D6.1: PoC functional architecture document

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Abstract	This deliverable elaborates on the functional architecture of the selected PoC, on the basis of D3.2 findings and related decision as to the SW/HW components to be integrated together.
Keywords	PoC, NTN, 3GPP, TN, Functional architecture

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EXECUTIVE SUMMARY

The present document addresses the definition of the physical layout and the functional architecture adopted for Proof-of-Concept (PoC[1]), which is one of the main outputs expected from the 5G-STARDUST project. As such, this deliverable represents a bridge between the first phase of the project mostly devoted to the definition of the system architecture and the second phase, where the development activities will provide the building blocks necessary for the realisation of the PoC, which will be then used at the end of the project in key dissemination and promotional activities, aimed at showing the research delta and the added technological value achieved by the project with respect to the existing state of the art.

As such, this document takes are reference the main indications drawn in the first phase of the project from an architectural standpoint and breaks down further the system into physical and logical components, constituting the terrestrial and non-terrestrial paths involved in the end-to-end connectivity concept developed in the project. In particular, it is worth noticing that the target TRL for the project is 4-5, so that key elements for the realisation of a fully integrated 5G-NTN system are here considered. In this respect, a key role is being played by the UE and gNB implementing the necessary NTN adaptation. Then one of the main merits of the architecture developed in the project is the use of a regenerative payload onboard satellite. Last but not the least, one of the objectives to be reached with the planned PoC is also to support the case of multi-connectivity, in order to show how switching from one path to another or even the simultaneous use of both can be beneficial for the overall system performance.

The overall PoC is then aimed at reproducing the performance of a realistic 5G-NTN integrated system with respect to a number of use cases and related possible configurations, hence reaching an important milestone in the demonstration of the capabilities that a unified technology system may offer.

The main findings contained in this document with respect to physical layout and functional architecture will be used as starting point for the definition of the actual PoC, in terms of the integration of SW/HW components and the related planning of the tests to be carried out towards the full system (intended as PoC) validation.

As such, the specific identification of KPI to be used as reference for the testing procedures and the related measurement tools are not addressed in this document, which solely reports the functional architecture. On the other hand, the validation procedure will be addressed in the next deliverables dealing with the technical specification of the PoC. Likewise, also the mapping between the architecture options illustrated in this document and the scenarios object of the demonstrations will be carefully discussed in the following phases of the PoC development.

[1] The project activity will also come up with a few other testbeds (TRL4), which however will stay standalone and not integrated in the PoC because of the reduced maturity or the time planning of the corresponding development activities.

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ABBREVIATIONS

AI	Artificial Intelligence,
CU	Centralised Unit
DU	Distributed Unit
GTP	Generic Tunnelling Protocol
HW	Hardware
IAB,	Integrated Access and Backhaul
IP	Internet Protocol
KPI	Key Performance Indicator,
MC	Multi Connectivity,
MEC	Multi-Access Edge Computing,
ML	Multi Link,
MP	Multi Path,
MPL	Multi-Path Layer, etc.
MPQUIC	Multi-Path QUIC
MPTCP	Multi-Path Transmission Control Protocol
NGAP	NG Application Protocol,
NTN	Non-Terrestrial Network,
PCI	Peripheral Component Interconnect,
PoC	Proof of Concept
PSA	PDU Session Anchor
RF	Radio Frequency,
RU	Radio Unit,
SCTP	Stream Control Transmission Protocol,
SDR	Software Defined Radio,
SLE	Satellite Link Emulator,
SMA	Sub-Miniature version A,
SU	Switching Unit

SW	Software
TCP	Transmission Control Protocol
TGA	Traffic Generator and Analyse,
TN	Terrestrial Network,
UE	User Equipment**,**

1 INTRODUCTION

1.1 POC CONCEPT AND DEVELOPMENT PHASES

Deliverable D6.1 is the first key step carried out in the context of WP6 'Integration, testing, and validation' overall aimed at the definition and integration of the PoC according to the system architecture defined in WP3 (Architecture Design) and on the basis of the activities carried out within WP4 (Radio Technologies) and WP5 (Networking Operations), whose main outputs in the form of SW/HW pieces are then the object of the PoC integration. In turn, once the PoC will be fully integrated and operational, the corresponding demonstration campaigns will be carried out, whose results analysis is performed immediately afterwards. A dedicated study-logic illustrating such a process is shown in Figure 1-1.

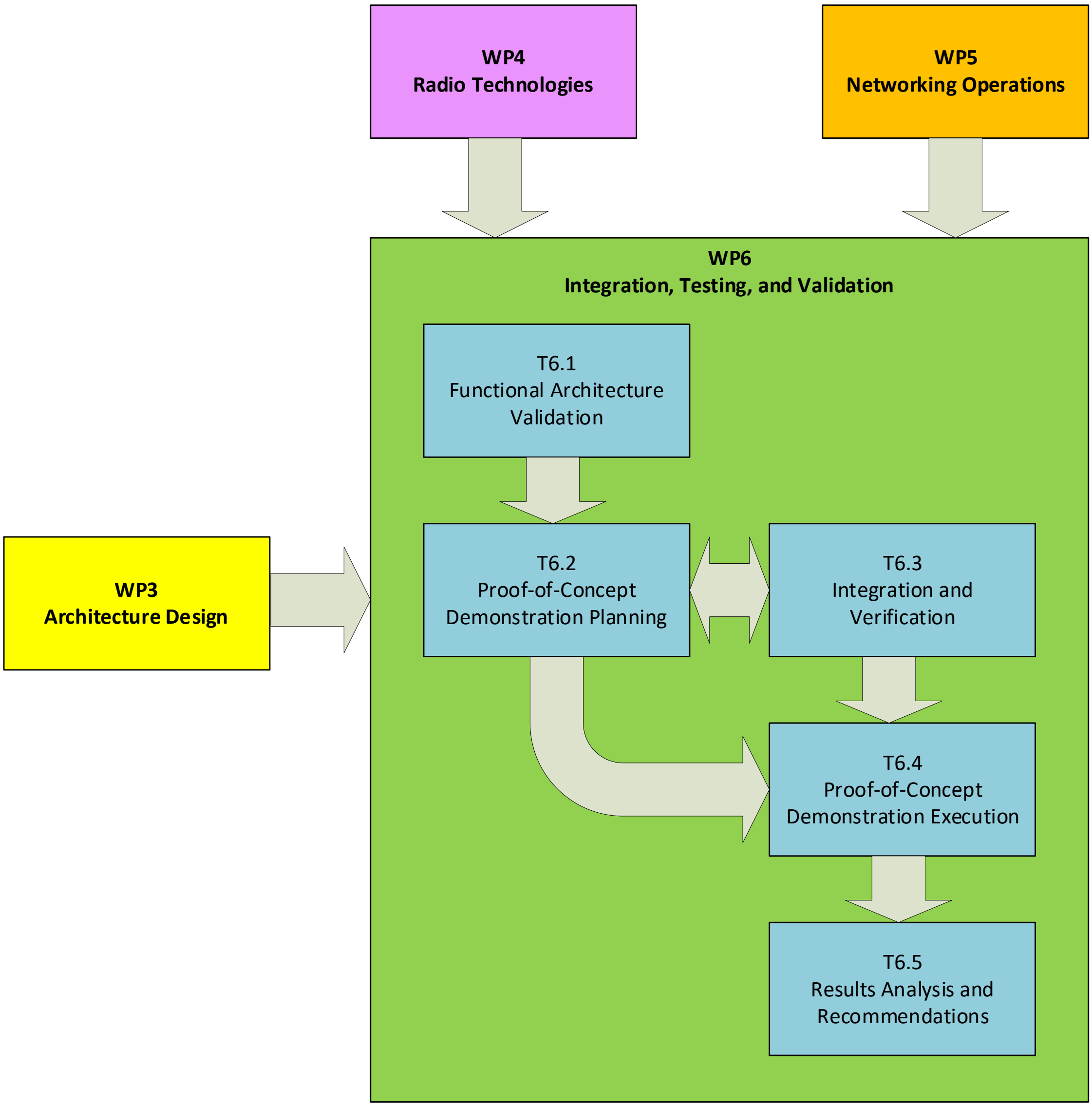

Figure 1-1 WP 6 interaction with development activities in 5G-STARDUST

From the above picture is then clear the role of this deliverable as output of Task 6.1 in providing the foundation of the PoC, as it elaborates on the functional architecture and overall physical layout of the PoC. As such, the main indications provided in this document will be later used to plan the actual demonstration and how the different building blocks here defined will be integrated and tested towards the full system verification. In this respect, obviously, a prerequisite for the definition of the functional architecture is the system design as developed in the course of WP3, so that in particular D3.2 [1] is the starting point for the definition of the PoC functional architecture.

