding,
      - PHY HARQ processing,
      - Rate matching.
    - ▪ TrCH decoder:
      - Same as in MNS-RAS-DU-PHY, commercial products (ASIC chips developed for Turbo decoder) will be used.
    - ▪ Uplink modulator:
      - As depicted in Figure 3-8, uplink baseband processing includes scrambling, modulation (QPSK, 16QAM, 64QAM), layer mapping (one spatial layer), precoding, mapping to assigned resources and antenna ports.
    - ▪ Downlink demodulator:

- Demodulate downlink signals.

▪ Front-end controller:

- Same as in MNS-RAS-DU-PHY, the front-end controller is responsible for controlling and monitoring the operation of the RF front-end.

▪ Cell searcher:

- Acquire time and frequency synchronization, frame timing, and cell identity.

✓ Interface with MNS-VES-L1C, LMAC of MHN-VES-MAC, and MHN-VES-RF (via ADC/DAC).

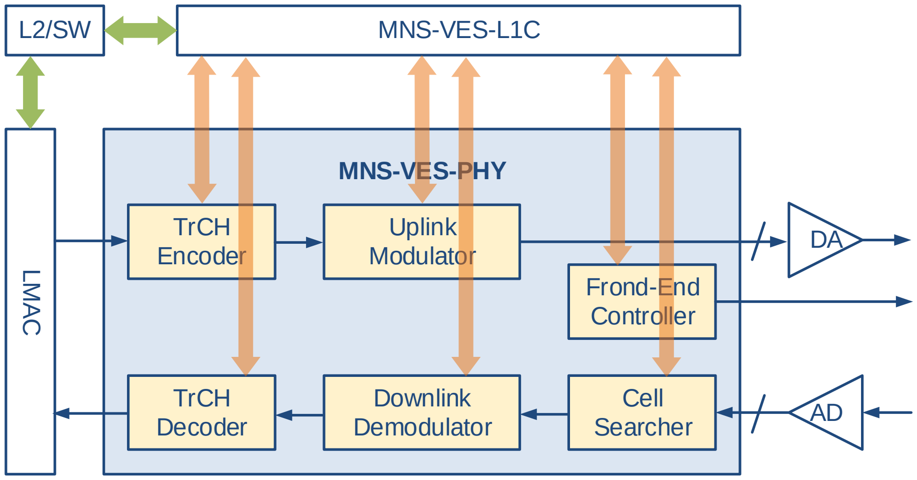


Figure 3-7: Functional architecture and interface design of MNS-VES-PHY.

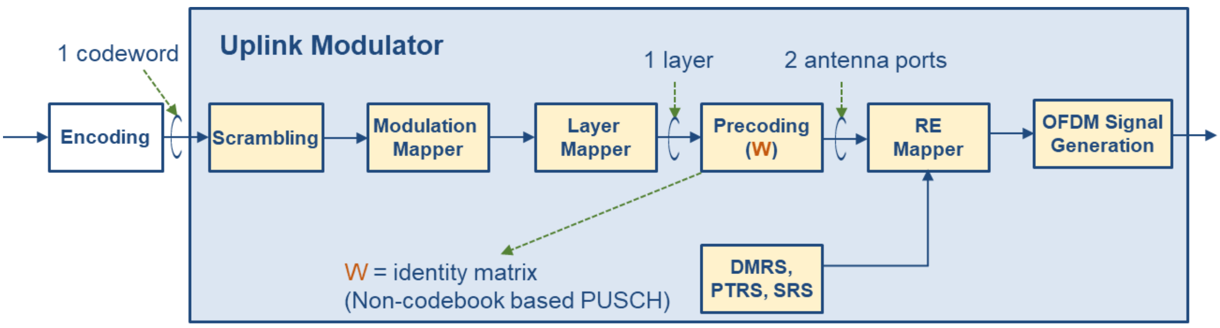


Figure 3-8: Uplink baseband processing.

- MNS-VES-RF

✓ Based on the conceptual design of MNS-VES-RF described in §5.1.1 of deliverable D2.2 [1], the preliminary design is done as depicted in Figure 3-9, which may be subject to change depending on the future activities in WP5, and the changes will be included in WP5 deliverable (e.g., D5.3). Same as MNS-RAS-DU-RF described in §3.1.1.2, a slotted waveguide array antenna will be employed for each antenna panel for MNS-VES-RF of KR PoC system. The array antenna also consists of 4x4 radiating elements with an array gain of around 19~20 dBi as shown in Figure 3-10, and it forms a fixed beam in the desired direction. Due to the EIRP regulation mentioned in

§3.1.1.2, the maximum allowable RF power emitted by the TX antenna is 36 dBm.

- ✓ As depicted in Figure 3-9, the antenna module consists of six independent antenna panels, each of which is physically separated. A pair of two antennas having orthogonal polarization (vertical and horizontal polarizations) create a set of two polarized beams in the same direction, and three antenna pairs radiate three different sets of beams. The angle between adjacent beam sets, α, is around 18 degrees, but the antenna direction is designed to adjust in the horizontal direction by tilting physically so that α can be set to a larger or smaller value in order to find the best beam angle α^* during the field test.

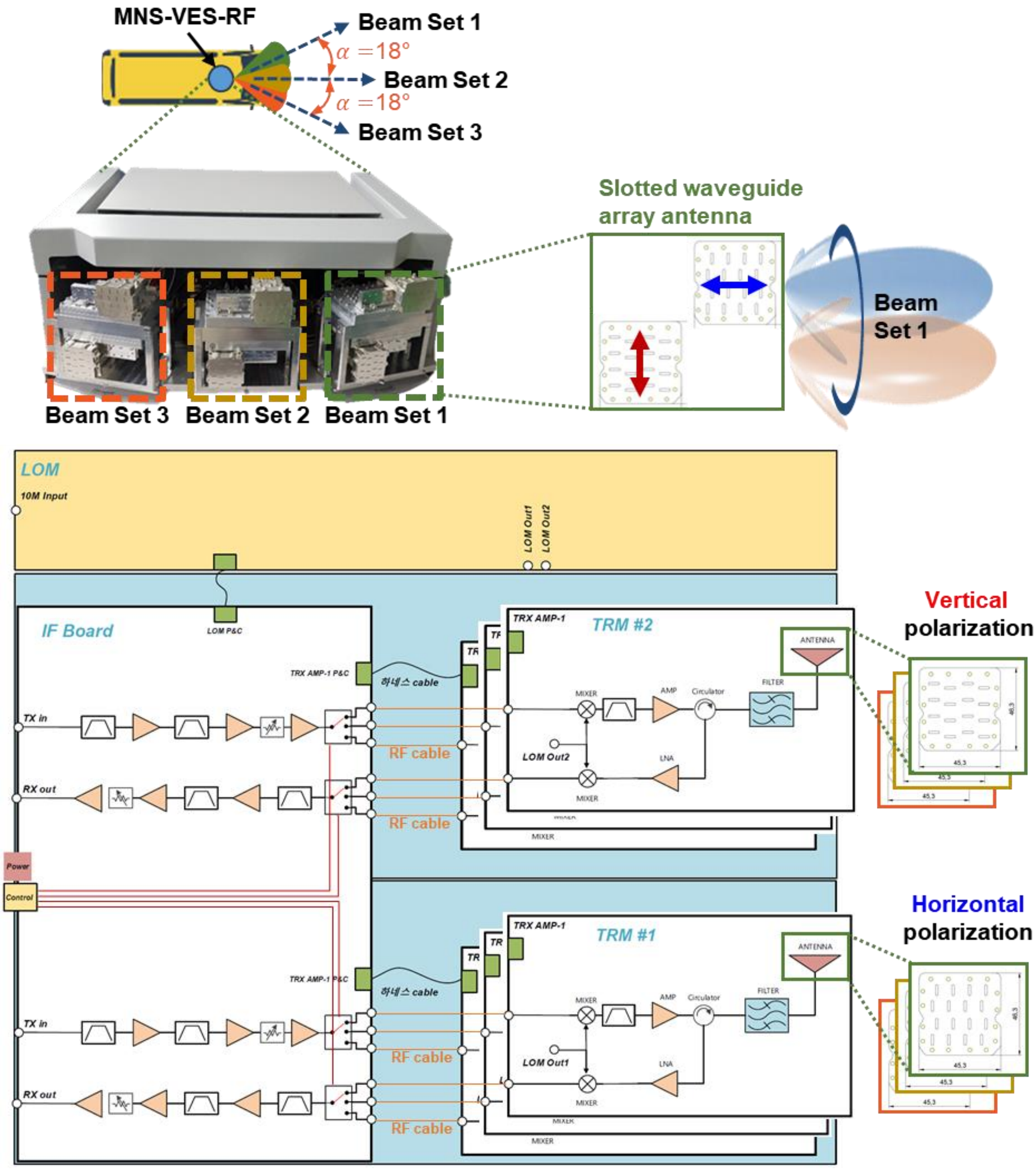


Figure 3-9: Preliminary design of MNS-VES-RF.

✓ The target beam radiation pattern of each antenna panel is depicted in Figure 3-10.

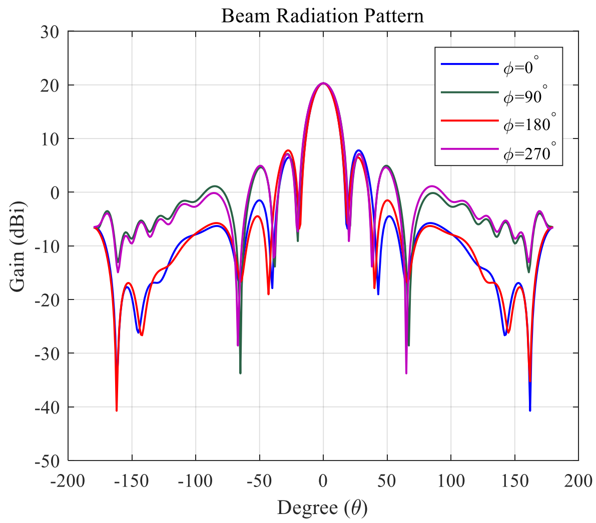


Figure 3-10: Target beam radiation pattern of each antenna panel.

3.1.1.4 SAT-RAS

As depicted in Figure 2-14, SAT-RAS is composed of two system components, SAT-RAS-GEO and SAT-RAS-ES.

SAT-RAS-GEO is KOREASAT 6, which is a South KR GEO communications satellite operated by KTsat. KOREASAT 6 has 24 FSS Ku-band transponders and 6 BSS Ku-band transponders. The satellite generates 3.4 kilowatts of payload power and has a 15-year on-orbit mission life. KOREASAT 6 was launched by Arianespace from Kourou, French Guiana in December 2010 to a final orbital slot at 116°E. The detailed specifications of KOREASAT 6 are summarized in Table 3-6, and the service coverage is shown in Figure 3-11.

KOREASAT 6 led Korea to digital switchover. The switchover has been completed and provides future broadcasting services such as HDTV, 3DTV, and even UHD. The satellite provides SkyLife with capacity and services for broadcasting to over 4 million subscribers. It delivers CATV program service, Satellite News Gathering, and various other services[2].

