Document Number: H2020-EUK-815323/5G-ALLSTAR/D5.1

Project Name:
5G AgiLe and fLexible integration of SaTellite And cellulaR (5G-ALLSTAR)

Deliverable D5.1

Specification of the European Testbed of 5G cellular and satellite access networks

Date of delivery: 30/06/2019
Start date of Project: 01/07/2018

Version: 1.0
Duration: 36 months

Deliverable D5.1

Specification of the European Testbed of 5G cellular and satellite access networks

Project Number:	H2020-EUK-815323
Project Name:	5G AgiLe and fLexible integration of SaTellite And cellu-laR

Document Number:	H2020-EUK-815323/5G-ALLSTAR/D5.1
Document Title:	Specification of the European Testbed of 5G cellular and satellite access networks
Editor(s):	Marjorie Thary (TAS)
Authors:	Guido Casati (FhG IIS), Federico Lisi (CRAT), Nicolas Cassiau (CEA Leti), Thomas Heyn (FhG IIS), Marjorie Thary (TAS)
Dissemination Level:	PU
Contractual Date of Delivery:	30/06/2019
Security:	Public
Status:	Reviewed
Version:	1
File Name:	5G-ALLSTAR_D5.1.docx

Abstract

This deliverable was created as part of the project Work Package 5 “Prototyping, Validation and Demonstration” activities, and details implementation, integration and testing of the European Testbed.

Keywords

5G ; Testbed ; Multi-Access ; specification

Acknowledgements

We would like to acknowledge the following people for the valuable reviews to the deliverable:
Heesang Chung (ETRI), Christian Debroas (TAS), Junhyeong Kim (ETRI)

Executive Summary

This document is the Specification of the European Testbed. It provides a description of how to implement, on this System “lab” demonstrator, multiple access (cellular and satellite) sharing the same spectrum.

Its integration steps will be described in D5.2[i] “Integration and system level testing for European Testbed of 5G cellular and satellite access networks”, as well as the tests to be supported.

This document is organized as follows:

- Chapter 1 introduces the deliverable into its related Work Package and Tasks,
- Chapter 2 details the 5G-ALLSTAR concepts, at system level as well as at key technology level, to be demonstrated on the testbed and their impacts on its architecture and components,
- Chapter 3 presents the testbed architecture, starting from the reference system architecture to be emulated and showing how it will be functionally implemented in terms of hardware and software components,
- Chapter 4 details and specifies the different hardware and software components that will be needed to build the testbed up and demonstrate the targeted concepts,
- Chapter 5 lists the testbed interfaces and shows how the standard 5G protocol stacks shall be implemented.

Contents

List of Figures

List of Tables

List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation
5GC	5G Core
5GPPP	5G Public-Private Partnership
5QI	5G QoS Identifier
ACM	Adaptive Coding and Modulation
ADC	Analogue to Digital Converter
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
ARM	Advanced Risc Machine
AWGN	Additive White Gaussian Noise
BS	Base Station
C&M	Command & Monitoring
CEA	Commissariat à l'Energie Atomique et aux energies alternatives
COTS	Component On The Shelf
CN	Core Network
CNES	Centre National d'Etudes Spatiales
CP	Control Plane
CP-OFDM	Cyclic Prefix OFDM
CPU	Core Processing Unit
C-RAN	Central Radio Access Network
CRAT	Consorzio per la Ricerca nell'Automatica e nelle Telecomunicazioni
cRRM	Central Radio Resource Management
CSI	Channel State Information
CSI-RSRP	CSI Reference Signal Received Power
CSI-RSRQ	CSI Reference Signal Received Quality
CSI-SINR	CSI Signal-to-Noise and Interference Ratio
CU	Centralized Unit

CW	Continuous Wave
Dx.y	Deliverable x.y
DAC	Digital to Analog Converter
DASH	Dynamic Adaptive Streaming over HTTP
DBB	Digital Base Band
DUC	Digital Up-Converter
DFT-OFDM	Discrete Fourier Transform OFDM
DL	Downlink
D-RAN	Distributed Radio Access Network
DRB	Data Radio Bearer
DSP	Digital Signal Processor
dRRM	Distributed Radio Resource Management
DVI	Digital Video Interface
DU	Distributed Unit
eICIC	enhanced Inter-Cell Interference Coordination
eMBB	Enhanced Mobile Broadband
ETRI	Electronics and Telecommunications Research Institute
EU	Europe
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FhG	Fraunhofer-Gesellschaft
FhG-HHI	FhG Heinrich Hertz Institut
FhG-IIS	FhG Institut für Integriete Schaltungen
FLC	Fuzzy Logic Controller
FPGA	Field Programmable Gate Array
FS	Fast Switch
GCM	Geometric Channel Modelling
GEO	Geostationary Earth Orbit
gNB-CU	next Generation Node B Central Unit

gNB-DU	next Generation Node B Distributed Unit
GPP	General Purpose Processor
GRA	Grey Relational Analysis
GUI	Graphical User Interface
HAPS	High Altitude Platform Station
HARQ	Hybrid Automatic Repeat Request
HDMI	High Definition Multimedia Interface
HetNets	Heterogeneous Networks
HH	Hard Handover
HMI	Human to Machine Interface
HTTP	Hypertext Transfer Protocol
HW	Hardware
IAB	Integrated Access Backhaul
ICD	Interface Control Document
Id	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
I/O	Input/Output
IoT	Internet of Things
IP	Internet Protocol
I/Q	In-phase and Quadrature (components)
IV&T	Integration, Validation & Test
KPI	Key Performance Indicator
KR	(South) Korea
KTSat	Korea Telecom Satellites
L1	Layer 1 (OSI model)
L2	Layer 2 (OSI model)
LAN	Local Area Network
LDPC	Low Density Parity Check Code
LEO	Low Earth Orbit
LETI	Laboratoire d'Electronique et de Technologie de l'Information
LLR	Low Latency Resilient

LOS	Line Of Sight
LTE	Long Term Evolution
Mx	Month x
MAC	Medium Access Control
MADM	Multiple attribute decision making
MC	Multi-Connectivity
MCG	Master Cell Group
MDP	Markov Decision Process
MIMO	Multiple Inputs Multiple Outputs
mMTC	Massive Machine Type Communications
mmWave	Millimetre Wave
MN	Master Node
NE	Nash Equilibrium
NGAP	NG Application Protocol
NG-RAN	New Generation Radio Access Network
NR	New Radio
NTN	Non-Terrestrial Network
OAI	Open Air Interface
OFDM	Orthogonal Frequency Division Multiplexing
OoB	Out of Band
OS	Operating System
OSA	OAI Software Alliance
PAPR	Peak to Average Power Ratio
PC	Personal Computer
PCIe	Peripheral Component Interconnect express
PDCP	Packet Data Convergence Protocol
PDR	Packet Detection Rule
PDU	Protocol Data Unit
PHY	Physical (layer)
PLL	Phase-Lock Loop
PoC	Proof-of-Concept
PT-RS	Phase Tracking Reference Signal
QAM	Quadrature Amplitude Modulation

QFI	QoS Flow Identifier
QoE	Quality of Experience
QoS	Quality of Service
QSPI	Queued Serial Peripheral Inter-face
RACH	Random Access Channel
RAM	Random Access Memory
RAN (C or D)	Radio Access Network (Central-ized or Distributed)
RAR	Random Access Request
RAT	Radio Access Technology
RF	Radio Frequency
RF-SoC	Radio Frequency System on Chip
RLC	Radio Link Control
RR	Radio Resource
RRC	Radio Resource Control
RRM	Radio Resource Management
RTT	Round Trip Time
Rx	Receive
SaaS	Software as a Service
Sce	Scenario
SCG	Secondary Cell Group
SCS	Sample Conditionning System
SCTP	Stream Control Transmission Protocol
SD-FEC	Soft Decision FEC
SDR	Software Defined Radio
SDAP	Service Data Adaptation Protocol
SISO	Simple Input Simple Output
SMF	Session Management Function
SN	Secondary Node
SNO	Satellite Network Operator

SNR	Signal to Noise Ratio
SoC	System on Chip
SO-DIMM	Small Outline Dual In-Line Memory Module
SPS	Samples Per Second
SW	Software
Tx.y	Task x.y
TAS	Thales Alenia Space
TBC	To Be Confirmed
TBD	To Be Defined
TBP	To Be Provided
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TN	Terrestrial Network
TR	Technical Release
Tx	Transmit
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra High Definition
UL	Uplink
UP	User Plane
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Com-munications
USB	Universal Serial Bus
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WP	Work Package

1 Introduction

1.1 Background and project context

The advent of 5th generation (5G) mobile communications will bring a wide range of potential opportunities and challenges.

5G will enable the introduction of new services and markets whereas imposing several unprecedented technical requirements. More specifically, support for the new services involves seamless connectivity across various vertical industries including multimedia, healthcare, internet-of-things (IoT), automotive, and manufacturing. Such verticals are into three main use cases, as follows:

- **Enhanced Mobile Broadband (eMBB)** originates from human-centric services requiring large amount of data rate such as internet browsing and multimedia streaming through smartphones, tablets, and so on. In addition to the high data rate, low latency and large coverage area are also considered.
- **Massive Machine Type Communications (mMTC)** targets to support communications between machines such as sensor monitoring and asset tracking, which are typically low-cost and battery-operated devices. It also requires wireless connectivity among the massive number of deployed devices.
- **Ultra-Reliable Low-Latency Communications (URLLC)** refers to application scenarios with very tight requirements for the reliability and latency. Examples of this use case include industrial manufacturing control, remote surgery, and self-driving cars.

These use cases can be supported in various 5G deployment scenarios such as indoor, urban, rural, high-speed trains, highways, etc. From scenario to scenario, deployment specific requirements are quite different.

Providing tight interworking and integration between 5G cellular and non-terrestrial (e.g., satellite) networks will be beneficial in terms of providing improved coverage and service continuity in a cost effective manner.

Therefore, the 5G-ALLSTAR project aims at developing a set of technologies enabling this tight interworking and integration between cellular and satellite links supporting a heterogeneous environment with multi-access technology.

1.2 Work Package objectives

WP5 is responsible for prototyping, validation, integration of the laboratory testbeds and trial platforms in Europe and Korea.

The trial platforms, each featuring multiple access, will be interconnected once validated separately and showcased at the end of the project.

This last phase will demonstrate the service scenarios defined in WP2 during the project, in conjunction with a relevant key event still to be defined.

During the project, WP5 pursues the following objectives:

- O5.1: Provide laboratory technology demonstration showing capability of mmWave-based multiple access network capable of providing reliable broadband 5G services with a perceived low latency for ubiquitous and zero-interruption connection.
- O5.2: Demonstrate that the proposed global interoperable architecture implemented through 5G core network can efficiently provide a variety of intercontinental 5G services.

- O5.3: Provide a Proof-of-Concept (PoC) based on regional trial platforms interconnected for demonstration at a key event.

1.3 Links with the other Work Packages

WP5 is depending on the other 5G-ALLSTAR Work Packages (WP) that will provide the necessary inputs to fulfil its objectives:

- WP2 delivers the definition of the PoCs, including key modules/solutions and target service scenarios and KPIs to be demonstrated.
- WP3 provides technical solutions for multiple access in spectrum sharing context, satellite friendly NR access and interference management schemes.
- WP4 provides the technical solutions to 5G cellular and satellite networks, and key functionalities for multi-connectivity and intercontinental connectivity.

Conversely, WP5 testing phases will provide some feedback to the three WPs, which may lead to potential technology improvements and alignments.

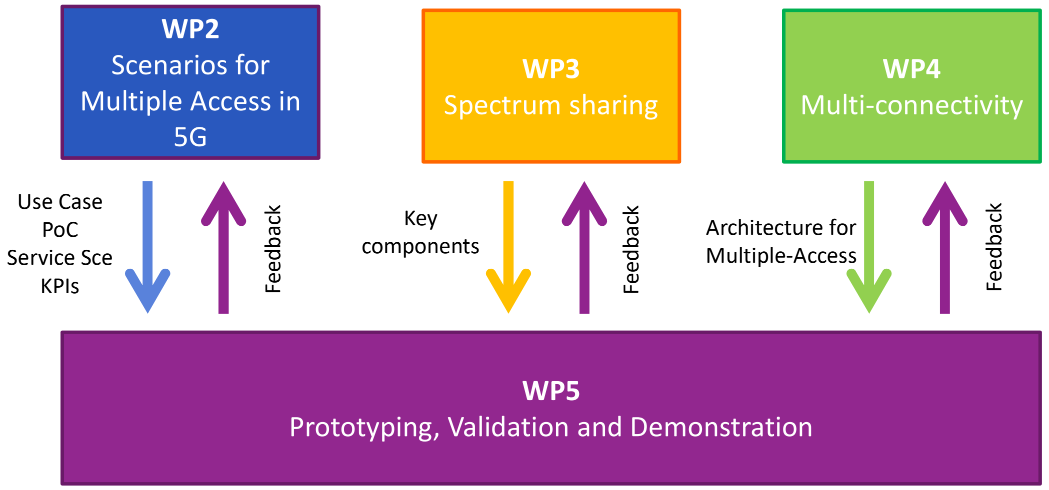

Figure 1: WP5 Tasks logic and associated Testbeds

1.4 Work Package Tasks

In order to demonstrate the 5G-ALLSTAR PoC of an integrated system architecture capable of multiple connectivity to provide consistent 5G QoS class with multiple access technology for critical applications, WP5 is made up of the following tasks:

- Task 5.1 aims at delivering an integrated European Testbed capable of supporting multiple access with NR and satellite access technologies operating in the same spectrum.
- Task 5.2 aims at delivering all the components for Korean 5G testbeds (terrestrial cellular and satellite).
- Task 5.3 aims at implementing an interface module for multi-connectivity support on the Korean trial platform.
- Task 5.4 aims at delivering, testing and calibrating the 5G-ALLSTAR PoC, first in the lab testbed, and in a second turn with a real GEO satellite link on the European trial platform.

This latter will then be interconnected with the Korean trial platform for the project's final demonstration at a key event.