In more detail, the discussions and findings summarised at the end of D3.2 allowed to define the macro-architecture (see Figure 1-2) for the project PoCs so as to address both direct and indirect access, hence offering the possibility to address multiple scenarios.

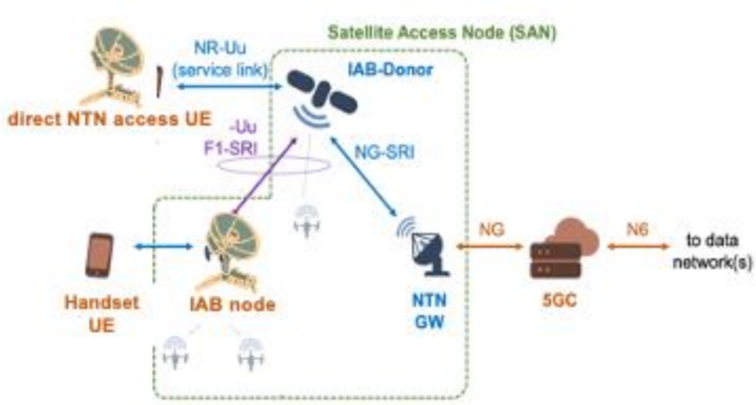

Figure 1-2 Macro-architecture of the NTN segment for the PoC (TN segment not shown here)

As a matter of fact, the access to the satellite in the indirect configuration will happen through a relay node, hence resembling that of IAB node functionality, although this is not exactly the approach taken in the project. The adopted methodology does not rely on IAB implementation (for which no NTN adaptations have been addressed so far in 3GPP), but on the contrary the idea is to take advantage of an intermediate node responsible for interacting with a UE and extending its connectivity so as to reach the gNB, which will be implemented (either fully or in distributed manner) in the space segment. Further to this, it is expected to have different classes of UE, able to achieve data connectivity in either FR1 or FR2 with different bandwidth availability. Last but not least, the satellite path is then complemented by a terrestrial counterpart in order to show the coexistence of different paths and demonstrate the added value of a unified network architecture, where both TN and NTN segments are available.

In general the main objective of the PoCs will be that of proving the added value coming from integrated TN and NTN networks implementing a regenerative LEO satellite system. In that respect, first of all it is assumed to consider a transparent LEO setup as actual benchmark. Then in turn, some of the main functions to be considered for the demonstration to prove the value of integrating TN and NTN will be about:

1) Support of FR1/FR2 frequency band
2) End-to-end connectivity through a unified radio interface
3) Multi-link/path achievement towards effective utilisation of the available TN/NTN resources

To this end, the overall PoC picture will address network disaggregation by considering different functional splitting models aimed at showing performance fluctations and corresponding configuration adjustment.

Last but not the least, the final version of the demonstrator will be plugging real user applications in order to have impactful demonstrations of the added value of the 5G-STARDUST concept by achieving a close-to-real setup (though still up to max. TRL 5). Specific details on this point too will be addressed in the forthcoming deliverables from WP6, where the final technical specification as well as the configuration of the overall demonstration system.

1.2 TRL REVIEW

On the basis of the first iteration presented at the end of D3.2, a successive refinement has been conducted to identify the macro-blocks necessary for the definition of the PoC, which are further summarised in Table 1, here below:

Table 1 PoC Macro-blocks and related TRL progression

Technology	Initial TRL	Estimated TRL	Support (full/partial)[2]	Notes
Regenerative payload	2	4	full	Key demonstration objective of the project, also in relation to embark a gNB in space with all necessary functions from physical layer up to PDCP
Unified UE interface	2	4/5	full	Key demonstration objective of the project, with respect to proving the benefits of integrating a UE into TN/NTN segments interchangeably.
ML supported TN/NTN MC on higher layers	2	4	partial	Multi-connectivity supported in terms of multi-path protocols and related integration between core network, RAN, and UEs
AI data driven networking solutions for MC (management)	2	4	partial	Multi-connectivity management carried out in static manner, since AI would not bring much benefit in a PoC of limited size (i.e. few UEs)
AI data driven networking solutions for MC (slicing)	2	4	partial	Network slicing supported in the sense of differentiating QoS classes, through static classes separation.
MEC platform for NTN nodes	2	4	TBC[3]	-
RAN softwarization	2	4	full	Pretty much oriented to the achievement of gNB in space, either in the form of full gNB in space or in distribute manner (i.e. function CU/DU splitting)
Core Network Functionality	**4**	**5**	**full**	The core network was tested already with gNBs placed at large distance, however not with gNBs at continuous variable delays. However, we do not expect to be a major issue

[2] In the case of partial support, not all functionalities as planned within 3GPP will be part of the PoC. Detailed description will be provided in the technical specification, object of D6.2 and D6.3.

[3] WP5 will come up with a dedicated testbed to show the potentials of a MEC agent in space. Its actual integration in the WP6-developed PoC is a nice-to-have feature, but not strictly fundamental to reach the objectives of the project. Such an opportunity will be better assessed in the next phases of WP6, while planning the integration of PoC and the related demonstration execution.

1.3 OBJECTIVE AND ORGANISATION OF THE DOCUMENT

According to what summarised in the previous subsections, it immediately emerges that this document represents the starting point for the PoC definition and integration, and as such will be used as baseline for the forthcoming steps to be carried out within WP6. In particular, the present document is aimed at defining the physical layout and the functional architecture, which will be then used as skeleton for integrating all pieces in the consequent steps of the PoC procurement. In particular, this document will be of key importance in that it is detailing the characteristics of the end-to-end connectivity path and the HW/SW elements responsible for achieving that. Last but not the least, this document will also help shedding some light on the protocol operations and the specific demonstrations that could be carried out later on with respect to the existing 3GPP procedures. The actual KPIs to be taken into account towards the definition of the PoC operations will be instead more precisely detailed in the next steps of WP6, aimed at providing the full definition of the PoC (as part of T6.2 and T6.3).

The remainder of this document is organised as follows:

- Section 2 analyses the three main architectural options identified to implement the PoC concept from a functional-splitting standpoint (i.e. full gNB onboard, CU/DU splitting between ground and space segments, and full gNB with selected CN functions onboard).
- Section 3 details the functional architecture by taking as reference key 3GPP procedures involved in end-to-end data connectivity process, as well recapping user KPIs (D2.1 [2]) and the identified use cases (D3.2).
- Section 4 draws the main conclusions from this document and addresses the next steps towards the procurement of the PoC.

2 FUNCTIONAL ARCHITECTURE

This section illustrates the overall functional architecture of the PoC, conveniently broken down into three separated options, 1) full gNB onboard, 2) CU-DU splitting, and 3) full gNB onboard with UPF functionalities.

Detailed description of the aforementioned options is accompanied by the illustration of the corresponding protocol stacks.

2.1 OPTION 1 – FULL GNB ONBOARD

2.1.1 Logical architecture

PoC will be constituted of several configurations that will be mainly based in the same hardware, with different software configurations.