Table 3-6: Specifications of KOREASAT 6

Parameter	Value
Number of Transponders	• FSS: 24x36MHz • BSS: 6x27MHz
Uplink/Downlink Frequencies (GHz)	• 14.0 – 14.5 / 12.25 – 12.75 • 14.5 – 14.8 / 11.7 – 12.0
Polarization	Linear(Horizontal or Vertical)
EIRP (Peak Value) (dBW)	62
G/T (dB/K)	12 - 20
Orbital Location (Longitude)	116°E
Geographic Coverage	Korea
Launch Service Provider	Arianespace

[2] https://www.ktsat.net/content/view.do?cttNm=coverage&cttNo=031

Launch Date	30 Dec 2010
Spacecraft(Model)	Star-2
Manufacturer	Orbital Sciences Corporation
Lifetime	15 years

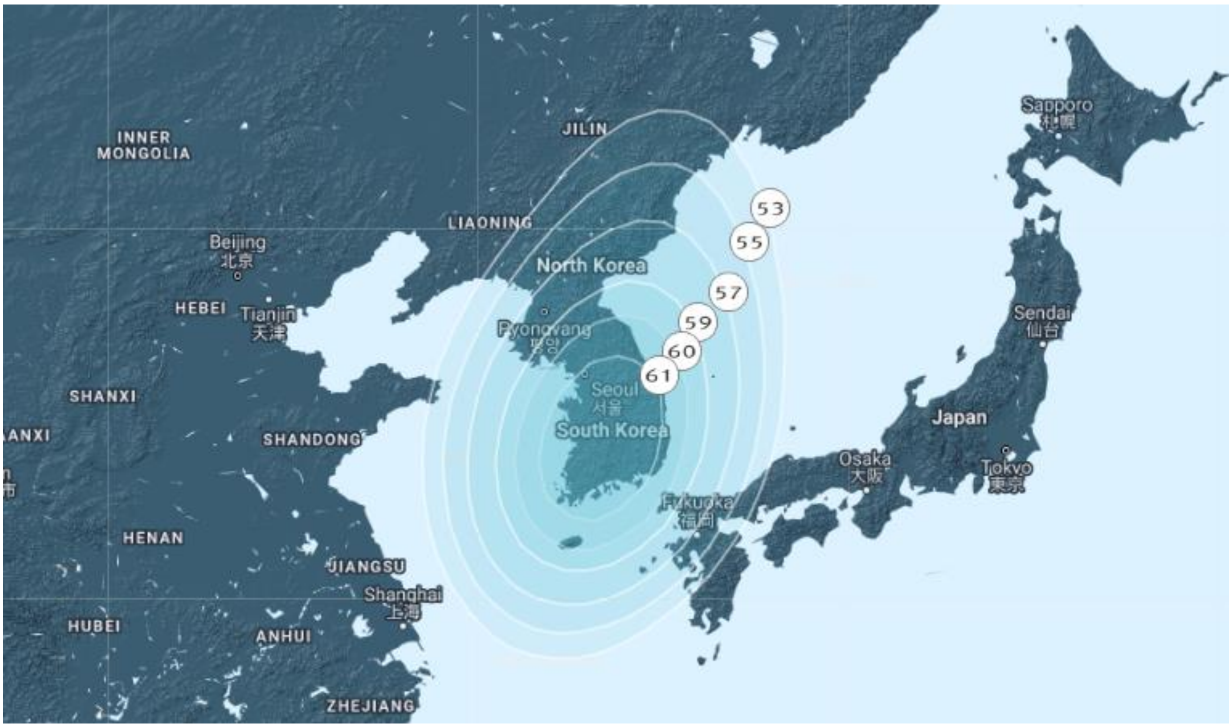
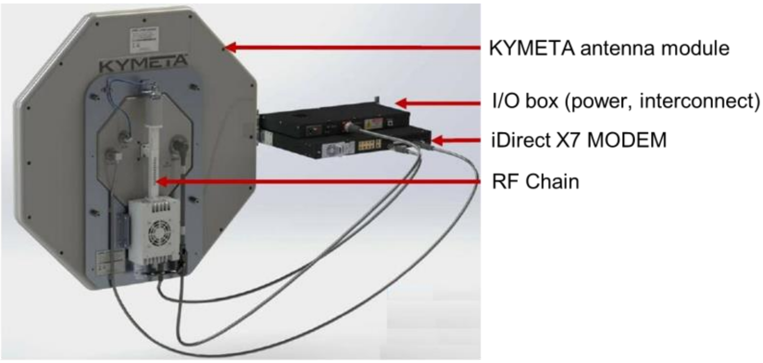


Figure 3-11: Coverage map of KOREASAT 6 (EIRP of FSS Ku-band beam).

3.1.1.5 SAT-VES

As shown in Figure 3-12, SAT-VES is composed of SAT-VES-RF (KYMETA antenna) and SAT-MODEM (iDirect X7 MODEM) including PHY and L2.



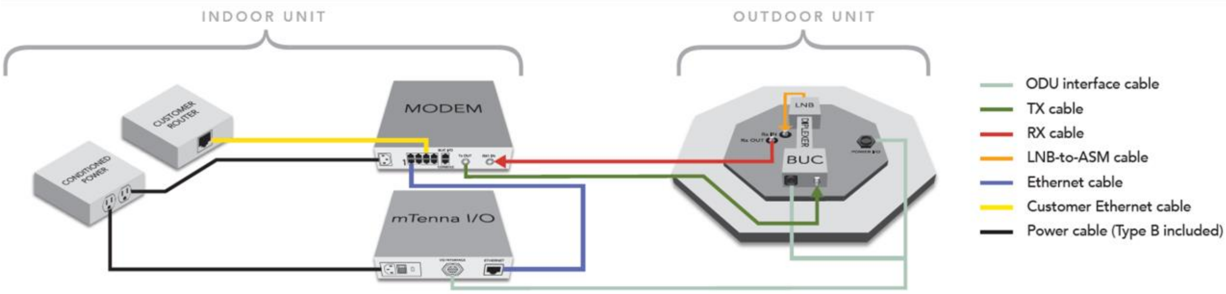


Figure 3-12: Architecture of SAT-VES.

The detailed specifications of KYMETA antenna are summarized in Table 3-7.

Table 3-7: KYMETA antenna specifications

Specification	Value
Band	Ku
Antenna type	Electronically scanned array
Polarization	Vertical and horizontal software defined
RX frequency range	11.3 – 12.3 GHz
RX gain	33.0 dB
RX G/T	9.5 dB/K
RX scan roll-off @60°(H-POL)	1.2
RX scan roll-off @60°(V-POL)	1.1
RX instantaneous bandwidth	>100 MHz
TX frequency range	13.75 – 14.5 GHz
TX gain	32.5 dB
TX G/T	9.5dB/K
TX scan roll-off @60°(H-POL)	1.4
TX scan roll-off @60°(V-POL) :	1.2
Antenna size	2.3cm(L)×22.21cm(D)×4.37cm(H)
Antenna weight	16.4 kg
Tracking rate	>20°/second
Scan angles	θ up to 75° off broadside and φ 360°
Tracking accuracy	<0.2°

3.1.1.6 TC

The architecture of TC is designed as depicted in Figure 2-14, and the TC is composed of two sub-components, TC-TE and TC-TS.

The functional blocks of the system components are:

- TC-TE:
  - ✓ UI,
  - ✓ Internet Application,
  - ✓ TCP/UDP.
- TC-TS

Table 3-8: List of sub-components in TC

Label	Sub-component	Description of the main features	Commercial device or not (Yes/No)
K-C0701	TE	UI: • Execution and control of MN service (attach, Detach, PDU session establishment/release) • Run and terminate applications Supported applications (e.g., voice service, video service, online VR game)	No
K-C0702	TS	Link switching: • One of satellite and cellular links is chosen to receive the appropriate packets to ensure service continuity (details will be provided in deliverable D4.3)	No

3.1.1.7 DM

DM, developed by ETRI, is a software component (the GUI is shown in Figure 3-13) running on a commercial PC (or laptop) that allows the operator to set up and control test parameters while monitoring and visualizing the target KPIs and other system performances indicators such as:

- PHY data rates of Tx and Rx, which is a target KPI of KR PoC (KPI0-KR0 in Table 4-3),
- Demodulation performance (Block Error Rate, BLER),
- Received signal quality:
  - ✓ Signal-to-Noise Ratio (SNR) in dB,
  - ✓ Rx power in dBm,
  - ✓ Constellation of received signals,
  - ✓ Reference Signals Received Power (RSRP) of vertically/horizontally polarized antenna in dBm,
- Time/frequency-domain channel response,
- Received power of three beams,
- Beam switching status.

Figure 3-13: DM.

In MNS, two PCs with DM are connected to MNS-RAS-DU-PHY and MNS-VES-PHY, respectively, through USB cable, respectively showing the performance of MNS. In addition, as shown in Figure 2-14, the PC can be also connected with TC-TE of V-UE for the purpose of evaluating the PHY data rate of KR PoC system with MC support.

3.1.1.8 DS

Two DS, such as TV screens or monitors, are connected to the PCs implementing higher-layer components (MAC, RLC, PDCP) of MNS-RAS-CU and MNS-VES, via an HDMI cable, respectively, and it is responsible for showcasing target PoC service scenarios/applications such as 4K/8K video streaming.

3.1.1.9 Wi-Fi-AP

A Wi-Fi AP is connected to the MNS-VES through an Ethernet cable, and it is responsible for providing passengers with broadband onboard Wi-Fi services, which is one of the target PoC service scenarios/applications.

3.1.1.10 UE

Passengers' mobile devices such as smartphones, tablets, and AR/VR headsets.

3.1.2 System interfaces

This subsection provides the internal and external interfaces of KR PoC system. The interfaces are depicted in Figure 3-14 and the details are summarized in Table 3-9. In Figure 3-14, the white block refers to the system component that is a commercial product while the yellow block represents the system component that will be designed and implemented within this project. Some of those system components of yellow block include sub-components that are developed in other relevant projects. As can be noted from this figure that since the detailed design of the system component, TC, will be described in deliverable D4.3, its associated interfaces with other system components (e.g., interfaces with MNS-VES and SAT-VES) will be also specified in the deliverable D4.3.

Table 3-9: List of interfaces KR PoC system

Interface label	Interface	From	To	Interface type (Physical/Logical)	Description
K-I0001	N5	MNS-CNS	Another system	Logical	See details in §3.1.2.1
K-I0002	802.11	Wi-Fi-AP	UE	Logical	See details in §3.1.2.2
K-I0004	N2/N3	MNS-RAS	MNS-CNS	Logical	See details in §3.1.2.3
K-I0005	Xn	MNS-RAS	MNS-RAS	Logical	See details in §3.1.2.4
K-I0006	Uu	MNS-RAS	MNS-VES	Logical	See details in §3.1.2.5
K-I0006	Su	SAT-RAS	SAT-VES	Logical	See details in §3.1.2.6
K-I0008	Wi	MNS-VES	Wi-Fi-AP	Logical	See details in §3.1.2.7

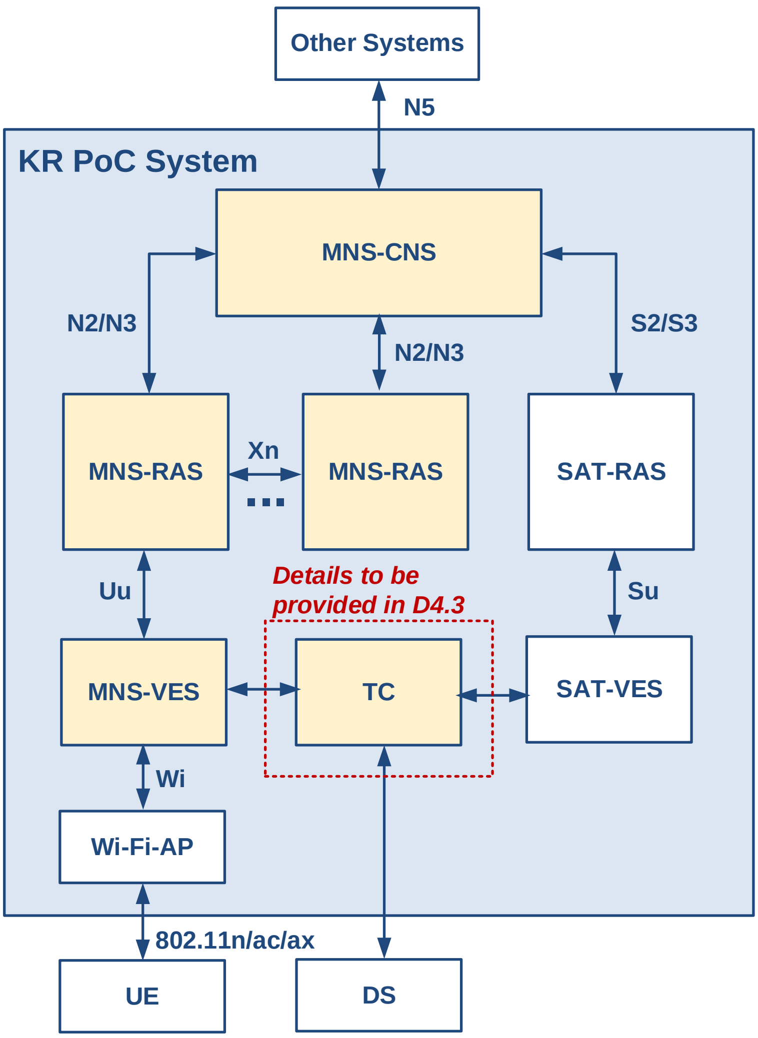


Figure 3-14: Overall interfaces for KR PoC system.