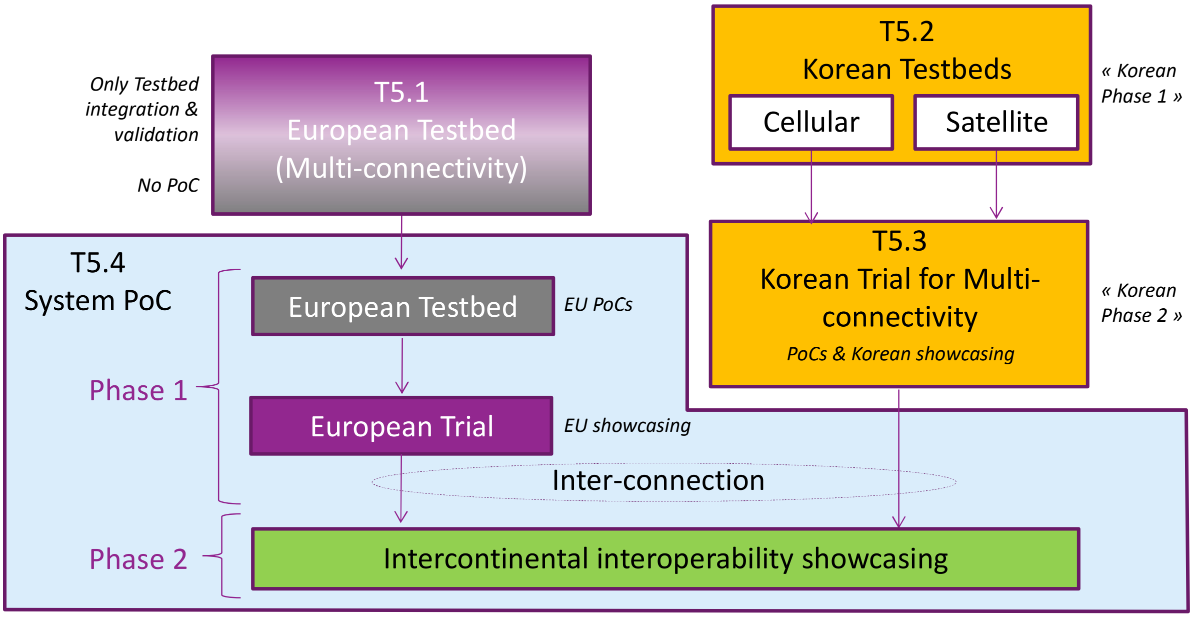

Figure 2: WP5 Tasks logic and associated Testbeds

The European Testbed will be mainly used to validate the developed spectrum sharing functionalities by testing suitably selected Key Performance Indicators (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 European Trial platform will reuse the European Testbed key components and combine them with real satellite and cellular terrestrial accesses.

The following figure shows how these different WP5 tasks are scheduled over the project duration.

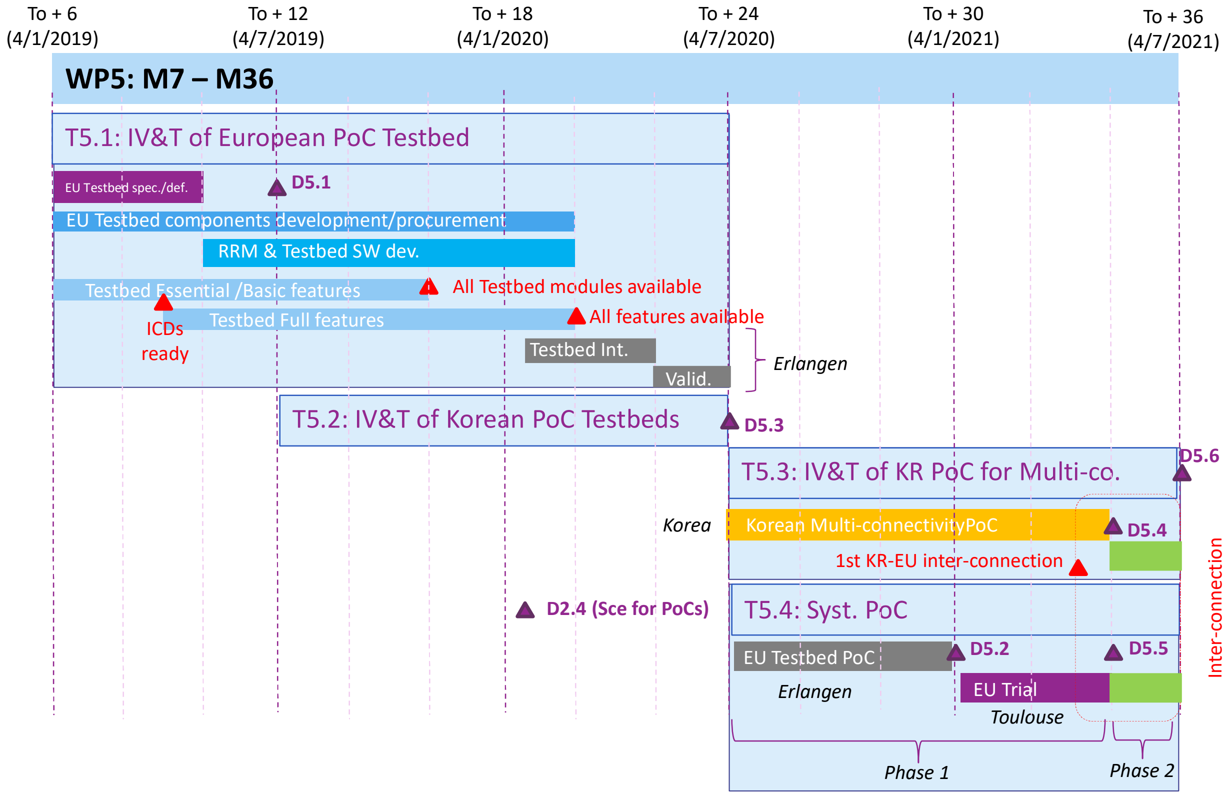

Figure 3: WP5 schedule

Table 1: WP5 deliverables

#	Deliverable name	Editor	Delivery date	Reviewers
D5.1 (D16)	Specification of the European testbed of 5G cellular and satellite access networks	TAS	M12 (30/6/19)	CEA/ETRI
D5.2 (D17)	Integration and system level testing for European testbed of 5G cellular and satellite access networks	FhG	M30 (31/12/20)	TAS/ SnetICT
D5.3 (D18)	Integration and system level testing for Korean testbeds of 5G cellular and satellite access networks	ETRI	M24 (31/6/20)	FhG/SnetICT
D5.4 (D19)	Integration and system level testing for Korean multi-connectivity	KATECH	M34 (30/4/21)	CRAT/ETRI
D5.5 (D20)	Integration and system level testing of proof of- concept phase 1	TAS	M34 (30/4/21)	FhG/ETRI
D5.6 (D21)	Integration and system level testing of proof of- concept phase 2	ETRI	M36 (30/6/21)	TAS/KTsat

2 Concepts to be demonstrated and impacts on the Testbed

2.1 Project objectives and associated Testbed requirements

Considering the H2020 EUK-02-2018 call targets and the technical challenges of 5GPPP phase 3, the PoC of the 5G-ALLSTAR project has the following objectives.

Table 2: Project objectives and impacts on the Testbed

Project objectives	Impacts on the Testbed
Implement a 5G cellular mmWave radio access for providing broadband (50 Mbit/s user experience) and low-latency (10 ms) 5G services. 5G-ALLSTAR will deliver implementation, integration, interoperability and testing of 5G mmWave cellular access components in the joint PoC system across Europe and Korea.	Even if Testbed RF interfaces and emulated channels are not directly operating in mmWave, NR waveform parameters shall be fully compatible with mmWave operation standard and transmission channels impairments (i.e. Doppler shift) shall be representative of those that would occur for mmWave actual transmissions.
Demonstrate feasibility of New Radio (NR) based mmWave satellite access for providing broadband and reliable 5G services. 5G-ALLSTAR PoC will verify that the defined 5G satellite access architecture as currently initially developed in the standardization organization 3GPP is working and that the various challenges coming from the mobility of satellite and propagation delay can be properly resolved.	1) Broadband: a service requiring a high data rate (large bandwidth) shall be demonstrated. 8K video streaming is chosen. 2) Reliable: it shall be possible to control (and play with) each channel (satellite and terrestrial) quality in order to show that when one is lost, the service continuity is maintained through the order channel. 3) 3GPP: the emulated system architecture, propagation channel features and RF components (gateway, satellite, terminals) performances shall be consistent with 3GPP assumptions detailed in TR 38.811ii and TR 38.821iii documents.
Implement multi-connectivity support and integrate 5G cellular access and satellite access systems along with its function testing. 5G-ALLSTAR will conduct field trials to validate the hybrid PoC system operated through the interface for aggregation.	The Testbed shall emulate at least one UE connected to its network operator through simultaneously one 5G terrestrial link and one 5G satellite link.

Project objectives	Impacts on the Testbed
Demonstrate the PoC of multiple access systems in shared spectrum context supporting multi-connectivity at a key event. It will be verified that all specified service scenarios run free of errors. KPIs like user-experience data rate and latency will be evaluated.	1) Shared spectrum context: both satellite and terrestrial emulated links shall use the same frequency band. 2) The Testbed shall allow to measure aggregated data rate at UE level. 3) The Testbed shall allow to measure the End-to-End latency. 4) The Testbed shall allow to measure the Packet Error Rate (PER) over the End-to-End links.
Enable cellular and satellite access to share the same spectrum. 5G-ALLSTAR will provide the design and implementation of spectrum harmonization among the different access technologies. 5G-ALLSTAR will also partake the interference between access technologies, e.g., between cellular and satellite links, between cellular links, and so on.	The interference environment shall be manageable at both system ends to demonstrate the system ability to harmonize spectrum use by heterogeneous technologies (terrestrial and satellite)

2.2 Project targeted Use Cases and impacts on Test Scenarios

The use cases for 5G-ALLSTAR are identified in the document D2.1[iv] of WP2. These use cases are framing the test scenarios to be run on the EU testbed. Their impact are identified in the table below.

Table 3: Project use cases impacts on the test scenarios

Project use cases for EU testbed	Impact on the test scenarios
Multi-connectivity (MC): MC between heterogeneous access links (e.g., between cellular and satellite links) enables a UE to simultaneously connect to the multiple base stations (BSs) built on different access technologies. MC is expected to provide improved data rate, latency, reliability, and service continuity. Hence, in the 5G-ALLSTAR project the following performance requirements need to be satisfied in the MC use case: - User experienced data rate: 50 Mbps for downlink and 10 Mbps for uplink - User plane latency: Less than 10 ms - Control plane latency: Less than 20 ms - Reliability: 99.999% success probability - Service continuity: No service interruption	1) Data rates achieved thanks to the aggregation of the different data rates available on the different links established by the User. 2) The latency requirements exclude GEO satellites. Only LEO satellites will be emulated. 3) Fixed UE, or at least moving sufficiently slowly to assume them as fixed with respect to the satellite motion. 4) Possibly very low gain terminals (handsets). An objective will be to demonstrate whether this kind of direct access link to the end user smart phone is really achievable, pending some constraints on satellite orbit and performance.
Broadband moving hotspot network: Large throughput in-vehicle Internet connectivity can be provided with the 5G-ALLSTAR technology for transportation applications. Main target requirements are user experienced data rate, latency, and service continuity: - Average data rate per vehicle: 500 Mbps (downlink) - User experienced data rate per vehicle: 50 Mbps (downlink) - User plane latency: Less than 4 ms - Control plane latency: Less than 10 ms - Service continuity: No service interruption	1) Data rate achieved thanks to the aggregation of the different data rates available on the different links established by the user. 2) The latency requirements exclude GEO satellites. Only LEO satellites will be emulated. 3) Vehicular mobile UE, with relatively high gain antenna, providing 5G services access to a group of 10 passengers. The UE is an Integrated Access Backhaul (IAB) node, as defined by 3GPP. The end users are connected to the Network through it, seamlessly, i.e. as if they were just connected to a terrestrial gNB. 4) The aggregated data rate per vehicle could only be demonstrated through analysis based on the actual demonstration of the 50 Mbps achievement for just one user. 5) UE mobility will be emulated by: - application of the proper Doppler effect - modification of the emulated channels characteristics (i.e. signal attenuation) reproducing terrestrial white spots crossing and/or satellite LOS screening.

Project use cases for EU testbed	Impact on the test scenarios
Ultra High Definition (UHD) video streaming through interoperable networks: This use case is for the global interoperability demonstration between European and Korean PoCs. Since the video streaming within transportation vehicles is the main application, eMBB-type service requirements are assumed: - User experienced data rate: 50 Mbps for downlink and 10 Mbps for uplink - User plane latency: Less than 10 ms (terrestrial), Less than 600 ms (satellite) - Service continuity: No service interruption	1) As this use case is for global interoperability demonstration with real satellite, the associated scenario(s) will mainly aim at preparing this trial phase, using real GEO satellites. The emulated case will thus be a GEO satellite using the same frequency bands (mmWave = Ka-band) as satellite used by the trial platform. 2) An UHD video streaming service shall be demonstrated on the Testbed.

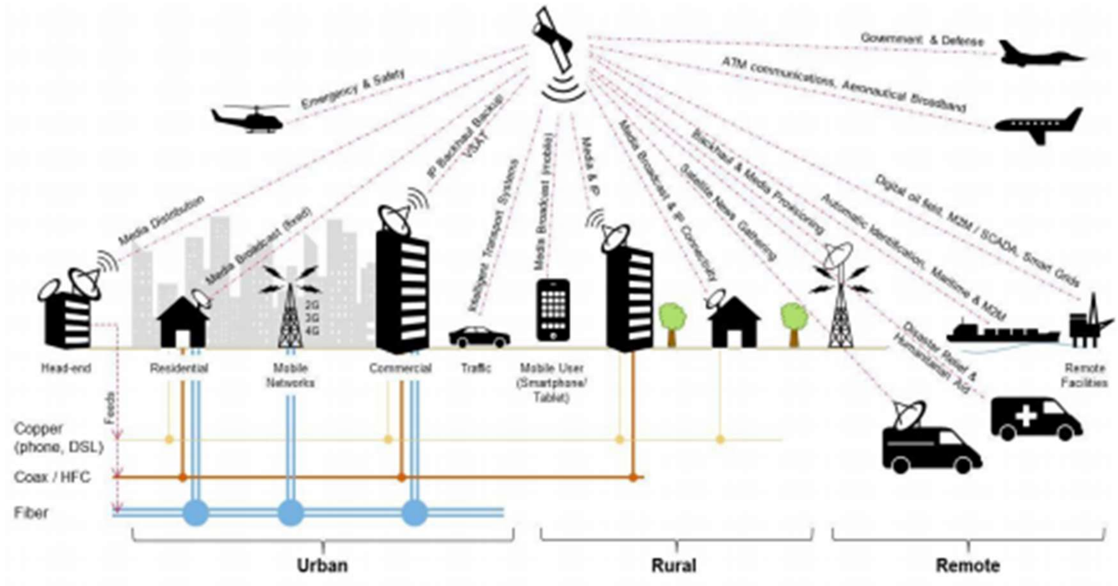

Figure 4: Satellite role integrated in 5G cellular system[v]

2.3 Key technologies in support to System PoC

5G-ALLSTAR, as an R&D project, also aims at allowing partners to investigate new techniques and technologies. The Testbed is then a tool to demonstrate their effectiveness and efficiency, so its test scenarios shall be defined accordingly.

