6G-INTEGRATION-01-E17: Integration testing report

6G-INTEGRATION

Full Title: Construction of an ecosystem for research and development in non-terrestrial networks (satellite and HAPS) and B5G (3GPP rel. 17 and beyond): NTN networks for LEO satellites and for HAPS platforms.

Program: UNICO 5G I+D 2021

Start date: Jan 1, 2024 End date: Jun 30, 2025

Duration: 18 months

Document type	Deliverable
Document Id	6G-INTEGRATION-04-E25
Document title	Integration testing report
Document responsible	Manuel Lorenzo (Ericsson)
Document editor	Jaime García (Ericsson)
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Version	1.0
Planned Due date	June 12, 2025
Actual submission date	June 12, 2025

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Executive Summary

This document provides a detailed description of the test and validation results performed by Ericsson for the 6G-Integration, where it has defined a scenario of a B5G network onboarded in non-terrestrial networks, included HAPS.

With version 17 ("Rel17") of the 3GPP, specifications for integrating Non-Terrestrial Networks (NTN) into 5G infrastructure have been introduced, marking a significant step towards global connectivity. NTN networks, which include satellites in low (LEO), medium (MEO), and geostationary (GEO) orbits, as well as high-altitude platforms (HAPs), extend 5G coverage to remote regions. Rel17 optimizes traffic management between terrestrial and non-terrestrial networks, improving latency, resilience, and spectral efficiency, solidifying NTN as a key pillar for next-generation critical services.

Ericsson provided the infrastructure for this validation activities that is based on a commercial 5G network system providing 5G "Stand-Alone" (SA) radio coverage in mid-band (n77, sub-6GHz - FR1).

The use case of “Radio channel emulation for validating on onboard B5G system“, emulating the radio channel with real traffic transmitted towards the 5G system in terms of throughput, latency, timing advance, SNR, MCS, and RSRP, has been validated.

Based on the test results with real uplink and downlink traffic reaching sustained rates of 50 Mbps, the system demonstrated performance levels aligned with the requirements for 5G service delivery. These outcomes prove the feasibility of deploying a gNB on a HAPS, confirming its capability to support consistent bidirectional communication and ensure reliable service in a non-terrestrial environment.

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Resumen ejecutivo

Este documento proporciona una descripción detallada de las pruebas y resultados de validación realizadas por Ericsson para el proyecto 6G-Integration, en el que se ha definido un escenario de una red B5G integrada en redes no terrestres, incluyendo plataformas de gran altitud (HAPS).

Con la versión 17 ("Rel17") del 3GPP, se han introducido especificaciones para la integración de redes no terrestres (NTN) en la infraestructura 5G, lo que marca un avance significativo hacia la conectividad global. Las redes NTN, que incluyen satélites en órbita baja (LEO), media (MEO) y geoestacionaria (GEO), así como plataformas de gran altitud (HAPS), permiten extender la cobertura 5G a regiones remotas. La Rel17 optimiza la gestión del tráfico entre redes terrestres y no terrestres, mejorando la latencia, la resiliencia y la eficiencia espectral, consolidando a las NTN como un pilar clave para los servicios críticos de próxima generación.

Ericsson proporcionó la infraestructura para estas actividades de validación, basada en un sistema comercial de red 5G que ofrece cobertura de radio 5G "Stand-Alone" (SA) en banda media (n77, sub-6GHz - FR1).

Se ha validado el caso de uso de "Emulación de canal radio para la validación de un sistema B5G a bordo", emulando el canal radio con tráfico real transmitido hacia el sistema 5G en términos de throughput, latencia, avance de temporización (timing advance), SNR, MCS y RSRP.

Con base en los resultados de las pruebas, en las que se transmitió tráfico real de subida y bajada alcanzando tasas sostenidas de 50 Mbps, el sistema demostró niveles de rendimiento alineados con los requisitos para la provisión de servicios 5G. Estos resultados prueban la viabilidad de desplegar un gNB en una plataforma HAPS, confirmando su capacidad para soportar comunicación bidireccional consistente y garantizar un servicio confiable en un entorno no terrestre.

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Glossary

3GPP	3rd Generation Partnership Project
5G	5th Generation technology standard for cellular networks
5GC	5G Core
5GS	5G System
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
B5G	Beyond 5G
CSP	Communication Service Providers
GEO	Geostationary Orbit
gNB	Next Generation NodeB
HAP	High Altitude Platform
IRU	Integrated Radio Unit
LEO	Low Earth Orbit
MCS	Modulation and Coding Scheme
MEO	Medium Earth Orbit
MPTCP	MultiPath TCP
NPN	Non-Public Network
NRF	Network Repository Function
NSSF	Network Slice Selection Function
NTN	Non-Terrestrial Network
PCF	Policy Control Function
PNI-NPN	Public Network Integrated Non-Public Network
RSRP	Reference Signal Received Power
SDR	Software Defined Radio

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SMF	Session Management Function
SNR	Signal to Noise Ratio
TCP	Transport Control Protocol
TA	Timing Advance
UE	User Equipment
UDM	Unified Data Management
UDR	Unified Data Repository
UPF	User Plane Function

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1 Solution Description

1.1 Overview

The evolution towards Beyond 5G (B5G) networks marks a critical milestone in telecommunications, with a strong focus on the seamless integration of Non-Terrestrial Networks (NTN) and terrestrial infrastructures. This integration, essential for extending connectivity to underserved regions and for enhancing network resilience, leverages advanced NTN technologies such as satellites and High-Altitude Platforms (HAPs). These components play a pivotal role in expanding the reach of networks by addressing connectivity challenges in remote areas and improving overall capacity.

NTN elements, including satellites operating across Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO), are complemented by HAPs situated in the stratosphere. Satellites provide global reach and are instrumental in broadband and IoT applications, while HAPs offer localized, high-capacity coverage, particularly valuable in disaster recovery scenarios and areas with challenging terrain. The integration of these technologies into terrestrial networks, as outlined in 3GPP Release 17 (R17), enables the delivery of reliable and efficient connectivity in diverse environments. However, this integration necessitates overcoming challenges such as signal delays and Doppler effects, ensuring service continuity and optimal spectrum usage to achieve seamless operation.

A 5G Non-Public Network (NPN) testbed has been deployed at the 5TONIC premises to evaluate the synergy between Non-Terrestrial Networks (NTNs) and terrestrial networks. With the support of Amarisoft infrastructure, it has been possible to validate the radio channel with real traffic of a gNodeB located on a HAPS (High Altitude Platform Station), providing service to terrestrial UEs. The testbed also supports critical use cases such as delivering enhanced mobile broadband (eMBB) in remote areas, enabling global IoT device communication, and providing resilient connectivity for public safety and disaster recovery operations. These capabilities highlight the transformative potential of NTNs in addressing the diverse demands of modern connectivity.

1.2 Portable Deployment Infrastructure

All servers, the router, and most of the essential components for this project used for the validation are integrated into the portable rack of the 5G NPN system. This infrastructure has been installed, configured, and validated in the 5TONIC laboratory.

Leveraging Amarisoft's validation capabilities, the system can emulate changes in the gNodeB's geographical location, enabling test scenarios where the base station is virtually positioned on aHigh-Altitude Platform Station (HAPS).

In parallel, the validation of terrestrial User Equipments (UEs) is carried out using the Amarisoft UE Simbox, which acts as a configurable CPE, allowing for realistic testing of downlink and uplink performance and radio conditions between a HAPS-based gNodeB and ground-level UEs.

The flight rack used in the validation of real traffic environment includes, as part of the gNodeB, the following commercial Ericsson components: 5G Baseband 6648, IRU 8846 and a Radio DOT 4479 system, all integrated and operating in FR1 midband spectrum (band n78). This configuration enables realistic validation of aerial deployment scenarios under laboratory conditions.

The synchronization in time and phase, needed for the 5G TDD RAN, is provided by an antenna and GPS module connected through the Ericsson Router 6675 (IEEE 1588 PTP protocol), which also serves as a traffic aggregator for the rest of NPN network components and connection to the control planes of the 5GC.

Baseband, IRU and Router 6675 are powered by the power supply unit (PSU) hosted in the portable rack.

The Local Packet Gateway (LPG) of Ericsson is also connected to the Router 6675, which provides the user plane (UPF) function of the 5GC. Additionally, an Ericsson CRU 0101 application server is connected, allowing the deployment of the user traffic part locally on the 5G NPN equipment.

Finally, the User Equipment/Customer Premises Equipment (UE/CPE) is emulated using the Amarisoft UE Simbox, which supports 5G SA in FR1 (midband) and enables the simulation of multiple configurable UEs simultaneously.

In Figure 1, can be seen the 5G NPN portable system, informally called as "Flamingo", where the different components described are located:

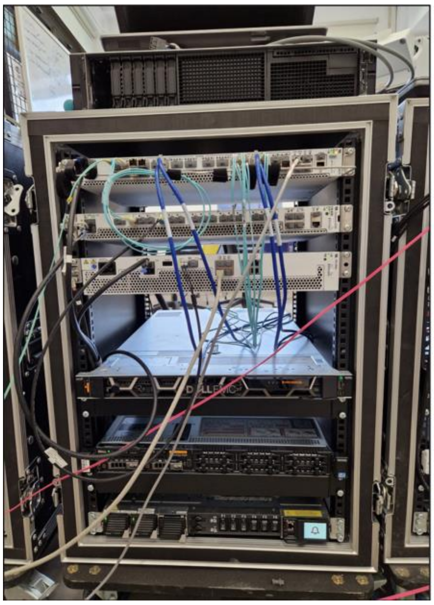

Figure 1 - 5G NPN portable system "Flamingo"

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In Figure 2, it is shown more in detail the Ericsson solution and diagram connection of the 5G NPN NTN system for 6G-Integration project:

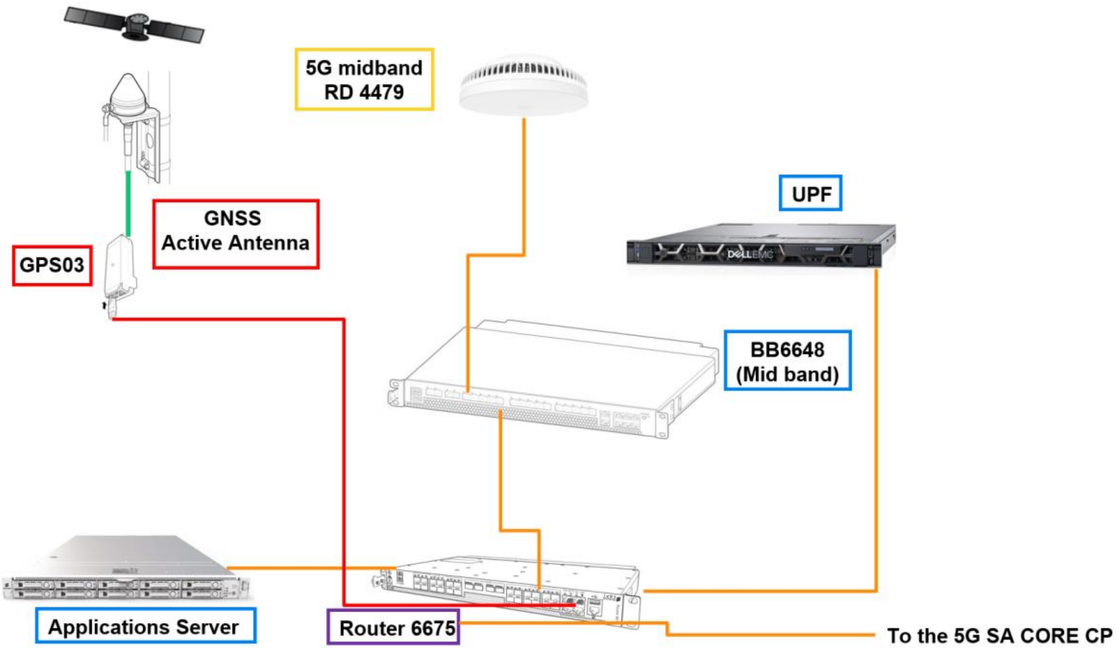

Figure 2 - Solution diagram of the 5G NPN

Next, it is summarized the components of the 5G NPN NTN system. More detailed information of each equipment can be found on *Solution Equipment* (section 2).