3.1.2.1 N5 interface

N5 interface, which is an Ethernet interface, is defined to interface with DNs for exchanging user data. In 3GPP, this corresponds a Reference Point (RP) between Application Function (AF) and PCF.

3.1.2.2 802.11 interface

IEEE 802.11 is part of the IEEE 802 set of Local Area Network (LAN) protocols, and specifies the set of MAC and PHY protocols for implementing wireless LAN (WLAN) Wi-Fi computer communication in various frequencies, including but not limited to 2.4 GHz, 5 GHz, and 60 GHz frequency bands. They are the most widely used wireless computer networking standards in the world, used in most home and office networks to allow laptops, printers, and smartphones to talk to each other and access the Internet without connecting wires.

The terms 802.11 and Wi-Fi are sometimes used interchangeably, but the Wi-Fi Alliance defines the term "Wi-Fi" as another set of standards. Thus, 802.11 and Wi-Fi are not synonymous. 802.11 has evolved in accordance with the IEEE standardization roadmap, and as it evolves, date rate performance improves. Among the IEEE 802.11 standards, 802.11n is the most widely used one, and recently, 802.11ax, the successor to 802.11ac and marketed as "Wi-Fi 6" by the Wi-Fi Alliance, has been released.

3.1.2.3 N2/N3 interface

According to the 5G RPs Architecture in TS 23.501 [8], the interface between AMF and RAN is defined as N2, and the interface between UPF and RAN is defined as N3. Since 3GPP RAN can be mapped to MNS-RAS of KR PoC system, and AMF and UPF can be mapped to the internal blocks of MNS-CNS, N2/N3 is considered as an interface between MNS-RAS and MNS-CNS.

3.1.2.4 Xn interface

The X2 interface is not defined in 2G/3G but is introduced since 4G to specify a direct interface between RAN nodes (e.g., eNBs in LTE). In 5G, Xn interface is newly specified between RAN nodes in standalone operation (e.g., between ng–eNB and ng–eNB/gNB and gNB/ng–eNB and gNB). In KR PoC system, since MNS-RAS correnponds to the base station (i.e., RAN), Xn can be used for the interface between MNS-RASs. Through the Xn interface, the information of the neighboring MNS-RAS can be obtained immediately without going through the MNS-CNS, and using this information, handover can be done without the intervention of the MNS-CNS. Figure 3-15 shows the Xn interface and protocol stack.

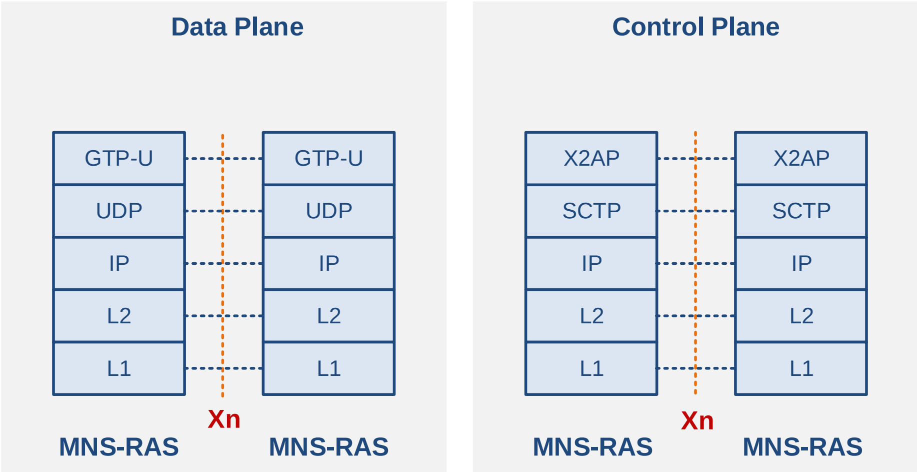


Figure 3-15: Xn interface and protocol stack.

3.1.2.5 Uu interface

The Uu interface defined in 3GPP to specify an interface between MNS-RAS and MNS-VES. Figure 3-16 shows its interface and protocol stack for UP and CP. PHY is responsible for the demodulation, encoding, and decoding functions of the baseband signals. MAC dynamically allocates radio resources to the MNS-VES and performs a QoS control function to guarantee the QoS for each Radio Bearer. It also performs the multiplexing of Radio Bearers for transmission to the PHY. RLC segments the packet received from the PDCP to transmit over the radio link, reassembles the packet received over the radio link to transmit it to the PDCP and handles packet re-ordering and re-transmission. PDCP allows IP packets to be efficiently transmitted over the radio link. It performs the ROHC function, AS security, and handles packet re-ordering and re-transmission during handover. The NAS of the CP performs MM and bearer control. RRC controls the radio signaling connection.

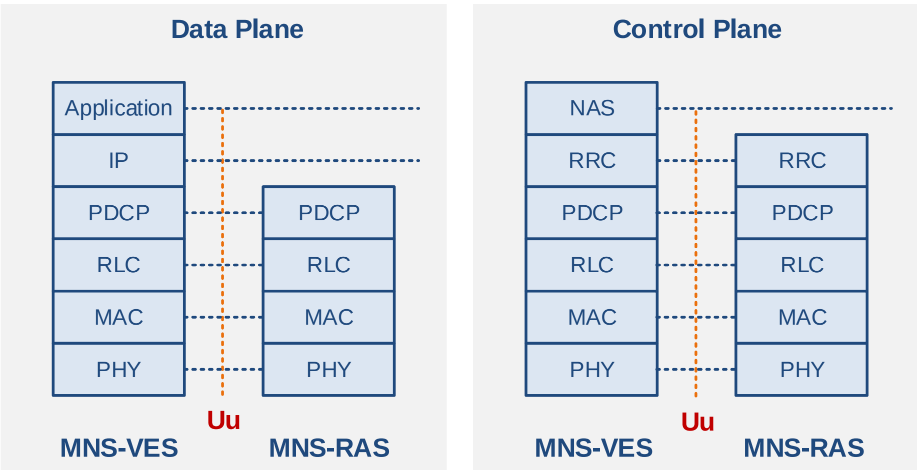


Figure 3-16: Uu interface and protocol stack.

3.1.2.6 Su interface

The Su interface is defined between SAT-RAS and SAT-VES as illustrated in Figure 3-17. To properly selecting one of IP packets received from SAT-VES and MNS-VES, TC is designed to be located between L2 and IP layers of SAT.

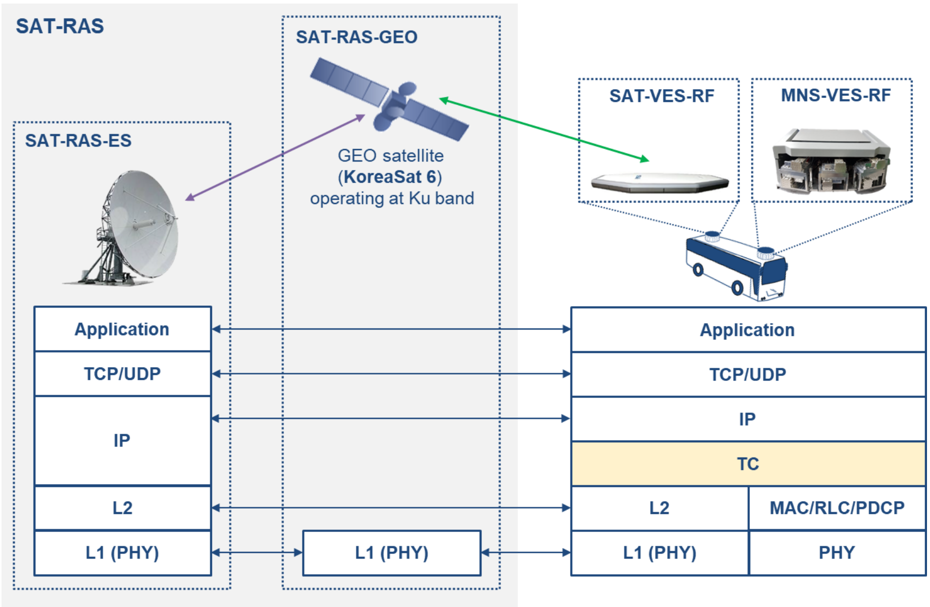


Figure 3-17: Su interface and protocol stack.

3.1.2.7 Wi interface

Wi interface is defined between MNS-VES and Wi-Fi-AP. This Wi-Fi-AP should support function as a router providing the port forwarding. The port forwarding is one of Network Address Translation (NAT) techniques. When a client sends a packet request along with a return address, which is a private IP address such as 192.168.1.22:18442. The router converts this to its own public IP address using NAT and sends it to the server. Then, the router saves this information in the address translation table. When the router receives the packet sent by the server to the public IP address, it sends the packet to the final destination address of 192.168.1.22:18442, which is searched by the address translation table.

3.1.3 Key functionalities

The key technologies supported in KR PoC system (trial platform) are listed in Figure 3-18.

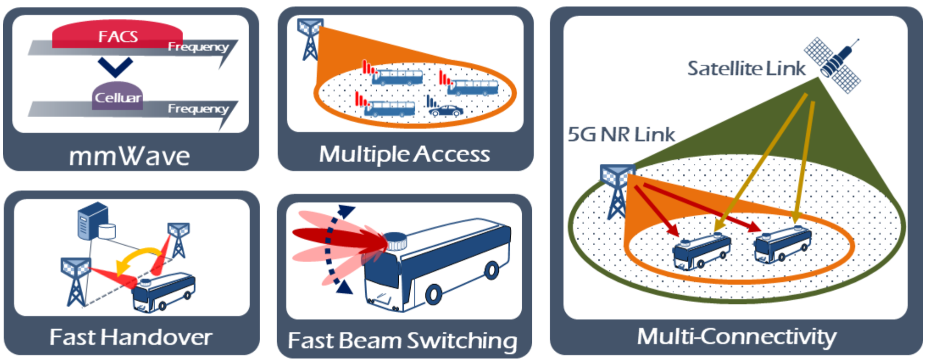


Figure 3-18: Key enabling technologies for vehicular communications.