The following table identifies the impacts on the test scenarios that the key technologies to be demonstrated on the Testbed shall have.

Table 4: Project objectives and impacts on the Testbed

Project objectives	Impacts on the Testbed
Traffic Steering, Switching and Splitting The Traffic Flow Control that will be implemented in European Testbed will be able to perform traffic steering switching and splitting according to measures from the RRM. Its efficiency in re-scheduling traffic when unpredictable events occur will be demonstrated.	Scenarios shall emulate cases where Adaptive Traffic Steering, Switching and Splitting is required. This implies some variations either in terms of user service demand or propagation channels characteristics over time (test running time frame).
Radio Resource Management (RRM) As part of the 5G ALL-STAR, a new concept will be researched based on a dynamic coupling of both cellular and satellite access at radio resource management to ensure safe coexistence of both systems. This will require to investigate the parameters (e.g. spectrum partitioning, flux density, transmission power, antenna characteristics) to be exchanged between the RRM scheme of both access technologies concurrently accessing the same spectrum. The RRM will be defined taking into account most relevant interference scenarios associated to typical satellite system deployment scenarios foreseen for 5G system (see 3GPP TR 38.811[ii]). Great care will be taken to integrate joint RRM scheme in the 5G system/radio access network architecture and 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), an interference control technology, to Hetnets that include satellite component into account will be considered to mitigate inter access technologies (cellular/satellite) interferences and the need to modify the relevant protocols will be assessed.	The testbed shall allow variations over time of the interference environments at UE and gNB levels, in order to allow RRM functions to reallocate time and frequency resource.

Project objectives	Impacts on the Testbed
Satellite friendly NR Physical layer (L1) The end-to-end physical layer chain will be adapted to the NR standard (3GPP series 38.xxx) the following way: - To maximise the throughput / power ratio, the operation points of the satellite or UE power amplifiers shall be set as close as possible to the saturation point. To support this, the following techniques can be considered and possibly combined together: Uplink: use of DFT-S OFDM waveform as it has lower PAPR than CP-OFDM. Downlink: use of PAPR reduction techniques of CP-OFDM waveform. - To cope with long propagation delays, open loop instead of close loops procedures such as power control and Automatic Coding and Modulation (ACM), seem to be more feasible. - Phase Tracking Reference Signal (PT-RS) is needed in NR supporting Non-Terrestrial Networks (NTN) for phase error compensation, in order to avoid disruption of orthogonality of OFDM-based subcarriers, common phase errors, inter-carrier interference, etc.	1) It shall be possible to emulate GEO satellites. 2) It shall be possible to introduce phase errors, inter-carrier interference, etc. on the emulated propagation channels.
Satellite friendly MAC NTN long propagation delays are requiring the following MAC layer adaptations: - Introduction of an offset for the start or an extension of the UE RAR window on the Random Access channel (RACH). - Limitation or disabling of HARQ capabilities, with consequent absence of UL feedback about the DL transmission. In this case, the UE should receive from the gNB the indication of whether the HARQ is active or not - Should HARQ be enabled in a NTN access scenario, the DL/UL drx-HARQ-RTT timers (indicating the minimum time interval before a downlink/uplink assignment for HARQ retransmission is expected) might be adjusted (e.g. through extension or introduction of offset). - The prohibit timer of Scheduling requests might be extended	It shall be possible to emulate GEO satellites.

Project objectives	Impacts on the Testbed
Signal processing 5G-ALLSTAR aims at demonstrating satellite and cellular MC; more particularly, WP3 is dedicated to (cellular and satellite) spectrum sharing studies. RRM is the entity that decides how to allocate the spectrum; one of its goal is to save bandwidth. In WP3, cellular physical layer enablers for RRM are developed: a) assessment of the interference regime for an in-band interferer, and b) waveforms for out-of-band (OoB) rejection. The former enabler a) allows the cellular receiver to indicate to the Radio Resource (RR) manager if it can be spectrally scheduled in a band already used by the satellite. This enabler possibly provides a high bandwidth saving. In case the interferer power is too high, the RR manager may allocate adjacent cellular and satellite spectra. In this case, the closer to each other are the spectra, the higher is the spectral gain. The second enabler b) indicates to RRM how close to each other the spectra can be scheduled, depending on the power levels and on the waveform. In the WP5 testbed, these two enablers will be evaluated. A waveform with high OoB rejection will be implemented and signal and interferer power measurement will be done in order to determine the interference regime. These information will be provided to the RRM.	The Testbed, with its channel emulation capability, shall allow to apply and modify different in-band and out-of-band interferers of the useful signals.

3 Testbed architecture

3.1 Reference architecture to be emulated

The main objective of the 5G-ALLSTAR project is to implement advanced functionalities at both Core Network (CN) side and RAN side. The functionalities that will be developed, implemented and tested during the project are:

- Advanced RRM functionalities for the multi-Radio Access Technologies (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.
- 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.

These functionalities are placed on the reference architecture described below.

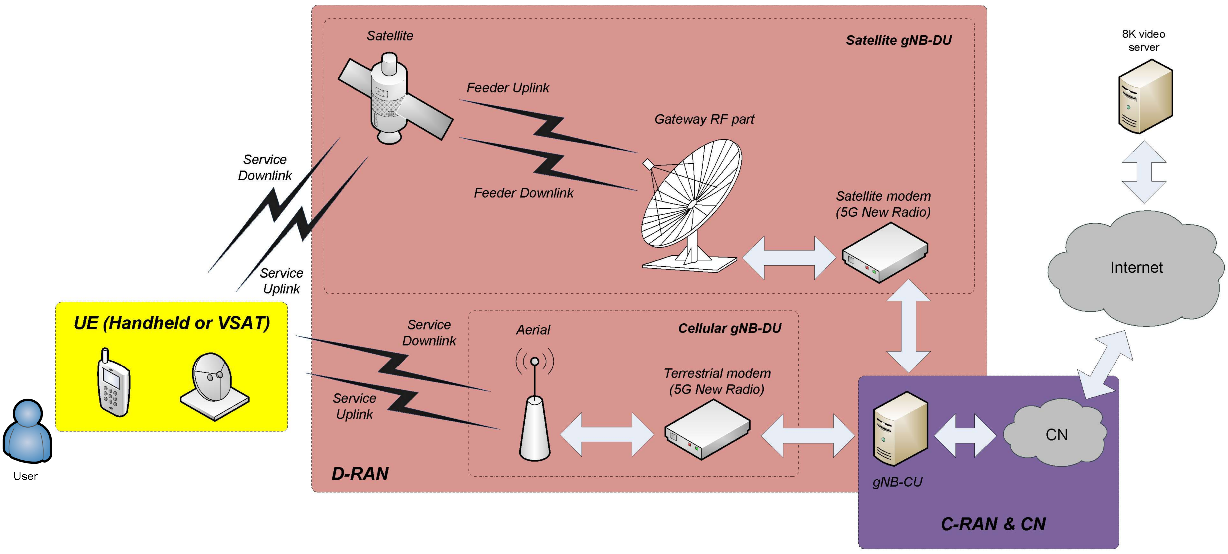

Figure 5: Testbed reference architecture

3GPP define a series of reference scenarios for 5G NTNs. Their main features are presented in the following table.

Table 5: TR 38.811[ii] version 15.0.0 NTN deployment cases

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Platform orbit and altitude	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	UAS between 8 km and 50 km including HAPS
Carrier Frequency on the link between Air / space-borne platform and UE	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Around 2 GHz for both DL and UL (S band)	Around 2 GHz for both DL and UL (S band)	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Below and above 6 GHz
Beam pattern	Earth fixed beams	Earth fixed beams	Moving beams	Earth fixed beams	Earth fixed beams
Duplexing	FDD	FDD	FDD	FDD	FDD
Channel Bandwidth (DL + UL)	Up to 2 * 800 MHz	Up to 2 * 20 MHz	Up to 2 * 20MHz	Up to 2 * 800 MHz	Up to 2 * 80 MHz in mobile use and 2 * 1800 MHz in fixed use
NTN architecture options	A3	A1	A2	A4	A2
NTN Terminal type	Very Small Aperture Terminal (VSAT, fixed or mounted on Moving Platforms) implementing a relay node	Up to 3GPP class 3 UE	Up to 3GPP class 3 UE	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a Relay node	Up to 3GPP class 3 UE Also VSATs
NTN terminal Distribution	100% Outdoors	100% Outdoors	100% Outdoors	100% Outdoors	Indoor and Outdoor
NTN terminal Speed	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 500 km/h (e.g. high speed trains)
Main rationales	GEO based indirect access via relay node	GEO based direct access	Non-GEO based direct access	Non-GEO based indirect access via relay node	Support of low latency services for 3GPP mobile UEs, both indoors and outdoors

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Supported Uses cases	1/ eMBB: multi-connectivity, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, edge network delivery, Mobile cell hybrid connectivity, Direct To Node multicast/ broadcast	1/eMBB: Regional area public safety, Wide area public safety, Direct to mobile broadcast, Wide area IoT service	1/eMBB: Regional area public safety, Wide area public safety, Wide area IoT service	1/ eMBB: multi-homing, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, Mobile cell hybrid connectivity	1/ eMBB: Hot spot on demand

Consistently to section 2 “Concepts to be demonstrated and impacts on the Testbed”, 5G-ALLSTAR will focus on the following 3GPP TR 38.811[ii] scenarios:

- GEO satellite deployment in Ka-band (D1): with a channel emulator on the European Testbed and a real Ka-band Satellite (most likely Athena-Fidus) on the trial platform for showcasing and the project’s final demonstration.
- LEO satellite deployment in S-band (D3): as it would better complement the first case by addressing the other frequency range and satellite orbit considered in the TR 38.811[ii].

In both scenarios, the satellites, LEO or GEO are considered transparent, as bent-pipe payload repeaters (analogue or digital) are currently the most widely used and ordered by Satellite Network Operators (SNOs). It’s thus of a high interest to demonstrate whether such “classical” and cost-effective space segments can, when associated to the appropriate ground segment elements, be efficiently integrated into wider 5G terrestrial networks.

Note that these deployment scenarios are also framing the choice of the ground terminals by providing specifications for some of their parameters such as their antenna types.

3.2 Testbed functional architecture

The European Testbed architecture is built up according to the reference architecture designed in WP2 and reported in D2.2[vi].

The European Testbed will include all the main 5G-ALLSTAR components able to demonstrate the efficiency of the developed modules. It is also designed to include some 5G-ALLSTAR facilities as presented in the D2.2[vi] architecture for target system.

The European Testbed will emulate an End-to-End 5G System between a video server (it is able to provide up to 8K video services) and a client application.

It will be designed to involve the minimal hardware and software components required to study and demonstrate the concepts enabling a UE to be connected to its network simultaneously through one terrestrial link and one satellite link.

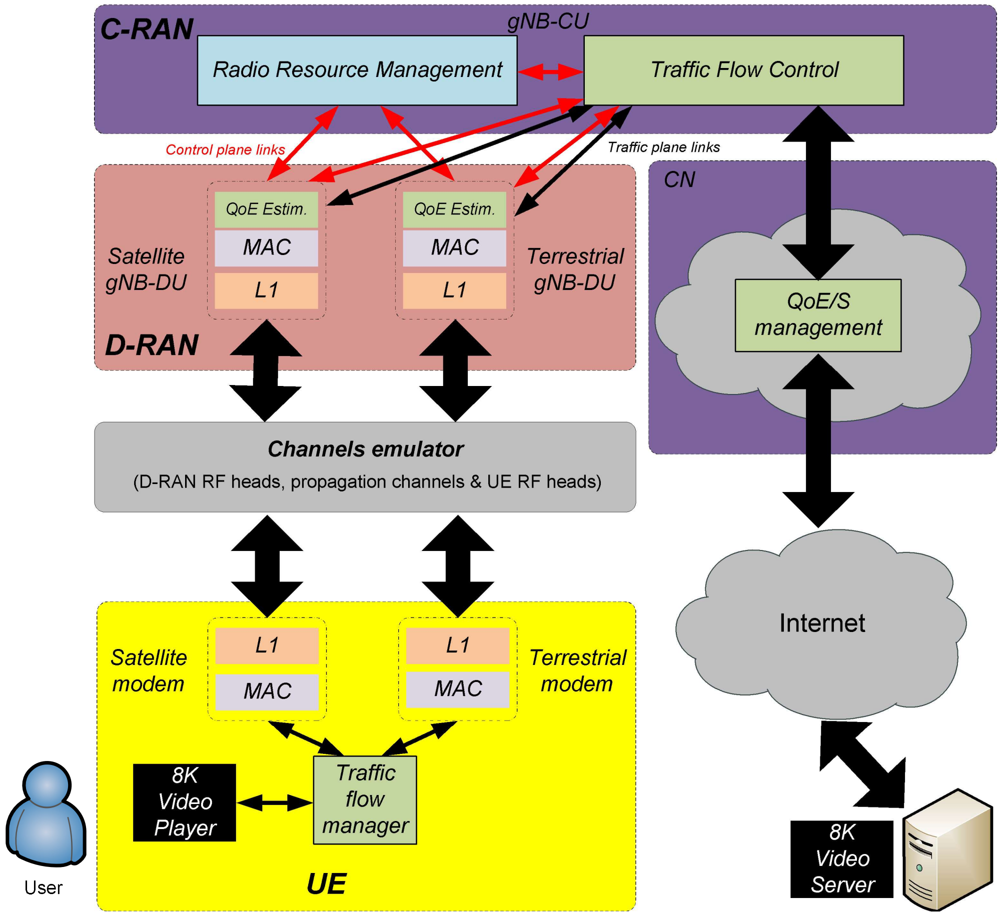

Figure 6: Testbed functional architecture

3.3 Testbed physical architecture and hardware components list

The physical architecture of the testbed shows its different HW components and how they physically interface.

It aims at being representative of the real physical architecture to be emulated.