- RadioDot 4479 (B78L, 3300-3500 MHz), a single-band indoor radio optimized for capacity deployments.
- Baseband 6648 is the baseband processing unit for mid-band. It handles the digital processing required for signals received from the antennas before routing them through the network.
- UPF (User Plane Function) is a crucial component of the 5G Core network, responsible for handling user data traffic. It processes data coming from the BB6648 unit.
- Router 6675 is the routing device that connects the network to the 5G Standalone (SA) Core Control Plane (CP).
- GNSS Active Antenna and GPS Module (GRU 04 01), compose the Global Navigation Satellite System (GNSS) antenna system, likely used for precise timing and location synchronization.
  - **Note:** GPS cable connected to the Router 6675 is a standard RJ45 cable but with a special PIN definition.

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Note: The PIN definition of the extension cable depends on the port of the remote device. For example, if the remote device is Ericsson GPS, following pin swapping should be used.

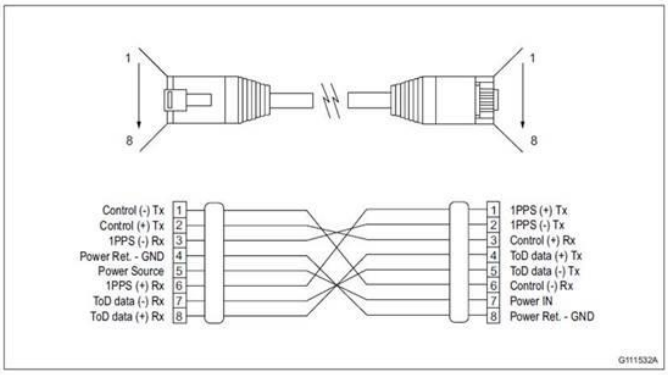

Figure 3 - GPS cable special PIN definition for Router 6675

On the other hand, the Control Plane of the 5G Core is deployed in the central Data Center of 5TONIC (Figure 4).

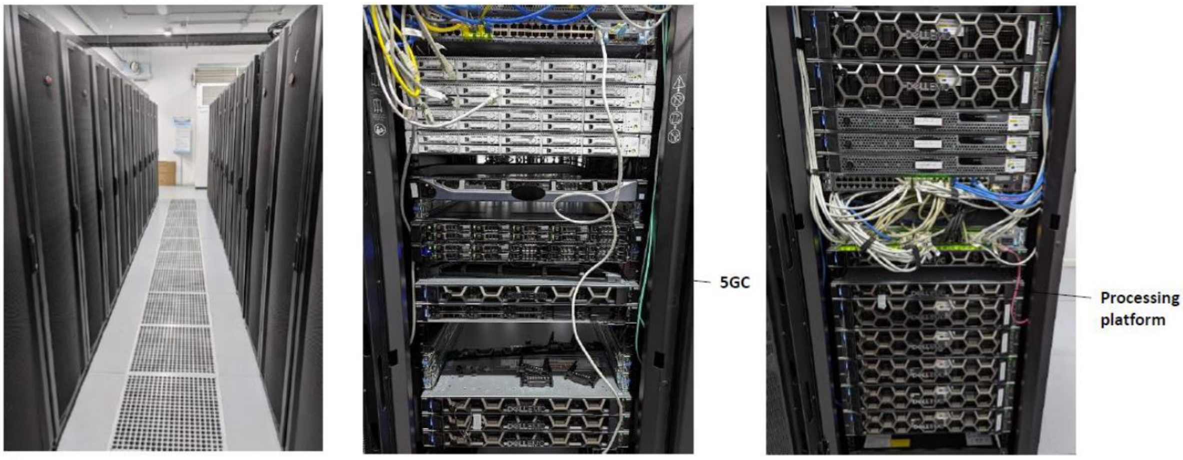

Figure 4 - Central data center servers located at 5TONIC, Madrid

It contains the core network functions required to support the 5G System:

- Basic NF: NRF, NSSF
- Subscriber NF: UDM, UDR
- Control NF: AMF, SMF, PCF
- User Plane NF: UPF
- Exposing: NEF

This 5G Core is the cloud-native version of the Ericsson 5GC and runs on Kubernetes.

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In addition to the equipment within the rack, the deployment includes the Amarisoft UE Simbox, which is used externally to validate terrestrial UEs connecting to the gNodeB virtually positioned onboard a HAPS. This system emulates up to 64 simultaneous 5G standalone UEs, allowing controlled testing of network performance under realistic radio conditions.

1.3 Network Architecture Simulated

The provided diagram illustrates the simulated architecture.

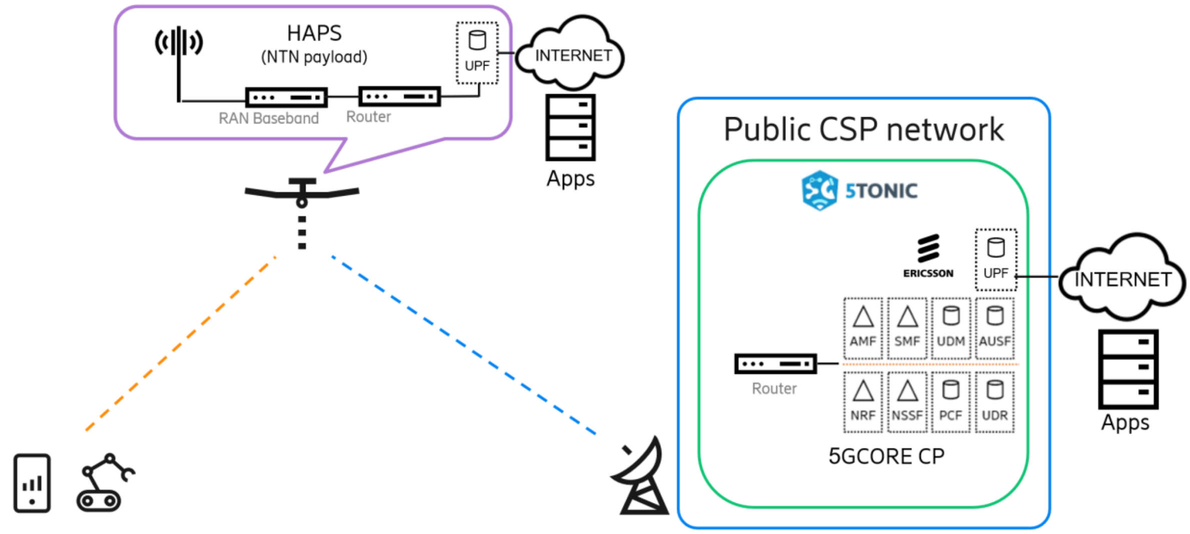

Figure 5 – 5G RAN on-board a HAPS

The diagram provides a possible non-public network deployment, where an industrial use case is served through the local deployment of the radio access network (RAN) and the user plane function (UPF) which are on-board a HAPS, while the public network provides the service for the rest of the 5G core.

1.3.1 Key Components:

- **HAPS:**

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RAN Baseband: This component handles the radio access network processing. It interfaces with the router and is responsible for managing the radio signals received from and transmitted to the user equipment (UE).

Router: Connects the RAN Baseband to the satellite communication system. It facilitates the routing of data packets to and from the RAN Baseband.

UPF (User Plane Function): Handles data traffic routing and forwarding. It interfaces with the internet for local data traffic and the router for data requiring backhaul.

➢ **Public CSP Network:**

The Public CSP Network serves as a bridge to connect users to the private 5G Core Network. It includes several critical components and functions within its 5G Core Network (5GC), which can be divided into the Control Plane (CP) and User Plane (UP).

- Control Plane (CP) Functions:
  - ❖ AMF (Access and Mobility Management Function): Manages connection and mobility aspects, handling user registration, connection setup, and mobility.
  - ❖ SMF (Session Management Function): Manages session contexts and configurations, establishing and maintaining user sessions.
  - ❖ UDM (Unified Data Management): Manages subscription data, storing user profiles, and authentication information.
  - ❖ AUSF (Authentication Server Function): Handles authentication, verifying user credentials and ensuring secure access.
  - ❖ NRF (Network Repository Function): Stores and manages NF (Network Function) profiles, facilitating service discovery and interaction between network functions.
  - ❖ NSSF (Network Slice Selection Function): Handles network slice selection, enabling differentiated service levels by directing traffic to appropriate network slices.
  - ❖ PCF (Policy Control Function): Manages policy decisions, enforcing rules for QoS (Quality of Service), resource allocation, and service access.
  - ❖ UDR (Unified Data Repository): Stores structured data used by various network functions for operations like subscriber management, policy control, and session management.

- User Plane (UP) Functions:
  - ❖ UPF (User Plane Function): Handles data traffic routing and forwarding, interfacing with the internet and the 5G Core Network. It manages packet forwarding, QoS enforcement, and traffic shaping.

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1.3.2 Data Flow and Interactions

- **User Equipment (UE) Connectivity:**

  The UE connects to the HAPS´s RAN Baseband, which processes the radio signals and forwards data packets to the router.

- **Backhaul Connectivity:**

  The router installed in the HAPS payload makes use of the HAPS communication services to set up a secure tunnel with the 5TONIC site router, enabling end-to-end backhaul connectivity

- **Integration with 5G Core Network:**

  The 5G Core network processes these packets, manages session and mobility, applies policies, and routes the data appropriately, either towards the internet or other parts of the network.

- **Service Continuity and Coverage:**

  By hosting the gNodeB directly onboard the HAPS, 5G radio access can be delivered to remote or underserved areas without relying on terrestrial infrastructure. This configuration ensures continuous service availability and extended coverage, enabling users in isolated regions to access reliable 5G connectivity seamlessly.

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2 Solution Equipment

2.1 Radio Access Network - Equipment

2.1.1 Baseband 6648

Baseband 6648 is developed for 5G high-capacity sites and is the natural choice for sites with 5G midband and 5G highband implementations.

Clear benefits with Baseband 6648 are higher capacity and simplified installation using 25G interfaces to new AIR and Radio products for midband and highband.

Figure 6 - Baseband 6648 (Front and rear views)

Baseband 6648 provides switching, traffic management, timing, baseband processing, and radio interfacing. The baseband units are in the 19-inch format. Baseband 6648 has 12 Common Public Radio Interface (CPRI or eCPRI) ports, enabling increased connectivity for radio units.

Baseband 6648 is self-contained 19-inch unit with an easily removable fan tray unit. Each unit can be installed standalone in any 19-inch rack. The units support both horizontal and vertical installation.

Baseband 6648 facilitates a scalable, modular system with one or more indoor 19-inch baseband units and various external radios.