- MC (traffic switching/selection):
  - ✓ Due to propagation characteristics of mmWave band to be used for cellular/vehicular communications, the performance of the cellular access is

generally vulnerable to not only the misalignment between Tx and Rx beams due to the constant motion of the vehicles, but also to the limited coverage. To increase the throughput and link reliability provided to the V-UE of KR PoC system, link switching will be developed to switch between the cellular access link and the satellite access link based on the measurements reported by MNS-VES and SAT-VES (e.g., channel/link/traffic quality). The link switching will be done by TC, which will be specified in deliverable D4.3 along with the link switching algorithm. The reason for choosing this link switching as the MC technique for KR PoC system is that SAT-RAS and SAT-VES are commercial products and the Su interface between them (§3.1.2.6) is not based on NR.

- mmWave-based vehicular communications:
  - ✓ By taking advantage of a vast amount of spectrum underutilized, mmWave enables high data rate transmission between MNS-RAS and MNS-VES.
  - ✓ MNS of KR PoC system will be designed to support the maximum bandwidth of 600 MHz through Carrier Aggregation (CA) of 6 Component Carriers (CCs), but the specification is designed to support the CA of up to 10 CCs (1 GHz bandwidth).
- PHY design for high-mobility support:
  - ✓ Numerology: KR PoC system will be designed to operate in the FACS that is close to FR2 band in NR. In addition, it is specified in NR specification that in the FR2, μ=2 and μ=3 are supported (an example of the frame structures for μ=2 and μ=3 is shown in Figure 3-19). Therefore, the system also supports both of them that have large enough subcarrier spacings to combat high Doppler frequency spread.
  - ✓ Doppler mitigation by AFC technique: this technique can compensate not only Doppler frequency shift caused by the mobility of vehicle but also frequency offset by local oscillator.
  - ✓ Efficient DMRS patterns for high-mobility scenarios under given numerology: it can be seen from Figure 3-19 that as compared with the case of μ=2, μ=3 can reduce the time interval between adjacent DMRSs with a smaller amount of DMRSs in the time domain.

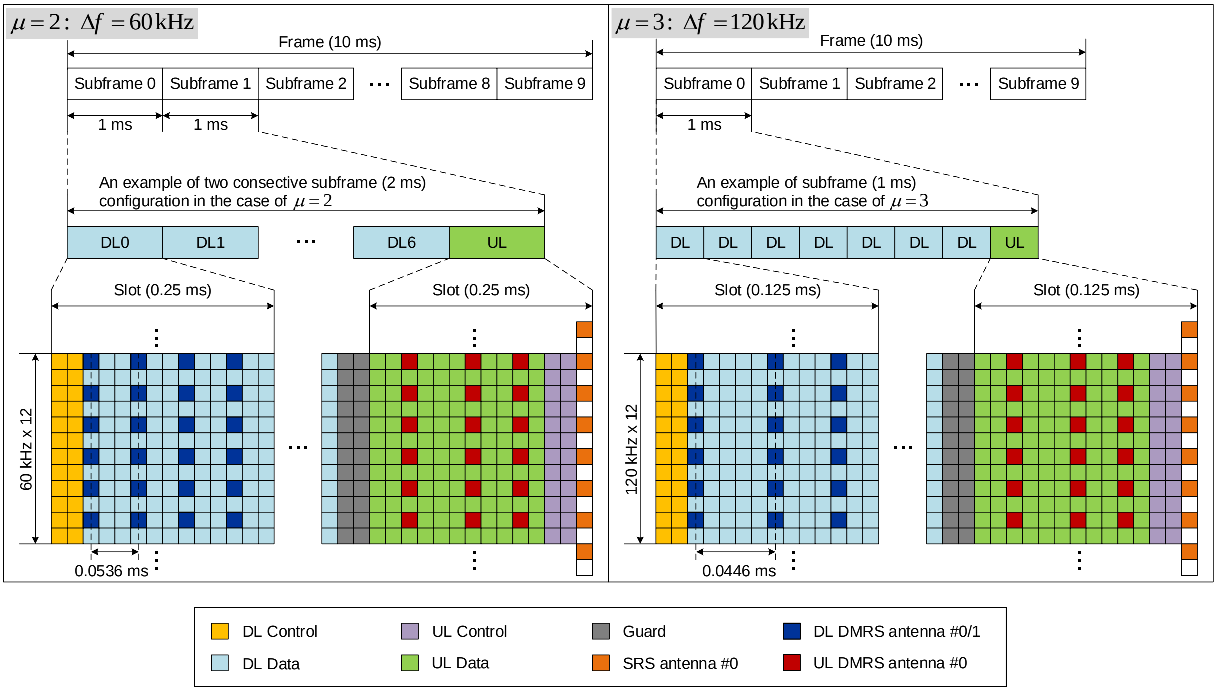


Figure 3-19: Frame structure (numerology and DMRS pattern).

- MIMO transmissions [10]:
  - ✓ Array beamforming is one of the key solutions to deal with serious propagation loss in mmWave-band communications
  - ✓ A polarization-based multi-antenna scheme will be used since it is particularly effective in a Line-of-Sight (LoS) dominant channel environment like in mmWave-band communications. With the polarization antenna, a spatial-multiplexing technique supporting up to 2 spatial layers will be introduced.
- Multiple access: a technology that allows multiple vehicles in a cell covered by an MNS-RAS to simultaneously receive MWB links for broadband Wi-Fi services. In addition, by effectively scheduling radio resources to vehicles in the coverage, multiple access technique is able to offer increased system throughput.
- Fast handover: a key technology to provide seamless handover to minimize the communication interruption time when a vehicle crosses a cell edge.
- Fast beam switching: a technology to align TX/RX beam in the best direction in order to maximize received signal quality and to combat unexpected signal blockage by the motion of the vehicle and/or surrounding:
  - ✓ Beam sweeping is performed at a specific period by measuring the received power of synchronization signal, and measurement mechanisms like measuring the received power of Channel State Information Reference Signal (CSI-RS) or DMRS can be also considered. For beam selection, the best beam is chosen for Tx or Rx at each time instance (e.g. slot).
  - ✓ Figure 3-20 shows an example of beam switching (beam sweeping and beam selection) with three available beams:

$$b^* = \underset{b \in B}{\operatorname{argmax}}(P_{\text{RSRP},b}), \text{ where } B = \{b_1, b_2, b_3\} \quad (3\text{-}1)$$

- $P_{\mathrm{RSRP},b}$ in Eq. (3-1) represents RSRP at b-th beam

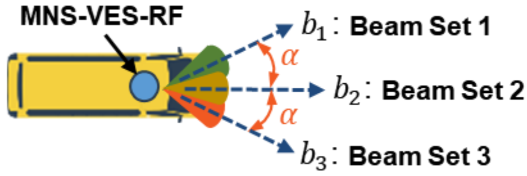


Figure 3-20: An example of beam switching with three available beams.

3.2 EU PoC system

This section provides a description of the interfaces and the key functionalities of the EU testbed and the specification and key functionalities of the EU trial platform.

3.2.1 Testbed system components

The EU testbed components have been described in deliverable D5.1 [14]. The reader is therefore referred to this document for the description of the physical and software components.

3.2.2 Testbed system interfaces

The EU testbed physical interfaces have been described in deliverable D5.1 [14]. The software interfaces dedicated to MC have been described in deliverable D4.1 [15]. In order to complete these descriptions, all the software interfaces of the EU testbed are detailed below. Figure 3-21 lists these interfaces (I-x). The names of the software components are written in the blue rectangles, the equivalence with Figure 2-17 is written in red. In this figure, the channel emulator equipment is split into two for clarity of the drawing.

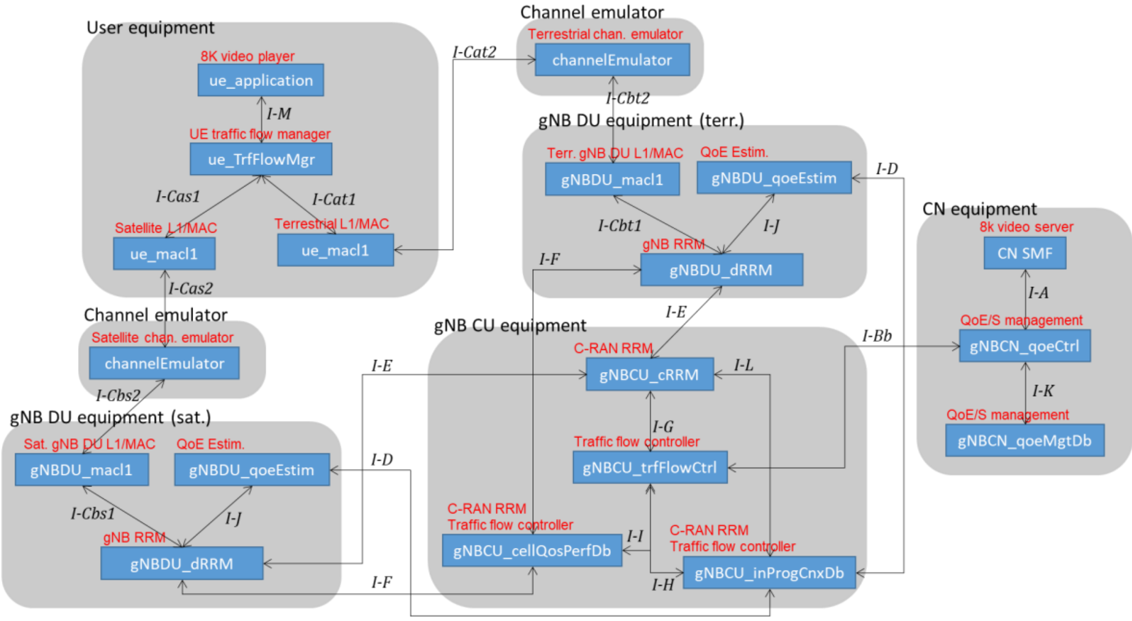


Figure 3-21: EU testbed software interfaces.

Message sequence charts related to the interfaces described below can be found in Annex 1, page 63.

3.2.2.1 Interface between equipment

Interface *I-C*

This is an external interface between gNB DU equipment and UE (thanks to channel emulator equipment in the testbed) equipment. The protocol used on this interface are JavaScript Object Notation (JSON), over TCP, over IP, over MAC/L1.

Note that this interface uses the services of the MAC/L1 level so gNBDU_dRRM also interfaces with MAC/L1 of gNB DU and the UE equipment. Those MAC/L1 use the service of the channel emulator. In Figure 3-21 this interface is explicitly split to depict all the layers involved in the exchange.

The interface between modules gNBDU_dRRM and gNBDU_macl1 modules is internal to the gNB DU equipment and possibly differ between terrestrial and satellite equipments. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-D*

This is an external interface between gNB DU and gNB Central equipment. In the real system, this component will be a Structured Query Language (SQL) database with a dedicated database protocol. In the testbed, it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over Ethernet.

Interface *I-E*

This is an external interface between gNB DU and gNB Central equipment. The protocol used on this interface are JSON, over TCP, over IP, over Ethernet.

Interface *I-F*

This is an external interface between gNB DU and gNB Central equipment. In the real system, this component will be a SQL database with a dedicated database protocol. In the testbed it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over Ethernet.

Interface *I-A*

This is an external interface between gNB Central equipment and CN equipment. The protocol used on this interface are JSON, over TCP, over IP, over Ethernet.