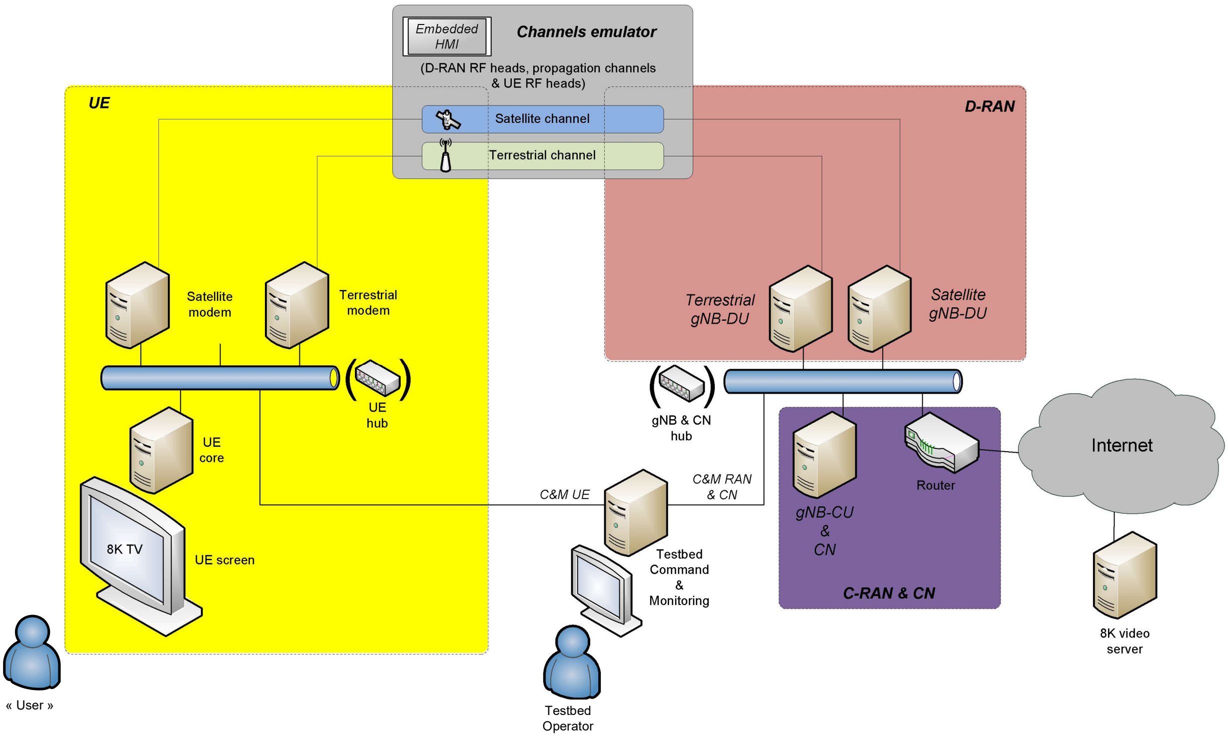

Figure 7: Testbed Physical Architecture

Table 6: Testbed hardware components list

Component ID	Component name	Description	Providing partner
HW#01	UE satellite modem	High-performance PC and software defined radio (SDR) platform to implement satellite friendly UE Tx/Rx L1 & MAC layers able to operate NR radio protocol in FDD mode via satellite channel (GEO and LEO) with implemented NR adaptations compliant to 3GPP TR 38.811[ii] “NR support Non terrestrial networks” This PC shall also incorporate a 10 Gbps Ethernet card in order to be connected to the other hardware components emulating the UE	FhG IIS
HW#02	UE terrestrial modem	PC with Flex board to implement UE Tx/Rx L1 & MAC layers able to operate in FDD mode via terrestrial channel This PC shall also incorporate a 10 Gbps Ethernet card in order to be connected to the other hardware components emulating the UE	CEA

Component ID	Component name	Description	Providing partner
HW#03	UE core	PC emulating the operating system of a 5G User Equipment with satellite/cellular multi-access capabilities. It interfaces with both satellite and terrestrial modems and hosts all the software components needed to emulate the UE in multi-access. This PC shall incorporate a 10 Gbps Ethernet card in order to be connected to the other hardware components emulating the UE. It also includes screen, mouse and keyboard.	CRAT
HW#04	UE screen	8K video screen at UE level	CRAT
HW#05	UE hub	Standard 10 Gbps Ethernet hub interconnecting all the PCs composing the emulated UE	FhG IIS
HW#06	Channel emulator	Dual channel emulator (cellular and satellite respectively based on the models defined in 3GPP TR 38.901[vii] and TR 38.811[ii]).	FhG IIS
HW#07	Satellite gNB-DU	High-performance PC and SDR platform to implement satellite-friendly gNB-DU Tx/Rx L1 & MAC layers able to operate NR radio protocol in FDD mode via satellite channel (GEO) with implemented NR adaptations compliant to 3GPP TR 38.811[ii] “NR support Non terrestrial networks”	FhG IIS
HW#08	Terrestrial gNB-DU	PC with Flex board to implement terrestrial gNB-DU Tx/Rx L1 & MAC layers able to operate in FDD mode via terrestrial channel This PC shall incorporate a 10 Gbps Ethernet card in order to be connected to the other relevant Testbed HW components.	CEA
HW#09	gNB-CU & CN	PC emulating all the required functionalities of a 5G C-RAN and CN This PC shall incorporate a 10 Gbps Ethernet card in order to be connected to the other relevant Testbed HW components.	TAS

Component ID	Component name	Description	Providing partner
HW#10	Testbed Command & Monitoring	PC (with screen, mouse and keyboard) able to configure and monitor each testbed component, except the channel emulator. This PC shall incorporate two 10 Gbps Ethernet cards in order to be separately connected, on one hand to the EU components, and on the hand to the gNB and CN components.	TAS
HW#11	RAN & CN hub	Standard 10 Gbps Ethernet hub interconnecting all the equipment composing the emulated C-RAN and CN	FhG IIS
HW#12	CN router	IP router (with firewall function) providing the Testbed with an access to the public data net-work (the Internet)	FhG IIS
HW#13	8K video server	8K video server with adaptive quality, accessible through public data network.	CRAT

3.4 Software components list and mapping to physical architecture

The SW components are derived from the testbed functional architecture mapping to its chosen HW architecture.

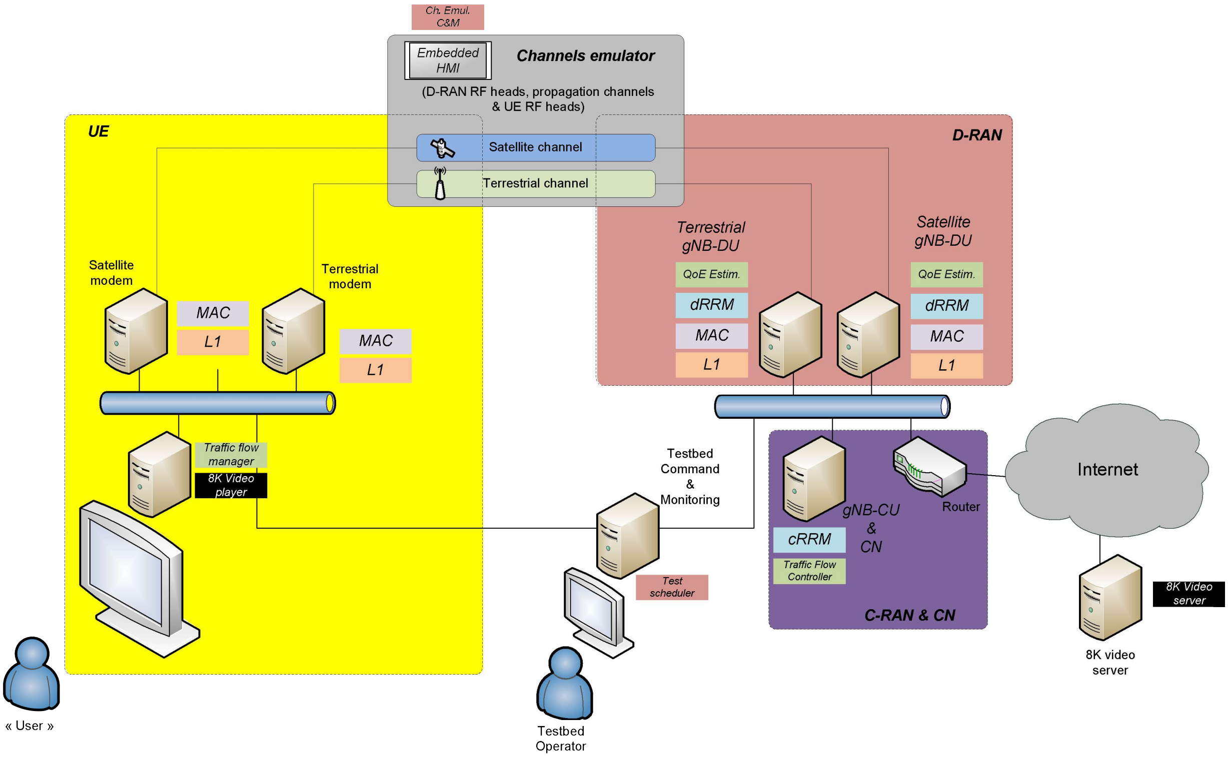

Figure 8: Testbed Software components mapping on physical architecture

Table 7: Testbed software components list

Component ID	Component name	Associated Hardware component(s)	Description	Providing partner
SW#01	UE Satellite L1/MAC	UE Satellite modem	Satellite friendly UE Tx/Rx L1 & MAC layers able to operate NR radio protocol in FDD mode via satellite channel (GEO) and implementing the NR adaptations compliant to 3GPP TR 38.811[ii] "NR support Non Terrestrial networks"	FhG IIS
SW#02	Satellite gNB L1/MAC	Satellite gNB-DU	Satellite friendly UE Tx/Rx L1 & MAC layers able to operate NR radio protocol in FDD mode via satellite channel (GEO) and implementing the NR adaptations compliant to 3GPP TR 38.811[ii] "NR support Non Terrestrial networks"	FhG IIS
SW#03	UE Terrestrial L1/MAC	UE Terrestrial modem	UE Tx/Rx L1 & MAC layers able to operate in FDD mode via terrestrial channel	CEA

Component ID	Component name	Associated Hardware component(s)	Description	Providing partner
SW#04	Terrestrial gNB L1/MAC	Terrestrial gNB-DU	UE Tx/Rx L1 & MAC layers able to operate in FDD mode via terrestrial channel	CEA
SW#05	UE traffic flow manager	UE Core	Software component able to manage (mainly order) traffic data packets received on both satellite and terrestrial links	CRAT
SW#06	8K video player	UE Core	Client application of the distant 8K video server	CRAT
SW#07	8K video server	8K video server	8K video server with adaptive quality, accessible through public data network	CRAT (via sub-contractor)
SW#08	QoE Estimator	Satellite gNB-DU Terrestrial gNB-DU	This module integrates the algorithms in charge of managing the Implicit QoE Feedbacks (i.e. feedbacks related to the Perceived QoE computed by the QoE Estimation).	CRAT
SW#09	Traffic flow controller	gNB-CU & CN	This module contains a set of strategies and algorithms (based on advanced control methodologies) able to dynamically decide, for each in progress connection, the traffic bit rates that have to be managed by each cell of the gNB-CU area.	CRAT
SW#10	cRRM	gNB-DU & CN	The centralized RRM (cRRM) manages a set of decentralized RRM (dRRM) modules (see below). It includes algorithms and strategies able to control the multi-RAT radio bearers, i.e. able to dynamically select the appropriate radio bearers which should support the various connections following the allocations decided by the Traffic Flow Control.	TAS
SW#11	Satellite dRRM	Satellite gNB-DU	Adaptation layer between the cRRM and the satellite MAC layer	FhG IIS

Component ID	Component name	Associated Hardware component(s)	Description	Providing partner
SW#12	Terrestrial dRRM	Terrestrial gNB-DU	Adaptation layer between the cRRM and the terrestrial MAC layer	CEA
SW#13	Channel emulator C&M	Channel emulator	Software allowing the testbed operator to configure, command and monitor the channel emulator.	FhG IIS
SW#14	Test scheduler	Testbed Command & Monitoring	Software enabling the configuration, control and monitoring of the different testbed components at both UE and RAN/CN edges. Includes an HMI for direct C&M but allows also to run automatic test scenarios	TAS

4 Testbed Hardware & Software components

4.1 Hardware components

4.1.1 UE satellite modem & satellite gNB-DU

This component consists in a real-time modem that will provide the basic functionality of NR for the relevant use cases and scenarios in 5G-ALLSTAR, with special focus on the necessary adjustments to accommodate GEO satellites constraints according to 3GPP TR 38.811[ii] and TR 38.822[viii].

5G NR platform at Fraunhofer IIS facilities consists in two SDR platforms based on the Xilinx ZYNQ-7000 SoC (ZC706) and the Analog Device motherboard ADRV9371, an RF board which features a wideband integrated RF transceiver. The same hardware is used for the emulation of both the gNB and the UE (once the software for relevant target, i.e. UE and gNB, is built). The FhG IIS testbed, consisting in two PCs and some additional hardware for gNB and UE is depicted in Figure 9.

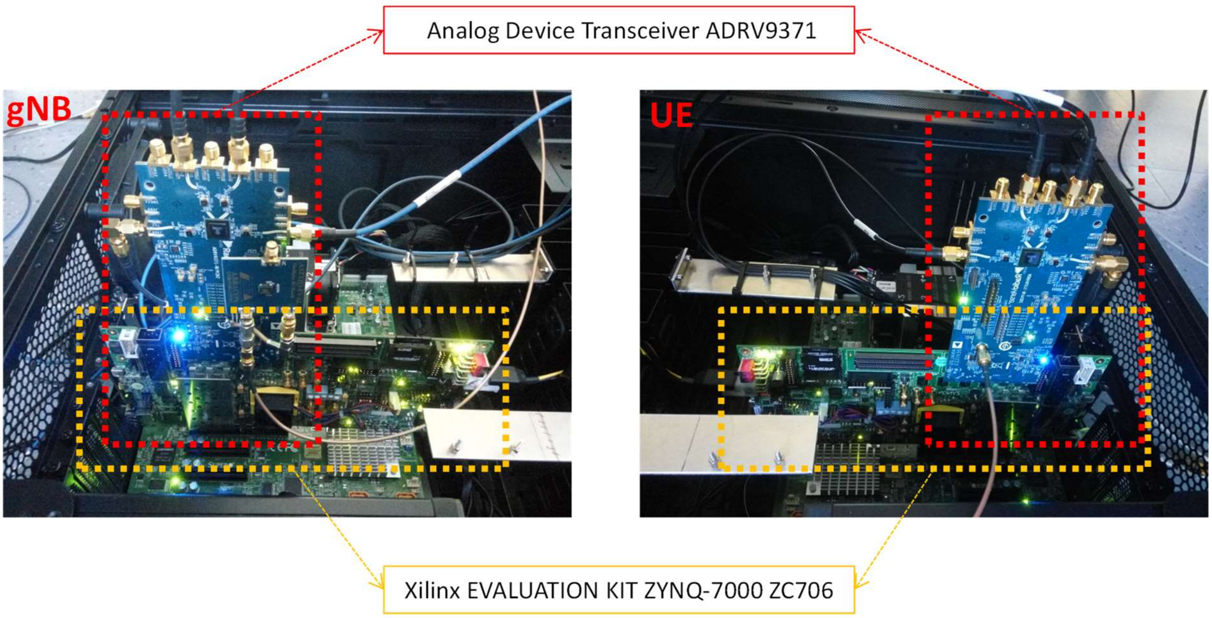

Figure 9: 5G NR setup at the Fraunhofer IIS facilities

The ADRV9371 operates over a tuning range from 300MHz up to 6 GHz. The transceiver performs up and down wideband conversion, DC offset correction, quadrature error correction (QEC), analog-to-digital conversion (ADC), digital-to-analog conversion (DACs) and clock generation applicable for both TDD and FDD operation.