The architecture will be structured in 3 paths: NTN path (in blue), TN path (in green) and indirect access (in yellow). The last one represents the link until the end user, who could receive data through NTN or TN path.

Each module is further described in next sections (chapter 2.4.x) . The interfaces will be detailed in upcoming deliverables.

The IAB is presented in the orange contour. It is composed of the two UE (one dedicated to TN and one to the NTN part), one switch which ensures the handover between the two connection types, one gNB and associated RU as bridge to the UE.

The green contour is a reminder for the whole the SAN (Satellite Access Network).

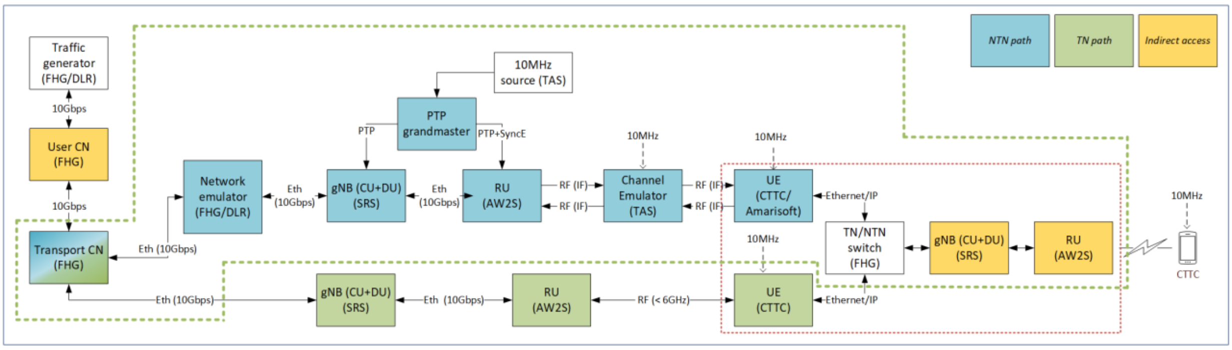

Figure 2-1 PoC logical architecture with full gNB onboard.

The first architecture, in Figure 2-1 represents the full gNB on board of the satellite (CU+DU+RU). A channel emulator will be placed between gNB and UE in order to emulate air interface/channel in the user link.

2.1.2 Protocol architecture

Figure 2-2 illustrates the protocol stack for the PoC with full gNB onboard, the colour coding follows that of Figure 2-1. The NTN and the TN transport path are illustrated in blue; for better visibility only one path is shown. At the PoC this path must be implemented twice. Shown in orange is the end-to-end connection for the user provided by the orange gNB and the UPF PDU Session Anchor (PSA) which is part of the User CN in Figure 2-1. In white the multi-connectivity function is shown consisting of a Switching Unit (SU) or Multipath (MP) function and an MP Anchor merging the separated flows. The specific implementation of the multi-connectivity function is to be defined. Two options are considered: (I) to enable a split at bearer level depending on the GTP header to switch between the links, or (II) to enable switching, splitting, and steering at application level by allowing the SU to forward data traffic to a higher layer MP function. Therefore, the SU/MP is divided into MPH (High) and MPL (Low). Candidate protocols in this case could be MPTCP or MPQUIC for MPH and TCP or UDP for MPL. Also, the interface between the orange gNB the SU/MP split and the blue UE stack of the transport path is to be specified, it will be either an internal interface or at Layer2/3. Hence, no link between the MP Split and the blue UE stack is illustrated, the MPH and MPL stream will rather be used as input for the NTN and TN UE, i.e. encapsulated within the blue PDCP. Same holds for the yellow gNB which outgoing GTP connection will be encapsulated within the MP protocols.

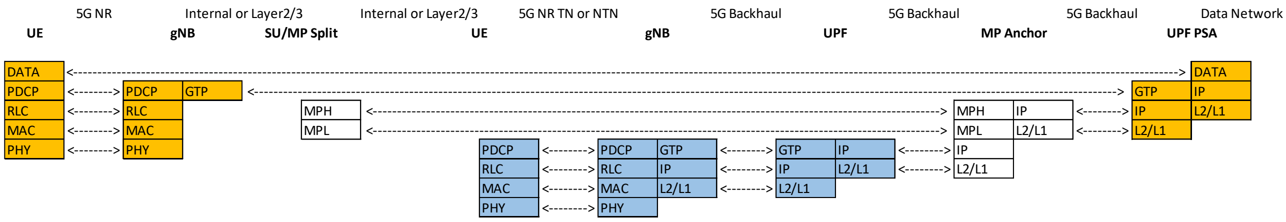

Figure 2-2: PoC protocol stack with full gNB onboard

2.2 OPTION 2 – CU/DU SPLITTING

2.2.1 Logical architecture

For the second architecture, high layers of the gNB are splitted, with the CU on-ground and DU+RU on-board, as represented in Figure 2-3

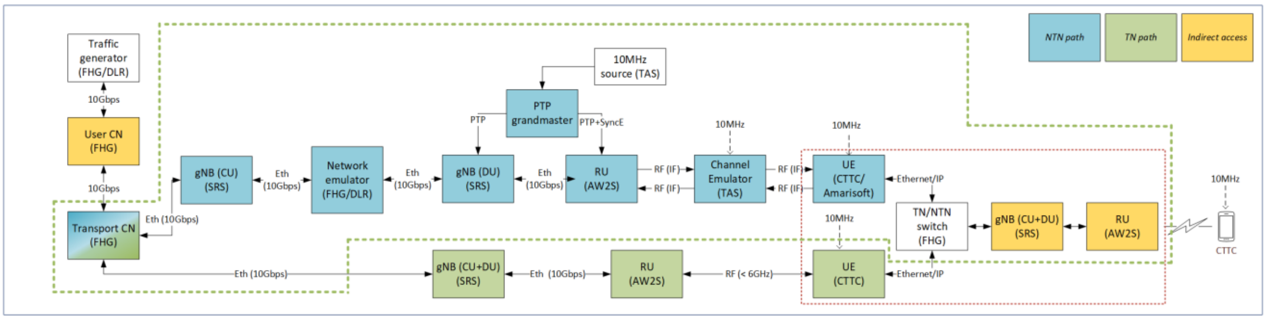

Figure 2-3 PoC logical architecture with CU/DU splitting.

All components are described in the paragraph 2.4 Main components

2.2.2 Protocol architecture

Figure 2-4 shows the protocol stack with CU/DU splitting. The interface between DU and CU is to be defined. The multi-connectivity function could be used if a TN is available. As for the previous case the outgoing GTP connection of the yellow gNB is encapsulated by the MP protocol, which again is encapsulated by the PDCP of the dedicated transport UE stack.

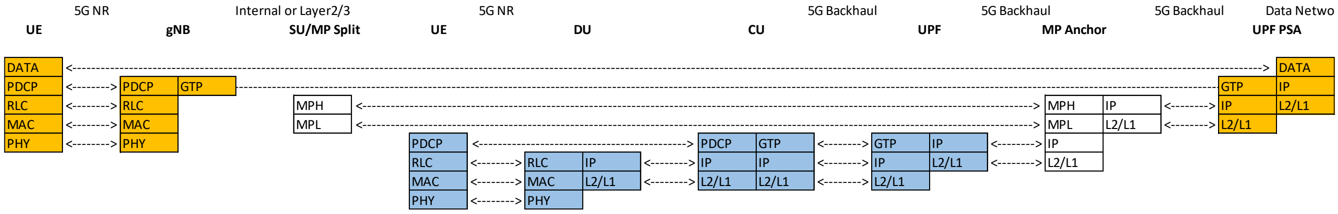

Figure 2-4: PoC protocol stack with CU/DU splitting

2.3 OPTION 3 – FULL GNB ONBOARD WITH 5GC FUNCTIONS

2.3.1 Logical architecture

Last architecture is presented in Figure 2-5. Here the gNB is fully integrated on board, with a part of the Core Network called UPF.