3.2.2.2 Interface within equipment

Interface *I-J*

This is an internal interface of gNB DU. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-B*

This is an internal interface of gNB Central equipment. This interface is explicitly split in Figure 3-21. Even if this component in the real system will be a SQL database with a dedicated database protocol, in the testbed it is assumed to be a table with records or a repertory with files that contains the data. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-G*

This is an internal interface of gNB Central equipment. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-H*

This is an internal interface of gNB Central equipment. Even if this component in the real system will be a SQL database with a dedicated database protocol, in the testbed it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-I*

This is an internal interface of gNB Central equipment. Even if this component in the real system will be a SQL database with a dedicated database protocol, in the testbed it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-K*

This is an internal interface of gNB Central equipment. Even if this component in the real system will be a SQL database with a dedicated database protocol, in the testbed it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-L*

This is an internal interface of gNB Central equipment. Even if this component in the real system will be a SQL database with a dedicated database protocol, in the testbed it is assumed to be a table with records or a repertory with files that contain the data. The protocol used on this interface are JSON, over TCP, over IP, over socket.

Interface *I-M*

This interface is an internal interface of the UE. This interface belongs to the kernel of the UE and the UE application will perform a system call to obtain the data.

3.2.3 Testbed key functionalities

The key technologies supported in the EU testbed are listed in Figure 3-22.

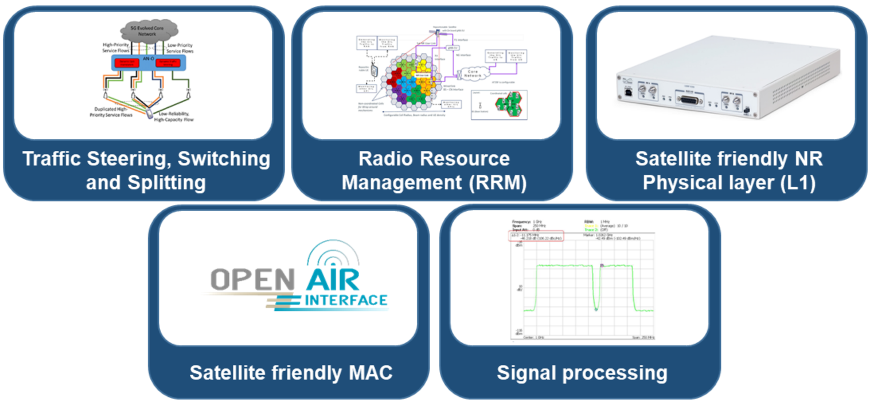


Figure 3-22: Key enabling technologies for EU testbed.

The testbed functionalities resulting from these technologies are described in deliverable D5.1 [14] and summarized below.

- Traffic Steering, Switching, and Splitting:

- ✓ Traffic steering is defined as the function of distributing the traffic load optimally across different network entities and spectrum bands, considering operator and user preferences.
- ✓ Traffic Switching is the function that allows to dynamically redistribute the traffic over the different available APs and radio technologies.
- ✓ Traffic Splitting is the function that enables the duplication of a traffic flow over two (or potentially more) different APs or radio technologies, allowing an increase of connection reliability and stricter QoS requirement satisfaction for certain services.
- ✓ The Traffic Flow Control that will be implemented in the EU testbed will be able to perform traffic steering, switching and splitting according to RRM. Its efficiency in re-scheduling (resp. scheduling) traffic when unpredictable (resp. predictable) events occur will be demonstrated.

- RRM:
  - ✓ Dynamic coupling of both cellular and satellite access at RRM level to ensure the safe coexistence of both systems.
  - ✓ The RRM will be defined taking into account the most relevant interference scenarios associated with typical satellite system deployment scenarios foreseen for 5G system (see 3GPP TR 38.811 [13]).
  - ✓ Comply as much as possible with relevant protocols/interfaces under definition at 3GPP (e.g. F1, X2 interfaces).
  - ✓ Possible extension of enhanced Inter-Cell Interference Coordination (eICIC).
- Satellite-friendly NR PHY (L1):

  The E2E PHY chain implements a subset of the NR 3GPP standard (series 38.xxx) with selected adaptations to support NTNs as specified in TR 38.811 and TR 38.821. Some of the planned features are:
  - ✓ FDD support,
  - ✓ Use of DFT-S OFDM waveform in UL as it has lower PAPR than CP-OFDM,
  - ✓ Open loop instead of close loops procedures such as power control in order to cope with long propagation delays (GEO satellites),
  - ✓ One selected configuration for Phase Tracking Reference Signal (PT-RS) for phase error compensation,
  - ✓ Frequency offset tracking.
- Satellite-friendly MAC:

  MAC layer implementing a subset of the procedures found in the 3GPP TS 38.321 with some adaptations to support NTNs as specified in TR 38.811 and TR 38.821. In order to be functional to the PoC, the focus is set on coping with long propagation delays through:
  - ✓ Adapted Random Access (RA) procedure,
  - ✓ Limitation or disablement of HARQ capabilities,
  - ✓ Extension of the timer of scheduling requests.

- Signal processing:
  - ✓ Terrestrial waveform designed for RRM: high Out-of-Band rejections (reduced interference on adjacent spectrum) and ability to create spectrum holes, with reduced complexity.
  - ✓ NR compatible waveform.
  - ✓ Measurements of the interference level at the PHY provided to the RRM.

3.2.4 Trial platform system components

In this subsection, the trial platform components listed in Table 2-2 and their possible sub-components are further detailed.

3.2.4.1 gNB upconverter

This off-the-shelf component is required for the DL of the terrestrial RAT. It is used to convert the IF signal at the output of the gNB board to the target frequency (18.3 – 21.2 GHz) in the K-band. It is foreseen to use the Analog Devices ADMV1011 upconverter.

3.2.4.2 gNB transmit antenna

This component is required for the DL of the terrestrial RAT. It is used to transmit the RF signal at the output of the gNB upconverter into the channel. An off-the-shelf K-band antenna will be purchased.

3.2.4.3 UE terrestrial receive antenna

This component is required for the DL of the terrestrial RAT. It is used to receive the RF signal from the channel at the input of the UE downconverter. An off-the-shelf K-band antenna will be purchased.

3.2.4.4 UE terrestrial downconverter

This off-the-shelf component is required for the DL of the terrestrial RAT. It is used to convert the RF signal at the output of the UE receive antenna to IF at the input of the UE board. It is foreseen to use the Analog Devices ADMV4420 downconverter.

3.2.4.5 UE terrestrial upconverter

This off-the-shelf component is required for the UL of the terrestrial RAT. It is used to convert the IF signal at the output of the UE board to the target frequency (28,45 – 31 GHz) in the Ka-band. It is foreseen to use the Analog Devices ADMV1013 upconverter.

3.2.4.6 UE terrestrial transmit antenna

This component is required for the UL of the terrestrial RAT. It is used to transmit the RF signal at the output of the UE upconverter into the channel. An off-the-shelf Ka-band antenna will be purchased.

3.2.4.7 gNB receive antenna

This component is required for the UL of the terrestrial RAT. It is used to receive the RF signal from the channel at the input of the gNB downconverter. An off-the-shelf Ka-band antenna will be purchased.

3.2.4.8 gNB downconverter

This off-the-shelf component is required for the UL of the terrestrial RAT. It is used to convert the RF signal at the output of the gNB receive antenna to the IF at the input of the gNB board. It is foreseen to use the Analog Devices ADMV1014 downconverter.

3.2.4.9 Gateway

This component is provided by CNES. The specifications are confidential.

3.2.4.10 Satellite

This component is provided by CNES. The satellite involved will be a standard Ka-band bent-pipe GEO satellite, similar to those already operated by many Satellite Network Operators all over the world. This is to show that the technologies developed in this project can be applied to most existing satellites without the use of a specific satellite and only require a standard bent-pipe (transparent) payload architecture. The service downlink is in the K-band, between 18.3 and 21.2 GHz. The service uplink is in the Ka-band, between 28,45 and 31 GHz. The detailed specifications are confidential.

3.2.4.11 Satellite antenna

This component is provided by CNES. The receive antenna operates in the K-band, between 18.3 and 21.2 GHz. The transmit antenna operates in the Ka-band, between 28,45 and 31 GHz. The detailed specifications are confidential.

3.2.4.12 Satellite RF

This component is provided by CNES. The detailed specifications are confidential.

3.2.5 Trial platform system interfaces

As already stated in §2.3.2, the EU trial platform is very similar to the EU testbed. Interfaces (logical and physical) for the EU testbed have been extensively described in §3.2.1 and deliverable D5.1 [14]. Therefore, only the interfaces not yet described are detailed below. Interface labels refer to Figure 2-19.

Table 3-10: List of physical interfaces of the EU trial platform (interfaces identical to testbed are not listed)

Interface label	From	To	Interface type (Physical/Logical)	Description
E-I2000	Terrestr. gNB DU	Terrestr. gNB RF	Physical	Connection through RF cables
E-I3000	Terrestr. gNB RF	Terrestr. gNB DU	Physical	Connection through RF cables
E-I2001	Satellite-friendly gNB-DU	Gateway	Physical	Connection through RF cables working at an intermediate frequency (IF) and up-converter.
E-I3001	Gateway	Satellite-friendly gNB-DU	Physical	Connection through RF cables working at IF and down-converter.
E-I2002	Satellite	Gateway	Physical	Over-the-air transmission. This is an RF link serving as feeder downlink.
E-I2003	Gateway	Satellite	Physical	Over-the-air transmission. This is an RF link serving as feeder uplink.

E-I2004	Terrestr. UE RF	Terrestr. gNB RF	Physical	Over-the-air transmission
E-I2005	Satellite antenna (e.g. VSAT)	Satellite	Physical	Over-the-air transmission. This is an RF link in Ka band serving as service uplink.
E-I2006	Satellite	Satellite antenna (e.g. VSAT)	Physical	Over-the-air transmission. This is an RF link in Ka band serving as service downlink.
E-I2007	Terrestr. gNB RF	Terrestr. UE RF	Physical	Over the air transmission
E-I2008	UE RF	UE terrestr. modem	Physical	Connection through RF cables
E-I3008	UE terrestr. modem	UE RF	Physical	Connection through RF cables
E-I2009	Satellite antenna (e.g. VSAT)	Satellite-friendly UE modem	Physical	Connection through RF cables working at IF and down-converter. The IF is in the range: 1200 MHz - 6000 MHz with maximum output power: 22 dBm @ (1.2GHz ~ 3GHz) 12 ~ 22 dBm @ (3GHz ~ 6GHz) and maximum input power: -15 dBm Female SMA connectors for both the TX/RX and RX2 connectors are in use
E-I3009	Satellite-friendly UE modem	Satellite antenna (e.g. VSAT)	Physical	Connection through RF cables working at IF and up-converter. The IF is in the range: 1200 MHz - 6000 MHz with maximum output power: 22 dBm @ (1.2GHz ~ 3GHz) 12 ~ 22 dBm @ (3GHz ~ 6GHz) and maximum input power: -15 dBm Female SMA connectors for both the TX/RX and RX2 connectors are in use.

3.2.6 Trial platform key functionalities

The key functionalities of the EU trial platform are the same as the ones of the testbed (§3.2.3). The main difference consists in mmWave over-the-air transmission for the trial platform: contrary to the testbed, the trial platform deploys RF equipment and antennas in the over-the-air satellite segments and the terrestrial links in the Ka and Ku bands.

3.3 Integrated KR-EU PoC system

This section provides the functionalities and interface specification of integrated KR and EU PoC system, particularly focusing on its additional components, API/interfaces, and functionalities required for the final joint PoC demonstration to showcase intercontinental interoperability services at a key event (possibly Roland Garros 2021).