The radio card is connected through a FMC (FPGA Mezzanine Card connector) to the ZC706 motherboard. The FPGA manages the PCIe interface, configures the RF chip sets and the data acquisition, basically relaying I/Q samples to the GPP.

The ZC706 motherboard is plugged via PCIe into a GPP (Intel Xeon Gold 6154 CPU 3.00GHz, 18 cores) which is running a Linux Ubuntu operating system extended with low latency kernel, achieving 122,88 MHz of sampling rate. The baseband processing is performed on the GPP.

Table 8: UE satellite modem & satellite gNB-DU specification

Sub-component	Feature	Required	Achieved
Operating System	Type	Linux	Ubuntu with low latency kernel
CPU	Type	Compatible with installer SW and HW card	Intel Xeon Gold 6154
	Number of cores		18
	Clock frequency		3 GHz
Ethernet card	Type	10 Gbps base T	10 Gbps base T
	I/O port connector type	RJ45	RJ-45
SDR platform	Type	TBP	Analog Device Transceiver ADRV9371 + Xilinx Evaluation Kit ZYNQ-7000 ZC706
	Number of RF I/O ports	2 Inputs 2 Outputs	4 I/O
	Carrier frequency range	300 MHz - 6 GHz	300 MHz - 6 GHz
	OFDM channel maximum bandwidth	at least 20 MHz 50 MHz whishable	20 - 80 MHz
	Maximum output power	TBP	< 10 dBm peak
	Maximum input power	TBP	-14 dBm (CW at 0 dB attenuation)
	Operating modes	FDD	FDD/TDD
	MIMO capability	at least SISO	SISO only

4.1.2 UE terrestrial modem & Terrestrial gNB-DU

Figure 10 shows a schematic of the implementation of the terrestrial links in the EU testbed.

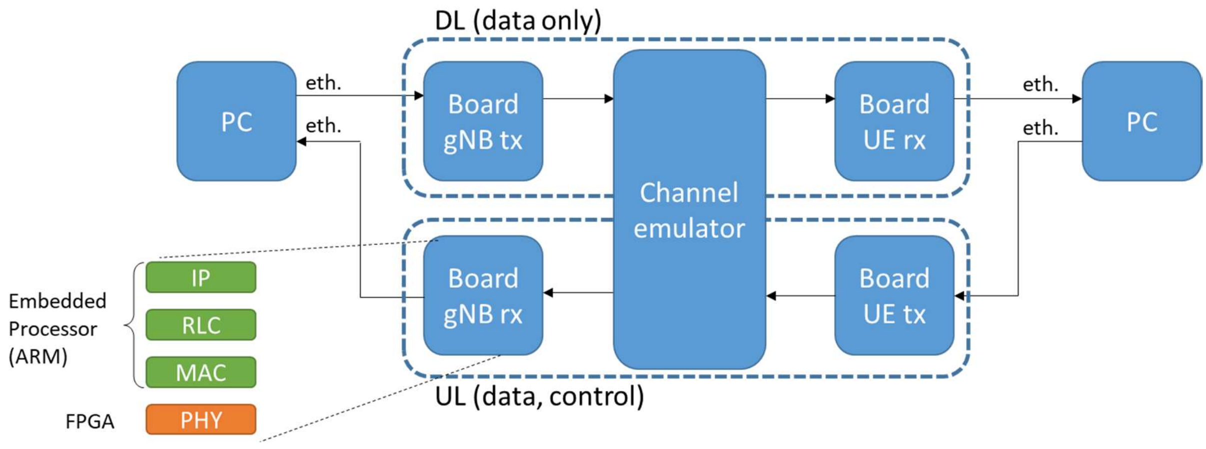

Figure 10: Schematic of the implementation of terrestrial UL and DL

For gNB Tx and UE Rx (i.e. for the DL), the Digital BaseBand (DBB) and the MAC will be implemented on a RFSoC. The Zynq UltraScale+ RFSoC chip XCZU28DR shown Figure 11 has been selected. It allows for a better hardware integration, with design flexibility on a highly programmable SoC platform. This chip combines the processing system with UltraScale architecture programmable logic, RF-ADCs, RF-DACs, and soft-decision FECs, delivering both a powerful processing system (PS) and programmable logic (PL) in the same device.

The Zynq UltraScale+ RFSoC XCZU28DR integrates 8 channels of RF-ADCs and RF-DACs. The RF-ADCs can sample input frequencies up to 4 GHz at 4.096 GSPS with excellent noise spectral density. The RF-DACs generate output carrier frequencies up to 4GHz using the 2nd Nyquist zone with excellent noise spectral density at an update rate of 6.554 GSPS. The RF data converters also include power efficient digital down converters (DDCs) and digital up converters (DUCs) that include programmable interpolation and decimation, NCO, and complex mixer. The DDCs and DUCs can also support dual-band operation. The presence of these RF-DACs was also a key selection criterion of this Zynq platform.

The soft-decision FEC (SD-FEC) is a highly flexible forward error correction engine capable of operating in Turbo decoding mode for wireless applications such as LDPC encode/decode mode used in 5G wireless.

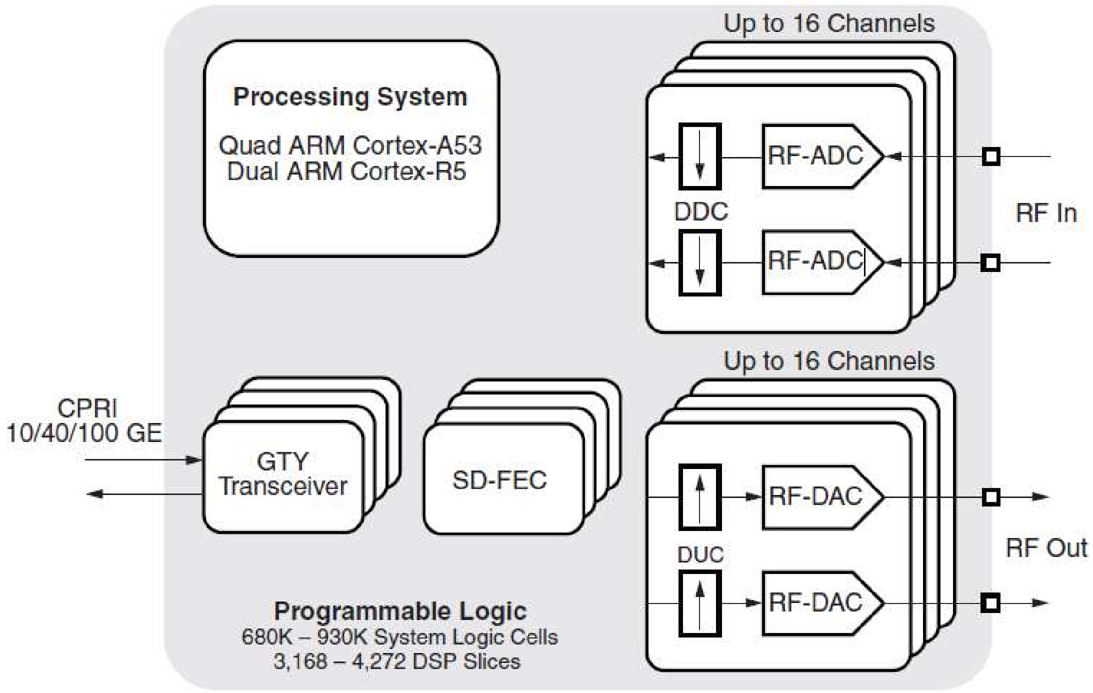

Figure 11: Zynq UltraScale+ RFSoC

The RF SoC chip XCZU28DR is available on the ZCU111 Xilinx evaluation board (Figure 12). This evaluation board integrates the main components to run the ZCU28DR RFSoC chip: power supplies, SDRAM DDR4 memories, networking interfaces, Ethernet and USB.

It integrates also the clock generation system with several PLLs chips which generate the programmable sample clocks of the RF-ADCs and RF-DACs. The LMX2594 PLL clocks can be configured either as direct RF clocks or as reference clock sources for the internal PLL contained within the RFSoC data converter tile itself.

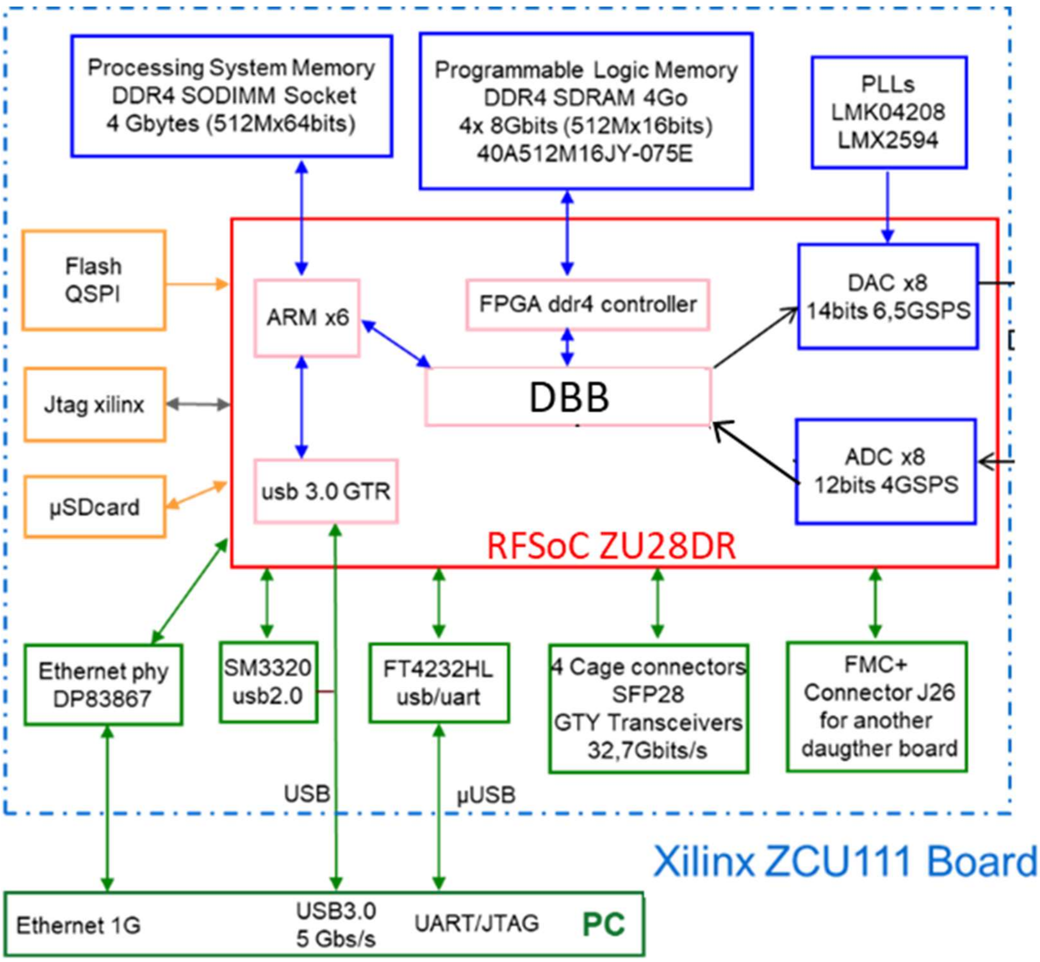

Figure 12: Xilinx ZCU111

The RFSoC chip XCZU28DR of ZCU111 Xilinx evaluation board includes 16 GTY-Transceivers for a future possible extension of the FPGA design, with serial data transfers towards another Xilinx FPGA (through the FMC+ expansion connector, or the four SFP28 cage connectors).

At the time this document is written, the boards that will be used for UE Tx and gNB Rx (i.e. the UL) are not selected. The bandwidth requirements in the UL are less stringent than in the DL, therefore boards less powerful than ZCU111 can be chosen.

4.1.3 UE core

The UE core is a PC emulating the core of the 5G UE and in particular its multi-access capability.

It interfaces with both satellite and terrestrial modems and hosts all the software components needed to emulate the UE in multi-access.

This PC is interconnected with:

- the two UE modems via an 10 Gbps Ethernet card (and the UE hub),
- the 8K video screen via a HDMI port.

Moreover, the 8K platform distributes the video streams using the standard HTTP protocol, so the only requirement for the clients is using a modern web browser (e.g. Chromium, Google Chrome, Mozilla Firefox, Safari) on a PC with at least 8GB RAM and 8 core CPU. It is preferred using a PC equipped with a dedicated video card (e.g. Nvidia or AMD) in order to speed up the video decoding process using the Graphical Processing Unit (GPU).

The installed operating system shall be Linux-based.

4.1.4 UE screen

8K video screen emulating the User Terminal high definition video screen.

This screen is connected to the UE core PC by an HDMI port.

4.1.5 UE hub

This 10 Gbps Ethernet standard hub interconnects all the emulated base band components of the UE and also provides access to the testbed Control & Monitoring PC for the remote management of all these components.

It shall have at least 8 I/O RJ45 ports.

4.1.6 Channel emulator

Channel modelling in 5G-ALLSTAR is addressed in deliverable 3.1. The channel model for cellular and NTN systems will be developed according to 3GPP TR 38.811[ii], extended and implemented within the QuaDRiGa channel simulator. Outputs from this work will be fed to the channel emulator in the European testbed in order to achieve a combined satellite/cellular file-based emulation of test scenarios.

A conceptual drawing inherited from TR 38.811[ii] is depicted in Figure 13.