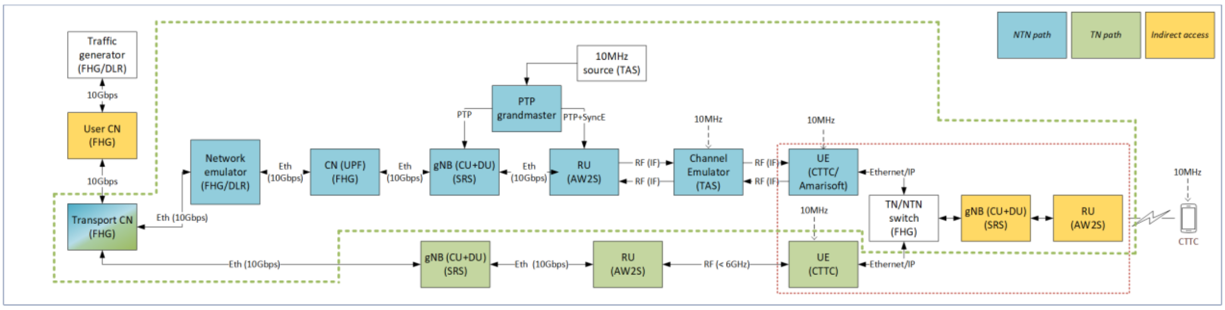

Figure 2-5 PoC logical architecture with full gNB and UPF (Core Network) on board.

All components are described in the subsection 2.4 “Main components”.

2.3.2 Protocol architecture

In Figure 2-6 the protocol stack with full gNB and UPF onboard a satellite is shown. The multi-connectivity function could be used if a TN is available. From protocol stack perspective this case is similar to the full-gNB onboard but after the blue transport gNB the UPFs are chained as specified by 3GPP.

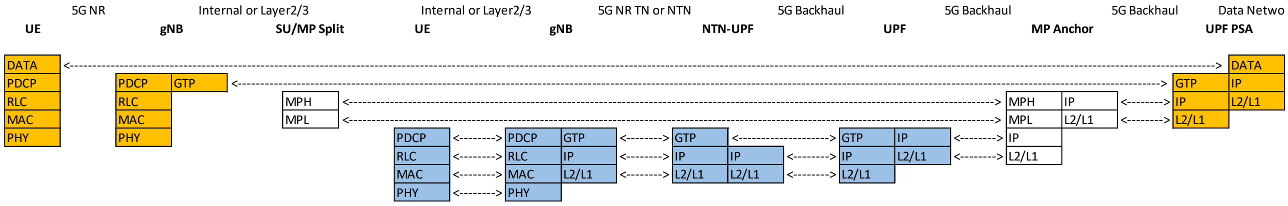

Figure 2-6: PoC protocol stack with full gNB onboard and UPF onboard

2.4 MAIN COMPONENTS

2.4.1 UE

The UE is the device that is used by the end user. Thus, it is responsible for initiating the communication with the cellular network. It is important to remark that two different software implementations will be used in the PoC.
The first UE is implemented in Task 4.1 building upon the open-source code developed by SRS. This UE is compliant with FR1 specifications and supports up to 20 MHz bandwidth. Hence, it will be used to demonstrate the FR1 setup.
The second UE is a commercial solution offered by Amarisoft. This software supports performance testing of 5G with a 100 MHz bandwidth. Accordingly, it will be used to test the FR2 setup.

2.4.1.1 UE – Bandwidth 20 MHz

The UE protocol stack, which terminates at Layer 3, runs on a Linux machine with Core i7. The UE supports a bandwidth up to 20 MHz. The I/Q samples at the output of the PHY are fed into the SDR frontend (USRP B210). The host computer and the SDR frontend are connected with a USB cable. The USRP is locked into an external 10 MHz reference clock. The RF signal can be transmitted over the air or to the channel emulator with an SMA cable.

The UEs that are placed in the backhaul segment, which are represented in green and blue in Figure xx, have an additional connection to the switching unit using an Ethernet cable. The schematic view is illustrated in the Figure xx.

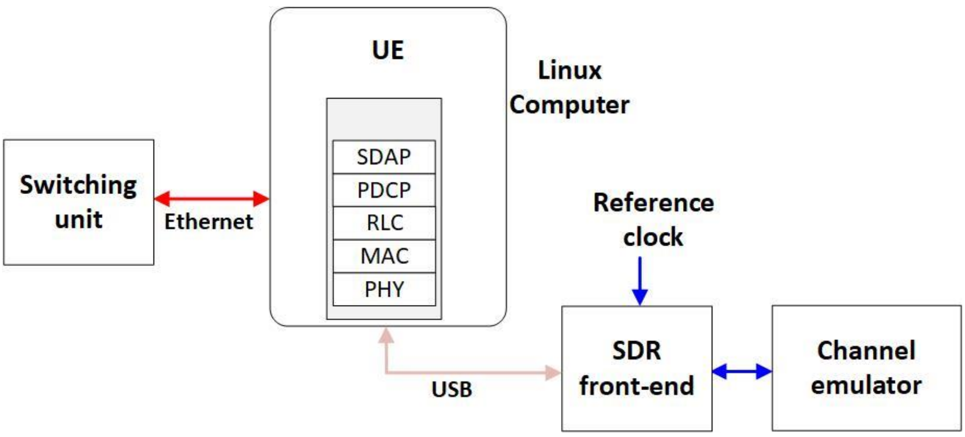

Figure 2-7 Block diagram of the UE

2.4.1.2 UE – Bandwidth 100 MHz

The second UE (Amarisoft UE) is similar to the first UE in most aspects in terms of architecture. It will also run on a Linux computer, consisting of L1-L3 as a software application. It will connect to an SDR frontend over PCI which will be trained by a PTP grandmaster. This SDR front end will be connected to the channel emulator in the same way, over SMA cables.
The Radio Units deployed for each UE will be different. The 20MHz UE will use the NI USRP B210 Bus Series [4] whereas the 100MHz UE will use a version of the AW2S RU which has been adapted for UE compatibility.

2.4.2 TN/NTN Switching Unit

In order to allow the usage of different links (TN and NTN) with indirect access, the standard protocol must be extended. For this we introduce an TN/NTN Switching Unit (SU) which is an internal routing element of the edge node of the terrestrial network towards the UE.

For uplink, it can receive the data traffic from the gNB and to route it towards the UEs for TN and NTN. Specifically, it receives datapackets encapsulated by the gNB in GTP data packets, tunnels which are established end-to-end from the user UE (yellow) to the user core network and are sent to the core network UPF PSA (PDU Session Anchor). The data packets together with their GTP header are then transmitted as payload to the UEs of the TN and NTN network. The TN/NTN switching is capable of executing the following functionality as part of the switching:

- To know when the TN and/or the NTN links are available – with this, the SU knows how to forward the data traffic to the specific available links

- To select over which link to send some specific data traffic – depending on the GTP header the data traffic would be forwarded to one or the other of the links, enabling the multi-access to be split at bearer level.

- If an additional application level splitting must be added (e.g. MPTCP or MPQUIC) the SU can forward all the data traffic to the MPTCP aggregator.

Similar functionality is added for the downlink.

2.4.3 gNB

The gNodeB will consist of two software applications running on either one Linux server or two. Specifically, this consists of the Central Unit (CU) and the Distributed Unit (DU). These two network components will make up the gNodeB.
They can flexibly either run together on the same machine or separately on two different machines with an SCTP connection between them. The DU will then connect to the RU over a PCI interface and the CU will connect to the CN over the NGAP.
The split case is shown in Figure 2-8. The RU will be trained by a PTP grandmaster.

