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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 ; Integration ; Testing ; Proof-of-Concept ;

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Executive Summary

This document provides the results of each regional PoC trial platform (European and Korean) as well as the preliminary testing results of each regional functionality that will be involved on the intercontinental interoperability demonstration (PoC “Phase 2”).

Indeed, the PoC trials on both Korean and European platforms are performed independently in a first turn (PoC “Phase 1”), mainly focusing on the showcasing of the respective target service scenarios and associated KPIs specified in WP2.

Both of these phases are performed in the frame of Task 5.4 whose ultimate goal is to validate the 5G-ALLSTAR Project’s reference system architecture identified in WP2.

This document is organized as follows:

- Chapter 1 introduces the deliverable into its related Work Package and Task and shows how the Phase 1 trial platforms bridge the testbeds phase and the final demonstration phase. The chapter reminds also the different high level System Proofs-of-Concepts (PoCs) leading to what will be demonstrated on both regional trial platforms.
- Chapter 2 focuses on the European trial platform and details its architecture, the incremental integration and validation process followed to make the European testbed evolve into the European trial platform.
- Chapter 3 focuses on the Korean trial platform and details its architecture, the incremental integration and validation process followed to make the Korean testbeds evolve into the Korean trial platform.
- Chapter 4 concludes on the results obtained on both regional sides for the PoC Phase 1 and opens on their impacts on the PoC Phase 2 and its final demonstration.

Contents

List of Figures

List of Tables

List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation
APP	Application
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
CEA	Commissariat à l'Energie Atomique et aux energies alternatives
C/N	Carrier to Noise ratio
CRAT	Consorzio per la Ricerca nell'Automatica e nelle Telecomunicazioni
cRRM	Central Radio Resource Management
CU	Centralized Unit
Dx.y	Deliverable x.y
DASH	Dynamic Adaptive Streaming over HTTP
DC	Dual-connectivity
dRRM	Distributed Radio Resource Management
DVB	Digital Video Broadcast
DU	Distributed Unit
eMBB	Enhanced Mobile Broadband
ETRI	Electronics and Telecommunications Research Institute
EU	Europe
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FhG	Fraunhofer-Gesellschaft
FhG-IIS	FhG Institut für Integriete Schaltungen
FSS	Fixed Satellite Service
GEO	Geostationary Earth Orbit
gNB-CU	next Generation Node B Central Unit
gNB-DU	next Generation Node B Distributed Unit
GSE	Generic Stream Encapsulation
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IT	Information Technology
KPI	Key Performance Indicator
KR	(South) Korea
KTP	Korean Trial Platform
KTSat	Korea Telecom Satellites

L1	Layer 1 (OSI model)
LETI	Laboratoire d'Electronique et de Technologie de l'Information
Mx	Month x
MAC	Medium Access Control
MC	Multi-Connectivity
mmWave	Millimetre Wave
NR	New Radio
NTN	Non-Terrestrial Network
NW	Network
OAI	Open Air Interface
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
PC	Personal Computer
PCIe	Peripheral Component Interconnect express
PHY	Physical (layer)
PLL	Phase-Lock Loop
PoC	Proof-of-Concept
PT-RS	Phase Tracking Reference Signal
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RF	Radio Frequency
RRM	Radio Resource Management
RTT	Round Trip Time
Rx	Receive
Sce	Scenario
SNR	Signal to Noise Ratio
SW	Software
Tx.y	Task x.y
TAS	Thales Alenia Space
TC	Traffic Controller
TCP	Transmission Control Protocol
TN	Terrestrial Network
Tx	Transmit
UC	Use Case
UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra High Definition
UL	Uplink
VPN	Virtual Private Network
VR	Virtual Reality
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
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 enables 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 and heterogeneous Communication Networks.

Providing tight interworking and integration especially between terrestrial and non-terrestrial (e.g., satellite) networks might be a cost-effective manner to improve coverage and service quality.

The 5G-ALLSTAR project aims at developing a series of key technologies enabling 5G User Equipments to access services via multiple and simultaneous radio links, indifferently of their nature, may they be exclusively terrestrial or based on the use of a Communication Satellite (Satcom) infrastructure.

This multi-connectivity can be offered to Users in two different manners:

- With a Direct Access to User Equipments (UEs): UEs are directly accessing the 5G networks and are able to manage the hybrid Satellite-Terrestrial connection. For this, different types of terminals can be considered, depending on the data rates expected: from terminals with dual RF sections (involving a dedicated VSAT for satellite links in addition to the terrestrial antenna) to a single handset.
- With an Indirect Access to UEs: the UE connects in Wi-Fi or equivalent non 5G point-to-point technology to an intermediate 5G relay. The satellite link can use standard low layer protocols customized to satellite transmissions such as DVB and on transport higher protocol levels of the 5G standard. The hybrid connection management is performed by the local relay and fully transparent for the User Terminal.

Both connectivity options are studied in parallel by the 5G-ALLSTAR partners, Europeans focusing on Direct Access and Koreans on Indirect Access.

1.2 WP5 activities overview & T5.4 objectives

WP5 is responsible for prototyping, integration and validation 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.

These testing tools will demonstrate the service scenarios defined in WP2 during the project.

WP5 pursues indeed 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.

In order to demonstrate the 5G-ALLSTAR PoCs of an integrated system architecture capable of multiple connectivity to provide 5G services, WP5 is composed of the following tasks:

- Task 5.1 aims at delivering an integrated and validated European testbed implementing partner's key concepts for a hybrid satellite-terrestrial multi-connectivity offered to a UE, all the RF links being in 5G NR and sharing 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 demonstrating the 5G-ALLSTAR PoCs, first with the testbeds, and in a second turn with real over-the-air links on the trial platforms. These activities are initially undergone independently by European and Korean teams, each one implementing slightly different concepts. Then, both trial platforms will be interconnected for a final demonstration, not only of all the concepts developed on the project, but also of their full interoperability.

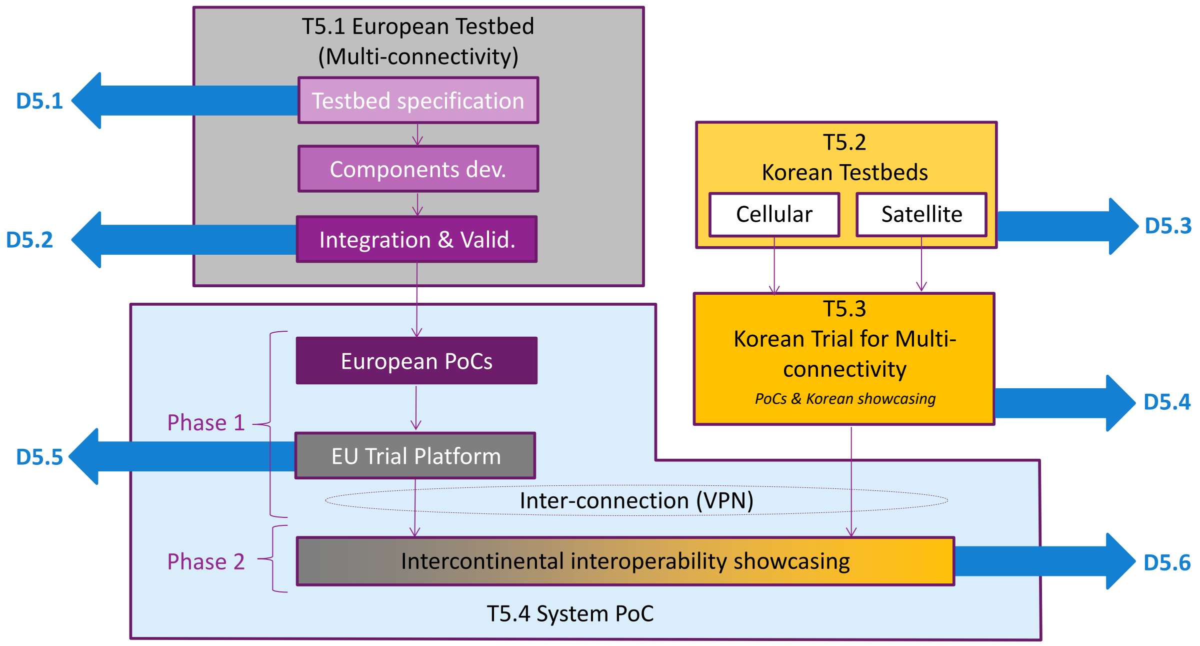

Figure 1: WP5 Tasks logic, Testing means & Deliverables

T5.4, dedicated to concepts proving, is composed of two distinct and sequential phases:

- Phase 1: for data collecting on the European multi-connectivity testbed and then its evolution to the European trial platform configuration with the introduction of real over-the-air links.
- Phase 2: for the interconnection of the European and the Korean trial platforms by the introduction of an inter-continental VPN. Once validated, this inter-continental platform will be used for the project's final demonstration.

1.3 European multi-connectivity concept: 5G NR in the same frequency bands for Direct Access

1.3.1 European technological concepts

On the European side, the high-level System concept derived into Technological concepts to be implemented on key components is the Non Terrestrial Networks seamless integration into 5G Terrestrial Networks with Direct Access.

In this case, Satellites coverages can be considered as fully standard 5G cells complementing the Terrestrial cells.

Service links (up and down, or also called forward and return links) offered by Satellites to User Equipments shall allow Direct Access thanks to:

- The use of 5G NR waveform over Satellite links
- Satellites Service links available in the same frequency bands as 5G Terrestrial Networks

These two pretty high-level requirements can be then flown-down to the different key components of the reference system architecture defined in WP2.

This leads to the identification of the following series of key components concepts to be implemented and then proven with the different Project’s Testbeds and Trial Platforms :

- PoC#1: possibility to coordinated efficiently NTN and TN in common FDD frequency bands, despite the large propagation delays introduced by Geostationary satellites (large delay control loops)
- PoC#2: hybrid TN-NTN dual connection management by traffic switching and steering based on links relative qualities monitoring
- PoC#3: 5G NR L1 and MAC layers adaptations to be compatible with large propagation delays introduced by Geostationary Satellites
- PoC#4: compatibility of 5G NR and its large PAPR with transparent Payloads
- PoC#5: traffic steering and network selection in 5G networks based on reinforcement learning
- PoC#6: wardrop equilibrium based control
- PoC#7: transmissions in BF-OFDM for a more spectral-efficient use of the Radio Resource (high out-of-band rejections)
- PoC#8: full compatibility of BF-OFDM transmissions with 5G NR (CP OFDM) receivers

Depending on their respective backgrounds and interests, European partners shared between them the implementation of these Technical Concepts on the key components:

- NTN-TN hybrid Radio Resource Management with PoC#1 and PoC#2: TAS
- 5G NR Satellite modems with PoC#3 and PoC#4: FhG IIS
- Multi-Connectivity and QoE management with PoC#5 and PoC#6: CRAT
- Terrestrial modems with improved channel filtering with PoC#7 and PoC#8: CEA Leti

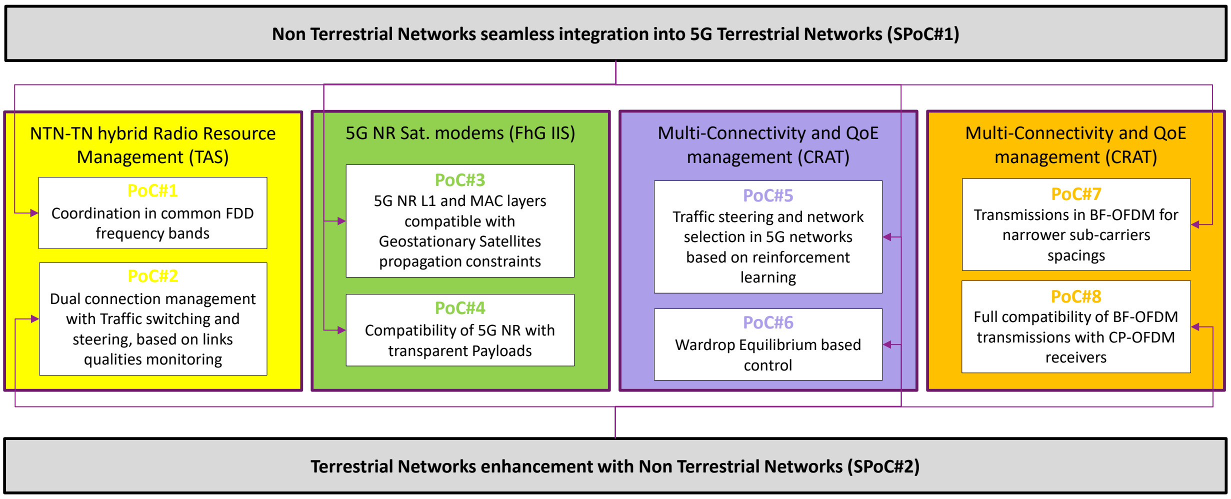

Figure 2: Flow-down of the System-level Concepts (SPoCs) to Technical Concepts (PoCs) for System Key Components

1.3.2 Tools for European Concepts proving (PoCs): form Testbed to Trial Platform

Two different testing tools were considered on European side to prove the different System-level and Key components-level concepts:

- Testbed: the reference architecture is implemented with emulated RF paths thanks to the use of a channel emulator
- Trial platform: identical to the Testbed, but with real over-the-air service down-links (or ”forward” links)

This two steps approach was adopted, not only for incremental integration reasons, but also for the different added-value, each step could bring to PoCs proving.