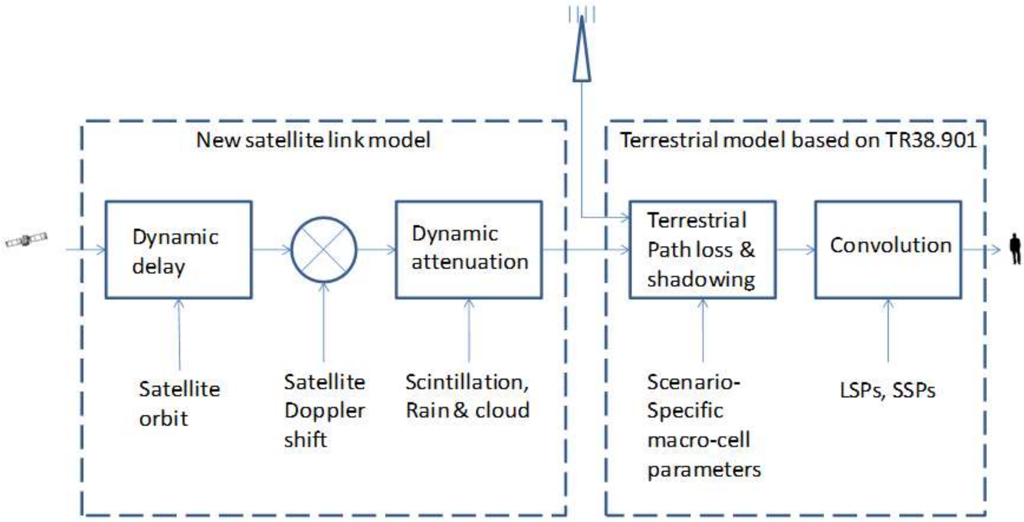

Figure 13: Channels emulator functional block diagram

The European testbed is equipped with two channel emulators: the F8 PROPSIM and the F64 PROPSIM, both engineered by Keysight Technologies (https://www.keysight.com).

Both channel emulators enable recreating the wireless channel propagation effects in a controlled laboratory environment and features:

- 5G RF channel modelling as defined in 3GPP TR 38.901[vii] through the Geometric Channel Modelling tool (GCM tool)

- Emulation of impairments produced by complex radio channel propagation effects, such as:
  - Dynamic multipath propagation
  - Pathloss, shadowing and fast fading
  - Doppler effect from mobility
  - Noise and synchronous programmable interference
- Antenna pattern embedding
- Scalable channel capacity (e.g. up to 64 MIMO channels)
- Wide bandwidth (e.g. up to 100 MHz)
- bi-directional emulation
- delay spread for terrestrial channel emulation up to 3 ms
- multiple fading channels (fading, Doppler, pat amplitude and phase offset are independently configurable through GUI) (e.g. up to 64)
- multiple fading paths per interface channel (e.g. up to 48)

The F64 PROPSIM (Figure 14 left) is equipped also with an Aerospace and Satellite Modelling tool for testing airborne, aerospace and satellite radio communication devices and systems in order to emulate SISO topologies with high Doppler shift (up to +/- 1.5 MHz), long propagation delay spread (up to 1.3 s) and high range rates in a laboratory environment.

Figure 14: (left) Keysight PROPSIM F64 (right) available unit at FhG IIS facilities during a running test environment

The PROPSIM emulator scope is limited to the radio channel, thus excluding transmitters and receivers. Each channel unit is equipped with RF input/output duplex ports and output only RF connectors that allow interconnection with third-party devices to be tested (e.g. RF transceiver), irrespective of the system technology or modulation (as the PROPSIM supports all major wireless standards and waveforms).

The emulator is also equipped with external local oscillators and interfaces to laboratory hardware (i.e. DVI display port, USB for external I/O, RJ45 Ethernet for LAN connectivity and IEEE 488 connector for automated test control) that is used to monitor and control purposes.

Main specifications of the channels emulator are listed in Table 9.

Table 9: Channels emulator specification

Sub-component	Feature	Required	Achieved
Command & Monitoring	Interface type	10 Gbps base T RJ45	10 Gbps base T RJ45
	Software HMI	Control and monitor live the emulated channels features	Yes
	Automatic scenarios loading	Satellite channel emulation: from LEO at 600 km to GEO satellite	Yes
		Terrestrial channel	Yes
	Dual mode use	Control and monitor live the emulated channels features while an automatic scenario is running	Yes
RF I/O	Number of channels	2 for FDD satellite links 2 for FDD/TDD terrestrial links	up to 8
	Connector type	N female	N female, 50 Ohm nominal
	Input signal frequency range	(reference)	450 MHz - 6 GHz
	RF bandwidth	(reference)	up to 800 MHz
	Max. output power	25 dBm RMS 33 dBm peak	Yes
External frequency reference	Local oscillator input	TBP	SMA female, 50 Ohm nominal

Sub-component	Feature	Required	Achieved
	Local oscillator output	TBP	SMA female, 50 Ohm nominal
Channel emulation functionalities	Propagation delay	up to 250 ms	Yes
	Range rate	TBP	20 km/s
	Acceleration	TBP	100 g
	Doppler shift	TBP	+/-750 kHz
	Interference generation	TBP	AWGN
		independent per chan-nel	independent per chan-nel
	Number of fading paths	TBP	1 LOS + 3 reflections

4.1.7 gNB-CU & CN

This PC, running under Linux OS is emulating all the required functionalities of a 5G C-RAN and CN needed to demonstrate the 5G-ALLSTAR concepts:

- RRM (C-RAN functionality)
- Traffic Flow Control (C-RAN functionality)
- QoE/S Management (CN functionality)

This gNB-CU & CN PC shall incorporate a 10 Gbps Ethernet card in order to be connected to the other hardware components emulating the gNB-DU.

4.1.8 8K video server

The 8K video server can be installed both on local machines and on cloud providers equipped with the Linux operating system. The software is deployed using Docker containers and Kubernetes cloud orchestrator, thus allowing to easily replicate the software environment and scale it over a large number of cluster nodes, if required. The machine minimum requirements for the encoding of 8K video flows are:

- CPU: 16 cores;
- Memory: 32 GB;
- Disk space: 60 GB.

The machine minimum requirements for the distribution (streaming) of 8K video flows are:

- CPU: 8 cores;
- Memory: 16 GB;

- Disk space: variable depending on the number and duration of the video streams;

Network connectivity (per flow): 100 Mbps uplink. Testing multiple concurrent video flows requires a higher uplink capacity.

4.1.9 Testbed Command & Monitoring

This PC, running under Linux OS is allowing the Testbed operator to command and monitor all the Testbed components, except the channel emulator.

It shall incorporate two 10 Gbps Ethernet cards in order to be connected to the other hardware components emulating the gNB-DU.

4.1.10 C-RAN & CN hub

This 10 Gbps Ethernet standard hub interconnects all the emulated base band components of the C-RAN & CN. It also provides an access to the Testbed C&M PC for the remote management of all these components.

It shall have at least 8 I/O RJ45 ports.

4.1.11 CN router

This is a standard IP router (with firewall function) allowing the Testbed to be interconnected remotely through the Internet to the 8K video server.

4.1.12 Connecting cables

Each Testbed component shall be delivered by the providing partner with its power supply cable and, when necessary an adaptor to the French power supply plug format.

The other cables and wires required for the assembly shall be provided by the partner hosting and integrating the Testbed (FhG IIS).

4.2 Software components

4.2.1 UE and gNB Satellite L1/MAC

The prototype modem for the satellite-friendly UE and gNB will be based on OpenAirInterface (OAI, www.openairinterface.org), an open source software-based implementation of 3GPP 5G NR.

OAI is an open source software implementation of fully real-time 3GPP compliant stack (e.g. eNB, gNB, UE and EPC) running on general purpose processors (e.g. x86, ARM) that is conceived to offer a relatively fast and cheap SDRs for prototyping purposes. OAI currently supports the most common COTS RF boards, including but not limited to most of the USRP platforms by Ettus Research.

The OpenAirInterface Software Alliance (OSA) is a French non-profit organization funded by corporate sponsors with the mission to provide a common framework for open source software development to all academic and industrial partners, while at the same time supporting the legal procedures and protecting intellectual property. OSA is also striving to foster innovation and collaboration in 5G related projects.

Fraunhofer IIS is member of the technical board of OSA and contributor to OAI NR development along with other associate and strategic members of the alliance, such as Eurecom, Orange and TCL.

LTE is currently the most mature implementation of OAI. The physical layer implements 3GPP 36.211[ix], 36.212[x], 36.213[xi], the MAC layer implements a subset of the 3GPP 36.321[xii], PDCP is header compliant with 3GPP 36.323[xiii] Rel. 10.1.0, RLC layer implements a full specification of the 3GPP 36.322[xiv] release v9.3 and RRC is based on 3GPP 36.331[xv] v14.3.0.

OAI 5G NR is currently under development and is aiming at implementing the most recent 3GPP standard for NR (e.g. 38.211[iii], 38.212[x], 38.321[iii], etc.). The current OAI LTE stack will be its baseline. A high level representation of the full NR OAI stack is depicted in Figure 15. Some of the features already implemented are:

- CP-OFDM and DFT-s-OFDM waveform
- NR numerology (SCS 30 KHz)
- NR multiplexing and channel coding (3GPP compliant LDPC encoder and decoder, polar encoder and decoder)
- Wide carrier bandwidth (40 MHz)
- NR-PSS, NR-SSS and NR-PBCH single beam
- NR DM-RS configuration type 1
- NR-PDCCH formats 0, 1, 2, 3
- NR PDSCH mapping type A
- NR-PUSCH mapping type A
- NR-PRACH

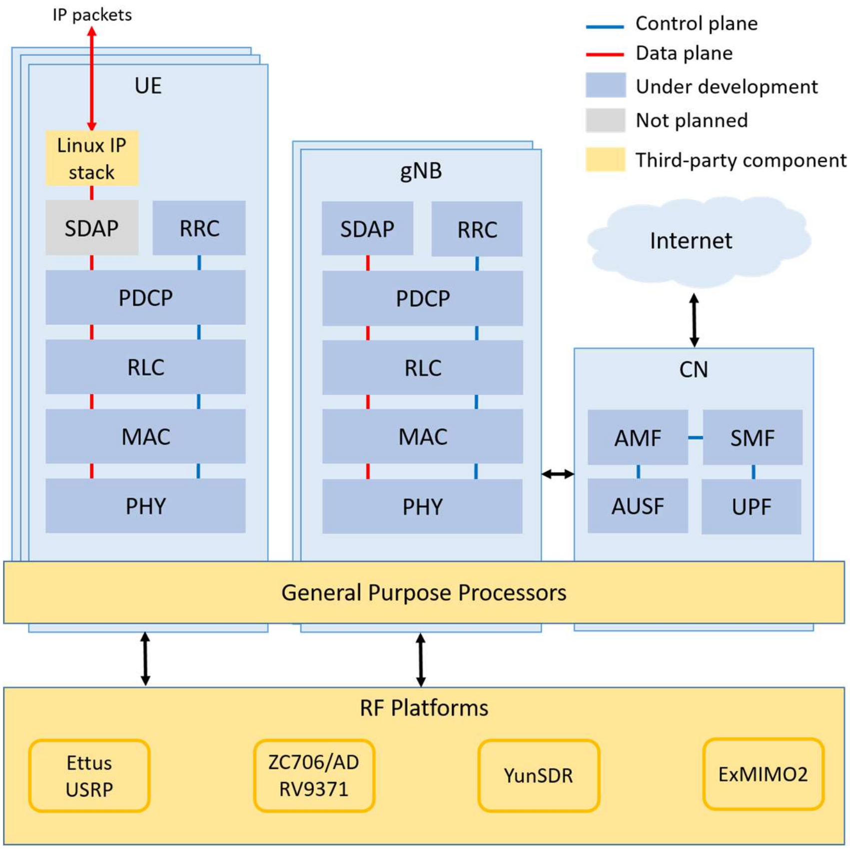

Figure 15: NR OAI stack

4.2.2 UE and gNB Terrestrial L1/MAC

The 5G transmit gNB and the 5G receive UE (i.e. the DL) L1 and MAC will be implemented in Xilinx ZCU111 boards (see §4.1.2). Figure 16 left and right resp. details the implementation of the UE and the gNB. The DBB, i.e. the physical layer (PHY), will be implemented in the FPGA of the board; the MAC will be implemented in the embedded processor of the board.

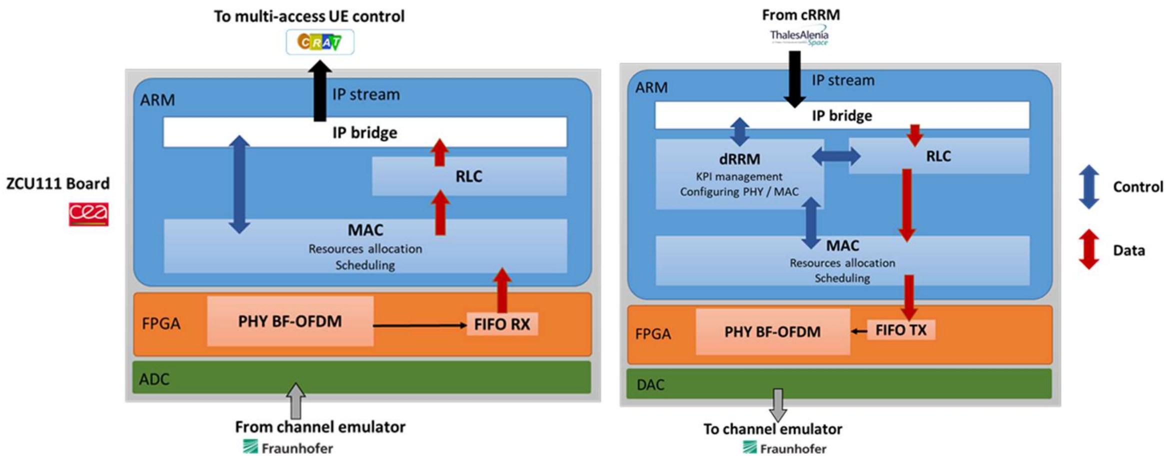

Figure 16: 5G UE (left) gNB (right) implementation

In the DL, the UE DBB converts the digital signal from the ADC to data bits to be exploited by the MAC. The cellular UE will be compliant to 5G NR standard (release 15), it is a CP-OFDM receiver. The MAC prepares the bits for sending them to the multi-access UE control through IP streams.

In the DL, the gNB DBB is in charge of preparing the data bits, provided by the MAC, for analog conversion and transmission through the RF. The waveform implemented is Block-Filtered (BF)-OFDM, described in WP3. The main modules of the DBB are: channel coding (LDPC), pre-distortion, OFDM precoding and filter bank stage. The targeted large bandwidth of the signal (200 MHz) will challenge the design: parallelisation of the algorithms is required to match the frequency of the board.

The dRRM collects and forwards the KPIs, e.g. estimation of the INR/CNR (Interference/Carrier to Noise Ratio), and provides information to the MAC for PHY configuration (e.g. modulation and coding scheme) and time and frequency resource allocation.

As stated in §4.1.2, the boards for the implementation of the UL (i.e. Tx UE and Rx gNB) are not chosen yet. In the testbed, the UL will be used for transmission of control information (e.g. channel state information, CNR estimation…) on the control plane, or for transmission of acknowledgements on the data plane (like for example with Dynamic Adaptive Streaming over HTTP).

It is for further study if the duplexing mode in the terrestrial part of the tested will be TDD or FDD. The proposed implementation is suited for both solutions.