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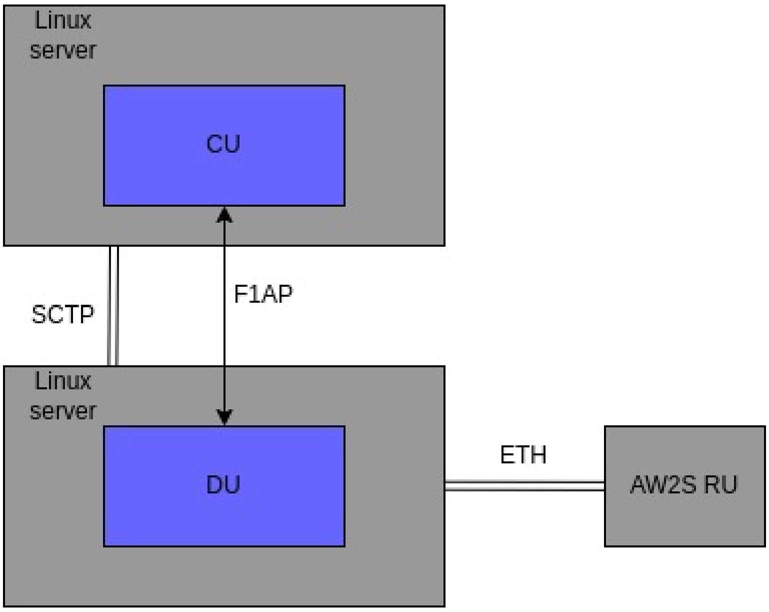

Figure 2-8: Functional architecture of gNodeB

2.4.4 Satellite user-link emulator

2.4.4.1 Impairments phenomenon

This section aims to list all the impairments that would usually be introduced by a typical satellite payload and satellite link. Also, the chosen piece of hardware emulating the satellite payload and link shall be able take into account and specify at least some of these impairments.

The following impairments are intrinsically linked to/introduced by the hardware equipment of a satellite payload (Radio Unit):

- **Noise and Interferences:** some noise will automatically be induced by the chosen hardware for the POC (RU), but the overall level of signal to noise ratio shall also be adjustable. Additionally, the emulation of an interfering signal could be necessary to reach a certain level of required signal to interference ratio.
- **Gain Flatness and Group Delay:** will automatically be induced by the chosen hardware for the POC (RU).
- **Phase Noise:** will automatically be induced by the chosen hardware for the POC (RU). If deemed interesting, it could also be simulated in the Satellite Link Emulator (SLE) with a certain frequency response (or mask) to study the impact of phase noise on the performances.
- **Nonlinearities:** will automatically be induced by the chosen hardware for the POC (RU). If deemed interesting, it could also be simulated in the Satellite Link Emulator (SLE) with a certain AM/AM profile to study the impact of non-linearities on the performances.

The following impairments are more related to the physical path from the satellite to the UE and vice versa:

- **Ionosphere:** the SLE shall simulate the time dispersive effect of the ionosphere.
- **Mutli-path Channel model:** optional. Some SLEs can include and recombine several propagation paths.
- **Fast fading model:** to model rain fades and scintillation, the signal can be weighed down with complex coefficients which are continually streamed (time series). Another approach is to define a fading slope in dB/s.
- **Delay and Doppler:** the SLE shall simulate a variable link delay. The variation of this delay is tied to the Doppler simulation of the link.

2.4.4.2 Satellite Link Emulator (SLE) element

The SLE shall be able to simulate the behaviour of a real link between the UE and the RU installed in the satellite regarding the different proposed architectures.
For this purpose, the SLE is taking into account the satellite trajectory and the RF disturbances that could occur.
Regarding the TR 38.411, for LEO, the Doppler associated to frequency and its variation is summarized here below:

Table 2 Doppler vs. reference carrier frequency

Frequency (GHz)	Max Doppler	Relative Doppler	Max Doppler shift variation
2	+/- 48 kHz	0.0024 %	- 544 Hz/s
20	+/- 480 kHz	0.0024 %	-5.44 kHz/s
30	+/- 720 kHz	0.0024 %	-8.16 kHz/s

In the same way, the estimate delay is summarised in this table:

Table 3 Reference LEO satellite orbit and overall geometry parameters

		LEO at 600 km	
Elevation angle	**Path**	**Distance D (km)**	**Delay (ms)**
UE: 10°	satellite - UE	1932.24	6,440
GW: 5°	satellite - gateway	2329.01	7.763
90°	satellite - UE	600	2
Bent pipe satellite			
One way delay	Gateway-satellite_UE	4261.2	14.204
Round Trip Delay	Twice	8522.5	28.408
Regenerative satellite			
One way delay	Satellite -UE	1932.24	6.44
Round Trip Delay	Satellite-UE-Satellite	3864.48	12.88

The phase noise and transmission losses are also simulated regarding the different scenario conditions. The value of the losses will be computed for each demonstration scenarios and the equipment will be set to reflect them.

Regarding the market capacity, there is the following potential equipment that could be used:

- ECA SLE-600
- IZT C3040, C5040 or C6000
- KRATOS
- Dbm ACE9600

The following table (Table 4) gives a first view of the SLE main characteristics:

Table 4 SLE main characteristics

	Parameters	ECA SLE-600	IZT C3040	IZT C5040	IZT C6000	KRATOS (channel simulator)	Dbm ACE9600
	Links	https://www.ecagroup.com/en/solutions/pce-600-propagation-channel-emulator-600mhz	https://www.izt-labs.de/satellite-channel-emulators-izt-c3040/	https://www.izt-labs.de/izt-c5040/	https://www.izt-labs.de/satellite-channel-emulators-izt-c6000/	https://www.kratosdefense.com/-/media/communications/pdf/fact-sheet---channel-simulator-options.pdf	https://dbmcorp.com/product-category/channel-emulators/ace9600/
	Main functions	Doppler Propagation delay Fading AGWN QPSK jammers Multipath	Doppler Delay Fading Phase noise Ionosphere simulation	Doppler (simul or file for 24h) Propagation delay Fading (rain & mutlipath) AWGN Interference	Same as C5040 + Phase delay	Doopler Propagation delay AWGN	Doppler Phase continuous delay Attenaution AWGN & Eb/No Fading (multipath)
RF Frequency	Frequency range	1-1.6 GHz	Up to 3GHz	100-3000 MHz	450 or 1250 MHz (IF)	900-2450MHz	800-2600MHz
	Maximum Bandwidth	Up to 600 MHz	Up to 600 MHz	Up to 250 MHz	400MHz	600MHz	600MHz
	Input power range	N/A	20 dBm to - 30 dBm	-10 to -50 dBM	N/A	N/A	N/A
	Output power range	N/A	15 dBm to -120dBm	+10 to -50 dBm	N/A	N/A	N/A
Time	Delay	0,02 - 295ms	150µs - 800 ms	1 ms - 1s	10us - 800ms	0,007 - 1250ms	0,007 - 700ms
	Steps	1ns	1 ns	0,1 ns	1ns	1,2ps	0,1ns stat / 0,5ps Dyn
Doppler	Time Doppler	N/A	N/A	N/A	+/- 80us /s	+/-61us/s	0,1ps/s to 2ms/s
	Time Doppler Step	N/A	N/A	N/A	5ps/s	N/A	N/A
	Phase continuity	Yes	N/A	N/A	Yes	Yes	Yes
	Fresquency Doppler	+/-2MHz	+/- 50 MHz	+/- 1MHz	+/-1MHz	+/-300MHz or +/- 1,33MHz	+/- 5MHz
	Frequency Doppler step	+/- 1mHz	1 Hz	1 Hz	0,1Hz	0,18Hz or 0,0003Hz	0,01Hz

They are able to emulate the two-way link (Uplink and Downlink) for one UE / RU link. They are mainly interfaced at frequency < 6 GHz, and able to support 100 MHz bandwidth to be compatible with identified UEs.