3.3.1 System components

3.3.1.1 Virtual tennis server

As mentioned in §2.3.3, since the VR tennis game is a delay-sensitive application, the VR tennis game server will be physically located somewhere in EU, which can minimize the physical distance between two players to avoid the unnecessary communication delay.

The implementation of the VR tennis game server by Photon Cloud[3] can be also considered as an option. Photon is a network engine that can be used in various game development environments. Photon Cloud has servers in several regions as listed in Table 3-11, distributed across multiple hosting centers over the world. It can build any kind of multiplayer game and create fully authoritative servers for users, and the server can be hosted and run in users' own premises. In addition, it can easily implement network functions such as real-time multiplayer and matchmaking, and it can be used in conjunction with major platforms such as Unity.

Table 3-11: Available regions of Photon Cloud

Region	Hosted in
Asia	Singapore
Australia	Melbourne
Canada, East	Montreal
Chinese Mainland	Shanghai
Europe	***Amsterdam***
India	Chennai
Japan	Tokyo
Russia	Moscow
Russia, East	Khabarovsk
South America	Sao Paulo
South Korea	Seoul
USA, East	Washington D.C.
USA, West	San José

3.3.2 System interfaces

The interfaces specific to the joint PoC are described hereafter. The name of the interface refers to Figure 2-21.

3.3.2.1 KREONET

KREONET is a principal national Research & Education (R&E) network supported by government, managed and operated by KISTI since 1988. It uniquely provides production research network services for around 200 R&E organizations including non-profit research and educational organizations government research institutes, universities,

[3] https://www.photonengine.com/en-US/Photon

public sectors, libraries, and so on, based on hybrid (IP and non-IP) network infrastructure with a total number of 21 network centers distributed among Korea (17), USA (2), China (1), and Netherlands (1). The network centers are divided into:

- 17 domestic regional GigaPoPs:
  - ✓ Based in Korea (Seoul, Daejeon, Gwangju, Busan, Changwon),
- international GigaPoPs:
  - ✓ Based in US (Chicago and Seattle), the Netherlands (Amsterdam) and Hong Kong.

KREONET can provide the following performance:

- KREONET backbone availability: 99.99% in 2017,
- KREONet2/GLORIAD backbone availability: 99.90% in 2017.

As shown in Figure 3-23, KREONET ensures a global connection of up to 10 Gbps between Daejeon PoP and Amsterdam PoP via Chicago PoP, which is sufficient to simultaneously demonstrate multiple broadband intercontinental interoperability services between KR and EU trial sites.

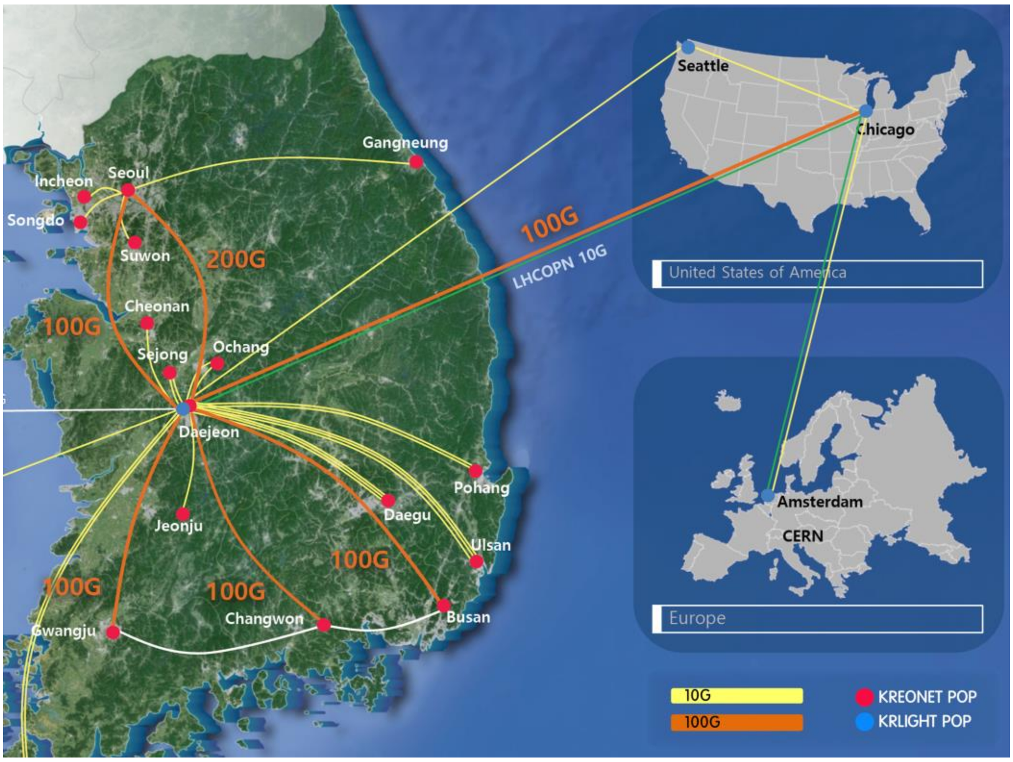


Figure 3-23: Map of KREONET in 2017[17].

3.3.2.2 Last-mile connectivity

This is the interface between the KREONET Amsterdam network center and the EU trial sites (Roland Garros and Toulouse) that must be connected to each other. Two solutions are envisioned:

(i) use of an R&D-dedicated network (e.g. RENATER),

(ii) use of a commercial network.

The former solution may be cheaper than the latter, however, it must be verified what level of reliability (offered data rate) a non-commercial network can guarantee. At the time this document is written, investigation on this topic is ongoing.

3.3.2.3 Virtual tennis server to other components

The virtual tennis server of “Tennis Kings VR” developed by Appnori is located somewhere in EU and interfaces with other system components via the Public Internet network. Besides, a direct connection of the server to the EU CN can be considered as an alternative for the interface with other system components.

3.3.3 Key functionalities

In addition to the key functionalities supported by the KR PoC system (see §3.1.3) and the EU PoC system (see §3.2.3 and §3.2.6), as depicted in Figure 2-21, it is required to support the following functionalities for the integrated KR-EU PoC system:

- data exchange between three different trial sites via KREONET and last-mile connectivity,
- Access to the VR game server located in the EU from each trial site.

4 KPIs for PoC

5G-ALLSTAR aims at displaying the PoC of multiple access systems in a shared spectrum context supporting MC. Table 4-1 inherited from deliverable D2.2 [1] presents the overall KPIs of 5G-ALLSTAR project and the corresponding target performance requirements to be validated through PoC demonstrations. The performance values are basically referred to the ITU-R M2410 "Minimum requirements related to technical performance for IMT-2020 radio interface(s)"

Table 4-1: Overall target KPIs verification during the 5G-ALLSTAR PoC stage

Label	KPI	Target performance	Methodology of KPI evaluation	
			Testbed	Field trial
KPI0	User experienced data rate	Downlink: 50 Mbps Uplink: 10 Mbps	✓	✓
KPI1	UP latency	< 10 ms for delay sensitive traffic	✓	✓
KPI2	CP latency	< 20 ms	✓	
KPI3	Reliability	99.999 % success probability of transmission	✓	
KPI4	Service continuity	No service interruption (verifying null interruption time[4] when one of a link fails abruptly or disappears due to mobility, or during handover)	✓	✓

In Table 4-1, the method of estimating the KPIs is indicated and the detailed KPIs are defined in the following subsections. For the evaluation of the detailed KPIs, several tools listed in Table 4-2 are used. It is highly important to note that the basic goal of verifying these KPIs is to show the accomplishment of the target performance when the MC technologies developed in this project for the integration of cellular and satellite networks are applied. This does not apply to the KPIs (e.g., UP and CP latencies) that are physically impossible to fulfill due to a fundamental limit, which is long distances between satellite and the ground.

Table 4-2: KPI evaluation methodologies

Label	Methodology	Description
KR-Trial0	KR trial platform without MC	See details in §2.3.1 and §3.1
KR-Trial1	KR trial platform with MC	See details in §2.3.1 and §3.1
EU-Testbed	EU testbed	See details in §2.3.2.1, §3.2.1, §3.2.2, §3.2.3
EU-Trial	EU trial platform	See details in §2.3.2.2, §3.2.4, §3.2.5, §3.2.6
Joint-Trial	Joint KR-EU trial platform	See details in §2.3.3, §3.3

4.1 KPIs for KR standalone PoC

The main service scenario of KR testbed/trial platform is broadband and reliable moving hotspot network enabled by mmWave-band vehicular communications and its main applications to be showcased are onboard 8K video streaming and real-time VR/AR game match watching. Table 4-3 and Table 4-4 summarize the detailed target KPIs to be validated through the testbed/trial platform.

[4] Interruption time: the shortest time duration supported by the system during which a user terminal cannot exchange UP packets with any base station during transitions

Table 4-3: Selected target KPIs for KR PoC (without MC support)

KPI label	Target KPI description		Value	Methodology (Table 4-2)	Associated KPI (Table 4-1)
KPI0-KR0	Average PHY data rate of cellular access link to a bus (downlink)		500 Mbps	KR-Trial0	KPI0
KPI0-KR1	Average PHY data rate of satellite access link to a bus (downlink)		2 Mbps[NOTE1]	KR-Trial0	KPI0
KPI0-KR2	Average user-experienced data rate (downlink)		50 Mbps	KR-Trial0	KPI0
KPI1-KR0	Latency (cellular)	UP latency	8 ms	KR-Trial0	KPI1
KPI2-KR0		CP latency	20 ms	KR-Trial0	KPI2
KPI4-KR0	Handover latency		4 ms	KR-Trial0	KPI4

NOTE1: This is the target data rate to be measured under the satellite bandwidth of 2 MHz (1.6 MHz for downlink and 0.4 MHz for uplink).

Table 4-4: Selected target KPIs for KR PoC (with MC support)

KPI label	Target KPI description	Value	Methodology (Table 4-2)	Associated KPI (Table 4-1)
KPI0-KR3	Average PHY data rate of link to a bus (downlink with MC)	500 Mbps	KR-Trial1	KPI0
KPI0-KR4	Average user-experienced data rate (downlink with MC)[NOTE1]	50 Mbps	KR-Trial1	KPI0
KPI3-KR0	Reliability (e.g., packet error rate, BLER)[NOTE1]	99.999 %	KR-Trial1	KPI3
KPI4-KR1	Service continuity[NOTE1]	Interruption time: 2 ms	KR-Trial1	KPI4

NOTE1: These KPIs may be removed or replaced by other types of KPIs after a thorough review on the possibility/feasibility of measuring the KPIs using KR PoC trial platform, and the changes will be described in D2.4.

4.2 KPIs for EU standalone PoC

The definition of the KPIs for the EU standalone PoC has taken into account both the reference requirements for 5G-ALLSTAR (Table 4-1) and the KPIs defined by ITU-R and 3GPP, that have been deemed relevant to the project for eMBB use cases (Table 4-5).