Indeed, the Testbed, with its channel emulator offers the possibility to emulate different propagation channel profiles as well as different UE terminal types and even, potentially, different satellite orbits.

The Trial Platform, on its side, introduces on service down-links over-the-air transmission channels to implement a real 5G cellular mmW radio access in a frequency band reserved by Europe for 5G (n257: 26.5 – 29.5 GHz) to prove the whole European concepts chain with actual over-the-air satellite and terrestrial links sharing the same spectrum.

The accurate frequency band which will be used is actually a fraction of the 5G band as our prototype modems have limitations in terms of bandwidth and an authorization to transmit over-the-air had to be obtained. CEA is allowed to use on its Grenoble site the 26.5 – 27.0 GHz frequency band which is far enough in terms of bandwidth for 5G-ALLSTAR purposes.

Note that no satellite is currently operating in this frequency band so the use of actual in-orbit resources was not possible on the trial platform. The nearest Satellite-dedicated frequency band is indeed the FSS Downlink Ka-band (27.5 – 31 GHz).

It was considered by the 5G-ALLSTAR partners more technically relevant to use a real 5G frequency band even if no real satellite link could be involved rather than using real in-orbit resources in frequency bands not allocated to 5G.

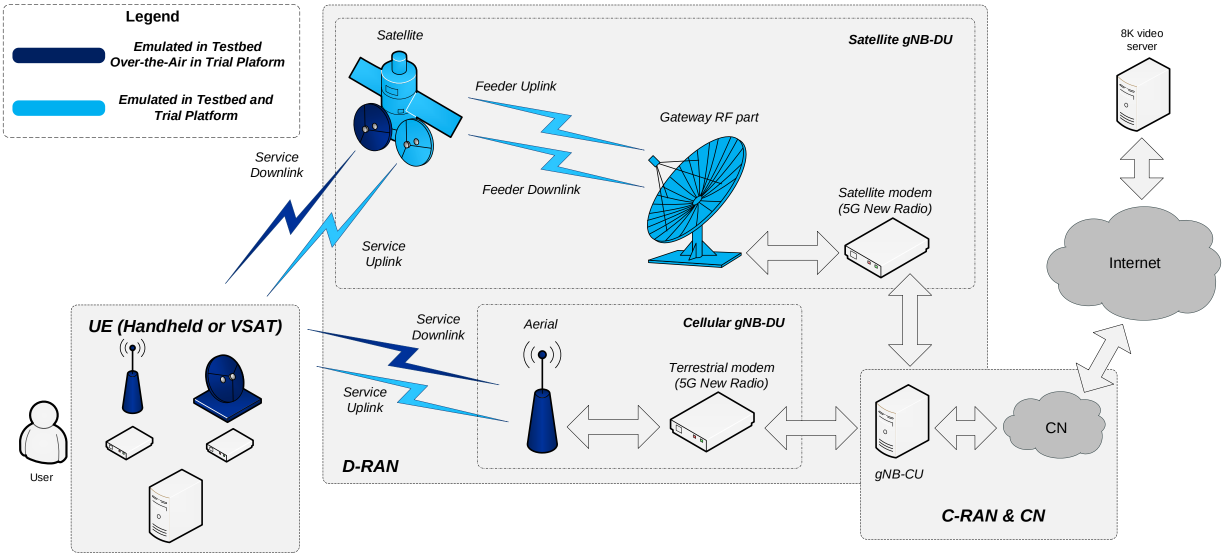

Figure 3: respective roles of Channel Emulator in European Testbed and Trial Platform

1.4 Korean dual-connectivity concept: heterogeneous network aggregation at the IP layer

Korean dual-connectivity (DC) is based on an IP (Internet Protocol) layer traffic aggregation of heterogeneous networks consisting of a satellite network and a cellular network. In the DC, the satellite network does not support any 5G-like air interface, and adopts a waveform of digital video broadcasting (DVB), which has been used widely in commercial satellite service networks. In the DC, the cellular network adopts the 3GPP Release-15 standards as the baseline for the implementation. The cellular and satellite networks are integrated with an IP layer traffic controller (TC) located at a UE side. In the DC schemes, two paths of different networks should have common layer(s). That can be physical layer (PHY), media access control (MAC) layer, network (NW) layer, transport (TRA) layer, or application (APP[1]) layer. In the Korean DC scheme, each radio access technology (RAT) has separate layers up to the TRA layer, and has the APP layer in common. The APP can be smartphone applications, e.g., an application for video streaming in the Korean side platform.

The Korean DC concept is illustrated in Figure 4 where a vehicle UE is associated with a TC. Note that the TC module is located at the UE side rather than the network side. With the TC configuration, all the packets from an application server to the TC are duplicated, and one stream is selected before the output of the TC. With the redundancy from the duplication, overall reliability in transmitting data can be improved, which can facilitate the service continuity in the video streaming service. Meanwhile, for improvement of data throughput or lower latency, sophisticated algorithms for load balancing or packet splitting need to be considered while the TC location should be changed to the network side.

[1] M. T. Suer, C. Thein, H. Tchouankem, and L. Wolf, "Multi-connectivity as an enabler for reliable low latency communications – An overview," *IEEE Commun. Survey & Tutorials*, vol. 22, no. 1, First Quarter 2020.

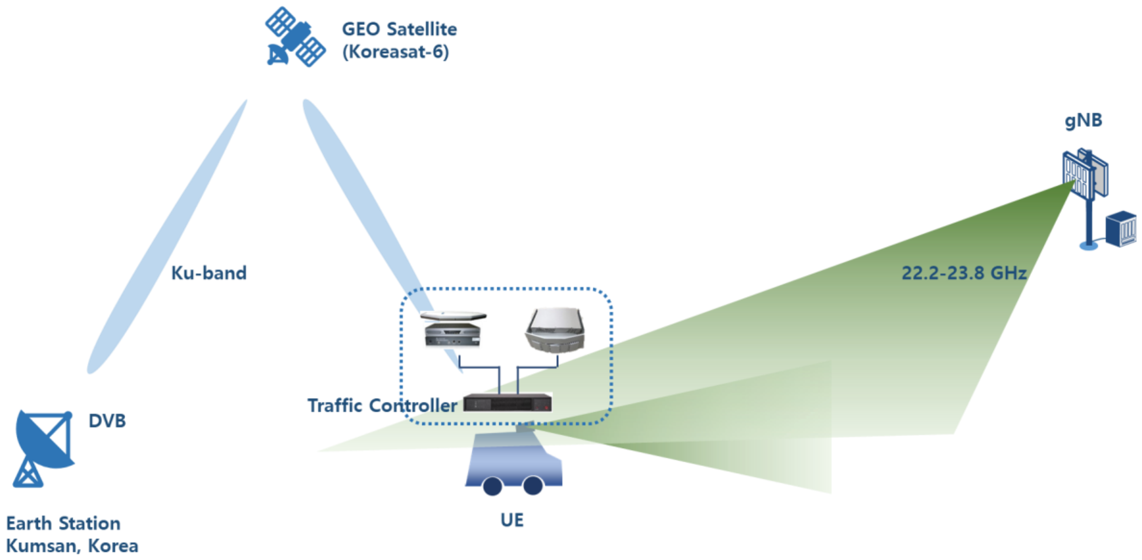

Figure 4: The concept of the Korean dual-connectivity

Another characteristic of the Koran DC concept is involved with the asymmetry of the capability of data throughput. The cellular access network can allocate 300 MHz for a vehicle whereas the satellite access network can allocate up to 2 MHz for a vehicle UE, which is proportional to the available budget for the commercial service. With the difference in the allocated bandwidth, the cellular access path can support high-definition video streaming services over 4K, whereas the satellite access path has some limitation on the video quality or buffering problems. Thus, the service scenarios of the use cases for the Korean consortium have to take this reality into account.

2 European Trial Platform

2.1 Difficulties encountered for Trial Platform implementation

2.1.1 Summary of difficulties during trial platform preparation phase

The main element which impacted WP5 activities is, from far, the Covid-19 crisis and the different lockdown periods it produced in each one of the partners countries, leading to some activities freezing and then tasks durations stretching… when it was possible to resume them.

Keeping initially the project's end date unchanged, the induced drifting of developments, unitary validations and first integration steps lead to a squeezing of the durations allocated to the last testbed integration steps (especially multi-connectivity testbed) and the following two PoC phases (trial and intercontinental platforms).

The initial plan that was set to reach the multi-connectivity testbed, and then trial platform configuration, is described on Figure 5. Terrestrial connectivity testbed (in Grenoble) and satellite connectivity testbed (in Erlangen) were supposed to be merged at Fraunhofer premises in Erlangen to obtain the multi-connectivity testbed.

The multi-connectivity testbed, could then be upgraded to the European trial platform configuration by the integration of all the required RF equipments to implement over-the-air service down-links.

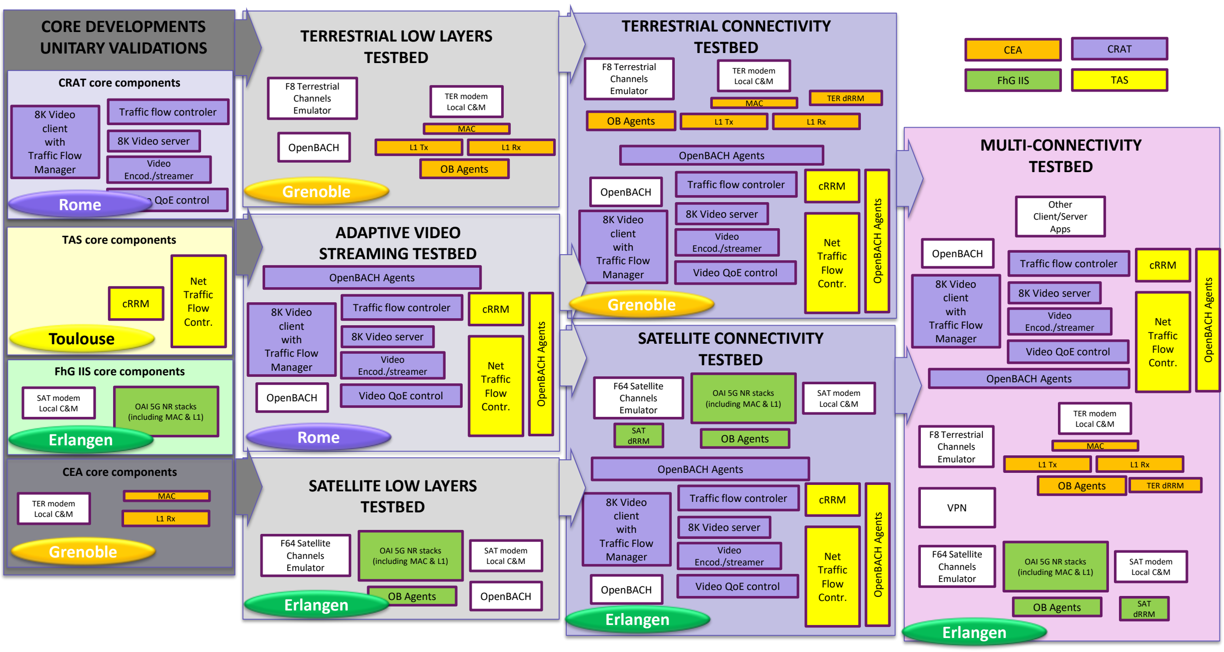

Figure 5: European MC testbed incremental Integration & Validation (initial plan)

But, in early 2021, as it was still impossible for European partners to travel, and as Germany was facing a new lockdown period, it was decided to perform the multi-connectivity testbed integration in Grenoble instead of Erlangen. German partners were thus meant to ship their components (satellite modems and F64 channel emulator) to Grenoble and then come at CEA's premises to integrate these components with the rest of the testbed in June. No remote support from FhG IIS to CEA would have been efficient enough to fully complete this task with respect to its complexity, so German partners had to come in Grenoble for this.