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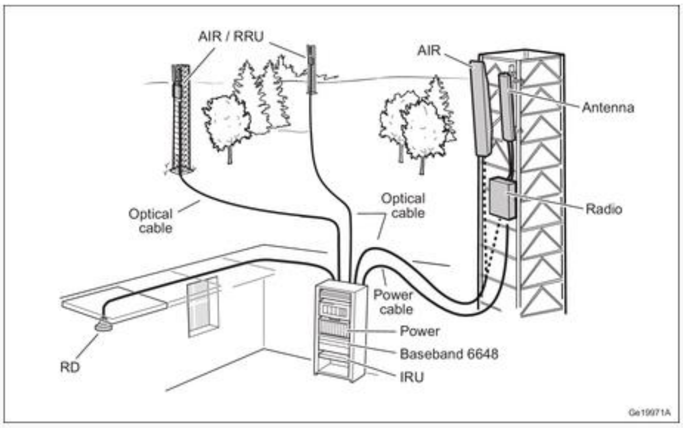

Figure 7 – 19 Inch Baseband connected to external radios

The unit has the following functions:

- Timing function
- Loadable software
- Downlink (DL) baseband processing
- Uplink (UL) baseband processing
- IP traffic management
- Radio interface
- Backhaul handling
- External synchronization

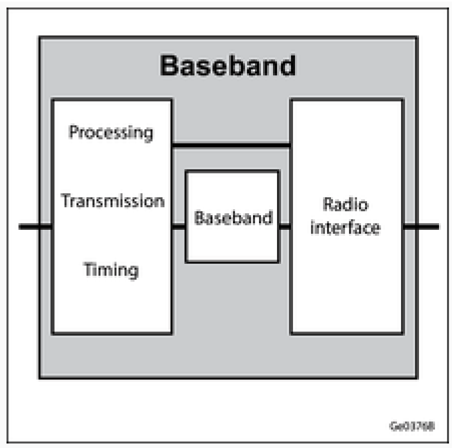

Figure 8 - Baseband unit block diagram

Baseband 6648 - Technical data

<u>The unit has the following dimensions:</u>

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Table 1 - Baseband 6648 dimensions and weight

Baseband	Height	Width	Depth With Protrusion	Depth Without Protrusion	Weight
Baseband 6648	44 mm (1U)	483 mm (19-inch)	383 mm	352 mm	Max 8.5 kg

The unit has the following environmental characteristics:

Table 2 - Baseband 6648 environmental data

Description	Value
Temperature	0°C to +55°C
Relative humidity	5–95%
Absolute humidity	1–29 g/m3
Maximum temperature change	0.5°C/min

The unit has the following power characteristics:

Table 3 - Baseband 6648 DC power supply requirements

Condition	Value
Nominal voltage	−48 V DC
Operating voltage range	−38.0 to −58.5 V DC(1)
Non-destructive range	0 to −60 V DC

(1) During cold startup the supply voltage must be between -46 V DC and -58.5 V DC.

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Baseband 6648 - Hardware Architecture and Interfaces

Baseband 6648 has the following hardware characteristics:

- 1 x 4x25 Gbps (QSFP28)
- 3 x 25/10/1Gbps ports (SFP28/SFP+/SFP)
- 1 x 100Mbps/1Gbps RJ45 electrical port
- Support for NR (5G high/mid/low band) or LTE
- Support for Mixed Mode baseband NR (5G) + LTE
- 12 x 2.5/4.9/9.8/10.1/10.3/24.3/25 Gbps Radio Interface ports
    - 12 CPRI ports or 12 eCPRI ports or 12 ports with a mix of CPRI and eCPRI

The hardware is prepared for the following 5G-NR capacities:

- Users: 10k
- Mixed mode: NR+LTE
- Maximum throughput:
    - DL 10-15Gbps
    - UL 3Gbps
- Band support:
    - NR High-band: 4800MHz (3 sectors , 2 layers, 800MHz carries)
    - NR Mid-band: 9600MHz (3 sectors , 16 layers, 200MHz carries; 6 sectors, 16 layers, 100MHz carriers)
    - NR Low band: 4800MHz (20MHz, 4T4R carries)

Baseband 6648 has the following front panel interfaces:

Figure 9 - Baseband 6648 (Front panel interfaces)

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Table 4 - Baseband 6648 front panel interfaces

Ports	Quantity	Comments
Power	2	-48V
LMT	1	RJ45
TN/IDL	4	3 x SFP28 (25G) 1 x QSFP28 (4x 25G)
Radio Interface	12	SFP+/SFP28
Sync	1	RJ45
External alarms	8	2 x RJ45
USB 3.0	1	USB C

2.1.2 IRU 8846

The Indoor Radio Unit (IRU) is a component in the Radio Dot System (RDS). The IRU must be used together with Radio Dots to have full radio functionality.

The IRU has three purposes:

- Provides an interface to the Baseband unit through a CPRI cable.
- Provides signaling and power interface to the Radio Dot over the Radio Dot Interface (RDI).
- Collects external alarms and transmits them to the Baseband Unit.

Indoor Radio Unit (IRU) 8846 provides support for connectivity to up to 8 single band 4T4R Radio Dots with a single CAT 6A cable. IRU 8846 can be mounted in a standard 19" rack, or in a remote location using the included wall mounting brackets. Distributing Indoor Radio Units throughout a building allows for flexible, scalable deployment of Radio Dot System across a variety of venue sizes. It can utilize either AC or DC power supply.

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Figure 10 – IRU 8846

IRU 8846 - Technical data

The unit has the following dimensions:

Table 5 – IRU 8846 dimensions and weight

Baseband	Height	Width	Depth	Weight
IRU 8846	70 mm (1.5U)	442 mm (19-inch)	347 mm	Max 8.62 kg

The unit has the following environmental characteristics:

Table 6 – IRU 8846 environmental data

Description	Value
Temperature	5°C to +50°C
Relative humidity	10–95%
Absolute Humidity (g/m3)	1 to 25
Maximum Temperature Change (ºC/min)	0.5

The unit has the following power characteristics:

Table 7 – IRU 8846 DC power supply requirements

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Condition	Value
Nominal voltage	−48 V DC
Normal voltage range at radio input	-36.0 to -58.5 V DC
Maximum Current	20 A
Inrush current	27 A
Hold up time	10 ms

Table 8 – IRU 8846 AC power supply requirements

Condition	Value
Nominal voltage	100-250 V AC
Voltage Rage with Tolerance	90-275 V AC
Max Non-destructive Voltage Range	325 V AC
Nominal frequency range	45-65 Hz
Maximum Current	9 A
Inrush current	22.2 A
Power supply cable impedance	0.03 ohm

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Hold up time	20 ms

IRU 8846 Main features

IRU 8846 supports the following:

- Two CPRI ports.
- Ethernet based RDI ports to connect Dots:
- 8 ports of 10 Gbps
- Two alarm ports.
- Power Supply input: AC and DC.
- Mixed mode and multi-standard operation.
- Up to eight branches per Dot.

2.1.3 Dot 4479 B78L

Dot 4479 B78L is a single-band indoor radio optimized for capacity deployments. Features include:

- 250 mW output power per antenna branch
- Instantaneous bandwidth (IBW) is 100 MHz with 4 x 4 MIMO TDD
- Flexible IT-like deployment with CAT6A and hybrid fiber cables for extended reach

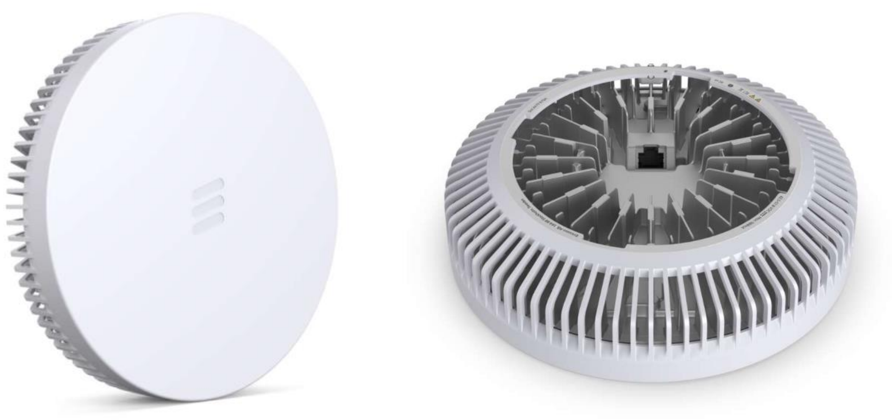

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Figure 11 – Dot 4479 B78L (Front and interface view)

Dot 4479 B78L – Components

The Radio Dot components are shown in the following figure. Refer to Table for the components descriptions.

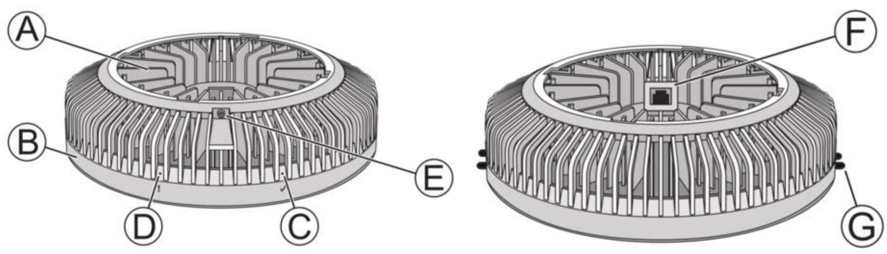

Figure 12 – Dot 4479 B78L components

Table 9 – Dot 4479 B78L components

Position	Component
A	Cooling flanges
B	Housing
C	Optical indicator
D	Optical indicator
E	Locking screw
F	RDI interface (RJ45) for electrical Ethernet
G	External Antenna Connector

Dot 4479 B78L - Technical data

This section describes the physical characteristics and environmental data.

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Table 10 – Dot 4479 B78L unit dimensions

Unit Type	Height (H) × Width (W) × Depth (D)
Dot 4479 B78L	53 × 200 × 200 mm

Table 11 - Dot 4479 B78L unit weight

Unit Type	Unit Weight
Dot 4479 B78L	1 kg

Table 12 - Dot 4479 B78L antenna gain

Unit Type	Average Gain (dBi)	Peak Gain (dBi)
Dot 4479 B78L	0.09	5.70

Table 13 – Dot 4479 B78L operating environment

Description	Value
Temperature	5°C to +40°C
Relative humidity	5–85%
Absolute Humidity (g/m3)	1 to 25
Maximum Temperature Change (ºC/min)	0.5

Dot 4479 B78L – Main Features

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The Dot 4479 B78L is a high-capacity single band Radio Dot with internal antennas. It is available for the TDD B78L (3500 MHz – 3800 MHz) band.

The Dot has the following features:

- 4 TX and 4 RX branches per Dot
- 256-QAM Downlink and 256-QAM Uplink
- Output Power with 4T4R capability:
- TDD: 4 x 24 dBm / Dot (250 mW / Branch) DL power
- Power supply over LAN cable (PoE++)
- Supports TDD NR + LTE Mixed
  Mode, TDD NR +NR MORAN and TDD LTE + LTE MORAN configurations

Dot 4479 B78L – Limitations

The following applies:

- Only 20 MHz is supported with LTE.
- 2x2 MIMO configuration is not supported for mixed mode and multi carrier.
- A 2x2 carrier can be NR or LTE.
- In 2x2 mode, both RF branch pair A/B and C/D must have a carrier with the same bandwidth.
- Dot 4479 only supports Contiguous Carriers regardless if it is Mixed mode or not.
- Minimum software required for Dot 4479 is 19.Q3.

2.1.4 GNSS Antenna and GPS Module

The Global Navigation Satellite System (GNSS) receiver system receives a GNSS timing signal that is used to synchronize the GNB.