2.4.5 5G Core Network

The Fraunhofer FOKUS Open5GCore toolkit is the worldwide first practical implementation of the 3GPP 5G core network. It currently prototypes 3GPP Release 16 and 17 core network functionalities, in a form suitable for R&D activities. Open5GCore is interoperable with many 5G NR base stations and user endpoints (UEs). Open5GCore was designed to provide support and speeding up research, by facilitating the know-how transfer from Fraunhofer FOKUS towards customers and project partners. It serves as a consistent basis for 5G testbed deployments for trials and pilots, and for the further development of new beyond-5G and 6G standard-oriented functional features.

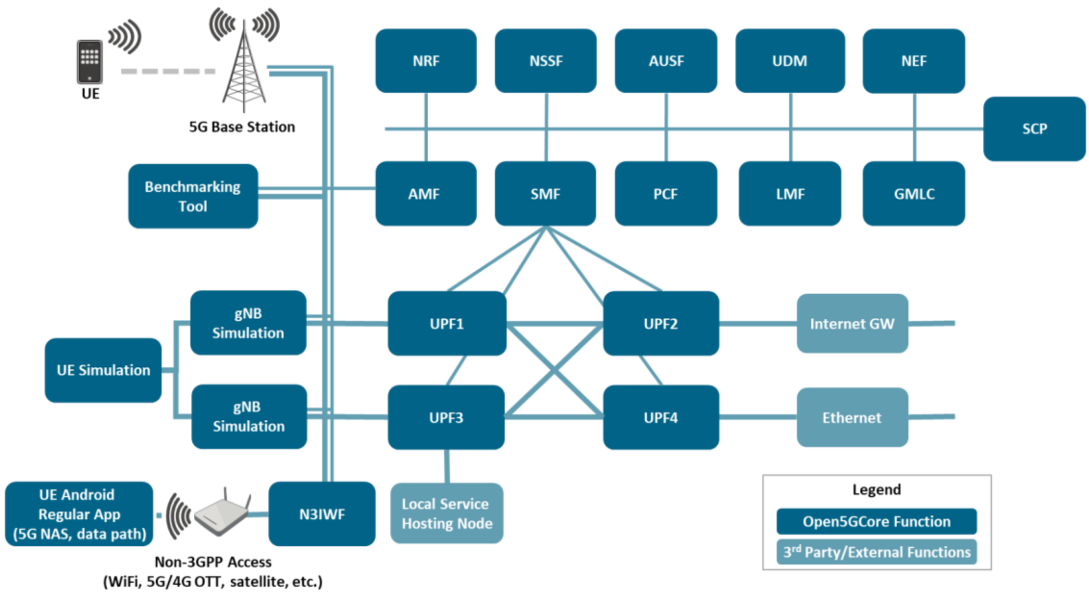

Figure 2-9 – Open5GCore Rel. 8 Architecture

Open5GCore represents a first 5G core network implementation addressing the needs of 5G testbeds for FOKUS and for partner activities. Open5GCore Rel. 8 main features are:

- Fundamental 5G core network functionality (AMF, SMF, AUSF, UDM, NRF, UPF)
- Implementation of Service Based Architecture [HTTP/2 OpenAPI, REST]
- Integration with standard 5G NR using the 5G interfaces [N1, N2, N3], 5G NAS and NG-AP
- Implementing control-user plane split with PFCP [N4]
- Advanced QoS and session management with traffic influence
- Network slice support
- Comprehensive non-3GPP access convergence
- Location Service Support
- Benchmarking Tools

Open5GCore Rel. 8 integrates with 5G New Radio Stand-Alone (SA) base stations and user equipment enabling immediate demonstration of different features and applications and supporting the current need to have a flexible 5G Core Network.

Open5GCore runs on top of common hardware platforms and can be deployed with containers, pods or virtual machines on top of a large number of virtualization environments. The required hardware for a testbed setup, highly depends on the expected capacity. Open5GCore scales from Raspberry PI to a complete rack of servers.

Open5GCore is highly customizable, enabling the deployment of instances addressing the needs of the specific use cases. Specifically, for deployment together with NTN networks, Open5GCore was deployed since 2019 as a back-end for satellite based gNB as part of the ESA SATis5 project as well as later adapted to be deployed in full or partially as part of satellite payloads as part of the ESA ARTES 5GEOSiS (work in progress) and ESA ARTES 6G-SmartSat (work in progress) with this showcasing together with SRS 5G NR SA gNB a comprehensive space-deployed system.

In order to support multi-connectivity setup of the PoC, there are some options which need to be supported by the Open5GCore. A splitting functionality is required able to split or switch traffic between two links. These two flows need to be merged at the UPF function of the UE-serving Open5GCore. In contrast to the reference specification of ATSSS, the splitting functionality is not necessarily provided at the UE requiring some flexibility of the placement.

2.4.6 Network emulators

In the last years, as part of ESA HydRON [3] projects, Fraunhofer FOKUS has implemented a large-scale network emulator enabling the automatically testing of new concepts in a large number of real-networks, named OpenLanes. The OpenLanes network emulator is able to:

- Emulate large-scale networks at network layer including more than 200 different nodes. The emulation includes both the TN and NTN support, enabling the development of a comprehensive system. Links are emulated at network layer including parameters such as delay, capacity, packet loss and jitter. This emulation feature could be used for reproducing the characteristics of the NTN feeder link, while the user link will be characterised by an actual satellite link emulator, since the user link is generally more subject to RF impairments.

- Support for static and dynamic topologies – OpenLanes enables automated tests across multiple network topologies enabling the assessment of newly implemented systems across multiple situations which can happen in the real systems, including limit situations which may be rarely or never be met by them. With this OpenLanes enable the assessment of the technologies with all the potential situations, giving a very good coverage of testing use cases. Additionally, OpenLanes natively-includes the option to test the technologies in changing topologies such as LEO-satellite constellations. The topology changes are described as time-series vectors across the different parameters of the links, enabling to test the impact of the specific deployment on the given technologies.

- OpenLanes is highly configurable through either using an intuitive configuration GUI for the deployment scenario and situation selection as well as automatic configuration mechanisms. In a next version, the OpenLanes will include a large number of telecom backbone and satellite constellation relevant topologies with this being able to provide the support for the 5G Stardust end-to-end testbed deployment.

- OpenLanes can be interfaced with real nodes/hardware devices with this showcasing the behaviour of the different nodes in a realistic complex network. It represents the ideal emulation version for end-to-end prototypes as in the case of 5G Stardust, as it provides the inter-node networking for the different components and their software as employed in the PoC. However, its actual full use in the PoC might be limited depending on the specific scenario to be reproduced and by keeping under consideration the complexity possibly arising from a large network instantiation.