In early March, as heavy uncertainties were still remaining on the possibility for German partners to travel, and as just some few months were still remaining to complete the project, it was decided to shift to what was called the "splitted configuration" for the multi-connectivity testbed. All the testbed components, except the FhG IIS ones, were supposed to be integrated together at CEA in Grenoble and then connected with a VPN to the FhG IIS components in Erlangen.

This solution was implying first to integrate all the CRAT and TAS components with the CEA components in Grenoble. As these components were purely software, no shipping was required and their integration with the CEA's components was pretty straight forward, only requiring some prompt remote support from CRAT and TAS. This defined a "terrestrial connectivity testbed" on which partial validations could be undergone, first for the multi-connectivity testbed preparation and then for the trial platform anticipation with the integration of RF equipments on the terrestrial service down-link. Meanwhile FhG IIS could, on its side, integrate cRRM with their "satellite low layers testbed" and proceed thus also to some partial validations preparing the multi-connectivity testbed final integration.

For the last testbed integration step, the aim was to interconnect the Grenoble and Erlangen sites with a VPN. Unfortunately, the IT security policies in both institutes prevented European partners from circulating data as expected. The CEA IT department tried to get around these rules, without success, as explained in [D5.2].

So in May, as the multi-connectivity testbed was still remaining to be integrated and validated whereas travels were still significantly restricted in Europe, partners asked for a project duration extension of 4 months, shifting the project's end from end of June to end of October 2021.

The integration plan was therefore modified one more time, as detailed on Figure 7. It was preferred to postpone the multi-connectivity testbed integration to a period where all the partners could be together at the same time in Grenoble as it was thought that working altogether in a collocated and fully integrated team would maximize work efficiency. With respect to partner's respective availabilities, but also to FhG IIS hardware components availabilities (F64 is a resource shared between different projects at FhG… and 5G-ALLSTAR was initially meant to end in June), this integrated team phase was decided to be limited to a single week ("trial integration week"), scheduled in October. The primary objective of this week would thus be to obtain an operating multi-connectivity testbed and, if time would allow, to proceed to the following PoC phases (trial and then intercontinental platforms).

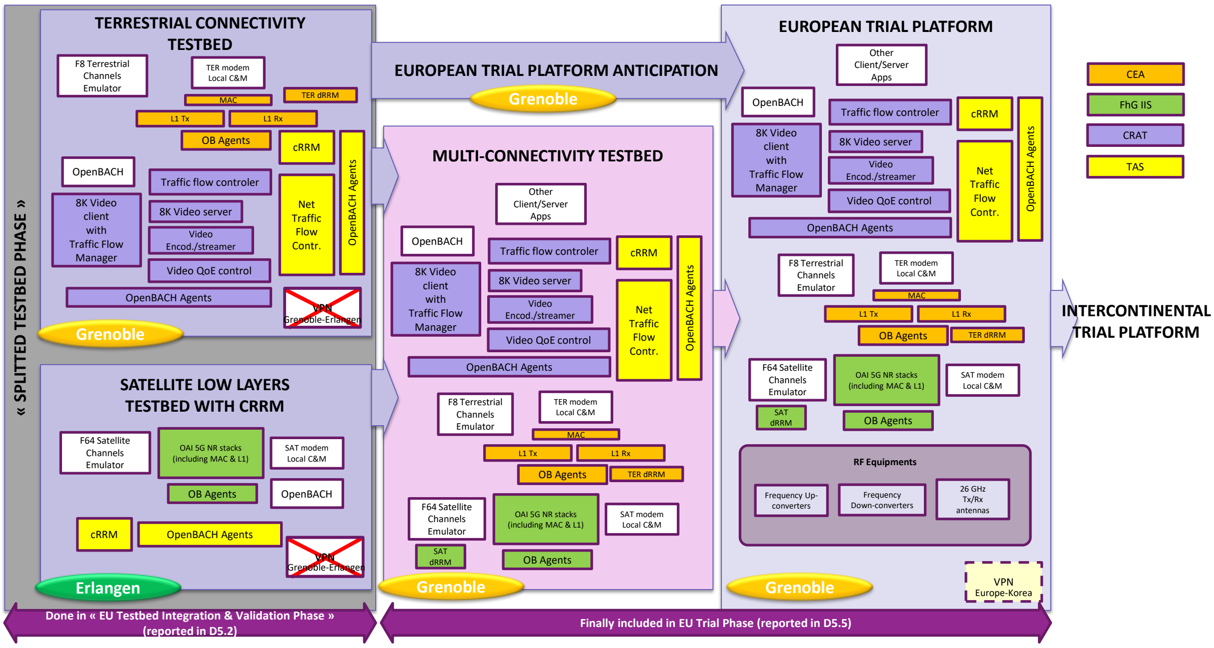

Figure 6: European Testbeds and trial platform incremental integration

Figure 7 summarizes in a graphical way the difficulties encountered on WP5 and how its schedule was adapted.

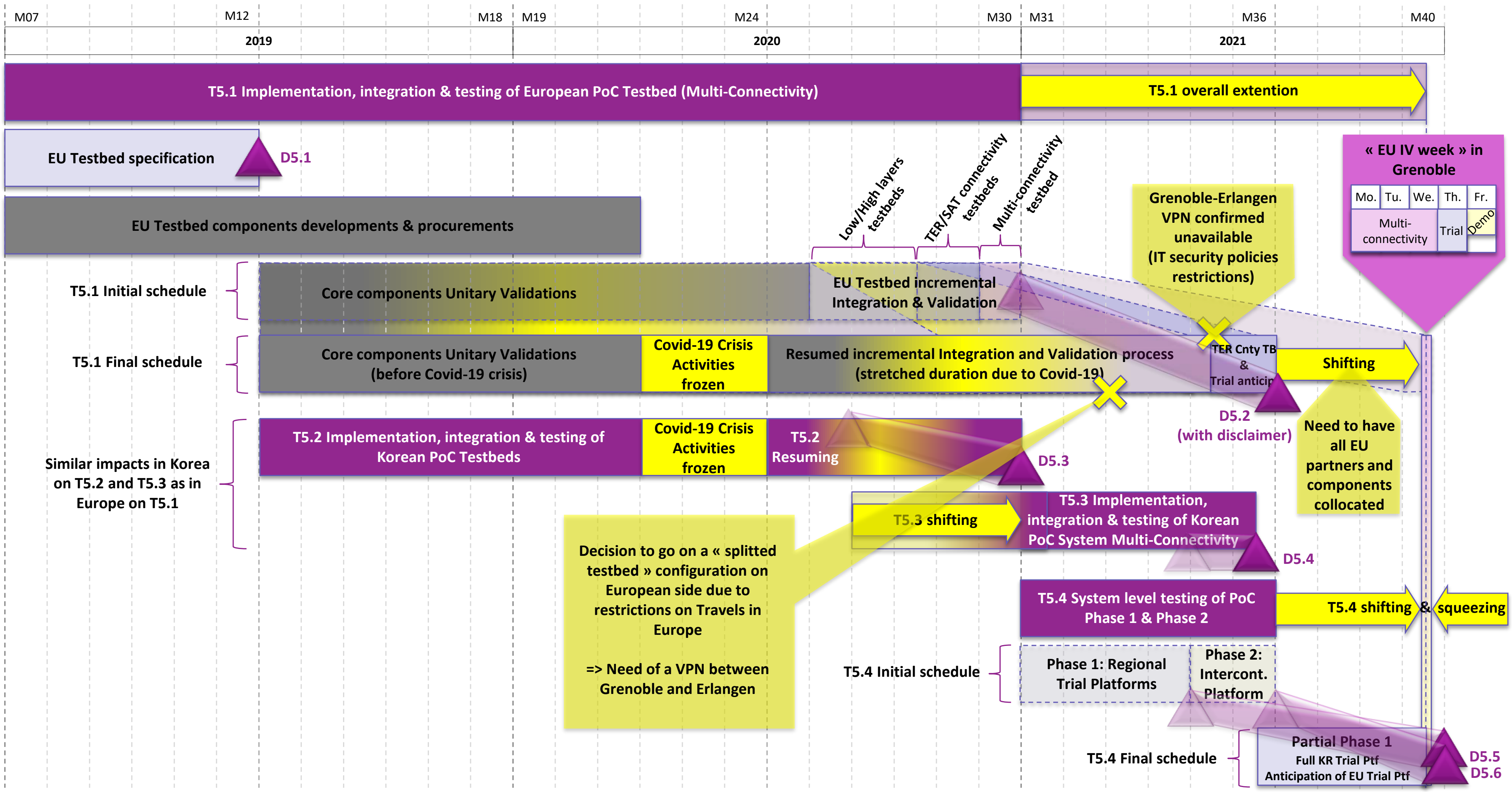

Figure 7: WP5 schedule evolutions

2.1.2 Summary of difficulties during the trial integration week

As shown in the previous paragraph, if Covid-19 crisis had not happened, several weeks would have been available to do, not only the testbeds and trial platforms integrations and validations, but also to proceed to pretty extensive testing sessions in order to prove the relevancy of the different project's concepts and, when appearing necessary, tune the different components and algorithms partners developed. Potentially, this could have even been done differently, depending on the different use cases considered. The obtained conclusions and the collected data were expected to support then some standardization actions, mainly at 3GPP level.

When, in June, the project extension was agreed and the schedule and integration plan were revised, it appeared clearly that the project had no more time for extensive data collection campaigns and had now, on the top of all, to focus on validating at least the overall system concept, with subcomponents in their primary states, rather than trying to find out optimizations for the different use cases considered.

Even with this scope, the objectives of validating the multi-connectivity testbed and then the trial and intercontinental platforms were still pretty ambitious with respect to the remaining project's time.

Unfortunately several problems occurred that dramatically slowed the integration work (see below). Some significant time was also required to configure/re-configure the network setups for the different tests and trials (unitary validations ; EU trial platform; intercontinental trial platform).

Taking collegial decisions at the right time during the week revealed to be necessary, while managing the remaining time according to the available possible solutions and their constraints.

Finally the different encountered problems have led to the simplified architecture of the trial platform described in §2.2.1.