GPS signal is needed to have a Time & Phase Synchronization required for 5G with TDD (Time-Division Duplexing) strategy. Precise signal is needed to synch the DL and UL frames and to synch between 5G nodes.

The main components in the GNSS receiver system are the GNSS active antenna and the GNSS receiver unit.

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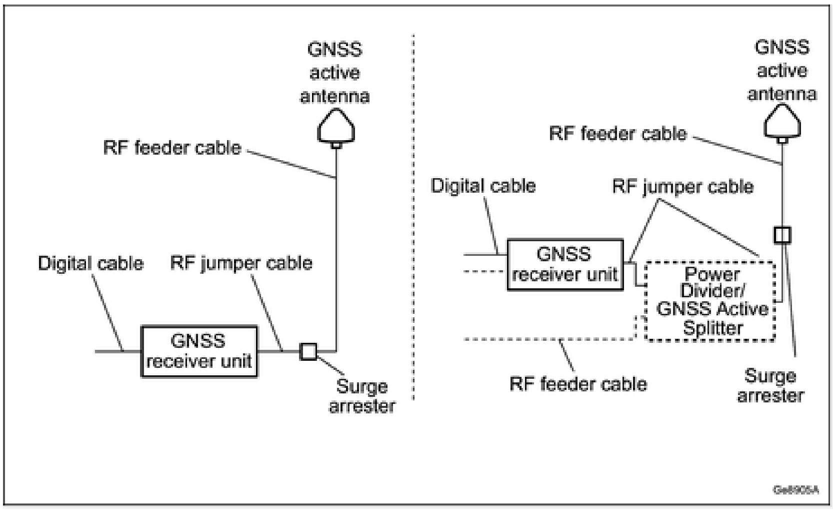

Figure 13 - Cables in the GNSS receiver system

The GNSS receiver unit is powered by the GNB through digital interfaces. The GNSS receiver unit supplies power through the RF interface to the GNSS active antenna and, if used, to the GNSS active splitter and inline amplifier.

When the GNSS receiver unit is powered, it continuously sends status sentences to the GNB and searches for satellites on received RF signals. An indicator shows that the power is activated.

The GNSS active antenna receives signals from the GNSS satellites. The signals are sent through the RF cables to the GNSS receiver units.

When the GNSS receiver unit locks to the satellites, this is shown on the indicator, and the unit starts to send One Pulse Per Second (1PPS) and time of day information to the GNB.

Active Antenna - Technical data

The GNSS active antenna is powered by the GNSS receiver unit, which can be up to 170 m from the antenna when a 0.5-inch cable is used, or 90 m from antenna when a 0.25-inch cable is used.

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Figure 14 - GNSS active antenna

GNSS Active Antenna Interfaces

N-type (female)

GNSS Active Antenna Size

Table 14 - GNSS active antenna size

Unit	Width	Height	Depth
GPS active antenna (Rosenberger)	69 mm	74 mm 94 mm (1) 178 mm (2)	69 mm 87 mm (2) 103 mm (2) (3)

(1) Including RF connector
(2) Including brackets
(3) Including earth lug

GNSS Active Antenna Technical Data

Table 15 - GPS/GNSS active antenna technical data

	GPS Active Antenna KRE 101 2182/1, Rosenberger

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Satellite system support	GPS
Frequency	1575.42 ± 10 MHz
Gain(2)	35 ± 5 dBi
Out-of-band rejection	>40 dB at 1575.42 ± 50 MHz >45 dB at 1575.42 ± 70 MHz
Operating temperature	−40°C to + 55°C
Operating voltage	+4 V DC to +6 V DC
Non-destructive abnormal voltage	-32 V DC to + 4 V DC +6 V DC to + 32 V DC
Current consumption	≤35 mA
Encapsulation class	IP 65
Active antenna delay(3)	40 ns

(1) Use of BeiDou requires client SW (RBS or Router 6000) to support the configuration of GPS 03 to use BeiDou
(2) At zenith including LNA gain
(3) Used when delay compensation is defined in RBS SW

GNSS Antenna System Characteristics

The antenna system gain is the RF front-end gain with the GNSS antenna, RF cable, and RF jumper cable before the GNSS receiver.

Table 16 - GNSS antenna system characteristics

Antenna system gain	15–35 dB (1)
Frequency band	L1

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Nominal impedance	50 Ohm
Noise	< 3 dB
Operating voltage	4–6 V DC
GRU antenna port current consumption	< 65 mA(2)
Lightning current immunity	±5 kA, 10/350 µs and ±20 kA, 8/20 µs
Maximum capacitive load	30 uF(3)

(1) Minimum recommended system gain is 20 dB
(2) Shared amongst any active component that draws power from the GRU antenna port
(3) Valid for GPS 02 R3A and newer

GNSS Receiver Unit (GRU 04 01) - Technical data

GRU 04 01 support GPS and GLONASS by default after power on.

Figure 15 - GNSS receiver unit

In multi-GNSS constellations such as GPS and GLONASS as well as GPS and BDS, GRU 04 01 use the best satellites from both GNSS constellations.

GRU 04 01 supports configurations with:

- One or two DUs or Baseband through individual GNSS digital interfaces

GRU 04 01 have built-in surge protection, so a separate surge arrester is required only if a GNSS active splitter or a power divider is used.

GNSS Receiver Unit Interfaces

Table 17 - GNSS receiver unit interfaces

Unit	Connector
GRU 04 01	SMA connector (female) 2 × RJ-45 (female)

GNSS Receiver Unit Size

Table 18 - GNSS receiver unit size

Unit	Width	Height	Depth
GRU 04 01	37 mm	32 mm	103 mm

GNSS Receiver Unit Technical Data

Table 19 - GNSS receiver unit, technical data

	GRU 04 01
Operating voltage (digital interface)	+8 V DC to +30 V DC(1)

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Non-destructive voltage (digital interface)	0 V DC to +30 V DC
Output voltage (RF interface)	+4.8 V DC to +6 V DC
Maximum output current (RF interface)	50 mA(2)
Encapsulation class	IP 20
Other	Short-circuit safe
Lightning current immunity(3)	±1.5 kA, 2 Ohm, 10/350 µs according to IEC 62305-1, direct injection to antenna port center conductor

(1) +8 V DC to +13 V DC for GRU 04 01 and GRU 04 02 when power is supplied directly from a DU
(2) If the digital cable is 2 m or shorter, the output current is up to 65 mA.
(3) Only for GPS 02 R2B and later. Performance criterion C as defined in IEC 61000-6-2

2.2 Transmission - Equipment

2.2.1 Router 6675

The Router 6675 is a high-capacity pre-aggregation and aggregation router, designed to enable high quality network service delivery while at the same time lowering operating costs through features such as a completely filter-less mechanical design. It provides high density 10G and 100GE port densities, with 320Gbps switching capacity in a compact and hardened 1RU form factor enabling lower rental costs and lower OPEX.

It supports VPN services over IP/MPLS networks, service provider SDN, service exposure using NETCONF/YANG, extensive quality of service and precise synchronization features.

The Router 6675 has strong security features such as IPSec, vendor credential and vendor software authentication ensuring data security even in insecure environments.

The Router 6675 is part of the Ericsson Router 6000 Series, a radio integrated, service provider SDN enabled and subscriber aware IP transport family of products. The Router 6000 offers a range of high-performance routers with resiliency features and form factors optimized for the various needs of metro and backhaul networks.

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With 320Gbps of switching capacity, the Router 6675 delivers performance needed to fully support LTE, LTE Advanced, 5G, access sites for years to come.

Figure 16 - Router 6675 (Front view)

Router 6675 - Technical data

The Ericsson R6000 is a radio integrated family of products. Ericsson R6000 offers a range of high-performance routers with resiliency features and form factors optimized for the various needs of metro and backhaul networks. The Ericsson R6000 is tightly integrated with Ericsson Radio and Microwave to provide high-capacity mobile backhaul with unprecedented quality of experience.

The main hardware components of an Ericsson R6000 product are the Line Card and the Route Processor card:

The Line Card houses the traffic ports.

- For Router 6675, only one Line Card is embedded in the node and not replaceable.

The Route Processor (RP) is the main processor of the system and supports Operation, Administration and Maintenance (OAM), and routing functions.

- For Router 6675, only one RP is embedded in the node and not replaceable.

<u>The Router 6675 includes the following parts:</u>

- One Rack Unit (RU) chassis that fits into the 19-inch rack.
- A fan tray with five high-performance fans, which can still effectively cool the chassis even when one fan fails.
- Dual Direct Current (DC) power feeding with front cabling. 320 Gbps throughput with full duplex.
- 24 Gbit DRAM packet buffer.

- Variety of interfaces including:
  - Twenty-four 1GE SFP/10GE SFP+ ports

- Four 40GE QSFP+/100GE QSFP28 ports. The router supports 1×100GE, 1×40GE, 4×10GE, 4×25GE, 1×10GE QSA mode, or 1×25GE QSA mode on each 40GE/100GE port.
- One 100/1000 Base-T Ethernet for Out-of-Band management (LMT)
- One RJ45 console port
- One RJ45 alarm port for 3 input and 1 output alarm contacts
- One USB 2.0 Type A port used as USB storage
    - Note: The 6675 does not support USB 1.1 devices.
- One RJ45 1PPS+TOD (ITU-T G.703 Amd1) port
- One RJ48C port for 2.048 MHz, E1/T1 (BITS) input/output

Mechanical details:

- System weight: 8kg / 17.6lbs
- Dimension (H x W x D): 1RU 43.6mm x 442.8mm x 315mm
- Air flow: Filter-less design, Front to Back with field swappable fan tray

Electrical details:

- Power supply DC: -48 VDC, dual feed
- Power consumption: Typical 79 Watts, Max (with optics) 225 Watts

2.3 Amarisoft - Equipment

The 5TONIC laboratory hosts an advanced 5G testing environment featuring the Amarisoft AMARI UE Simbox E Series, designed for functional and performance testing of 4G LTE eNodeBs, 5G NR gNodeBs, and core networks.