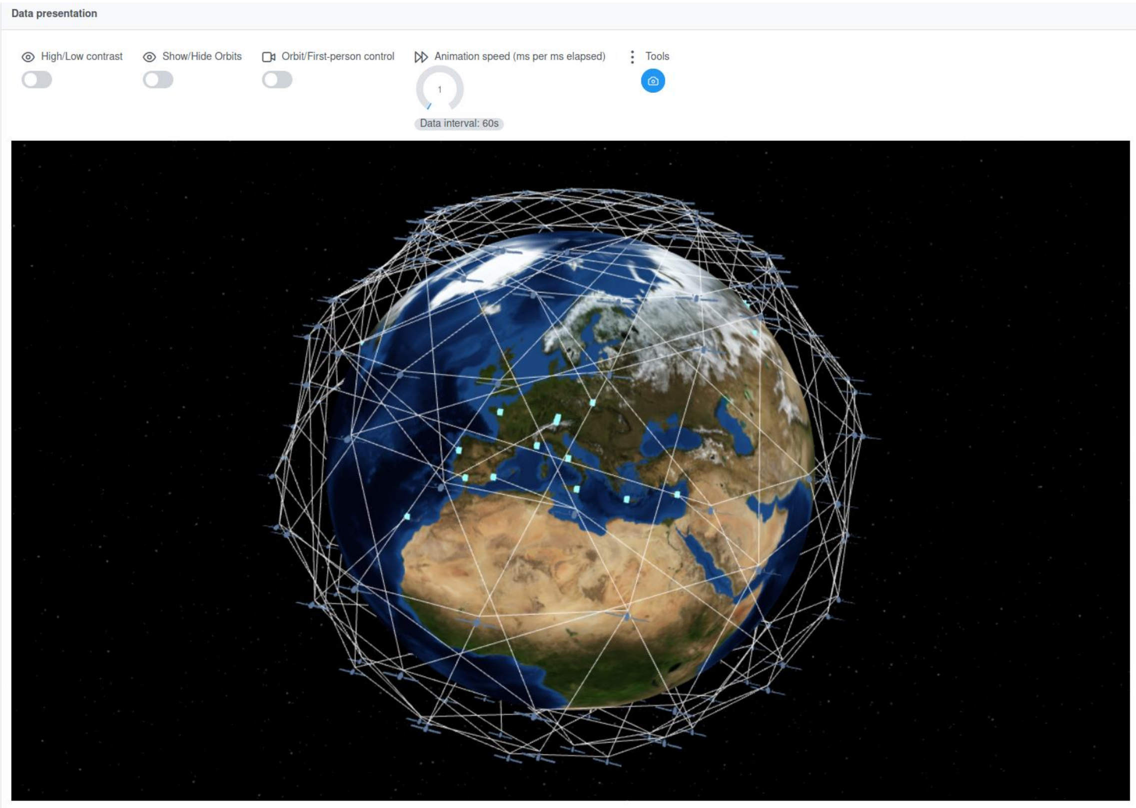

Figure 2-10 - OpenLanes GUI

DLR also developed a real time link emulation software for PCs with a FreeBSD/Linux operating system to be able to impose packet delay, packet loss/errors, and throughput limitations (via traffic shaping) on packets transmitted via Ethernet. A PC with this software and Ethernet ports can be plugged into bidirectional Ethernet links to impose the configurable link behaviour. This real time link emulator fully supports bidirectional Ethernet links and can be used for protocol testing, especially when transmission delay (e.g. via ISLs) or packet errors play a role.

The link emulation software emulates packet delay (with a granularity imposed by the hardware clock rate of the PC), packet loss (with a configurable loss/error rate), and throughput limitations (with configurable shaping parameters). If necessary, the configuration parameters can be read from an input file to generate time-variant behaviour. Furthermore, the link emulation software generates statistics for monitoring purposes.

2.4.7 Traffic generators

Two different traffic generators are considered for use in the PoC, whose actual integration will be discussed in D6.2, while elaborating on the measurement and analysis tools to be used in support to the validation procedures. The two traffic generators available within the consortium are shortly illustrated in the following.

2.4.7.1 FHG Traffic generators

The Fraunhofer FOKUS Open5GCore is able to generate a comprehensive load emulating UEs and gNBs to be able to provide quantitative evaluations of the different customized core networks on top of different resource infrastructures. It includes:

- Flexible and intuitive gNB configurations
- Flexible subscriber mobility and load patterns
- Support for x10k emulated subscribers and x100 gNBs
- Support for N1/N2/N3 procedures
- Monitoring parameters - 50+ metrics including:
    - Quality: Success rate, procedure delay at UE/gNB
    - Performance: procedure delay, used compute and storage

In the context of 5G Stardust, the Open5GCore Benchmarking tool will be used only for the initial testing of the packet core deployment, as it replaces the UEs and the gNBs with emulated devices and plays no role in the end-to-end PoC.

2.4.7.2 DLR Traffic generators

DLR also developed a PC based real time traffic generator/performance analyser (TGA) , which can be controlled via SNMP. The traffic models of the TGA have also been developed by DLR to reproduce the pattern of most relevant traffic protocols. The generated IP packets contain time stamps and packet numbers. On the receiving end, performance parameters such as packet dropping rate, delay, and delay jitter can be measured and analysed by this software. The TGA software requires a FreeBSD operating system and Ethernet Interfaces to run properly. It is planned to use this TGA in the Demonstrator.

Figure 2-11: DLR traffic generator/performance analyser (TGA)

3 SUPPORTED 3GPP PROCEDURES

3.1 OBJECTIVE

The aim of the functional architecture description provided in this section is to identify the reference functions, which will be accommodated in the final PoC. As such, the exercise here carried out is mostly focus on the interaction between UEs and gNBs, while the other interconnected elements will provide standard IP-based networking functions, which are intrinsically available in the considered platform and therefore not necessitating particular focus.

Then, the second step is to address KPI and the reference scenarios that will be demonstrated by means of the developed PoC. Nevertheless, a finer consolidation of what already presented in D2.1 and D3.2 will be carried in the next phases of WP6, since this will be jointly performed as part of the technical specification definition, objective of T6.2 and T6.3.

3.2 DISCUSSION OF THE SUPPORTED PROCEDURES

As pointed out in the previous section, a key ingredient for the definition of the functional architecture is to identify the procedures involved in the interaction between UEs and gNB, which will be also supported in the final implementation of the PoC.

To this end, the 3GPP procedures as defined in 3GPP TS 38.331 have been carefully considered and a final set of recommendations has been worked out, by considering the functionalities that could be supported by the UE and gNB implementations developed within WP4 or in any case available from the involved partners. It is important to note that is assumed that the identified functions or procedures are identically supported for both terrestrial and non-terrestrial networks (TN and NTN), so as to achieve consistent path characterisation from a functional standpoint within the same PoC. Moreover, for the sake of the completeness each supported procedure has been studied with respect to the main characterising steps involved in the performed operations.

The overall set of supported procedures is summarised in Table 5.

Table 5 Supported 3GPP procedures

Procedure from TS 38.331			Applicability	
			TN/NTN	**Needs (description / initial state)**
Chapter	**Title**	**Page**		
	Initial registration to the network		**YES**	- UE entrying the network the 1st time - UE lost primary connection (PLMN reselection f.e.) - Fixed/moving UE
5.2.2	System information acquisition	44	**YES**	The UE applies the SI acquisition procedure to acquire the AS, NAS- and positioning assistance data information. The procedure applies to UEs in RRC_IDLE, in RRC_INACTIVE and in RRC_CONNECTED.
5.3.2	Paging	72	**YES**	The purpose of this procedure is: - to transmit paging information to a UE in RRC_IDLE or RRC_INACTIVE. - to transmit paging information for a L2 U2N Remote UE in RRC_IDLE or RRC_INACTIVE to its serving L2 U2N Relay UE in any RRC state.
5.3.3	RRC connection establishment	75	**YES**	This the initial step for a UE to be able to communicate with the cellular network: -The UE sends the RRCSetupRequest -Upon Reception of RRCSetupRequest, the gNB sends the RRCSetup message -After successful connection, the UE responds with RRCSetupComplete message
5.3.4	Initial AS security activation	85	**YES**	The network activates the AS security by seding SecurityModeCommand message to a UE RRC_CONNECTED. After successful activation, the UE sends the SecurityModeComplete message back to the gNB. Otherwise, the UE sends the SecurityModeFailure commands
5.3.7	RRC connection re-establishment	160	**YES**	This is a recovery mechanism to re-establish RRC the connection when a radio link failure is detected: -The UE initiates the procedure by sending a RRCRestablishmentRequest message to the gNB. -The gNB respondss with a RRCRestablishment message assigning a new configuration for the device. -The UE sends a RRCRestablishmentComplete message to confirm the successful re-establishment of the RRC connection.
5.3.8	RRC connection release	172	**YES**	This procedure is initiated by the network to put the UE in IDLE state by sending the RRCConnectionRelease message
5.3.15	RRC connection reject	209	**YES**	The UE informs upper layers about the failure to establish the RRC connection. The RRCReject message is received in response of the RRCSetupRequest message.
5.5.3	Performing measurements	228	**YES**	Derive measurements based on SSB: energy per resource element (EPRE), Reference Signal Received Power (RSRP), noise, snr, cfo, delay

It is important to note that the first indicated function "initial registration to the network" is actually not directly derived from 3GPP TS 38.331, but has been introduced to give completeness to the list of functions necessary to establish a connection and then allow starting the nominal user/control plane functions.