Table 1: issues encountered during the trial integration week in Grenoble

Component	Issue	Solution or descoping decided
SAT Modems USRPs	Return link not working	Add a common time/frequency reference to both USRPs
F64	Additive unexpected transit time when TER channels added	**Descoping**: F64 removed
SAT Modems OAI	OAI crash when traffic throughput too high (critical for TCP)	Add throughput limitations on network interfaces via Linux Kernel
IP addressing	IP addressing plan inconsistency with CEA network restrictions (security rules)	IP addressing plan update
IP routing	IP routes not working correctly in multi-connectivity (2 answers …)	Limit validations only to paths involved in the considered use cases
SAT Modems	Real IP throughputs not estimated	Find real throughputs achievable with iPerf tests
TER Modems	Real IP throughputs not estimated	Find real throughputs achievable with iPerf tests
SAT Modems	Wrong transit time applied digitally when F64 removed (twice the right value)	Set to the right value

Component	Issue	Solution or descoping decided
SAT Modems	250 ms transit time not tested on F64 (only 125 ms)	**Descoping**: remove F64 and USRPs as timing advance tuning process for this case takes too much time
TER Modems	Real MCS thresholds to be verified	Measurement session performed
SAT Modems	Real MCS thresholds to be verified	Other issues on SAT Modems prevented from performing a measurement session **Descoping**: cRRM will not modify SAT modems MCS
cRRM	No time to validate on the final testbed in Grenoble the dynamic allocation of RB on satellite links	**Descoping**: use only fixed satellite bandwidth with static number of RB (independent from cRRM)
YouTube streaming	Not possible to stream from UE PCs to YouTube	Install OBS (Open Broadcast Software)
OpenBACH	Disk space saturation on the VM hosted on the physical machine running gNB-Terrestrial, and where the OpenBACH and 8K video servers are installed due to too heavy and numerous log files	Find a solution with available tool to extend the allocated disk space to the VM without virtual hard disk reformating in order not to lose already installed content
SAT Modems	Very low IP throughput in QPSK (3 Mbps in 40 MHz BW)	**Descoping**: only use 16-QAM
SAT Modems	Live debug and configuration changes of OAI setup very long	No solution Participates to the different descoping related to SAT links
IP routing	IP forwarding rules configuration with the final testbed setup: error introduced at client level when configuring/debugging the application of Forwarding rules on other machines	Reapply correct configuration But detection of the misconfiguration took time after multiple tests with alternative MP-TCP path configurations and network setup
Video streaming	Problem in gathering terrestrial path KPIs for Video Streaming in Grafana (Openbach visualization system)	Not enough time to fix this issue

As mentioned above, the multi-connectivity testbed phase and the trial platform phase were merged in some way. Only 4 days with all partners physically together in Grenoble were dedicated to this phase, with all the following operations to be done: unpacking and assembly of the satellite testbed package from Erlangen, tests to obtain the same performance than in Erlangen, plugging of the RF and antennas to the satellite USRP (and calibration), connection of the terrestrial and satellite testbeds, setup and calibration of the channel emulator, addressing, forwarding and routing rules (requiring non-standard configuration for multi-connectivity), parallel cRRM calibration and update, and finally playing of scenarios and measurement collection, physical and logical network integration of all machines external to CEA and adjustment of their configuration.

2.2 Implemented Trial Platform architecture & components

2.2.1 Trial platform architecture overview

Due to the difficulties encountered during the integration week (see §2.1.2), the architecture of the trial platform was downsized to Figure 8.

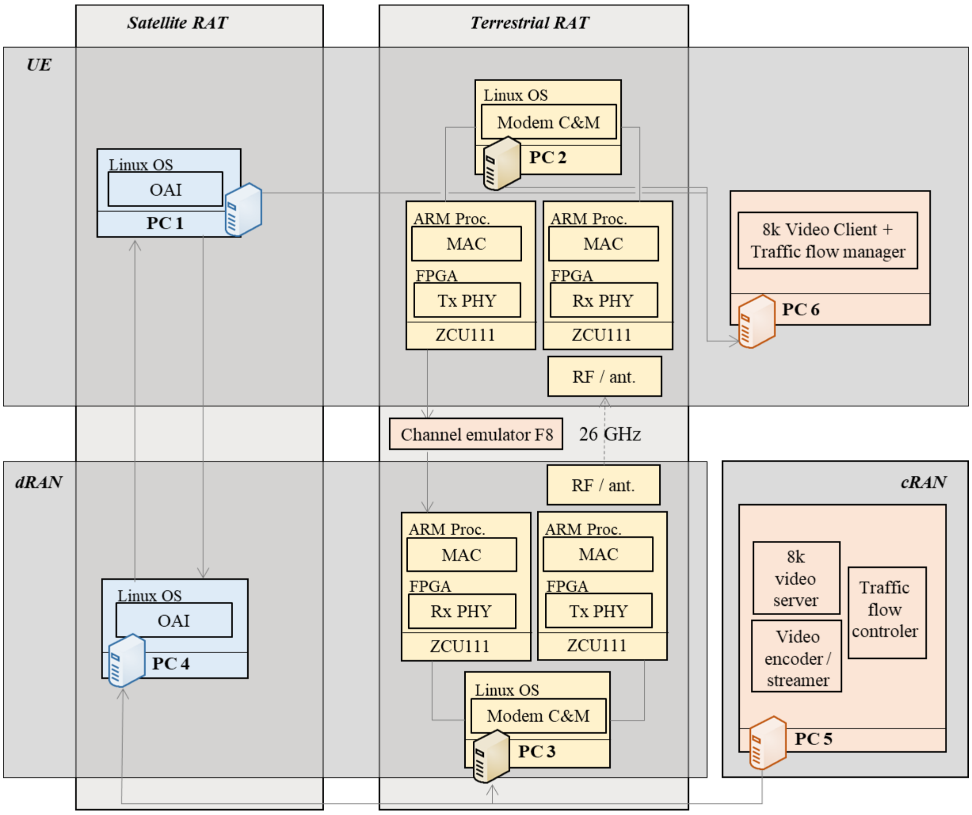

Figure 8: European trial platform architecture

2.2.2 New components specific to trial platform

The role of the new components added to the terrestrial testbed to insert it into the trial platform is to implement real over-the-air transmission links in a 5G millimetre wave frequency band. To limit the involved hardware, it was decided to restrict these over-the-air transmissions to service terrestrial down-link only (see §2.1.2). Service down-link is indeed the most demanding link, compared to service up-link, so demonstrating successfully the frequency band sharing mechanisms on this link should validate also the applicability of the concepts on service up-link.

2.2.2.1 Frequency up-converters

The role of the frequency up-converters is to translate the modems output signals, from intermediate frequency band (~ 1 GHz) to the selected 5G frequency band (26.5 – 27.0 GHz).

The RF up-conversion module is based on an assembly of RF analog devices (PLL and Upconverter) and control components. The RF module is controlled by USB. This interface allows the RF to be controlled directly by the Modem (ZCU card) or by a PC. The schematic diagram is shown below:

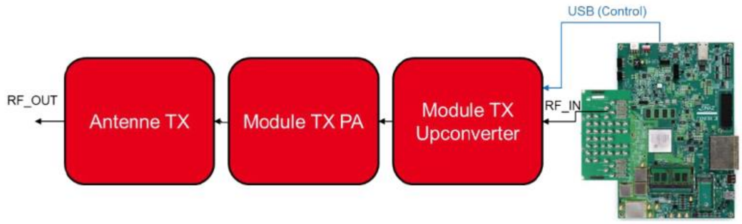

Figure 9. Frequency up-conversion

The detail of the assembly is shown on Figure 10.

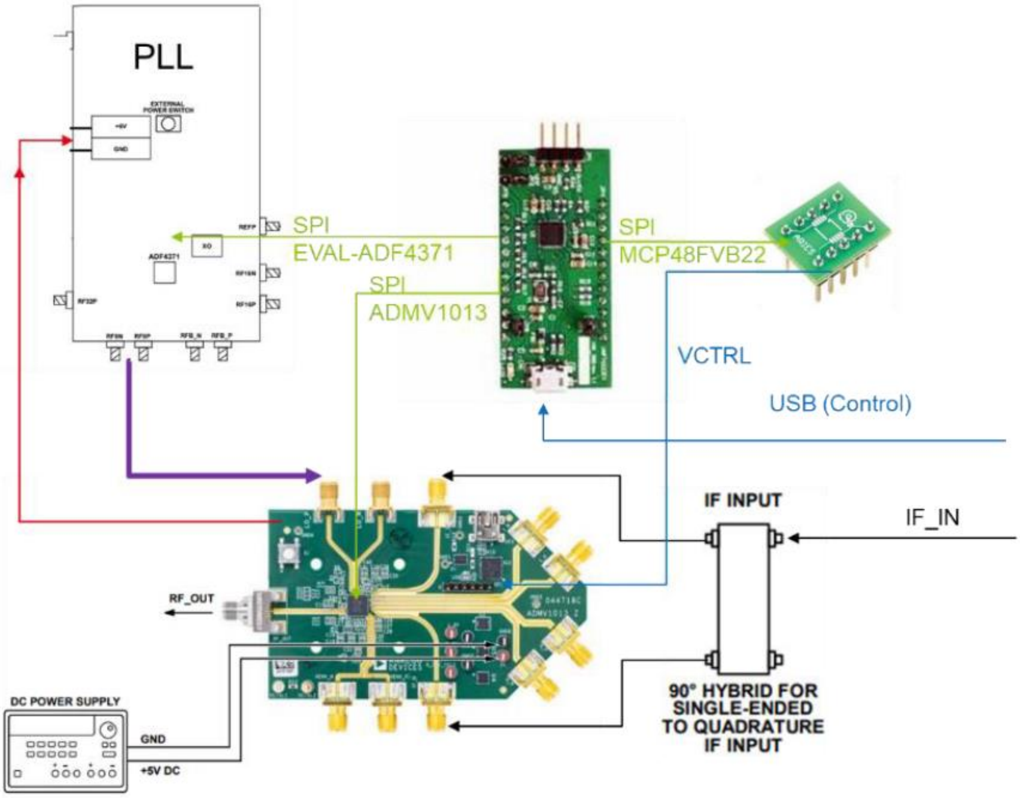

Figure 10. Detail of assembly of frequency up-conversion

The PLL board (AD4371) is configured to provide an LO at Fc/4 to the up-conversion circuit (AD1013). We use the RF-8N/RF-8P differential channel. The signal to transpose in frequency is a signal in intermediate frequency (F_{IF}~1GHz). A hybrid is implemented to feed the differential inputs. This hybrid also allows us to choose the strategy of the position of the LO with respect to the signal (F_{RF}±F_{IF}). These two possibilities are made possible by changing the input port of the hybrid.

The assembly of the boards is shown on Figure 11.

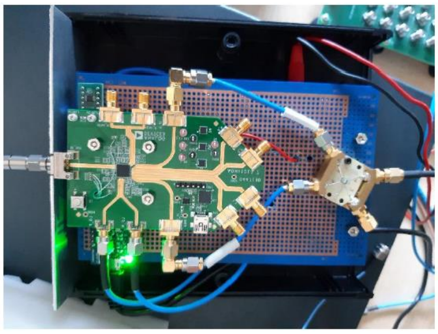

Figure 11. Assembly of the RF up-converter boards

2.2.2.2 Frequency down-converters

The role of the frequency down-converters is to translate the 5G frequency band (26.5 – 27.0 GHz) signals received by the UE and gNBs receive antennas to intermediate frequency band (~ 1 GHz) compatible with the modems.

The RF down-conversion module is based on an assembly of RF analog devices (PLL and Up-down converter) and control components. The RF module is controlled by USB. This interface allows to control the RF directly from the Modem (ZCU card) or from a PC. In particular, it is possible to control an attenuator which can act as an AGC (Automatic Gain Control). The schematic diagram is shown below.