Table 4-5: ITU/3GPP minimum requirements for the IMT-2020 radio interface relevant to 5G-ALLSTAR under the eMBB use case

KPI	Target performance for eMBB
Peak data rate	Minimum requirements: • Downlink peak data rate is 20 Gbit/s. • Uplink peak data rate is 10 Gbit/s.
Peak spectral efficiency	• Downlink peak spectral efficiency is 30 bit/s/Hz (with eight spatial layers). • Uplink peak spectral efficiency is 15 bit/s/Hz (with four spatial layers).
User experienced data rate	• Downlink user experienced data rate is 100 Mbit/s. • Uplink user experienced data rate is 50 Mbit/s.
5th percentile user spectral efficiency	Minimum requirements: • Indoor Hotspot: 0.3 bit/s/Hz (downlink), 0.21 bit/s/Hz (uplink) • Dense Urban: 0.225 bits/s/Hz (downlink), 0.15 bits/s/Hz (uplink) • Rural: 0.12 bits/s/Hz (downlink), 0.045 bits/s/Hz (uplink)
Average spectral efficiency	minimum requirements: • Indoor Hotspot: 9 bit/s/Hz/TRxP (downlink), 6.75 bit/s/Hz/TRxP (uplink) • Dense Urban: 7.8 bits/s/Hz/TRxP (downlink), 5.4 bits/s/Hz/TRxP (uplink)

KPI	Target performance for eMBB
	• Rural: 3.3 bits/s/Hz/TRxP (downlink), 1.6 bits/s/Hz/TRxP (uplink)
Area traffic capacity	The target value for Area traffic capacity in downlink is 10 Mbit/s/m2 in the Indoor Hotspot – eMBB test environment.
Latency	The minimum requirements for UP latency are: • 4 ms for eMBB • 1 ms for URLLC The minimum requirement for CP latency is 20 ms, for both eMBB and URLLC use cases.
Mobility	• Indoor Hotspot: 1.5 bit/s/Hz at 10 km/h • Dense Urban: 1.12 bits/s/Hz at 30 km/h • Rural: 0.8 or 0.45 bits/s/Hz at 120 or 500 km/h
Mobility interruption time	The minimum requirement for mobility interruption time is 0 ms, for both eMBB and URLLC use cases.

Based on the above-mentioned inputs, Table 4-6 provides the KPIs selected for the assessment during the EU testbed/trial stage.

Table 4-6: Selected target KPIs for PoC of EU testbed/trial platform

KPI label	Target KPI description	Value	Methodology (Testbed/Trial)	Associated KPI (Table 4-1)
KPI0-EU0	Average PHY data rate of UE access link (downlink)	Downlink: 100 Mbps	EU-Trial / EU-Testbed	KPI0
KPI0-EU1	Average data rate of UE access link	Uplink: 10 Mbps	EU-Trial / EU-Testbed	KPI0
KPI1-EU0	UP latency (terrestrial)	< 4 ms	EU-Trial / EU-Testbed	KPI1
KPI2-EU0	CP latency (terrestrial)	< 20 ms	EU-Trial / EU-Testbed	KPI2
KPI3-EU0	Reliability	99.999 % success probability of transmission	EU-Trial / EU-Testbed	KPI3
KPI4-EU0	Service continuity (if both satellite and terrestrial links available)	Interruption time: 0 ms	EU-Testbed	KPI4
KPI4-EU1	Service continuity (if link failure)	Interruption time: <4 ms		
KPI4-EU2	Service continuity (if buffering)	Interruption time: 0 ms		

4.3 KPIs for joint KR and EU PoC

This section defines the KPIs to be validated through the joint PoC of KR and EU trial platforms, which will be showcased at Roland Garros 2021.

Table 4-7: Target KPIs for joint PoC of KR and EU trial platforms

KPI label	Target KPI description	Value	Methodology (Table 4-2)	Associated KPI (Table 4-1)
KPI0-JK0	Average PHY data rate of link to a bus (downlink with MC)	500 Mbps	Joint-Trial	KPI0

KPI1-JE0	Latency of VR tennis game	20 ms	Joint-Trial	KPI1
KPI0-JE0	Average PHY data rate of link from Toulouse site to Paris site.	100 Mbps	Joint-Trial	KPI0

5 Conclusion

This deliverable presented the overall high-level system architecture for the 5G-ALLSTAR system and its main interfaces.

The WP specific architectures, which were specialized from the general one, were also reported, summarizing the results coming from WP4 and WP5 and mapping their functionalities into specific modules and interfaces.

The architecture from WP4 reflects the studies related to MC conducted in the project to integrate 5G cellular and satellite access networks.

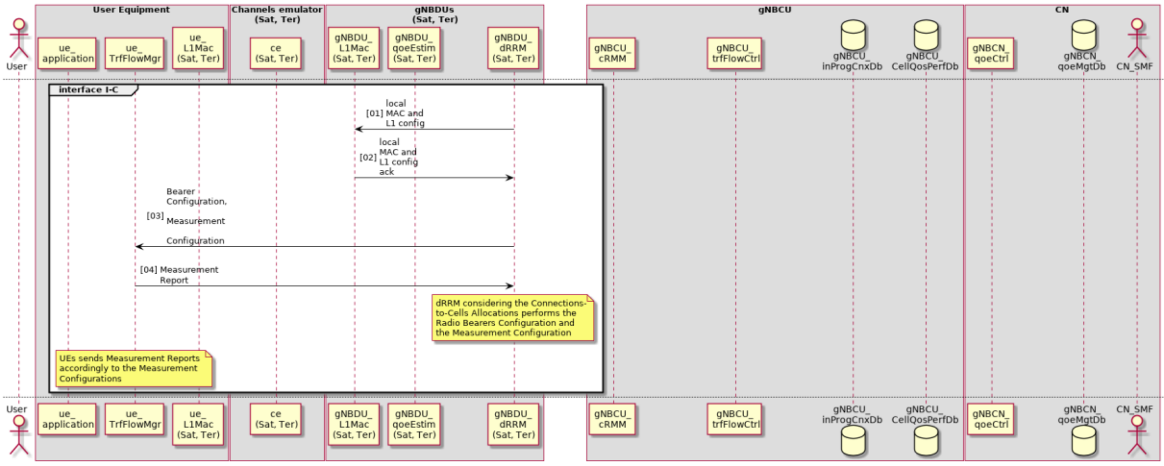
The architectures developed in the scope of WP5 are related to the test and trial platforms that will be used to demonstrate the functionalities and the output of the project. Details on the interfaces and main components were provided for the KR and the EU PoC systems, as well as for the overall integrated KR-EU one.

Finally, a set of relevant KPIs to assess the performance and functionalities of the PoCs were identified and reported.

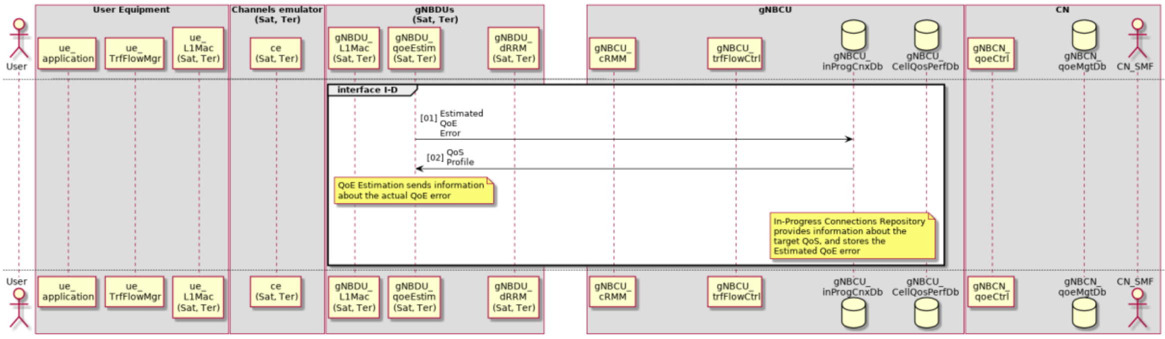
Eventual updates or modifications to the architecture, its modules or interfaces, required due to new developments in the technical WPs will be included in the deliverables of the corresponding WPs and in the annual reports.