UE Simbox Configuration

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Figure 17 – Amarisoft UE Simbox

- Model: AMARI UE Simbox E Series
- UE Emulation Capacity: Up to 64 simultaneous UEs
- Supported Technologies: 5G NR (SA/NSA), LTE, LTE-M, NB-IoT
- Server Specifications:
    - CPU: Intel Core i9-10980XE @ 3.0 GHz (18 cores / 36 threads)
    - RAM: 32 GB
    - Storage: NVMe SSD with 24.8 MiB L3 cache
    - Network: 10 GbE interface for core network connectivity
- Operating System: Linux Fedora
- Simbox Dimensions: 46.5 cm × 23.3 cm × 53.3 cm
- Weight: 14 kg

SDRs and Antenna Configuration

- SDR Cards: 2 × AMARI PCIe SDR 100 4x4

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Figure 18 – PCIe Software Defined Radio (SDR) cards

    - Frequency Range: 500 MHz to 6.0 GHz
    - RF Bandwidth: 1.4 MHz to 100 MHz
    - MIMO Support: 4x4
    - Operation Modes: FDD and TDD
    - ADC/DAC Sample Rate: 122.88 MS/s
    - ADC/DAC Resolution: 12 bits
    - Frequency Accuracy: < 1 ppm
    - PCIe Requirements: 8x / Gen 3
    - Synchronization: Internal clock, PPS signal, GPS, external reference clock (LVDS)
- Antenna Setup:
    - Configuration: Dual antennas configured as 2×2 MIMO for both uplink and downlink
    - Operating Band: 5G NR FR1 (band n78)
    - Bandwidth: Up to 100 MHz
- Clock Synchronization: PTP/NTP, with optional GPSDO for sub-microsecond precision

<u>Software and Automation</u>

- Simulator Version: Amarisoft lteue/nrue v2024-06-14
- Supported Modes: 5G SA in TDD, LTE, LTE-M, NB-IoT
- API Access:
    - Type: REST/JSON over port 9002 or via UDP socket

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- Capabilities:
  - Reading configuration files in JSON format
  - Generating nr-erc.cfg and users-scenario.cfg files
  - Executing simulations and capturing logs
- Automation Tools: Python and Bash scripts managing the entire pipeline from configuration to data extraction

Advanced Features

- Multi-UE Programmable Scenarios: Define topologies, channel simulations, mobility patterns, and events (e.g., power_on, ping, iperf3) via JSON
- Carrier Aggregation: Support for up to 4 carriers in downlink and 2 in uplink
- MIMO Configurations: Support for up to 4x4 MIMO
- VoLTE and VoNR Testing: Enabled through collaboration with Simnovus
- Traffic Simulation: Emulation of TCP, UDP, RTP, HTTP, and VoIP traffic with configurable packet sizes
- Handover Support: Intra and inter eNB/gNB handovers
- Encryption and Integrity: AES, SNOW3G, ZUC
- 3GPP Compliance: LTE (Release 8 to 15), 5G NR (Release 15)

This setup provides a robust and flexible platform for 5G research and development, allowing for the emulation of various scenarios and validation of diverse functionalities in a controlled environment.

2.4 Core Network - Equipment

2.4.1 Local Packet Gateway 1.3

Figure 19 – Local Packet Gateway 1.3

The Local Packet Gateway (LPG) is an important part of the Dual-Mode 5G Cloud Core solution, which also includes the Packet Core Controller (PCC) and other Cloud Core products. The LPG provides a single-server bare-metal cloud-native solution to host the Packet Core Gateway

(PCG). The LPG can be located at customer premises close to the network edge for optimum performance.

The LPG consists of the following parts:

- A hardware platform
- A software platform
- The PCG

The LPG can be deployed at enterprise level on premise or at a mobile network operator network. The LPG can be deployed on a specified single server to provide lightweight Kubernetes (K3s) in a bare-metal environment in order to deploy the PCG.

After the PCG is deployed through the LPG, the PCG can provide the following 5GS functionality:

For 5GS:

- LTE
- NR
- Wi-Fi

Architecture

The LPG provides the functionality of the UPF in the 5GS. In the 5GS network, the LPG can act as a UPF.

The LPG architecture is built around microservices running in containers provided by the PCG. Each microservice in the LPG is mapped to a pod type. In the LPG, K3s CaaS, which is a lightweight Cloud Native Computing Foundation (CNCF)-certified Kubernetes™ distribution, is used to manage and deploy containerized microservices. K3s runs on the underlying operating system and the supported hardware.

The LPG architecture can be divided into four layers:

- The PCG
- K3 Container as a Service (CaaS)
- The operating system
- Hardware

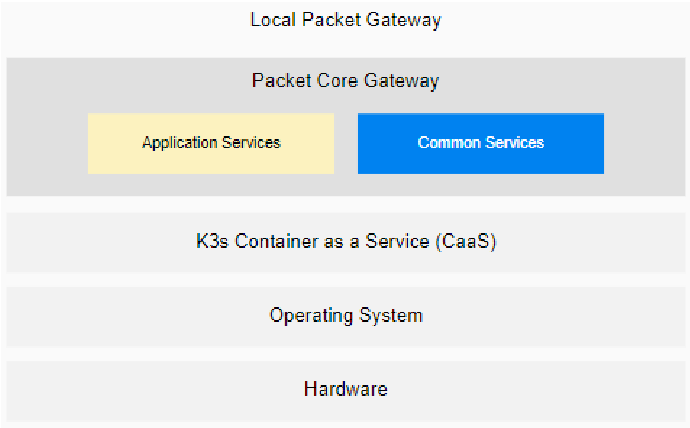

Figure 20 - LPG architecture

Packet Core Gateway

The microservices in the PCG are divided into application services and common services.

Application Services:
Application services implement protocols, functions, and procedures that are required to comply with the network function behaviors specified in 3GPP standards.
Some microservices used in the application services are shared across multiple network functions. This means that one microservice can affect more than one network function. The division into microservices allows for separate scaling and life cycle management.

Note: Scaling is not allowed in the LPG.

The user plane application services consist of the Routing Engine, the PC UP Data Plane, the PCFW, the PC UP PFCP Endpoint and the internal support services.

Common Services:

Common services implement support functions that are common to several microservices within the PCG such as operation and maintenance, data storage, load balancing, and external network-cluster integration. Examples of common services are performance management, fault management, and user management. This common management layer allows for easy integration of new network functions.

K3s (CaaS):

K3s CaaS is built for Edge computing. K3s implements the Kubernetes API completely while not being functionally different from Kubernetes. However, K3s does not include the optional components of Kubernetes that are not critical to run a bare minimum cluster. The storage volume plug-ins and cloud provider APIs are also excluded, but the following essential elements are included:

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- Container runtime
- Overlay network
- DNS server
- Container network interface
- Ingress controller
- Local storage provisioner
- Embedded service load balancer
- Integrated network policy controller
- Lightweight database for cluster state management

By default, every installation of K3s includes a control plane, primary node agent, and a container runtime that are sufficient to run the Kubernetes workload. In a K3s cluster, a node that runs the control plane components along with the node agent is called a server while a node that only runs the node agent is called an agent.

The LPG takes advantage of the K3s behavior to create a single Kubernetes cluster with only one server node running in the K3s CaaS on the single server. This single node is sufficient to run the Kubernetes workload, meaning that the application layer can be deployed on top. The LPG uses Helm for application deployment.

The LPG runs the PCG as an application, which requires the LPG to use some K3s components to ensure compatibility and proper operation.

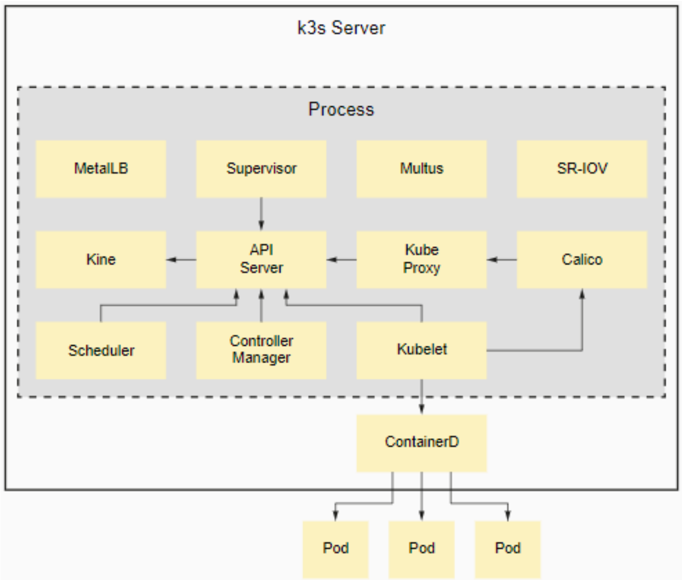

Figure 21 - K3s architecture

Operating System:

The SUSE Linux Enterprise Server 15 Service Package 4 operating system is used to run the CaaS layer. The operating system contains only the necessary parts to complete the direct networking configurations. Also, the components required to install and operate the CaaS layer are included in the operating system.

Hardware:

The LPG only supports one server type for installing the operating system, the CaaS layer, and the PCG.

Table 20 - LPG hardware

Vendor Code	Description
Dell EMC™ R640 14G	A carrier-grade or NEBS level 3 server based on Intel Xeon SP Cascade Lake Dell EMC R640 14G

Table 21 - Main characteristics of Dell EMC R640 14G

Functional Block	Characteristics
CPU	Xeon G-6230R 2x26c
Memory	384GB
Storage	2x960GB SSD SATA RI
Network	2x1GbE, 2x10GbE, 6x25GbE ports

Table 22 - Physical and environmental parameters

Description	Value

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C13 Power Connector	2
Weight	22.0 kg
Height	1U
Depth	757.75 mm
Minimum Operating Temperature	-5 °C
Maximum Operating Temperature	40 °C
Theoretical Current Amp@208V	2.2 A
Theoretical Power	491.00 VA
Cubic Feet Per Minute	51 cu ft/min
Heat Dissipation	1675.4 BTU
Acoustic Noise - Sound Power	78.0 dB

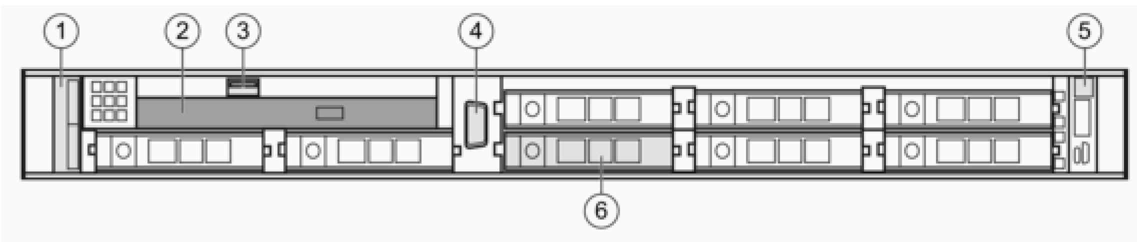

Figure 22 - Dell EMC R640 (Front panel view)

Table 23 - Front panel operators

Item	Ports, Panels, or Slots
1	Left control panel

2	Optical drive (currently not included)
3	USB port (currently not included)
4	VGA port
5	Right control panel
6	Drive slots (x8)

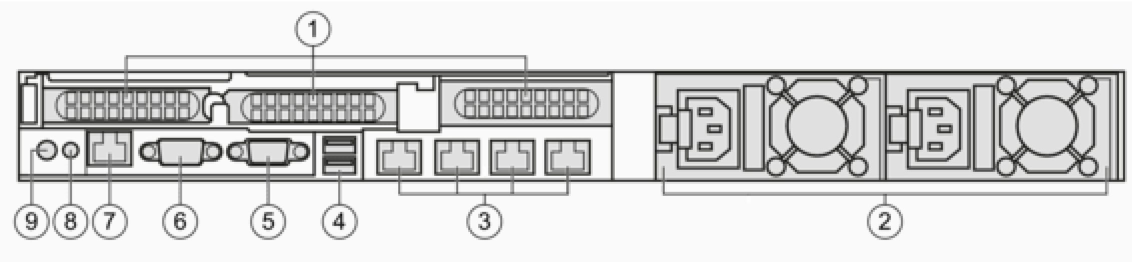

Figure 23 - Dell EMC R640 (Rear panel view)

Table 24 - Rear panel operators

Item	Ports, Panels, or Slots
1	PCIe expansion card slot (x3)
2	Power supply unit (x2)
3	NIC port on network daughter card (NDC) (x4)
4	USB 3.0 port (x2)
5	VGA port
6	Serial port

7	iDRAC9 dedicated network port
8	System status indicator cable port
9	System identification button

Software:

The LPG platform software is delivered in an ISO package that is based on the ISO-9660 standard. The LPG platform ISO contains the following:

- The operating system
- Related packages and software
- The CaaS software
- Related plug-ins and scripts used to install different LPG components

The PCG is delivered in a VNF package compliant with the ETSI NFV-SOL 004 specification, which is based on the TOSCA CSAR standard.