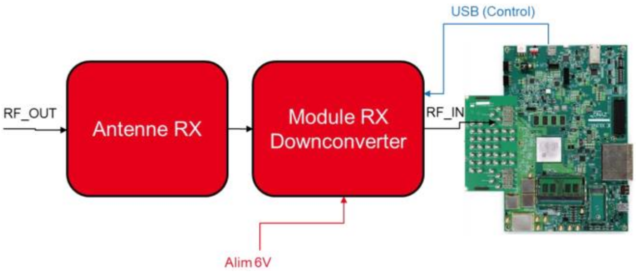

Figure 12. Frequency down-conversion

The PLL board (AD4371) is configured to provide an LO at Fc/4 to the "down-conversion" circuit (AD1014). We use the RF-8N/RF-8P differential channel. The resulting signal is an intermediate frequency signal (~1GHz). A hybrid is implemented to convert the differential output into a single ended format. The assembly diagram is shown

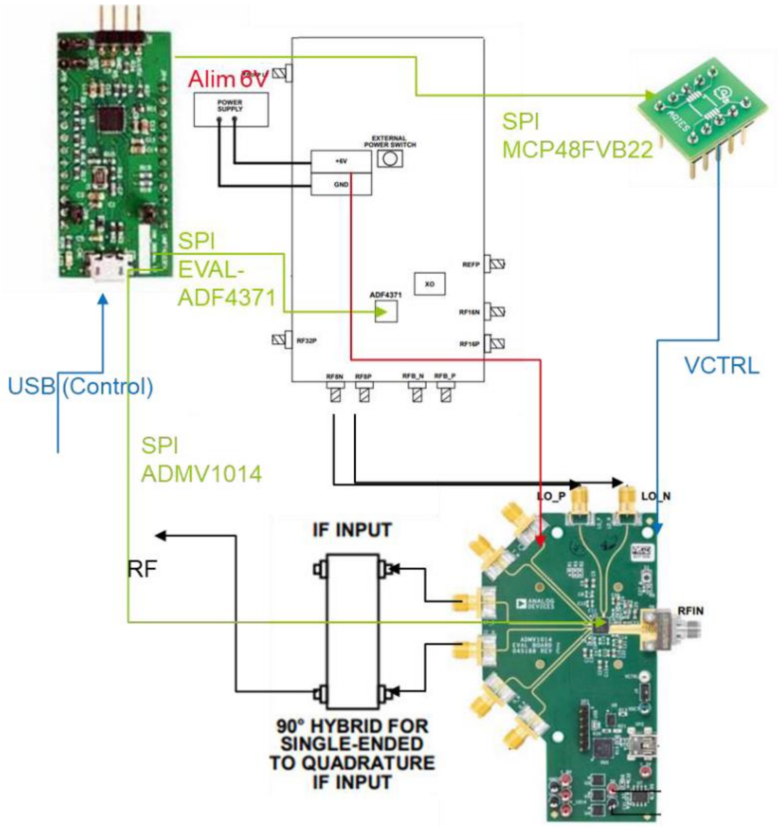

Figure 13. Detail of assembly of frequency down-conversion

2.2.2.3 26 GHz Tx/Rx antennas

Receive and Transmit antennas are used for the 26 GHz over-the-air links. These antennas are identical on User and gNBs sides. We use 10 dBi horn antennas, see Figure 14.

Figure 14. 26 GHz antenna

2.2.3 Integration & Validation with new components

2.2.3.1 Terrestrial over the air transmission

Before the final integration of satellite and terrestrial links in the EU trial platform, validations have been done on the terrestrial part. The link from UE to gNB was set over the air at 26 GHz and the downlink was wired through the F8 channel emulator. A webcam stream was sent from UE to gNB. Figure 15 shows the setup.

Figure 16 presents the screen on which the webcam stream is displayed and the Graphical Interface on which some KPIs are shown. Here we checked 256-QAM transmission to be transmitted error-free.

Note that the downlink tests – not reported here - was performing with equivalent performances.

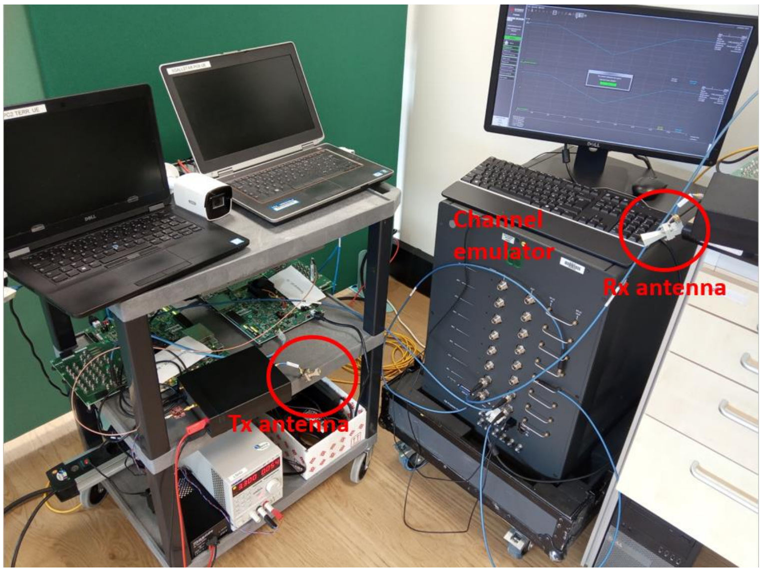

Figure 15. Validation of over the air uplink. View of the antennas and of the channel emulator

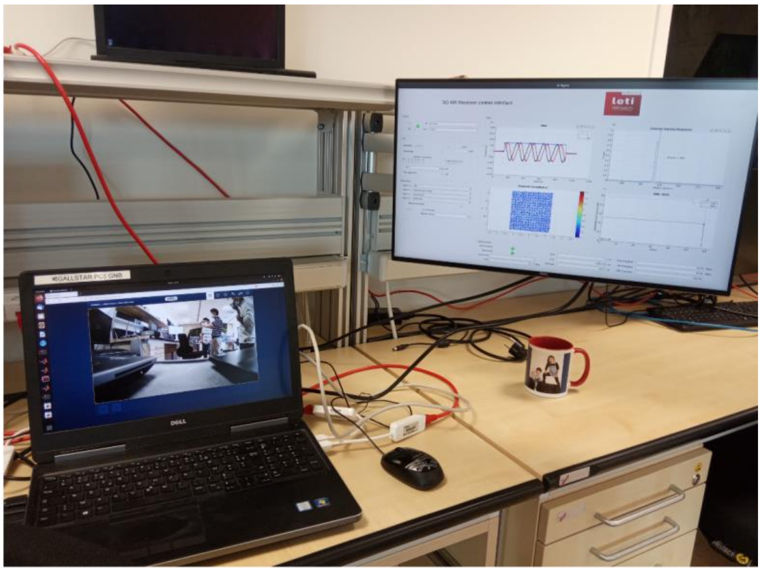

Figure 16. Validation of over the air uplink. View of the webcam display and of the KPIs GUI.

2.2.3.2 Terrestrial MCS thresholds

We validated MCS thresholds by setting up standard AWGN behaviour in the channel emulator. The thresholds were identified when first errors could be detected by modem KPIs. The channel SNR was not directly injected in the channel emulator (we played on some intermediate input gain) but reported by the modem receiver.

From a total channel band of 100 MHz, a specific Resource Block configuration setup was also configured such that only external carriers made of two sub-bands were transmitted such that the satellite carriers could have been transmitted in the central sub-band (see picture below).

This RB configuration was required to be configured at the terrestrial modem start and therefore could not be changed during transmissions.

To prevent from additional interferences with the satellite transmission to be expected at next step, a conservative configuration with ~40 MHz (sum of two terrestrial sub-bands) has been set.

This would have implied ~80 MHz of bandwidth usage (while satellite transmission was spanning over central 40 MHz channel).

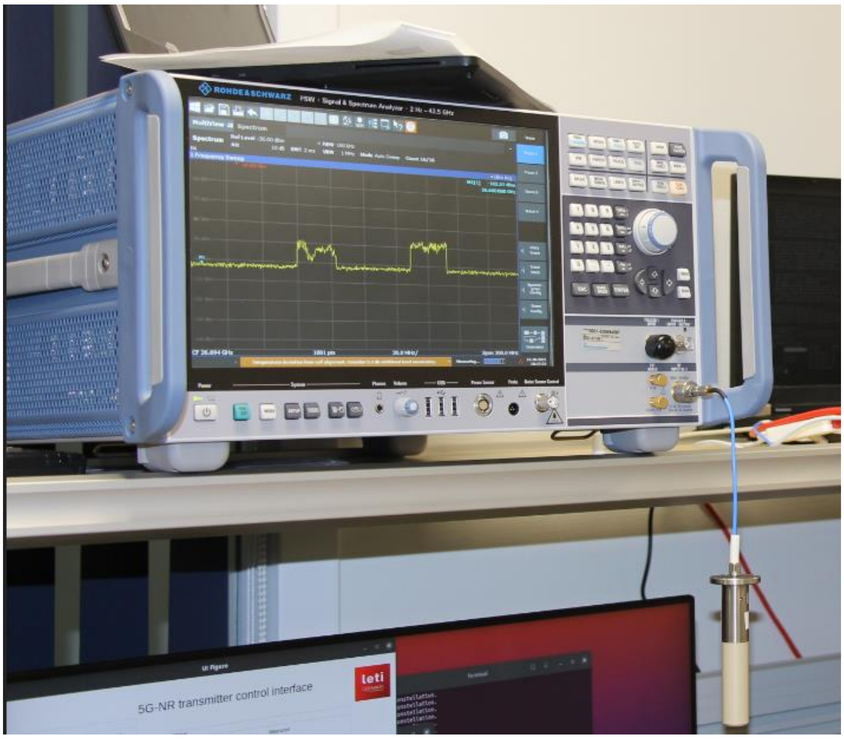

Figure 17 : RF spectrum monitoring of terrestrial transmission with RB configuration ready before satellite transmission

From this configuration, the following performances have been obtained (red indicate measurements).

Table 2: measured TER modem MCS performances

MCS ID	code rate (fraction of 1024)	Modulation	Spectral efficiency	Data Rate (Mbps)	SNR (dB)
3	449	QPSK	0,88	23.4	**8**
4	602	QPSK	1,18	35	**8**
5	378	16 QAM	1,48	46.7	**9**
7	490	16 QAM	1.91	58.4	**10**
9	616	16 QAM	2,41	70.1	**11**
11	466	64 QAM	2,73	81.8	**14**
13	567	64 QAM	3,32	93.4	**15,5**
15	666	64 QAM	3,90	105	**17**
17	772	64 QAM	4,52	129	**18**
19	873	64 QAM	5,12	140	**20**

Note : Indicated Spectral efficiency here is ideal, without taking into accounts any NR nor MAC overhead

2.2.4 Integration & Validation of Satellite components

As shown in Table 1, some unexpected issues were experienced with the satellite emulation.

After having assembled the satellite testbed nearly as it was in Erlangen, the setup was not working. The setup actually lacked from an external reference clock unit that was required to synchronize both USRPs. This has not been immediately found out since the acquisition of the service down-link was apparently made and reported correctly by the OAI logs.

Once fixed, the satellite RF finally was still not working through the Channel Emulator.

We had to change the propagation delay which was previously set incorrectly in the Channel Emulator.

The configuration actually changed from Erlangen setup with 4 more interfaces plugged (2 inputs and 2 outputs for the emulation of the Uplink + Downlink terrestrial channel)

The reason behind this is that the OAI UE modem operating in NTN (None Terrestrial Network) mode need in input a timing advance value corresponding to the number of samples necessary to compensate the long delay introduced by the channel emulator. Also, the PROPSIM F64 introduces an extra hardware delay depending on the emulation scenario which adds up to the total delay. Finding the correct initial value of the timing advance is an iterative process that requires to add and remove samples until uplink synchronization is successfully achieved. This process can be very time-consuming, therefore, given the limited time available, it was decided for the sake of the final demo to dispense with the RF/wireless link and to connect the two USRPs directly to each other, with modem operating in RF simulation mode and the long delay corresponding to a GEO channel simulated by OAI.

Finally we got low performance of the satellite testbed setup. In this setup the maximal stable achieved satellite bitrate was 10 Mbps. However transient data rates larger than 10 Mbps of incoming traffic systematically made the OAI software to crash. Sending of UDP / or Ping traffic below that data rate was possible, but not TCP (therefore no with DASH streaming video) since TCP continuously probe network capacity and has to change its instantaneous data rate. Solution found was to add a rate limiter function that we implemented at the machine hosting OAI transmitter. The function was available as Linux kernel (dedicated to QoS management) named *tc* (for traffic control). Unfortunately the calibration was hard to find to get a satisfactory data rate close to the 10 Mbps, as traffic regulation is actually based on Token Buckets and allowing control of bursts.

2.3 European trial platform results

2.3.1 Configuration of Video quality Layers

The following table shows the different video qualities considered on the multi-connectivity testbed and the trial platform and indicates for each of them minimum required data rates at applicative level.

Table 3: considered video qualities

Video quality ID	Name	Resolution (pixels)	Minimal required data rate at applicative level (kbps)
L1	SD	640 x 360	500
L2	qHD	960 x 540	1000

Video quality ID	Name	Resolution (pixels)	Minimal required data rate at applicative level (kbps)
L3	HD/WXGA (720p)	1280 x 720	2000
L4	Full HD (1080p)	1920 x 1080	6000
L5	4K (UHD)	3840 x 2160	20000
L6	8K (FUHD)	7680 x 4320	30000

2.3.2 cRRM algorithm update

Given the difficulties encountered, the cRRM could not be validated during integration tests. To cope with that, The cRRM was updated during the week to be demonstrated with the Trial scenario (see section 2.3.4). This means the following modifications have been made in parallel to the integrations test:

- Static band sharing between satellite and terrestrial to simplify further testing
- Update of the different MCS and their corresponding data rates on the terrestrial links accordingly to the band sharing
- Static 2 dB margin configured to force data to be switched to the satellite in case measured SNR is below the SNR requirement for MCS 9 (arbitrary choice).