4.2.3 UE traffic flow manager

The traffic flow manager from the UE perspective is a software component able to aggregate different packets from the different radio technologies involved in the data transmission. During the testbed implementation the 5G-ALLSTAR project is investigating algorithms to aggregate data at higher layers (e.g., IP-Level) coming from the terrestrial and satellite testbed modems.

4.2.4 8K video server

The 8K video server component is a Software as a Service (SaaS) video streaming platform aimed at the distribution of live and on-demand video streams over the Internet. The platform supports the streaming standards HLS (HTTP Live Streaming) and DASH (Dynamic Adaptive Streaming over HTTP), which allow to automatically send to clients the best possible video quality avoiding buffering phases. The video server will be used for encoding and distributing video flows at 8K video resolution. The streaming platform is composed of the following modules:

- WebServer: it is the main interface to the system. It has a typical structure of a video streaming web server (e.g. Youtube) presenting to the user a list of available video-on-demand contents
- DashEncoder: it is software encodes the 8K audio/video source into several flows at different quality and resolution levels and save them to persistent storage
- DashStreamer: read the encoded audio/video flows from the storage module and makes them available to the web viewers

4.2.5 8K video player

WebDashPlayer is the 8K video player for the end-users. It automatically selects the best possible video quality depending on the available bandwidth and the device capabilities (screen resolution, CPU), avoiding view interruptions due to re-buffering phases.

4.2.6 QoE estimator

This software component will be able to monitor and evaluate the perceived QoE by end-user during testbed simulation. This module receives the real-time QoS parameters for the on-going service and estimates the QoE by using the IQX hypothesis (the implementation details are described in 5G-ALLSTAR Deliverable 4.1).]

4.2.7 Traffic flow controller

As introduced in 5G-ALLSTAR Deliverable 4.1, the traffic flow controller will be in charge of dynamically splitting/switching/steering to the most appropriate radio access technologies the real-time data traffic coming from the data network. In the testbed implementation a selected algorithm from the set implemented and simulated in WP4 will be investigated to guarantee an efficient link steering to potentially demonstrate the effectiveness of MC approaches for the optimization of the throughput and network reliability.

4.2.8 cRRM

The cRRM manages a set of decentralized Radio Resource Management (dRRM) modules. The cRRM, in cooperation with the managed dRRMs, includes algorithms and strategies able to control the multi-RAT radio bearers, i.e. able to dynamically select the appropriate radio bearers which should support the various connections following the allocations (as explained below, referred to as Connection-to-Cell Allocations) decided by the Traffic Flow Control.

In addition, the cRRM, in cooperation with the managed dRRMs, is in charge, for each of the cell included in the gNB-CU area and for each possible 5QI, of periodically computing the cell QoS Performance, i.e. the performance, in terms of QoS Parameters (e.g., bit rate, latency, etc..) experienced in the considered cell by the connections characterized by the considered 5QI; this means that the cell QoS Performance is expected to include a number of subfields equal to the number of different QoS Parameters; each QoS Parameter is computed as the weighted mean of the performance experienced, with respect to such parameter, by all the connections served by the considered Cell and characterized by the considered 5QI. The information included in the cell QoS performance is periodically sent, together with the associated 5QI and the associated Cell_Id from the cRRM to the Traffic Flow Control. This latter stores such information and, in turn, forwards an elaborated version of such information towards the QoS/QoE Management.

Furthermore, the cRRM, in cooperation with the managed dRRMs, is in charge, for each of the in progress connections, to continuously monitor which are the cells of the gNB-CU area that, potentially, can serve the connection in question; such cells will be referred to as Potential Serving Cells. For each in progress connection, the Potential Serving Cells_Id (i.e., the list of the Ids of all Potential Serving Cells of a given connection) together with the relevant Connection_Id is periodically sent from the cRRM to the Traffic Flow Control which stores this important information in the in-progress connection repository.

4.2.9 Satellite dRRM

The distributed RRM, from the Traffic Flow Control point of view, is designed to be in any gNB-DU to estimate the radio performance as closest as possible to the UE. The dRRM of any given gNB-DU provides, in real-time, the cRRM with the cell QoS performance and associated 5QI relevant to the cells of its gNB-DU area.

4.2.10 Terrestrial dRRM

The distributed RRM, from the traffic flow control point of view, is designed to be in any gNB-DU for estimating the radio performance as closest as possible to the UE. The dRRM of a given gNB-DU provides, in real-time, the cRRM with the Cell QoS Performance and associated 5QI relevant to the Cells of its gNB-DU Area.

4.2.11 Channel emulator C&M

The PROPSIM can be controlled either through Graphical User Interface (GUI) or through remote control commands. The PROPSIM GUI runs on Windows OS for embedded environments and can be used for command and monitoring purposes. The Remote Control, which covers to a large extent the operations available in the Running view application, can be used to operate the unit remotely via GPIB (IEEE 488) or LAN SCPI commands.

Multiple test scenarios can be setup either by a file interface which allows to import customer specific data from third party scenario tools or by editing tool which supports the creation of dynamic multipath scenarios by defining Doppler profile, power delay profile, distance, speed, terrain and trajectories. The Geometric Channel Modelling (GCM) tool allows the creation of customized channel models. Multiple radios can be connected into one scenario, with possibility to set up the frequency of each individual radio and to enable AWGN interference sources to be added for each channel independently.

Once the emulation is built, a channel emulation files is generated and stored in the unit. Then the emulation can be run and emulation parameters can be controlled in runtime through the Running View application. Multiple emulation files can be stored in the unit and pre-stored standard emulations are also available.

In a typical test scenario performed at Fraunhofer IIS facilities (Figure 16 right), the transmitter and receiver to be tested (e.g. Ettus B210 USRPs generating LTE/NR signals through OAI software) are connected to the PROPSIM, which then emulates a wireless propagation environment, replacing the real radio channel. The complete setup is illustrated in Figure 17 left. Real-time emulation run and parameter control can be performed through the Running View of the PROPSIM F64 software GUI while monitoring of the impaired radio channel and received signal characteristics can be performed through the OAI Soft Scope on the host PCs running OAI Figure 17 left. This OAI user interface (Soft Scope) allows indeed real time plotting of PHY layer characteristics such as received signal power, channel impulse response, channel frequency response, LLRs, throughput and I/Q components (e.g., 4-QAM constellation).

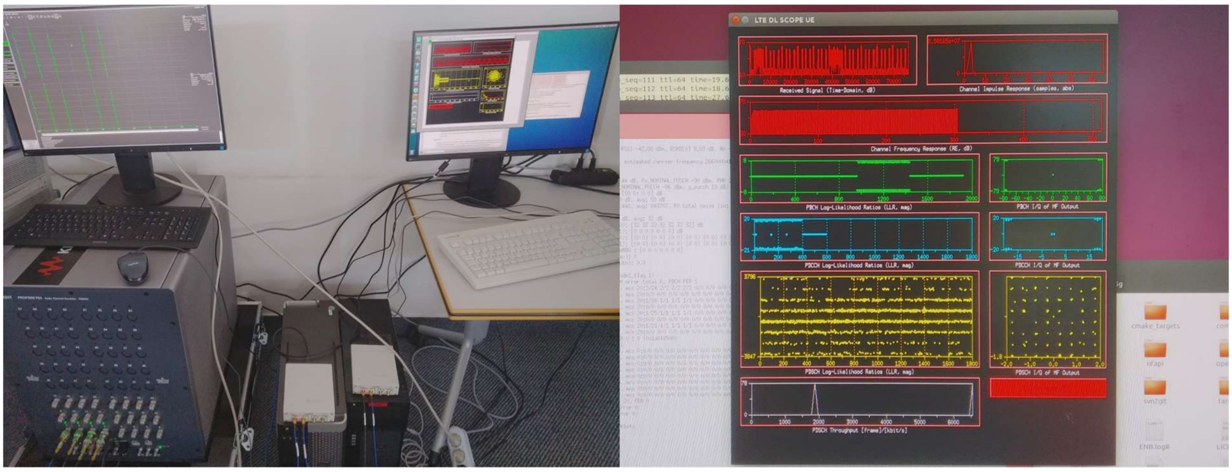

Figure 17: (left) PROPSIM 64 running test scenario with OAI and USRPs B210 (right) OAI Soft Scope

4.2.12 Test scheduler

The testbed will have two different modes of utilizations:

- Automatic mode: run of automatic test scenarios in order to validate concepts through extensive test campaigns. The output data sets will be collected and will eventually serve to prove that 5G-ALLSTAR will bring an added value to the 5G systems through its innovative solutions.
- Manual mode: configuration through an HMI specific tests or verifications, but also for commented demonstrations and showcasing.

A joint use of both modes will also be made, the automatic mode running Testbed configuration scenarios pre-setting the different Testbed components and the manual mode being then used by the Testbed operator for specific purposes, such as live demonstrations.

A specific software, able to configure and monitor each Testbed component shall be used.

OpenBACH is a user-friendly and efficient benchmark to configure, supervise and control your network under test (e.g. terrestrial networks, satellite networks, WAN, LAN, etc.). It provides an efficient modular structure to facilitate the additions of new software tools, monitoring parameters, tasks, etc. The benchmark is able to be integrated in different types of equipment, servers, clients, hardware and software with minimal adaptation effort.

This platform has been promoted by CNES (French Space Center) as a reference open-source software tool within its research and development studies and activities in the domain of satellite network communications systems.

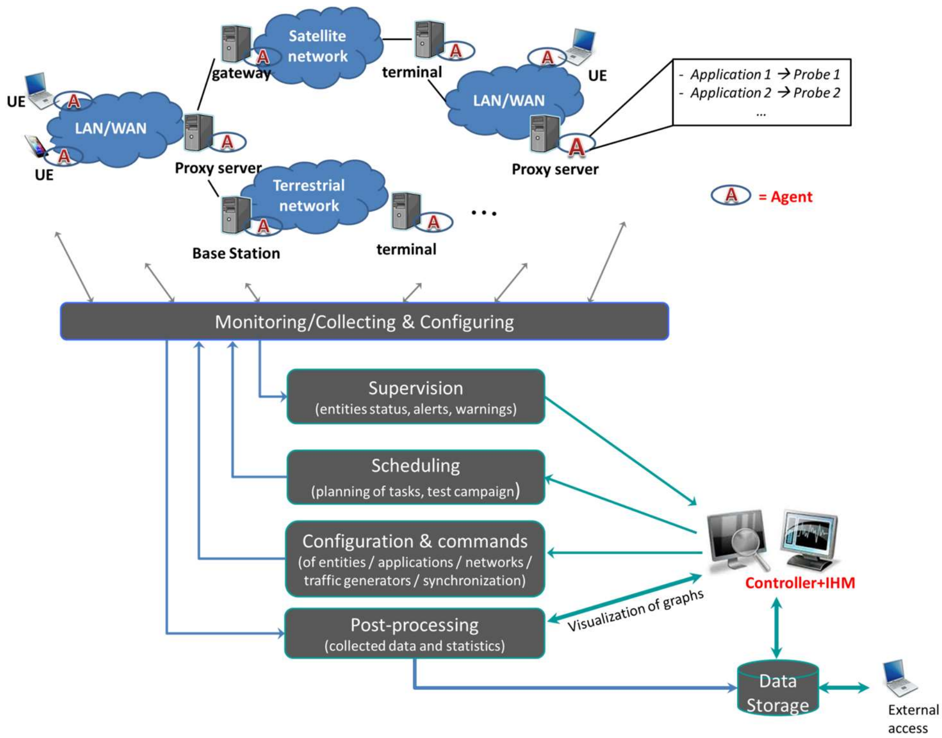

Figure 18: Test schedule architecture principle

5 Testbed interfaces

5.1 Physical interfaces

The table below identifies all the physical internal and external interfaces involved in the Testbed.

Table 10: Testbed physical interfaces list

Interface label	From	To	Type	Description
I0607	Channel emulator / satellite channel	Satellite gNB-DU	Internal Simplex RF	Emulates the interface between the Gateway RF reception chain (RF-to-IF down-converter output) and the gNB-DU satellite modem Rx input
I0706	Satellite gNB-DU	Channel emulator / satellite channel	Internal Simplex RF	Emulates the interface between the Gateway RF transmission chain (IF-to-RF up-converter input) and the gNB-DU satellite modem Tx output
I0608	Channel emulator / terrestrial channel	Terrestrial gNB-DU	Internal Simplex RF	Emulates the interface between the Terrestrial gNB RF reception chain (RF-to-IF down-converter output) and the gNB-DU terrestrial modem Rx input
I0806	Terrestrial gNB-DU	Channel emulator / terrestrial channel	Internal Simplex RF	Emulates the interface between the terrestrial gNB RF transmission chain (IF-to-RF up-converter input) and the gNB-DU terrestrial modem Tx output
I0601	Channel emulator / satellite channel	UE Satellite modem	Internal Simplex RF	Emulates the interface between the UE satellite RF reception chain (RF-to-IF down-converter output) and the EU satellite modem Rx input
I0106	UE Satellite modem	Channel emulator / satellite channel	Internal Simplex RF	Emulates the interface between the EU satellite RF transmission chain (IF-to-RF up-converter input) and the EU satellite modem Tx output

Interface label	From	To	Type	Description
I0602	Channel emulator / terrestrial channel	UE Terrestrial modem	Internal Simplex RF	Emulates the interface between the EU terrestrial RF reception chain (RF-to-IF down-converter output) and the EU terrestrial modem Rx input
I0206	UE Terrestrial modem	Channel emulator / terrestrial channel	Internal Simplex RF	Emulates the interface between the EU terrestrial RF transmission chain (IF-to-RF up-converter input) and the EU terrestrial modem Tx output
I0105	UE satellite	UE hub	Internal Duplex Ethernet	Emulates UE sub-components internal interface
I0205	UE terrestrial modem	UE hub	Internal Duplex Ethernet	Emulates UE sub-components internal interface
I0305	UE core	UE hub	Internal Duplex Ethernet	Emulates UE sub-components internal interface
I0304	UE core	UE screen	Internal Duplex HDMI	Emulates UE sub-components internal interface
I0711	Satellite gNB-DU	RAN & CN hub	Internal Duplex Ethernet	Emulates interface between satellite gNB-DU and gNB-CU
I0811	Terrestrial gNB-DU	RAN & CN hub	Internal Duplex Ethernet	Emulates interface between terrestrial gNB-DU and gNB-CU

Interface label	From	To	Type	Description
I0911	gNB-CU & CN	RAN & CN hub	Internal Duplex Ethernet	Emulates gNB-CU interfaces with gNB-DUs and CN
I1211	CN router	RAN & CN hub	Internal Duplex Ethernet	Emulates internal CN interface with its Web/In-ternet router (for 8K video server interfacing)
I1213	CN router	Web/In-ternet	External Duplex	Emulated CN Web/Internet access point (for 8K video server interfacing)
I1005	Testbed Command & Monitoring	UE hub	Duplex Ethernet	UE components C&M interface
I1011	Testbed Command & Monitoring	RAN & CN hub	Duplex Ethernet	RAN & CN C&M interface