The CSAR package is a ZIP file that contains the following:

- Metadata
- VNF Descriptor (VNF)
- Helm charts
- Docker images

The VNFD is partly compliant with the ETSI NFV-SOL 001 specification, which is based on the TOSCA standard. ETSI NFV-SOL 001 does not support deployment on Kubernetes, and as a result, the TOSCA VNFD is complemented with Helm charts that specify deployment using Kubernetes. The same Helm charts are used for manual life cycle management.

2.4.2 Ericsson CRU 0101 - Applications Sever

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Figure 24 – Ericsson CRU 0101 applications server (Front view)

The system is a 2-socket 1U server powered by the Intel® Xeon® processor E5-2600 v3 family.

It features significant performance with 24 DDR4 RDIMM/LRDIMM memory slots, 4 hotplug disk drives for 3.5" HDD SKU or 10 hot-plug disk drives for 2.5" HDD SKU, up to 2 PCIe expansion slots, and 1GbE/10GbE Base-T/10G SFP+ networking options.

These rich features list as below:

- Greener and More Powerful
- Full-Featured Design for Demanding Virtualization Workload
- Flexible and Scalable I/O options

Ericsson CRU 0101 - System Specifications:

SPECIFICATIONS	DESCRIPTION
Form factor	1U rack mount
Chassis dimensions (W x H x D)	17.24 x 1.7 x 29.21 inches 438 x 43.2 x 742 mm
Processor	**Processor type:** Intel® Xeon® processor E5-2600 v3 product family **Max. TDP support:** • 145W with limited HDD Qty • 135W with max configuration **Number of processors:** 2 **Internal Interconnect:** 6.4 / 8.0 / 9.6 GT/s **Last Level Cache (LLC):** Up to 35 MB
Chipset	Intel® C610
Memory	**Total slots:** 24 **Capacity:** Up to 384GB RDIMM / Up to 768GB LRDIMM **Memory type:** 2133 MHz DDR4 RDIMM / LRDIMM **Memory size:** 16 GB, 8 GB RDIMM / 32 GB LRDIMM
Storage controller	**Onboard (Intel® C610):** • 10x SATA 6Gb/s ports • SATA RAID 0, 1, 10 **Optional controller:** • Quanta LSI® 2308 6Gb/s SAS mezzanine, RAID 0, 1, 10 • Quanta LSI® 3008 12Gb/s SAS mezzanine, RAID 0, 1, 10 • Quanta LSI® 2108 6Gb/s RAID mezzanine, RAID 0, 1, 5, 10, RAID 6 with additional RAID key • Quanta LSI® 2208 6Gb/s RAID mezzanine, RAID 0, 1, 5, 10, RAID 6 with additional RAID key

Figure 25 - Ericsson CRU 0101 system specifications (1/2)

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SPECIFICATIONS	DESCRIPTION
Networking	**LOM:** ● Intel® I350 dual-port 1GbE or Intel® X540 dual-port 10GbE BASE-T ● Dedicated 1GbE management port **Optional NIC:** (more options refer to the AVL) ● Quanta Intel® i350 dual-port OCP mezzanine ● Quanta Intel® X540 dual-port 10GbE BASE-T OCP mezzanine ● Quanta Intel® 82599ES dual-port 10G SFP+ OCP mezzanine
Expansion slots	**Riser 1** ● (default): One x8 PCIe 3.0 SAS mezzanine slot (CPU0) ● (option 2): One x16 PCIe 3.0, Low profile MD-2 (CPU0) **Riser 2** ● One x16 PCIe 3.0, Low profile MD-2 (CPU1) **OCP mezz slot** ● One x8 PCIe Connector (CPU0)
Storage	● 4x 3.5" hot-plug HDD/SSD (3.5" HDD SKU) ● 10x 2.5" hot-plug HDD/SSD (2.5" HDD SKU; requiring additional LSI SAS/ MegaRAID card to connect to the expander backplane) ● 10x 2.5" hot-plug HDD/SSD (2.5" HDD SKU: including 2x optional 2.5" NVMe PCIe SSD)
Onboard storage	2x SATADOM (optional*) (*Option not supported if these on-board SATA ports are used up to activate front HDD 0-1 for 2.5" HDD SKU)
Video	Integrated Aspeed AST2400 with 8MB DDR3 video memory
Front I/O	● Power/ID/Reset Buttons ● LAN/HDD/Status/ID LEDs ● 2x USB 2.0 ports (3.5" HDD SKU)
Rear I/O	● 2x USB 3.0 ports ● 1x VGA port ● 1x RS232 serial Port ● 2x 1 GbE or 10G BASE-T RJ45 port ● 1x GbE RJ45 management port ● 1x ID LED ● 1x Port 80 Debug Port (optional)
Optical drive	NA
TPM	Yes (optional)
Power supply	1 High efficiency redundant hot-plug 500W PSU, 80 Plus Platinum (2nd PSU optional)
Fan	6x dual rotor fans (11+1 redundant)
System management	IPMI v2.0 Compliant, on board "KVM over IP" support
Weight (Max. configuration)	● 15.77 Kg (3.5" HDD SKU) ● 14.5 Kg (2.5" HDD SKU)
SPECIFICATIONS	DESCRIPTION
Operating environment	● Operating temperature: 5°C to 40°C (41°F to 104°F) ● Non-operating temperature: -40°C to 70°C (-40°F to 158°F) ● Operating relative humidity: 50% to 85%RH. ● Non-operating relative humidity: 20% to 90%RH

Figure 26 - Ericsson CRU 0101 system specifications (2/2)

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System front view:

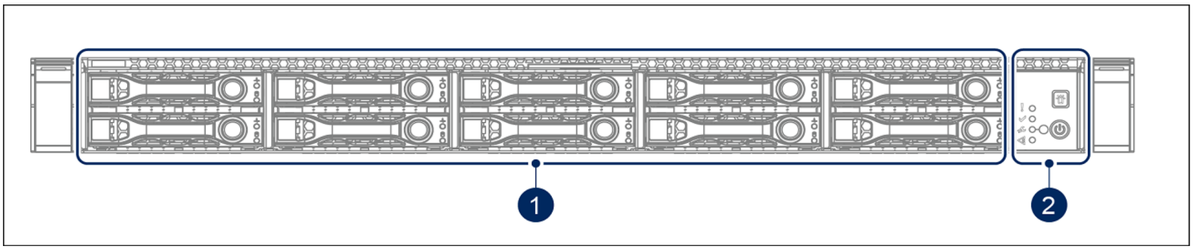

Figure 27 – Ericsson CRU 0101 (Front panel view)

Table 25 - CRU 0101 front panel components

No.	Item	Description
1	Drive Bays	10 × SAS HDD
2	Front Control Panel	

System rear view:

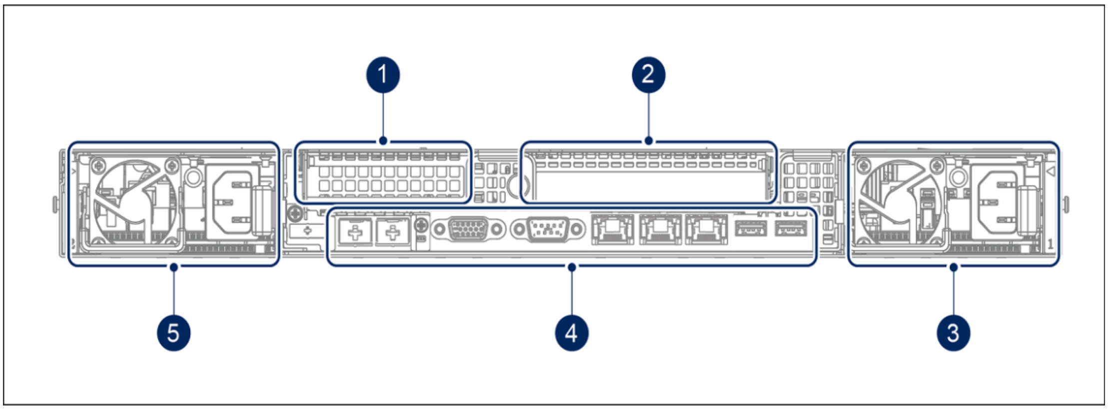

Figure 28 - Ericsson CRU 0101 (Rear panel view)

Table 26 - CRU 0101 rear view components

No.	Item	Description
1	Expansion Slot	PCIe expansion slot with PCIe × 8 signal

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2	Expansion Slot	PCIe expansion slot with PCIe × 8 signal
3	Power Sub-System	Main PSU (PSU1)
4	System Input Output ports	
5	Power Sub-System	Secondary PSU (PSU2)

System rear I/O:

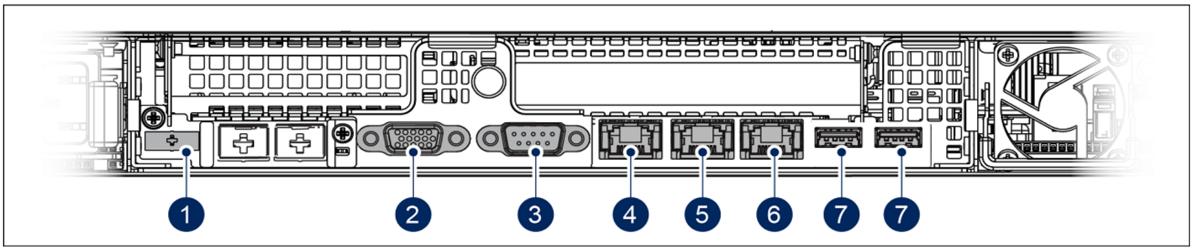

Figure 29 - Ericsson CRU 0101 (Rear I/O components)

Table 27 - CRU 0101 rear input & output components

No.	Item	Description
1	OCP connector	OCP debug connector (optional)
2	VGA connector	Maximum display resolution: 1920 × 1200 32 bpp @ 60 Hz (reduced blanking)
3	COM port A	DB9 port (Serial_A) for a/the debug or terminal concentrator
4	NIC 2	RJ45 connector
5	NIC 1	RJ45 connector

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6	Dedicated NIC	NIC to BMC
7	USB ports	USB ports (2.0 or 3.0)

2.5 Miscellaneous - Equipment

2.5.1 Delta CellD 40 – DPS 850B-48-3 – Power Supply Unit

CellD systems are small, just like cells. They can be embedded in the telecom infrastructure and are often used in outdoor solutions. The products in this series are light and designed especially for installations with limited space offering high density of the installed power. The system includes high efficiency rectifiers, AC and DC connections, battery connection and either ORION or PSC 3 controller. In addition to advanced supervision, short depth and easy installation are the success factors of the system. Delta is known for quality and product reliability – in this solution that has been combined to optimize the total cost of ownership.