2.3.3 Experiments and Results

During the last day, once all the above-mentioned connectivity and addressing/routing problems were fixed, a partial validation of the multi-connectivity concept could be done. It was not possible to validate all the scenarios planned for European trial platform due to lack of remaining time, so the multi-connectivity was demonstrated in its basic concept, anyway, giving some expected results and some hints on how the complete European trial platform would have behaved without any descoping.

In particular the validation included basic multi-path connectivity test with iperf3 tool (i.e. simple file transfer), validation of the 8K video streaming system transmitting on both paths at the same time and validation of 8K video streaming with an abrupt channel interruption – close to a particular Handover case.

Moreover, the European trial platform was tested running multiple services at the same time (e.g., 8K video streaming and real-time webcam streaming) on the available paths. This validated the European trial platform readiness for its integration into the intercontinental trial platform (PoC Phase 2).

For terrestrial links, in addition to channel interruption cases, we configured terrestrial transmissions with AWGN transmission configured on Channel Emulator, forced MCS 9 at modem startup, and set gains in the Channel Emulator so that to get a reported SNR greater than 11 dB (9 dB + 2 dB Margin). Channel Interruption case were modeled by putting obstacle or a person on the antennas Line of Sight.

For satellite links, the achieved software emulated SNR was set to be ideal (50 dB) with fixed MCS 16-QAM of coding rate 378/1024. As previously indicated the maximum was 10 Mbps, but with a rate limiter, only a much lower actual rate was possible (between 1.5 and 3 Mbps, in average).

These validation tests can be mapped in the following scenarios from the Table 23 of D5.2:

- Scenario 5: *Basic multi-connectivity*
- Scenario 8: *Realistic multi-connectivity, no handover, single application*
- Scenario 10: *Realistic multi-connectivity, no handover, multiple applications → this is final scenario demonstration : see D6.5*
- Scenario 11 : *Realistic multi-connectivity, seamless handover, single application*

The *Basic Multi-Connectivity* case **(Scenario 5)** has been run both with MPTCP round-robin scheduler (with quotas fixed to 70% for terrestrial link and 30% for satellite link, i.e., 70% of the TCP packets are sent to the MPTCP sub-flow related to the terrestrial link while 30% of the packets are sent to the one related to the satellite link). The redundant scheduler was also tested as additional verification mean ; with that scheme both active path are used to transfer data; only the first copy is then validated by the receiver, other being dropped. This scheduler allows in theory to get the lowest transit delay for any packet but at the expense of over-utilisation of the global link resources; hence it can easily bring congestion of the links).

Results

An aggregate TCP peak data-rate of about 35 Mbps with the round-robin scheduler was obtained, while 10 Mbps have been obtained with the redundant scheduler.

Related to schedulers, the result is as expected, since the redundant scheduler does not slide the TCP congestion window until the ACKs are received by at least one of the subflows (thus achieving the smallest RTT between the terrestrial and the satellite ones), while the round robin scheduler, even if it experiences a higher delay (due to the delay of the satellite subflow), is able to perform better results in terms of total throughput and channel utilization.

With the presented results, it is possible to consider the Basic Multi-Connectivity scenario as successfully validated, since the data were transferred by using both paths at the same time (i.e., one of the identified goals for Scenario 5 in D5.2).

Realistic multi-connectivity with no handover scenario **(scenario 8)** has been run setting MPTCP scheduler to round-robin (with fixed quotas of 70% for the terrestrial path and 30% for the satellite path) and running the 8K video streaming platform. Figure 18 contains two different experiments, one starting at about 13:47 and ending at 13:50, while another one starting at 14:00 and ending at 14:03. The discussion presented below refers only to the experiment from 14:00 to 14:03. Moreover, the data shown in the second row of plots belongs only to the satellite path; indeed, we encountered problems in displaying terrestrial path data, but we didn't have time to fix this issue. Anyway, from Figure 19 it is possible to see the terrestrial throughput logs for this scenario.

In the third row of plots of Figure 18, the video player KPIs are represented, including Video Player download rate (first plot) and Video Quality level (second plot). From these two plots it is possible to notice how multi-connectivity managed to reach quality level 6 (i.e., 8K), maintaining a player queue (fourth plot) of about 20 seconds, and so without rebuffering events. Anyway, due to the small throughput available, the video streaming platform was able to reach this quality level just before the end of the video, so this explains the sudden drop to quality level 0. The peak data rates achieved have been respectively up to 36 Mbps for terrestrial subflow (report seen from Terrestrial modem logs, see next figure) and up to 1.5 Mbps for satellite subflow.

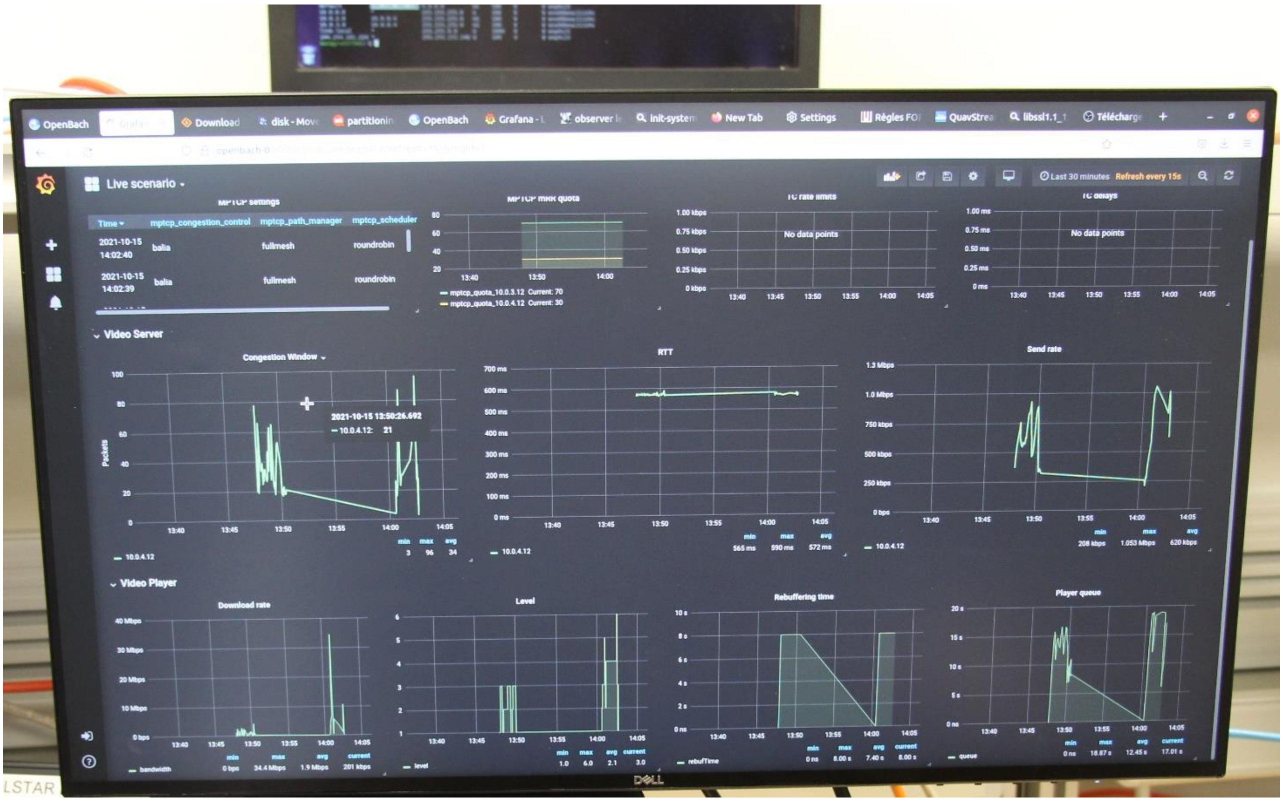

Figure 18 Realistic Multi-Connectivity Scenario experiment

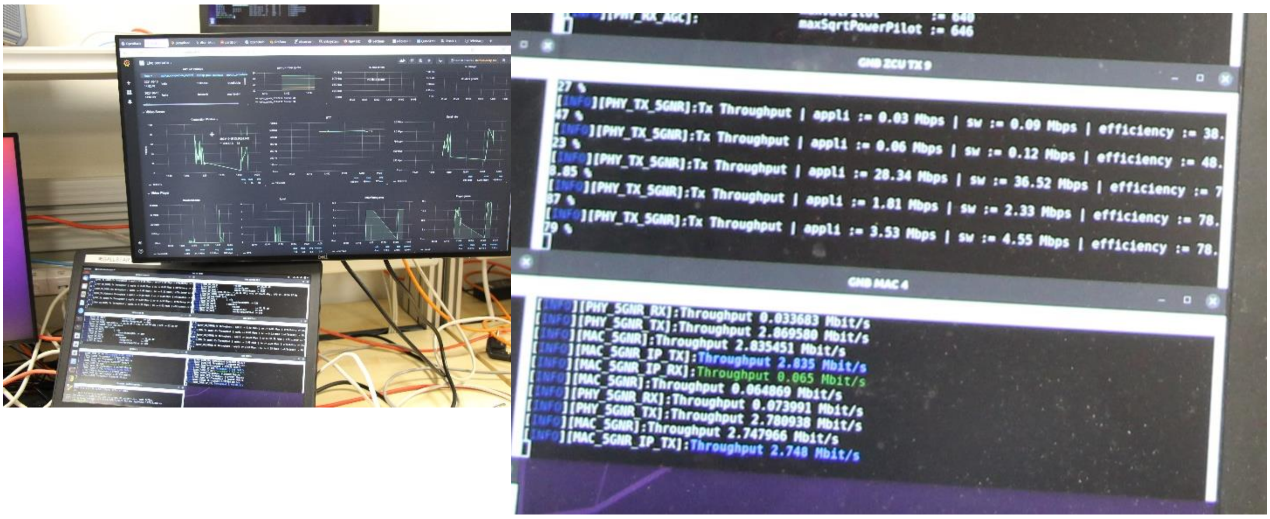

Figure 19 : Realistic Multi-Connectivity Scenario with focus on terrestrial throughput

Finally, this scenario has been extended **(Scenario 11)** with conditions showing abrupt interruption of one of the two paths, and in particular the terrestrial path, that was the one carrying most of the data (see next two figures).

Again, in Figure 20 two different experiments are depicted: one starting at 14:37 and ending at 14:38, and another one starting at 14:40 and ending at 14:42. The next discussion will focus on experiment running from 14:40 to 14:42. Figure 20 shows the terrestrial channel interruption, and the corresponding measured throughput of terrestrial channel (i.e., 0 kBps transmitted by the terrestrial gNB to the terrestrial UE). In correspondence to this event, in few seconds after time 14:41, the satellite throughput increases (last plot of the second row) to sustain the traffic load and at the same time the quality level decreases (second plot of the third row). The player queue reduced to 15 seconds and then recovered to 20 seconds, but with a lower quality level (i.e., level 3 – 720p instead of level 6 – 8K)

Figure 20 : Realistic Multi-Connectivity Scenario experiment with abrupt terrestrial channel interruption

Figure 21 : Realistic Multi-Connectivity Scenario experiment with abrupt terrestrial channel interruption

2.3.4 Trial scenario

In parallel to the validation of integration scenario presented in last section, we also wanted to demonstrate an ambitious “Trial scenario”. It was decided at the end of Day 3 to setup the European trial platform use to demonstrate the following situation:

1) A satellite Macro-cell and a standard terrestrial cell are operated in the same overall area, and using a shared frequency plan. Due to constraints explained in D5.2, the frequency plan always allocates a central share of the frequency band for the satellite transmission, while the terrestrial uses 2 exterior bands (see Figure 17), avoiding overlap with satellite band.