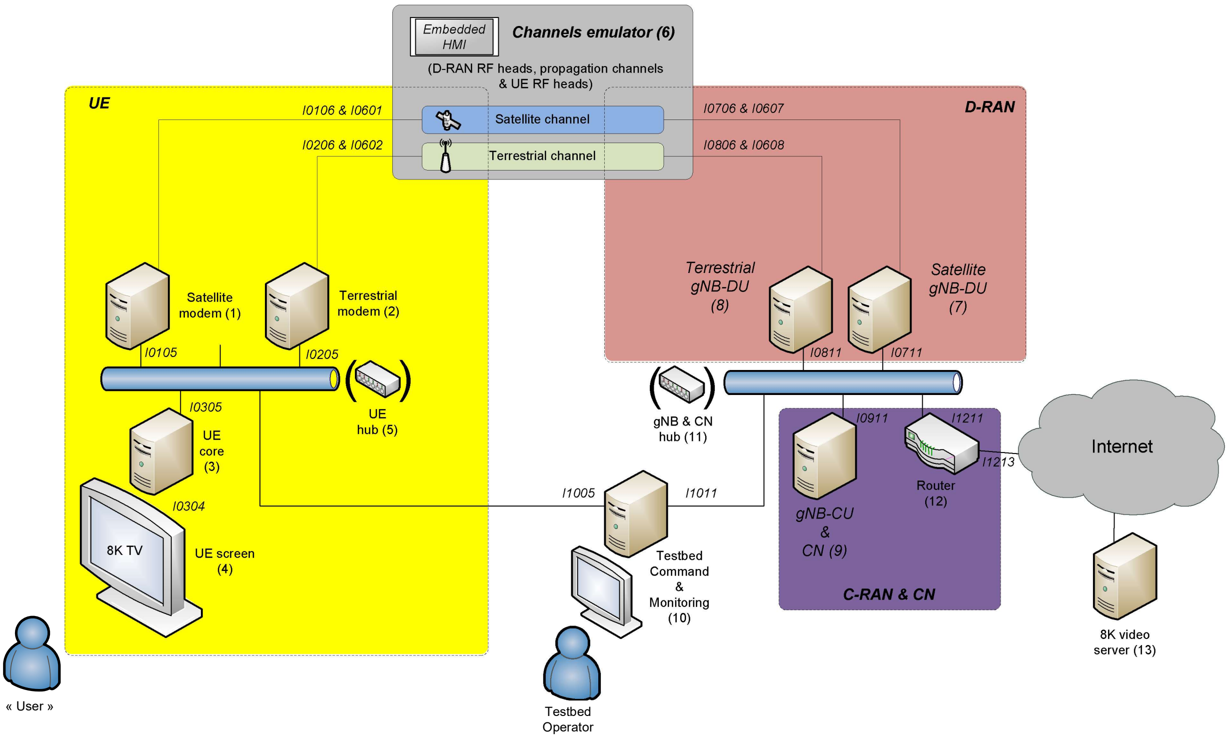

Figure 19: Testbed physical interfaces

5.2Logical interfaces

The MC, as already introduced in D4.1[xvi], is performed to configure a UE to be connected to multiple and heterogeneous access nodes. In a MC scenario, the UE is capable of sending/receiving traffic through radio bearers established with different radio technologies, performing traffic split and switch cases. In the former case, the traffic is split and sent simultaneously to different radio bearers. In the latter case, the traffic sent or received through a radio bearer, can be switched into one or more radio bearers.

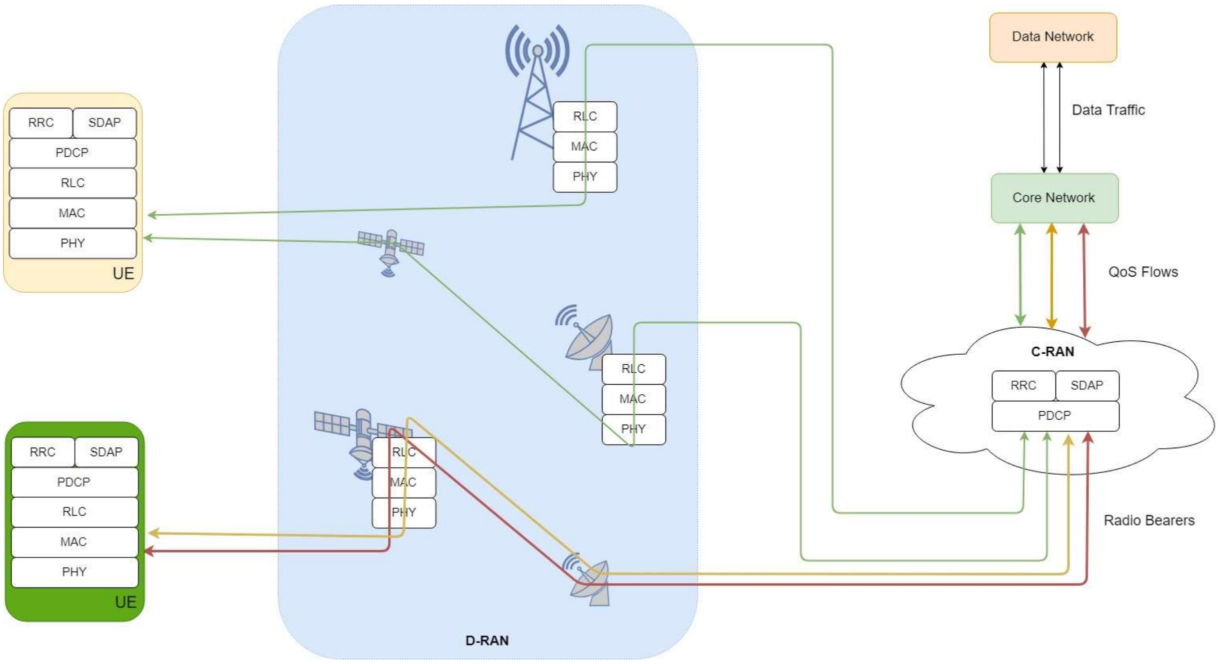

Figure 20: Protocol stacks splitting in the 5G-ALLSTAR multi-connectivity architecture

The 5G NR logical node, the gNB, is split between Central Units (CUs) and Deployed Units (DUs). The benefits for such an architecture are:

- flexible hardware implementation
- coordination of performance features, load management and real-time performance optimization
- adaptation to various use cases

The European Testbed will be arranged in such a way that the PDCP (or higher layer) dynamic traffic splitting/steering/aggregation (addressed in WP4) be tightly integrated with MAC/PHY aggregation functions (addressed in WP3), thus fostering the harmonization, on the one hand, among the relevant protocol stack layers, and, on the other hand, among the different radio access technologies.

The protocol stack in the End-to-End 5G System will indeed be limited to only the functionalities really required to run the scenarios targeted by the project.

The following sections describe these required functionalities in both traffic/user and control planes.

5.2.1.1 User plane

The following figure presents the protocol stacks involved on the Testbed in the User (or "Traffic") plane and how they are split over the different network components. Only the satellite link is represented, as the stacks and split are exactly the same on the terrestrial link.

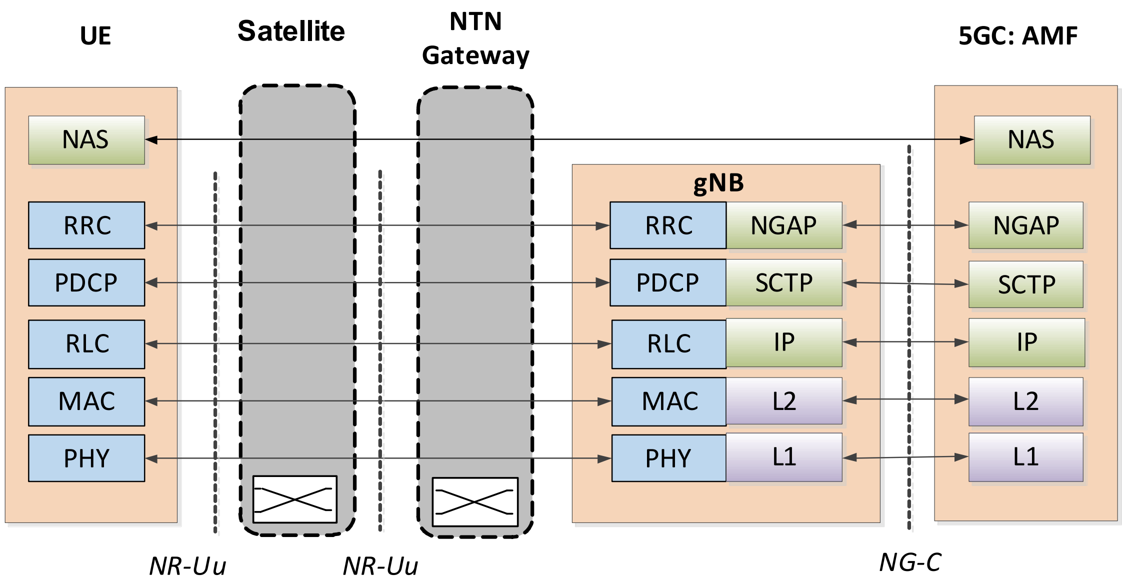

Figure 21: Protocol stacks in the Traffic plane

5.2.1.2 Control plane

The following figure presents the protocol stacks involved on the Testbed in the Control plane and how they are split over the different network components. Only the satellite link is represented, as the stacks and split are exactly the same on the terrestrial link.

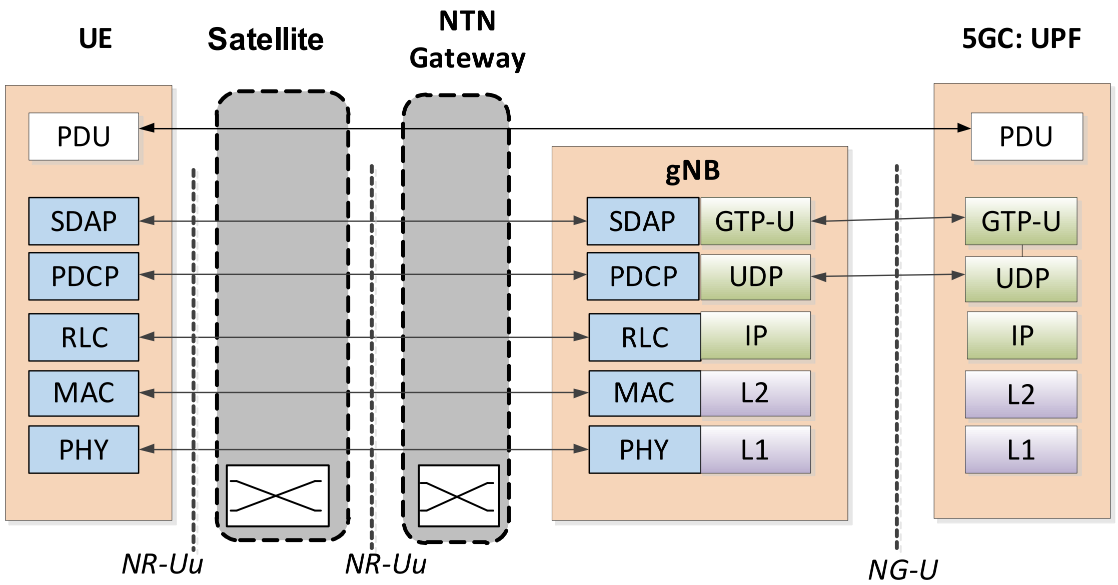

Figure 22: Protocol stacks in the Control plane

6 Conclusion

This document deals with the European Testbed specification. The way the Testbed will be integrated and then validated will be provided in the document D5.6[xvii].

In a later stage of the project, deliverable D2.4[xviii] will provide the further details on the scenarios run on the testbed to validate the 5G-ALLSTAR concepts. This latter will not be limited to the European testbed but will also present scenarios to be run on EU trial platform and on the joint EU-KR Intercontinental platform.

The European Testbed is the first step in a series of concept validation tools to be developed by 5G-ALLSTAR in an incremental way. This incremental integration will be carried out in two distinct phases, each one described in a dedicated document:

- D5.3[xix] for the Testbed integration into the European trial platform
- D5.2[xx] for the European trial platform into EU-KR Intercontinental platform.

This document may need to be revised during the course of the project to take into account:

- the progress on the project, especially at architecture and research pillars (e.g. RRM) levels,
- the evolving 5G standardization context.

Therefore, some further releases of this document may be issued along the project lifetime.

END OF DOCUMENT

References

i D2.1 5G-ALLSTAR, “5G ALL-STAR vision document: Vision, Scope and Goals,” October 2018.

ii 3GPP TR 38.811, “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on New Radio (NR) to support non terrestrial networks (Release 15),” 2018.

iii 3GPP TR 38.821, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Solutions for NR to support Non-Terrestrial Networks (Release 16),” 2019.

iv “Preliminary document of 5G-ALLSTAR architecture, API and interface specifications”.

v From Booz&Co, “Why satellites matter”, http://www.esoa.net/news-info-30.html.

vi D2.2 5G-ALLSTAR “Preliminary document of 5G ALL-STAR architecture, API and interface specifications”, March 2019.

vii 3GPP TR 38.901, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Study on channel model for frequencies from 0.5 to 100 GHz (Release 14),” 2018.

viii 3GPP TR 38.822, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; NR User Equipment feature list (Release 15),” 2019.

ix TR 36.211, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 15),” 2019.

x TR 36.212, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (Release 15),” 2019.

xi TR 36.213, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 15),” 2019.

xii TR 36.321, “3rd Generation Partnership Project; Technical Report Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (Release 15),” 2019.

xiii TS 36.323, “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification (Release 15),” 2019.

xiv TS 36.322, “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification (Release 15),” 2019.

xv TS 36.331, “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (Release 15),” 2019.

xvi D4.1 5G-ALLSTAR, “Mapping of the multi-connectivity functions onto the 5G network architecture”, March 2019.

xvii D5.6 5G-ALLSTAR, “Integration and system level testing for European testbed of 5G cellular and satellite access networks”, January 2021.

xviii D2.4 5G-ALLSTAR, “Final document of service scenarios/applications for PoC”, February 2020.

xix D5.3 5G-ALLSTAR, “Integration and system level testing of proof of- concept phase 1”, May 2021.

xx D5.2 5G-ALLSTAR, “Integration and system level testing of proof of- concept phase 2”, July 2021.