Figure 30 - Delta PSU (Front View)

Features & Benefits

- 19" rack mounted system up to 2.55 kW
- Complete integrated system in 1U
- High efficiency rectifiers up to 95,2 %
- All connections easily accessible from the top, or optionally rear side
- All battery and load breakers accessible at the front
- Sliding mechanism to support easy access to the top output connections
- Option for enhanced monitoring and controlling

Applications

- Mobile telecommunication
- Fixed line telecommunication
- Broadband networks

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- Data centers
- Switching centers
- Modular UPS configurations

Technical Specifications

	DPS 850B-48-3 CellD 40
Rectifier module	DPR 850B-48 (max. 3 pcs.)
Efficiency	95.2 %
Install power (max. config.)	2.55 kW
Input current (per 1 phase)	12 A_{RMS}
Input protection (recom.)	25 A gL/gG type
Height (overall)	43.6 mm (1U)
Width (body)	444 mm (19")
Depth (overall)	280 mm
Weight	4.1 kg

AC input	
AC configuration	(L + N + PE)
Input voltage range	80 … 300 V_{RMS}
Frequency range	45 - 66 Hz
Mains connection	Screw terminals/ optionally 2 m cable (schuko / open end)
Input protection	N loss Internal OVP Inbuilt fuses (L+N) High input voltage

DC output	
Output voltage range	42-58 V_{DC}; 53.5 $V_{DC\ nom.}$
Output current (max.)	40 A
Load breakers	6 x (2 - 30 A) or 2 x (6 - 50 A)
Battery breakers	2 x 50 A
LVD (battery)	Yes
PLD (not critical loads)	No
Output protection	Inbuilt fuses (both poles) Over-temperature protection

Control / Monitoring	
Controller	ORION or PSC 3
Local interface	Display, menu structure, key-pads, LEDs
Remote monitoring	6 alarm relays, modems, WEB Interface, SNMP protocol

Others	
Operating temperature	-45 - +65 °C
Humidity (relative)	95 % max, non cond.
Environment standard	ETSI EN 300 019-1-3
Safety standard	IEC 60950
EMC standard	EN 300 386

Figure 31 - Delta PSU technical specifications

2.5.2 Fonestar FRS-160 - Flight Rack 19"

19" black-finished flight rack case for professional mixer or other equipment. Manufactured in coated plywood. Protection against impacts based on 25 mm high-density foam

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Hermetically closing lid, carrying handles, rubber feet, and metal protective corner pieces. Robust construction for transporting and protecting the equipment inside the rack.

Figure 32 - Fonestar FRS-160 Flight rack (Front view)

Mechanical details:

Capacity:

- Rack unit: 16U / 19'' = 71.2 cm

Size:

- Outside (with wheels): 60 x 97.5 x 77.5 cm
- Inside: 48.5 x 71.2 x 57 cm

Weight:

- 47 Kg

3 Performance Tests and Results

3.1 Scenario Setup

Performance validation tests of the onboard B5G system emulation in non-terrestrial networks (including HAPS) were conducted using a portable gNB, leveraging the "Flamingo" Flight Rack unit and the Amarisoft infrastructure.

The system was integrated, configured and tested at 5TONIC premises (Leganés, Madrid). In Figure 33 and Figure 34, can be seen the indoor equipment of the testbed, composed by the flight rack (with the gNodeB, LPG and server) and the radio access based on the Ericsson Radio DOT system, both located indoors in the 5TONIC X3 laboratory room.

Figure 33 – 5TONIC premises – Lab

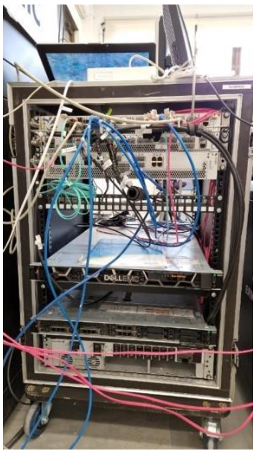

Figure 34 – "Flamingo" Flight Rack

The 5TONIC facilities also host Amarisoft infrastructure consisting of an AMARISOFT UE Simbox (supporting up to 64 simultaneous UEs) and dual SDR units configured for 5G NR in

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band n78 with a 2×2 MIMO antenna setup. This system complements the testbed by enabling controlled, high-capacity 5G standalone emulation in a laboratory environment.

In this chapter, the methodology and measurement conditions followed by the different tests performed are described.

Table 28 - "Flamingo" RAN details used for the tests

Sectors	Radio HW	NR Band - arfcn
FLAMINGO_5G_DOT-1	RD4479 B78L	Mid-band - N78 636666

Table 28 summarizes the HW configuration of the 5G cells involved in the testing ("Flamingo" mid-band gNodeB).

Table 29 – "Flamingo" RAN configuration

Band	Bandwidth	TDD pattern	Power	DL modulation	UL modulation	DL Layers	UL Layers
Mid-band (MB)	100 MHz	10:2:2 - DDDSUDDSU	1W	256 QAM	64 QAM	4	1

Table 29 highlights the RAN configuration parameters considered during the use case executions.

Additionally, to enable the maximum cell range for mid-band cells (15,000 meters), several configuration adjustments were required in Flamingo gNB:

- The Random Access Channel (RACH) Preamble Format had to be set to RACH_PREAMBLE_FORMAT_00 (Format 0), which is mandatory when the cell range exceeds 5000 meters.

- In order to enable this specific preamble format, it was necessary to update the TDD slot configuration to the supported special slot pattern - DDDSUDDSU.
- Moreover, **PRACH enhancements for mid-band** feature has to be activated. This feature allows the use of longer-range access procedures and improved synchronization

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support, which are critical for extended coverage scenarios such as HAPS or rural deployments.

3.2 Model Channel Validation Considerations

To assess system behavior in a non-terrestrial environment, a set of parameters has been defined to govern the radio channel validation conditions. These parameters are divided into two categories: generic and channel-specific.

3.2.1 Generic Parameters

- **Maximum Distance (max_distance)**: 15 km, constrained by the RACH preamble format and TDD pattern limitations of a 5G mid-band node.
- **Minimum Distance (min_distance)**: 12 km, corresponding to the minimum safe altitude for aerial traffic.
- **Noise Spectral Density (noise_spd)**: -174 dBm/Hz. Considering a 100 MHz bandwidth, the estimated total noise is approximately -94 dBm (computed as noise_spd + 10·log10(BW)).
- **Mobility Parameters**:
    - Initial Position: [10.99, 20.99]
    - Direction: 10.99
    - Speed: 10.99 (units km/h)
- **Channel Simulation Enabled**: "channel_sim": true

3.2.2 Channel-Specific Parameters

TDLA Channel Type (open urban environment with low mobility):

- **Type**: "tdla"
- **Doppler Frequency (freq_doppler)**: 10 Hz, indicating reduced mobility.
- **MIMO Correlation**: "medium" (moderate correlation between MIMO antennas).
- **Attenuation Parameters**: A = 10.9, B = 10.9
- **Delay Spread**: 20 ns, characteristic of open urban areas with limited multipath components.

TDLB Channel Type (dense urban environment with higher mobility):

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- **Type**: "tdlb"
- **Doppler Frequency (freq_doppler)**: 100 Hz, representative of higher mobility scenarios.
- **MIMO Correlation**: "high", due to more similar propagation paths between antennas, typical in dense urban environments.
- **Attenuation Parameters**: A = 12.2, B = 12.2
- **Delay Spread**: 100 ns, indicating a larger number of propagation paths and greater variation in signal arrival times.

These models enable realistic evaluation of the communication link under varying propagation conditions, supporting the validation of system performance in non-terrestrial scenarios across different mobility and urban density profiles.

3.3 Use case — Radio channel emulation for validating on onboard B5G system

This use case aims to demonstrate the capability of an onboard Beyond 5G (B5G) system, supported by Amarisoft, to efficiently emulate and manage radio channels under realistic conditions. It focuses on assessing system resilience and integration with a gNB deployed on a high-altitude platform (HAPS), using advanced channel simulation techniques.

All 5G components are deployed in the 5TONIC lab, including an Amarisoft CPE as the user terminal and Flamingo gNB configured to emulate operation from a High-Altitude Platform Station (HAPS). Using Amarisoft's platform, the radio channel between the CPE and gNB is realistically validated, replicating key non-terrestrial effects like path loss, latency, and Doppler shift to assess link performance.

Performance metrics considered were:

- **Throughput**: Measure the throughput at the network edge and core to compare performance.
- **Timing Advance (TA) Measurement**: Record and analyze Timing Advance (TA) values reported by the gNB. These values provide an estimate of the simulated UE distance from the gNB and can be used to approximate the user location within the emulated environment.
- **Signal-to-Noise Ratio (SNR)**: Collect SNR values during the tests to monitor radio link quality and correlate signal conditions with network performance.
- **Modulation and Coding Scheme (MCS):** Track the MCS levels assigned by the gNB to evaluate how modulation and coding adapt to varying radio conditions.

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- **Reference Signal Received Power (RSRP)**: Measure RSRP to assess the received signal strength at the UE and its impact on connectivity and throughput.

- **Distance (meters):** According to 3GPP TS 38.213 Section 4.2, each Timing Advance (TA) unit in 5G NR corresponds to a time offset of ~488.28 ns, equivalent to a round-trip distance of ~146.5 meters (or ~73.25 meters one-way). For practical purposes and alignment with the emulation setup and taking into account a 30kHz SCS, we adopt a simplified value where 1 TA unit is considered equivalent to 39 meters. This approximation facilitates consistent user distance estimation within the simulated environment.

The following section presents the results and analysis obtained from the experimentation phase, considering a set of controlled variations. These include the type of traffic (UDP), the user speed (10 km/h or 100 km/h), the channel model used (TDLA or TDLB), and the traffic direction (Uplink). In all scenarios, the target transmission rate was fixed at 50 Mbps.

3.3.1 TDLA – UDP – 10kmh

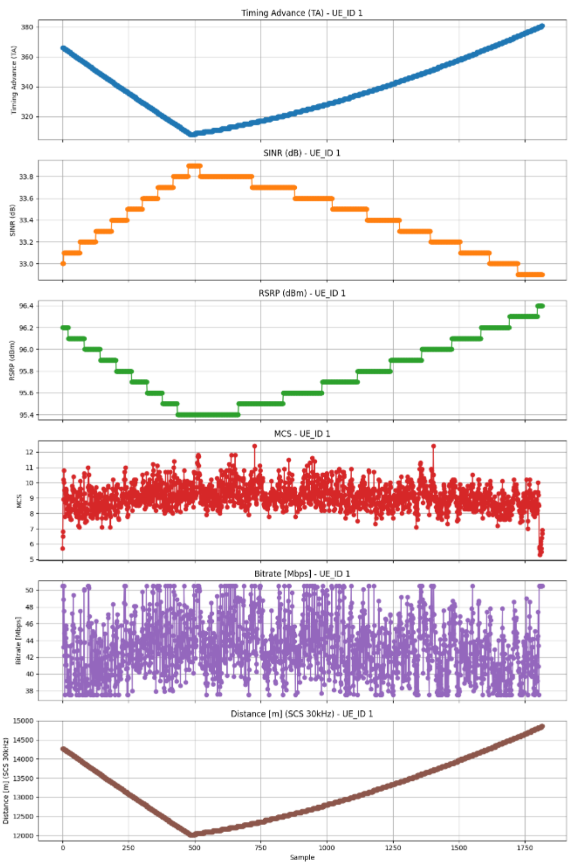

Figure 35 – TDL-A, 10 km/h, UDP 50 Mbps metrics

- **Timing Advance (TA)**
  - The TA evolves consistently with the user's distance, showing a concave shape (outward and return movement).
- **SINR (dB)**
  - A progressive improvement in SINR is observed as the UE moves closer to the gNB (peak around 12,000 m), followed by degradation as it moves away again.
  - The variation range is limited (~33 dB to ~34 dB), reflecting stable and controlled channel conditions, typical of the TDL-A model.
- **RSRP (dBm)**
  - The RSRP exhibits an almost symmetric inverse shape relative to distance: it improves when approaching the gNB and worsens when moving away.
  - Values remain between -95.4 and -96.4 dBm, indicating good signal conditions even at 15 km, consistent with a low-attenuation channel model without major obstructions.
- **MCS (Modulation and Coding Scheme)**
  - The MCS ranges between 5 and 12, with typical values between 8 and 11.
  - Although the channel remains stable, the MCS shows some variability, likely due to minor channel fluctuations (fading) or scheduler decisions to ensure uplink reliability.
- **Bitrate (Mbps)**
  - Despite 50 Mbps of UDP traffic being sent, the throughput varies and typically stays between 40–50 Mbps, with noticeable oscillations.
- **Correlation Between Metrics**
  - Higher SINR and RSRP values coincide with shorter distances, enabling higher MCS values and therefore peak bitrates.
  - However, the bitrate is not perfectly constant, which is expected in mobile scenarios with real-time traffic.
- **Technical Conclusion**
  - This simulation coherently validates the relationship between distance, TA, channel quality (SINR/RSRP), MCS, and bitrate in an uplink scenario with smooth mobility (10 km/h) and a TDL-A channel model. The system maintains

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a stable uplink transmission close to the 50 Mbps target up to 15 km, demonstrating strong coverage and performance in the defined test environment.