2) A given moving UE of interest starts from a region where it can be served by the Terrestrial cell. For cost efficiency reasons, the system chooses not to allocate any satellite RB to that UE.

3) As the moving UE gets further from the terrestrial cell its radio performances and available data rate performance decrease. The system resource coordinator (modelled within the cRRM) implements a pre-defined policy in which a trigger is activated when the terrestrial SNR goes below a configured value (that would also match a minimal viable MCS). Hence in case of a sole adaptive Video Streaming test, the aim is to demonstrate:
    - The acceptability of the video quality degradation, up to the given required SNR for decoding MCS at target BLER (e.g. 10^{-3})
    - A progressive utilization of satellite resource (progressive since the terrestrial can still provide some service) by the streaming application, in order to maintain at least a minimal video quality. This quality would correspond to the "worst case" when transmission over terrestrial is not possible anymore (SNR below the highest robust MCS).

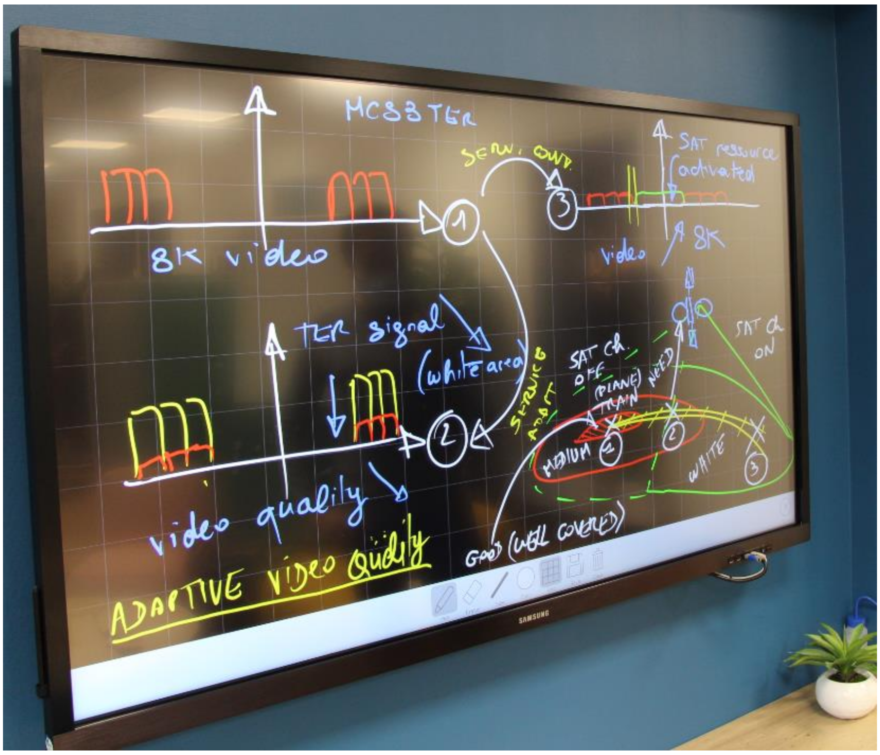

Figure 22: View of Trial scenario being discussed with partners in Grenoble

Unfortunately, for the reasons explained in the beginning of Section 2, we could not finish validating this scenario by lack of time.

3 Korean trial platform

The Korean trial platform (KTP) of the 5G-ALLSTAR encompasses three component systems or subsystems. The first subsystem is a mmWave based 5G cellular access testbed, and the second one is a satellite access testbed. These had been detailed in D5.3. The third component is a multi-connectivity (MC) system testbed, which is the combined testbed of the 5G cellular access and the satellite access. D5.4 is the deliverable for the Korean MC system. In Task 5.2 and Task 5.3, the component systems had been regarded as stand-alone platforms. In Task 5.4, the KTP is considered to be the final version of the integrated system. Thus, the KTP had been through step-wise validations for the final demonstration.

This chapter has three sections. S3.1 recalls the use cases that is related to the Korean PoCs, S3.2 deals with the integration and validation of the KTP, and S3.3 describes some important testing results.

3.1 Korean System-level Use Cases to be demonstrated

In WP2, four use cases (UCs) had been identified in relation with the 5G-ALLSTAR trial platforms, and D2.4 describes each use case in detail. Of them, UC 1 and UC 4 are related closely with the KTP.

First, the UC 1 is about broadband moving hotspot network, which can be also regarded as one of 5G eMBB service scenarios. The UC deals with two specific scenarios and corresponding KPIs that need to be addressed within each usage scenarios. Two tables summarizing each KPIs are as follows.

Table 4: KPIs for scenario 1 of UC 1

KPI label	Target KPI description		Value	PoC tool	Associated KPI (Table 4-1 of D2.3)
KPI0-KR0	Average physical layer (PHY) data rate of cellular access link to a bus (downlink)		500 Mbps	KR-Trial0	KPI0
KPI0-KR1	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

Table 5: KPIs for scenario 2 of UC 1

KPI label	Target KPI description	Value	PoC tool	Associated KPI (Table 4-1 of D2.3)
KPI0-KR2	Average PHY data rate of cellular access link to a bus (downlink)	500 Mbps	KR-Trial1	KPI0
KPI0-KR3	Average PHY data rate of satellite access link to a bus (downlink)	2 Mbps[NOTE1]	KR-Trial1	KPI0
KPI3-KR0	Reliability of cellular link: Block Error Rate (BLER)	$< 10^{-1}$	KR-Trial1	KPI3
KPI3-KR1	Reliability of satellite link: E_b/N_0[NOTE3] for Quasi Error Free (QEF)[NOTE4]	$>\gamma_{th}$ dB[NOTE1]	KR-Trial1	KPI3

KPI label	Target KPI description	Value	PoC tool	Associated KPI (Table 4-1 of D2.3)
KPI4-KR1	Service continuity	No video streaming interruption NOTE2	KR-Trial1	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).

NOTE2: This can be demonstrated by showing that video streaming is maintained without interruption even when the cellular link is lost.

NOTE3: E_b/N_0 = C/N - $10\log_{10}(K_b/N_s)$, where C/N is the ratio of signal power spectral density to noise power spectral density at the modem input, K_b is the number of payload bits per baseband frame and N_s is the number of transmitted symbols per PHY frame. Internet Protocol (IP) and other network layer packets are transported on the baseband frame using the highly efficient DVB-S2 Generic Stream Encapsulation (GSE) protocol. The parameter K_b does not include the moderate GSE overhead (roughly 1 to 2%).

NOTE4: QEF operation is defined as no BBHEADER CRC-8 errors with BER better than $1e^{-8}$ for an IF-loopback (L-band).

Second, the UC 4 is about intercontinental interoperability. This UC depends upon the joint trial platform connecting the Korean and the EU trial platforms. This chapter describes the Korean PoC platform - key services like video streaming and VR contents are included. Meanwhile, the intercontinental network connection will be discussed in D5.6.

3.2 Korean Trial Platform Integration & Validation

The service scenarios of the UC 1 are to be demonstrated with the KR-Trial0 and the KR-Trial1. The KR-Trial0 is the 5G cellular access trial platform and the KR-Trial1 is the multi-connectivity trial platform. These platforms are described in D5.3 and D5.4, respectively. In this section, the KPIs associated with corresponding trial platform are discussed.

3.2.1 KPIs associated with KR-Trial0

The KPIs associated with the KR-Trial0 are listed in the previous section (S3.1). With the 5G cellular access trial platform, each had been measured as follows.

- Average data rate
  - Downlink data rate from a gNB to a terminal equipment (TE) in the physical layer
  - Figure 23 shows 3.1 Gbps of maximum data rate (600 MHz of mmWave bandwidth). This data was captured in an indoor experimental setup with good signal-to-noise ratios (SNRs) of larger than 25 dB. On the contrary, outdoor measurements showed varying data rates depending on the SNRs. Typical measured values were larger than 2.5 Gbps at larger than 22 dB of SNRs.

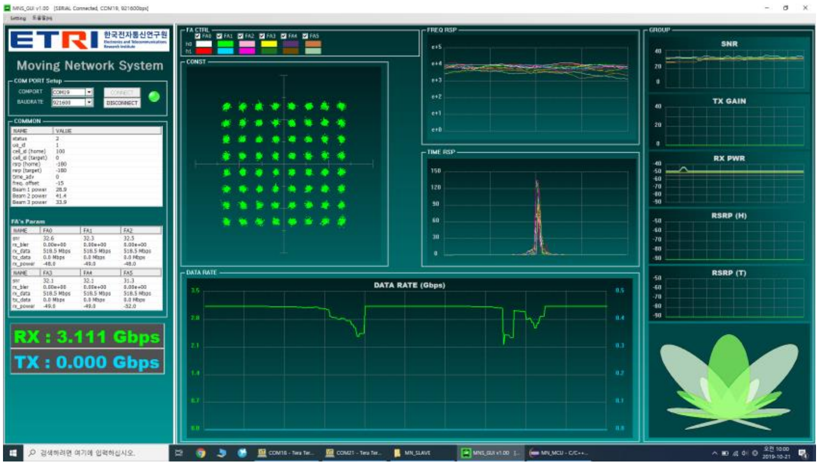

Figure 23: Average downlink data rate

- Average user-experienced data rate
  - Average data rate of passengers in a vehicle
  - 7 users in a vehicle held smartphones, and measured download speeds with an Android App named “Benchbee”. The measured data is summarized in Table 6.

Table 6: Average user-experienced data rate

Passenger ID	Download Speed (Mbps)
1	248
2	127
3	210
4	463
5	602
6	124
7	587
Average	337

- User plane latency
  - PING round trip time (RTT) is measured at the UE side with an indoor setup.
  - User plane latency value is a half of the RTT. Measured values were 4-5ms.

Figure 24: PING RTT

- Control plane latency
  - Transition time between RRC Inactive mode and RRC Connected mode is measured with an indoor setup.
  - Measured values were 16-17 ms.

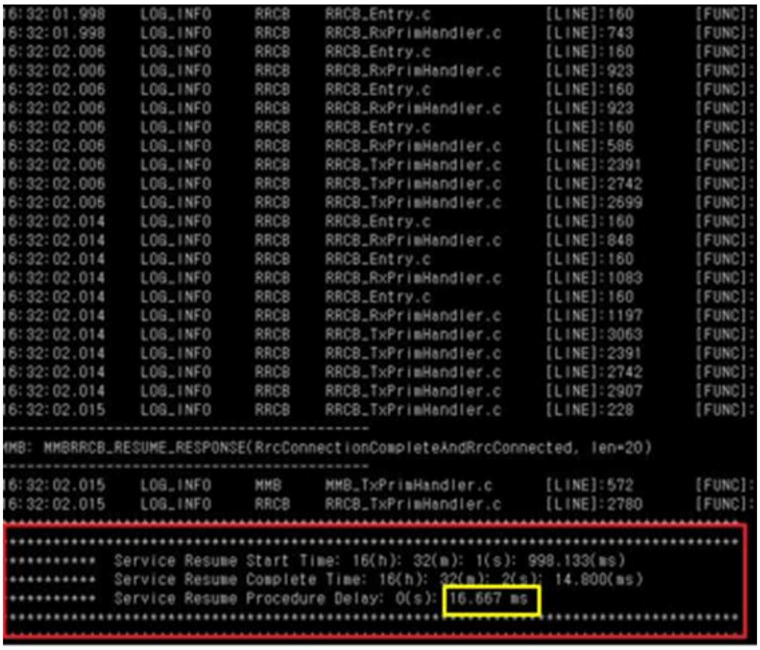

Figure 25: C-plane latency

- Handover latency
  - An indoor setup was used to measure the handover characteristics. Measured data shows 15 slots for handover latency. Since one slot equals 250 us, it is 3.75 ms.