6 Annex 1: message sequence charts of EU testbed interfaces

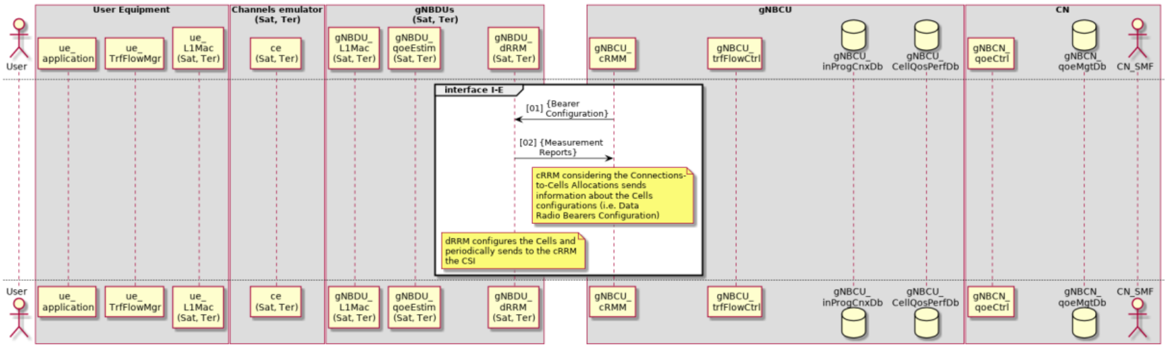
Interface *I-C*



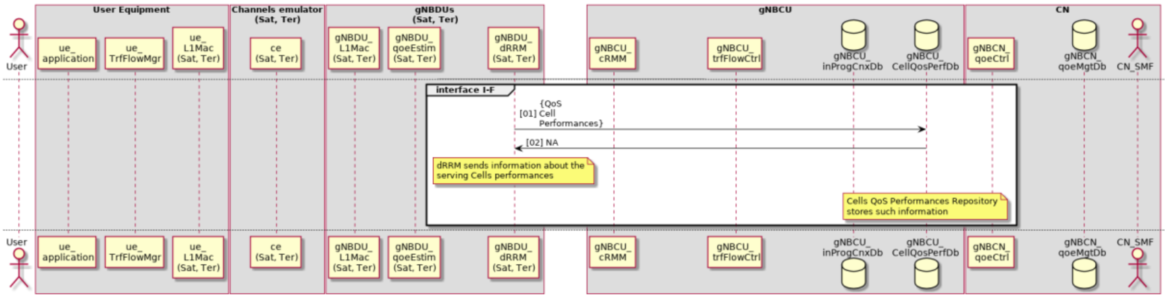
Interface *I-D*



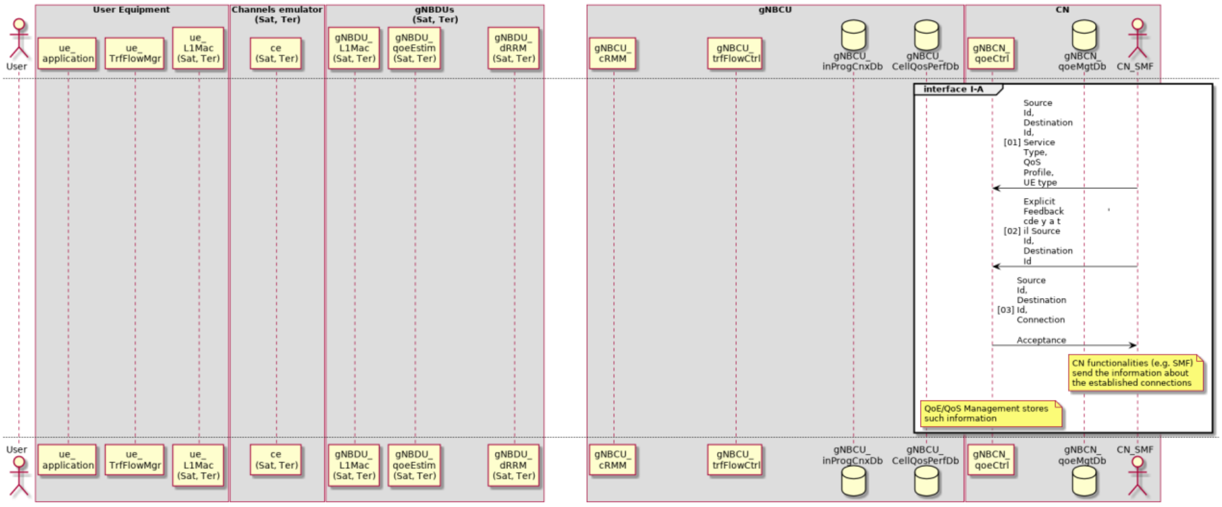
Interface *I-E*



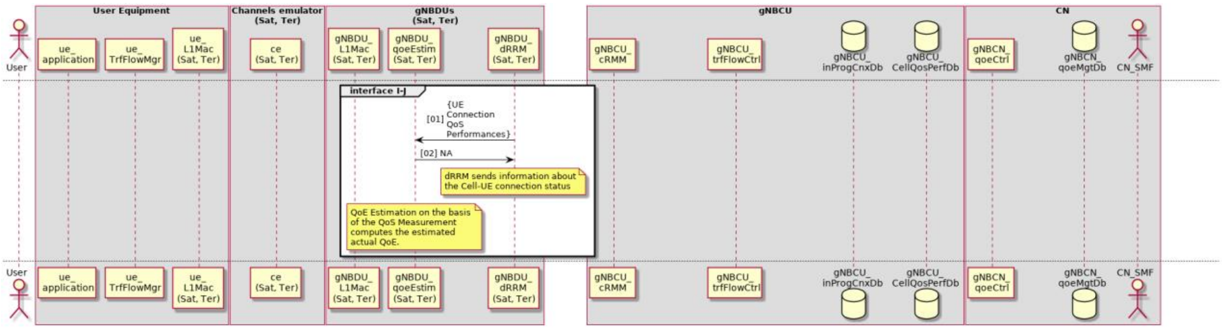
Interface *I-F*



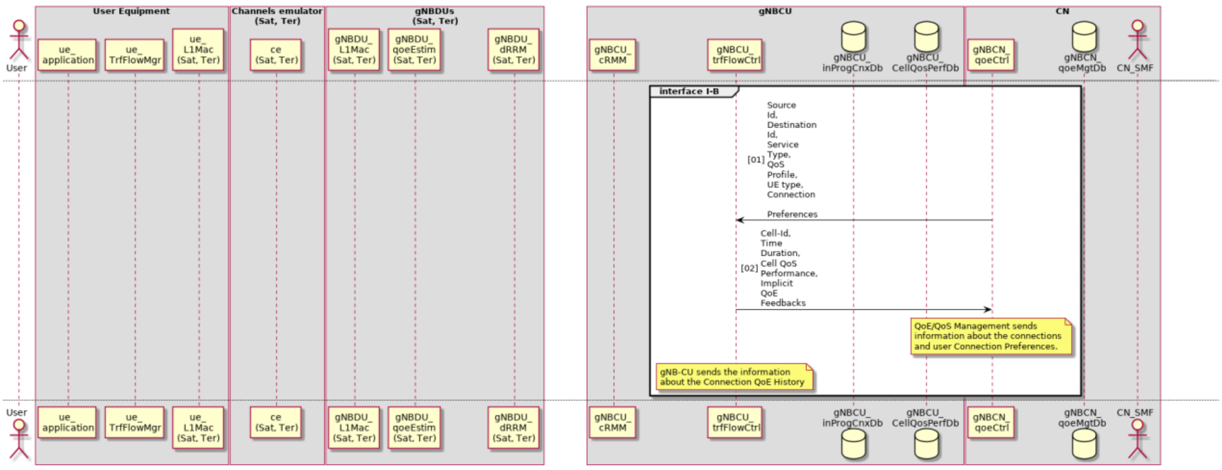
Interface *I-A*



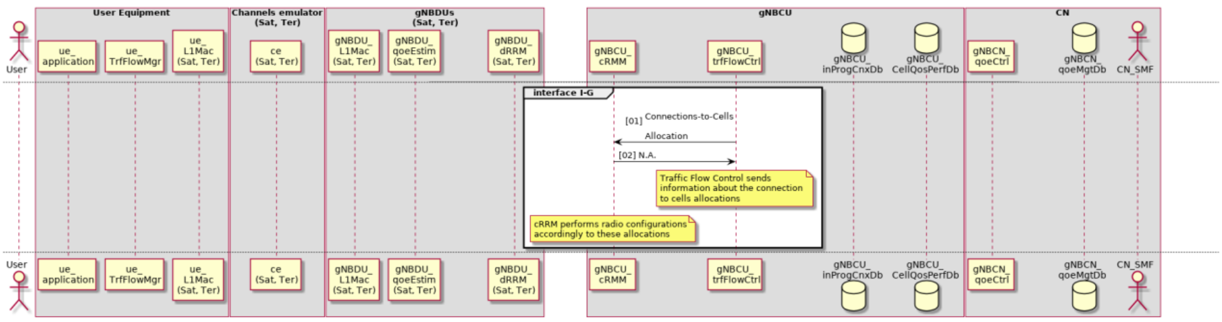
Interface *I-J*



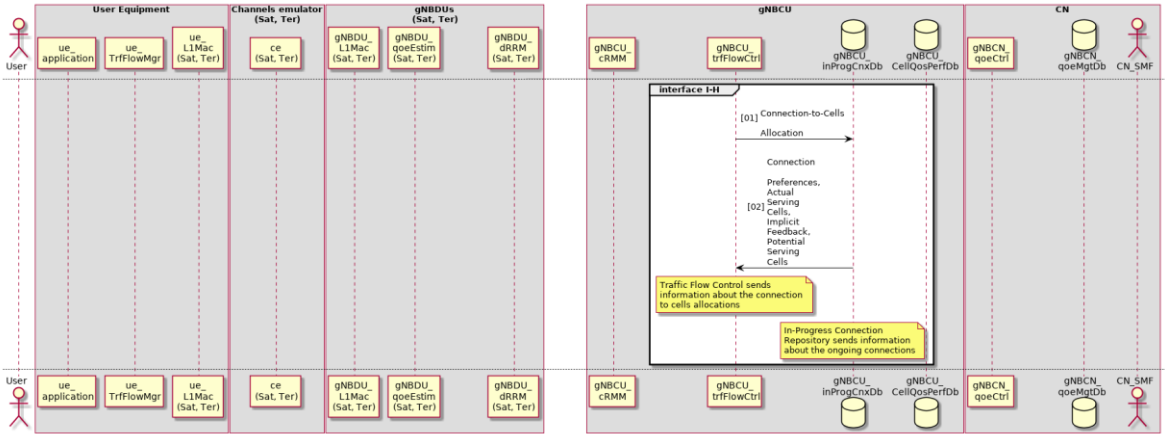
Interface *I-B*



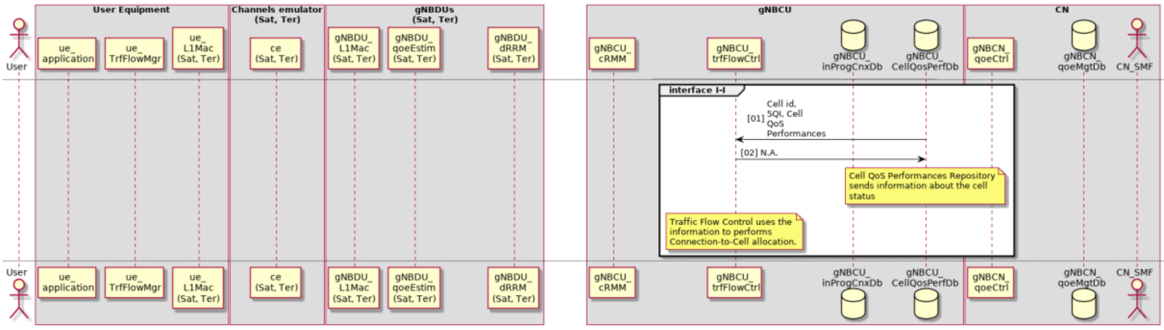
Interface *I-G*



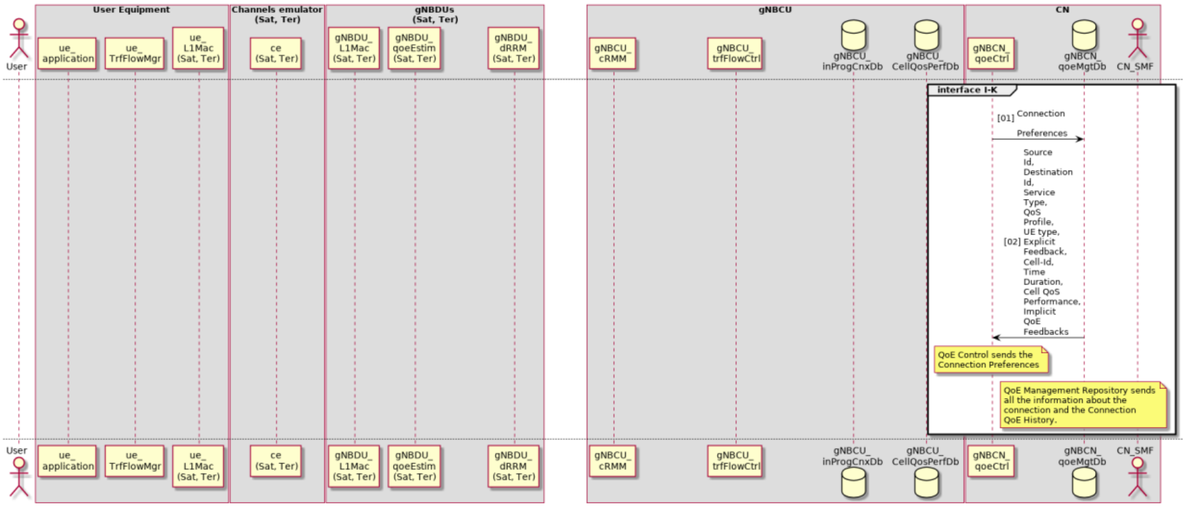
Interface *I-H*



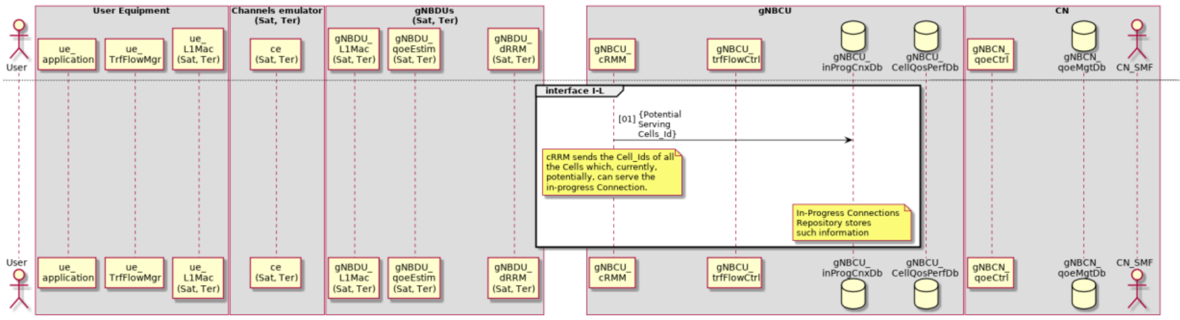
Interface *I-I*



Interface *I-K*



Interface *I-L*



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