Last but not the least, the actual methodology for validating the supported 3GPP procedures will be pretty much linked to the identification/definition of the specific functional KPI, which is going to happen in Task 6.2 and 6.3 of WP6.

3.3 USER KPI SUPPORT

The review of the user KPI is actually the first step towards the functional KPI to be defined in the next phases of WP6 towards the full system integration and validation. In this respect, Deliverable D2.1 has provided a first iteration on the KPI definition towards the instantiation of meaningful use cases, consisting of the following classes ('R' stands for recommended, 'O' for optional, and 'N/A' not applicable for the PoC implementation):

1) User Application Capabilities:

a. KPI_1.1 User experienced data rate (R)
b. KPI_1.2 End-to-end Latency (R)
c. KPI_1.3 User service packet error rate (R)

2) Service Continuity:
    a. KPI_2.1 Phase 1 duration (O)
    b. KPI_2.2 # expected switching attempts (N/A)
    c. KPI_2.3 Phase 2 duration (O)
    d. KPI_2.4 # effective switching attempts (N/A)
    e. KPI_2.5 Switching success rate (O)
    f. KPI_2.6 Number of drop calls (R)
    g. KPI_2.7 User rate evolution (O)
    h. KPI_2.8 User latency evolution (O)
    i. KPI_2.9 User application failure ratio (O)

3) Service Ubiquity:
    a. KPI_3.1 Area efficiency (R)
    b. KPI_3.2 Area Traffic Capacity (N/A)
    c. KPI_3.3 Area Spectral Efficiency (N/A)
    d. KPI_3.4 # expected connection establishments (N/A)
    e. KPI_3.5 # connection establishments attempts(N/A)
    f. KPI_3.6 Connection establishment success rate (R)

It is however worth noting that the service ubiquity KPIs (3.1-3.6) listed above are very likely not directly applicable to the PoC, since they relate more to real scenario or network deployment where a meaningful number of real nodes will be considered. On the contrary, the final setup (as already sketched in Fig. 2) will be mostly consisting of few TN and NTN nodes, whereby items such as area efficiency, traffic capacity, and spectral efficiency are deemed not so meaningful for demonstration purposes. Similar considerations also hold for the items dealing with the connection establishment.

All in all, as already stated at the beginning of this section user application capabilities are certainly pretty much related to specific use case characteristics and the PoC configuration, so that refinement of the values provided in D2.1 will be carried out during the PoC technical specification phase as part of D6.2 and D6.3. Likewise, the KPI dealing with service continuity recognised as recommended for the PoC implementation will be pretty much based on the actual scenario configuration and specific operations being reproduced. For instance, the support of multi-link connectivity towards the coexistence of TN and NTN segments should allow to measure the corresponding KPIs identified for the service continuity. On the other hand, the case of service ubiquity support in terms of KPI might need an additional refinement, since the PoC will reach TRL4/5 and hence demonstrated in lab, implying a limited number of nodes (UEs and gNB), whereby the service ubiquity demonstration could have a limited impact. In this perspective, therefore, scenario and platform configuration as part of the technical specification and validation exercise happening in T6.2 and T6.3 will be fundamental to have a more refined and final iteration on KPI and hence come up to a specific list of indicators to be analysed and the related measurement methodology.

3.4 USE CASES IMPLEMENTATION

A first iteration on the selection of use cases to be object of demonstration was provided in D3.2, which eventually identified the following options:

- Residential broadband:
    - Residential broadband for energy saving, consisting in switching off the terrestrial network during night and hand over to NTN for the corresponding data services.
    - Residential broadband for large sparsely populated areas, exploiting the coexistence of TN and NTN towards a better user experience, depending on the resources available on either network infrastructures
- Air traffic
    - TN/NTN switch at boarding, consisting in the case where prior to aircraft take-off, possible migration of data connectivity from TN and NTN is being managed and eventually established
    - In-flight connectivity, addressing the case of connectivity onboard aircraft via TN (for continental flights only) and NTN, whereby dedicated switching operations will be in place.

From a functional standpoint, the plan is to support both direct and indirect accesses as shown in Section 2 of this document and the list of supported 3GPP procedures (Section 3.1) allows to actually considers all configurations envisioned in D3.2. In particular, the three architectures options (full gNB, CU-DU splitting, full gNB+UPF onboard) will be considered for the considered scenarios, in order to better evaluate the pros and cons of each functional splitting approach against the specific user KPI, whose numerical instantiation will also happen during in the next phases of WP6 (i.e. in Task 6.2). Likewise, the specific multi-path/link concepts along with the network switching unit will be carefully assessed to prove the benefits that they can bring to the considered scenario and the specific configuration that bring the most promising performance results.

However, the actual characterisation of the use cases going to be demonstrated is happening through the final iteration on functional KPI in order to have the final configuration. As such, the final selection and characterisation of the use cases to be demonstrated will be object of T6.2 and T6.3, aimed at carrying out the technical specification and elaborating a testing plan. Numerical instantiation of KPIs will be in this regard very important towards a precise characterisation of the link configurations, which as already stated in Section 3.3 can happen only at technical specification phase.

4 CONCLUSIONS

This present deliverable D6.1 addressed the overall layout of the planned PoC with respect to the building blocks and their interconnection from a functional and interface definition standpoint. In particular three different architectures have been identified on the basis of the main conclusions drawn in D3.2, i.e. in terms of:

a) Full gNB onboard

b) CU/DU function splitting across ground and space segments

c) Full gNB onboard with some core-network functionalities there implemented

Options a) and c) are considered quite in cascade as c) is essentially an extension of option a). On the other hand it is observed that option b) might introduce some challenges because of latency requirements on the interconnection between CU and DU components according to the current definition of the F1 interface. Further elaborations on these points will then happen in the course of T6.2 and T6.3 towards the full definition and integration of the PoC.

Another important point is with respect to demonstrating FR1 or FR2 setup along with moderate (up to 20 MHz) or large bandwidth (i.e. 100 MHz), for which separated configurations have been identified, resulting in the use of different UEs and corresponding radio units.

Finally, the document shed some lights on the scenarios being possible to reproduce by means of the so considered PoC architecture and hence paving the way towards an effective demonstration of key scenarios in the context of integrated 5G-NTN systems, which will be further addressed also in the context of T7.4 as part of the exploitation analysis and roadmap beyond the project lifetime (i.e. post-2025).

The next steps will be then to come up with the finalised definition of the PoC as part of T6.2 and T6.3, which will eventually also elaborate on the integration and related validation plan. In this respect, T6.2 and T6.3 will take as reference the functional and physical architecture developed in the present document and KPIs will be in turn identified in order to validate the adopted 3GPP procedures and define accordingly the integration plan. In more details, the tentative roadmap towards the PoC integration will consist of the following points:

- Definition of the technical specification
- Definition of the validation procedures in terms of testing plan and identification of the measurements tools to be used for this purpose. This exercise will come along with the identification of the specific KPIs for validation purpose and the finalised mapping between use cases and architectures supported by the PoC(s).
- Overall integration of the components building the NTN path and related validation
- Overall integration of the components building the TN path and related validation
- Overall integration of the TN/NTN, with particular attention on the multi-link/path and network switching elements.

This list will be further broken down in the upcoming tasks of WP6 towards the actual planning in time of all phases, bearing in mind that the fully integrated setup will be hosted by TAS-F in Toulouse and therefore dedicated SW/HW components will have to be made available for actual integration and testing onsite.

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