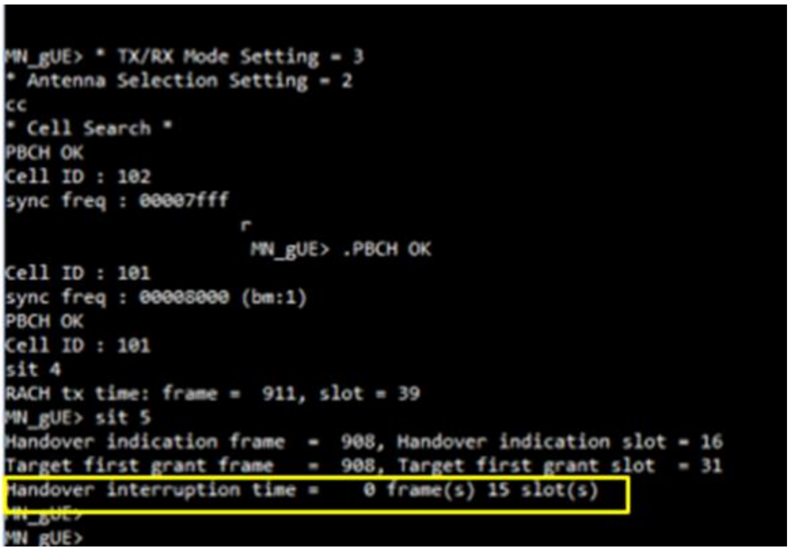

Figure 26: Handover latency

3.2.2 KPIs associated with KR-Trial1

The KPIs associated with the KR-Trial1 are listed in the previous section (S3.1). With the multi-connectivity trial platform, each had been measured as follows.

- Average cellular data rate
  - Downlink data rate was measured while a vehicle UE was moving towards a gNB
  - The measured data rates in the figure below shows larger than 1 Gbps over the whole locations.

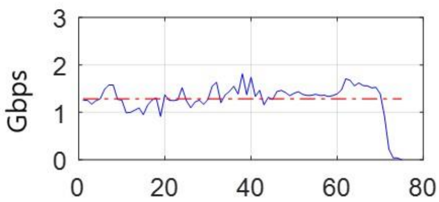

Figure 27: Cellular downlink data rate

- Average satellite data rate
  - Satellite downlink data rate was measured in a vehicle
  - Measured download speed with an APP in the figure below shows larger than 2 Mbps

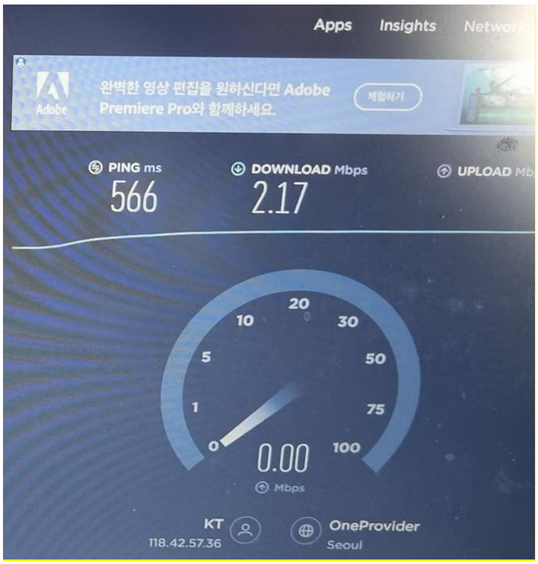

Figure 28: Satellite downlink data rate

- Reliability of cellular link
    - BLER (Block Error Rate) was measured while a vehicle UE was moving towards a gNB
    - Target BLER was below 1E-1 and the figure below shows that the measured values were smaller than 1E-1 for the most locations.

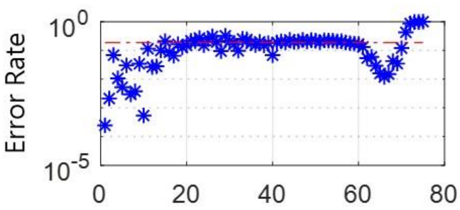

Figure 29: Reliability of cellular link

- Reliability of satellite link
    - Measured carrier-to-noise ratios (C/N) at the earth station were 7.9-9.9dB.

- Service continuity
    - To prove the concept of the service continuity, the video streaming service was used.
    - Video contents were delivered via the dual paths of the cellular access and satellite access.
    - A traffic controller in a vehicle was utilized to aggregate these traffic and output to the user
    - Unless the two paths failed at the same time, the end user can enjoy the video contents seamlessly

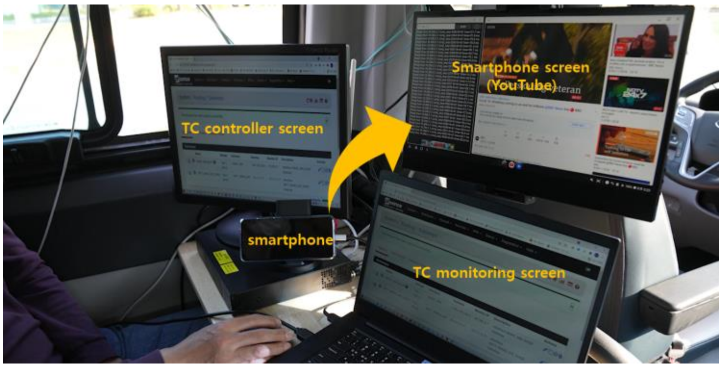

Figure 30: Video streaming with the dual-connectivity trial platform

3.3 Korean Trial Platform PoCs and associated results

The UC4 dealing with the intercontinental interoperability PoC between EU and Korea has eMBB service scenarios such as the video streaming and the VR gaming. The Korean side services are shown in Figure 31. The passengers in the vehicle of the Korean trial platform may watch the live/recorded high-quality videos. For this, a video server located in the EU can be used, and another video server located in Korea also can be used. The passengers may put on VR gears to follow VR tennis matches through intercontinental networks. Before the final inter-continental interoperability demonstration, these services had been checked with the KTP.

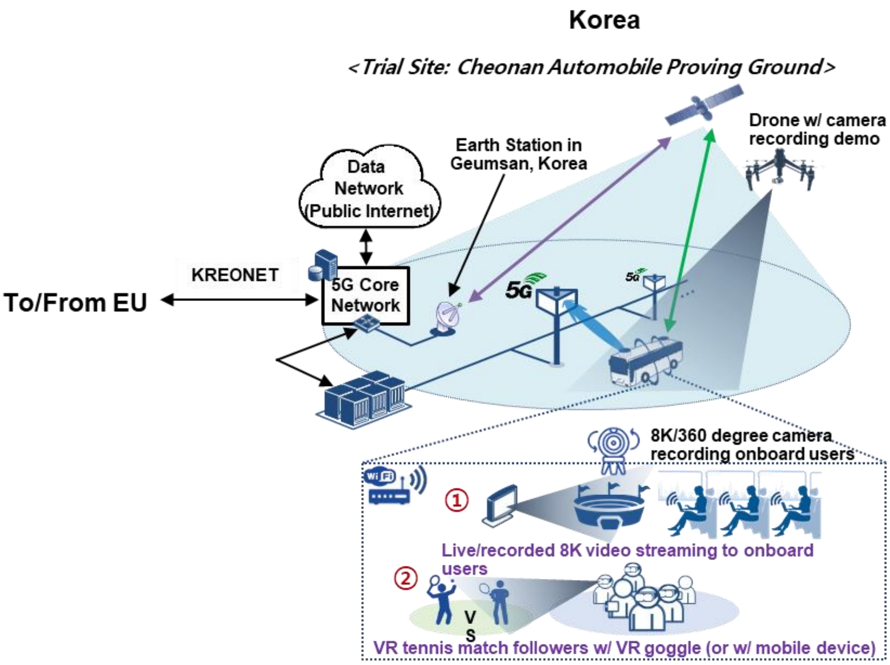

Figure 31: Service scenarios for the KTP

3.3.1 Video streaming

The video streaming is one of typical eMBB services that had been adopted for proving the key concepts, i.e., service availability and service continuity. YouTube may be the most popular one, and that surely was used in the process of the platform validation. Meanwhile, a customized video streaming is necessary sometimes, when you want some special contents also with customized encoding with various resolutions. Once the customized video server is prepared, it can give the advantage of flexibility in configuring the test setup; if a test site does not provide connection to the Internet, the customized video server can be used. In the final demo of the 5G-ALLSTAR, two customized video servers will be included – one will be located in the EU trial site and another will be located in the Korean trial site. Details on the Korean video server can be found in S2.2.2 of D5.4. Figure 32 shows the picture of the video streaming service with the customized video server.

Figure 32: The video streaming in the vehicle

3.3.2 VR service

In the 5G-ALLSTAR, some VR games supporting various sports have been considered for the PoC. Of them, the VR tennis game had been selected; it is aligned with the Rolland Garros which was the prominent candidate for the final key event. It is worth mentioning that the final event had been cancelled due to the COVID-19 impact. The VR tennis game, however, still remains the main service for the PoC. The VR tennis game supports “watch mode” as well as “play mode”. If there is enough space, “player mode”, single or multiple players, are appropriate. If there is not enough space like some seats in the vehicle, “watch mode” is appropriate

3.3.2.1 VR service

This use case with the trial platform mainly showcases the scenario where the two players located in remote places play VR tennis game thanks to the technologies introduced in EU-Testbed/EU-Trial Platform. The VR tennis game is called Tennis Kings VR. Figure 33 shows screenshots of Appnori VR tennis game. Two players are at the same site can enjoy the VR tennis match. Even if they are not at the same site but within 20 ms delay, the game can be played without delay.

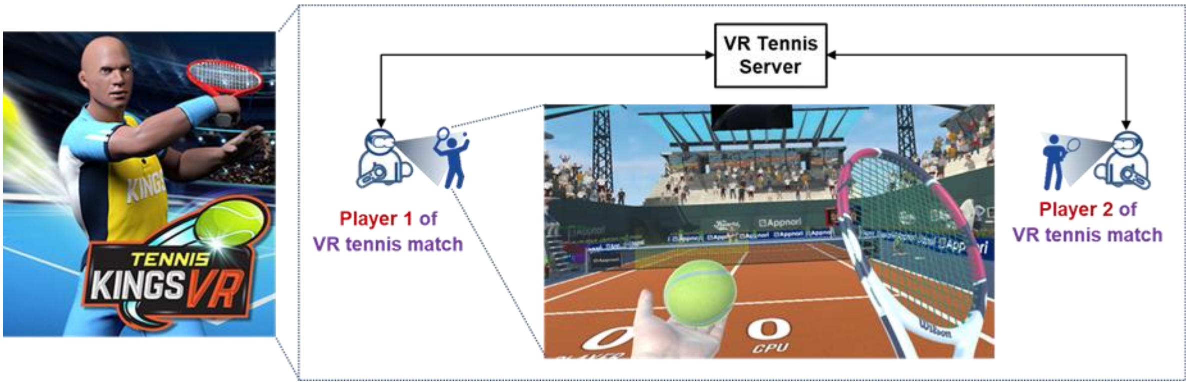

Figure 33: VR tennis game

3.3.2.2 VR tennis followers

The passengers in the vehicle usually do not have enough space to play the VR tennis game. In this case, they can participate the VR tennis match as audience, which is called the VR tennis followers (see Figure 33). Since the users of the KTP are in the vehicle, they can enjoy the VR tennis game as the VR tennis followers while some real-time VR gaming is going at the EU trial

4 Conclusion

Despite the different difficulties encountered all along the 5G-ALLSTAR project's course, and especially the unprecedented Covid-19 crisis which occurred right in the middle of WP5 activities, partners appeared to be pretty resilient, trying their best to find out solutions and adapt their activities as much as possible to stick at best to the initial project's objectives.

All the adaptations and, unfortunately, sometimes, descopings were decided always with the same top priority: keeping the possibility to perform a common European and Korean trial phase and then demonstration at the very end of the project.

Therefore, at each stage of the incremental integration and validation process, and as time was more and more running out, going forward in the integration was always preferred to performing extensive data collecting sessions which could have appeared to be valuable though for some further standardization actions pushing forward not only the advantages but above all the perfect feasibility of hybrid satellite-terrestrial access for 5G User Equipments.

The WP5 orientation favored thus the European and Korean teams collaboration, a major pillar of the 5G-ALLSTAR project anyway for which, the trial integration week gathering all the European partners in Grenoble, was crucial. This pretty harsh yet efficient week, concentrated indeed by itself not only the end of the European multi-connectivity testbed phase but also most of the European trial platform phase, completing PoC Phase 1, object of this document D5.5 and enabling a successful PoC Phase 2, to be described in D5.6.