3.3.2 TDLA – UDP – 100kmh

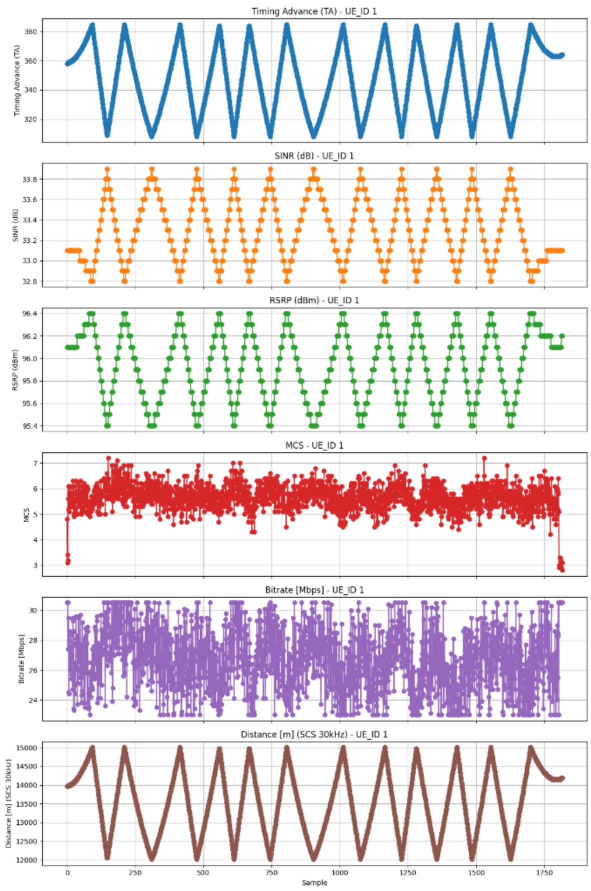

Figure 36 – TDL-A, 100 km/h, UDP 50 Mbps metrics

- **Timing Advance (TA)**
  - TA shows a clear oscillatory pattern, consistent with periodic changes in UE distance due to mobility, reflecting a smooth back-and-forth trajectory.
- **SINR (dB)**
  - SINR values range between approximately 32.8 dB and 33.8 dB.
  - Despite the high mobility, SINR remains stable with only slight variations, indicating a controlled and favorable propagation environment modeled by TDL-A.

- **RSRP (dBm)**
  - RSRP follows a symmetrical shape relative to the UE's distance, varying between -95.4 and -96.4 dBm.
  - This suggests strong signal strength throughout the trajectory, with minimal degradation even under fast movement.

- **MCS (Modulation and Coding Scheme)**
  - MCS values range mostly between 5 and 7.
  - Variability in MCS reflects the dynamic adaptation of the link to fast-changing channel conditions, ensuring reliability under high mobility.

- **Bitrate (Mbps)**
  - The uplink bitrate fluctuates between roughly 24 Mbps and 30 Mbps, with continuous oscillations.

- **Correlation Between Metrics**
  - Higher SINR and RSRP values coincide with reduced distance to the gNB, enabling higher MCS and peaks in bitrate.
  - Nonetheless, throughput remains variable, which is expected under real-time traffic and high-speed mobility.

- **Technical Conclusion**
  - This uplink simulation confirms the consistent relationship between distance, TA, channel quality (SINR/RSRP), MCS, and throughput in a mobile scenario at 100 km/h with a TDL-A model. The system maintains stable signal quality and achieves uplink rates up to 30 Mbps despite fast movement, demonstrating robust performance in high-mobility environments.

3.3.3 Comparative Analysis: TDLA – UDP 10 km/h and 100 km/h simulations

- **Timing Advance (TA) and Distance**
  - At 10 km/h, the TA and corresponding distance show a smooth curve, suggesting linear movement with gradual transitions.
  - At 100 km/h, TA exhibits sharp oscillations consistent with repeated motion patterns, simulating rapid linear sweeps.

- **Signal Quality (SINR and RSRP)**
  - Low-speed scenario: SINR remains stable around 33.5–33.9 dB, and RSRP shows minimal variation, indicating stable radio conditions.
  - High-speed scenario: Both SINR and RSRP show clear periodic degradation, likely due to increased Doppler effects and fast fading induced by rapid mobility.

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- **Modulation and Coding Scheme (MCS)**
  - MCS values remain high and stable (mostly between 7 and 11) at 10 km/h. At 100 km/h, MCS levels decrease (range between 3 and 7) and fluctuate more, reflecting reduced confidence in channel quality and adaptation to increased channel dynamics.

- **Bitrate**
  - The maximum bitrate (~50 Mbps) is nearly sustained in the low-speed case. In contrast, the high-speed scenario yields a lower and less stable bitrate (~24–30 Mbps), despite similar traffic configuration, due to lower MCS and increased retransmissions.
- **Conclusion**
  - The analysis confirms that higher UE speeds negatively impact link quality and throughput, even under line-of-sight conditions with controlled distance. The experiment demonstrates the Amarisoft UE Simbox's value in accurately modeling realistic radio behavior, including mobility effects, and underscores the importance of robust link adaptation and channel estimation techniques in NTN and HAPS scenarios involving moving UEs.

3.3.4 TDLB – UDP – 10kmh

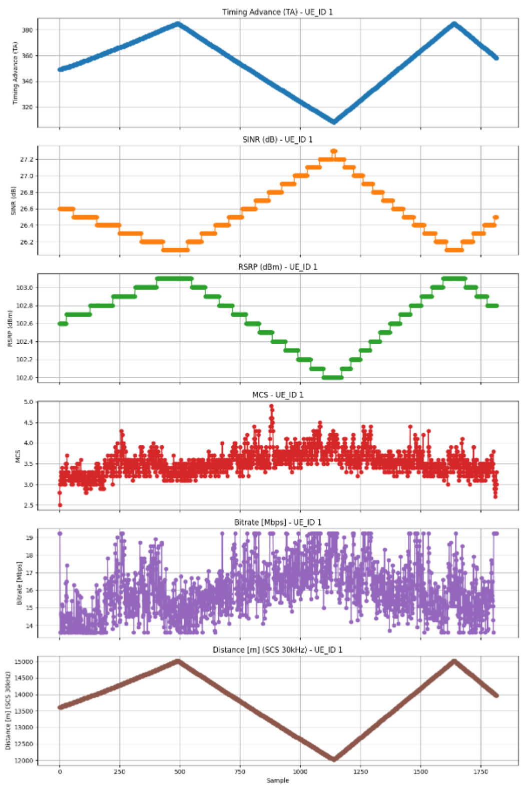

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Figure 37 – TDL-B, 10 km/h, UDP 50 Mbps metrics

- **Timing Advance (TA)**
    - The TA curve shows a clear concave pattern that corresponds to the UE's round trip movement relative to the gNB.
    - This behavior confirms correct tracking of UE distance and consistent uplink timing alignment.
- **SINR (dB)**
    - The SINR ranges between 26.2 and 27.3 dB, showing a relatively small fluctuation.
    - A peak is observed when the UE is closest to the gNB (~12,000 m), and it degrades symmetrically as distance increases.
    - These values reflect a more challenging multipath environment, as expected from the TDL-B model.
- **• RSRP (dBm)**
    - RSRP values fluctuate between -102 and -103.1 dBm, indicating higher signal attenuation.
    - The signal improves when the UE approaches the gNB and worsens as it moves away, following the expected distance pattern.
    - Despite the lower values, signal presence remains consistent throughout the trajectory.
- **MCS (Modulation and Coding Scheme)**
    - MCS values stay between 2.5 and 5, reflecting limited channel quality.
    - The system opts for more robust modulation and coding schemes to ensure uplink reliability in degraded conditions.
- **Bitrate (Mbps)**
    - The actual throughput ranges from 14 to 19 Mbps, despite the 50 Mbps traffic demand. The limited throughput can be attributed to: Low MCS values, Uplink retransmissions (HARQ), Scheduling inefficiencies due to challenging SINR conditions, constraints inherent to mobile uplink under TDL-B conditions
- **Correlation Between Metrics**

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- Shorter distances coincide with peaks in SINR and RSRP, leading to higher MCS and slightly better throughput.
- Nevertheless, performance remains restricted across the board, revealing the limits imposed by TDL-B.

- **Technical Conclusion**

  - This simulation highlights the constraints of uplink transmission under the TDL-B channel model, even with moderate mobility (10 km/h). The system maintains connectivity and stability, but throughput and spectral efficiency are severely limited due to increased multipath effects and signal degradation. While functional, the uplink performance stays far from the target 50 Mbps, reinforcing the importance of channel conditions in uplink capacity planning.

3.3.5 Comparative Analysis: TDL-A vs TDL-B – 50 Mbps UDP Uplink (10 km/h)

- **Channel Model and Stability**
  - TDL-A provides a cleaner channel environment with lower multipath dispersion and more predictable behavior.
  - TDL-B, in contrast, introduces higher dispersion, degrading channel quality and uplink performance stability.

- **SINR**
  - TDL-B shows lower average SINR, ranging from ~26.2 to ~27.3 dB, compared to ~33–34 dB in TDL-A.
  - This indicates a significant deterioration in channel quality due to the harsher propagation profile of TDL-B.

- **RSRP**
  - In TDL-B, RSRP values range between −102 and −103.1 dBm, while TDL-A shows values between −95.4 and −96.4 dBm.
  - In other words, TDL-B presents weaker signal strength, as lower (more negative) RSRP indicates greater signal attenuation.
- **MCS**
  - TDL-B exhibits a marked reduction in MCS values, which drop to 2.5–5, compared to 8–11 in TDL-A.
  - This reflects the need for more robust (but less efficient) modulation and coding to counteract poor channel conditions.

- **Bitrate**
  - TDL-B achieves significantly lower throughput, fluctuating between 14 and 19 Mbps, while TDL-A maintains 40–50 Mbps.
  - Despite identical traffic generation (50 Mbps), TDL-B cannot sustain the rate due to reduced spectral efficiency caused by lower MCS values.

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- **Overall Uplink Efficiency**
    - TDL-A efficiently utilizes the channel capacity, staying close to the target uplink throughput.
    - TDL-B reveals strong limitations even under low-speed mobility, which is consistent with the more challenging multipath environment it represents.

- **Conclusion**
    - This comparison clearly demonstrates the critical impact of channel model characteristics on uplink performance. TDL-A supports reliable, high-throughput transmission, while TDL-B suffers from degraded signal quality and significantly reduced efficiency. The system's ability to maintain performance is strongly constrained under the TDL-B model, even with minimal mobility.

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